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RICE UNIVERSITY

**Tectonic and Thermal History of the Western Serranía del Interior Foreland Fold
and Thrust Belt and Guárico Basin, North Central Venezuela: Implications of new
Apatite Fission Track Analysis and Seismic Interpretation**

by

Jaime Gonzalo Perez De Armas

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IN PARTIAL FULFILLMENT OF THE

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ABSTRACT

Tectonic and Thermal History of the Western Serranía del Interior Foreland Fold and Thrust Belt and Guárico Basin, North Central Venezuela: New Evidence from Apatite Fission Track Analysis and Reflection Seismology

by

Jaime Gonzalo Pérez De Armas

Structural analysis, interpretation of seismic reflection lines, and apatite fission-track analysis in the Western Serranía del Interior fold and thrust belt and in the Guárico basin of north-central Venezuela indicate that the area underwent Mesozoic and Tertiary-to-Recent deformation. Mesozoic deformation, related to the breakup of Pangea, resulted in the formation of the Espino graben in the southernmost portion of the Guárico basin and in the formation of the Proto-Caribbean lithosphere between the diverging North and South American plates. The northern margin of Venezuela became a northward facing passive margin. Minor normal faults formed in the Guárico basin.

The most intense deformation took place in the Neogene when the Leeward Antilles volcanic island arc collided obliquely with South America. The inception of the basal foredeep unconformity in the Late Eocene-Early Oligocene marks the formation of a perisutural basin on top of a buried graben system. It is coeval with minor extension and possible reactivation of Cretaceous normal faults in the Guárico basin. It marks the deepening of the foredeep. Cooling ages derived from apatite fission-tracks suggest that the obduction of the fold and thrust belt in the study area occurred in the Late Oligocene

through the Middle Miocene. Field data and seismic interpretations suggest also that contractional deformation began during the Neogene, and specifically during the Miocene.

The most surprising results of the detrital apatite fission-track study are the ages acquired in the sedimentary rocks of the easternmost part of the study area in the foreland fold and thrust belt. They indicate an Eocene thermal event. This event may be related to the Eocene NW-SE convergence of the North and South American plates that must have caused the Proto-Caribbean lithosphere to be shortened. This event is not related to the collision of the arc with South America, as the arc was far to the west during the Eocene.

ACKNOWLEDGMENTS

This work does not pretend to solve all of the puzzling and riddling problems of the northern Venezuelan geology. Instead, this work humbly tries to add more facts, and its intention is to give way to new and possibly more difficult questions, while trying to unravel the exciting and stimulating problems the tectonics of the southern Caribbean and northern Venezuela offers. The conclusions of this work are merely the interpretation of such facts. While these facts could remain as the truth for the scientific community for some time, until proven obsolete or discarded by the dawning of new technologies; the interpretation has been done by a mortal, and in no way they have to be considered as fixed in time. This work tries to be another stepping stone, another building block in the understanding of our living and vibrating world, and of course it would not have been possible without the concourse, convergence, help and generosity of a great deal of brilliant people and the monetary help from several oil companies and foundations. No work is achieved with only two hands and two eyes.

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PREFACE

This dissertation is written in a non-traditional format, and includes one scientific paper and six appendixes contentive of background information and data of the research. The scientific paper entitled “Tectonic and thermal history of the western Serranía del Interior foreland fold and thrust belt and Guárico basin, north central Venezuela: Implications of new apatite fission-track analysis and reflection seismology” was submitted for publication in a Geological Society of America Special Paper entitled “Caribbean / South American plate Interactions, Venezuela,” edited by Dr. Hans Ave Lallemant and Dr. Virginia Sisson.

***Tectonic and thermal history of the western Serranía del Interior foreland fold
and thrust belt and Guárico basin, north-central Venezuela: Implications of new
apatite fission-track analysis and seismic interpretation***

by

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ABSTRACT

Structural analysis, interpretation of seismic reflection lines, and apatite fission-track analysis in the Western Serranía del Interior fold and thrust belt and in the Guárico basin of north-central Venezuela indicate that the area underwent Mesozoic and Tertiary-to-Recent deformation. Mesozoic deformation, related to the breakup of Pangea, resulted in the formation of the Espino graben in the southernmost portion of the Guárico basin and in the formation of the Proto-Caribbean lithosphere between the diverging North and South American plates. The northern margin of Venezuela became a northward facing passive margin. Minor normal faults formed in the Guárico basin.

The most intense deformation took place in the Neogene when the Leeward Antilles volcanic island arc collided obliquely with South America. The inception of the basal foredeep unconformity in the Late Eocene-Early Oligocene marks the formation of a perisutural basin on top of a buried graben system. It is coeval with minor extension and possible reactivation of Cretaceous normal faults in the Guárico basin. It marks the deepening of the foredeep. Cooling ages derived from apatite fission-tracks suggest that the obduction of the fold and thrust belt in the study area occurred in the Late Oligocene through the Middle Miocene. Field data and seismic interpretations suggest also that contractional deformation began during the Neogene, and specifically during the Miocene.

The most surprising results of the detrital apatite fission-track study are the ages acquired in the sedimentary rocks of the easternmost part of the study area in the foreland fold and thrust belt. They indicate an Eocene thermal event. This event may be related to the Eocene NW-SE convergence of the North and South American plates that must have caused the Proto-Caribbean lithosphere to be shortened. This event is not related to the collision of the arc with South America, as the arc was far to the west during the Eocene.

Figure 1. Tectono-stratigraphic map of northern Venezuela and southern Caribbean showing the main tectonic belts and lithological units. After Ysaccis (1997).

INTRODUCTION

The Western Serranía del Interior foreland fold and thrust belt and the Guárico basin in north-central Venezuela are part of the complex Caribbean-South American plate boundary zone that includes different Mesozoic-Cenozoic orogenic cycles and records obduction of allochthonous terranes onto the continental plate. The Caribbean-South American plate boundary zone can be considered as a megasuture (Bally and Snelson, 1980) that developed since the Late Cretaceous in western Venezuela and migrated to eastern Venezuela until Recent times (Lugo and Mann, 1995) (Fig.1).

The convergence between the Caribbean and South American plates may have been NW-SE for most of the time. The convergence with respect to the E-W trending continental margin of South America, was highly right-oblique. Therefore, collision of the Caribbean plate and the Leeward Antilles volcanic island arc with the South American continent is highly diachronous: it happened in Paleocene-Eocene time in western Venezuela, in the Oligocene in north-central Venezuela, and in the Miocene in eastern Venezuela (Lugo and Mann, 1995).

Convergence between North and South America started during the Paleocene (e.g., Pindell, 1993). One important question is whether the convergence caused Eocene deformation in north-central and eastern Venezuela before formation of the collisional deformation structures. Pindell (1997) suggests that contraction between the North and South American plates may have deformed the Proto-Caribbean crust, forming an incipient subduction zone and subsequent early uplift of the Northern Range of Trinidad and possibly the northern Serranía.

The present study was undertaken in order to determine how many deformation phases occurred in north-central Venezuela and how these structures relate to the plate tectonic history of the Caribbean. The study included mapping along four N-S trending transects through the area, structural analysis, interpretation of seismic reflection lines and fission-track analyses. Fieldwork was carried out in 1995, 1996, and 1997.

Peirson (1963, 1965), Menéndez (1966), Bell (1968) and Beck (1978, 1985a, 1985b) mapped the area previously. In this study, the interpretations of their work were utilized for checking the stratigraphy and the structure in the field. Changes were made when deemed necessary, in view of the relatively new concept of displacement partitioning (e.g., Fitch, 1972; Oldow et al., 1989; Cashman et al., 1992). Generally, in plate boundary zones where the convergence rate vector is oblique, the normal component causes the development of folds and thrust faults (sub) parallel to the boundary and the parallel component results in displacements along margin-parallel strike-slip faults (Avé Lallemant and Guth, 1990; Tikoff and Teyssier, 1994; Avé Lallemant, 1996, 1997).

Fission-track analysis of detrital apatites was performed to determine thermal effects associated with the uplift and denudation of the Western Serranía del Interior. The primary goal of this analysis was to find out whether the area had been deformed during one or two events.

REGIONAL TECTONICS OF NORTH-CENTRAL VENEZUELA

The Caribbean-South American plate boundary in north-central Venezuela is a megasuture that includes different complex Mesozoic-Cenozoic orogenic cycles. It

records the exhumation and obduction of an accretionary fold and thrust belt that includes High Pressure / Low Temperature (HP/ LT) metamorphic rocks (blueschist and eclogite), ophiolite, greenschist, island-arc igneous rocks, passive-margin derived metamorphic rocks, volcanogenic turbidites and passive-margin derived sedimentary rocks of different ages and tectonic history. Paleogene north-dipping subduction associated with the obduction of the Lara nappes was followed by the development of a south-dipping Neogene Benioff zone with no associated volcanism. Both the north-dipping, and the south-dipping subductions were previously inferred by tomographic studies and by gravimetric and magnetic modeling (Van der Hilst, 1990; Bosch and Rodriguez, 1992; Van der Hilst and Mann, 1994) ages and tectonic history. Paleogene north-dipping subduction associated with the obduction of the Lara nappes was followed by the development of a south-dipping Neogene Benioff zone with no associated volcanism. Both the north-dipping, and the south-dipping subductions were previously inferred by tomographic studies and by gravimetric and magnetic modeling (Van der Hilst, 1990; Bosch and Rodriguez, 1992; Van der Hilst and Mann, 1994).

The regional tectonics of the area must be understood within the South American and Caribbean plate tectonic context (for a more detailed discussion, see Pindell, 1993; Summa et al., 2003). The northern part of the South American plate consists mainly of the Precambrian Guyana shield and three allochthonous belts, two accreted in the Paleozoic and one in the Cenozoic (e.g., Feo-Codecido et al., 1984).

In Early Jurassic time, the super continent Pangea started to break up and subsequently, North and South America drifted apart and the Proto-Caribbean lithosphere formed between the two Americas. The northern margin of South America became a

Figure 4. Tectonostratigraphic units in the Western Serranía del Interior, north-central Venezuela, showing their relationship with the tectonic belts, thicknesses of the units measured from cross sections and their lateral relationships.

TABLE 1. Thickness of sedimentary units in the Western Serranía del Interior estimated from the transects

Formation / Transect / Thickness (m)	Stratigraphic Age	Platillón Tiznados	Camatagüita Valle Morín	Altigracia de Orituco	San José de Guaribe
<i>Quiamare</i>	Miocene	N/A	N/A	N/A	650
<i>Quebradón</i>	Upper Miocene- Middle Miocene	1500 with Quiamare	N/A	3000 with Quiamare	700
<i>Naricual</i>	Oligocene-Lower Miocene	N/A	N/A	N/A	650
<i>Roblecito</i>	Upper Eocene- Lower Miocene	N/A	1500	N/A	N/A
<i>Peñas Blancas</i>	Middle Eocene	N/A	10*	N/A	N/A
<i>Guárico</i>	Cretaceous- Paleocene	1500	2500	1500	500
<i>Mucaria</i>	Cretaceous	2000	810	2000	400
<i>Querecual</i>	Cretaceous	180	375	125	N/A
<i>Garrapata</i>	Cretaceous- Paleocene (?)	2000	500	1500	700

* Estimated by Bell
(1968)

N/A Non-applicable /
Not measured

passive continental margin. Since mid-Cretaceous time, the Farallon plate (later the Caribbean plate) moved first northeastward (120 Ma to approximately 55 Ma) and subsequently eastward (55 Ma to Recent) inserting itself between the North and South American plates (e.g., Pindell 1993). Convergence between the latter two plates started at about 55 Ma (e.g., Pindell, 1993). The relative eastward passage of the Caribbean plate resulted in diachronous deformation of the northern margin of South America.

The Caribbean/South American plate boundary zone consists of many allochthonous and parautochthonous belts that approximate a general E-W trend (Fig. 1). From north to south these belts are: (1) the South Caribbean deformed belt, (2) the Leeward Antilles volcanic island arc, (3) a zone of Tertiary pull-apart basins, (4) the Caribbean Mountain system and (5) a belt of foreland basins (Ostos et al., 2005). Most of these belts are separated by major fault systems (Figs. 1 and 2).

The Caribbean Mountain system is subdivided into several sub-belts (e.g., Menéndez, 1966). The two most southerly sub-belts are the Villa de Cura complex in the north and the Western Serranía del Interior fold and thrust belt in the south (Fig. 1). The two are separated by the Cantagallo fault, a low-angle, north-dipping thrust fault that is the southernmost limit of the allochthonous metamorphic belts. The Western Serranía del Interior is a south-facing foreland fold and thrust belt that has been sub-divided into four belts which are from north to south: (1) "Piedmont belt," (2) "Belt of thrust faults," (3) "Belt of overturned beds" and (4) "Belt of gently-dipping beds". The Western Serranía del Interior and the Guárico foreland basin in the south are the subject of the present study (Figs. 1 and 2).

Figure 5. Location map of 2D seismic lines used in this study.

GUÁRICO BASIN

Seismic stratigraphy of the Guárico basin

Introduction. The stratigraphy of the Guárico basin and the Serranía is shown in Figs. 3 and 4. Although very little structure of the Guárico basin is seen at the surface (“Belt of gently dipping beds,” Bell, 1968), larger deformation structures are recognized on seismic reflection profiles (Aymard et al., 1985; Blanco et al., 1988; Daal and Lander, 1993). The oldest structures in the region are NE-SW trending normal faults related to the divergence of the North and South American plates (e.g., Espino graben). Several tectonic pulses have been defined previously in the Guárico basin and are summarized here: (1) Triassic-Jurassic extension associated with the breakup of Pangea forming the Espino graben, (2) Cretaceous extension and syn-tectonic sedimentation possibly extending to the Late Eocene, (3) Middle to Late Eocene uplift of the El Baúl arch generating a regional unconformity, (4) Oligocene subsidence and formation of a deep basin; (5) Middle-to-Late Miocene compressional event resulting in south-vergent structures, reactivation of Cretaceous normal faults and loading of the thrust sheets onto Oligo-Miocene stratigraphic sequences (e.g., González and Lander, 1980; Aymard et al., 1985; Blanco et al., 1988).

Data set. A regional grid of 1400 km of industry 2D seismic reflection profiles, shot in the mid-80’s, well data, time-velocity surveys and synthetic seismograms were used to interpret the tectonic evolution of the Guárico basin. Location of the seismic grid is shown in Fig. 5. Petróleos de Venezuela (PDVSA) kindly provided the data set. The

Figure 6. Legend for interpreted 2D seismic lines.

seismic grid is denser in hydrocarbon producing areas, such as the Yucal-Placer field (Daal and Lander, 1993). Published biostratigraphic reports on the area are scarce. This paper uses the biostratigraphy of Fasola et al. (1985) as a guide to determine the ages of the different stratigraphic units.

Methodology. Interpretation and subdivision of seismic units into correlatable entities throughout the Guárico basin are based on the principles established by Vail et al. (1977) and Vail (1987). In the present study, subdivisions in stratigraphic units and their regional correlation were based on Fasola et al. (1985).

Synthetic seismograms generated from transit time well logs in conjunction with biostratigraphy for the same wells studied by Fasola et al. (1985) and in previously published papers (e.g., Daal and Lander, 1993) were used to calibrate the seismic sections. In this project, six regional seismic transects were studied, five oriented northwest-southeast and one oriented ENE-WSW (Figs. 5 to 12). Velocity surveys allowed converting time sections into depth sections (Figs. 7 to 11).

On the basis of the interpreted 2D seismic reflection lines, the Guárico basin was subdivided into five major seismic sequences or megasequences bounded by sequence boundaries: (1) Precambrian-Paleozoic pre-rift, (Pre-K); (2) Triassic-Jurassic syn-rift, (T-J); (3) Cretaceous post-rift, (K); (4) Oligocene-Miocene Roblecito-Chaguaramas foredeep and includes two seismic sequences, (OA, OB, OC, OM, N1); (5) Neogene Roblecito-Chaguaramas foredeep, (N2), (Figs. 3 and 6 to 12).

Precambrian-Paleozoic pre-rift rock units. In north-central Venezuela, the pre-Cretaceous basement consists of Precambrian crystalline rocks that are in tectonic contact

Figure 7. Time and depth-converted composite line-drawings of seismic section G2, south of the Platillón-Tiznados transect. Legend as in Figure 6.

with Paleozoic metamorphic and sedimentary rocks (Feo-Codecido et al., 1984). Previously interpreted well logs indicate the presence of sedimentary Paleozoic units in the area, but it was not possible to recognize them on the available seismic lines. Cambrian to Lower Ordovician siliciclastic rocks may be preserved in the Espino graben. In this study, all undifferentiated Precambrian and Paleozoic rocks are combined and labeled Pre-K (pre-Cretaceous), (Figs. 7 to 12).

Triassic-Jurassic syn-rift sequence. This seismic unit is recognized in the Espino graben and includes thick Triassic-Jurassic (T-J) sedimentary rocks, but may include Paleozoic (Cambrian-Ordovician) sedimentary units as well. The graben is located in the southernmost portion of the basin. In the interpreted seismic section (Fig. 11), units tend to expand toward the faults that bound the graben and are in fault contact with the Precambrian and Paleozoic basement.

The Triassic-Jurassic Espino graben is a rift system that probably formed during the breakup of Pangea and the subsequent North and South American plate divergence (e.g., Pindell and Dewey, 1982; Summa et al., 2003). In the Guárico basin, the Espino graben trends NE-SW. It extends to the NE towards the Eastern Venezuela basin and to the SW towards the Venezuelan and Colombian Llanos (Feo-Codecido et al., 1984). This rift developed on older accreted Paleozoic metamorphic and Precambrian igneous-metamorphic terranes of the Guyana craton. The Triassic to Jurassic units contain an intraformational volcanic flow dated at 157 and 162 Ma (K/Ar; Feo-Codecido et al., 1984).

In some areas, the Paleozoic sedimentary deposits are not present. Instead, underlying the Cretaceous and younger deposits, there is either an accreted Paleozoic

Figure 8. Time and depth-converted composite line-drawings of seismic section G3, south of the city of San Juan de Los Morros, in the Guárico Basin. Legend as in Figure 6.

metamorphic terrane or the Guyana crystalline basement. Ysaccis (1997) presented a tectonic map of northern Venezuela that depicts the subsurface extension of the Precambrian and Paleozoic metamorphic folded belts, Paleozoic foreland folds, Espino graben deposits and undeformed Paleozoic and Precambrian Guyana shield (Fig. 1).

Post-rift sequences. Passive margin sequence. Cretaceous (K). The Cretaceous seismic unit in the Guárico basin (K) is bounded at its base by a regional unconformity that marks the encroachment of the Cretaceous seas onto continental South America (Figs. 3, 7 to 12) (González de Juana et al., 1980). The top of this unit represents a Late Eocene-Early Oligocene basal foredeep unconformity that marks the beginning of the loading of the Lara nappes onto the South American craton in north-central Venezuela (Fasola et al., 1985; Kiser, 1997). This unit thickens toward the east of the basin and is thinner to the south towards the Guyana craton and also to the west toward the El Baúl high (Figs. 7 to 12). The westward thinning of the K unit could be due to erosion, which might have occurred during the uplift of the El Baúl high in Middle to Late Eocene time (Blanco et al., 1988). In the present study, analysis of 2D seismic lines suggests that a minor extensional phase occurred during the sedimentation of the Cretaceous sequence. These structures were reactivated during the loading of the Lara nappes onto South America in Early Oligocene (Figs. 7 to 12).

Roblecito-Chaguaramas foredeep: Late Eocene-Early Oligocene to Miocene (OA to OM, NI). The seismic stratigraphic unit that onlaps the Cretaceous sequence (OA) and marks the inception of the foredeep in north-central Venezuela is Late Eocene-Early Oligocene (González de Juana et al., 1980; Fasola et al., 1985; Kiser, 1997). In the present study, this seismic sequence includes four Late Eocene-Early Oligocene to Early

Figure 9. Time and depth-converted composite line-framings of seismic section G4, south of the Valle Morín-Camatagüita transect in the Guárico Basin. Legend in Figure 6.

Miocene seismic units. They are correlated on the basis of the report by Fasola et al., (1985). The units from older to younger are: OA, OB, OC and OM (Figs. 7 to 12).

In the northern parts of the Guárico basin, the base of the unit OA is represented by the transgressive La Pascua Formation (Late Eocene-Early Oligocene) and its transition to the Roblecito Formation. The units OB and OC (Oligocene) represent the deepening phase of the basin represented solely by the Roblecito Formation. The unit OM (Oligocene-Miocene) represents the basal units of the filling and capping phase of the foredeep by the Roblecito and Chaguaramas Formations (Fasola et al., 1985).

Deposition of the units OA and OB is coeval with the development or reactivation of extensional structures during the inception of the Guárico foredeep in the Late Eocene-Early Oligocene (Figs. 7 to 12). Some normal faults were possibly inverted during the Middle Miocene tectonic event (Fig. 9).

In the Guárico basin, two Neogene stratigraphic sequences are divided by a regional unconformity (Figs. 3, 11 and 12). These units are named in this study Neogene 1 and Neogene 2 (Figs. 11 and 12). The Neogene 1 seismic unit was divided into three subunits for the purpose of seismic correlation: NA, NB and NC (Figs. 11 and 12). There is no biostratigraphic control of these units since they are near-shore marine to continental deposits.

Neogene Roblecito-Chaguaramas foredeep: Neogene N2. This seismic unit, Neogene 2 (N2), represents the capping and filling of the foredeep basin. It is divided into four seismic packages: ND, NE, NF and NG (Figs. 11 and 12). These subdivisions were constructed solely on seismic characteristics in order to allow regional correlation. Seismic units NA to NG correspond to the Neogene Chaguaramas Formation in the

Figure 10. Time and depth-converted composite line-drawings of seismic section G5, south of the Altagracia de Orituco transect, in the Guárico Basin. Legend in Figure 6.

Venezuelan geological literature (Fig. 3). Figure 12 shows how the basin was uplifted and tilted to the east by a post-Miocene tectonic event (Fig. 12)

Deformation history of the Guárico basin

There are two quite distinctive structural styles observed in the seismic sections. First, the Neogene decollement or decoupling level along OB (Roblecito Formation) serves as a relative “boundary” for this structural architecture. Below the decollement, there is an extensional regime initiated in the Mesozoic with the opening of the Espino graben. A younger extensional regime occurred during the Tertiary in response to the tectonic loading of the Lara nappes that generated the Roblecito foredeep. Secondly, Neogene contraction in the Guárico basin (Figs. 7 to 12) resulted in imbricate thrust faults merging into the decollement.

Based on the analysis of 1400 km of 2D seismic reflection profiles and other interpretations from the literature, it is suggested here that there are, at least, five separate deformation episodes in the Guárico basin and the Serranía del Interior foreland fold and thrust belt. Deformation phases 1 and 2 are related to the rifting and drifting of the Americas since the Triassic-Jurassic. Phases 3 through 5 are related to the continuous interaction between the Caribbean and South American plates since Late Eocene-Early Oligocene time.

(1) Formation of a Triassic-Jurassic rift. Extension and opening of the Espino graben system occurred in the southernmost portion of the Guárico basin (Fig. 11). The formation of this extensional system was related to the opening of the Atlantic Ocean.

Figure 11. Time and depth-converted composite line-drawings of seismic section G6, south of the San José de Guaribe transect in Guárico Basin. Legend in Figure 6.

The graben-bounding faults crosscut sedimentary and metamorphic Paleozoic rocks and Precambrian crystalline basement of the Guyana craton. This structure may extend beneath the Eastern Serranía del Interior to the east and to the Apure and Colombian Llanos in the west (e.g., Feo-Codecido et al., 1984).

(2) *Passive margin*. In the Cretaceous, a north-facing passive margin was formed that subsequently underwent thermal subsidence (e.g., Pindell, 1993). This is the time of the encroachment of the proto-Caribbean seas onto continental South America and the formation of normal faults (Figs. 7 to 12).

(3) *Foredeep unconformity*. A basal foredeep unconformity formed in the Late-Eocene-Early Oligocene (González de Juana et al., 1980; Fasola et al., 1985; Kiser, 1997). It was coeval with minor extension in the Guárico basin. In Late Eocene-Early Oligocene, during the deposition of units OA and OB, normal faults were either reactivated or developed newly in the autochthonous terranes of the South American plate (Figs. 7 to 12). They extend well south into the basin and could have been formed in response to the flexure due to loading of the Lara nappes onto the Guyana craton and to the peneplained Paleozoic folded belt during the early stages of the formation of the foredeep (e.g., Summa et al., 2003)

(4) *Contraction*. In north-central Venezuela, contractional structures formed during the Miocene. The Guárico basin is decoupled along marine shales of the stratigraphic sequence OB of the Roblecito Formation. From this sole thrust or detachment level, south-vergent thrust imbricates emerged in the Oligocene-Miocene sedimentary sequences of the Guárico foredeep. Several small triangle zones developed within the basin. Deformation of sub-sequence ND by thrust imbrication might mark the

Figure 12. Time line-drawing of an east-west 2D seismic line composite section across the Guarico basin (G1) showing uplift and peneplanation of the Guarico basin during Pliocene-Pleistocene times. Legend as in Figure 6.

end of contractional deformation within the basin (Fig. 11). Data quality is very poor within the “Piedmont belt” and beneath both the “Piedmont belt” and the Villa de Cura nappes, allowing room for a wide range of structural interpretations (Figs. 8 and 9).

Two of the interpreted 2D seismic lines cut across the contact of the “Piedmont belt” with the Villa de Cura complex (Figs. 8 and 9). Modeling based on gravimetric and magnetic data support the idea that the Villa de Cura nappe is a klippe (Bosch and Rodriguez, 1992; Smith et al., 1999). The klippe might be very thin, possibly between 1 and 2 km (Figs. 3 and 4 of Bosch and Rodriguez, 1992).

Projection of the proximal passive margin and its basement suggest that the interpreted Cretaceous sequence K and, probably, the Late Eocene-Oligocene units OA and OB may extend northward beneath the Serranía del Interior and the Villa de Cura nappes (Figs. 8 and 9).

(5) ***Regional uplift.*** A post-Miocene tectonic event uplifted, peneplaned and tilted the Guárico basin to the east (Fig. 12). Minor Neogene and a younger extension are observed throughout the basin deforming Oligocene sedimentary sequences as well (Figs. 10 and 11). The available seismic data do not constrain the orientation of the latter extensional structures. Based on analysis of 2D seismic data, Blanco et al., (1988) and Daal and Lander (1993) suggest that these normal faults are NE-SW trending.

Figure 13. Legend for maps and transects used in this study.

WESTERN SERRANÍA DEL INTERIOR

Stratigraphy

In this study, the stratigraphy of the western Serranía del Interior, also known as Guárico mountain front (Bell, 1968; Bellizzia, 1972; González and Picard, 1972), is complicated because of severe deformation. South of the Villa de Cura blueschist unit, the Western Serranía del Interior consists of a series of Cretaceous-Tertiary tectonic belts of different origin (Figs. 1 and 2). Beck (1978) subdivided the area into several belts and units, but in this paper I will follow the structures described by Peirson (1965) and Bell (1968). These belts are from north to south: (1) "Piedmont belt," (2) "Belt of thrust faults" (Chacual complex), (3) "Belt of overturned beds" and (4) "Belt of gently dipping beds" (Fig. 2).

The oldest rocks in the Serranía del Interior are Lower to Upper Cretaceous shelfal limestones of the Querecual Formation and siltstones of the Mucaria Formation. They constitute the remnant of the Cretaceous passive margin included in the accretionary wedge (Fig. 4). Mapable volcanogenic turbidites with olistoliths of mafic and ultramafic rocks of the Garrapata Formation are considered of Coniacian-Santonian age (Bell, 1968), but its age and stratigraphic relationships are still in debate (Fig. 4) (Albertos et al., 1989). The Mucaria Formation sequence grades upward into Upper Cretaceous-Paleocene turbidites of the Guárico Formation (Fig. 4). The Guárico Formation is equivalent to other turbidite facies found in western Venezuela, i.e., Río Guache, Trujillo and Moran Formations (e.g., Blin, 1989). Dismembered limestone blocks of Cretaceous-Paleocene age are embedded within the Garrapata and Guárico

Figure 14. Geological map of the Platillón-Tiznados transect showing (1) the structural contact between the Villa de Cura nappes and the "Piedmont belt" in the Western Serranía del Interior and (2) sample location and fission-track pooled age data (± 1 sigma). Modified after Creole Petroleum Corporation (1961a and c). Topography from Cartografía Nacional de Venezuela 1:25,000. UTM grid. Legend as in Figure 13.

faults” (Chacual complex), (3) “Belt of overturned beds” and (4) “Belt of gently dipping beds” (Fig. 2).

Formation along the Serranía del Interior foreland fold and thrust belt (Fig. 4), (Platillón Limestone, Las Colonias Limestone, Morros de San Juan, Morros de Macaira). The stratigraphic top of the Guárico Formation in the Camatagua area has been removed by erosion and is overlain unconformably by the Upper Eocene Peñas Blancas carbonates (Fig. 4), (Peirson, 1965; Bell, 1968). The Oligocene-Miocene foredeep stratigraphic sequence involved in the Serranía is composed of a regressive unit of open marine shales to terrestrial deposits (Roblecito, Quebradón, Naricual and Quiamare Formation).

Deformation history of the Western Serranía del Interior

(1) ***“Piedmont belt.”*** The first and northernmost belt is the Piedmont belt. It is separated from the Villa de Cura complex to the north by the Cantagallo fault and to the south either by the “Belt of thrust faults” or by the “Belt of overturned beds” (Figs. 1 and 2). The “Piedmont belt” is characterized by south-vergent, tight-to-isoclinal folds and south-vergent thrust and reverse faults.

(2) ***“Belt of thrust faults.”*** It crops out discontinuously along the Serranía del Interior between the “Piedmont belt” and the “Belt of overturned beds” (Fig. 2). This structural province is intensely deformed by south-vergent, imbricate thrust faults that juxtapose Cretaceous, Paleogene and Neogene sedimentary units. Beck (1978; 1985a, 1985b) suggested that the sedimentary cover that forms the Serranía is detached along an Albian or pre-Albian horizon. This belt probably represents a detachment zone that has been unroofed.

Figure 15. Geological map of the Valle Morín-Camatagüita transect showing (1) the structural contact between the Villa de Cura nappes and the "Piedmont belt" in the Western Serranía del Interior and (2) sample location, fission-track pooled and modeled age data (± 1 sigma). Modified after Bell (1968). Topography from Cartografía Nacional de Venezuela 1:25,000. UTM grid. Legend as in Figure 13.

(3) ***“Belt of overturned beds.”*** It consists of a southward overturned syncline. It possibly is cut by a fault parallel to the fold-axial plane.

(4) ***“Belt of gently dipping beds.”*** The “Belt of gently dipping beds” is the most southerly zone and includes a mildly deformed rock sequence of the Guárico basin (Figs. 1 and 2). Open folds and a few south-vergent thrust faults occur, but with minor displacement.

Regional geological transects.

Four N-S-trending regional transects (Figs. 1 and 2) were selected for study based on maps (Creole Petroleum Corporation, 1961a to d; Peirson, 1965; Bell, 1968, Albertos et al., 1989) and on previous geological papers and dissertations (Peirson, 1965; Peirson et al., 1966; Bell, 1968; Bellizzia et al., 1976; Beck, 1986a and b; Albertos et al., 1989; Blin, 1989; Blin et al., 1989; Bellizzia and Dengo, 1990). The four transects are from west to east: (1) Platillón-Tiznados (PTZ), (2) Camatagüita-Valle Morín (CAM), (3) Altagracia de Orituco (AO) and (4) San José de Guaribe (SJG), (Figs. 1, 2, 13 to 17).

Structural analysis of the four study transects (Creole Petroleum Corporation, 1961a to d; Peirson, 1965; Bell, 1968; Beck, 1978; Beck 1985 a and b; Albertos et al., 1989) suggest that the Serranía del Interior fold and thrust belt can be subdivided into internal (northern) and external (southern) zones. Beck (1978, 1985a and 1985b) recognized that the northern portion of the “Piedmont belt” consists of an olistolith complex embedded in a Paleocene-Lower Eocene matrix. The internal (northern) zone is the belt of rocks that lie near the tectonic contact with the Villa de Cura nappes along the Cantagallo fault and includes the “Piedmont belt” of Bell (1968). It consists of a chaotic suite of olistoliths embedded in a coarse matrix of rocks of varied provenance (Figs. 14 to

Figure 16. Geological map of the Altigracia de Orituco transect showing the stratigraphic sequence. Modified after Albertos et al., (1989). Topography from Cartografía Nacional (1980).

Showing the structural "Belt of gently-dipping beds" in the Western Serranía del Interior. Nacional de Venezuela 1:25,000. UTM grid. Legend as in Figure 13.

16). It has been correlated with the Garrapata Formation and the chaotic facies of the Guárico Formation (e.g., Bell, 1968). The olistoliths seen in the study areas are light grey platform limestones (Platillón-Tiznados limestone; Morros de San Juan; Peirson et al., 1966), black carbonates, serpentinites, greenstones and diorites (PTZ and CAM). The heterogeneity in rock composition suggests a sedimentary environment of feeder channels at the toe of a turbidite system (Albertos et al., 1989; Yoris, 1999, personal communication). In the easternmost SJG transect, the contact of this innermost belt with the Villa de Cura nappes is not observed (Fig. 17). The contact between the external and internal zones is always of structural origin. In all four transects, the external (southern) zone consists of several units: (1) Cretaceous parautochthonous platform carbonates of the Querecual Formation and siliciclastics of the Mucaria Formation, (2) allochthonous-parautochthonous Cretaceous-Paleogene mid-to-external facies turbidites, (3) the Guárico Formation and (4) the foredeep Oligocene-Miocene siliciclastic rocks of the Roblecito, Naricual, Quebradón and Quiamare Formations (Figs. 14 to 17).

The interpreted structure of the “Piedmont belt” is a hinterland dipping thrust with imbricates or unroofed duplexes with south-vergent folds, bounded by south-vergent high-angle reverse faults (Figs. 14 to 17). The northeast-striking high-angle faults are displaced by northwest-southeast striking dextral tear faults (e.g., Guárico fault). The latter faults may correspond to unroofed lateral ramps.

The lack of pre-Cretaceous rocks involved in the deformation suggests that the relatively high-angle faults of the imbricates have to flatten out and merge with a detachment surface located at some level within the autochthonous platformal Cretaceous

Figure 17. Geological map of the San José de Guaribe transect showing the structure within the "Piedmont belt" in the Western Serranía del Interior and sample location, fission-track pooled and modeled age data (± 1 sigma.) Modified after Creole Petroleum Corporation (1961d) Topography from Cartografía Nacional de Venezuela 1:25,000. UTM grid. Legend as in Figure 13.

carbonates whose surface expression is interpreted to be the “Belt of thrust faults” (Chacual complex), (Figs. 16, 17).

Mesoscopic structures

Ductile and brittle mesoscopic structures were analyzed for two reasons. First, they might reveal whether displacement partitioning had occurred. Secondly, they might indicate whether or not more than one orogenic event had occurred.

Ductile deformation structures. The orientations of bedding planes (S_o), fold axial planes (S_{ap}), cleavage (S) and fold axes (F) were determined. The data were plotted on lower-hemisphere, equal-area diagrams (Ramsay and Huber, 1987) using the Stereonet program (Allmendinger, 1995a).

Bedding planes (S_o), fold-axial planes (S_{ap}) and axial-plane cleavages (S) generally strike ENE-WSW and dip moderately to the north in the three westerly transects (Figs. 14 to 16; Fig. 18). However, in the San José de Guaribe transect (Figs. 17 and 18) they strike E-W and dip moderately to the north. Fold axes (FA) occur in a moderately NNW-dipping great-circle girdle with an ENE-WSW trending maximum in the three westerly domains (Fig. 18); they are steeply N plunging in the Guaribe area (Fig. 18).

The structures in the west are compatible with SSE-directed tectonic transport and in the Guaribe domain they are compatible with S directed thrusting. The steep attitude of the fold axes in the Guaribe transect indicates that this domain has undergone much larger contractional strain and strain rotation than the other three areas. Mesoscopic ductile structures indicating more than one deformation event were not observed. However, Neogene rocks are much less deformed than Cretaceous-Paleogene rocks. This

Figure 18. Equal-area, lower-hemisphere projection of ductile structural elements measured in the following regional transects: (1) Platillón-Tiznados; (2) Camatagüita-Valle Morín, (3) Altagracia de Orituco; and (4) San José de Guaribe. In (1): 678 poles to bedding plane (So), 81 poles to fold axial planes (AP), 81 fold axes (FA) and 21 poles to axial plane cleavages (S1). In (2): 915 poles to bedding plane (So), 156 poles to fold axial planes (AP), 180 fold axes (FA) and 68 poles to axial plane cleavages (S1). In (3): 356 poles to bedding plane (So), 3 poles to fold axial planes (AP) and 3 fold axes (FA), and poles to 14 axial plane cleavages (S1). In (4): 233 poles to bedding plane (So), 10 poles to fold axial planes (AP) and 10 fold axes (FA). See Figure 2 for location of transects.

Figure 19. Equal-area, lower-hemisphere projection of brittle structural elements measured in the following regional transects: (1) Platillón-Tiznados and (2) Camatagüita-Valle Morín. Arrows indicate relative movement of missing block. Beach balls represent lower-hemisphere moment tensor solutions for the respective group of family faults. P and T represent strain axes, P (contractional) and T (extensional). In (1): 19 thrust faults (TF); 13 left-lateral faults (LL); 11 right-lateral faults (RL); 5 normal faults (N1); 9 normal faults (N2) and 4 normal faults (N3). In (2): 41 thrust faults (FT); 29 left-lateral faults (LL); 26 right-lateral faults (RL); 6 normal faults (N1); 5 normal faults (N2) and 5 normal faults (N3). See Figure 2 for location of transects.

may indicate that at least two phases of deformation have occurred, but, due to a similar displacement field, it is likely that similar deformation structures may have formed.

Brittle deformation structures. Mesoscopic faults and slickenside striations were measured to determine the mode of deformation as well as the tectonic transport direction. Determination of the sense of slip on the faults was based on established techniques (Petit, 1987; Gamond, 1987; Ramsay and Huber, 1987). Data (Figs. 19 and 20) were plotted using FaultKin (Marret and Allmendinger, 1990, 1991, 1992; Allmendinger, 1995b).

Thrust faults in all four domains are compatible with a NW- to NNW-trending contraction axis (major principal contraction axis Z) and a subvertical extension axis (minor principal extension axis X), (Figs. 19 and 20). In the Guaribe domain, some thrust faults indicate NNE-SSW shortening (Fig. 20). Mesoscopic left- and right-lateral strike-slip faults in all domains are compatible with N-S contraction and E-W extension (Figs. 19 and 20). Several sets of mesoscopic normal faults occur in the region. They are compatible with NW-SE and NE-SW to ENE-WSW extension (Figs. 19 and 20). Crosscutting relationships suggest that the mesoscopic thrust faults formed simultaneously with the tear faults. These tear faults may be associated with regional lateral ramps (Figs. 1, 2, 6 and 14 to 17). The youngest structures are the normal faults.

In the allochthonous belts north of the right-lateral La Victoria fault (Schubert, 1988), displacement partitioning has clearly occurred (e.g., Avé Lallemant, 1997). However, south of the La Victoria fault only N-S to NW-SE contraction has occurred.

Figure 20. Equal-area, lower-hemisphere projection of brittle structural elements measured in the following regional transects: (3) Altagracia de Orituco and (4) San José de Guaribe. Arrows indicate relative movement of missing block. Beach balls represent lower-hemisphere moment tensor solutions for the respective group of family faults. P and T represent strain axes, P (contractional) and T (extensional). In (3): 18 thrust faults (TF), 9 left-lateral faults (LL), 3 right-lateral faults (RL), 3 right-lateral faults (RL') and 3 normal faults (N). In (4): 5 thrust faults (TF), 7 thrust faults (FT'), 8 left-lateral faults (LL), 8 right-lateral faults (RL), 3 normal faults (N1), and 2 normal faults (N2).

Timing of the deformation. A summary of the timing of the structures studied in the field is shown in Fig. 21. Based on structural data gathered in the field and previously discussed, there are at least three important contractional phases that affected the foreland fold belt: (1) a Middle Eocene NW-SE contraction responsible for the accretion of the Cretaceous-Tertiary turbidites and passive margin deposits into the accretionary wedge, Lara nappes, in the west; (2) a Middle to Late Miocene contractional event with a very similar strain field as that of the Eocene that involves the Oligocene-Miocene deposits in the deformation; and (3) a N-S Pliocene-Pleistocene contractional event that involves the molasse in the foreland fold belt.

Integrated geological transects

An attempt to merge the geological information obtained from field work along the four studied transects and along the depth-converted 2D seismic lines was made to assess the structural geometry of both allochthonous and autochthonous stratigraphic units and to postulate a tectonic evolution for the area (Figs. 22 to 25). On the first three integrated transects the structural relationships are shown between the allochthonous blueschists of the Villa de Cura nappes, the allochthonous-parautochthonous sequences of the Western Serranía del Interior and the autochthonous sequences of the Guárico foredeep (Figs. 22 to 24). The last transect does not show the contact of the Villa de Cura nappes and the “Piedmont belt” (Fig. 25). The structural contact between the western Serranía del Interior and the Guárico foredeep occurs along the Guárico frontal thrust (Figs. 22 to 25). The Villa de Cura nappes are interpreted as a klippe based on

Figure 21. Summary of timing of deformation for the Western Serranía del Interior.

gravimetric and magnetic models (Bosch and Rodriguez, 1992). They are in structural contact with the Western Serranía del Interior along the Cantagallo thrust (Figs. 14 to 16, 22 to 24). In the integrated Tiznados-Platillón transect, the “Piedmont belt” overrides the autochthonous sequences of the perisutural Guárico foredeep, forming a triangle-zone in the vicinity of the San Francisco de Tiznados village (Fig. 22).

The general structure consists of south-vergent hinterland-dipping imbricates that merge to a sole thrust or decollement along the basinal Oligocene horizon deforming the western Serranía del Interior and the Guárico foredeep (Figs. 22 to 26). This detachment level probably ramps down farther north since Cretaceous sequences are included in the deformation (“Piedmont belt”).

Surface expression of this decoupling level is found in the “Belt of thrust faults” or Chacual complex where Cretaceous and Tertiary rocks are intensely deformed (Fig. 25). In summary, deformation and strain are more intense in the north, within the Cretaceous-Paleogene rocks of the “Piedmont belt,” suggesting a north-south strain gradient. This intense deformation could have taken place in the Middle Eocene, prior to the final Neogene emplacement of the nappes to the south. Minor faults formed during the Cretaceous and were later reactivated during the inception of the basal foredeep unconformity due to flexure of the South American continental crust during the emplacement of the nappes. The “Piedmont belt” is projected to extend beneath the Villa de Cura nappes and in turn the Cretaceous-Paleogene basinal deposits are interpreted to extend beneath both the “Piedmont belt” and the Villa de Cura nappes. Some Neogene reverse faults are observed in the Camatagüita-Valle Morín integrated transect, affecting the Pre-Cretaceous, Cretaceous and Paleogene rocks of the Guárico basin.

On the basis of the four integrated seismic transects and the E-W trending seismic line, a hypothetical NS-trending cross section was constructed through the Caribbean-South American plate boundary zone (Fig. 26) that included interpretation of previous work in offshore Venezuela by Biju-Duval et al. (1983) in the Cordillera de la Costa and Villa de Cura belts by Ostos (1990) and in the Villa de Cura nappes by Smith et al. (1999). Figure 26 shows a southward-dipping Neogene subduction zone in the north, where the Caribbean is subducting beneath the South American plate and a northward dipping Paleogene subduction zone in the south, where the allochthons were obducted onto South America continental crust. These terranes are detached along deep decollement levels and can be considered as an orogenic float as defined by Oldow et al. (1989, 1990). The allochthonous terranes are from north to south: (1) Cretaceous-Oligocene (K-OL) in the Venezuela basin; (2) Neogene (N) sediments in the Los Roques trough, Curaçao ridge, and Venezuela; (3) Crystalline basement of the Bonaire Basin (Mz-T) that includes the Leeward islands; (4) Eocene-Miocene (E-M) and Miocene-Pliocene sediments (M-P) in the Bonaire basin; (5) Obducted Mesozoic metasediments and Paleozoic metaigneous rocks of the Caracas Group in the Cordillera de la Costa Belt (Mz) and Cretaceous Villa de Cura nappe (VDC); (6) Platform and basinal parautochthonous sedimentary rocks of the Serranía del Interior (K-T)_p; (7) Tertiary autochthonous sequences (foredeep deposits) above decollement level in the Guárico basin (T); and (8) autochthonous Cretaceous-Tertiary sequences in the Guárico basin (K-T).

Reconstruction and balancing of the integrated Caribbean-South American geological cross section uses a combination of line length and area conservation that

although not unique is consistent with the geology and its structural style (e.g., Dalstrom, 1969). The datum utilized for this restoration is the level OB (Oligocene ~32 Ma). Pinning the Caribbean-South America geological cross section to the south, in Guárico basin, the calculated minimum shortening obtained from its reconstruction is about 200 km since Oligocene times (32 Ma). A minimum calculated strain rate would be 0.6 cm/yr.

APATITE FISSION-TRACK ANALYSIS

Introduction

Apatite fission-track (AFT) analysis and modeling can yield important thermochronometric data, which can constrain several variables associated with low-temperature (~110 °C) geological events occurring at shallow levels in the earth crust such as basin subsidence, sedimentary provenance and mountain-building processes (e.g., Gallagher et al., 1998). Depth of burial, peak burial temperature and timing of peak burial temperature can be assessed, as well as cooling events associated with uplift, exhumation and erosion of buried rocks (e.g., Andriessen, 1995). The technique has been in use since the early 1960s, but relatively recent advances aid understanding of fission track annealing such as its relationship with temperature and chemistry (Naeser and Faul, 1969; Laslett et al., 1987; Carlson et al., 1999; Donelick et al., 1999; Ketcham et al., 1999) and the derivation of time-temperature paths when combined with track length data (e.g., Green et al., 1989). In this study, detrital AFT data yield new information that helps in interpreting the history of the accretionary wedge obducted onto the Guyana craton.

Figure 24. Integrated geological cross section using seismic line G5 and geological cross section from the Altagracia de Orituco transect. Legend as in figure 13

Previous work

Relatively few zircon and apatite fission-track ages have been published for north-central Venezuela. Zircon fission-track ages for samples from the Cordillera de la Costa belt are 19.7 ± 2.1 Ma (Kohn et al., 1984) and 19.8 ± 1.2 Ma (Sisson et al., 2005). AFT ages from the Cordillera de la Costa belt are 16.3 ± 1.6 Ma, 15.0 ± 1.4 Ma and 14.1 ± 1.6 Ma (Sisson et al., 2005).

AFT ages for samples of the Serranía del Interior in north-central Venezuela are 15.8 ± 2.8 , 14.2 ± 2.0 Ma and 123.5 ± 1.8 Ma (Sisson et al., 2005). In the Eastern Serranía del Interior, Locke (2001) acquired nineteen (19) AFT ages of which thirteen (13) were between about 35 and 18 Ma with peak ages decreasing from north to south and six (6) ages between about 13 and 3 Ma, indicating that two thermal events had occurred (Locke, 2001).

Methods

Sampling. Thirty samples were collected along each of the four regional transects (Platillón–Tiznados, Camatagiüita-Valle Morín, Altagracia de Orituco and San José de Guaribe) through the Western Serranía del Interior and the Guárico foreland basin. Each transect cut across the allochthonous, parautochthonous and autochthonous terranes.

Laboratory analysis. Preparation of samples for AFT analysis followed the procedures listed in Pérez (2005). Fission-track ages of apatite grains were obtained using the external detector method of Naeser and Faul (1969) and a zeta calibration factor

Figure 25. Integrated geological cross section using seismic line G6 and geological cross section from the San José de Guaribe transect. Legend as in Figure 13.

(Fleischer et al., 1975; Hurford and Green, 1983) of $\xi = 128.5 \pm 7.9$ (Pérez, 2005) relative to U-standard glass (Corning Glass, CN-1). Irradiation was done at Texas A&M University Radiation Center. Polished mounts were etched to reveal fission-tracks by immersing the mounts in a 5.5 M HNO₃ solution for 20 seconds at 21°C. The Zeta (ξ) calibration factor used in the apatite fission-track age equation is a weighted mean of ξ values calculated for the Durango de Mercado and Fish Canyon Tuff apatites relative to Corning Glass CN-1.

Following Donelick and Miller (1991), AFT wafer mounts for track length population analysis were irradiated with a 50 μCi ²⁵²Cf radioactive source in a vacuum chamber. Samples were immersed in a 5.5 M HNO₃ solution for 20 seconds at 21 °C to etch horizontal and fully confined fission-tracks within apatite crystals. AFT lengths in Fish Canyon Tuff ($14.91 \pm 0.15 \mu\text{m}$) and Durango de Mercado ($15.03 \pm 0.15 \mu\text{m}$) apatites were measured for calibration purposes. Sample preparation and AFT data measurement and analysis were performed by the author of the present study at Rice University and at Donelick Analytical, Inc. in Houston, Texas (now Apatite to Zircon, Inc. in Moscow, Idaho).

Age determination. The chemical composition of apatite is correlated with fission-track annealing kinetics (Carlson et al., 1999; Ketcham et al., 1999). Apatites with high fluorine concentration anneal faster at lower temperatures than their relatively more chlorinated counterparts (Green et al., 1986; Donelick et al., 1999). AFT analysis was performed using AFTSolve (Ketcham et al., 2000). AFTSolve allows grouping of populations of apatite crystals into kinetic classes, usually correlated with etch pit dimensions (Donelick, R., 1993, U.S. Patent Number 5,267,274 and Donelick, R., 1995,

Figure 26. Regional north-south cross-section across the Caribbean-South American plate boundary zone sho

boundary zone showing an orogenic float as defined by Oldow et al. (1989) and Oldow et al. (1990). See text for discussion.

Australian Patent Number 658,800). There is also a correlation between the chemical composition of apatite and the diameter of the etch figure parallel to crystallographic c-axis (e.g., Burtner and Nigrini, 1994; Burtner et al., 1994). Likewise, AFTSolve includes several laboratory-derived calibrations that predict fission-track response to either heating or cooling (e.g., Carlson et al., 1999). AFTSolve generates thermal histories (time-temperature paths) for a given sample by performing Monte Carlo simulations.

The resultant thermal history of a sedimentary sample depends on three factors: (1) provenance (monotonically cooling from the source to deposition in sedimentary environment), (2) burial (monotonically heating; reflecting the path from time of deposition to time of peak burial temperature) and (3) exhumation (monotonically cooling; from time of peak of burial temperature to present day conditions (Ketcham et al., 2000). The provenance segment is included in the thermal history since apatites can preserve non-reset pre-depositional fission tracks. The stratigraphic age (age of deposition) used in the determination of the time-temperature history path in all studied samples was obtained from the Códico Geológico de Venezuela (PDVSA, 2004) and from González de Juana et al. (1980). The burial segment can be calibrated against independent geological and geochemical data, i.e. stratigraphic age and vitrinite reflectance, respectively.

Using AFTSolve, forward models for each sample are made with the measured AFT age and length to determine timing of peak temperature and peak of burial temperature. Timing of peak temperature is then used as a constraint in the overall time-temperature history in the Monte Carlo simulations. The exhumation segment can be calibrated with geochemical data as well. Time-temperature paths converge to a range of

Figure 27. Modeling of apatite fission-track data for samples PFT-6 and PFT-8 in the Camatagiita-Valle Morin transect, suggesting a relatively rapid cooling that initiated at 25.1 ± 4.8 Ma (Late Oligocene and 17.1 ± 2.6 Ma (Early Miocene), respectively. These ages correspond to the time of generation and preservation of the first fission-tracks once the sample cooled and reached temperatures below ~ 100 °C.

possible solutions and are: (1) acceptable (Acceptable Fit; a broad range of solutions within a dark gray band, Figs. 27 and 28) when both the model fission track age and the model fission-track length distribution fit the measured fission track age and length with a level of confidence (Kolmogorov-Smirnov test [K-S] and Age Goodness-of-Fit) of 0.05 or greater; (2) good (Good fit; a range of solutions within a light gray band, Figs. 27 and 28) when both the model fission-track age and the model fission-track length distribution fit the measured fission track age and length with a level of confidence (K-S test and Age Goodness-of-Fit) of 0.5 or greater; and (3) best fit (black line) (Figs. 27 and 28).

AFTSolve gives an estimate of the vitrinite reflectance or maturity of the rock following the EasyRo method of Sweeney and Burnham (1990). Quality of output and its interpretation are dependent on the quality of age and track length measurements, accuracy of stratigraphy age of sample and independent geochemical studies. A pooled fission-track age is based on a statistical procedure that assumes that a population of apatite crystals within a sample underwent the same thermal history and has the same kinetics. The age of the oldest fission track denotes the earliest-formed track population in a simulation that is not fully annealed by model's end. It marks the earliest time constrained by the fission-track data. If it post-dates the onset of final cooling as set by model constraints, it indicates that the peak reheating temperature is not constrained by the AFT data. Conversely, if it predates the provenance age then it indicates that the fission-track data may contain an inherited (pre-depositional) component.

Depth of burial (z) and uplift rate (U_r) were calculated only in the Camatagüita-Valle Morín and San José de Guaribe transects. The former follows this relationship:

Figure 28. Modeling of apatite fission-track data for samples GU-1 and GU-8 in the San José de Guaribe transect, suggest cooling that initiated at 55.8 ± 5.5 Ma (Paleocene-Eocene) and 43.7 ± 5.2 Ma (Early to Middle Eocene) respectively.

$$z = (T_{\max} - 25^{\circ}\text{C})/G,$$

where z = maximum burial depth, $T_{\max}$ = peak burial temperature and G = geothermal gradient, assuming a present day temperature of 25°C . Two geothermal gradients of $27^{\circ}\text{C} / \text{km}$ and $39^{\circ}\text{C} / \text{km}$, the latter value estimated in the Yucal-Placer field (Daal and Lander, 1993) was used in the calculations. It is assumed that the geothermal gradient has been constant since the emplacement of the tectonic slivers in the Neogene, since there is no data regarding paleogradients in the area.

The uplift rate (U_r) follows this relationship:

$$U_r = z / t_c,$$

where U_r = uplift rate, z = burial depth and t_c = timing of cooling event.

As it was discussed above, the timing of the cooling event is not given by the oldest track but by the model constraints. If the oldest track is younger than the re-heating time constraint, then t_c should be the time of this constraint, as it is the time at which $T_{\max}$ was reached. Conversely, if the oldest track is younger than the re-heating time constraint, then the peak temperature is basically unconstrained. In this case, $T_{\max}$ should be the temperature at the time given by the oldest track, not the time of the re-heating constraint.

Figure 29. Tectonic model for north central Venezuela. This cartoon shows how an Eocene apatite fission-track age can be preserved. Fission tracks form continuously within a uranium-238-bearing host crystal (e.g. apatite). All fission tracks within a detrital apatite at temperatures well above ~110 °C will anneal. As soon as there is a geological event (e.g., generation of a perisutural foreland fold and thrust belt), the apatite fission-tracks in the rocks that are uplifted and cooled below ~110 °C will be preserved and therefore will time the thrusting event. Subsequent younger events can be preserved in this very same manner. However, the loading of an allochthonous terrane on top of the hinterland portion of the belt (i.e. the one preserving an Eocene cooling event) could cause the preserved Eocene cooling ages to anneal at temperatures above ~110 °C.

Results of present study

One hundred and twenty samples were collected: 30 in each of the four transects. The samples of the Altagracia de Orituco area are still pending for future analysis. Of the 90 remaining samples, 56 yielded enough apatite to obtain fission-track ages. Of the latter group, only 37 samples had enough good quality track lengths for apatite fission-track modeling. Table 2 shows a summary of the apatite fission-track ages. Table 3 summarizes apatite fission-track length data for all apatite grains. A summary of thermal histories and implications of the AFT data for 37 samples is presented in Table 4. Pooled AFT ages, oldest track ages and calculated vitrinite reflectance for selected samples are shown in Figs. 27 and 28.

Stratigraphic ages for the units of the Serranía were obtained from previous published reports (e.g., González de Juana et al., 1980).

Platillón–Tiznados transect. In the Platillón-Tiznados area (Fig. 14), siliciclastic samples yielded enough apatite for fission-track age analysis (PFT-37 to PFT-65). No mounts for AFT length analysis were prepared. Therefore, no estimates of peak burial temperatures, time of peak burial and depth of burial could be assessed.

In the Platillón-Tiznados area, pooled AFT ages obtained in samples of the Mucaria, Garrapata and Guárico Formations in the “Piedmont belt” (allochthonous-parautochthonous terranes) range from 26.5 ± 4.8 to 13 ± 2.4 Ma (Late Oligocene to Middle Miocene; Table 3, PFT-37 to PFT-49). These ages are younger than the stratigraphic ages of the sampled units (Tables 2 and 3), suggesting a cooling event associated with mountain building processes that started in the area in the Late

Oligocene, that is the emplacement of the Serranía del Interior nappes onto the South American autochthonous terranes. In this transect, there is an apparent cooling age gradient, Late Oligocene to the north and Middle Miocene ages to the south (Fig. 14).

AFT ages from the Galera Member of the Quebradón and Quiamare Formations in the “Belt of overturned beds” (autochthonous- parautochthonous terrane) are as old as or older than their estimated stratigraphic age (PFT-53, 55 and 61), suggesting influence from the provenance, in this case Eocene-Oligocene (Tables 2 and 4).

Camatagüita-Valle Morín transect. In the “Piedmont belt” of the Camatagüita-Valle Morín transect (Fig. 15), samples collected from the Cretaceous-Tertiary units (Garrapata-Guárico Formations) clearly show reset AFT ages (stratigraphic age is greater than the fission-track age; Tables 2 and 4). Pooled AFT ages range from 21.3 ± 2.8 to 14.5 ± 2.2 Ma (Early to Middle Miocene; PFT-6 to PFT 25). Modeling of AFT data and track length using AFTSolve suggests that the time of the cooling event ranges from Late Oligocene to Middle Miocene where peak temperatures reached well above ~ 110 °C, enough to reset all previous/older cooling events (Figs. 15, 27 and Table 4).

Estimates of vitrinite reflectance or EasyRo calculated by AFTSolve, following Sweeney and Burnham (1990), suggest that all samples are mature to overmature ($>0.65 \pm 0.01\%$ in all study samples). No independent vitrinite reflectance analysis was undertaken in the samples to constrain such estimates. Estimates of cooling rates for the samples range from 4 to 8 °C / my, with values clustering between 7 and 8 °C / my for four samples and 4 and 5 °C / my for three samples.

The best temperature of burial calculated from the modeling algorithm AFTSolve provides an estimate of maximum depth of burial given a particular geothermal gradient.

TABLE 3. SUMMARY OF APATITE FISSION-TRACK LENGTH DATA

Sample ID	Sample Location	Tracks	Mean Length (μm)	Standard Deviation (μm)	0.1 (μm)	1.3 (μm)	2.3 (μm)	3.4 (μm)	4.5 (μm)	5.6 (μm)	6.7 (μm)	7.8 (μm)	8.9 (μm)	9.10 (μm)	10.11 (μm)	11.12 (μm)	12.13 (μm)	13.14 (μm)	14.15 (μm)	15.16 (μm)	16.17 (μm)	17.18 (μm)	18.19 (μm)	19.20 (μm)
1	PFT-00	CAM	13	13.49 $\pm$ 0.53	1.84	2.22	0.63																	
2	PFT-01	CAM	5	13.08 $\pm$ 0.86	1.76	2.16	0.67																	
3	PFT-02	CAM	5	14.43 $\pm$ 0.89	1.26	2.36	0.74																	
4	PFT-03	CAM	3	13.23 $\pm$ 1.32	3.23	2.01	0.36																	
5	PFT-12	CAM	7	11.22 $\pm$ 2.86	4.06	1.71	0.36																	
6	PFT-13	CAM	3	11.17 $\pm$ 0.65	2.77	1.2	0.65																	
7	PFT-15	CAM	3	13.24 $\pm$ 0.63	1.76	1.8	0.65																	
8	PFT-17	CAM	3	11.22 $\pm$ 2.86	4.06	1.71	0.36																	
9	PFT-18	CAM	3	11.17 $\pm$ 0.65	2.77	1.2	0.65																	
10	PFT-20	CAM	3	13.24 $\pm$ 0.63	1.76	1.8	0.65																	
11	PFT-31	CAM	29	12.20 $\pm$ 0.61	3.24	2.05	0.52																	
12	PFT-33	CAM	12	13.53 $\pm$ 1.2	3.96	2.25	0.46																	
13	PFT-25	CAM	12	13.53 $\pm$ 1.2	3.96	2.25	0.46																	
14	PFT-26	CAM	27	12.86 $\pm$ 0.49	2.49	1.81	0.45																	
15	PFT-29	CAM	64	11.81 $\pm$ 0.36	3	2.04	0.42																	
16	PFT-37	PTZ	-	-	-	-	-																	
17	PFT-38	PTZ	-	-	-	-	-																	
18	PFT-42	PTZ	-	-	-	-	-																	
19	PFT-43	PTZ	-	-	-	-	-																	
20	PFT-44	PTZ	-	-	-	-	-																	
21	PFT-45	PTZ	-	-	-	-	-																	
22	PFT-47	PTZ	-	-	-	-	-																	
23	PFT-48	PTZ	-	-	-	-	-																	
24	PFT-53	PTZ	-	-	-	-	-																	
25	PFT-54	PTZ	-	-	-	-	-																	
26	PFT-61	PTZ	-	-	-	-	-																	
27	PFT-66	PTZ	-	-	-	-	-																	
28	OU-01	SJO	102	11.77 $\pm$ 0.31	3.13	2.05	0.74																	
29	OU-02	SJO	100	11.82 $\pm$ 0.32	3.16	2.01	0.74																	
30	OU-03	SJO	101	13.36 $\pm$ 0.2	2.03	2.23	0.87																	
31	OU-04	SJO	17	9.48 $\pm$ 0.9	3.96	1.61	0.45																	
32	OU-05	SJO	100	11.89 $\pm$ 0.3	3.06	1.82	0.65																	
33	OU-06	SJO	100	11.89 $\pm$ 0.3	3.06	1.82	0.65																	
34	OU-07	SJO	80	10.98 $\pm$ 0.35	3.1	1.51	0.44																	
35	OU-08	SJO	100	12.04 $\pm$ 0.27	2.72	1.66	0.47																	
36	OU-09	SJO	18	12.22 $\pm$ 0.47	1.62	1.57	0.49																	
37	OU-10	SJO	107	11.71 $\pm$ 0.26	2.86	1.64	0.44																	
38	OU-11	SJO	56	11.62 $\pm$ 0.37	2.82	1.56	0.45																	
39	OU-12	SJO	-	-	-	-	-																	
40	OU-13	SJO	26	10.04 $\pm$ 0.43	2.26	1.73	0.47																	
41	OU-14	SJO	26	10.04 $\pm$ 0.43	2.26	1.73	0.47																	
42	OU-15	SJO	97	9.58 $\pm$ 0.18	1.86	1.66	0.41																	
43	OU-16	SJO	-	-	-	-	-																	
44	OU-17	SJO	8	10.04 $\pm$ 0.85	2.5	1.5	0.42																	
45	OU-18	SJO	64	10.82 $\pm$ 0.37	2.84	1.72	0.5																	
46	OU-19	SJO	44	10.87 $\pm$ 0.32	2.07	1.67	0.4																	
47	OU-20	SJO	30	10.22 $\pm$ 0.50	2.99	1.8	0.46																	
48	OU-21	SJO	6	8.62 $\pm$ 0.64	1.44	1.53	0.39																	
49	OU-22	SJO	114	10.52 $\pm$ 0.18	1.75	1.69	0.4																	
50	OU-23	SJO	34	9.83 $\pm$ 0.13	1.72	1.69	0.4																	
51	OU-24	SJO	8	9.83 $\pm$ 0.13	1.72	1.69	0.4																	
52	OU-25	SJO	10	10.81 $\pm$ 0.68	2.08	1.76	0.42																	
53	OU-26	SJO	1	8.65 $\pm$ 1.39	0.34	-	-																	
54	OU-27	SJO	2	9.4 $\pm$ 2.95	2.95	1.75	0.44																	
55	OU-28	SJO	-	-	-	-	-																	
56	OU-29	SJO	22	10.4 $\pm$ 0.5	2.77	1.85	0.43																	

Table 3. Summary of the apatite fission-track length data for all apatite grains combined

Table 5 shows such estimates for modeled samples of the track-reset Cretaceous-Tertiary Garrapata and Guárico Formations, assuming two geothermal gradients of 27°C / km and 39°C / km as estimated for the Yucal-Placer field (Daal and Lander, 1993).

Results suggest that depth of burial for the samples range from 3 km to 5 km for a geothermal gradient of 27 °C / km and from 2 to 4 km when the geothermal gradient is 39 °C / km. These depths of burial values may be equivalent to the thickness of the sedimentary section eroded since the onset of the deformation. Thus, erosion may have removed up to 5 km of sediment.

A summary of calculated uplift rates for the Garrapata and Guárico Formations samples is shown in Table 6. Uplift rates vary from 0.11 to 0.30 mm/yr for a geothermal gradient of 27 °C / km and from 0.08 to 0.21 mm/yr for a geothermal gradient of 39°C / km. One sample collected in the Neogene Galera Member of the Quebradón Formation in the “Belt of overturned beds” yields an apatite fission-track age (PFT-2, 81.9 ± 6.6 Ma) that is older than its stratigraphic age (Table 4). This AFT age suggests that burial, subsidence and subsequent heating of this sample was not enough to anneal completely any previous thermal events. The latter age is influenced by the provenance.

No evident age-gradient is observed from north to south along the Camatagüita-Valle Morín transect. Almost all ages are similar within a small statistical error.

TABLE 4. SUMMARY OF APATITE FISSION-TRACK THERMAL HISTORY

Sample Number	Formation	Age (My)	Transect	Surface Temperature (°C)	Timing of Peak Temperature (Ma)	Timing of Cooling Events	Timing of Cooling Events*	Peak Burial Temperature	Peak Burial Temperature (Best)	Cooling Rate °C/My	EasyRo (% Reflectance)
PFT-6	Garrapata	86	CAM	25	25.0	25.1±4.8	25.1	125-172°C; best = 134°C	134.0	4.3	>0.85±0.02
PFT-8	Guárico	63	CAM	25	17.4	17.1±2.6	17.1	117-180°C; best = 146°C	146.0	7.1	>0.78±0.01
PFT-12	Guárico	63	CAM	25	12.8	13.2±1.8	13.2	102-179 °C; best = 127°C	127.0	7.7	>0.67±0.01
PFT-13	Guárico	63	CAM	25	15.0	16.8±1.0	16.8	105-184°C; best = 120°C	120.0	5.7	>0.70±0.01
PFT-17	Guárico	63	CAM	25	28.0	25.1±3.8	25.1	97-187°C; best = 115°C	115.0	3.6	>0.65±0.01
PFT-19	Guárico	63	CAM	25	20.0	17.0±4.2	17.0	104-187°C; best = 164°C	164.0	8.2	>0.65±0.01
PFT-20	Guárico	63	CAM	25	24.0	21.1±3.6	21.1	94-184°C; best = 162°C	162.0	6.5	>0.65±0.01
PFT-23	Guárico	63	CAM	25	21.0	18.7±1.2	19.7	103-183°C; best = 117°C	117.0	4.7	>0.70±0.01
PFT-25	Guárico	63	CAM	25	16.7	16.5±1.0	16.5	103-188°C; best = 136°C	136.0	6.7	>0.68±0.01
PFT-28	Roblecito	32	CAM	25	29.0	33.0±4.2	33.0	108-160°C; best = 124°C	124.0	3.0	>0.77±0.01
PFT-29	Guárico	63	CAM	25	23.0	21.8±2.2	21.8	123-147°C; best = 128°C	128.0	4.7	>0.77±0.01
GU-1	Garrapata	86	SJG	25	45.0	55.8±5.5	55.8	119-130°C; best = 128°C	128.0	1.8	>0.80±0.01
GU-2	Garrapata	86	SJG	25	59.0	59.2±5.8	59.2	120-142°C; best = 128°C	129.0	1.8	>0.79±0.01
GU-3	Guárico	63	SJG	25	43.0	43.7±3.8	43.7	127-169°C; best = 139°C	139.0	2.6	>0.82±0.01
GU-4	Guárico	63	SJG	25	58.0	55.5±1.1	55.5	91-183°C; best = 107°C	107.0	1.5	>0.63±0.01
GU-5	Guárico	63	SJG	25	42.0	39.3±7.6	39.3	143-167°C; best = 162°C	162.0	3.5	>1.43±0.01
GU-6	Guárico	63	SJG	25	56.0	47.8±7.4	47.8	86-168°C; best = 144°C	144.0	2.5	>1.00±0.02
GU-7	Guárico	63	SJG	25	54.0	49.3±7.4	49.3	84-151°C; best = 144°C	144.0	2.4	>1.00±0.02
GU-8	Guárico	63	SJG	25	48.0	45.6±5.2	45.6	100-156°C; best = 108°C	108.0	1.8	>0.64±0.01
GU-9	Guárico	63	SJG	25	45.0	35.1±5.2	35.1	98-175°C; best = 102°C	102.0	2.2	>0.64±0.00
GU-10	Guárico	63	SJG	25	28.0	25.0±4.4	25.0	101-135°C; best = 109°C	109.0	3.4	>0.63±0.00
GU-11	Guárico	63	SJG	25	40.0	37.7±7.4	37.7	96-173°C; best = 106°C	106.0	2.1	>0.63±0.00
GU-13	Naricual	23	SJG	25	14.8	35.4±6.0	35.4	98-119°C; best = 107°C	107.0	0.2	>0.75±0.02
GU-14	Naricual	23	SJG	25	14.5	54.3±7.2	54.3	59-110°C; best = 90°C	90.0	0.1	>0.75±0.02
GU-15	Naricual	23	SJG	25	14.5	315.0±28	315.0	91-108°C; best = 83°C	93.0	0.2	>0.63±0.01
GU-17	Quebradón	20	SJG	25	14.5	52.1±6.1	52.1	90-130°C; best = 108°C	108.0	1.6	>0.78±0.01
GU-18	Quebradón	20	SJG	25	14.5	44.4±4.2	44.4	102-122°C; best = 104°C	104.0	1.8	>0.78±0.01
GU-19	Quebradón	20	SJG	25	14.5	49.4±5.8	49.4	93-113°C; best = 104°C	104.0	1.6	>0.69±0.01
GU-20	Quilamare	20	SJG	25	14.5	65.6±4.8	65.6	101-127°C; best = 104°C	104.0	1.2	>0.69±0.01
GU-21	Quilamare	20	SJG	25	14.5	141±23	141.0	105-131°C; best = 124°C	124.0	0.7	>0.80±0.01
GU-22	Quilamare	20	SJG	25	14.5	104±16	104.0	81-98°C; best = 81°C	81.0	0.5	>0.63±0.01
GU-23	Quilamare	20	SJG	25	14.5	43.5±9	43.5	87-112°C; best = 97°C	97.0	1.7	>0.64±0.01
GU-24	Quilamare	20	SJG	25	14.5	289±43.9	289.0	72-105°C; best = 98°C	98.0	0.3	>0.65±0.01
GU-25	Quilamare	20	SJG	25	14.5	153±14.1	153.0	81-108°C; best = 96°C	96.0	0.5	>0.65±0.01
GU-26	Quilamare	20	SJG	25	14.5	38.6±11.2	38.6	54-120°C; best = 109°C	109.0	2.2	>0.69±0.01
GU-28	Quilamare	20	SJG	25	14.5	31.4±4.4	31.4	104-125°C; best = 120°C	120.0	3.0	>0.69±0.01
GU-29	Quilamare	20	SJG	25	14.5	91±11	91.0	101-117°C; best = 104°C	104.0	0.9	>0.69±0.01

Table 4. Summary of thermal history of apatite fission-track data for selected samples. Timing of peak temperature, timing of cooling events, peak burial temperature and estimated Easy Ro (% reflectance) obtained by modeling apatite fission-track age and length data in AFTSolve.

San José de Guaribe transect. AFT data in samples collected along the San José de Guaribe transect show cooling ages that are older than those of the previously studied transects but still younger than the stratigraphic ages (Figs. 17, 28 and Table 4). They do not seem to fit previous models for the interaction of the Caribbean-South American plates in northern Venezuela and the subsequent mountain building process. Samples collected along the “Piedmont belt” in the siliciclastic units Guárico Formation and in a unit lithologically similar to the Garrapata Formation yield pooled AFT ages that range from 44.1 ± 5.4 Ma to 16.2 ± 2.9 Ma (Early Eocene to Middle Miocene (GU-1 to GU-11; Table 2 and 4). Thermal histories for 24 out of 26 studied samples have K-S tests and Age GOF of 0.5 or greater indicating a high level of confidence. Time of cooling events for the Garrapata and the Guárico Formations obtained from the models is ~ 45 Ma.

The Venezuelan geological literature (e.g., Gonzalez de Juana et al., 1980) suggests that the age of the Guárico Formation ranges from Late Cretaceous to Early Eocene. However, Erlich and Barret (1992) suggest that the formation is as young as Late Paleocene. Thus, the stratigraphic age of the samples may be older than the cooling events. Table 5 shows paleodepth or burial depth estimates for modeled samples of the track-reset Cretaceous-Tertiary Garrapata and Guárico Formations assuming two geothermal gradients, $27^{\circ}\text{C} / \text{km}$ and $39^{\circ}\text{C} / \text{km}$, as estimated for the Yucal-Placer field (Daal and Lander, 1993). As in the Camatagüita-Valle Morín transect, the geothermal gradient is assumed constant since the emplacement of the tectonic slivers in the Neogene.

As in the Camatagüita-Valle Morín transect, results suggest that depth of burial for the samples range from 3 km to 5 km for a geothermal gradient of $27^{\circ}\text{C} / \text{km}$ and

TABLE 5. DEPTH OF BURIAL

Sample Number	Formation	Transect	Surface Temperature (°C)	Peak Burial Temperature from AFTSolve modeling (°C)	Depth of Burial Geothermal Gradient of 27 °C / Km	Depth of Burial Geothermal Gradient of 39 °C / Km	EasyRo (% Reflectance)
PFT-6	Garrapata	CAM	25	134	4	3	>0.85 ± 0.01%
PFT-8	Guárico	CAM	25	146	4	3	>0.78 ± 0.01%
PFT-12	Guárico	CAM	25	127	4	3	>0.67 ± 0.01%
PFT-13	Guárico	CAM	25	120	4	2	>0.70 ± 0.01%
PFT-17	Guárico	CAM	25	115	3	2	>0.65 ± 0.01%
PFT-19	Guárico	CAM	25	164	5	4	>0.65 ± 0.01%
PFT-20	Guárico	CAM	25	164	5	4	>0.65 ± 0.01%
PFT-23	Guárico	CAM	25	117	3	2	>0.70 ± 0.01%
PFT-25	Guárico	CAM	25	136	4	3	>0.68 ± 0.01%
PFT-28	Guárico	CAM	25	124	4	3	>0.77 ± 0.01%
PFT-29	Guárico	CAM	25	128	4	3	>0.67 ± 0.01%
GU-1	Garrapata	SJG	25	128	4	3	>0.80 ± 0.01%
GU-2	Garrapata	SJG	25	129	4	3	>0.79 ± 0.01%
GU-3	Guárico	SJG	25	139	4	3	>0.82 ± 0.01%
GU-4	Guárico	SJG	25	107	3	2	>0.63 ± 0.01%
GU-5	Guárico	SJG	25	162	5	4	>1.43 ± 0.01%
GU-6	Guárico	SJG	25	144	4	3	>1.00 ± 0.02%
GU-7	Guárico	SJG	25	144	4	3	>1.00 ± 0.02%
GU-8	Guárico	SJG	25	106	3	2	>0.64 ± 0.01%
GU-9	Guárico	SJG	25	102	3	2	>0.64 ± 0.00%
GU-10	Guárico	SJG	25	109	3	2	>0.63 ± 0.00%
GU-11	Guárico	SJG	25	106	3	2	>0.63 ± 0.00%
GU-13	Naricual	SJG	25	107	3	2	>0.75 ± 0.02%
GU-14	Naricual	SJG	25	90	2	2	>0.75 ± 0.02%
GU-15	Naricual	SJG	25	93	3	2	>0.63 ± 0.01%
GU-17	Quebradón	SJG	25	108	3	2	>0.78 ± 0.01%
GU-18	Quebradón	SJG	25	104	3	2	>0.69 ± 0.01%
GU-19	Quebradón	SJG	25	104	3	2	>0.69 ± 0.01%
GU-20	Quilamare	SJG	25	104	3	2	>0.69 ± 0.01%
GU-21	Quilamare	SJG	25	124	4	3	>0.80 ± 0.01%
GU-22	Quilamare	SJG	25	81	2	1	>0.63 ± 0.01%
GU-23	Quilamare	SJG	25	97	3	2	>0.64 ± 0.01%
GU-24	Quilamare	SJG	25	98	3	2	>0.65 ± 0.01%
GU-25	Quilamare	SJG	25	96	3	2	>0.65 ± 0.01%
GU-26	Quilamare	SJG	25	109	3	2	>0.68 ± 0.01%
GU-28	Quilamare	SJG	25	120	4	2	>0.69 ± 0.01%
GU-29	Quilamare	SJG	25	104	3	2	>0.69 ± 0.01%

Table 5. Calculation of depth of burial given Peak Burial Temperatures calculated from AFTSolve and possible geothermal gradients, for samples in the Camatagüita-Valle Morín and San José de Guaribe transects.

from 2 to 4 km for a geothermal gradient of $39\text{ }^{\circ}\text{C} / \text{km}$. Depth of burial values may be equivalent to the thickness of the sedimentary section eroded since the onset of the deformation. Thus, the maximum thickness of sedimentary rocks removed by erosion could be as high as 5 km. Uplift rates vary from 0.07 to 0.13 mm/yr for a geothermal gradient of $27\text{ }^{\circ}\text{C} / \text{km}$ and from 0.05 to 0.09 mm/yr for a geothermal gradient of $39\text{ }^{\circ}\text{C} / \text{km}$. These calculated uplift rates are small because the time of the cooling events (Eocene) is considered in the calculations.

Samples of the Neogene Naricual, Quebradón and Quiamare Formations collected along the “Belt of thrusts faults,” “Belt of overturned beds,” and “Belt of gently dipping beds,” yield AFT ages influenced by provenance, because their stratigraphic ages are younger than their estimated cooling ages. The provenance of these rocks might have had many sources varying from the Guyana craton in the south, to the emerging mountain range to the north. Samples from the Naricual Formation yielded both Paleozoic and Eocene AFT cooling ages (Tables 2 and 4). Thus, the sampled sedimentary rocks of the Neogene Naricual, Quebradón and Quiamare Formations involved in the “Belt of thrust faults,” “Belt of overturned beds” and “Belt of gently dipping beds” (Guárico Basin) never reached temperatures higher than $110\text{--}150\text{ }^{\circ}\text{C}$, temperatures necessary to completely obliterate evidence of former thermal events. Therefore, for thermal gradients $27\text{ }^{\circ}\text{C} / \text{km}$ and $39\text{ }^{\circ}\text{C} / \text{km}$, the maximum depth of burial varies between 2 to 4 km and 1 to 3 km, respectively (Table 5). AFTSolve analysis indicates that for the model to converge to an acceptable or good time-temperature path solution, the non-reset samples of the “Belt of thrust faults,” “Belt of overturned beds” and “Belt of gently dipping beds” should have had an approximate timing of cooling events at $\sim 15\text{ Ma}$.

TABLE 6. UPLIFT RATES

Sample Number	Formation	Transect	Time of cooling event (Ma)	Time of cooling event (Ma). Only central value	Depth of Burial (Geothermal Gradient of 27 °C / Km)	Uplift Rate mm /yr (Geothermal Gradient of 27 °C / Km)	Depth of Burial (Geothermal Gradient of 39 °C / Km)	Uplift Rate mm /yr (Geothermal Gradient of 39 °C / Km)
PFT-6	Garapala	CAM	25.1±4.8	25.1	4	0.16	3	0.11
PFT-8	Guárico	CAM	17.1±2.6	17.1	4	0.26	3	0.18
PFT-12	Guárico	CAM	13.2±1.8	13.2	4	0.29	3	0.20
PFT-13	Guárico	CAM	18.8±1.0	18.8	4	0.21	2	0.14
PFT-17	Guárico	CAM	25.1±3.8	25.1	3	0.13	2	0.09
PFT-19	Guárico	CAM	17.0±4.2	17	5	0.30	4	0.21
PFT-20	Guárico	CAM	21.1±3.6	21.1	5	0.24	4	0.17
PFT-23	Guárico	CAM	19.0±1.2	19	3	0.18	2	0.12
PFT-25	Guárico	CAM	16.5±1.0	16.5	4	0.25	3	0.17
PFT-28	Guárico	CAM	33.0±4.2	33	4	0.11	3	0.08
PFT-29	Guárico	CAM	21.8±2.2	21.8	4	0.17	3	0.12
GU-1	Garapala	SJG	55.8 ±5.5	55.8	4	0.13	3	0.05
GU-2	Garapala	SJG	59.2±5.8	59.2	4	0.07	3	0.05
GU-3	Guárico	SJG	43.7±3.8	43.7	4	0.10	3	0.07
GU-4	Guárico	SJG	55.5±1.1	55.5	3	0.05	2	0.04
GU-5	Guárico	SJG	39.3±7.6	39.3	5	0.13	4	0.09
GU-6	Guárico	SJG	47.8±7.4	47.8	4	0.09	3	0.06
GU-7	Guárico	SJG	49.3±7.4	49.3	4	0.09	3	0.06
GU-8	Guárico	SJG	45.6±5.2	45.6	3	0.07	2	0.05
GU-9	Guárico	SJG	35.1±5.2	35.1	3	0.08	2	0.06
GU-10	Guárico	SJG	25.0±4.4	25	3	0.12	2	0.09
GU-11	Guárico	SJG	37.7±7.4	37.7	3	0.08	2	0.06

Table 6. Calculation of uplift rates given depth of burial and timing of cooling events calculated from AFTSolve and possible geothermal gradients, for samples in the Camataguita-Valle Morin and San José de Guaribe transects.

Pooled AFT ages and oldest track ages suggest a north-south cooling-age gradient within the “Piedmont belt” of the San José de Guaribe section (Fig. 17). Pooled AFT ages range from Middle Eocene in the north, to Late Oligocene in the south. Likewise, oldest track ages range from Middle Eocene in the north, to Late Oligocene in the south. This suggests that the uplift, cooling and exhumation of the accretionary wedge occurred in the Middle Eocene. Thus, the emplacement of a southward-vergent folded foreland belt may have started in the Middle Eocene.

As previously mentioned, Locke (2001) suggested that in eastern Serranía del Interior there is a Middle Eocene-Early Miocene north-south AFT cooling age gradient. Although Locke (2001) sampled units that differ in age and depositional environment from those analyzed in this work, it is interesting to note that the events are younger from west to east and from north to south beginning in San José de Guaribe continuing to Locke’s (2001) regional transect in the eastern Serranía del Interior. The Middle Eocene-Late Oligocene pooled AFT north-south age gradient in the “Piedmont belt” of the Guaribe transect compares well to the Middle Eocene-Early Miocene pooled AFT north-south age gradient in Locke’s (2001) regional transect.

Discussion of the AFT study

Fission-track data generated and analyzed in this study suggest that an important mountain building process was active in north-central Venezuela from, at least, the Late Oligocene time and throughout the Neogene. Middle Miocene AFT ages are related to the final obduction of the Lara and the Western Serranía del Interior nappes. The Cordillera

de la Costa belt was rising and eroding as well, as indicated by several Middle Miocene AFT ages (Avé Lallemant and Sisson, 1993). It is possible that the final obduction of the allochthonous nappes onto continental South America in the Middle Miocene is related to a flip in subduction polarity from a north- to south-dipping. The stratigraphic record and structural analysis of this study suggest that the mountain building process did not stop during the Middle Miocene. Instead, it continued possibly until the Plio-Pleistocene, as the Early-Late Miocene Quiamare Formation is included in the Serranía del Interior foreland fold and thrust belt and as the Guárico basin was tilted to the east marking the inception of a foredeep in northeastern South America.

The Late Oligocene-Middle Miocene signatures observed in the apatite grains (Pérez de Armas, 1998; Pérez de Armas, 2005) suggest that the Roblecito foredeep was involved in the deformation during the Late Oligocene cooling event. The Oligocene time of peak burial, peak burial temperature and depth of burial of the allochthonous-parautochthonous accretionary wedge (Querecual, Garrapata and Guárico Formations) in the Camatagüita-Valle Morín area and possibly the Platillón-Tiznados area can be associated with the arrival of the Villa de Cura nappes in north-central Venezuela. Clearly, AFT data from the Villa de Cura nappes are needed to support this statement. On-going contraction between the North and South American plates and their westward motion with respect to the Caribbean plate caused the subsequent south-directed tectonic transport of the nappes of the western Serranía del Interior in the Miocene. This is the time of the inception of the foredeep in eastern Venezuela (Hung, 1997).

The cooling ages obtained in rocks of the “Piedmont belt” in the San José de Guaribe transect do not follow the same pattern observed in the western transects and

also do not fit with recent models proposed for the Caribbean-South America plate boundary (e.g., Pindell et al., 1998). AFT ages were not reset during the Miocene and there is a north-south apatite fission-track cooling age gradient from Middle Eocene to Late Oligocene. One possible explanation for these Eocene cooling ages is that in eastern Venezuela deformation began during the Middle Eocene due to North and South American plate convergence (Pindell, 1997; Pindell et al., 1998). Therefore, it is possible that eastern Venezuela was no longer a passive margin at that early time. Convergence between North and South America started during the Paleocene and by Middle Eocene time shortening could have been about 70 km (e.g., Pindell, 1997). Pindell (1997) and Pindell et al., (1998) suggest that contraction between the North and South American plates could have deformed the Proto-Caribbean crust. A subduction zone may have formed already in the Eocene causing subsequent early uplift of the Cordillera de la Costa and possibly of the northern Serranía as early as Early Paleocene.

The recognition of deformation in eastern Venezuela since the Paleogene does not preclude the generation of a roughly N-S oriented forearc basin in northwestern Venezuela as a result of the interaction of the Caribbean and South American plates. Therefore, it is possible that there was an evolving south-vergent foreland fold and thrust belt and associated foredeep along northern Venezuela during most of the Paleogene (Lugo and Mann, 1995).

Alternatively, AFT ages in the Garrapata and Guárico Formations along the San José de Guaribe transect may reflect the influence of provenance. Non-reset AFT age values may suggest that the cooling event represents a thermal event of the provenance rock, possibly caused by the emplacement of the Lara nappes in western Venezuela.

However, a question still lingers as to how these cooling ages were preserved in the rocks within the Piedmont zone in the San José de Guaribe transect while the same rock types to the west, in the Camatagua-Valle Morín and Platillón-Tiznados transects, underwent burial causing the previous thermal events to be reset.

TECTONIC MODEL

According to most plate tectonic models for the Proto-Caribbean and Caribbean lithosphere (e.g., Pindell et al., 1998), the North and South American plates rifted apart during Jurassic and Lower Cretaceous time as a result of the break-up of the super continent Pangea (Bartok, 1993). Upper Jurassic and Lower Cretaceous sediments were deposited on the passive continental margin of South America. In Paleocene-Eocene time North and South America started to converge again. As a result of this convergence, the northern margin of South America evolved from a passive margin to a foredeep as suggested by Pindell et al. (1998).

Beck (1978) suggested on the basis of sedimentary structures that the Serranía del Interior fold and thrust belt and the Guárico basin underwent two phases of contraction: first in the Eocene and later in the Miocene. The Eocene cooling ages derived from the AFT data in the eastern part of the study area (San José de Guaribe) are consistent with Beck's model and with the N-S convergence. New $^{40}\text{Ar}/^{39}\text{Ar}$ ages record exhumation of the Cordillera de la Costa belt in the Eocene as well (Sisson et al., 2005). The Cretaceous/Paleogene sedimentary rocks were probably incorporated in the accretionary wedge and deformed in the Eocene. The Cretaceous/Paleogene rocks of the "Piedmont

belt” in the north are more intensely deformed than the rocks in the south. The deformation that affected the younger rock sequences started in the Neogene and continued through the Plio-Pleistocene.

The Cretaceous and Paleogene rocks in the western part of the study area were uplifted, eroded and exhumed and they went through the AFT annealing temperature of 110 °C in the Late Oligocene through the Middle Miocene (Fig. 29). Initiation of mountain building occurred in Late Oligocene, west of the site of its final emplacement that occurred in the Middle Miocene. This is the time that the Leeward Antilles and the allochthonous Caribbean terranes collided with South America (e.g., Pindell, 1998). The final obduction of the allochthonous nappes onto continental South America in Middle Miocene time marks the flip in the polarity of the subduction from a north-dipping Paleogene subduction to a south-dipping Benioff subduction zone (e.g., Fig. 9 of Avé Lallemant, 1997). Likewise, the inception of the basal foredeep unconformity in the eastern Venezuela basin occurred in Early Miocene. An Early to Middle Miocene tectonic event is recorded as well, offshore of north-central Venezuela. Here, Paleogene extensional structures north of the Margarita-Los Testigos high, La Tortuga, La Blanquilla basins and Cubagua sub-basin were inverted (Ysaccis, 1997). Biological evidence suggests that major divergence in marine species of stingrays occurred in northern South America as a result of physiographical isolation during the Miocene (Lovejoy et al., 1998). Fresh-water stingray species can be observed in the Platillón and Tiznados Rivers today.

Any pre-Oligocene fission tracks in the Cretaceous-Paleogene rocks from the Platillón-Tiznados and Camatagüita-Valle Morín transects must have been completely

annealed prior to the Late Oligocene-Middle Miocene events. Only in the San José de Guaribe area, AFT ages were not reset. Here, the rocks in the Paleogene accretionary wedge did not get hot enough for the fission tracks to be completely annealed. The accretionary wedge may have formed as the result of N-S convergence of the Americas. Pindell et al. (1998) suggested that a sutural basin might have formed along the margin of central and eastern Venezuela prior to the emplacement of the nappes. The collision of the Leeward Antilles volcanic arc caused the Villa de Cura nappes to be obducted and thrust to the south. Final emplacement of the nappes uplifted the entire northern margin resetting the apatite thermochronometer and resulting in the Middle Miocene ages observed in the Cordillera de la Costa belt. More AFT data of rocks along the Villa de Cura nappes are needed to better constrain its cooling history and to corroborate the hypothesis that the final obduction of this allochthonous terrane occurred in the Middle Miocene (Fig. 29). The thrust faults along which the allochthonous belts (inclusive of the Villa de Cura nappes) were emplaced can be considered as out-of sequence or envelopment thrusts, but, of course, there is considerable time between the two events.

As noted above, during Early to Middle Miocene, metamorphic rocks of the accretionary wedge, specifically in the Cordillera de la Costa belt, experienced cooling below $\sim 110^{\circ}\text{C}$ (Sisson et al., 2005). Likewise, Middle Miocene AFT age data are widespread in the study area, in particular in the “Piedmont belt”. Presence of blueschists along the Venezuelan coast and in the Villa de Cura nappes (klippe; Avé Lallemant and Sisson, 1993) and the antiformal structure of the Cordillera de la Costa rock suite (Ostos, 1990) suggest also that regional uplift occurred during the Pliocene-Pleistocene. All these arguments suggest that a regional tectonic pulse or rebound took place in the Middle

Miocene to Recent times, due to the interaction of the Caribbean and South American plates.

SUMMARY AND CONCLUSIONS

The E-W trending Caribbean – South American plate boundary zone in north-central Venezuela consists from north to south of several E-W trending belts: North Caribbean deformed belt, Leeward Antilles volcanic island arc, a zone of Neogene extension, Caribbean Mountain system and the Guárico foreland basin. The Caribbean Mountain system consists of several belts of which the Serranía del Interior foreland fold and thrust belt is the most southerly one. The Serranía is divided into four belts, the most northerly of which is the “Piedmont belt,” tectonically underlying the Villa de Cura blueschist nappes (klippe). The present study involves only the Serranía and the Guárico foreland basin.

Cenozoic deformation and thermal histories of the Serranía del Interior foreland fold and thrust belt in north-central Venezuela were studied by applying structural analysis, interpretation of seismic lines and apatite fission-track (AFT) analysis. Four north-south trending transects were investigated. They are from west to east: (1) Platillón-Tiznados, (2) Valle Morín-Camatagüita, (3) Altagracia de Orituco and (4) San José de Guaribe. Analysis of regional 2D seismic lines and field data suggests that the South American plate in north-central Venezuela underwent several phases of deformation:

(1) *NW-SE extension*. Extension and the opening of the Espino graben in the southernmost portion of the Guárico basin occurred in Triassic-Jurassic time. The graben-bounding faults displace sedimentary and metamorphic Paleozoic rocks and Precambrian crystalline basement of the Guyana shield. The graben may extend beneath the eastern Serranía del Interior to the east and to the Apure and Colombia Llanos in the west.

(2) *Passive margin*. In the Cretaceous, a north-facing passive margin formed that subsequently subsided due to cooling (e.g., Pindell, 1993). This is the time of sea level rise, transgression and encroachment of the proto-Caribbean seas onto continental South America.

(3) *Contraction I*. In the Paleocene-Eocene, the North and South American plates started to converge in a NW-SE direction. The trend of the plate boundary zone was E-W; thus, convergence was highly oblique. This caused displacement partitioning in the most northerly allochthonous terranes of the Caribbean Mountains (Avé Lallemant, 1997). Thrusting and folding were the result of N-S shortening related to the boundary-normal component of convergence and the boundary-parallel component was expressed by displacements along EW-trending right-lateral strike-slip faults and shear zones. However, the deformation structures in the Serranía del Interior fold and thrust belt formed only by NS shortening. The La Victoria fault zone, north of the Serranía del Interior, may be the most southerly structure along which major strike-slip displacements have occurred.

As contraction was highly right-oblique, collision of the Leeward Antilles arc with South America was strongly diachronous: it happened in Paleocene and Eocene time in the west (Lara nappes); in the Oligocene and Miocene in the Western Serranía del

Interior of north-central Venezuela; and in the Eastern Serranía del Interior during Miocene, Pliocene and Pleistocene. The AFT ages in the Western Serranía as presented here support the model of diachronous collision.

During the Middle Miocene, a major regional event occurred that caused the inverted basins in the Venezuelan platform and resulted in uplift of the entire area. It is possible that the final obduction of the allochthonous nappes onto continental South America in Middle Miocene was caused by the change in the polarity of the subduction from a north-dipping in the Paleogene to a south-dipping in the Neogene.

(4) *Foredeep.* Late Eocene-Early Oligocene inception of the basal foredeep unconformity in the study area was coeval with extension in the Guárico basin. Normal faults in the autochthonous terranes of the South American plate were either reactivated older faults or they were newly formed. They extend well south into the basin and may have formed during early stages of the development of the foredeep, in response to the loading of the Lara nappes on the Guyana shield and on the peneplaned Paleozoic folded belt.

During the contractional phase, the Guárico basin was decoupled along marine shales of the Roblecito Formation. From this sole thrust or detachment level, south-vergent thrust imbricates emerged crosscutting Oligocene-Miocene sedimentary sequences of the Roblecito and Chaguaramas foredeep. Several small triangle zones developed within the basin. AFT show that for most of the area the onset of uplift and cooling was in Late Oligocene-Middle Miocene.

(5) *Guárico basin.* The Guárico basin was tilted to the east during a regional tectonic uplift that occurred in Pliocene-Pleistocene time. This caused the uplift and

peneplanation of the Guárico basin. Field data support the hypothesis that during this time contractional tectonics occurred as the Miocene molasse was incorporated into the mountain range. Minor Neogene and younger extension is observed throughout the basin, affecting Oligocene sedimentary sequences as well (Figs. 18 to 20). The available seismic data do not constrain the orientation of the extensional structures. Even so, based on analysis of 2D seismic data, Blanco et al. (1988) and Daal and Lander (1993) suggest that these normal faults are NE-SW trending.

A NNE-SSW trending 2D composite seismic line through the Guárico basin shows the Pliocene-Pleistocene uplift and exhumation of the Guárico basin deposits (Fig. 12). The latter deposits are much thinner in the east and they are overlain by very thick sequences of the Chaguaramas Formation and lateral equivalents.

(6) *Contraction II.* One of the most stunning results of the AFT analysis is the age of many samples from the easternmost transect (San José de Guaribe). This age is Paleogene and is younger than the stratigraphic age suggesting that deformation had already begun in north-central Venezuela prior to the arrival of the Leeward volcanic island arc and the emplacement of the Serranía del Interior thrust sheets. Convergence of the North and South American plates in the Eocene may have been the driving force that generated the foreland basin in central-eastern Venezuela, involving the passive margin in the deformation since the Middle Eocene.

(7) *Villa de Cura.* Within the “Piedmont belt” and beneath it and the Villa de Cura nappes, the seismic resolution is quite poor, allowing for two contrasting structural interpretations: klippe or imbricate thrust sheet (Figs. 8 and 9). Two of the interpreted 2D seismic lines cross the contact of the “Piedmont belt” with the Villa de Cura Group

(Figs.8 and 9), but the lines cannot resolve the question. Modeling of gravimetric and magnetic data suggests that the Villa de Cura nappes are very thin (between 1 and 2 km thick; Figs. 3 and 4 of Bosch and Rodriguez, 1992) and, thus, may better be described as klippe. Projection of the proximal passive margin and its basement suggests that the interpreted Cretaceous sequence and probably the Lower Oligocene units may extend northward beneath the Serranía and the Villa de Cura nappes (Figs. 8, 9, 22 to 26).

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APPENDIX 1

THE CARIBBEAN PLATE

Introduction

The tectonic history of northern South America, mainly since the Late Cretaceous, is linked to its interaction and coupling with the Caribbean plate. The tectonic evolution of the western Serranía del Interior foreland fold and thrust belt and its associated foredeep, the Guárico basin, is a direct consequence of such interactions. Therefore, it is necessary to understand the evolution of the Caribbean plate for generating hypotheses of the tectonic evolution of northern South America. This chapter describes and summarizes the different physiographic provinces of the Caribbean plate and associated basins. Also discussed here are possible internal deformation, the Caribbean-South America plate kinematics, and the different hypotheses, mobilist and fixed, for its generation and evolution through time.

The geographic distribution of earthquakes, active calc-alkaline volcanoes, and active spreading centers defines the present day Caribbean plate boundaries (Fig. 1) (Carr and Stoiber, 1990; McCann and Pennington, 1990; Dewey and Suarez, 1991; Mann, 1999). The western and eastern boundaries of the Caribbean plate are B-type subduction zones related to the volcanic island arcs of Central America (subduction of the Cocos-Nazca plates) and the Lesser Antilles (subduction of the North and South America plates), respectively (e.g. Pindell and Barret, 1990; Mann, 1999). The Caribbean plate is bounded to the north and south, by the North and South American plates, by complex and broad zones of deformation that include strike-slip, thrust and, locally

Figure 1. The Caribbean plate is roughly defined by earthquake focal mechanisms and interacts with three major tectonic plates i.e. South America, North America, Cocos-Nazca. Numbers and arrows are relative plate movements relative to the Caribbean plate based on NUVEL-1.

normal faults (Fig. 2). They developed from the Eocene to Recent (Mann and Burke, 1984; Rosencrantz and Sclater, 1986; Mann et al., 1990; Pindell and Barret, 1990; Pindell, 1993).

Caribbean geological provinces

In this chapter, the Caribbean plate (Figs. 2 to 4) is divided into five major geological provinces. The first four provinces are associated with the boundary zones of the Caribbean plate and its interaction with the Pacific (Nazca-Cocos), North American, South American plates and Atlantic lithosphere: 1) western province, represented by the Maya (Yucatán) block, Chortís block and Chorotega-Chocó blocks; 2) northern province, represented by the Yucatán Basin, Nicaragua Rise, Cayman Trough, Gulf of Mexico, Greater Antilles deformed belt and the Bahamas Platform; 3) eastern province consisting of the Lesser Antilles and Barbados Ridge, Grenada Basin and the Aves Ridge; 4) southern province represented by wide and complex megasuture with the South American plate; and 5) oceanic plate and basins of the Caribbean plate interior, represented by the Colombian and Venezuela basins and the Beata Ridge.

Western province

Maya block (Yucatán block). The Maya block is located north of the Chortís block along the Motagua-Polochic suture zone and belongs to the North American plate (Fig. 3). The connection of the northern Caribbean plate boundary zone with the Central American subduction zone is not exposed because late Tertiary/Quaternary volcanic rocks cover it (Mann and Burke, 1984; Mann et al., 1990, 1991). There is no clear geological or geophysical evidence for how this strike-slip fault system joins the Middle American Trench.

The crust of the Maya block is continental to accretionary and is 20-25 km thick (Case et al., 1990). The crystalline basement that crops out in the Maya block includes Pre- Pennsylvanian metamorphic rocks represented by mica schists, augengneiss, quartzite, marble and metavolcanic layers of the Chuacús Series, and it also includes a series of plutonic rocks of Paleozoic, Mesozoic and Cenozoic age (Donnelly et al., 1990). The metamorphic basement was found in several wells in Yucatán and Belize; consisting of quartz-chlorite schist, rhyolite, quartzite and phyllite of unknown age (Donnelly et al. 1990). An unconformable sedimentary sequence overlies the metamorphic basement and includes 1) an Upper Paleozoic sequence deposited in a rift basin, the result of the generation of the Proto-Caribbean, subdivided into a lower siliciclastic unit with tuffaceous beds (Santa Rosa Group) and an upper limestone unit (Chochal Limestone); 2) Jurassic-Early Cretaceous continental sedimentation represented by Upper Jurassic red beds, with limestones and evaporites (Todos Santos Group); 3) Lower Cretaceous dolomites, thin-bedded limestones and evaporites (Cobán Formation) and fine-grained limestone with rudist debris (Campur Formation) overlain by; 4) disconformable thick Upper Cretaceous-Early Tertiary turbidites with ophiolites ranging from detrital serpentinite to large slump olistostromes (Sepur Group) that records a Late Cretaceous tectonic emplacement and suturing of the Maya and Chortís blocks ; 5) Tertiary continental deposits.

Dismembered ophiolites occur along the Motagua suture zone (El Tambor Group) that include serpentinite, wackes, pillow basalts and associated chert and deep-water limestone, gabbros and diabase (Donnelly et al., 1990).

Figure 2. Present Caribbean plate boundaries. After Pindell and Barret (1990)

Miocene oceanic crust of the Cocos plate that is being subducted beneath the North American and Caribbean plates along the Middle America Trench that defines the western edge of the Caribbean plate, generated recent volcanic activity from Mexico to Central America (Dewey and Suarez, 1991). In Central Mexico, west of 96°W, the subducting Cocos plate dips about 15° and seismic activity has been recorded to depths of 100 km. The Central American Wadati-Benioff zone that extends from southern Mexico to Costa Rica has steeper dips and reaches depths of 200 km. According to DeMets et al. (1990) horizontal slip vectors along the trench in Nicaragua and Honduras, south of the Motagua-Polochic-Jocotán fault system and west of 100°W, may be biased due to east-west extension and generation of north-trending grabens. They also argue that east-west extension in El Salvador and Honduras, from 88°W to 96°W, is slower than the trench convergence rate.

Chortís block. Included within the Caribbean plate, the Chortís block comprises the countries of Nicaragua, Honduras and Guatemala and it is separated from the Maya block by the Motagua-Polochic suture fault complex (Fig. 3). It consists of pre-Mesozoic metamorphic units including high-grade quartzofeldspathic gneiss, mica schists, marble and amphibolites, low-grade quartzomaceous and graphitic phyllites, as well as metavolcanic sequences, Cretaceous calc-alkaline plutonic rocks and Mesozoic ophiolite sequences (Donnelly et al., 1990). Case et al. (1990) suggests a mixed origin-continental, oceanic and accretionary- for the crust. The Mesozoic stratigraphy (Donnelly et al., 1990) includes red beds, massive carbonate units and volcanic rocks (andesitic rocks and ignimbrites). Finally, the Cenozoic consists of a marine to terrestrial deposits, Paleogene continental clastics and upper Cenozoic volcanics (Donnelly et al., 1990).

Figure 3. Tectonic features of northern Central America showing the three major geological blocks: Maya, Chortis and Chorotega (From Donnelly et al., 1990).

However, Avé Lallemant and Gordon (1999) found that on Roatán Island, offshore Honduras, ductile structures formed during the left-oblique collision of the Chortís and Maya blocks in the Late Cretaceous-Early Tertiary and brittle deformation formed as a result of Late Eocene or Early Oligocene exhumation.

There is evidence for Miocene and younger volcanic activity along north-trending grabens located south of the Jocotán fault, within the Chortís block. These grabens have been attributed to localized extension during the eastward migration of the Caribbean plate along the continental promontory of the North American plate (Mann and Burke, 1984).

Chorotega and Chocó blocks. This geological province (Fig. 5) serves as the link between the continental crust of Central America (Chortís and Maya blocks) and the more complex northwestern South American plate. It has a very complex geological history that encompasses Cenozoic calc-alkalic volcanism and deformation, dismemberment of Late Jurassic-Early Cretaceous ophiolite complexes, Late Cretaceous-Paleogene magmatism superimposed on older oceanic crust and Neogene convergence with the Caribbean plate (Case et al., 1984). The Santa Elena fault zone separates the Chorotega and Chocó blocks from the Chortís block and the North Panamá Deformed Belt from the Caribbean plate. To the west and southwest the Middle American Trench and the Nazca-Cocos plates bound the province. The Romeral fault zone separates it from the South American plate to the east (Fig. 5). The Chorotega and Chocó blocks include the countries of Nicaragua, Costa Rica and northwestern Colombia, coinciding with drastic changes in gravity values along the fault system (Case,

Figure 4. East-West cross section showing the extent of geological features Central America to the Lesser Antilles. From Donelly 1994.

1974). Other differences between the blocks (Escalante, 1990) include 1) differences in thickness of the oceanic crust; 2) ophiolite complexes located in the Chorotega block, 3) scarce presence of Cenozoic ignimbrites and igneous intrusive bodies in the Chocó block and 4) Recent to Quaternary volcanism in the Chocó block has been scarce compared to the Chorotega block.

The basement of the blocks is oceanic in nature and is represented by mafic igneous flows identified as dismembered ophiolites in Costa Rica (Nicoya Complex) (Escalante, 1990). Radiolarite beds (chert) associated with these ophiolite suites yield ages that range from Early Jurassic to Late Jurassic-Early Cretaceous (Escalante, 1990). The Cretaceous is represented by carbonate and siliciclastic sequences while the Cenozoic contains marine and continental deposits along with volcanoclastics and occasionally thick intervals of volcanic rocks, mainly at the base of the Tertiary (Escalante, 1990).

Draper et al. (1994) suggest that the oceanic crust of both the Chorotega block, associated to older Middle America Trench and Chocó block, associated to older Colombia trench, was uplifted in Late Cretaceous to Early Tertiary. Deformation rates were highest in the Miocene when emplacement of intrusive rocks occurred (Escalante, 1990).

Northern Province

Yucatán basin. The Yucatán basin is bordered by the Yucatán block (Maya block) and the Yucatán platform in the west, the Greater Antilles deformed belt to the north

(Cuba), and by the Cayman Ridge and Cayman Trough to the south (Fig. 2). The Yucatán basin records the Late Cretaceous-Paleogene convergence between the North American and Caribbean plates (Rosencrantz, 1990). Based on seismic reflection character and surface topography, Rosencrantz (1990) postulates that the basement of the Yucatán basin includes three distinctive crustal types. The first is located in the western portion of the basin (Yucatán borderland domain extending from Honduras to Cuba); here, the crust is an eastern extension of the basement present in the Yucatán platform including Paleozoic crystalline rocks, Jurassic red beds and Cretaceous carbonates and evaporates. Infilling sediments are represented by Tertiary platform carbonates. The second type is present in the eastern portion of the basin (eastern basin, Cayman Rise, Cayman Ridge and Camaguey trench domains). The topographically heterogeneous crust includes a thick Late Cretaceous-Tertiary extrusive sequence and plutons that overly an older oceanic crust of uncertain age. The third type consists of Late Paleocene-Middle Eocene oceanic crust that occurs in a rectangular-shaped pull-apart basin, separated by a left-lateral paleo-transform boundary from the Yucatán platform.

According to Mann (1999) the Yucatán basin could be subdivided into several physiographic provinces: 1) West Yucatán basin, 2) Central Yucatán basin and Cayman Rise, and 3) Cayman Ridge. The first is a pull-apart basin with crust of oceanic affinity. The nature of the crust of the Central Yucatán basin is poorly understood and could be either a stretched island arc or continental crust. The latter physiographic province, the Cayman Rise, is probably a remnant arc affected by strike-slip faulting.

Nicaragua Rise. The Nicaragua Rise (Fig. 2) has been subdivided into the upper Nicaragua Rise and the southern Nicaragua Rise (Case et al., 1984; Case et al., 1990).

The upper Nicaragua Rise extends from Nicaragua / Honduras to the island of Jamaica. The relationship of pre-Mesozoic continental crust of the Chortís block with the crust of island arc affinity in the Nicaragua Rise is poorly understood. However, Donnelly (1994) argues that the shallower portions of the Nicaragua Rise could be the offshore extensions of the continental crust of the Chortís block.

The crust of the upper Nicaragua Rise comprises Paleozoic metamorphic rocks and Upper Cretaceous- lower Cenozoic intrusives such as granodiorites. The continental crust of the Chortís block might extend to the western portion of the upper Nicaragua Rise while the remaining crustal composition is of island-arc affinity (Holcombe et al., 1990). The crust in the lower Nicaragua rise has been defined solely by seismic-refraction surveys. However, it appears to be a crustal block bounded by escarpments to the northwest and southeast (Pedro Bank and Hess escarpments respectively) and by troughs in the northeast and southwest (Morant and San Andres troughs, respectively). The sedimentary strata in the upper Nicaragua Rise are predominantly Paleocene calcareous shale, Eocene limestones or carbonate banks, Miocene marlstones and fine-grained continental to nearshore sandstone and Pliocene-Quaternary karstic carbonate. The Oligocene is thin or not present in the area. The Cretaceous and possibly Cenozoic sedimentary deposits in the lower Nicaragua Rise are predominantly pelagic carbonate with minor proportion of clay. Horizons A'' and B'' were drilled at DSDP site 152 and are represented by Eocene chert and chalk sequence and basalts, respectively.

Cayman Trough. This 6-km deep pull-apart basin extends east west for over 1100 km along the North American and Caribbean plates (Fig. 2). The trough is 100 km long that joins the Oriente transform in the north and the Swan transform in the south (Case et

al., 1990; Rosencrantz and Scatler, 1986). The Cayman Trough nucleated as a pull-apart basin coeval with the opening of the Yucatán Basin in Middle to Late Eocene (Pindell, 1993).

The oceanic crust of the Cayman Trough has an anomalous thickness of 5 km, when compared to that of world ocean basins. A very thin sedimentary cover, 0.5 to 1 km thick, drapes the trough (Case et al., 1990). Two major phases of spreading have been proposed for the Cayman Trough (Rosencrantz and Scatler, 1986): 1) Pre-Oligocene (30 Ma) causing low topographic relief of the basement with a fast spreading rate (30 mm/yr) and minor subsidence; and 2) Post Oligocene (30 Ma) causing marked topographic relief of basement with slow spreading rates (~ 15 mm/yr). Likewise, Rosencrantz et al. (1988) proposed two slightly different rates of 30 to 25 mm/yr from 50 to 26 Ma and 15 mm/yr from 26 to 0 Ma. Likewise Ladd et al. (1990) proposed Miocene-Recent spreading rates of 40 mm/yr from 6 to 2.4 Ma and 20 mm/yr from 2.4 to 0 Ma based on magnetic anomalies identified within 150 km of the spreading center.

Gulf of Mexico. The western Pangea region began to break up during the Late Triassic to late Middle Jurassic to accommodate space between the Maya-Yucatán blocks and North America for the Gulf of Mexico region (e.g., Pindell and Dewey, 1982; Pindell and Barret, 1990; Marton and Buffler, 1999). During the Callovian the rifting phase and subsidence below sea level ceased, and regional deposition of evaporites started in the Gulf of Mexico region (Salvador, 1991). Also, the formation of oceanic crust started in the latter area (Marton and Buffler, 1999).

Figure 6. Seismic reflection profile showing the main geological elements in the Gulf of Mexico basin. J =Jurassic, TB = top Berriasian post-rift unconformity; LK= Lower Cretaceous; MCSB= Mid-Cretaceous sequence boundary; UK-C= Upper Cretaceous-Cenozoic. After Marton and Buffler, (1999).

Based on seismic reflection profiles (Fig. 6) and the result of DSDP Leg 77, Marton and Buffler (1999) define four major tectono-stratigraphic sequences: 1) In the central and southern portions of the area, basement consists of metamorphic rocks, which are intruded by mafic rocks (continental crust) and oceanic crust beneath the Florida plains; 2) Paleozoic (?) pre-rift rocks; 3) Late Jurassic syn-rift sequence consists of a lower non-marine unit underlying a upper marine-unit represented by carbonate build-ups and deepwater sediments; and 4) Early Cretaceous post-rift sequence represented by deep-water carbonates along the axial part of southeastern Gulf of Mexico flanked by carbonate platforms in the Yucatán and Florida areas.

Greater Antilles deformed belt. The northern segment of the island arc, the Greater Antilles Deformed Belt (Fig. 2) includes the islands of Cuba, Jamaica, Hispaniola, Puerto Rico and the Virgin Islands and it has been inactive since its diachronous collision with the Bahamas platform in Late Paleocene-Early Eocene in western Cuba, Early to Middle Eocene in central Cuba, Middle Eocene to Recent in Hispaniola and Late Eocene-Early Oligocene in Puerto Rico (e.g., Lewis and Draper, 1990; Mann et al., 1991; Bralower and Iturralde-Vinent, 1997; Gordon et al., 1997; Mann, 1999).

Cuba. Iturralde-Vinent (1994) postulates two different geological units in Cuba: a foldbelt and a neautochthon. The foldbelt comprises continental and oceanic units (northern ophiolite belt). The continental units comprises: 1) the Mesozoic Bahamas platform and slope deposits overlain by a Paleocene-Late Eocene foreland basin; and 2)

Figure 7. Main physiographic provinces in the eastern Caribbean. After Bird et al., (2001).

the allochthonous Cuban terranes of Guaniguanico (low to very low grade metamorphic rocks and locally high-P metamorphic rocks), Escambray (high-P/low-T metamorphic rocks) and Pinos (mid-P/mid-T Barrovian metamorphism). Likewise, the oceanic units encompass a Cretaceous volcanic arc and associated Late Cretaceous-Late Eocene basins and Paleocene-Middle Eocene volcanic arc and related Eocene basins.

The neo-autochthon unconformably overlies the foldbelt and comprises gently deformed Upper Eocene-Recent sedimentary rocks.

Based on nannofossil and foraminiferal biostratigraphic data, Bralower and Iturralde-Vinent (1997) postulate that the timing of collision of the Cretaceous Greater Antilles island arc with the Jurassic-Cretaceous North America passive margin occurred 20 m.y. after the extinction of the island arc, proposing a Late Paleocene to Early Eocene event for the final collision in western Cuba.

Jamaica. The composition of the crust in this geological province is oceanic with a sedimentary sequence that is up to 6,500 meters in thickness and between 5,000 to 6,000 meters of Cretaceous and Paleogene clastic, volcanoclastics and carbonate deposits and 1,500 meters of Neogene carbonates (Case et al., 1984).

Robinson (1994) postulates that the stratigraphy of Jamaica comprises a succession of Cretaceous volcanogenic rocks including flows and Upper Cretaceous back-arc basin carbonates in minor proportions. The Tertiary history is represented by a siliciclastic sequence marking Late Cretaceous-Paleocene uplift in the central and western portions of the island. To the east, the clastic section is coarse-grained, thick and associated with volcanic flows. Middle Eocene limestones mark a period of transition and

quiescence in central and western Jamaica. The middle Miocene is composed of a carbonate and clastic sequence with occasional of pillow lavas.

Hispaniola. Draper et al. (1994) postulate that Hispaniola, which includes the countries of Haiti and the Dominican Republic, consists of the juxtaposition of twelve different litho-tectonic belts or terranes ranging from Lower Cretaceous to Upper Eocene, classifying them into four main types: 1) forearc/accretionary prism of an island arc, 2) magmatic portion of an island arc, 3) portions of a back-arc basin and 4) oceanic crust. Following Draper et al. (1994), four phases are recorded in the island arc terranes: 1) Early Cretaceous to Middle Eocene island arc volcanism and magmatism; 2) Middle-Late Eocene collision with the Bahamas platform and uplift and cessation of island arc activity; 3) Late Eocene-Early Miocene shearing; and 4) Early Miocene transpression. Likewise, the oceanic crust portions registered four main phases as well: 1) Santonian-Maastrichtian formation in a oceanic island or intraplate setting; 2) Late Cretaceous deformation with sudden uplift and erosion; 3) Paleocene-Early Miocene strike-slip shearing, subsidence, a deposition of platform carbonates; and 4) Early Miocene transpression. Early Miocene-Recent tectonic activity generated oblique-slip faults that cut the terranes.

Puerto Rico and the Virgin Islands. Puerto Rico appears to be bounded by two subduction zones: the north-dipping Muertos Trough in the south and the south-dipping Puerto Rico Trench in the north (Fig. 2). The Septentrional fault crosscuts the north-trending Mona Basin that separates Hispaniola from Puerto Rico. The Virgin Islands and Saint Croix basins and the Anegada Passage are northwest-trending structures that

separate the Puerto Rico-Virgin Islands block from Saint Croix and the Lesser Antilles island arc (Larue, 1994).

In Puerto Rico, the Jurassic-Cenozoic rocks are subdivided into three lithotectonic blocks: Southwest, Central and Northeast (Larue, 1994). In the Southwest block of Puerto Rico, the oldest rock assemblage is the Jurassic (Kimmeridgian) dismembered ophiolite suite of the Bermeja Complex (Larue, 1994). The latter rock complex also contains Lower Cretaceous igneous rocks of oceanic island arc affinity and amphibolite and chert of oceanic origin (Larue, 1994). Shallow-water and slope basinal carbonate deposits, volcanoclastics rocks and lava flows represent the Upper Cretaceous units within the Southwest block of Puerto Rico (Larue, 1994). The Southcentral block comprises Upper Cretaceous deep-water volcanoclastic turbidites with Cretaceous to Eocene intrusives cutting the latter sequence (Larue, 1994). In the Central block of Puerto Rico, the rock units comprise shallow water rudists-bearing limestones, capped by Upper Cretaceous shallow volcanoclastics deposits and Cretaceous-Late Eocene intrusives (Larue, 1994). Lower and Upper Cretaceous volcanic, volcanoclastics rocks, limestones and early Tertiary basaltic dyke swarms represent the lithologies that crop out in the Northeast block of Puerto Rico (Larue, 1994).

The northern Virgin Islands consists of thick volcanic and volcanoclastics pile with Lower Cretaceous deep-water lava flows; breccias, tuffs and radiolarites; Cenomanian early Santonian volcanoclastics turbidites and minor limestone; Eocene deep-water volcanoclastics deposits; and Oligocene volcanic deposits. They are intruded by an Oligocene batolith, capped by Upper Miocene to Holocene limestones (Larue, 1994).

Larue (1994) postulates nine different phases of evolution for these islands of the Greater Antilles deformed belt: 1) development of oceanic crust during the Late Jurassic (amphibolites in the Bermeja Complex); 2) volcanic arc build-up during early Cretaceous (Central block of Puerto Rico and northern Virgin Islands); 3) a serpentinite mélange (Bermeja complex) is associated with a Cretaceous disruption of the island arc; 4) Late Cretaceous thick volcanic sequence marks the renewal of arc build-up in Puerto Rico, northern Virgin Islands and Saint Croix; 5) localized Maastrichtian disruption of the island arc in Saint Croix; 6) early Tertiary volcanic arc growth; 7) cessation of island-arc volcanism, major uplift and rotation of the island arc in Late Eocene-Middle Oligocene in Puerto Rico and Oligocene in northern Virgin Islands; 8) Late Oligocene-Miocene and Late Miocene carbonate sedimentation in Puerto Rico and the northern Virgin Islands; and 9) Middle Miocene to Recent strain-partitioned-associated structures, local subsidence and 25° anticlockwise rotation of Puerto Rico and the northern Virgin Islands.

Bahamas platform. Case et al. (1984) suggest that the affinity of the crust beneath 6 km of Jurassic-Neogene carbonates of the Bahamas platform is uncertain and could be oceanic in the south and continental in the north. Based on seismic reflection profiles, Masferro and Eberli (1999) propose three major tectonic events for the southern Great Bahama Bank: 1) Extensional phase: Early-Middle Jurassic extension linked to a transform plate boundary zone fault in the Florida-Bahamas area connecting the Central Atlantic and Gulf of Mexico spreading ridges. Coeval with this rifting phase occurred sedimentation of a clastic sequence, deep water carbonates and evaporites; 2) Passive margin phase: passive margin subsidence and growth of a thick platform carbonate sequence (5 km) in the Lower Cretaceous followed by middle Cretaceous

reactivation of Jurassic faults and its propagation to the Upper Jurassic-Lower Cretaceous carbonate platform; 3) Collisional phase: Late Cretaceous-Eocene collision of the Greater Antilles arc with the platform and generation of a foreland basin followed by a period of vertical growth of a carbonate platform up to the present.

Eastern Province

Lesser Antilles Volcanic Arc. The Lesser Antilles volcanic island arc extends for 850 km from the Anegada Passage, in the north, to possibly the islands of Margarita and Los Testigos in the South American continental margin (Figs. 2 and 7) (Maury et al., 1990). This north-south trending volcanic island arc represents the leading edge of the eastward drifting Caribbean plate with respect to the Americas. It is the result of the west dipping underplating of Jurassic-Cretaceous Atlantic oceanic crust beneath the Caribbean plate. This volcanic island arc initiated its activity since the Eocene and possibly since Late Cretaceous and is still active (e.g., Biju-Duval et al., 1983).

Old Atlantic oceanic crust is being subducted beneath the Caribbean plateau at a low convergence rate of 12 mm/yr (De Mets et al., 1990). Aseismic buoyant ridges appear to be subducting beneath the island arc forming a shallow dipping seismic zone. Much of the slip occurs aseismically (McCann and Pennington, 1990). The Wadati-Benioff zone beneath the island arc reaches 200 km depth with an average dip of 50-60° (McCann and Pennington 1990).

The Atlantic oceanic crust is probably segmented in two in the vicinity of the Lesser Antilles Islands. The two slabs belong to the North and South American plates

that are converging along wide zone of deformation, northeast of northern Antilles at 19° N (R. Gordon, personal communication, 2000). The accretionary prism associated with the island arc, the Barbados Ridge, is 300 km wide and up to 20 km thick outcropping near the island of Barbados. Here, the accretionary prism consist of early Tertiary turbidites, pelagic early-mid Tertiary and Neogene uplifted carbonates (Biju-Duval et al., 1983).

The crust of the Lesser Antilles is subdivided into three different units based on seismic refraction experiments (e.g., Boynton et al., 1979): 1) a lowermost layer represented by the primeval crust of oceanic affinity onto which the volcanic arc was built and subsequently thickened by mafic plutons; 2) a intermediate layer of lateral compositional variation represented by plutonic rocks of intermediate composition; and 3) an uppermost layer composed by lavas, pyroclastic deposits and sediments (Maury et al., 1990).

In the northern Lesser Antilles, the Pre-Eocene basement consists of Upper Jurassic-Lower Cretaceous rocks (La Désirade) and Late Cretaceous plutonic and volcanic island-arc rocks (Maury et al., 1990). Bouysse and Westercamp (1990) defined the Lesser Antilles as a double-arc based on Cenozoic and Quaternary volcanic activity. The older and external arc (northern islands to Guadeloupe) was active from Eocene to Oligocene times and was capped by Neogene limestones, Limestone Caribbes, (Maury et al., 1990). The inner arc (Volcanic Caribbes) represents the Late Miocene-to Quaternary uplift and reactivation of volcanic activity that ended carbonate deposition (Tomblin, 1975).

Aves Ridge. The Lesser Antilles volcanic island arc split during the Early Paleogene to form the Grenada back-arc basin (Pindell 1994; Mann, 1999), leaving behind a volcanic inactive portion of the island arc known as the Aves Ridge. This elongated structure runs from the Margarita Island in northern Venezuela to south of the Anegada Passage in the Neogene Lesser Antilles and is represented by a series of seamounts. Upper Cretaceous-Paleocene volcanic rocks, granodiorites, basalts andesites and Tertiary sedimentary rocks are present in the Aves Ridge (Biju-Duval et al., 1983; Draper et al., 1994). Gravity models and seismic data suggest that the thickness of the crust in the Aves Ridge could be 28 to 31 km (Case et al., 1990). Holcombe et al. (1990) suggest a heterogeneous upper crustal structure with volcanic mounts and associated plutons in the Aves Ridge. Drilling and dredging suggest that there was a significant subsidence event on the Aves Ridge of uncertain origin since the Miocene.

Grenada Basin. This early Paleogene back-arc basin contains a thick oceanic crust (~18 km) with a structure similar to that of the Venezuelan basin (two layers) and is older than 40 Ma. A relatively thin sedimentary cover (1.5 km) drapes the acoustic basement (Holcombe et al., 1990) becoming thicker towards the south (6 km) where volcanoclastics turbidites and deep marine deposits drape the basement (Draper et al., 1994). Tomblin (1975) proposed an east-west extension of the Lesser Antilles volcanic island arc, caused by the shift of the Aves Ridge to the west (Fig. 8). Pindell and Barret (1990) proposed that both the Aves Ridge and the Leeward Antilles were one block (Fig. 8). The Grenada basin formed as the result of the eastward migration of the Caribbean plate as a combination of north-south extension and right lateral shear. Bouysse (1980) proposed that the coupling of the southern portion of the Lesser Antilles with the South

American plate in combination with the eastward migration of the Caribbean plate caused northeast-southwest extension and the opening of the Grenada basin (Fig. 8). Holcombe et al. (1990) presents two possible theories for the origin of the Grenada Basin, being the first the most accepted: 1) formed by back-arc spreading, splitting the arc into the Aves Ridge and the Antilles; 2) The Grenada Basin is a former forearc crust isolated by an eastward jump of the subduction zone in Eocene times.

Southern Province. This province will be discussed in greater detail in Appendix 2, but a brief summary follows. Along its southern boundary, the Caribbean plate interacts with the South American plate forming a diffuse and wide zone of deformation, the Southern Caribbean deformation zone (e.g., Biju Duval et al., 1983). Van der Hilst and Mann (1994) proposed that the northern portion of the South Caribbean deformed belt is the boundary between the Caribbean plate and the Southern Caribbean deformation zone. The southern limit is located far south at the East Andean fault system and includes the San Jacinto and Sinú folded belts (Freymueller et al., 1993). In this discussion, the Leeward Antilles located in the northernmost portion of the continental megasuture represents the southernmost dismembered extension of the Great Arc of the Caribbean (Burke, 1988).

The Leeward Antilles is a series of extinct volcanic islands that extend linearly along the coast of Venezuela (González de Juana et al., 1980) and consists of Middle Cretaceous (?) tholeiites of oceanic crust affinity, Late Cretaceous tholeiites and volcanic rocks, Cretaceous-Cenozoic calc-alkaline plutons, Paleogene conglomerate and Neogene carbonate terraces (Case et al., 1984).

Figure 8. Three possible modes of generation of the Grenada basin include: 1) westward shift of the Aves Ridge causing east-west extension (Tomblin, 1975, Bird et al.); 2) north-south extension due to eastward movement of the Caribbean plate and the Leeward Antilles were part of the Aves Ridge prior to the opening of the Grenada basin (Pindell and Barrett, 1990); and 3) northeast-southwest extension similar to previous model (Boysse, 1988)

The tectonic framework in northern South America is complicated by the tectonic escape of the Maracaibo block towards the north (Kellogg and Bonini, 1982). This occurs along the Boconó right-lateral strike-slip fault system and the Santa Marta-Bucaramanga left-lateral strike-slip fault system. It resulted from the Miocene collision of the arc of Panama with Colombia in northwestern South America.

Along east- to east-northeast-trending right-lateral strike slip and thrust faults, allochthonous rocks of island arc, oceanic affinities and parautochthonous forearc turbidites were obducted southward on autochthonous passive-margin and Mesozoic-Cenozoic foreland rocks. The accretion resulted from the strongly diachronous collision of the Caribbean plate with northern South America. The collision occurred in Middle Eocene time in the Guajira area in the west and in Pliocene to Recent time in the Trinidad-Tobago area (e.g., Beck, 1978; González de Juana et al., 1980; Bellizzia and Dengo, 1990; Avé Lallemant and Sisson, 1993). Some of the east-trending right-lateral strike-slip faults show evidence of Pleistocene to Holocene tectonic activity. Quite commonly, motion on right-stepping, right-lateral strike-slip faults causes the formation of pull-apart basins (Schubert, 1988).

Oceanic plates and basins of the Caribbean interior. The Caribbean oceanic plateau of Mann (1999) is a crust with oceanic island affinities. It includes the oceanic crusts in the Colombian Basin, the Beata Ridge and the Venezuela Basin. Diebold and Driscoll (1999) argue that the crustal structure of both the Venezuelan and Colombian basins is more complex and could be subdivided into four very distinctive lithological suites: 1) thin ocean-like crust, 2) volcanic extrusives, 3) massive extrusives and intrusives, and 4) extrusive volcanic mounds.

Colombia Basin. The Colombian basin is bounded to the north by the northern Nicaragua Rise and to the south by the Panama and South Caribbean Deformed belts and is separated from the Venezuelan Basin by the Beata Ridge to the northeast (Case et al., 1990). In the Colombian basin, the crust has oceanic affinities and is 10 to 22 km thick, twice the average of a typical oceanic crust. It is of Late Cretaceous or older age. In the western Colombian Basin, the basement is formed by marine deposits interbedded with mafic flows underlying an older oceanic crust, while in the central Colombian Basin it is formed by Late Jurassic / Early Cretaceous oceanic crust and by Late Cretaceous intraplate volcanic rocks (Holcombe et al; 1990). Donnelly (1994) proposes that the nature of the crust in the Colombian basin is very similar to that of the Nicaragua Rise and that the fault between the two is poorly understood.

Holcombe et al. (1990) suggest several seismic units within the Colombia basin that cover the oceanic crust and are correlated to DSDP sites 152, 154 and 502 :1) A unit correlatable with the A'' and B'' (acoustic basement, Diebold and Driscoll, 1999) intervals that overlie a crust with oceanic affinities. Reflector A'' consists of top Upper Cretaceous-middle Eocene siliceous pelagic carbonates. The thick sedimentary sequence, associated to the seismic reflector B'', found in the Colombian basin could include basalt flows formed in the Late Cretaceous (Case et al., 1990; Holcombe et al., 1990); 2) Highly pressurized upper Miocene marine shales of volcanic origin; 3) two apparently mid-Eocene to upper Miocene turbidite sequences and a Neogene pelagic and gravity flows sequences.

Beata Ridge. This physiographic province (Figs. 2 and 9) of the Caribbean interior extends SW from Cape Beata in Hispaniola and separates the Venezuelan and

Figure 9. Seismic reflection line along the Beata Ridge showing normal faulting along its flanks including a large normal fault on its west side. Deformation occurred after emplacement of the volcanics in the Venezuela Basin. After Driscoll and Diebold (1999).

Colombian basins (Case et al., 1990; Holcombe, et al., 1990). The Beata Ridge was generated and uplifted by extensional unloading and flexural rebound (Driscoll and Diebold, 1999) that affected most of the northern Colombian Basin between the Late Cretaceous (after B" event) and Early Eocene prior to the Horizon A" event as suggested by Holcombe et al. (1990) or soon after the emplacement of the volcanics as suggested by Driscoll and Diebold (1990). However, Donnelly (1994) suggests that the Beata Ridge represents the western edge of the uplifted Venezuelan Basin.

The Beata Ridge is bounded on its western flank by a west-dipping normal fault (Hess Escarpment) giving a marked asymmetry to the ridge. Lately, this scarpment is thought to be left-lateral strike-slip fault (Avé Lallemant, personal communication, 2004). The crust of the Beata Ridge has oceanic affinities and it is close to 15 km thick (Holcombe et al., 1990). The Beata Ridge crust includes basalt, diabase, basalt porphyry and dolerite. Drill cores from DSDP site 151, consists of basalt, Cretaceous silicified "hard ground,"

foraminiferal limestone, lower Eocene-Paleocene pelagic oozes with high carbonate content and radiolaria and Oligocene-Pliocene of foraminiferal-nanofossil oozes (Edgar et al., 1973). Horizons A" and B" are present in the Beata Ridge with constant thickness suggesting that the ridge was formed after the emplacement of Horizon B" (Fox and Heezen, 1975).

Venezuelan Basin. The Venezuelan Basin is bounded to the north by the Muertos Trough, to the east by the Aves Ridge, to the south by the South Caribbean deformed belt and by the Beata Ridge to the west (Fig. 2). Donnelly (1994) proposes that the

Figure 10. Geologic development of the Caribbean crust. See text for discussion (Diebold and Driscoll, 1999).

Venezuelan basin has subducted beneath the Aves Ridge during Cretaceous and Paleogene. The Venezuelan basin is a starving basin with depths ranging from 3000 to 5000 m (Case et al., 1990). The crust of the Venezuelan basin is anomalously thick for an oceanic crust. Based on seismic character and interval velocities, it has been suggested that this basin could be divided into a northwestern and a southeastern sections where the seismic event B'' is either smooth or rough. On a regional multichannel seismic survey, Diebold and Driscoll (1999) identify two very distinctive vertically stacked volcanic sequences with extrusive material within the Venezuelan Basin. The lower sequence is made up local highs rimmed by steep-dipping volcanic flows (rough B'') and a thin crust of oceanic affinity made up of ridges. The uppermost thick sequence, more extensive, consists of extrusion of volcanic flows, intrusion of dikes and sills and underplating. The top of the latter sequence is correlated with the smooth B'' horizon previously defined. Diebold and Driscoll (1999) propose a two-phase volcanic history for the Caribbean plateau: 1) slow extension and crustal thickening forming local volcanic highs and dipping flows followed by 2) extension and magmatic emplacement (Fig. 10). In general, the DSDP drilling surveys in the Venezuelan Basin penetrated deep-water pelagic deposits ranging from Cretaceous to Recent. The sedimentary column consists of calcareous oozes, marlstones and limestones rich in radiolarians and nannofossils, clays, chert and volcanic ashes before reaching the volcanic flows and sills of acoustic basement B''. The seismic horizon A'' has been penetrated in the wells and it is always associated with a soft-hard interface, mainly at the contact between radiolarian oozes and cherts and limestones (Holcombe et al., 1990). Driscoll and Diebold (1999) suggest that the maximum thickness of the sequence between the B'' and A'' horizons in the

Venezuelan Basin is between 600 to 800 m based on velocity information. Its distribution coincides with the rough basement area. The latter sediment sequence is thickest in the southeast area of the Venezuela Basin (Driscoll and Diebold, 1999).

DSDP holes 146, 149 and 153 drilled the top of the acoustic basement B” represented by basalt flows (Holcombe et al., 1990). In the first two DSDP holes, the Cretaceous sedimentary sequence is represented by radiolarian limestone, nannofossil chalk with radiolaria, chert and volcanic ashes (Holcombe et al. 1990). The Paleocene is represented by a barren sequence of clay with volcanic origin followed by lower Eocene-Paleocene limestone and Miocene-Lower Eocene oozes. The interface soft-hard of the last two sequences coincides with the Horizon A” (Holcombe et al., 1990). Chert and limestone occur in the Lower Eocene-Paleocene section, while volcanic-rich oozes and radiolarian-nannofossil chalks represent the Lower Miocene-Lower Eocene deposits. Chalk oozes rich in foraminifera and nannofossils, marl oozes and clay represent the Recent-Lower Miocene deposits (Holcombe et al., 1990).

Rates of sedimentation within the Venezuelan Basin reached several peaks during the Late Cretaceous-Paleocene and Early Miocene and from 3 to 5 Ma, with a nadir between the Eocene to Early Miocene (Holcombe et al., 1990).

Internal deformation of the Caribbean plate.

The kinematics of the Caribbean relative to the adjacent plates is highly controversial. The inconsistencies of global plate circuits that involve the Caribbean plate (De Mets et al., 1990) give rise to new concerns regarding its rigidity. High rigidity is one of the major axioms of the plate tectonic theory. The rotation pole related to the

convergence between the Americas is located east of the Lesser Antilles island arc at latitude of 19°N (R. Gordon, personal communication, 2000). The convergence between the North and South American plates together with the collision of the Panama volcanic arc with northwestern South America from Miocene to Recent, is responsible for much of the internal deformation within the Caribbean plate.

Masle et al. (1984) argue that the Caribbean crust has been underthrust beneath northern South America from Middle Miocene to Recent. Van Der Hilst and Mann (1994) used 2D tomographic images to reveal the shape of a slab underthrust beneath the northern portion of South America.

The Southern Caribbean and the Panama deformed belt, the Muertos Trough, the Mono Rise, the Pedro Bank fault zone, the Hess Escarpment, Morant Trough, San Andres Trough, the Beata Ridge and the Grenada basin are representative structures of Caribbean internal deformation. According to Mann et al. (1990), these structures subdivide the Caribbean plate into four zones: 1) Central American zone, bound by the Middle America Trench, the Honduras Depression and the northern plate boundary zone (NPBZ); 2) Nicaragua Rise, north of the Hess Escarpment; 3) the Venezuelan Basin, between the Beata Ridge and the Aves Ridge; and 4) the Colombian Basin, between the Beata Ridge, the Hess Escarpment and the Panama and South Caribbean deformed belts.

Examples of internal deformation include the following:

- 1) East-West extension formed recent north-trending grabens south of the Polochic-Motagua-Jocotán strike slip fault zone, in Central America (Burkart, 1994).
- 2) The Nicaraguan Rise is in turn subdivided into an upper and a lower Nicaraguan Rise separated by the ENE-trending Pedro Bank fault and the San Andres Trough. This

zone seems to join with the Enriquillo-Plantain Garden fault zone east of Jamaica (Fig.16) (Droxler et al., 1996). Multi-channel seismic reflection lines crossing the Pedro Bank fault zone suggest that it is a left-lateral strike-slip fault zone.

3) The NNE-trending San Andres Trough is an extensional structure that separates the Nicaraguan continental margin from the lower Nicaraguan Rise in which folded strata suggests recent tectonic activity (Holcombe et al., 1990).

4) The Morant Trough is thought to be an active pull-apart basin formed at a releasing bend along the northern Caribbean plate boundary zone. Evidence for young deformational events can also be seen in the Nicaraguan Rise along the Jamaica plain (Holcombe et al., 1990).

5) The Hess escarpment, separating the Colombian Basin from the Nicaraguan Rise, is a northeast trending structure of variable relief and is thought to juxtapose basement of different acoustic character and elevation, probably formed under transpression and could be as old as Late Cretaceous (Holcombe et al., 1990).

6) Holcombe et al. (1990) suggest that the Pedro and Hess escarpments are part of a left-lateral wrench zone related to the structures and volcanism observed in the lower Nicaraguan Rise from Miocene to Recent. Recent earthquake activity suggests an epicenter near the Caribbean coast of Costa Rica on the extension of the Hess escarpment that indicates left-lateral displacement (N. Maternovskaya and G. Ekstrom, unpublished data, 08-13-2000). Mann et al. (1990) suggest that internal plate deformation is the main cause for present-day extension in the Nicaragua Rise in which Paleocene-Miocene deformation structures were reactivated as Cenozoic rifts. An example of this is found at DSDP Site 152 and ODP Site 1001. Data show that continuous faulting occurred since

late Cretaceous. Faulting was active (half-grabens) during deposition of B'-A' interval (80-53 Ma) and could be younger than 53 Ma. There is also recent tectonic activity since faults displace seafloor.

In the Colombian Basin, there is a major unconformity near NW trending faults that bound the Mono Rise. This implies that uplift began in Middle Miocene during the northwestward accretion of the Panama deformed belt to the Colombian Basin (Mann et al., 1990).

7) The Beata Ridge is a southwest-trending structure that represents the western edge of the uptilted Venezuelan Basin and is the western boundary of a basalt escarpment (Donnelly, 1994). The main ridge has north-striking subsidiary ridges that extend southward and southeastward from the main ridge disappearing to the south under deposits of the Colombian Plain. Case and Holcombe (1980) interpreted normal faults along the flanks of the Beata Ridge, with east down-thrown flanks with displacements along the western escarpment that diminishes to the southwest being buried beneath the Colombian Plain.

Evidence of Miocene to Recent tectonic activity is present in the southern edge of the Beata Ridge where displacements along young normal faults offset strata up to 1,000 m. Holcombe et al. (1990) proposed a late Cretaceous time for the formation of the Beata Ridge with later periods of thermal uplift and subsidence. It is quite possible that the normal fault reactivation and east-west extension of the Beata Ridge during the latest portion of the Neogene is related to the relative convergence between the North and South American plates.

Leroy and Mauffret (1996) studied seismic reflection profiles and proposed that transpression occurred along the Pecos fault zone located in the southern portion of the Beata Ridge that separates the Venezuelan and Colombian Basins. This occurred since the Early Miocene. They propose a northeast-southwest to east-west compression and 170 km of shortening. Both deformational prisms have been formed by the north-south compression caused by the relative movement between the North and South American plates. Leroy and Mauffret (1996) propose the existence of only two microplates within the Caribbean Figure, i.e., the Colombian and Venezuelan plates separated by the Beata Ridge. The Venezuelan plate includes the Gonave, Hispaniola and Puerto Rico areas even though the Muertos Trough separates the last two areas from the Venezuelan basin. The Colombian plate includes the Pedro and Hess escarpments, which are thought to have a component of right-lateral strike-slip motion (Leroy and Mauffret 1990).

Larue (1994) proposed that the Puerto Rico-northern Virgin Islands block (PRNVI) has rotated 25° counterclockwise in the late Miocene-early Pliocene based on paleomagnetic studies of Oligocene to Pliocene limestones. Seismic reflection analysis and GLORIA surveys along the Puerto Rico Trench show that the amount of subduction increases toward the east and extension increases to the west. The opposite occurs along the Muertos Trench. Larue (1994) also argues that the Puerto Rico-Virgin Island (PRNVI) block is a microplate that moves independently from the Caribbean plate itself.

There is no systematic arrangement of large earthquakes (>5 M) within the Caribbean plate. This lack does not help to define various microplates as part of the Caribbean plate. The scarcity of earthquakes may be related to the small plate convergence rate and, thus, to long earthquake cycles. Even faults within the southern

Caribbean plate boundary zone have very small earthquake recurrence rates. For example, Audemard (1996) estimates that recurrence rates of seismic events along the Venezuelan E-W trending, right-lateral Ancon fault system may be as small as one in 1900 years and about one in 4300 years along the Oca fault.

Caribbean-South America plate kinematics. It has been suggested that most of the present day eastward Caribbean plate movement is driven by the convergence of the North and South American plates (e.g., Sykes et al., 1982) escaping towards the East and overriding North and South American oceanic crust.

Estimates of the relative motion of the Caribbean with respect to its surrounding plates are improving with the development of new techniques, although there is still much debate about the reported values. Global Positioning System and, recently, VLBI (Very Long Baseline Interferometry) measurements have been evolving since the early 1990's, which allow researchers to estimate more accurately relative velocity data and Euler vectors that predict strain and deformation with greater confidence (Freymueller et al., 1993; Kellog and Vega, 1995; Dixon and Mao, 1997; Dixon, 1998; MacMillan and Ma, 1999; Weber et al., 2001; Pérez et al., 2001).

During the past decade, GPS measurements have been used to assess the incongruence of global plate circuits that include the Caribbean plate (NUVEL1, NUVEL 1A). The Caribbean plate may not be moving as one solid unit; instead, strain and slip partitioning at its collisional boundaries may generate terranes that move independently with respect to the Caribbean plate.

NUVEL-1 (De Mets et al., 1990) describes the present relative motion between 12 rigid plates. It predicts that the angular velocity vector between the Caribbean and South

American plates (CA-SA) is $0.13^{\circ}/\text{my}$ at 63.1°N , 15.2°W . This vector is not based on slip vectors from the Lesser Antilles island arc. NUVEL-1 also suggests slip vectors at the Lesser Antilles island arc to be 13 mm/yr with an azimuth of $\text{S}68^{\circ}\text{E}$ (oblique convergence) near the El Pilar Fault (11°N , 62°W). The RM2 model of Jordan (1975) estimated a faster rate of 22 mm/yr at $\text{N}77^{\circ} \text{ W}$ (oblique convergence), and Deng and Sykes (1995) estimated that the pole of rotation for CA-SA motion is located at (52°N , 81°W) giving an azimuth of $\text{N}75^{\circ}\text{E}$ (oblique extension) and a rate of 22 mm/yr .

The first two models, NUVEL-1 and RM2, were based on transform azimuths, spreading rates and slip vectors that encompass global plates. Sykes et al. (1982), however, used a relationship between the lengths of Wadati-Benioff seismicity zone, the age of the subducting lithosphere and only three plates - North America, Caribbean and South America - to constrain the model (Stein et al., 1988).

The difference between NUVEL-1 and RM2 lies in the use of slip vectors from the Greater Antilles. NUVEL-1 uses no slip vectors from focal mechanisms in the Greater Antilles while RM2 does (Stein et al., 1988). The NUVEL-1 and RM2 models predict convergence between CA-SA at least for the last 3 my. Algar and Pindell (1993) and later Deng and Sykes (1995) propose that in the late Miocene there was a major change in deformation style for CA-SA from right lateral transpression to right-lateral transtension at azimuth 080° . Pre-existing faults with an azimuth greater than 080° show a component of extension, and those faults with an azimuth smaller than 080° exhibit a component of shortening. However, Deng and Sykes (1995) record moment tensor solutions for earthquakes generated by either strike-slip or thrust fault.

More recent GPS satellite data suggest that the North and South American plates converge at a rate of 8 mm/yr in the northwest part of the Caribbean plate (Dixon and Mao, 1997) and between 11 ± 5 mm/yr to 13 ± 10 mm/yr in the North Panama deformed belt (e.g., Dixon, 1993). Dixon et al. (1998) estimated that the relative movement of the Caribbean plate relative to North America is about 21 ± 1 mm/yr in the vicinity of the Dominican Republic, twice the velocity predicted by NUVEL-1A of 11 ± 3 mm/yr. Likewise, Weber et al. (2000) suggest that the Caribbean moves eastward past the South American plate at 20 mm/yr along the El Pilar fault system and at 14 mm/yr along the Central Range fault in the island of Trinidad. The difference in relative plate vector motion between the Caribbean plate and South American plate in Venezuela and Trinidad could be possible if the Central Range fault is either creeping aseismically or accumulating elastic strain.

Plate tectonic reconstructions.

The origin and evolution of the Caribbean plate is still an issue of debate. Plate reconstructions that include the Caribbean necessarily need to address its possible place of generation (Pacific vs. in-situ) and its relationship with the surrounding plates: Pacific (Nazca-Cocos), North America, South America (e.g., Pindell and Dewey, 1982). The fixist theory proposes that the buoyant, anomalously thick Caribbean crust was either formed in a location near Central America during the middle to Late Cretaceous (Meschede, 1998; Meschede and Frisch, 1998), or as lately suggested by James (2002), properly “in-situ” during Aptian time, filling the space left by the Americas when they drifted apart during the Jurassic. Alternatively, Pindell and Barret (1990), Pindell (1994)

Figure 11. The Pangea super-continent showing a Late Paleozoic fold belt across it (vertical lines). After Bartok (1993).

and Driscoll and Diebold (1999) propose that the Caribbean crust formed in the eastern Pacific by sea-floor spreading in the Late Jurassic-Early Cretaceous with an initial thickness of approximately 6 km. Pindell et al. (2001) argue that a mobilist theory (Pacific origin of the Caribbean plate) is needed in order to explain the regional puzzling geology: 1) The Greater Antilles Arc (Cuba, Jamaica, Hispaniola, Puerto Rico and northern Virgin Islands) is older than the Central American arc, and (2) A Pacific position is needed to explain the Campanian tectonic interaction of the Caribbean plate with northern Colombia and southern Yucatán.

New geochemical data seem to support the theory that the bulk of the Caribbean plate originated as discrete regional basalt flood events at 90 Ma and 76 Ma, where regional and extensive volcanism occurred at fast rates and in large volumes (Sinton et al., 1998). The source of material for the above massive events was thought to be the Galápagos hot spot (Sinton et al., 1998).

Bartok (1993) postulates that the Mesozoic rifts systems in west-central Pangea (South America, Gulf of Mexico, and West Africa) were controlled by the late Precambrian, early Paleozoic and the Pangea suture orogenies. The older grain of deformation served as a zone of weakness where the above rift system would develop. The Triassic rifting parallels the trend of the Alleghenian / Ouachita orogenies, the early Paleozoic trends of eastern / southern North America and Florida / northern Yucatán continue along the Sierra Madre Oriental of Mexico and along the eastern portion of the Central Cordillera of Colombia, respectively (Bartok, 1993). Likewise, the grain of the Late Precambrian orogenic belt in northwest Gondwana served as the weakness zone by

Figure 12. Mid-Jurassic rift trend in central Pangea showing the location of the Hispanic Corridor and minor graben systems. After Bartok, (1993).

which the Jurassic rifting would be initiated between the Maya block and northern South America (Fig. 11).

Late Triassic-Early Jurassic. The breakup phase between the Americas resulted in graben systems filled with red beds and volcanics that parallel the Alleghenian / Ouachita orogen in North America (Bartok, 1993; Pindell, 1993). North America (Yucatán Block) begins to drift away from Gondwana forming the Hispanic Corridor (Fig. 12), initiating a massive biotic exchange between the Tethys and Pacific oceans during the Bajocian / Bathonian (Westermann, 1980; Smith, 1983; Bartok et al., 1985). In Gondwana (northern South America), the Mid-Jurassic rift event also generated the Girón-La Quinta, Mantecal, Guarumen and Espino grabens (Bartok, 1993).

According to Pindell (1993), the Americas began to drift apart (Figs. 13 and 14) in a northwest-southeast direction during the Bathonian (175Ma). Oceanic crust was formed in the Gulf of Mexico. During the Valanginian (130 Ma) the Late Jurassic ridge system in the Gulf of Mexico ceased its activity (Pindell and Barret, 1990; Pindell, 1993). Subsequently, the Proto-Caribbean crust was formed. The stretching of the Pre-Cretaceous basement was followed by drifting, thermal subsidence and the accumulation of a non-volcanic sedimentary cover, which consists of marine clastics and carbonates in minor proportions, forming an extensive passive margin along northern South America.

Cretaceous. During the Berriasian, spreading ceased in the Gulf of Mexico and the Yucatán Block became part of the North American plate (Figs. 13 and 15). The North America-Gondwana drift occurred only in Proto-Caribbean Sea. Until mid-Cretaceous (Figs. 13, 15 and 16), North and South America and the Proto-Caribbean were flanked in the west by a west-facing volcanic arc (Great Arc of the Caribbean; Burke, 1988). Basalts

intruded into the oceanic crust, west of the arc in mid-Cretaceous and resulted in the so-called Caribbean B' event. This event caused the Farallon plate to thicken (15-25 Km), making it more buoyant and resistant to subduction (Duncan and Hargraves, 1988; Burke, 1988; Pindell and Barret, 1990; Pindell 1993). This may have been the cause of the change in subduction polarity, the Farallon plate started to move northeastward in between North and South America (Fig. 16). Another possibility for the cause of polarity reversal is accelerated spreading rates due to Mid-Cretaceous opening of the South Atlantic (Pindell, 1993). The timing of the reversal of subduction polarity is controversial. Kerr et al. (1997) and Sinton et al. (1998) believe that it happened in Late Cretaceous time, whereas Draper et al. (1996), Smith et al. (1999) and Snoke and Noble (2001) suggested that the change occurred in pre-Albian time. Seafloor spreading between the Americas ceased in the late Albian while subduction of the Proto-Caribbean oceanic crust beneath the Farallon plate, the Greater Antilles and the Aves Ridge arc system continued. At that time, the northern Venezuela margin was still a passive margin. Eastward-dipping subduction and arc magmatism began in the Panama-Costa Rica arc system in the southwest Pacific in the Santonian-Campanian times whereby the Caribbean plate became separated from the Farallon plate. The Great arc of the Caribbean began to interact with the northwestern corner of the South America plate during the Maastrichtian (Figs. 13 and 17).

Paleocene-Eocene. The Cenozoic marks an intense deformation, extensional and contractional, in the outer rim of the Caribbean plate as it continued its northeast migration during the Paleocene (59 Ma), (Figs. 13 and 18). By this time, the Grenada and Yucatán back-arc basins opened, and the Greater Antilles collided with the Bahamas

platform. During the Paleocene the Lara nappes began to be incorporated onto continental South America in western Venezuela, becoming younger towards the east (Mann and Lugo, 1993). Likewise, the Middle to Late Eocene (49 Ma) marks the cessation of the collision of the Greater Antilles with the Bahamas Platform becoming part of the North American plate (Figs. 13 and 19). Volcanism jumped eastwards from the Aves Ridge to the Lesser Antilles. Pindell and Barret (1990) propose that the Americas converged by 250-300km in a north-northwesterly direction since the middle Eocene (Figs. 13 and 20). The Cayman Through began to open along the northern Caribbean plate boundary zone (Figs. 13 and 19).

The Caribbean plate migration and collision azimuth changed from northeast to east accentuating the intense deformation along northern South America (e.g., Ostos, 1990; Avé Lallemant and Guth, 1990; Pindell, 1993).

Eocene-Recent. From Eocene to Recent the Caribbean plate moved continuously eastward, while North and South America converged in highly oblique transpression along the two eastwest trending plate boundaries. The transpression and its associated foredeeps began in the Paleogene in western Venezuela (Mann and Lugo, 1995) and affected eastern Venezuela and the Trinidad-Tobago areas during the Late Oligocene-Middle Miocene (Hung, 1997; Di Croce, 1995). Strike-slip faults overprinted the obducted terranes in northern Venezuela developing pull-apart basins during the Oligocene-Early Miocene (Schubert, 1988; Muessig, 1984; Ysaccis, 1997). During the Miocene, the Lara nappes were finally overthrust onto the craton overriding the Oligocene-Early Miocene Roblecito foredeep (Figs. 21 and 22). Likewise, during the Miocene, the Panamá arc collided with the northwestern corner of South America,

causing the isolation of the Caribbean biota and change of water circulation patterns. Likewise this collision triggered the northward tectonic escape of the Maracaibo block and subsequent uplift of the Western Cordillera, the Andes and Perijá mountain ranges in Colombia and Venezuela, as well as the generation of the Southern Caribbean deformed belt and the North Panamá Folded Belt (Kellog and Bonini, 1984; Maze, 1984, Dewey and Pindell, 1985; Audemard, 1990).

PLATE BOUNDARY EVOLUTION

NORTH AMERICA - CARIBBEAN - SOUTH AMERICA

Mesozoic-Cenozoic Period

After Pindell (1994)

PALEOGEOGRAPHY

■	Deep Marine
■	Shallow Shelf
■	Volcanic Arc
■	Non-Marine

GRAPHIC SCALE

0 500 1000 (km)

Figure 13. Legend for Caribbean plate tectonic reconstructions. After Pindell (1994).

Bathonian

Figure 14. North America and South America plates drifting apart. From Pindell (1994).

Barremian-Early Aptian

Figure 15. Northern South America is a passive margin. After Pindell (1994).

Late Albian

Figure 16. Generation of the Great arc of the Caribbean. Proto-Caribbean crust is subducted beneath this island arc. After Pindell (1994).

Maastrichtian

Figure 17. The Great Arc of the Caribbean (Burke 1988) is colliding with the northwest corner of the South American plate in the Maastrichtian and the present Caribbean plate is defined by the formation of the Costa Rica-Panama Arc in the west. After Pindell (1994).

Palaeocene

Figure 18. During the Paleocene, the Grenada and Yucatán back-arc basins opened, the Greater Antilles collided with the Bahamas platform and the Lara nappes were obducted onto the South America plate. After Pindell (1994)

Middle Eocene

Figure 19. The Eocene marks the cessation of the collision of the Greater Antilles with the Bahamas Platform, becoming part of the North American plate. Volcanism jumped eastwards from the Aves Ridge to the Lesser Antilles. The Americas converged by 250-300km in a north-northwesterly direction since the middle Eocene. The Cayman Through began to open along the northern Caribbean plate boundary zone. The Caribbean plate migration and collision azimuth changed from northeast to east, accentuating the intense deformation along northern South America. After Pindell (1994).

Figure 20. Vectors of relative motion of South America with respect to North America since Jurassic time. Note that strong 250-300 km convergence between the above two plates started since Middle Eocene in a north-northwest direction (After Pindell and Barret, 1990).

Early Oligocene

Figure 21. The inception of the basal foredeep unconformity in north-central Venezuela occurred in Late Eocene-Early Oligocene times, while the Caribbean plate moved in an easterly fashion. After Pindell (1994).

Early Miocene

Figure 22. The final emplacement of the Lara nappes including the Villa de Cura occurred in the Miocene. After Pindell (1994).

APPENDIX 2

TECTONIC FRAMEWORK OF NORTH CENTRAL VENEZUELA

Introduction

In recent years, it has become clear that displacement and strain are partitioned along most transconvergent (transpressional) and transextensional (transtensional) plate boundaries (e.g., Fitch, 1972). Partitioning of displacement and strain results in the generation of coeval plate boundary-perpendicular and parallel movements: the first is expressed as boundary-parallel thrust faults and the second as boundary-parallel strike-slip faults (Fig. 1) (e.g., Avé Lallemant and Guth, 1990; Oldow et al., 1990; Cashman et al., 1992).

Transpression and transtension are described in terms of simple shear and pure shear in which kinematic parameters such as plate motion, instantaneous strain axes and degree of strike-slip partitioning play an important role (e.g., Tikoff and Teyssier, 1994).

Horizontal slip vector azimuths obtained from shallow earthquakes (<70 Km depth) in collisional boundaries are assumed to parallel the direction of convergence between two plates, but in reality, generally they are perpendicular to the trench. Moment tensor solutions also show earthquakes generated by strike-slip faults that are nearly coeval with the thrust faults along collisional boundaries (Cashman et al., 1992; Dseng and L.Sykes, 1995).

Unlike oceanic plate boundaries, contractional continental plate boundaries consist of a wide and diffuse zone that bounds the plates. In this framework,

Figure 1. The Hikurangi trench in New Zealand is an example of how the displacement is partitioned at oblique convergent margins. Note the coexistence of strike-slip faults and thrusts along the margin (Cashman et al., 1992).

Figure 2. A megasuture includes the geological outcomes of several orogenic phases and the basins within it. The diagram shows three different megasutures and basin types. After Bally and Snelson (1980).

Figure 3. Tectono-stratigraphic map of northern Venezuela and southern Caribbean showing the main tectonic belts and lithological units. After Ysaccis (1997).

Bally and Snelson (1980) defined the term megasuture and apply it to wide and diffuse plate boundaries (Fig. 2). In this context, the Caribbean-South American plate boundary is an example of a wide megasuture (Bally and Snelson, 1980) that extends for approximately 300 and 400 km between the Venezuelan-Colombian Guajira to the islands of Trinidad-Tobago (Fig. 3). The diachronous oblique collision between the Caribbean and the South American plates generated the megasuture from the Eocene to Recent.

As a consequence, this thesis shows allochthonous and parautochthonous terranes have been accreted onto the Guyana Craton from Middle Eocene in the Guajira area to Pliocene-Recent in the Trinidad-Tobago area (Fig. 3), (e.g., Beck 1978; González de Juana et al., 1980; Bellizzia and Dengo, 1990; Lugo and Mann, 1995; Pindell and Barret, 1990; Avé Lallemant and Sisson, 1993; Pindell, 1993, 1998; Ysaccis, 1997).

Geological provinces.

The Caribbean-South American plate megasuture along north-central Venezuela can be generalized into three major E-W trending belts (Fig. 3): (1) Dutch and Venezuelan Leeward Antilles, (2) Caribbean Mountain system and (3) Foreland basin (e.g., Bellizzia and Dengo, 1990). Likewise, Stephan (1976) and Beck (1986) subdivide the Caribbean-South American collisional zone into four different terranes, from north to south: 1) the Coastal Fringe-Margarita Zone (Zone Interne); 2) the Cordillera de la Costa Zone; 3) the Aragua Nappes (Internal nappes) that includes the Caucagua-El Tinaco nappe, Loma de Hierro ophiolite (Beck, 1978) and Villa de Cura nappe -- note that these nappes are included in the Caribbean Mountain system of Bellizzia and Dengo, (1990); 4) Piedmont Zone (External zone); this zone is also included in the Caribbean Mountain

system of Bellizzia and Dengo, (1990). The former subdivision will be followed in order to simplify the discussion.

Deformation structures in the plate boundary zone indicate partitioning of the right-oblique convergence-rate vector into two components resulting in south-vergent thrusting and dextral displacements along E-W trending faults (Figs. 1 and 3). These megascopic structures are expressed along north-central Venezuela, from north to south, as the low angle Benioff zone (B-type) of the South Caribbean deformed belt; the pull-apart fault system of the Bonaire basin; the east-west trending San Sebastian-La Victoria-El Pilar strike-slip fault system; and the southernmost thrust-system of the Serranía del Interior, which ends with the frontal thrust in the Guárico Basin (A-type subduction), (e.g., Biju Duval et al., 1983) (Fig. 3).

Ysaccis (1997) made a geological interpretation of the tomographic studies by van der Hilst (1990) showing the geometrical relationships between the Atlantic, Caribbean and South American plates along northern Venezuela (Figs. 4 to 6). The Caribbean crust seems to be underplating beneath the South American continental crust at deeper levels in western Venezuela, and it changes gradually to shallow levels in central and eastern Venezuela (Figs. 4 to 6). Based on his interpretation, Ysaccis (1997) divided the subduction zones in the southern Caribbean in two distinctive domains: Caribbean domain and Atlantic domain (Fig. 4). In the first domain, limited to western and central Venezuela, the Caribbean is underplating South America to the southeast (Fig. 5). The Caribbean-South American plate subduction becomes shallower

Fig. 4. Plate tectonic interactions between the Caribbean, South America and the Atlantic plates along northern South America. The Caribbean oceanic crust is represented by the shaded area. The Atlantic oceanic crust is represented by the dotted area. Map shows depth contour for subducting slabs. After Ysaccis (1997).

Figure 5. Geological interpretation of tomography studies (Van der hilst, 1990) along the southern Caribbean by Yssacis (1997). The Caribbean subduction domain is characterized by south dipping underplating of Caribbean crust beneath the South American plate along western and northern Venezuela.

Figure 6. In eastern Venezuela and Trinidad, the interaction between the Caribbean and the South American plate is mostly strike-slip, while the Atlantic subduction zone occurs at deeper levels (Atlantic domain) (Ysaccis, 1997).

towards the east and is mostly strike-slip along the Paria Peninsula (Fig. 6) (Ysaccis, 1997). The Atlantic domain is constrained to northeastern Venezuela and Trinidad, where the Atlantic oceanic slab is dipping to the west-northwest (Ysaccis, 1997).

Gravimetry and magnetic studies by Bosch and Rodriguez (1992) in north-central Venezuela (Fig. 7) also suggest underplating of the Caribbean crust beneath a thick South American crust. Within the Caribbean mountain system, the post-Miocene La Victoria fault zone is the southernmost expression of dextral strike-slip motion in continental north-central Venezuela (Schubert, 1988). To the South, deformation is taken up solely by the plate-boundary perpendicular shortening component (See Appendix 3).

Dutch and Venezuelan Leeward Antilles terrane

The Dutch and Venezuelan Leeward Antilles terrane (Fig. 3), south of the submarine South Caribbean deformed belt, is composed of the Dutch Leeward islands (Aruba, Curacao and Bonaire) and the smaller Venezuelan islands (Los Monjes, Los Roques, La Orchila, La Tortuga, La Blanquilla, Los Hermanos, Los Frailes and Los Testigos) related to the Lesser Antilles volcanic arc. It consists of a ruptured chain of Lower to Middle Cretaceous oceanic rocks and Upper Cretaceous-Paleogene volcanic rocks of island arc origin, intruded by batholiths of silicic to intermediate composition and dikes and sills of silicic to mafic composition (e.g., Bellizzia and Dengo, 1990; Ostos, 1990; Thompson et al.). They are overlain by Neogene marine calcareous sequences. K/Ar analysis of mafic intrusives in the western islands (Los Monjes) yielded ages of 120 Ma (Early Cretaceous) and about 46 Ma (Middle Eocene) in the most eastern islands (Los Testigos), suggesting that this volcanic arc terrane was progressively deactivated since Early Cretaceous time (Santamaría and Schubert, 1974) when it collided with the northern margin of South

Figure 7. Magnetic and gravimetry studies in north-central Venezuela also suggest the Caribbean oceanic crust underplating a thick South America continental crust. After Bosch and Rodriguez (1992).

Figure 8. Map of tectonic belts in the north-central Caribbean Mountain system as defined by Menéndez (1966), Peirson (1965), Bell (1968), and Beck (1978). The dashed areas represent the studied transects: (1) Platillón-Tiznados, (2) Valle Morin-Camatagüita, (3) Altagracia de Orituco, and (4) San José de Guaribe.

America. Likewise, paleomagnetic data suggest large block rotations (clockwise) since the Cretaceous (Stearns et al., 1982; Case et al., 1984). Stearns et al. (1982) analyzed oriented igneous samples from the Aruba and Bonaire islands and concluded that these islands underwent a 90° clockwise rotation since the Late Cretaceous with respect to stable South America.

Caribbean Mountain system

In north-central Venezuela, the Caribbean Mountain system (Figs. 3 and 8) consists of six elongated east-west trending poly-deformed terranes consisting of metasedimentary and metagranitic rocks, peridotite-gabbro complexes and volcanoclastic and volcanic rocks that crop out discontinuously as elongated northeast-southwest trending belts, deformed by northeast-southwest younger strike-slip faults complicating the relationships among the units (e.g., Menéndez, 1966; Bellizzia and Dengo, 1990). They are the remnants of island arcs, subduction complexes and continental margin deposits (Avé Lallemant and Sisson, 1993; Erikson and Pindell, 1993).

Menéndez (1966) and Bellizzia and Dengo (1990) subdivided the Caribbean mountain system into four tectonic belts based on similarity of rock type and structural characteristics. These belts parallel the mountain range and are separated by faults of regional extent. They are from north to south: 1) Margarita coastal ophiolite nappe, 2) Cordillera de La Costa nappe, 3) Caucagua-El Tinaco nappe, 4) Loma de Hierro-Paracotos nappe, 5) Villa de Cura nappe, and Piemontina (Piedmont) nappe (Figs. 3 and 8).

Margarita coastal ophiolite nappe. The Margarita coastal ophiolite nappe crops out discontinuously from the Guajira Peninsula in the west, along portions of the Cordillera de la Costa, Araya-Paria Peninsulas and Margarita Island, in the east. It consists of metagabbros, serpentinites, amphibolites, greenschists, gneisses, marbles, and has granites and basaltic dykes (Stephan, 1985; Ave Lallemant, 1997). In the Guajira and Paraguana Peninsulas, the nappe consists of metavolcanics and minor sedimentary rocks (e.g., Bellizzia and Dengo, 1990). In the Cordillera de la Costa, the nappe consists of High P /LowT rocks including eclogite, blueschist garnet amphibolite, amphibolite and low grade greenschist, with embedded ultramaphic rocks (e.g., Bellizzia and Dengo, 1990). To the east, in the Araya-Paria Peninsulas, the nappe consists of greenschist, amphibolite and serpentinite (e.g., Bellizzia and Dengo, 1990). On Margarita Island, the nappe includes metabasalt, metagabbro, amphibolitic gneiss, peridotite, eclogite, serpentinite and marble. Beck (1986) proposes that the Margarita coastal ophiolite nappe consists of two main units: an ophiolitic unit and a pre-Mesozoic basement with intrusions. Both units are draped by Lower Cretaceous-Lower Senonian metasedimentary and metavolcanic rocks, Upper Senonian unit of chert and diabase capped by Middle Eocene-Upper Eocene turbidites.

Cordillera de La Costa nappe. The Cordillera de La Costa nappe is the next southernmost part of the Margarita coastal ophiolite nappe (Figs. 3 and 8). It is bound to the south by the La Victoria fault zone (Menéndez, 1966). Avé Lallemant and Sisson (1993) proposed that this belt consists of three different rock assemblages: (1) An assemblage of oceanic affinities that includes serpentinites, amphibolites, leucotonalitic

gneisses and actinolite, garnet, mica and chlorite schists and eclogite and blueschists. This assemblage is thought to be part of a subduction complex of mid-Cretaceous age; (2) A continental margin assemblage including graphite, garnet and mica schists; marble; quartzites; and quartz feldspar gneisses. This assemblage of rocks is thought to be part of the proto-Caribbean passive continental margin. (3) Coarse-grained augengneisses and granites of Early Paleozoic age probably derived from the South American cratonic basement (Avé Lallemant and Sisson, 1993).

Caucagua-El Tinaco nappe. The Caucagua-El Tinaco belt (Figs. 3 and 8) consists of Paleozoic or older basement: hornblende gneisses and trondhjemitic rocks (El Tinaco Complex), mafic to ultramafic complexes (Tinaquillo peridotite) and a volcanic sedimentary sequence overlying the Cretaceous sedimentary units (Menéndez, 1966; Bellizzia and Dengo, 1990; Ostos et al., 2004). Beck (1986) includes this nappe in his Aragua nappes. This author describes a pre-Mesozoic basement consisting of amphibolite, quartzite, trondjemite and diorite, overlain by metasedimentary rocks with Lower Cretaceous-Lower Senonian basalt flows. This belt is located south of the La Victoria fault zone and north of the Santa Rosa fault (Figs. 3 and 8).

Loma de Hierro-Paracotos nappe. The Loma de Hierro-Paracotos nappe is located south of the Santa Rosa fault and north of the Agua Fría fault and consists of a narrow belt (200 km) that to the east disappears below the Tertiary Tuy basin (e.g., Menéndez, 1966; Bellizzia and Dengo, 1990).

The Loma de Hierro ophiolite and the Paracotos Formation compose the Loma de Hierro-Paracotos nappe (Aragua nappes of Beck, 1986), (Figs. 3 and 8). The Loma de

Hierro unit is a dismembered oceanic floor ophiolite complex composed of hazburgite, serpentinite and layered gabbro, volcanic breccias, pillow basalts capped by deep-water radiolarian cherts (e.g., Bellizzia and Dengo, 1990; Ostos, 1990). The Paracotos Formation consists of gray to pale green aphanitic limestones with fossils that suggest a Maastrichtian age, conglomerates, and volcanic rocks embedded within argillaceous and carbonaceous phyllites (Menéndez, 1966; González de Juana et al., 1980; Bellizzia and Dengo, 1990). González de Juana et al., (1980) suggest that this lithologic body might represent a "wildflysch" probably formed during Paleogene times. Beck (1986) includes this nappe into his Aragua Nappes classification.

Villa de Cura Nappe. The Villa de Cura nappe is bounded to the north by the Agua Fria fault and to the south by the Cantagallo fault (Fig. 8). The participants of the Caribbean Project from Princeton University led by Dr. Harry Hess in the 1960's was the first to recognize and propose the allochthonous nature of this blueschist belt based on the different lithological types and metamorphic conditions of the rocks with respect to the surrounding units to the north and south (e.g. Smith, 1962; Oxburgh, 1962; Menéndez, 1966; Bell, 1968). Considered a klippe, this nappe was originally proposed to have slumped in a regional Maastrichtian-Paleocene trench located along the northern Venezuelan margin (e.g., Menéndez, 1966; Bell, 1968, 1972), instead of a tectonic-derived allochthonous nappe, derived from the fragmentation of the Cretaceous Great Caribbean arc (e.g., Burke, 1988), where exhumation, and displacement along regional strike-slip faults, rotation and accretion to the South American took place. Paleomagnetic data from rocks from the Villa de Cura and Caucagua-El Tinaco nappes suggest a 90° clockwise rotation of these nappes from a north-south trending island arc complex to its

present northeast-southwest geometry, possibly occurring between the Maastrichtian and the Paleocene during their emplacement onto the South American craton (Skerlec and Hargraves, 1982).

The thickness of this complex has been estimated between 5 and 13 Km (Case et al., 1984; Smith, 1996). Crustal models derived from gravimetric and magnetic data along the Caribbean-South American megasuture suggest that the Villa de Cura Nappe is a klippe with thicknesses varying between 1 and 2 km (Fig. 7), (Bosch and Rodriguez, 1992).

The Villa de Cura nappe (Figs. 3 and 8) consists of the Villa de Cura Group and the Las Hermanas Formation (Shagam, 1960). The former is made of metabasalt, metalava, metatuff and intercalated metachert, metavolcaniclastic rocks, metachert and graphitic schist (Stiles, 2000). The Villa de Cura Group has been metamorphosed at high P/low T conditions (blueschist facies) and has been subdivided into four distinctive metamorphic sub-belts from north to south (Fig. 9): 1) pumpellyite-actinolite belt, 2) glaucophane-lawsonite belt, 3) glaucophane-epidote belt, and 4) Higher T, barroisite belt (Smith, 1999). Retrograde and prograde P-T paths for the former three belts parallel each other, which is typical for low geothermal gradients during exhumation of the rocks during subduction (Franciscan-style; Smith, 1999). The barroisite belt shows same P conditions but higher T than the former three belts. $^{40}\text{Ar}/^{39}\text{Ar}$ ages of metamorphism ranges from 96.3 ± 0.4 Ma for the barroisite belt to 79.8 ± 0.4 Ma for the northern belts (blue amphibole and white mica ages, respectively) (Smith et al., 1999). Geochemical studies suggest that the Villa de Cura blueschist nappe is indeed a subducted and later exhumed island arc terrane and is similar in chemical composition as the Albian-Aptian

island arc tholeiites present along the rim of the Caribbean plate including Cuba, Hispaniola, Puerto Rico, Bonaire and Tobago (Ostos et al., 2004; Stiles, 2000). The Villa de Cura group shows both tholeiitic composition and a maturation trend from metatuff to metaankaramite (Stiles, 2000). Metabasalts from the Villa de Cura group show a marked correlation with volcanic arc and basaltic arc tholeiite zones (Stiles, 2000). The southernmost belt, Las Hermanas Formation (Tiara volcanics), is in tectonic contact with the Villa de Cura Group (Smith, 1996) and is composed mainly of volcanic ash breccias and lithic tuffs metamorphosed to prehnite-pumpellyite facies.

Western Serranía del Interior foreland-fold and thrust belt. In the present study, the Western Serranía del Interior foreland-fold and thrust belt, also known as Guárico mountain front or Piedmont belt (e.g., Peirson, 1965; Bell, 1968; Beck, 1986; Bellizia and Dengo, 1990) lies south of the Villa de Cura nappe and north of the Guárico basin (Figs. 3 and 8 and Appendix 4). This mountain range consists of non-metamorphosed Lower Cretaceous calcareous rocks to Lower Tertiary siliciclastic rocks of marine to terrestrial origin, respectively (e.g., Peirson, 1965; Bell, 1968; Beck, 1986; Bellizia and Dengo, 1990). Peirson (1965) and Bell (1968) subdivided the north-central Serranía del Interior in four geological provinces from north to south: 1) Piedmont belt, 2) Belt of thrust faults, 3) Belt of overturned beds and 4) Belt of gently-dipping-beds (Fig. 8).

The first and northernmost belt, the Piedmont zone, is bound to the north by the Villa de Cura complex along the Cantagallo fault and to the south either by the Belt of thrust faults or by the Belt of overturned beds (Fig. 8). The Cantagallo fault separates the metamorphic allochthonous from the parautochthonous rock assemblages. The Piedmont

belt is characterized by south-vergent isoclinal to tight folds and by south-vergent thrust and reverse faults that deform parautochthonous Lower to Upper Cretaceous platformal rocks (Querecual and Mucaria Formations), allochthonous (?) to parautochthonous (?) Upper Cretaceous to Lower Eocene deep-water turbidites (Garrapata and Guárico Formations) and autochthonous basinal Oligocene-Miocene siliciclastic rocks (Naricual, Quebradón and Quiamare Formations) (e.g. Bell, 1968).

The Belt of thrust faults or Chacual complex crops out discontinuously along the *Serranía del Interior* between the Piedmont and the Overturned belt (Peirson, 1965; Bell, 1968) (Fig. 8). This structural province is strongly faulted by south-vergent imbricate thrust faults that juxtapose Cretaceous, Paleogene and Neogene sedimentary units in a tectonic *mélange* (Peirson, 1965). Given its complex structural mixture of different lithologies, this zone probably represents an unroofed regional decoupling level localised along the Cretaceous sequence. Beck (1977a, b and 1986) was the first to suggest that the sedimentary cover of the *Serranía* could be detached along an Albian to pre-Albian stratigraphic level.

The Overturned belt is located immediately south of the Belt of thrust faults and north of the Belt of gently-dipping beds. Here, Oligo-Miocene foredeep siliciclastic units form a southward overturned syncline, cut by an axial parallel fault (Fig. 8).

The Belt of gently-dipping beds (Fig. 8) is a structural province that exhibits regional open folds, the axes of which are almost parallel to the strike of the Piedmont thrust faults and are developed in Oligo-Miocene basinal sedimentary sequences (Quebradón, Quiamare Formations and their time equivalent Chaguaramas Formation). Some south-

Fig. 9. Geologic map and associated cross section along the Rio Caramacate transect in the Aragua State, Venezuela. The Villa de Cura belt outcrops along this transect. The map shows the metamorphic sub-belts: PA, pumpellyite-actinolite; GL, glaucophane-lawsonite; GE, glaucophane-epidote; BA, garroisite. After Smith et al. (1999).

vergent thrust faults with minor displacements and tear faults or lateral ramps developed in this province (see also Appendix 4).

Guárico basin and Eastern Venezuela basin. The Eastern Venezuela basin lies south of the igneous-metamorphic complex of the Villa de Cura and Cordillera de la Costa belts in the west and south of the Araya -Paria igneous metamorphic belt in the east. It lies east of the El Baúl high, north of the Pre-Cambrian Guayana shield and west of the equatorial Atlantic oceanic crust (Fig. 10).

The Eastern Venezuela Basin is divided into the Maturín basin to the east and the Guárico basin to the west (Fig. 10). These basins are separated by the poorly understood Urica arch that formed in the Miocene. The present study focusses on the Guárico basin, where the Paleocene-Lower Eocene sedimentary section is missing, suggesting that the foredeep was developed no later than in the Middle Eocene. Thickness of the sedimentary rocks is about 5000 m (e.g., González de Juana et al., 1980; Erlich and Barret, 1992).

Figure 10. Sedimentary basins of Venezuela and physiographic provinces. AF: Anaco fault; BAP: Barbados accretionary prism; BF: Bocono fault; EPF: El Pilar fault; IF: Icotea fault; LBJ: Los Bajos fault; OF: Oca fault; SF: San Francisco fault; SMBF: Santa Marta-Bucaramanga fault; SSF: San Sebastian fault; UF: Urica fault. After DiCroce (1995).

VOLUME II

***Tectonic and thermal history of the western Serranía del Interior foreland fold
and thrust belt and Guárico basin, north-central Venezuela: Implications of new
apatite fission-track analysis and seismic interpretation***

by

Jaime Pérez De Armas

APPENDIX 3

STRATIGRAPHY AND STRUCTURE OF THE GUARICO BASIN, NORTH-CENTRAL VENEZUELA

Guárico basin

Introduction. The Eastern Venezuela basin lies south of the igneous-metamorphic complex of the Villa de Cura and Cordillera de la Costa belts in the west and south of the Araya -Paria igneous metamorphic belt in the east. It lies east of the El Baúl high, north of the Precambrian Guayana shield and west of the equatorial Atlantic oceanic crust (Fig. 1). The Eastern Venezuela basin is divided into the Maturín sub-basin to the east and the Guárico sub-basin to the west (Fig. 1). These subbasins are separated by the Urica arch, (UF on Fig. 1), that formed in the Miocene. The present study focusses on the Guárico sub-basin. Here, the Paleocene-Lower Eocene sedimentary section is missing, suggesting that the foredeep developed no later than Middle Eocene. The thickness of the Guárico foredeep is about 4900 m (González de Juana et al., 1980; Erlich and Barret, 1992). The Guárico sub-basin produces oil and gas (Fig. 2) from Cretaceous and Tertiary units (Patterson and Wilson, 1953; Aymard et al., 1985; Daal and Lander, 1993).

Figure 1. Main Venezuela sedimentary basins and physiographic provinces. The Eastern Venezuela basin comprises the oil and gas prolific Guarico and Maturin sub-basins. AF: Anaco fault; BAP: Barbados accretionary prism; BF: Bocono fault; EPP: El Pilar fault; IF: Icotea fault; LBJ: Los Bajos fault; OF: Oca fault; SF: San Francisco fault; SMBF: Santa Marta-Bucaramanga fault; San Sebastian fault; UF: Urica fault. After Di Croce (1995)

STRATIGRAPHY

The stratigraphy of the Guárico sub-basin (Fig.2) can be divided into four major tectonostratigraphic units: (1) pre-rift, Precambrian-Paleozoic crystalline basement and Paleozoic sedimentary rocks; (2) syn-rift Triassic-Jurassic Ipire Formation in the Espino graben, the equivalent of the La Quinta Formation in western Venezuela (Maze, 1984); (3) post-rift Cretaceous passive-margin stratigraphic units; and (4) foredeep basin (foreland basin) deposits.

Pre-rift rock units

In north-central Venezuela the pre-Cretaceous basement is made of a crystalline Precambrian basement that is in tectonic contact with Paleozoic metamorphic and age-equivalent sedimentary rocks (Fig. 3) (Feo Codecido et al., 1984).

Precambrian basement. In Venezuela, Precambrian rocks are the basement upon which all known sedimentary basins were developed (Fig. 3). The Precambrian basement is exposed in the Guyana shield, Venezuelan Andes, and Perijá Ranges and possibly extends beneath the Paleozoic basement and the Mesozoic-Tertiary ranges of the Caribbean Mountain system and eastern Serranía del Interior on the north (Feo Codecido et al., 1984).

In Las Mercedes field area of the Guárico sub-basin, the crystalline basement consists of coarse-grained pink and light granites (Patterson and Wilson, 1953). In the Machete area, southern Guárico basin, the basement consists of Precambrian igneous and metamorphic rocks of the Guyana craton (Kiser, 1987).

CHRONO-STRATIGRAPHY		AGE (Ma)	THICKNESS (range in m)	HYDROCARBON TYPE	SOURCE ROCKS	SEAL & TRAP	MAJOR FIELDS	FORMATION	LITHOLOGY	DESCRIPTION	DEPOSITIONAL ENVIRONMENT	TECTONIC REGIME	SEISMIC UNITS
TERTIARY	NEOGENE	Pliocene	1.8										
		Late	5.2				Jabal Zuron						
		Middle	10.4			SEAL: Intra-Chaguaramas shales	Yucal Placer						
	MIOCENE	Early	16.3			TRAP: Pinchouts, Folds.	Palacio						
		Late	23.3			SEAL: Roblequito shales.	Tuxupido Ruiz						
		Early	29.3										
	PALEOGENE	Late	35.4			TRAP: Pinchouts, Folds, Faults.	Yucal Placer						
		Middle	38.6				Las Mercedes						
		Early	50.0				Palacio						
MESOZOIC	CRETACEOUS	Early	56.5				Guaypita						
		Late	60.5				Pinagua Ruiz						
		Early	65.0				Orinoco Oil Belt						
	JURASSIC	Late	157.1				Yucal Placer						
		Middle	178.0				Las Mercedes						
		Early	208.0				Orinoco Oil Belt						
	TRIASSIC	Late	245.0										
		Middle	290.0										
		Early	363.0										
PALEOZOIC	PERMIAN	Late	409.0										
		Middle	439.0										
		Early	510.0										
	CARBONIFEROUS	Late	1827										
		Middle	91										
		Early											
	DEVONIAN	Late											
		Middle											
		Early											
	SILURIAN	Late											
		Middle											
		Early											
PRE-CAMBRIAN	ORDOVICIAN	Late											
		Middle											
		Early											
	CAMBRIAN	Late											
		Middle											
		Early											
	PRE-CAMBRIAN	Late											
		Middle											
		Early											
	PRE-CAMBRIAN	Late											
		Middle											
		Early											

Figure 2. Stratigraphy of Guárico Basin, north-central Venezuela compiled from several authors (e.g., González de Juana et al., 1980; Fasola et al., 1985; Aymard et al., 1985; Erlich and Barret, 1992; Daal and Lander, 1993).

Paleozoic basement: Igneous and metamorphic rocks. The Paleozoic basement (Fig. 3) is represented by an accreted igneous-metamorphic terrane of Late Ordovician-Permian age that extends from western Venezuela to Las Mercedes oil field in central Guárico and includes granites, syenites and schists (González de Juana et al., 1980; Feo Codecido et al., 1984).

The Apure fault zone bounds this Paleozoic orogenic belt in the south while the Oca fault zone bounds it to the north. The Paleozoic basement crops out in the El Baul region in western Venezuela. Age of this complex is constrained by radiometric determinations that range from 433 to 233 Ma (Feo Codecido et al., 1984). The igneous-metamorphic Paleozoic complex is in structural contact to the south with Cambrian sedimentary rocks (Carrizal Formation) along the Apure fault zone.

Paleozoic basement: Sedimentary units. The Paleozoic pre-rift sedimentary units (Fig. 3) are represented by a siliciclastic sequence of Early Cambrian to early Ordovician age (Hato Viejo and Carrizal Formations). Fossil-barren quartzitic and arkosic sandstones of the Hato Viejo Formation are overlain by a very fine-grained sandstone and siltstone sequence with acritarch assemblages (Feo Codecido et al., 1984). Hedberg (1950) describes the Hato Viejo Formation as a unit that consists of medium to coarse-grained quartzitic, arkosic sandstones and green argillites which grades upward into the Carrizal Formation. In some areas of the Eastern Venezuela basin, the Carboniferous Carrizal Formation consists of a massive and dense green argillite, interbedded locally with sandstones and conglomerates (Hedberg, 1950). The Carrizal Formation is the oldest sedimentary section found in the Las Mercedes area and consists

Figure 3. Subcrop and outcrop distribution of PreCambrian and early Paleozoic rocks in northern South America. After Bartok (1993).

of fine-grained glauconitic red sandstones and shales. In the Machete area, the Pre-Cretaceous facies consist of Jurassic, Carboniferous and Cambro-Ordovician rocks preserved in the Espino graben (Fig. 4) (Kiser, 1987).

Syn-rift Triassic-Jurassic sedimentary rocks

Aeromagnetic data show a rectilinear depression that extends from Anzoategui State in northeastern Venezuela, via the Guárico basin in north-central Venezuela, and the Barinas basin (Apure-Mantecal graben) in southwest Venezuela, to the Colombian border (Feo Codecido et al., 1984). In the Guárico area, this depression, known as the Espino graben, is located near the structural contact of the Paleozoic basement with the Precambrian rock units of the Guyana shield (Fig. 4).

In the Las Mercedes area, the Espino graben contains possibly pre-rift Cambrian and Carboniferous rocks and syn-rift Jurassic Ipire Formation, equivalent of the Triassic-Jurassic La Quinta Formation of western Venezuela (Maze, 1984). The Ipire Formation, described in its type locality (the well NZZ-88X drilled near Santa Maria de Ipire), is a thick sedimentary unit (1540 m) that consists of fluvial and lacustrine arkosic sandstones, shales, siltstones and conglomerates with a 113 m thick basalt flow known as the Altamira flow. The basalt has yielded K/Ar ages of 162 to 157 Ma. This age is corroborated by palinological studies that suggest a middle-late Jurassic age for the Ipire Formation (Feo Codecido et al., 1984; PDVSA, *Léxico Estratigráfico de Venezuela*, 2005, <http://www.pdv.com/lexico/i6w.htm>).

Post-rift sedimentary sequence: Cretaceous

In the Guárico sub-basin (Fig. 2), only Cretaceous units have been identified lying unconformably on the Precambrian-Paleozoic basement. The near-shore Cretaceous marine facies within the Guárico basin (Temblador Group) contrast lithologically with the Cretaceous open-marine facies that crop out in the Piedmont zone of the Serranía del Interior foreland fold and thrust belt (Querecual Formation). In the Las Mercedes area, of the southern Guárico basin, the base of the Cretaceous Canoa Formation consists of a non-marine mottled shale section and some sandstones. It overlies the crystalline basement and changes toward the top into the more marine sequence of the Tigre Formation and its three members: La Cruz, Infante and Guavinita Members. In the Yucal-Placer area in northern Guárico, the Canoa Formation (275 m thick) consists of lenticular continental sandstones and shale beds (Daal and Lander, 1993).

In the Las Mercedes field, the lower half of the La Cruz Member consists of kaolinitic, coarse sandstone lenses and intercalations of fossiliferous black shales. The upper half of the La Cruz Member consists of lower black fossiliferous shales with ammonites (*Inocerami sp.*) and Cretaceous foraminifera. Highly glauconitic, calcareous, fine-grained sandstones occur in the upper section of the La Cruz Member. In the Las Mercedes field, this sedimentary unit produces 30° API gravity oil from sandstones of this formation (Patterson and Wilson, 1953). The thickness of the La Cruz Member varies regionally, thinning towards the southwest and thickening to the northeast. In the Yucal-Placer field, the La Cruz Member consists of paralic to shallow marine sandstones and shales (Aymard et al., 1985; Daal and Lander, 1993).

Figure 4. Espino graben in eastern Venezuela. Kiser in Bartok (1993).

The Infante Member (Fig. 3) or Limestone "N" horizon, is a compact fossiliferous limestone whose thickness in the Las Mercedes area varies from 0 to 20 m. Although this unit is fairly thin, it is an outstanding mappable seismic horizon in the northeast area of the Guárico basin. In the southeastern area of the Guárico basin, siliciclastic units replace most of this limestone facies. In the northern Guárico basin, in the Yucal-Placer field, the Infante Limestone consists of fossiliferous, glauconitic limestones deposited in a platform environment (Aymard et al., 1985; Daal and Lander, 1993).

The uppermost portion of the Cretaceous sedimentary unit, the Guavinita Member, is truncated at the top by a regional unconformity (Patterson and Wilson, 1953; Aymard et al., 1985). Eastward tilting of the basin removed either partially or totally this Cretaceous sedimentary section (Patterson and Wilson, 1953). In the type section (well M-8 of the Las Mercedes field), (Fig.5) sandstones, fossiliferous thin limestones and chert horizons overlie a basal shale. In the Yucal-Placer field, the Guavinita Member consists of calcareous, glauconitic and kaolinitic sandstones, limestones and black shales (Aymard et al., 1985; Daal and Lander, 1993).

In the Machete area, south of the Las Mercedes field, age of the Cretaceous rocks range from Albian to Coniacian, with a thickness of the entire section of 2440 m (Kiser, 1987). Here, the Cretaceous sequence consists of the fluvial unconsolidated massive sands of the Canoa Formation and the Tigre Formation. In the Machete area the latter unit also consists of three members: (1) shallow marine glauconitic sandstones and fossiliferous shales of the La Cruz Member, (2) light limestones interbedded with dark shales of the Infante member and 3) Glauconitic sandstones intercalated with marine

Figure 5. Main oil fields in the Guarico basin and location of wells. After Fasola et al., (1985).

shales of the Guavinita member (Kiser, 1987). The Cretaceous reservoirs average 46 m thickness, producing extra heavy oil with an average of 7° API (Kiser, 1987).

No Paleocene-Eocene rocks are identified or recognized in the Las Mercedes area of the Guárico basin (Patterson and Wilson, 1953). However, Blanco et al., (1988) indicate the existence of a preserved Middle Eocene sequence in the Guarumen basin that is eroded away in the El Baul area.

Foredeep (Foreland) basin: Tertiary

During the Late Eocene-Early Oligocene, mountain building processes all along northwestern and north central Venezuela generated physiographic barriers that split the Late Eocene Venezuelan basin (Mencher et al., 1953). A tongue-shaped basin extended in a southwest-northeast direction from the Cojedes State to Trinidad and the Atlantic Ocean (Mencher et al., 1953). The marine transgression that occurred during the Tertiary led to the accumulation of a thick sedimentary sequence whose depocenter was located northwest of the Guárico area (Meneven, 1985). The inception of the foredeep basin in north central Venezuela occurred in the Late Eocene- Early Oligocene. However, based on foraminifera studies, Fasola et al., (1985) suggest an Early Oligocene age in northern Guaricosub-basin (*Pseudohastigerina micra*, *Cassigerinella chipolensis* and *Globigerina ampliapertura* zones) for the beginning of the deposition of the La Pascua Formation (Figs. 5 to 10). Kiser (1997) in www.pdv.com/lexico/l26w.htm suggests that the La Pascua Formation is mainly Early Oligocene in the basin but Late Eocene in the northern Guárico sub-basin.

Figure 6. Tertiary planktonic foraminifera zonation and ranges in northern Guarico basin, north-central Venezuela. Redrawn after Fasola et al., (1985).

The Late Eocene-Oligocene cycle begins with the basal transgressive La Pascua Formation and continues with the neritic to bathial Roblecito Formation (Figs. 9 to 12). Paleobathymetric studies suggest that the depths of the Guárico basin during the deposition of the La Pascua-Roblecito Formations varied from shallow to neritic conditions (0-300 meters) towards the northwest (Meneven, 1985). Fasola et al., (1985) suggest that the La Pascua-Roblecito paleoenvironments (Fig. 9) changed from internal neritic (0-30 m) to medium neritic (30-90 m) in the Early Oligocene and to external neritic (90-180 m), upper bathial (180-600 m) and internal neritic (0-30 m) in the Middle Oligocene. It remained internal neritic during the Late Oligocene (Figs. 9 -12)

In the southern Guarico, the Upper Eocene-Oligocene La Pascua Formation is a basal siliciclastic unit that diachronously overlaps older Cretaceous rocks from northeast to southwest, but it also rests either unconformably on crystalline basement or upon the Carrizal Formation (Patterson and Wilson, 1953). Peirson (1965) suggests that the Peñas Blancas Formation that crops out discontinuously in the western Serranía del Interior is a lateral equivalent of the La Pascua Formation observed only within the basin.

Approximately 60% of the La Pascua Formation consists of gray to gray-brown, very fine- to very coarse-grained, good to poor cemented sandstones that are divided into six hydrocarbon-bearing horizons in the Las Mercedes field area (Mencher, 1953; Patterson and Wilson, 1953). Lignite beds as well as thin kaolinite beds are part of this formation in the Las Mercedes field (Mencher, 1953; Patterson and Wilson, 1953). According to Patterson and Wilson (1953), the fauna found in shales of the La Pascua

Figure 7. Correlation of planktonic zones along the Guarico basin. See also figure 5. Redrawn after Fasola et al., (1985).

Formation suggests marine to brackish environments. In the Orinoco oil belt, Machete area, the La Pascua Formation (122-137 m thick) consists of transgressive near-shore deposits (litoral bar, tidal inlets, lagoons and estuaries; Isea, 1987). Compact and massive sandstones interstratified with thin shale beds typical of coastal marine environments, 250 to 560 m thick, represent the transgressive La Pascua Formation in the northern Guárico basin, Yucal-Placer field (Aymard et al., 1985; Daal and Lander, 1993).

Until Middle Miocene, the Roblecito Formation represents the deepening of the Oligocene seas in the Guárico basin (Figs. 9-12). This stratigraphic unit consists of dark gray to black marine shales with sandstone bodies in its lower and upper portions. Abundant foraminiferal fauna make it possible to correlate with the Carapita Formation in the Maturín basin (Hedberg, 1950). In the Las Mercedes, Guavinita and Palacio fields in the southern Guárico basin, the thickness of this unit may vary from 450 to 570 meters. Sandstone bodies are oil and gas productive in the Las Mercedes and Yucal-Placer fields (Mencher et al., 1953; Patterson and Wilson, 1953; Daal and Lander, 1993). In the Orinoco oil belt, of the Machete area, the Roblecito Formation consists of a 580-meters thick shale unit deposited in a restricted neritic platform (Isea, 1987). In the Yucal-Placer area, of the northern Guárico basin, the entire Roblecito Formation is middle to late Oligocene in age and consists of platform, turbidite and shallow marine deposits (Fig. 12), (Daal and Lander, 1993).

The Chaguaramas Formation is a regressive Miocene unit that represents the sedimentary filling of the La Pascua-Roblecito basin (Figs. 2-12). The Chaguaramas Formation is time-equivalent of the Oficina and Merecure Formations of the eastern Venezuela basin and of the Naricual, Quebradón, Capiricual and

FORMATION	PLANTONIC ZONE	AGE
Chaguaramas (base)	G. Kugleri	Oligocene-Miocene
Roblecito	G. Ciproensis G. Opima / G. Ciproensis G. Opima G. Ampliapertura	Late Oligocene Middle to Late Oligocene Middle Oligocene Middle Oligocene
La Pascua	G. Ampliapertura P. Micra-C. Chipolensis	Middle Oligocene Early Oligocene
Tigre	G. Gansseri / A. Mayoensis	Maastrichtian

Figure 8. Formation, planktonic foraminifera zones and related ages in northern Guarico basin. Redrawn after Fasola et al., (1985).

Quiamare Formations of the Serranía del Interior as well (Figs. 13 and 14) (González de Juana, 1980; Meneven, 1985). Although affected by erosion, it has been estimated that in northern Guárico this sedimentary unit could have had a thickness of up to 4200 meters (Patterson and Wilson, 1953). The Chaguaramas Formation consists mainly of continental mottled sandstones, lignites and shales (Meneven, 1985). This entire unit thickens to the northwest. Meneven (1985) defined four main lithostratigraphic intervals within this sedimentary unit in the Guárico area: 1) basal sandy-glauconitic section (shallow water marine influence), 2) sandy-coaly-calcareous section (very shallow-continental sedimentation), 3) mottled section (continental influence, without fossils) and 4) Oficina-influenced upper section (faunal content similar to that of the Oficina Formation in eastern Venezuela). Oil varying from 18° to 42° API gravity and gas have been produced from Chaguaramas sandstone bodies in the Tucupido, Saban and Ruiz fields in southeastern Guárico State. In the Machete area, of the Orinoco oil belt, the basal sands of the Chaguaramas Formation contain large volumes of heavy to extra heavy oil.

Structural analysis of the Guárico basin.

Introduction. In the central Guárico area, the Las Mercedes, Palacio and Guavinita oil fields produce from the Cretaceous Temblador Group and the Tertiary La Pascua, Roblecito and Chaguaramas Formations. They are the westernmost hydrocarbon producing fields in the Eastern Venezuela basin (Patterson and Wilson, 1953). Thickness of the Cretaceous Temblador Group varies from 0 to 750 meters while the Tertiary La

Pascua and Roblecito Formations combined are up to 2700 meters thick (Patterson and Wilson, 1953).

During the 1930's, refraction and reflection seismic surveys establish the regional structures and depth to basement in the Guárico area. Although the results of the first drillhole spudded in November 1938 (El Guayabo 1) were discouraging, the Mercedes-2 well was successful producing 35° API oil from the Tertiary section (Patterson and Wilson, 1953). During the mid 40's, the number of seismic surveys increased, resulting in more hydrocarbon discoveries. By 1953, the field was producing 24,340 barrels per day.

In the northern Guárico basin, near the Serranía del Interior Mountain front, the most important gas reserves in the study area were found primarily in the El Yucal - Placer field (Fig. 5). This field was discovered by the Placer-1 well (1947) and Yucal-1 (1957) (Aymard et al., 1985). During the early 80's, exploration in this field continued with five new discoveries (Aymard et al., 1985). In the Yucal-Placer field, gas accumulations are mainly in Oligocene marine sandstones at depths of 390 to 930 meters. The most important traps were stratigraphic pinch-outs (Aymard et al., 1985).

Blanco et al. (1988) suggested that there are four major depositional sequences in the Guárico and Guarumen basins. They are from old to young: (1) Cretaceous to Lower Eocene (Sequence 4, marginal marine outer neritic); (2) Oligocene-Lower Miocene (Sequence 3, marginal marine-outer neritic); (3) Lower to Middle Miocene (Sequence 2, marginal marine-outer neritic); and (4) Upper Miocene-Pleistocene (Sequence 1, continental conditions). Blanco et al. (1988) also interpreted cylindrical folds and NE-SW striking thrust faults that deform Cretaceous and Tertiary rocks in northeastern

Figure 9. Benthic foraminifera correlation along the Guarico basin. See also figure 5. Redrawn after Fasola et al., (1985).

FORMATION	ZONE	PALEOENVIRONMENT (BATHYMETRY)
Chaguaramas (base)	<i>M. fusca</i> / <i>T. laevigata</i> <i>E. antillarum</i>	<i>Marginal marine (0-6 m)</i> <i>Internal neritic (0-30 m)</i>
Roblecito	<i>M. fusca</i> / <i>T. laevigata</i> <i>E. antillarum</i> <i>A. diversus</i> <i>H. carinatum</i> <i>B. rudderi</i>	<i>Marginal marine (0-6 m)</i> <i>Internal neritic (0-30 m)</i> <i>Marginal marine to Internal neritic (0-30 m)</i> <i>Upper bathyal (300-600 m)</i> <i>Middle to external neritic (90-180 m)</i>
La Pascua	<i>B. rudderi</i> <i>M. fusca</i> / <i>T. laevigata</i> (Inf)	<i>Internal to external neritic (30-180 m)</i> <i>Marginal marine (0-6 m)</i>
Tigre	<i>P. kickapoensis</i>	<i>Upper bathyal (300-600 m)</i>

Figure 10. Paleobathymetry in northeast Guarico basin. Redrawn after Fasola et al., (1985).

Anzoátegui State as a result of a Middle to Late Miocene contractional event. Furthermore, Blanco et al. (1988) interpreted anticlines and thrust faults in northern Guárico, Cojedes and Portuguesa that deformed the Oligo-Miocene sedimentary sequence reactivating some Cretaceous extensional faults. González and Lander (1990) identified 8 stratigraphic sequences in the Guárico basin: (1) a Triassic-Jurassic stratigraphic sequence with Late Jurassic interstratified basalt flows; (2) a Lower to Upper Cretaceous sequence associated with an Early Cretaceous compressional pulse; (3) a Paleocene-Eocene sequence; (4) an Oligocene sequence; and (5) Lower to Middle Miocene sequences

Arnstein et al. (1985) re-analyzed and re-interpreted the biostratigraphy and the stratigraphy of the Eastern Venezuela basin and its sub-basins, the Guárico to the west and Maturín to the east. Based on biostratigraphy, Arnstein et al. (1985) subdivided the Eastern Venezuela basin into four zones: (1) Zone A (Maturín sub-basin), characterized by the presence of an uninterrupted sequence of Cretaceous to Middle Miocene age; (2) Zone B (Guárico sub-basin) where an Oligocene-Lower Miocene and, occasionally, a Middle Miocene sequence overlaid unconformably an Cretaceous sequence; (3) Zone C (Maturín sub-basin) characterized by a Middle Miocene-Oligocene unconformity and by the identification of a Middle Eocene-Upper Eocene rock sequence (Soledad 1 well); and (4) Zone D (Maturín sub-basin) characterized by a Middle Miocene- Cretaceous unconformity.

Furthermore, Arnstein et al. (1985) recognized four major sedimentary cycles in the Oligocene to Pliocene sedimentary rocks of the Eastern Venezuela basin: (1) Oligocene, (2) Lower Miocene, (3) Middle Miocene, and (4) Miocene to Pliocene.

Figure 11. Classification of marine environments and bathymetry profile. Redrawn after Fasola et al., (1985).

The sedimentary rocks of the Oligocene cycle rest unconformably on pre-Eocene formations. The cycle consists from bottom to top of the La Pascua Formation in the Guárico-sub-basin and its equivalent Merecure Group (Los Jabillos-Naricual) in the Maturín sub-basin. It is capped by the Oligocene Roblecito Formation in the Guárico sub-basin and in the Areo Formation in the Maturín sub-basin (Fig. 14). These formations are characterized by the presence of the planktonic foraminifera *G. ciperensis*.

The fossiliferous shales of the Carapita, Oficina and Capiricual Formations represent the Early Miocene cycle in the Maturín sub-basin (Fig. 14). In the Guárico sub-basin, this cycle consists of an equivalent sequence represented by the Chaguaramas Formation. In northern Guárico sub-basin, this cycle is represented by the Quiamare and Quebradón Formations (Fig. 13).

In the Maturín sub-basin, the Middle Miocene cycle rests unconformably either on Oligocene or Cretaceous rocks (Oficina, Upper Carapita and Merecure Formations). These are not identified in the Guárico sub-basin.

The Miocene-Pliocene cycle is defined only in the Maturín sub-basin. It is represented by the La Pica, Las Piedras and Quiriquire Formations in the northeastern Maturín basin and by the Freitas and Las Piedras Formations in the southern Maturín sub-basin.

In the Orinoco oil belt (southern Guárico and Maturín sub-basins), the Cretaceous, Oligocene and Miocene sequences thin against the crystalline basement of the Guyana craton either by pinch-outs or by erosion (Kiser, 1987). Huge oil accumulations are associated with such pinch-outs in the Oligocene-Lower Miocene

Figure 12. Paleobathymetry in northeast Guarico basin. Redrawn after Fasola et al., (1985).

sequences and in the mature Cretaceous rocks of the Guárico and Maturín sub-basins (Kiser, 1987).

The El Baul arch is a major structural feature that controlled the Tertiary sedimentation in the Guárico basin and hampered southward migration of hydrocarbons (Kiser, 1987). The El Baul arch crops out in western Venezuela and has a S80°E orientation. Paleozoic igneous and metamorphic rocks and Triassic-Jurassic volcanics (Kiser, 1987) are exposed. In the subsurface, the El Baul arch changes azimuth near the village of Calabozo (S30°E) joining the Guyana shield near the village of Caicara del Orinoco in southern Venezuela (Kiser, 1987).

Analysis of 2D seismic reflection profiles

Seismic Stratigraphy

Data set. A regional grid of 1400 km of industry 2D seismic reflection profiles, of well data, including lithological description of stratigraphic units, time-velocity surveys and synthetic seismograms, were used for a regional study to constrain the tectonic evolution of the Guárico sub-basin. Location of the seismic grid is shown in Fig. 15. Petróleos de Venezuela, PDVSA, kindly provided the data set. The seismic grid is denser in hydrocarbon producing areas, like the Yucal-Placer field (Daal and Lander, 1993). Published biostratigraphic reports on the area are scarce. This thesis uses the biostratigraphy of Fasola et al. (1985) as a guide to assess the ages of the different stratigraphic units.

Figure 13. Time-Spatial relationships between the Tertiary units in the Western Serrania and the Guarico foredeep. Redrawn after Gonzalez de Juana et al., (1980).

Methodology. Interpretation and subdivision of seismic units into correlatable entities throughout the Guárico basin are based on the principles (Fig. 11) established by Vail et al., (1977), and Vail (1987). In the present study, subdivisions in stratigraphic units and their regional correlation were based on Fasola et al., (1985).

Synthetic seismograms, reports and biostratigraphy were used to calibrate seismic sections. In this study, six regional transects were made, five oriented northwest-southeast and one oriented east northeast-west southwest (Figs. 15, 17-23).

Velocity surveys allowed estimating and converting time sections into depth sections (Figs. 18-23). These depth-converted sections were tied to surface geology along the four studied transects to obtain regional geological cross sections across the basin (See Appendix 4).

Seismic Stratigraphic units. On the basis of the interpreted 2D seismic reflection lines, the Guárico basin was subdivided into five major seismic sequences or megasequences bounded by sequence boundaries: (1) Precambrian-Paleozoic pre-rift, (Pre-K); (2) Triassic-Jurassic syn-rift, (T-J); (3) Cretaceous post-rift, (K); (4) Oligocene-Miocene Roblecito-Chaguaramas foredeep which includes two seismic sequences (OA, OB, OC, OM, N1); and (5) Neogene Roblecito-Chaguaramas foredeep (N2) (Figs. 2, 17-23).

Precambrian-Paleozoic pre-rift rock units. In north-central Venezuela, the pre-Cretaceous basement consists of Precambrian crystalline rocks that are in tectonic contact with Paleozoic metamorphic and sedimentary rocks (Feo-Codecido et al., 1984). Previously interpreted well logs indicate the presence of sedimentary Paleozoic units in

AGE		FORMATION	THICK- NESS (m)	LITHOLOGY	TECTONIC ACTIVITY	OIL & GAS	FIGURE
TERTIARY	NEOGENE	PLEISTOCENE			FOREDEEP		
		PLIOCENE	200-2200	FLUVIAL DELTAIC SILTSTONES SHALES AND FINE GRAINED SANDSTONES			3.18
		UPPER	50-2200			OIL & GAS	3.15 - 3.16
		MIDDLE		DEEP WATER SHALES AND TURBIDITIC SEDIMENTS			3.15
	MIOCENE	CARAPITA B/C	100-6000	BLACK SHALES AND GLAUCONITIC CALCAREOUS SILTSTONE	PASSIVE MARGIN		3.13 - 3.14
		CARAPITA E/F					3.13
	OLIGOCENE	NARICUAL	250-1200	CARBONACEOUS SHALES SHALY SANDSTONES		OIL & GAS	3.13 - 3.14
		AREO		DARK GRAY GLAUCONITIC SHALES			3.13
	Eocene	LOS JABILLOS	150-350	COARSE GRAINED QUARTZITIC TO CONGLOMERATIC SANDSTONES		OIL & GAS	3.13 - 3.14
			HYATUS				3.13
	MIDDLE	TINAJITAS	300-600	DOLOMITIC/CALCITIC OR GLAUCONITIC LIMESTONE			3.12
		CARATAS		SILTSTONE AND SANDSTONE		OIL	3.12
	PALEOCENE	VIDOÑO	200-300	BLACK SHALES			3.11
MESOZOIC	CRETACEOUS	MAASTRICHTIAN			PASSIVE MARGIN		
		SANTONIAN	1400	WELL SORTED SANDSTONES & INTERCALATED SHALES		OIL	3.5 - 3.7 - 3.8
		TURONIAN		FOSSILIFEROUS AND GLAUCONITIC SHALES FINE GRAINED SANDSTONE ORGANIC RICH LAMINATED LIMESTONES & PYRITIC BLACK SHALES			3.5
		CENOMANIAN	250-650				3.6 - 3.8
		ALBIAN	270	SHALES			3.10
		APTIAN	860 100	LIMESTONES SANDSTONE & FLUVIAL TO COASTAL DEPOSITS		OIL	3.4
	BARREMIAN	BARBANQUIN	1300-1700	SANDSTONES LIMESTONE & INTERCALATED SHALES			3.3
				Fine grane sandstone and siltstone.			3.2
	JURASSIC	LA QUINTA	?	Non fossiliferous redbeds with basalts flows interbedded	RIFTING		
	CAMBRIAN	CARRIZAL HATO VIEJO	1800	Medium to coarse grain, arkosic and quartzitic sandstone Fine grane sandstone and siltstone.	BASEMENT		
PALEOZOIC	PRECAMBRIAN		?	Metasigneous and Metasedimentary rocks.			

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Figure 14. Stratigraphy of Maturin basin. The basal foredeep unconformity in the Maturin basin originated in Early Miocene. On the Guarico basin, the inception of the basal foredeep unconformity occurred in Late Eocene-Early Oligocene. After Hung, (1995).

the area, but it was not possible to recognize them on the available seismic lines. Cambrian to Lower Ordovician siliciclastic rocks may be preserved in the Espino graben.

In this study, all undifferentiated Precambrian and Paleozoic rocks are combined and labeled Pre-K (pre-Cretaceous) (Figs. 17 to 23).

Triassic-Jurassic syn-rift sequence. This seismic unit is recognized in the Espino graben and includes thick Triassic-Jurassic (T-J) sedimentary rocks, but it may include Paleozoic (Cambrian-Ordovician) sedimentary units as well. The graben is located in the southernmost portion of the basin. In the interpreted seismic section (Fig. 23), units tend to expand toward the faults that bound the graben and are in fault contact with the undifferentiated Precambrian and Paleozoic basement (Fig. 23).

The Triassic-Jurassic Espino graben is a rift system that probably formed during the breakup of Pangea and the subsequent North and South America plate divergence (e.g., Pindell and Dewey, 1982; Summa et al., 2003). In the Guárico basin, the Espino graben trends NE-SW. It extends to the NE towards the Eastern Venezuela basin and to the SW towards the Venezuelan and Colombian Llanos (Feo-Codecido et al., 1984). This rift developed on older accreted Paleozoic metamorphic and Precambrian igneous-metamorphic terranes of the Guyana craton. The Triassic to Jurassic units contain an intraformational volcanic flow dated at 157 and 162 Ma (K/Ar; Feo-Codecido et al., 1984).

In some areas, the Paleozoic sedimentary deposits are not present. Instead, underlying the Cretaceous and younger deposits, there is either an accreted Paleozoic metamorphic terrane or the Guyana crystalline basement (Fig. 3).

Figure 15. Location map of 2D seismic lines used in this study.

Post-rift sequences. Passive margin sequence. Cretaceous (K). The Cretaceous seismic unit in the Guárico basin (K) is bound at its base by a regional unconformity that marks the encroachment of the Cretaceous seas onto continental South America (Figs. 17 to 23) (González de Juana et al., 1980). The top of this unit represents a Late Eocene-Early Oligocene basal foredeep unconformity that marks the beginning of the loading of the Lara nappes onto the South American craton in north-central Venezuela (Fasola et al., 1985; Kiser, 1997). This unit thickens toward the east of the basin and is thinner to the south towards the Guyana craton and also to the west toward the El Baúl high (Figs. 17-23). The westward thinning of the K unit could be due to erosion, which might have occurred during the uplift of the El Baúl high in Middle to Late Eocene time (Blanco et al., 1988). In the present study, analysis of 2D seismic lines suggests that a minor extensional phase occurred during the sedimentation of the Cretaceous sequence. These structures were reactivated during the loading of the Lara nappes onto South America in Early Oligocene (Figs. 17-23).

Roblecito-Chaguaramas foredeep: Late Eocene-Early Oligocene to Miocene (OA to OM, N1). The seismic stratigraphic unit that onlaps the Cretaceous sequence (OA) and marks the inception of the foredeep in north-central Venezuela is Late Eocene-Early Oligocene (González de Juana et al., 1980; Fasola et al., 1985; Kiser, 1997). In the present study, this seismic sequence includes four Late Eocene-Early Oligocene to Early Miocene seismic units. They are correlated on the basis of the report by Fasola et al., (1985). The units from older to younger are: OA, OB, OC and OM (Figs. 17 to 23).

In the northern parts of the Guárico basin, the base of the unit OA is represented by the transgressive La Pascua Formation (Late Eocene-Early Oligocene) and its

Figure 16. Type of discontinuities as laid out by Vail (1987)

transition to the Roblecito Formation. The units OB and OC (Oligocene) represent the deepening phase of the basin represented solely by the Roblecito Formation. The unit OM (Oligocene-Miocene) represents the basal units of the filling and capping phase of the foredeep by the Roblecito and Chaguaramas Formations (Fasola et al., 1985).

Deposition of the units OA and OB is coeval with the development or reactivation of extensional structures during the inception of the Guárico foredeep in the Late Eocene-Early Oligocene (Figs. 17 to 23). Some normal faults were possibly inverted during the Middle Miocene tectonic event (Fig. 21).

In the Guárico basin, two Neogene stratigraphic sequences are divided by a regional unconformity (Figs. 2, 22 and 23). These units are named in this study Neogene 1 and Neogene 2 (Figs. 22 and 23). The Neogene (1) seismic unit was divided into three subunits for the purpose of seismic correlation: NA, NB and NC (Figs. 22 and 23). There is no biostratigraphic control of these units since they are near-shore marine to continental deposits

Neogene Roblecito-Chaguaramas foredeep: Neogene N2. This seismic unit, Neogene 2 (N2), represents the capping and filling of the foredeep basin. It is divided into four seismic packages: ND, NE, NF and NG (Figs. 22 and 23). These subdivisions were constructed solely on seismic characteristics in order to allow regional correlation. Seismic units NA to NG correspond to the Neogene Chaguaramas Formation in the Venezuelan geological literature (Fig. 2). Figure 18 shows how the basin was uplifted and tilted to the east by a post-Miocene tectonic event.

Figure 17. Legend for interpreted 2D seismic lines.

Deformation history of the Guárico basin

There are two quite distinctive structural styles observed in the seismic sections. First, the Neogene decollement or decoupling level along OB (Roblecito Formation) serves as a relative “boundary” for this structural architecture. Below the decollement, there is an extensional regime initiated in the Mesozoic with the opening of the Espino graben. A younger extensional regime occurred during the Tertiary in response to the tectonic loading of the Lara nappes that generated the Roblecito foredeep. Secondly, Neogene contraction in the Guárico basin (Figs. 17 to 23) resulted in imbricate thrust faults merging into the decollement.

Based on the analysis of 1400 km of 2D seismic reflection profiles and other interpretations from the literature, it is suggested here that there are, at least, five separate deformation episodes in the Guárico basin and the Serranía del Interior foreland fold and thrust belt. Deformation phases 1 and 2 are related to the rifting and drifting of the Americas since the Triassic-Jurassic. Phases 3 through 5 are related to the continuous interaction between the Caribbean and South American plates since Late Eocene-Early Oligocene time.

(1) Formation of a Triassic-Jurassic rift. Extension and opening of the Espino graben system occurred in the southernmost portion of the Guárico basin (Fig. 23). The formation of this extensional system was related to the opening of the Atlantic Ocean. The graben-bounding faults crosscut sedimentary and metamorphic Paleozoic rocks and Precambrian crystalline basement of the Guyana craton. This structure may extend

Figure 18. Time line-drawing of an east-west 2D seismic line composite section across the Guarico basin (G1) showing uplift and peneplanation of the Guarico basin during Pliocene-Pleistocene times. Legend as in Figure 6.

beneath the Eastern Serranía del Interior to the east and to the Apure and Colombian Llanos in the west (e.g., Feo-Codecido et al., 1984).

(2) *Passive margin*. In the Cretaceous, a north-facing passive margin was formed that subsequently underwent thermal subsidence (e.g., Pindell, 1993). This is the time of the encroachment of the proto-Caribbean seas onto continental South America and the formation of normal faults (Figs. 17 to 23).

(3) *Foredeep unconformity*. A basal foredeep unconformity formed in the Late-Eocene-Early Oligocene (González de Juana et al., 1980; Fasola et al., 1985; Kiser, 1997). It was coeval with minor extension in the Guárico basin. In Late Eocene-Early Oligocene, during the deposition of units OA and OB, normal faults were either reactivated or developed newly in the autochthonous terranes of the South American plate (Figs. 17 to 23). They extend well south into the basin and could have been formed in response to the flexure due to loading of the Lara nappes onto the Guyana craton and the peneplained Paleozoic folded belt during the early stages of the formation of the foredeep (e.g., Summa et al., 2003)

(4) *Contraction*. In north-central Venezuela, contractional structures formed during the Miocene. The Guárico basin is decoupled along marine shales of the stratigraphic sequence OB of the Roblecito Formation. From this sole thrust or detachment level, south-vergent thrust imbricates emerged in the Oligocene-Miocene sedimentary sequences of the Guárico foredeep. Several small triangle zones developed within the basin. Deformation of sub-sequence ND by thrust imbrication might mark the end of contractional deformation within the basin (Fig. 23). Seismic resolution is very poor within the “Piedmont belt” and beneath both the “Piedmont belt” and the Villa de

Figure 19. Time and depth-converted composite line-drawings of seismic section G2, south of the Platillón-Tiznados transect. Legend as in Figure 17.

Cura nappes allowing room for a wide range of structural interpretations (Figs. 20 and 21).

Two of the interpreted 2D seismic lines cut across the contact of the “Piedmont belt” with the Villa de Cura complex (Figs. 20 and 21). Modeling based on gravimetric and magnetic data support the idea that the Villa de Cura nappe is a klippe (Bosch and Rodriguez, 1992; Smith et al., 1999). The klippe might be very thin, possibly between 1 and 2 km (Figs. 3 and 4 of Bosch and Rodriguez, 1992).

Projection of the proximal passive margin and its basement suggests that the interpreted Cretaceous sequence K and, probably, the Late Eocene-Oligocene units OA and OB may extend northward beneath the Serranía del Interior and the Villa de Cura nappes (Figs. 20 and 21).

(5) *Regional uplift.* A post-Miocene tectonic event uplifted, peneplaned and tilted the Guárico basin to the east (Fig. 17). Minor Neogene and younger extension is observed throughout the basin deforming Oligocene sedimentary sequences as well (Figs. 22 and 23). The available seismic data do not constrain the orientation of the latter extensional structures. Based on analysis of 2D seismic data, Blanco et al., (1988) and Daal and Lander (1993) suggest that these normal faults are NE-SW trending.

Figure 20. Time and depth-converted composite line-drawings of seismic section G3, south of the city of San Juan de Los Morros, in the Guárico Basin. Legend as in Figure 17.

Figure 21. Time and depth-converted composite line-drawings of seismic section G4, south of the Valle Morin-Camatagüita transect in the Guárico Basin. Legend in Figure 17.

Figure 22. Time and depth-converted composite line-frawings of seismic section G5, south of the Altagracia de Orituco transect, in the Guárico Basin. Legend in Figure 17.

Figure 23. Time and depth-converted composite line-drawings of seismic section G6. Legend in figure 17

APPENDIX 4

STRATIGRAPHY AND STRUCTURE OF THE WESTERN SERRANÍA DEL INTERIOR FORELAND FOLD AND THRUST BELT, NORTH-CENTRAL VENEZUELA

Stratigraphy of the Western Serranía del Interior fold and thrust belt

Introduction. The western Serranía del Interior fold and thrust belt (Guárico mountain front) consists of non-metamorphosed parautochthonous and allochthonous marine Upper Cretaceous to Lower Eocene siliciclastic and carbonate rocks and of Middle Eocene to Upper Miocene marine to terrestrial parautochthonous and autochthonous carbonates and siliciclastic units (Figs. 1 and 2). Limestones with Jurassic-Neocomian and Aptian-Albian fauna, such as tintinnids or calpionellids and foraminifera, have been found as allochthonous blocks embedded in Upper Cretaceous-Lower Eocene turbidite units in the Piedmont zone and in the Belt of thrust faults in the western Serranía del Interior (Furrer, 1972; Beck and Furrer, 1977; Furrer, personal communication, 1998). In many cases, intense deformation obscures stratigraphic relationships between the exposed sedimentary sequences.

Previous works

The stratigraphy of the western Serranía del Interior (Fig. 3) consists of Cretaceous marine, parautochthonous, passive margin units of the Querecual (carbonates) and Mucaria (siliciclastics and limestone in minor proportions) Formations and the Las Colonias Limestones; Upper Cretaceous-Paleogene allochthonous (?)

Figure 1. Tectono-stratigraphic map of northern Venezuela and southern Caribbean showing the main tectonic belts and lithological units. After Ysaccis (1997).

turbidites and associated facies of the Garrapata and Guárico Formations; Middle Eocene parautochthonous marine Peñas Blancas Limestone, possibly time-equivalent of the La Pascua Formation of the Guárico basin; Oligocene-Miocene siliciclastics of the Roblecito Formation, representing first the tectonic controlled deepening of the Guárico foredeep (foreland) basin; Upper Oligocene-Lower Miocene siliciclastic Naricual Formation with coal beds; a siliciclastic Upper Oligocene-Middle Miocene Quebradón Formation; and the siliciclastic Lower to Upper Miocene Quiamare Formation. The latter three stratigraphic units are autochthonous and are time-equivalent with the Chaguaramas foredeep deposits of eastern Venezuela basin (Gonzalez de Juana et al., 1980).

Cretaceous

Querecual Formation. Liddle (1928) and later Hedberg (1937) were the first to describe the Querecual Formation in eastern Venezuela. The Albian-Santonian Querecual Formation crops out along the western (Piedmont belt) and eastern Serranía del Interior mountain range (Hedberg, 1937; Hedberg, 1950). It is the oldest exposed unit reported in the western Serranía (Erlich and Barret, 1992). The Querecual Formation is a platform unit that consists of black, anoxic, aphanitic and laminated shelf limestone as well as calcareous shale with calcareous concretions. Chert develops at the top of this stratigraphic unit (Fig. 2).

In the El Tinaco area, Menéndez (1965) found thin-bedded black limestone and shale with minor siltstone. Sandstone appears at the bottom of the unit while the top is capped by chert. Menéndez (1965) suggested that a pyroxene diorite breccia intrudes this upper chert horizon. In the El Tinaco area, the Querecual Formation

Transsects

Figure 2. Map of tectonic belts in the north-central Caribbean Mountain system as defined by Menéndez (1966), Peirson (1965), Bell (1968), and Beck (1978). The dashed areas represent the studied transects: (1) Platillón-Tiznados, (2) Valle Morín-Camatagüita, (3) Altagracia de Orituco, and (4) and San José de Guaribe.

Figure 3. Tectonostratigraphic units in the Western Serranía del Interior, north-central Venezuela, showing their relationship with the tectonic belts, thicknesses of the units measured from cross sections and their lateral relationships.

TABLE 1. Thickness of sedimentary units in the Western Serranía del Interior estimated from the transects

Formation / Transect / Thickness (m)	Stratigraphic Age	Platillón Tiznados	Camatagüita Valle Morín	Atagracia de Orituco	San José de Guaríbe
<i>Quíamare</i>	Miocene	N/A	N/A	N/A	650
<i>Quebradón</i>	Upper Miocene- Middle Miocene	1500 with Quíamare	N/A	3000 with Quíamare	700
<i>Naricual</i>	Oligocene-Lower Miocene	N/A	N/A	N/A	650
<i>Roblecito</i>	Upper Eocene- Lower Miocene	N/A	1500	N/A	N/A
<i>Peñas Blancas</i>	Middle Eocene	N/A	10*	N/A	N/A
<i>Guárico</i>	Cretaceous- Paleocene	1500	2500	1500	500
<i>Mucaria</i>	Cretaceous	2000	810	2000	400
<i>Querecual</i>	Cretaceous	180	375	125	N/A
<i>Garrapata</i>	Cretaceous- Paleocene (?)	2000	500	1500	700

* Estimated by Bell
(1968)

N/A Non-applicable /
Not measured

overlies unconformably the El Tinaco complex and conformably the Cojedes Formation. Paleontological studies suggest a Cenomanian to Coniacian age for the Querecual Formation (Menéndez, 1965).

In the Río Tiznados area, Jarvis (1966) described a 150-m-thick sequence of the Querecual Formation. The bottom of this unit consists of 15-to-20-m-thick dark gray calcareous shale and of thin aphanitic limestone lenses that grade upwards into a thick chert sequence (120 m). In the Camatagüa area (Fig. 1), Bell (1968) reported black to dark gray aphanitic and laminated limestone, calcareous and non-calcareous shale and chert. Beck (1985b) described Cretaceous (Turonian-Senonian) rocks that crop out in the western Serranía del Interior as aphanitic limestone often siliceous, chert, siliceous siltstone and shale. Blin (1989) reported that the Querecual Formation in the San Francisco de Tiznados area (Fig. 2) consists of black calcareous shale. The Querecual Formation grades upward into the Mucaria Formation (Fig. 3). Bell (1968) suggested that the Querecual Formation could be partially time-equivalent of the Garrapata Formation.

Mucaria Formation. Renz and Short (1960) described an Upper Cretaceous rock unit consisting of silicified shale, limestone and microconglomerate that crops out in southeastern Venezuela and named it the Mucaria Formation. In the El Tinaco area, Menéndez (1965) described a similar sequence that consists of up to 90 % dark gray, siliceous, sericitic shale; siltstone; and occasional chert. Menéndez (1965) stated that the Mucaria Formation grades upward into the Guárico Formation finding no stratigraphic relationship with the Cretaceous Querecual Formation. In the Tiznados area (Fig. 3), Jarvis (1966) described the Mucaria Formation as consisting mainly of dark gray to black siliceous, finely laminated shale; sandstone; conglomerate and; as minor constituents

gray aphanitic limestone and chert. In the Camatagüa area (Fig. 1) Bell (1968) found indurated siliceous siltstone, fine laminated shale, aphanitic limestone and sandstones that he correlated with the Mucaria Formation. Albertos et al., (1989) reported that in the Altagracia de Orituco-San Francisco de Macaira area this stratigraphic unit consists of dark gray chert, siliceous mudstone and calcareous chert. The Mucaria Formation is laterally equivalent to the San Antonio Formation of eastern Venezuela, and it grades transitionally upwards into the Paleocene-Eocene Guárico Formation (Fig.1). In the Camatagüa area the Mucaria Formation lies conformably on the Querecual Formation (Bell, 1968). The age of the Mucaria Formation is Late Cretaceous (Senonian) possibly extending to Maastrichtian-Early Paleocene (Albertos, 1989).

Las Colonias Limestone. This unit (Fig. 3) crops out north of Altagracia de Orituco near the village Las Colonias in Guatopo National Park. This Senonian unit consists of light gray massive limestone and gray chert with abundant planktonic fauna (Beck, 1985b). Albertos et al., (1989) report the occurrence of light to dark gray laminated recrystallized limestone, interstratified with gray sandstone and siltstone, north of Altagracia de Orituco. The age of this unit is Late Cretaceous, possibly Coniacian-Santonian (Beck, 1985b; Albertos, 1989). The contacts of this unit with the surrounding lithotypes are structural (Beck, 1985b; Albertos, 1989).

Cretaceous-Early Eocene

Garrapata Formation. Along the fault contact (Cantagallo fault) between the Villa de Cura complex and the sedimentary section, there are isolated elongate bodies of rocks composed mainly of volcanogenic turbidites with olistoliths of mafic and

ultramafic rocks of the Garrapata Formation (Figs. 1 to 3). Intense deformation in the Serranía masks the stratigraphic position of this sedimentary unit. Bell (1968) suggested that the Garrapata Formation is an olistostrome embedded within the Guárico Formation.

Jarvis (1966) suggested that the Mucaria Formation grades into the underlying Garrapata Formation. Based on Jarvis (1966) and Bell (1968), Garrapata Formation in the western Serranía del Interior is both an age and depositional equivalent of the Querecual Formation. In the El Tiznados area (Fig. 3), Jarvis (1966) found that the Garrapata Formation consists mainly of conglomerate and coarse sandstone, with fragments of dark limestone, pyroxenic diorite, chert, tuffs and lava.

In the Camatagüa area (Fig. 2), the Garrapata Formation consists of a rhythmic alternation of conglomerate, sandstone, siltstone and shale typical of turbidites (Bell, 1968). This unit exhibits a cyclic depositional sequence beginning with a basal conglomerate followed by graded intervals. Serpentinite and diorite bodies are included within the Garrapata Formation (Konigsmark, 1965; Bell, 1968).

In the Platillón area, the formation consists of dark gray conglomerate with limestone, chert, volcanic, intrusive and metamorphic clasts; sandstone; and gray siltstones (Konigsmark, 1965). Jarvis (1966) and Konigsmark (1965) proposed that a pyroxene diorite sill intrudes the Garrapata Formation and although Jarvis (1966) could not find the contacts, Konigsmark (1965) argued that the intrusion is concordant with the bedding plane in the Garrapata Formation and that the host rock underwent mineralogical alteration to prehnite, amphibole, calcite and chlorite.

In the transect Altagracia de Orituco-Agua Blanca-Gamelotal-San Francisco de Macaíra, Albertos et al., (1989) describe conglomerates, conglomeratic sandstones and

fine-grained sandstones in the Garrapata Formation. Conglomerates contain 3-10 cm-long lithic fragments that consist of metagabbros, metalavas, metatuffs, metadiorites, gneisses, schists and chert.

Konigsmark (1965) comments on a finding within the Garrapata Formation of a non-redeposited *Peroniceras* cf. *mouretti de Grossouvre* ammonite of Early Senonian (Late Cretaceous) age. In the same paper, Konigsmark (1965) discussed the discovery of a Turonian pelecypod (*Inoceramus labiatus*) by Wolcott. Bauduhin (1983; in Albertos et al., 1989) and Aquino (1983; in Albertos et al., 1989) found limestone fragments with radiolarians (*Dyctiomitra* sp.) and planktonic foraminifera (*Hedbergella* sp.), suggesting a Late Cretaceous age for the Garrapata Formation. It is possible that the top of the Garrapata Formation is Early Paleocene in age (Albertos et al., 1989).

Albertos et al. (1989) suggest that the upper portion of the Garrapata Formation in the Altagracia de Orituco-Macaira area could be age equivalent with the lower section of the Guárico Formation. The latter argue that the Garrapata Formation could represent an internal turbidite fan facies and the Guárico Formation a middle to external turbidite fan facies.

Guárico Formation. The Cretaceous-Tertiary transition in central Venezuela begins with Upper Cretaceous (Maastrichtian)-Lower Eocene (Gonzalez de Juana et al., 1980), (Upper-Cretaceous-Late Paleocene; Yoris 2001, personal communication) volcanogenic turbidites of the Guárico Formation (Fig. 2). This unit lies conformably on the Upper Cretaceous sedimentary sequence of the Mucaria Formation (Menéndez, 1965; Peirson et al., 1966). The Guárico Formation (Fig.2) is laterally equivalent to turbidite stratigraphic units of western Venezuela (Trujillo, Moran, Río Guache y Matatere

Formations) and lithologically dissimilar units of eastern Venezuela (Vidoño Formation) (Stephan, 1985; Blin, 1989; Peirson, 1965; Bell, 1968; González de Juana et al., 1980).

The Guárico Formation consists of turbidite deposits in which quartzitic wacke sandstone, siltstones and fissile shale alternate monotonously in thick sequences (flysch deposits of Peirson et al., 1966; flysch facies of Bell, 1968). The Guárico Formation has been subdivided into several members (e.g., Menéndez, 1965; Peirson et al. 1966; Bell, 1968): (1) Mamonal Member (Menéndez, 1965); (2) Los Cajones Member (Bell, 1968); (3) Morro del Faro Member (Renz, 1955); (4) Caramacate Member (Peirson, 1966); (5) Southern thick-bedded facies (Peirson et al., 1965); (6) Río Aragua Member (Campos et al., 1980); and (7) Río Chavez Member (Campos et al., 1980). These seven members are poorly dated and, thus, are not in chronological order.

Mamonal Member. Menéndez (1965) defined the Mamonal conglomerate Member of the Guárico Formation in the El Tinaco. It has a limited geographic distribution. It consists of lithic wacke conglomerate and sandstone with angular and sub-angular fragments, some of which could be related to the Querecual Formation. Clasts also include chert, serpentinite, lava and diorite fragments.

Los Cajones Member. The Los Cajones Member is a sequence of intercalated shale, calcareous shale, sandstone and lithic conglomerate with some olistoliths (wildflysch facies of Bell, 1968). These allochthonous olistoliths are embedded in a contorted and slumped matrix of shale and siltstone. Olistoliths (boulder size) consist of chert, quartzite, conglomerate, gneiss, schist and gray laminated aphanitic limestone.

Morro del Faro Member. This lithological unit consists of gray massive reef limestone that forms a conspicuous topography in the vicinity of the town San Juan de

Los Morros in Guárico State (Peirson et al., 1966; Bell, 1968). Strong recrystallization of these rocks overprinted original structure and organic content (Peirson et al., 1966). In the Camatagüa region, the Morro del Faro Member crops out as allochthonous blocks within the Guárico Formation..

Caramacate Member. This member (Peirson et al., 1966) consists of two facies: an embayed shelf facies and a near-reef facies found in the vicinity of the Morro del Faro Member. The embayed shelf facies consist of thin calcareous siltstone and silty mudstone beds that occasionally grade downsection into graywacke and pebble conglomerate (Peirson et al., 1966). The near-reef facies developed around the Morro del Faro Member and consist of calcareous sandstone, sandy fossiliferous limestone, oyster beds, coquina beds with turrilids, bedded foraminiferal limestone and conglomerate with pebbles and boulders of reef limestone and possibly volcanic rocks (Peirson, 1966).

Southern thick-bedded sandstone facies. This facies also called the Meridional facies (Bell, 1968) consist of thick-bedded quartzose sandstone associated with orbitoidal limestone (Peirson et al., 1966). From west to east the sandstones become better sorted and more quartzose, suggesting that the El Baul Arch is the source area (Bell, 1968). In the Camatagüa area, Bell (1968) found thick, highly-quartzose massive sandstones with no volcanic fragments and rare internal structures. These sandstones alternate with shales and siltstones.

Río Aragua Member. This member (Campos et al., 1980) is a 450 meter thick turbidite sequence. It consists of conglomerate with volcanic fragments, sandstone

Figure 4. The spatial relationship of the different subsea turbidite fan facies. The Garrapata Formation could represent the feeder channels in the upper fan facies. The Guarico Formation could represent more distal facies within the turbidite system. After Walker, (1978) in Reineck and Singh, (1986).

Río Aragua Member. This member (Campos et al., 1980) is a 450 meter thick turbidite sequence. It consists of conglomerate with volcanic fragments, sandstone sequences (50 m) intercalated with shales and monotonous sequences of alternating sandstone and shale.

Rio Chavez Member. This member was first described by Campos and Osuna (1977) and consists of a thin-bedded calcareous siliceous sequence of Paleocene age. Campos and Osuna (1977) suggest that it is similar to the Guayuta Group of eastern Venezuela.

In the Altagracia de Orituco-San Francisco de Macaira area (Fig. 2), Albertos et al. (1989) describe the Guárico Formation (flysch unit) as a sedimentary sequence consisting of coarse to very fine-grained sandstone (feldspathic and lithic graywacke and wacke sandstone) intercalated with conglomerate or conglomeratic sandstone, fissile shale and occasionally sandy limestone (diagenetically altered sandstones). These authors considered the Garrapata Formation as an internal fan facies of a turbidite system while the Guárico Formation represents more middle and external fan facies.

In the Altagracia de Orituco-San Francisco de Macaira area (Fig. 2), the Guárico Formation grades downward into the Upper Cretaceous Mucaria Formation (e.g., Menéndez, 1965; Peirson, 1965; Bell, 1968; Bell and Peirson, 1969; Beck, 1985b; Albertos et al., 1989). Likewise, Albertos et al., (1989) also postulate that the Guárico Formation overlies the Garrapata Formation. Stratigraphic relationships between the Garrapata and Mucaria Formations are still not fully resolved. However, if the above statements are correct, then the Mucaria Formation is a time-equivalent of the Garrapata Formation. This relationship was not observed in the field by Albertos et al. (1989).

Figure 5. Prograding turbidite fan sequence, from basin plain to channel fill and upper fan. After Walker, (1978) in Reineck and Singh, (1986).

A fauna consisting of Upper Jurassic-Lower Cretaceous tintinnids and calpionellids found in exotic blocks within the Guárico Formation may have an origin in the Yucatan Peninsula prior to the opening of Pangea (Furrer, 1972; Furrer, personal communication, 1998).

Middle Eocene

Peñas Blancas Formation. The parautochthonous middle Eocene (Galea, 1985) Peñas Blancas Formation crops out discontinuously along the western Serranía del Interior mountain front (Peirson, 1965; Bell, 1968). This unit (Fig. 3) consists of massive bioclastic limestone with orbitoidal foraminifera and algae (Gonzalez de Juana et al., 1980). In the Camatagüa area (Fig. 2), Bell (1968) described black limestone with black algal mat fragments, algal fragments, foraminifera and angular quartz clasts. The foraminifera fauna suggests that the Peñas Blancas Formation was deposited on an open platform (60-80 m) under moderate to high current activity (Galea, 1985). In the eastern Serranía del Interior, the Peñas Blancas Formation grades downward into the calcareous glauconitic sandstone of the Caratas Formation (Galea, 1985). The contact between the two is conformable. The contact of the Peñas Blancas with the overlying Roblecito Formation is unconformable (Galea, 1985). Bell (1968) suggests that the Peñas Blancas Formation correlates with the La Pascua Formation of the Guárico basin and with the Tinajitas Member of the Caratas Formation of the eastern Serranía del Interior.

Late Eocene-Early Miocene. Roblecito Formation. The Roblecito Formation is generally of Late Eocene to Late Oligocene age, although locally the uppermost parts

may be of Early Miocene age (Fig. 3). It is present in the western Serranía del Interior mountain front as well as in the Guárico basin (Hedberg, 1950; Peirson, 1965; Bell, 1968; Fasola et al., 1985; Daal and Lander, 1993). In the eastern Guárico basin, the marine to brackish water Roblecito Formation consists of a thick sequence (~ 600 m) of dark-gray shale with a few siltstone and sandstone beds.

In the Camatagüa area in western Serranía del Interior, the Roblecito Formation consists mainly of gray fissile shale and, in minor quantities of sandstone (Bell, 1968). Sandstone occurs in massive beds, thin discontinuous beds and lens-shaped or boudin-shaped blocks, the latter possibly resulting from tectonism (Bell, 1968). The Roblecito Formation represents the deepening of the seas in north-central Venezuela during the Late Eocene to Early Oligocene emplacement of the allochthonous and parautochthonous nappes (Mencher et al., 1953; Fasola et al., 1985).

Late Oligocene-Early Miocene. Naricual Formation. In its type locality, the deltaic Naricual Formation (PDVSA, Venezuela Stratigraphic Lexicon, 2005) consists of 400 m of carbonaceous shale, sandy shale and sandstone, followed by 1000 m of shale and sandstone with well-developed coal beds. The unit is capped by 400 m of gray shale, sandstone and coal beds (Hedberg and Pyre, 1944). In the western Serranía del Interior or Guárico mountain front, near Altagracia de Orituco and eastward, the Naricual Formation crops out in the 'Belt of overturned beds' (Evanoff, 1951). The Naricual Formation is conformable with the overlying Quebradón Formation (Fig. 3), although west of Altagracia de Orituco both formations could be partially time-equivalent (Peirson, 1965; González de Juana et al., 1980). The age of the formation is Late Oligocene to Early Miocene. It has been proposed that the Naricual Formation in the Guárico mountain front

overlies the Roblecito Formation gradationally (Peirson, 1965; Gonzalez de Juana, et al., 1980).

Late Oligocene-Late Miocene

Quebradón Formation. The Quebradón Formation is of Late Oligocene to Middle Miocene age (Fig. 3). It consists mainly of a shale unit that overlies the sandstones of the Naricual Formation conformably (Batatal Formation of Evanoff, 1951) and is overlain by the conglomerate and shale of the Quiamare Formation (Evanoff, 1951). The Quebradón Formation crops out in western Serranía del Interior (Guárico mountain front) in the 'Belt of overturned beds" and in the 'Belt of gently-dipping beds of Peirson (1965) and Bell (1968) (Figs. 1 and 2). The unit consists mainly of black, blue and gray friable carbonaceous shales intercalated occasionally with lignites impure sandstone with sedimentary structures (cross lamination and cross stratification) and conglomerate (Evanoff, 1951). Towards its base, the Quebradón Formation has a sandy unit named the Galera Member that forms straight ridges in the Dos Caminos-Tiznados area (Galeras de Guarumen; Peirson, 1963). The member consists mainly of highly quartzose, massive sandstone with cross-stratification. Field relationships suggest that the Galera Member of the Quebradón Formation is conformable with the underlying Roblecito Formation (Figs. 1 and 3) (Peirson, 1963; Bell, 1968).

In the Camatagüa area (Fig. 2), the Quebradón Formation consists mainly of gray mudstone shale and of light brown and gray sandstone with sedimentary structures (ripples, cross-lamination and loadcasts). Plant remains and lignite fragments are common in the sandstone (Bell, 1968). The Galera Member in this area consists of massive, quartzose sandstones with sedimentary structures (ripples, internal grain

gradation, cross lamination, cross stratification and load casts) intercalated with a few shale beds (Bell, 1968).

The type of fossils and the presence of sedimentary structures suggest that the Quebradón Formation constitutes a regressive unit with paleoenvironments changing from near-shore litoral bars represented by the Galera Member (Peirson, 1963; Bell, 1968) to estuarine environments (González de Juana et al., 1980).

Quiamare Formation. The Quiamare Formation of Early to Late Miocene age represents a stratigraphic unit deposited mainly in continental environments (González de Juana et al., 1980). Its type locality occurs near the town of Puerto La Cruz in eastern Venezuela. Here it is divided into three members: 1) the Revoltijo Member consisting mainly of carbonaceous shale, (2) the Salomón Member consisting of mottled mudstone, and (3) the San Mateo Member with calcareous sandstone and conglomerate (González de Juana et al., 1980). In the western Serranía del Interior the Quiamare Formation crops out along the 'Belt of overturned beds' and the 'Belt of gently-dipping beds' (Peirson, 1965; Bell, 1968). In the vicinity of Altagracia de Orituco, a conglomerate member occurs named Peña de Mota (Beck, 1985b). This member consists of red to maroon conglomerate and shale (Beck, 1978, 1985b). In the Camatagüa area, the Quiamare Formation consists of gray, greenish, brownish and reddish gray, ill-consolidated mudstone (90%) interstratified with conglomeratic sandstone and conglomerate. Clasts in conglomerates and conglomeratic sandstones consist of green volcanics, gray limestone, chert, white quartzite, schist and mudstone (Bell, 1968). The Quiamare Formation along with the Quebradón and Naricual Formations are lateral equivalents of the Chaguaramas Formation in the subsurface of the Guárico basin (González de Juana et al., 1980).

Stratigraphy of the study area

The stratigraphy of the rocks along the four studied transects--Platillón-Tiznados (PTZ), Camatagüita-Valle Morin (CAM), Altagracia de Orituco (AO) and San José de Güaribe (SJG)--was studied to constrain the complex deformational history that these rocks underwent. Published maps by Peirson (1963, 1965), Menéndez (1966), Creole (1966), Bell (1968), Bellizzia et al., (1976), Beck (1985b), Albertos et al. (1989), Blin (1989), Ostos (1990) and Smith (1997) were used to assess the stratigraphy in the field. However, in some cases, these maps have been slightly modified on the basis of the present study. Geology for each transect was laid and merged with topography maps from the Cartografía Nacional de Venezuela at scale 1:25,000. The result was useful as a guide in the field and to make the appropriate changes in structure and stratigraphy. The study area is structurally very complex. In many cases stratigraphic relationships were obscured as a result of the deformation. A summary of the thickness for each unit in the Serranía is shown on Fig. 3 and Table 1. Thicknesses were estimated from geological cross sections after bedding plane-cross section azimuth correction. Thickness of units could be overestimated due to structure. Detailed measurement of stratigraphic sections was not a primary goal of this study, but in some cases the author described and measured some interesting outcrops in detail.

Stratigraphy of the Platillón-Tiznados (PTZ) transect

The PTZ transect (Figs. 6 and 7) is underlain by allochthonous undifferentiated metamorphic rocks of the Villa de Cura Group, the Cretaceous parautochthonous

Querecual and Mucaria Formations, the Cretaceous-Lower Eocene Garrapata and Guárico Formations, the Upper Oligocene-Middle Miocene Quebradón Formation (Galera Member) and the Lower to Upper Miocene Quiamare Formation (Figs. 3, 6 and 7).

Cretaceous. The undifferentiated Villa de Cura Group is in fault contact with the Garrapata Formation along the Cantagallo fault (Fig. 7). The Villa de Cura Group in the field area consists of highly deformed massive greenstone with a multitude of joints filled with quartz (Fig. 8). Beyond the contact, the Villa de Cura Group was not studied in the present analysis. The Querecual Formation was observed in an outcrop along a tributary of the Tiznados reservoir (Fig. 7). It consists here of 15-m-thick laminated black shale with up to 30-cm-long black aphanitic limestone concretions and lenses (Fig. 9). The Querecual grades upwards into the siliceous shale and siltstone of the Mucaria Formation. The Mucaria Formation consists of a thick sequence of light to dark gray siliceous shale and siltstone, thin fine-grained sandstone beds and lenses and locally thin light gray limestones and chert horizons (Fig. 10). This unit exhibits intense folding and associated cleavage especially towards its tectonic contact with the Guárico Formation near the Tiznados reservoir.

Cretaceous-Early Eocene. The Villa de Cura nappe has overridden the Garrapata Formation along the Cantagallo fault (Figs. 7, 11 and 12). The Garrapata Formation in this transect is characterized by dark gray conglomerate, conglomeratic sandstone and coarse- to medium-grained sandstone interbedded with siltstone and shale in a typical turbidite suite (Figs. 4, 5, 13 and 14).

Figure 6. Legend for maps and transects used in this study.

Conglomerate and sandstone have clasts of chert, igneous rocks (diorite, pyroxenite) and metamorphic rocks (schist, phyllite, gneiss), along with sandstone and gray limestone fragments (Fig. 14). Occasional gray limestone boulders are embedded in a conglomeratic to coarse-grained sandstone.

Within the unit, there is a chaotic suite of olistoliths mainly characterized by kilometers-size light gray massive platform limestone (Figs. 15 to 17) (Los Totumos Limestone of Königsmark, 1965) and massive diorites (Platillón's pyroxene diorite of Königsmark, 1965). Limestone blocks are aphanitic calcareous mudstones, apparently recrystallized with no apparent internal structures and non-carbonaceous (Figs. 15 to 17). A chaotic suite of limestone blocks, 1 to 2 meters in length, of the same composition as the olistoliths are embedded on a very fine-to-fine-grained, dark gray sandstone matrix of the Garrapata Formation (Figs. 16 to 17).

Igneous rocks, present as blocks within the Garrapata Formation (diorite of Königsmark, 1958), are highly deformed massive greenstones. There is no evidence that these rocks intruded into the Garrapata Formation as suggested by Königsmark (1958), González de Juana and Picard (1972) and González de Juana et al. (1980). These massive igneous rocks were also observed as allochthonous blocks within the Garrapata Formation in the Camatagüita-Valle Morín and within the Altagracia de Orituco transects. The rhythmic alternation of thin fine- to coarse-grained gray sandstone and gray shale beds (1 to 2 cm thick) characterizes the Guárico Formation in the Tiznados reservoir area (Fig. 18 and Fig.19). These turbidites exhibit bed polarity indicators such as the classical Bouma sequence (Fig. 20) as well as sole markings (flute casts, groove

Figure 7. Geological map of the Platillón-Tiznados transect showing (1) the structural contact between the Villa de Cura nappes and the "Piedmont belt" in the Western Serranía del Interior and (2) sample location and fission-track pooled age data (± 1 sigma). Modified after Creole Petroleum Corporation (1961a and c). Topography from Cartografía Nacional de Venezuela 1:25,000. UTM grid. Legend as in Figure 13.

Figure 8. Detail of highly deformed rock units of the Villa de Cura Group along the fault contact with the Garrapata Formation in the Platillón River. Veins are infilled with quartz. View toward the NE.

Figure 9. Platillón-Tiznados transect. Laminated black shales with limestone nodules of the Cretaceous Querecual Formation grade to laminated, gray, silicified siltstones of the Cretaceous Mucaria Formation. See figure 7 for location (a).

Querecual / Mucaria Formations Platillon-Tiznados

Legend

Shale

Siltstone

Limestone

Kq Querecual Formation
(Cretaceous)

Km Mucaria Formation
(Cretaceous)

5 m

Figure 10. Platillón-Tiznados transect. Finely laminated, gray, silicified siltstones with fining-upward sandstone lenses of the Cretaceous Mucaria Formation. See map for location (b).

Mucaria
Formation
Platillon-Tiznados

Legend

Figure 11. View to the NE of the Platillón River (Garrapata Formation)

casts and load casts) and abundant ichnofossils. Near the confluence of the Tiznados and Platillón Rivers, the Guárico Formation is characterized by dark gray, thick (2 to 3 m) and massive, medium- to coarse-grained sandstone. The contact of the Guárico Formation with the Neogene basinal Quebradón and Quiamare Formations occurs along the Guárico Frontal thrust zone. Garrapata Formation is in structural contact with the Upper Cretaceous Mucaria Formation.

Late Oligocene-Middle Miocene. Linear and elongate ridges in the San Francisco de Tiznados area (Galeras de Guarumen) are the geomorphic expression of the Galera Member of the Quebradón Formation (Fig. 21). In the Platillón-Tiznados transect, the Quebradón Formation consists of medium- to coarse-grained clean, quartzose and very friable sandstone beds, 60 to 120 cm thick. They alternate with minor gray shale beds. Along the road from San Francisco de Tiznados and Dos Caminos, rare conglomeratic sandstone occurs in which the matrix consists of a fine-grained red sand (Fig. 22).

Figure 12. Garrapata Formation in the Platillón River. View is toward the SW.

Figure 13. Platillón-Tiznados transect. Garrapata Formation sequence in the Platillón River. Volcanogenic turbidites of the Cretaceous Garrapata Formation showing a rhythmic fining-upward sequence of gray laminated shales, conglomerates and conglomeratic sandstones. Sandstones and conglomerates show load and flute casts at their base, which are good bed-polarity indicators. Some sandstones show the Bouma sequence A-D, or A-C, being coarse to fine grain (A), plane parallel laminae (B), ripples (C) and upper parallel laminae (D). This sequence could have been deposited in suprafan lobes of mid fan turbidites. See text for discussion and map for location (c).

Garrapata Formation

Figure 14. Detail of the Garrapata Formation in the Platillón River. Conglomerates and conglomeratic sandstones include clasts of chert, metamorphic and metavolcanic rocks.

Figure 15. Recrystallized limestone blocks within the Garrapata Formation in the Platillón River. View is toward the NW.

Figure 16. Detail of limestone blocks embedded within the Garrapata Formation matrix in the Platillón River. View is toward the SW.

Figure 17. Detail of limestone blocks embedded within a Garrapata Formation matrix in the Platillón River. View is toward the SW.

Figure 18. Rhythmic sequence of sandstones and shales (turbidites) of the Guárico Formation along the Las Lajitas trail, NW of the San Francisco de Tiznados village. View is toward the SW.

Figure 19. Platillón-Tiznados transect. Guárico Formation sequence in Las Lajitas road. This Paleogene turbidite formation shows a rhythmic fining-upward sequence of gray laminated shales and sandstones. Sandstones show load and flute casts at their base, which are good bed-polarity indicators. Sandstones show the Bouma sequence A-C, being coarse to fine grain (A), plane parallel laminae (B), ripples (C) and upper parallel laminae (D). This sequence could have been deposited in a turbidite lower fan. See text for discussion and map for location (d).

Guarico Formation
Platillon-Tiznados

Legend

Figure 20. Sedimentary structures in turbidite deposits also known as Bouma sequence. After Walker (1978) in Reineck and Singh (1986).

Stratigraphy of the Camatagüita-Valle Morín (CAM) transect

The CAM transect (Figs. 23 and 24) is underlain by the Cretaceous Villa de Cura nappe in fault contact along the Cantagallo fault with the sedimentary foreland fold and thrust belt. The rock units cropping out along this belt are the Cretaceous Querecual and Mucaria Formations, the Cretaceous-Paleogene Garrapata and Guárico Formations, the Middle Eocene Peñas Blancas Formation and the Upper Eocene-Oligocene Roblecito Formation (Fig. 23). The Villa de Cura nappe near the fault contact consists of highly deformed aphanitic greenstones (Fig. 23). No further lithological study in this rock unit was undertaken.

Cretaceous. The Querecual Formation in the Camatagüita-Valle Morín transect (Fig. 26), consists of black laminated shale that alternates with thin black aphanitic limestones (0.5 to 1 cm thick), black aphanitic limestone lenses and beds (1 to 2 cm thick), and occasional coarse-grained calcareous sandstone. It is present in the tectonic slivers that make up the Piedmont zone in the area. This stratigraphic unit grades upwards into siliceous siltstone and shale of the Mucaria Formation (Fig. 27). The Mucaria Formation (Fig. 27) consists of thinly laminated, hardened siliceous siltstone and shale and conglomeratic to fine-grained gray micaceous sandstone. Beds are 0.5 to 1.5 m thick. The formation is characterized by many sedimentary structures such as ripple marks which are excellent indicators to establish polarity of the beds and its fossil rich. Most abundant fossils are trace fossils (F. Yoris, personal communication, 1995). This lithological unit is highly deformed exhibiting chevron-like folds and a penetrative tectonic cleavage. The Mucaria Formation changes gradually upwards into the Guárico

Figure 21. Galeras de Guarumen at the San Francisco de Tiznados village. View is towards the NE.

Figure 22. Quiamare Formation along the San Francisco de Tiznados-Dos Caminos road. View is towards the NW.

Formation. In the Camatagüita-Valle Morín transect no stratigraphic relationships could be established between the Mucaria and Garrapata Formations.

Cretaceous-Early Eocene. Bell (1968) and Bell and Peirson (1969) suggested that the Garrapata Formation is an allochthonous block within the Guárico Formation. The Garrapata Formation in the Camatagüita-Valle Morín area can be described as fining-upwards turbidite cycles (Bell, 1968) that begin with a cut and fill basal conglomerate (Fig. 28). In a measured section (Fig. 29), the Garrapata Formation consists of the following units: The lowermost 5 m are a sequence of alternating fine-grained greenish-gray sandstone, laminated black siltstone and thin horizons of dark aphanitic limestone, calcareous shale and chert. These rocks are overlain unconformably by a unit or cycle containing a conglomerate (1.5 to 2.5 m thick) grading upwards into coarse-grained laminated sandstone (0.5 to 1 m thick) and a 6-m-thick section of alternating fine-grained sandstone, laminated black siltstone and thin horizons of dark aphanitic limestone, calcareous shale and chert. A new cycle begins again with a cut and fill basal conglomerate. The clasts in the conglomerate are 0.1 to ~ 1 m in size. They are derived from several sources as there are sedimentary (sandstones, limestones, chert), igneous (intrusive and volcanic) and metamorphic clasts (gneiss, schist, phyllite).

Highly deformed massive greenstones (pyroxene diorite of Konigsmark, 1958), highly sheared serpentinite bodies and metamorphic rocks occur as allochthonous blocks within the Garrapata Formation. Disturbance in the sediments of the Garrapata Formation was observed at the contact with a gneiss block where the stratification was distorted by the slumping of the block. The serpentinite bodies embedded as allochthonous blocks in the Garrapata Formation are highly sheared. This deformation may be related the tectonic

Figure 23. Geological map of the Valle Morín-Camatagüita transect showing (1) the structural contact between the Villa de Cura nappes and the "Piedmont belt" in the Western Serranía del Interior and (2) sample location, fission-track pooled and modeled age data (± 1 sigma). Modified after Bell (1968). Topography from Cartografía Nacional de Venezuela 1:25,000. UTM grid. Legend as in Figure 13.

emplacement in the Serranía del Interior. However, it is more probable that all these multi-provenance blocks slumped into the basin where the Garrapata Formation was being deposited during Late Cretaceous-Early Eocene time. They were deformed later during the final emplacement of the nappes during the Miocene. Contacts of the Garrapata Formation with the Querecual Formation in the Camatagüita-Valle Morín transect are tectonic.

The Guárico Formation (Fig. 30) is a turbidite suite that exhibits alternating beds of dark gray sandstone and gray shale. The thickness of sandstone beds varies from outcrop to outcrop (0.5 to 3 m thick). The formation exhibits the classical Bouma sequence (fining-upward grain size, fine lamination, ripples) as well as sole markings (flute casts, groove casts and load casts) that show many good bed polarity markers. Slump structures can be seen within some sandstone beds. Rock boulders (50 cm long) of a lithology similar to that of the Garrapata Formation are embedded within the Guárico Formation.

Middle Eocene-Late Eocene. In the Camatagüita- Valle Morín transect, Peirson (1965) and later Bell (1968) describe a very thin (3-m) arenaceous, algal-orbitoidal limestone bed overlying the Guárico Formation. In the Camatagüita-Valle Morín transect, the unit was not found by the present author of this work.

Late Eocene-Oligocene. In the Camatagüita-Valle Morín transect (Fig. 23), the Roblecito Formation consists of dark gray to black finely laminated shale alternating with thin sandstone beds. Both the lower and upper contacts of the Roblecito are tectonic. Highly sheared fine-grained to conglomeratic sandstone bodies are included in this formation. The Roblecito Formation is a decoupling level within the Guárico basin. The

Figure 24. View to the NW of the topography of the Villa de Cura Group in the Camatagüita-Valle Morin transect.

Figure 25. Greenstones from the Villa de Cura Group, Camatagüita-Valle Morin transect. View is towards the east.

Figure 26. Camatagüita-Valle Morin transect. Laminated black shales and black limestones of the Cretaceous Querecual Formation. See map for location (a).

Querecual Formation
Camataguita-Valle Morin

Legend

Figure 27. Camatagüita-Valle Morin transect. Cretaceous Mucaria Formation. This sequence is formed by finely laminated, silicified and endured siltstones, mudstones with ripples. See map for location (b).

Mucaria Formation Camataguita-Valle Morin

Legend

Figure 28. Garrapata Formation (turbidites) in the Carnatagüita-Valle Morin transect. Conglomerates cutting through coarse sandstone. View is SE.

Figure 29. Camatagüita-Valle Morin transect. Volcanogenic turbidites of the Cretaceous Garrapata Formation showing a rhythmic fining-upward sequence of gray laminated shales, calcareous shales, conglomerates and conglomeratic sandstones. Sandstones and conglomerates show load and flute casts at their base, which are good bed-polarity indicators. Some sandstones show the complete Bouma sequence from A to D, or from A to C. Others show only A and C or solely B. The Bouma sequence is a qualitative measure of flow regime. The whole Bouma sequence develops from bottom to top within the same bed and is represented by five different divisions: 1) coarse to fine grain (A), 2) plane parallel laminae (B), 3) ripples (C), 4) upper parallel laminae (D) and 5) laminated shales (E). This sequence could have been deposited in suprafan lobes of mid fan turbidites. See text for discussion and map for location (c).

Garrapata Formation
Camataguita-Valle

Legend

Figure 30. Camatagüita-Valle Morin transect. Turbidites of the Paleogene Guárico Formation showing a rhythmic fining-upward sequence of gray laminated shales, conglomerates and conglomeratic sandstones. Sandstones and conglomerates show load and flute casts at their base, which are good bed-polarity indicators. Some sandstones show Bouma sequence from A to C. Others show only A and C or solely B. The Bouma sequence is a qualitative measure of flow regime within a turbidite current. The whole Bouma sequence develops from bottom to top within the same bed and is represented by five different divisions: 1) coarse to fine grain (A), 2) plane parallel laminae (B), 3) ripples (C), 4) upper parallel laminae (D) and 5) laminated shales (E). This sequence could have been deposited in suprafan lobes of mid fan turbidites. See text for discussion and map for location (d).

Guarico Formation Camataguita-Valle Morin

presence of these highly sheared sandstone bodies could be evidence that indeed this level is a decollement surface at depth.

Stratigraphy in the Altagracia de Orituco (AO) transect

The AO transect is underlain by the Cretaceous Villa de Cura nappe, Querecual Formation, Las Colonias Limestone and the Mucaria Formation; the Cretaceous-Lower Eocene Garrapata and Guárico Formations; and the Oligocene- Quebradón and Quiamare Formations (Fig. 31).

Cretaceous. In the Altagracia de Orituco area, the Villa de Cura Group is in structural contact with the the Garrapata Formation along the Cantagallo fault (Fig. 31). The Villa de Cura Group consists of massive greenstones. Urbani (1988) suggested that the rocks of this Group belong to the Las Hermanas Formation. No further work was undertaken in the Villa de Cura Group.

In the the Altagracia de Orituco transect, the Cretaceous Querecual Formation crops out as tectonic slivers near the entrance to the Guanapito dam site along the Carretera Nacional and also between 2 to 3.2 km south of the dam (Fig. 31). It consists of alternating black chert and shale beds that grade upward into the siliceous siltstone of the Mucaria Formation (Figs. 32 and 33). Along the Orituco River, this Formation consists of alternating beds of tabular aphanitic gray limestone, mudstone and hard gray laminated silicified siltstones with penetrative tectonic cleavage (Figs. 34 and 35). They are transitional to the overlying Upper Cretaceous-Lower Eocene Guárico Formation. Along the Uverito sector the Mucaria Formation consists of hardened gray silicified siltstone and dark gray calcareous siltstone intercalated with dark gray

Figure 31. Geological map of the Altigracia de Orituco transect showing the structural Modified after Albertos et al., (1989). Topography from Cartografía Nacional de Venez

showing the structural "Belt of gently-dipping beds" in the Western Serranía del Interior.
 a Nacional de Venezuela 1:25,000. UTM grid. Legend as in Figure 13.

Figure 32. Altagracia de Orituco transect. Transitional gradation from laminated black cherts of the Querecual Formation to laminated, silicified and endured siltstones and to mudstones of the Cretaceous Mucaria Formation along the Carretera Nacional Altagracia de Orituco-Guatopo. See text for discussion and map for location (a).

Figure 33. Altagracia de Orituco transect. Limestone lenses embedded in laminated black shales grading upward in the stratigraphic section to laminated black shaly siltstones and in the Cretaceous Querecual Formation along the Carretera Nacional Altagracia de Orituco-Guatopo. See text for discussion and map for location (b).

Querecual Formation
Altagracia de Orituco

Legend

Figure 34. Altagracia de Orituco transect. Cretaceous Mucaria Formation. Laminated, silicified and endured siltstones with dark gray limestone beds and lenses (mudstones) outcrop in the Orituco River. See text for discussion and map for location (c).

Mucaria Formation Altagracia de Orituco

Legend

Siltstone

Limestone

2 m

Figure 35. Altagracia de Orituco transect. Cretaceous Mucaria Formation. Gray shales grading upward to laminated, silicified and endured siltstones with dark gray limestone beds (mudstones) in the Orituco River. See text for discussion and map for location (d).

Mucaria Formation Altagracia de Orituco

Legend

Shale

Siltstone

Limestone

2 m

aphanitic limestone lenses. The lower contact of the Mucaria Formation is transitional to the black chert of the Cretaceous Querecual Formation (Figs. 34 and 35).

Cretaceous-Early Eocene. The Garrapata Formation turbidites are in structural contact with the rocks of the Cretaceous Villa de Cura nappe (Fig. 31). Along the Taguacita River, the La Casupera Creek, La Martinera Creek, La Blanca Creek, La Joaquinera Creek and Bucaral Creek, the Garrapata Formation contains dark gray to greenish gray conglomerate (3 to 6 m thick), medium-to coarse-grained tabular sandstones (2.5 to 6 m thick), fining-upward conglomerate, and sandstone lenses intercalated with laminated siltstone and shale (Fig. 36). Garrapata siltstone facies contain rounded chert, gray limestones and metavolcanic clasts. These metavolcanic clasts are similar to rock types in the Villa de Cura Group, (Figs. 37, 38, 39). The Garrapata Formation also contains conglomerate and sandstone lenses, intercalated with siltstone and shale. Olistoliths are present within the Garrapata Formation. Along the La Casupera and La Martinera Creeks there are blocks of limestone (5 to 12 cm in length) and volcanics (25 cm diameter) in a matrix of conglomeratic sandstone. Several green aphanitic metavolcanic blocks (12.5-50 cm in diameter) occur that are very similar to rocks of Villa de Cura lithology. Along the Guatopo River, the Garrapata Formation is characterized by a sequence of blocky sandstones (~ 4 m) which grade upwards into siltstones (6 m) with rounded clasts (Fig. 37). Sandstone channels cut and infill this silty sequence. Towards the interpreted fault contact with the Guárico Formation, the Garrapata Formation consists of a coarsening upward sequence of rhythmic sandstones and shales. Blocks (more than 9 meters in

Figure 36. Altagracia de Orituco transect. Turbidites of the Cretaceous-Paleogene (?) Garrapata Formation showing a rhythmic coarsening-upward sequence of gray laminated shales, siltstones, conglomerates and conglomeratic sandstones. Sandstones and conglomerates show load and flute casts at their base, which are good bed-polarity indicators. Some sandstones show Bouma sequence from A to C. Others show only A and C or solely B. The Bouma sequence is a qualitative measure of flow regime within a turbidite current. The whole Bouma sequence develops from bottom to top within the same bed and is represented by five different divisions: 1) coarse to fine grain (A), 2) plane parallel laminae (B), 3) ripples (C), 4) upper parallel laminae (D) and 5) laminated shales (E). This sequence could have been deposited in suprafan lobes of mid fan turbidites. See text for discussion and map for location (e).

diameter) of gray to black laminated limestones (Las Colonias Limestone of Beck, 1985b) intercalated with gray siltstone are ubiquitous.

Along the Taguacita River and El Ingenio Creek, several green aphanitic blocks (more than ten meters across) were found that are compositionally similar to the Villa de Cura metavolcanic greenstone rocks. They seem to be embedded as allochthonous blocks within the Garrapata Formation. Blocks of laminated (1 to 2.5 cm thick), black limestone intercalated with gray to black laminated siltstone, black shale and black limestone lenses may have been derived from the Las Colonias Limestone (Beck, 1985b; Albertos et al., 1989). Black limestone expels a pungent hydrocarbon odor when broken with the hammer. It is suggested here that the blocks of the Las Colonias Limestone and greenstone of the Villa de Cura nappe that are present in the Garrapata Formation were dumped into a foredeep basin and were later deformed by the Early to Middle Miocene final emplacement of the Caribbean nappes.

The Garrapata Formation is in structural contact with the Upper Cretaceous-Early Eocene Guárico Formation (Fig. 31). The Guárico Formation crops out discontinuously along the Orituco River and the Carretera Nacional (Fig. 31). It consists of a monotonous intercalation of dark gray, coarse- to fine-grained 2.50cm to 1.5-m thick sandstone, siltstone and shale (Figs. 36). Sandstone exhibits sedimentary structures such as Bouma sequences and sole marks. Bouma sequences consist from bottom to top of cut-and-fill structures, graded bedding, laminations and ripples (Fig. 20). Sole marks are represented by flute casts, groove casts, load casts and trace fossils.

Figure 37. Altagracia de Orituco transect. Turbidites of the Cretaceous-Paleogene (?) Garrapata Formation showing two fining-upward sequences. The basal sequence is represented by dark gray sandstones at the base, grading to laminated siltstones with chert clasts. The uppermost sequence is bounded on its bottom by cut-and-fill channels with conglomerates that grade to laminated siltstones with chert clasts. See map for location (f).

Garrapata Formation Altagracia de Orituco

Legend

Figure 38. Altagracia de Orituco transect. Turbidites of the Cretaceous-Paleogene (?) Garrapata Formation showing a sequence of laminated siltstones with chert clasts and cut-and-fill channels with conglomerates at the base. See map for location (g).

Garrapata Formation
Altagracia de Orituco

Legend

Load
Fining-
Sandston
Siltston
Conglomerat
Clas
2	[

2

Figure 39. Altagracia de Orituco transect. Turbidites of the Cretaceous-Paleogene (?) Garrapata Formation showing a rhythmic sequence of gray laminated shales, siltstones, sandstones and conglomeratic sandstones. Sandstones show load and flute casts at their base, which are good bed-polarity indicators. Some sandstones show Bouma sequence from A to C; solely B or C. The Bouma sequence is a qualitative measure of flow regime within a turbidite current. The whole Bouma sequence develops from bottom to top within the same bed and is represented by five different divisions: 1) coarse to fine grain (A), 2) plane parallel laminae (B), 3) ripples (C), 4) upper parallel laminae (D) and 5) laminated shales (E). This sequence could have been deposited in suprafan lobes of mid fan turbidites. See text for discussion and map for location (h).

Figure 40. Altagracia de Orituco transect. Turbidites of the Paleogene Guárico Formation showing a rhythmic fining-upward sequence of gray laminated shales, fine-grained and conglomeratic sandstones. Sandstones show load and flute casts at their base, which are good bed-polarity indicators. Some sandstones show Bouma sequence A and C or solely B. The Bouma sequence is a qualitative measure of flow regime within a turbidite current. The whole Bouma sequence develops from bottom to top within the same bed and is represented by five different divisions: 1) coarse to fine grain (A), 2) plane parallel laminae (B), 3) ripples (C), 4) upper parallel laminae (D) and 5) laminated shales (E). This sequence could have been deposited in suprafan lobes of mid fan turbidites. See text for discussion and map for location (i).

Figure 41. Altagracia de Orituco transect. Turbidites of the Paleogene Guárico Formation showing a rhythmic fining-upward sequence of gray laminated shales, fine-grained and conglomeratic sandstones. Sandstones show load and flute casts at their base, which are good bed-polarity indicators. Some sandstones show Bouma sequence A and C or solely C. The Bouma sequence is a qualitative measure of flow regime within a turbidite current. The whole Bouma sequence develops from bottom to top within the same bed and is represented by five different divisions: 1) coarse to fine grain (A), 2) plane parallel laminae (B), 3) ripples (C), 4) upper parallel laminae (D) and 5) laminated shales (E). This sequence could have been deposited in suprafan lobes of mid fan turbidites. See text for discussion and map for location (k).

Guarico Formation
Altagracia de Orituco

Figure 41b. Altagracia de Orituco transect. Neogene Quebradón Formation (Carretera Nacional Altagracia de Orituco-Guatopo). Laminated medium to fine grain sandstones with plant remains and laminated siltstones. See text for discussion and map for location (1).

Quebradon Formation Altagracia de Orituco

Legend

Figure 42. Guárico Formation at the Carretera Nacional Altagracia de Orituco-Guatopo. View is toward NE.

Oligocene- Miocene. The Quebradón Formation occurs along the Carretera Nacional near the town of Altagracia de Orituco as isolated outcrops within the El Chacual complex, (Fig. 42). A siliciclastic unit, it consists mainly of an intercalation of laminated sandstones (8 to 25 cm thick) with plant remains, coal fragments, and laminated siltstone (Fig. 25).

The Quiamare Formation crops out near Altagracia de Orituco, in the Peña de Mota area close to the Village of Altagracia de Orituco (Fig. 31). It mainly consists of reddish conglomerate and sandy shale (Peña de Mota Member). In the vicinity of the San José de Orituco, the Quiamare Formation consists of medium- to fine-grained laminated sandstone with plant fossils (Fig. 31).

Stratigraphy in the San José de Güaribe (SJG) transect

Cretaceous. The Villa de Cura nappe and its structural contact with the parautochthonous sedimentary cover does not occur in this regional transect (Fig. 43). Along the Güarebe River, black chert interstratified with laminated black shale, similar to rocks of the Querecual Formation, grade upwards into gray laminated silicified siltstone of the Mucaria Formation (Fig. 44). Likewise, the Mucaria Formation grades upwards into the younger turbidites of the Guárico Formation.

Cretaceous-Early Eocene. A lithological sequence with facies similar to that of the Garrapata Formation observed in the three previously studied transects crops out along the Santa Lucía Creek near its confluence with the San José River or Río Grande. The stratigraphic unit consists of thick conglomeratic sandstone and conglomerate beds (1 to 1.5 m thick) interstratified with siltstone and shale (Figs. 43 and 45). The grain

components in this unit are similar to those observed in the Platillón-Tiznados, Camatagüita and Altagracia de Orituco transects: metavolcanic, chert, limestone and schist clasts. The contact between the Garrapata and Guárico Formations along the Santa Lucía Creek is a thrust fault. Along the Santa Lucía Creek, thinly bedded sandstone beds (2.5 to 5 cm thick) interstratified with thin shale beds belong to the Guárico Formation. Top indicators such as sole marks (flute casts, groove casts, load casts), ichnofossils, parallel laminations and ripples are the dominant sedimentary structures observed in this intensely deformed unit (Fig. 46).

Along the San José and Güarebe rivers, the Guárico Formation consists of thick conglomerate, coarse-to medium-grained sandstone and finely laminated sandstone beds, interstratified with shale and siltstone: a typical turbidite suite (Figs. 47 and 48). Some shale beds contain sandstone lenses and sedimentary structures are abundant: cut-and-fill, Bouma sequence, flute casts, load casts and ichnofossils. A 12-m-measured section of the Guárico Formation along the Güarebe River is ~90% composed of shales. The measured section contains conspicuous thin sand layers (1.5 cm thick) along with siliceous concretions (Fig. 49).

Oligocene-Miocene. The Naricual, Quebradón and Quiamare Formations represent the Oligocene-Miocene cycle in the San José de Güaribe transect.

In the El Jengibre Creek, the siliciclastic Naricual Formation crops out as a sequence of fine- to medium-grained, light gray sandstone and coarse to conglomeratic white quartzitic sandstone interstratified with gray siltstone and gray shale (Fig. 51). The most relevant characteristic in the El Jengibre Creek is the presence of coal beds of up to 1 m thick interstratified with gray shale. Sandstone beds can be blocky and up to 4 m

Figure 44. San José de Güaribe transect. The Cretaceous is represented on this transect by the Querecual and Mucaria Formations. The former consists of laminated black shales and black chert. The latter consists of laminated, gray, silicified and endured siltstones. See map for location (a).

Querecual (?) \
Mucaria Formations
San Jose de

Legend

Figure 45. San José de Güaribe transect. Santa Lucía creek. Turbidites of the Cretaceous-Paleogene (?) Garrapata Formation (?). The measured sequence is represented by blocky conglomerates that grade to conglomeratic sandstones and by shales in minor proportions. Beds show load and flute casts at their base, which are good bed-polarity indicators. Sandstones show Bouma sequence from A to C. The Bouma sequence is a qualitative measure of flow regime within a turbidite current. The whole Bouma sequence develops from bottom to top within the same bed and is represented by five different divisions: 1) coarse to fine grain (A), 2) plane parallel laminae (B), 3) ripples (C), 4) upper parallel laminae (D) and 5) laminated shales (E). This sequence could have been deposited in the channeled portion of suprafan lobes. See text for discussion and map for location (b).

Garrapata Formation
San Jose de Guaribe

Figure 46. San José de Güaribe transect. Turbidites of the Paleogene Guárico Formation showing a rhythmic sequence of laminated shales cut by channels filled with conglomeratic sandstones and and by fine-grained and conglomeratic sandstones. Sandstones show load and flute casts at their base, which are good bed-polarity indicators. Sandstones show Bouma sequence A to C. The Bouma sequence is a qualitative measure of flow regime within a turbidite current. The whole Bouma sequence develops from bottom to top within the same bed and is represented by five different divisions: 1) coarse to fine grain (A), 2) plane parallel laminae (B), 3) ripples (C), 4) upper parallel laminae (D) and 5) laminated shales (E). This sequence could have been deposited on mid fan turbidites. See text for discussion and map for location (c).

Guárico Formation
San Jose de Güaribe

CU

Legend

Figure 47. San José de Güaribe transect. Turbidites of the Paleogene Guárico Formation showing a rhythmic sequence of laminated shales cut by channels filled with conglomeratic sandstones and of fine-grained and conglomeratic sandstones. Sandstones show load and flute casts at their base, which are good bed-polarity indicators. Some sandstone beds show bioturbation structures. Sandstones show Bouma sequence A to C. The Bouma sequence is a qualitative measure of flow regime within a turbidite current. The whole Bouma sequence develops from bottom to top within the same bed and is represented by five different divisions: 1) coarse to fine grain (A), 2) plane parallel laminae (B), 3) ripples (C), 4) upper parallel laminae (D) and 5) laminated shales (E). This sequence could have been deposited on mid fan turbidites. See text for discussion and map for location (d).

Figure 48. San José de Güaribe transect. Turbidites of the Paleogene Guárico Formation showing massive conglomerates that grade to conglomeratic sandstones (fining-upward), fine-grained sandstones, capped by ripples and shales in minor proportion. Sandstones show load and flute casts at their base, which are good bed-polarity indicators. Sandstones show mostly A on the Bouma sequence, suggesting relatively fast deposition, possibly in channels of an upper fan. Sandstones exhibiting only C could represent a quiescence period before another fast and coarse turbiditic flow arrive. The Bouma sequence is a qualitative measure of flow regime within a turbidite current. The whole Bouma sequence develops from bottom to top within the same bed and is represented by five different divisions: 1) coarse to fine grain (A), 2) plane parallel laminae (B), 3) ripples (C), 4) upper parallel laminae (D) and 5) laminated shales (E). This sequence could have been deposited on mid fan turbidites. See text for discussion and map for location (e).

Guárico Formation San Jose de Güaribe

Legend

Figure 49. San José de Güaribe transect. Distal facies of the Paleogene Guárico Formation showing a rhythmic sequence of laminated shales and thin sandstone beds and, in major proportion, dark grey shales with concretions. This sequence could have been deposited on the lower fan given the high shale/sand ratio. Sandstones show load and flute casts at their base, which are good bed-polarity indicators. See text for discussion and map for location (f).

Guárico Formation San Jose de Güaribe

Legend

Shale

Sandstone

Concretions

5 m

thick whereas other beds exhibit lamination, with each lamina varying in thickness from 1.5 cm to 2.5 cm. Ripples and evidence of organic activity (bioturbation) are the main sedimentary structures observed within this stratigraphic unit (Fig. 51).

thick whereas other beds exhibit lamination, with each lamina varying in thickness from 1.5 cm to 2.5 cm. Ripples and evidence of organic activity (bioturbation) are the main sedimentary structures observed within this stratigraphic unit (Fig. 51).

The Quebradón Formation along the El Jengibre Creek consists of conglomerate up to 3 m thick that grade into coarse-grained sandstone, a 1.5-to 3-m thick medium- to coarse-grained sandstone interstratified with gray siltstone. Sandstones exhibit reactivation surfaces, cross laminations and seldom contain plant remains and lignite fragments. Sandstones are also interstratified with greenish gray siltstone with nodules (Fig. 50). Along the El Jengibre Creek, the Quiamare Formation consists mainly of mottled shale and, in minor proportions, medium- to fine-grained reddish sandstone and yellowish medium- to coarse-grained sandstone interstratified with shale that weathers to grayish and reddish colors (Fig. 52). North of the San José de Güaribe village (~5 km) the Quiamare Formation consists of continental grayish-white cross-laminated sandstones at the base (2.5 m), brownish, friable, non-endured sandstones (3 m), purple, red, gray and brown siltstones and shales (6 m) (Fig. 53).

Figure 50. San José de Güaribe transect. Neogene Quebradón Formation showing a clastic sequence of relatively thick, coarse-to medium-grained sandstones with internal cross-lamination and siltstones with plant remains. See text for discussion and map for location (g).

Quebradon Formation San Jose de Guaribe

Legend

Figure 51. San José de Güaribe transect. Neogene Naricual Formation represented by thinly laminated very fine-grained sandstones, fine-to medium-grained sandstones with cross-lamination, very fine grained thin sandstones beds with ripples on top, siltstones and grey shales with plant remains, and conspicuous coal beds. See text for discussion and map for location (h).

Figure 52. San José de Güaribe transect. Neogene Quiamare Formation represented from bottom to top by thinly laminated greenish brown shales with concretions, thin-bedded sandstones and laminated shales cross-cut by channel infill. The sequence is capped by relatively thick conglomerates and conglomeratic sandstones. See text for discussion and map for location (i).

Quiamare Formation San Jose de Guaribe

Legend

	Fining-upward
	Shale
	Sandstone
	Conglomerate
	Concretions
2 m

Figure 53. Quiamare Formation near the San José de Güaribe village. View is toward the SW.

Deformation history of the Western Serrania del Interior foreland fold and thrust belt.

Introduction. The present study was undertaken to prove or to disprove the following: 1) two deformations occurred in north-central Venezuela as suggested by Beck (1977a), Beck (1977b) and Beck, (1986). Likewise; 2) how strain was partitioned along the western Serranía del Interior foreland fold and thrust belt and how much of it, at both megascopic and mesoscopic scales, was preserved in the rock units; and 3) how these structures are related to the regional plate tectonic framework. Thus, in order to gather data to confirm or discard these hypotheses, field work was carried out during the two summers of 1995 and 1997.

Regional Structure. The Western Serrania del Interior foreland fold and thrust belt has been the object of study for several decades [e.g., Peirson, (1966); Bell, (1968); Beck (1986)]. In this study, the author will follow the structural division followed by Bell (1968) in order to simplify the discussion. The western Serrania del Interior has been subdivided into four major tectonic belts that are from north to south:

(1) ***“Piedmont belt”***. The first and northernmost belt is the Piedmont belt. It is separated from the Villa de Cura complex to the north by the Cantagallo fault and to the south either by the “Belt of thrust faults” or by the “Belt of overturned beds” (Figs. 1 and 2). The “Piedmont belt” is characterized by south-vergent, tight-to-isoclinal folds and south-vergent thrust and reverse faults.

(2) ***“Belt of thrust faults”***. It crops out discontinuously along the Serranía del Interior between the “Piedmont belt” and the “Belt of overturned beds” (Fig. 2). This structural province is intensely deformed by south-vergent, imbricate thrust faults that juxtapose Cretaceous, Paleogene and Neogene sedimentary units. Beck (1978; 1985a,

1985b) suggested that the sedimentary cover that forms the Serranía is detached along an Albian or pre-Albian horizon. This belt probably represents a detachment zone that has been unroofed.

(3) “*Belt of overturned beds*”. It consists of a southward overturned syncline. It possibly is cut by a fault parallel to the fold-axial plane.

(4) “*Belt of gently dipping beds*”. The “Belt of gently dipping beds” is the most southerly zone and includes a mildly deformed rock sequence of the Guárico basin (Figs. 1 and 2). Open folds and a few south-vergent thrust faults occur, but with minor displacement.

Regional geological transects.

Four NS trending regional transects (Fig. 54) were selected for study based on previous geological reports and maps (Creole Petroleum Corporation 1960; Peirson, 1965; Peirson, 1966; Bell, 1968; Bellizzia et al., 1975; Beck, 1978; Beck, 1985a; Beck, 1985b; and Albertos et al., 1989).

These previously published maps along with fieldwork made it possible to reinterpret the regional structural fabric in view of the relatively new concept of displacement partitioning (e.g., Fitch, 1972; Avé Lallemant and Oldow, 1988; Cashman et al., 1992). The four transects are from west to east: 1) Platillón-Tiznados (PTZ), 2) Camatagüita-Valle Morín (CAM), 3) Altagracia de Orituco (AO) and 4) San José de Güaribe (SJG) (Fig. 54). Mesoscopic structural data including bedding (So), cleavages (S1), fold axes (FA), axial planes of folds (AP), fault planes and associated fault striae, were measured along these four transects to assess the architecture of strain partitioning,

Figure 54. Map of tectonic belts in the north-central Caribbean Mountain system as defined by Menéndez (1966), Peirson (1965), Bell (1968), and Beck (1978). The dashed areas represent the studied transects: (1) Platillón-Tiznados, (2) Valle Morín-Camatagüita, (3) Altagracia de Orituco, and (4) San José de Guaribe.

style of deformation and tectonic transport of the different belts within the Serranía del Interior fold and thrust belt.

The structural fabric was analyzed for two reasons. First, they might reveal whether displacement partitioning had occurred. Secondly, they might indicate whether or not more than one orogenic event has occurred. Poles to surfaces (bedding, cleavage, fold axial surfaces) and lineations (fold axes) were plotted and analyzed using Stereonet (Allmendinger, 1994). Fault data were plotted and analyzed to establish possible different episodes of deformation and their azimuth using FaultKin (Allmendinger, 1994).

Megascopic structures

Structural analysis of the four study transects (Creole, 1961a to c; Peirson, 1965; Bell, 1968; Beck, 1985a; Beck, 1985b; Albertos, 1989; and this study) suggests that the Serranía del Interior fold and thrust belt can be subdivided into an internal (northern) and external (southern) zones. Beck (1985b) recognized that the northern portion of the Piedmont belt consists of an olistolith complex embedded in a Paleocene-Lower Eocene matrix. The Internal (northern) zone is the belt of rocks that lie near the tectonic contact with the Villa de Cura nappe along the Cantagallo fault and includes the Piedmont belt of Bell (1968). It consists of a chaotic suite of olistoliths embedded in a coarse matrix of rocks of varied provenance (Figs. 23, 31, 43).

A. Hinterland dipping duplex

B. Stacked imbricate antiform

C. Foreland dipping duplex

Figure 55. Types of duplex structures (Boyer and Elliot, 1982).

Figure 56. Imbricates or splays bifurcating from a main fault or sole thrust. A horse is a volume of rock between two splay faults (Ramsay and Huber, 1987).

It has been correlated with the Garrapata Formation and the chaotic facies of the Guárico Formation (e.g. Bell, 1968). The olistoliths seen in the study areas are light grey platform limestones (Platillón-Tiznados limestone of MacKenzie, 1955; also Morros de San Juan, Peirson et al., 1965), black carbonates, serpentinites, greenstones and diorites (PTZ and CAM diorite intrusions of MacKenzie, 1955 and Bell, 1968). The heterogeneity in rock composition suggests a sedimentary environment of feeder channels at the toe of a turbidite system (Albertos 1989; Yoris, 1999, personal communication). In the easternmost SJG transect, the contact of this innermost belt with the Villa de Cura nappe is not observed (Fig. 43). The contact between the external and internal zones is always of structural origin. The external (southern) zone comprises Cretaceous parautochthonous platformal carbonates and siliciclastics of the Querecual and Mucaria Formations, respectively as well as allochthonous-parautochthonous (?) Cretaceous-Paleogene mid to external fan facies of the Guárico Formation turbidite system in all four transects (Figs. 7, 23, 31, 43). In all four study transects, the interpreted structure within the Piedmont zone is that of unroofed hinterland dipping duplex imbricates (Figs. 55 and 56) (Boyer and Elliot, 1982) with tectonic slivers with south-vergent folds, bounded by south-vergent high-angle reverse faults (Figs. 7, 23, 31, 43). On the map, the northeast-southwest high-angle faults are displaced by northwest-southeast striking dextral tear faults (e.g., Guárico fault, Fig. 23). The latter faults could correspond to unroofed lateral ramps. As it will be discussed in the next section, the above ductile and brittle structures are in agreement with the mesoscopic structures observed in the field.

Figure 57. Bedding-cleavage relationship in an overturned bed (Ramsay and Huber, 1986).

Figure 58. Bedding-cleavage relationship in an overturned fold (Ramsay and Huber, 1986).

The lack of pre-Cretaceous rocks involved in the deformation suggests that the relatively high-angle faults of the imbricates have to flatten out against a detachment surface located at some level within the autochthonous platformal Cretaceous carbonates whose surface expression is interpreted to be the Belt of thrust faults (Chacual complex of Peirson, 1965). Timing of uplift and unroofing of these units will be discussed in Appendix 5.

Ductile deformation structures.

Results. Poles to bedding planes (S_o), fold axial planes (PA) and cleavage planes (S_1) and orientation of fold axes (Fa) allow determination of both shortening axes and kinematics of the deformation or tectonic transport. Polarity of beds was assessed based on sedimentary structures and bedding-cleavage relationship (Figs. 57, 58, 59). The vergence of regional folds was determined by the bedding / cleavage relationship and by the asymmetry (S and Z parasitic folds) with respect to the stratigraphic facing (Fig. 59). Tectonic transport direction was inferred also from steeply plunging folds (Fig. 60).

The orientations of bedding planes (S_o), fold axial planes (S_{ap}), cleavage (S) and fold axes (F) were determined and plotted on lower-hemisphere, equal-area diagrams (Figs. 61 to 64) (Ramsay and Huber, 1987) using the Stereonet program (Allmendinger, 1995a).

Bedding planes (S_o), fold-axial planes (S_{ap}) and axial-plane cleavages (S) generally strike ENE-WSW and dip moderately to the north in the three westerly transects (Figs. 61 to 63). However, in the San José de Guaribe transect (Fig. 64) they

Figure 59. a) Detail of the relationship between bedding (S_0) and cleavage (S_1) in normal polarity beds of the Mucaria Formation in the Tiznados River, where cleavage is steeper than bedding. View is to the southeast. b) Chevron-folds (“S-type”) in the Guárico Formation along the Carretera Nacional Altagracia de Orituco-Guatopo. View is to the northeast.

a)

b)

strike E-W and dip moderately to the north. Fold axes (F) occur in a moderately NNW-dipping great-circle girdle with an ENE-WSW trending maximum in the three westerly domains (Figs. 61 to 63); they are steeply N plunging in the Guaribe area (Fig. 64). The structures in the west are compatible with SSE-directed tectonic transport and in the Guaribe domain they are compatible with S directed thrusting. The steep attitude of the fold axes in the Guaribe transect indicates that this domain has undergone much larger contractional strain and strain rotation than the other three areas. Mesoscopic ductile structures indicating more than one deformation event were not observed. However, Neogene rocks are much less deformed than Cretaceous-Paleogene rocks. This may indicate that at least two phases of deformation have occurred, but due to a similar displacement field, it is likely that similar deformation structures may have formed.

Two transects, PTZ and CAM, yielded the most fold data (Figs. 61, 62). Among the lithological units, the Upper Cretaceous Mucaria Formation shows the largest amount of deformation with tight folds and strong penetrative cleavage S_1 (Figs. 66, 67b, 68b, 69b, 71b). Only in the Querecual Formation of the Camatagüita-Valle Morín transect, is there a weak indication of an older cleavage fabric overprinted and almost parallel to S_1 (Figs. 67a, 68a, 71a). Although some of the folds in the Paleogene-Lower Eocene Guárico Formation are soft-sediment folds formed by slumping toward the basin (Fig. 70a), the most important group of folds have a penetrative cleavage, indicating that these folds are tectonic in origin (Figs. 65, 69b, 70b). Although presence of superimposed cleavage is an indication of different deformational events, no evidence of the latter was observed in any other rock formation along the four studied transects. Fold interlimb angles in all study transects suggest that folds are between 10° - 70° (close to

Figure 60. Detail of a hinge of steeply plunging tight fold in the Guárico Formation, Santa Lucía Creek, San José de Güaribe.

tight), independent of rock type. Hinges of folds for all the lithological units are angular with a narrow hinge zone and, thus, indicate chevron folds (Ramsay, 1974; Marshak and Mitra, 1988), especially the Upper Cretaceous Mucaria Formation. This lithological unit shows intense folding and a penetrative cleavage in the CAM area. (Fig. 69b)

Sheath folds are noncylindrical tongue-shape folds that indicate high strain in shear zones. They can form during one single phase of deformation (Marshak and Mitra, 1988).

The presence of a sheath-fold in the PTZ transect along the fault contact between the Upper Cretaceous Mucaria Formation and the Cretaceous-Paleocene rocks of the Garrapata Formation (Fig. 72) is indication that the area underwent a high shearing deformation (shear strain $\gamma > 10$). Figure 68a shows a cross section of an “a”-type sheath fold (Malavieille, 1987) along the fault contact. Poles to bedding of a sheath fold define a great-circle girdle on an equal-area net (Fig. 72). The pole to this girdle defines the NW-SE tectonic transport direction of the nappes associated with the sheath fold. Other kinematic indicators are necessary to assess the sense of such tectonic transport. Associated with both sheath-fold and fault surface, there are asymmetrically deformed sedimentary clasts (rip-up clasts, Fig. 73), suggesting tectonic transport to the SSE.

Discussion

The Cretaceous-Paleocene units (Garrapata, Querecual, Mucaria and Guárico Formations) of the allochthonous-parautochthonous terranes of the western Serranía del Interior (Piedmont belt) underwent an intense phase of ductile tectonic deformation

Figure 61. Equal-area, lower-hemisphere projections of ductile structural elements from the Platillón-Tiznados transect: a) 678 poles to bedding planes (S_0), b) 81 poles to fold axial planes (AP) and 81 fold axes (FA), and c) poles to 21 axial plane cleavages (S_1). These ductile structures suggest tectonic transport of the nappes to the SSE onto the South America craton (Guyana craton).

a) So

b) FA and AP

c) S1

Figure 62. Equal-area, lower-hemisphere projections of ductile structural elements from the Camatagüita-Valle Morin transect: a) 915 poles to bedding planes (S_0), b) 156 poles to fold axial planes (AP) and 180 fold axes (FA), and c) poles to 68 axial plane cleavages (S_1). These ductile structures suggest tectonic transport of the nappes to the SE onto the South America craton (Guyana craton).

a) So

b) FA and AP

c) SI

Figure 63. Equal-area, lower-hemisphere projections of ductile structural elements from Altagracia de Orituco transect: a) 356 poles to bedding planes (S_0), b) poles to 3 fold axial planes (AP) and 3 fold axes (FA), and c) poles to 14 axial plane cleavages (S_1). These ductile structures suggest tectonic transport of the nappes to the SE onto the South America craton (Guyana craton).

a) So

b) FA and AP

c) S1

Figure 64. Equal-area, lower-hemisphere projections of ductile structural elements from the San José de Güaribe transect: a) 233 poles to bedding planes (S_0) and b) 10 poles to fold axial planes (AP) and 10 fold axes (FA). These ductile structures suggest tectonic transport of the nappes to the SE onto the South America craton (Guyana craton).

a) So

b) FA and AP

Figure 65. Ductile-brittle structures developed in rhythmically stratified turbidite facies of the Cretaceous (?)–Paleogene Guárico Formation on the Platillón-Tiznados transect along the Las Lajitas road near the village of San Francisco de Tiznados. Figure a) shows a south-vergent thrust developed along the axial plane of a south-vergent fold. Figure b) shows a south-vergent drag fold associated to a possibly rotated thrust. The latter structures are located between two thrust faults. This structural geometry would imply out-of-sequence thrusting. Folds are south-vergent with northeast-southwest striking fold axis and have a penetrative north-dipping planar cleavage fabric. There is no evidence of superimposed cleavage. See station 1 for location on Figure 7.

SOUTH

NORTH

a)

SOUTH

NORTH

b)

during its incorporation into the accretionary wedge and emplacement onto the Guyana craton to the South. This ductile deformation is not observed in the Neogene rock units of the more exterior belts of the Serranía, towards the foreland (Roblecito, Naricual, Quebradón and Quiamare Formations). The ductile deformation occurred possibly during the Middle Eocene. In the Camatagüita-Valle Morín Creek transect, the Middle Eocene calcareous Peñas Blancas Formation rests unconformably on top of the Guárico Formation (Peirson, 1965; Bell, 1968, Yoris, personal communication, 2002).

Ductile structural data suggest that the azimuth of Middle Eocene deformation is NNW-SSE with tectonic transport to the SSE.

The lack of superimposed cleavage and the existence of a very penetrative fabric (S_1) suggests that: 1) no previous ductile deformation occurred prior to the incorporation of the nappes in the accretionary wedge in Middle Eocene as suggested by Beck, 1977, or 2) if a pre-Middle Eocene event had occurred, the azimuth of the strain and displacement field of such event would have been similar to that of S_1 .

A second phase of deformation occurred during the Neogene-Pliocene generating regional open folds (Peirson, 1965; Bell, 1968; Beck, 1978; this study). The Oligocene-Miocene units in the study area included in the Belt of overturned beds and Belt of gently-dipping beds do not exhibit the intense folding and penetrative cleavage observed in the Cretaceous-Paleocene Querecual, Garrapata, Mucaria and Guárico Formations. Folds regionally mapped in the Oligocene-Miocene units in the Belt of overturned beds and Belt of gently-dipping beds are open (e.g., Creole, 1966) and have the same orientation of fold axes and fold axial planes as those structures observed in the Cretaceous-Paleocene units of the Piedmont zone. Orientation of fold axes as well as

Figure 66. a) and b) show ductile structures developed in Cretaceous siltstones of the Mucaria Formation on the Platillón-Tiznados transect. These south-vergent folds have northeast-southwest trending axis and show no evidence of superimposed cleavage. Folds in the Mucaria Formation are closed to tight, chevron-like, with a very penetrative fabric (S_1).

Figure 67. Ductile structures developed on a) black shales and limestones of the Querecual Formation and b) dark gray siltstones of the Cretaceous Mucaria Formation in the Camatagüita-Valle Morin and Platillón-Tiznados transects respectively. Figure b) shows a northeast-southwest striking left-lateral fault cross-cutting south-vergent folds and is evidence of two possibly separate tectonic pulses in the area. Folds in the Mucaria Formation are closed to tight, chevron-like, with a very penetrative fabric (S_1). Folds are south-vergent with northeast-southwest striking fold axis and have a penetrative north-dipping planar cleavage fabric. There is no evidence of superimposed cleavage

a

b

Figure 68. Ductile structures developed on a) black shales and limestones of the Cretaceous Querecual Formation in the Camatagüita-Valle Morin transect and on b) siltstones of the Cretaceous Mucaria Formation in the Platillón-Tiznados transect. The former fold shows an intra-detachment surface atop the crest of the structure. The latter exhibits a high-plunging fold axis ($>20^\circ$) dipping to the east. Folds in the Mucaria Formation are closed to tight, chevron-like, with a very penetrative cleavage fabric (S_1). Folds are south-vergent with northeast-southwest trending fold axes. Folds have a penetrative north-dipping planar cleavage fabric. There is no evidence of superimposed cleavage on the above structures.

Figure 69. Ductile structures developed on a) dark grey sandstones and siltstones of the Cretaceous (?)–Paleogene Garrapata Formation in the Altagracia de Orituco transect; and b) siltstones of the Cretaceous Mucaria Formation in the Camatagüita-Valle Morin transect. The former fold shows a fold axial plane ($>20^\circ$) dipping to the north (recumbent fold). The latter shows the folding style in the Mucaria Formation with penetrative north-dipping planar cleavage fabric. Folds in the Mucaria Formation are closed to tight and chevron-like. Folds are south vergent with northeast-southwest trending fold axes. There is no evidence of superimposed cleavage on the above structures.

Figure 70. Figure a) shows ductile structures and b) ductile-brittle structures developed on a turbidite rhythmic sequence of sandstones, siltstones and shales of the Cretaceous (?)–Paleogene Guárico Formation in the Camatagüita-Valle Morin transect. Figure a) shows slumping structures in one sandstone bed, but the overall folding is tectonic as suggested by the highly penetrative north-dipping cleavage fabric. Figure b) shows folds cut by south-vergent intra-formational thrusts. Folds are south vergent with northeast-southwest trending fold axes. There is no evidence of superimposed cleavage on the above structures.

Figure 71. Line drawings of folds in the Camatagüita-Valle Morin transect. Folds are south vergent with northeast-southwest striking fold axes and no evidence of superimposed cleavage to a very penetrative north-dipping cleavage fabric. Figure (a) shows an “S-type” fold developed in black shales and limestones of the Cretaceous Querecual Formation. Figure (b) shows an excellent example of an exposed hinge and fold axis plunging to the NE in siltstones of the Cretaceous Mucaria Formation.

Figure 72. (a) Sheath-fold generated by large shear strain in silicified siltstones of the Cretaceous Mucaria Formation in the Tiznados River along a fault contact with the Cretaceous-Paleocene Garrapata Formation. Besides giving an estimation of strain, sheath folds are also useful in determining azimuth or direction of tectonic transport. View is West (left) / East (right). (b) Equal-area lower hemisphere projection of poles to bedding plane (S_0 , black dots) on the sheath fold on (a). Great circle is the plane containing all poles to bedding planes measured on the sheath-fold. Pole to this surface (filled square) represents azimuth of tectonic transport of rock slivers.

a)

b)

Figure 73. Asymmetrical deformed clast in the Mucaria Formation. Rip-up clast associated to a fault plane and the sheath-fold of Figure 72. This structural feature serves as kinematic indicator for sense of movement of a fault associated to the sheath-fold in the Mucaria Formation, Tiznados River. View is to the SE.

vergence of fold axial planes in the Cretaceous-Paleocene and Oligocene-Miocene terranes suggests that the strain field in the Middle Eocene was virtually parallel to that of the Neogene.

Brittle deformation

Kinematic analysis of fault populations. Mesoscopic faults and slickenside striations were measured to determine the mode of deformation as well as the tectonic transport direction. Determination of the sense of slip on the faults was based on established techniques (Petit, 1987; Gamond, 1987; Ramsay and Huber, 1987). Data (Figs. 19 and 20) were plotted using FaultKin (Marret and Allmendinger, 1990, 1991, 1992; Allmendinger, 1995b).

The faults were divided into groups or populations that had an internal consistency. Crosscutting relationships observed in the field suggest the relative timing of generation of such fault families. FaultKin (Allmendinger et al., 1989) was the algorithm used to determine strain fields, not stress fields as in models of Angelier and Mencher (1987). FaultKin is used to determine the moment tensor solution for each of these families. Shortening (P) and extension (T) axes denote the strain orientations present in the study (Figs. 74 and 75).

Three major populations of penetrative mesoscopic faults have been found in all four studied sections (Figs. 76 and 77). They are found in the Cretaceous to Oligocene allochthonous and parautochthonous nappes, but are rare in the autochthonous Miocene sedimentary deposits. These fault populations are: (1) NNE-SSW striking thrust and back-thrust faults with tectonic transport to the SSE and NNW, respectively; (2) NW-SE

Figure 74. Two perpendicular surfaces, the fault plane and a nodal plane, divide the body into compressional and tensional areas and can be represented in an equal area projection.

Figure 75. Main fault types and its associated fault plane solutions

striking dextral -tear-faults; and (3) NE-SW striking left-lateral tear-faults (Figs. 76 to 78). In the Camatagüita-Valle Morin and Platillón-Tiznados transects, there are, additionally, three distinctive normal fault populations. These populations strike NE-SW (N1), NW-SE (N2) and N-S striking (N3) normal faults (Fig. 76). The N1 and N2 faults occur in Cretaceous to Oligocene allochthonous and parautochthonous lithological units, while the N3 faults occur also in the Miocene rocks. Although data is scarce, another piece of evidence is that N3 faults deform the Villa de Cura nappe, Piedmont zone and Oligocene-Miocene basinal rocks. N3 normal faults could be associated with a Pliocene uplift event.

In the Altagracia de Orituco transect, only one set of normal faults (N2) was observed (Fig. 77). Additionally there are in this transect NNE-trending right-lateral strike-slip faults (RL' on Fig. 77), although they are relatively rare.

In the San José de Güaribe transect (Fig. 77), two sets of normal faults (N1 and N2) were recognized. Also, a set of NE-SW-striking thrust faults occur, suggesting tectonic transport either to the SW or NE (Fig. 77).

Discussion. A summary of timing of structures is shown on Figure 79. In a few places relative timing of fault movement could be determined where two fault sets crosscut each other. There are some cross-cutting relationships evident in the Cretaceous-Paleocene Garrapata Formation of the Platillón-Tiznados transect suggesting that thrust faults are older than left-lateral faults. In the same transect, it is also observed that the left-lateral faults also crosscut tight folds of the Upper Cretaceous Mucaria Formation.

Thrusting started in the Middle Eocene during the incorporation of the nappes into the accretionary wedge and continued through the Neogene, with the obduction of the

Figure 76. Equal-area, lower-hemisphere projection of brittle structural elements measured in the following regional transects: (1) Platillón-Tiznados and (2) Camatagüita-Valle Morín. Arrows indicate relative movement of missing block. Beach balls represent lower-hemisphere moment tensor solutions for the respective group of family faults. P and T represent strain axes, P (contractional) and T (extensional). In (1): 19 thrust faults (TF); 13 left-lateral faults (LL); 11 right-lateral faults (RL); 5 normal faults (N1); 9 normal faults (N2) and 4 normal faults (N3). In (2): 41 thrust faults (FT); 29 left-lateral faults (LL); 26 right-lateral faults (RL); 6 normal faults (N1); 5 normal faults (N2) and 5 normal faults (N3). See Figure 2 for location of transects.

Figure 77. Equal-area, lower-hemisphere projection of brittle structural elements measured in the following regional transects: (3) Altigracia de Orituco and (4) San José de Guaribe. Arrows indicate relative movement of missing block. Beach balls represent lower-hemisphere moment tensor solutions for the respective group of family faults. P and T represent strain axes, P (contractional) and T (extensional). In (3): 18 thrust faults (TF), 9 left-lateral faults (LL), 3 right-lateral faults (RL), 3 right-lateral faults (RL') and 3 normal faults (N). In (4): 5 thrust faults (TF), 7 thrust faults (FT'), 8 left-lateral faults (LL), 8 right-lateral faults (RL), 3 normal faults (N1), and 2 normal faults (N2).

Figure 78. a) High-angle NW-SE dextral tear-faults on silicified siltstones of the Mucaria Formation in the Camatagüita-Valle Morin transect. View is to the SE. b) Low-angle thrust fault in the Guárico Formation along the Las Lajitas roag, NW of the San Francisco de Tiznados village, Platillón-Tiznados area.

a)

b)

wedge onto the South American Guyana craton (NW-SE and NS contractional events). The NW-trending right-lateral tear-faults seem to have formed coeval with the thrust faults and may be as conjugates to NE-trending left-lateral strike-slip. Fault population N2 is coeval and consistent with thrusting (NW-SE contractional event). The N1 and N3 normal faults formed at the same time as the NE-SW trending left-lateral faults. Since field relationships show N3 cutting across Miocene rocks, N1 and N3 seem to be a post-Miocene deformational event, most likely Pliocene, possibly related to the final encroachment of the nappes to the south.

Conclusions. The analysis of the ductile and brittle structures presented in the study area suggests that there were three distinct deformations: (1) a Middle Eocene NW-SE contraction responsible for the accretion of the Cretaceous-Tertiary turbidites and passive margin deposits into the accretionary wedge, Lara nappes, in the west; (2) a Middle to Late Miocene contractional event with a very similar strain field as that of the Eocene that involves the Oligocene-Miocene deposits in the deformation; and (3) a N-S Pliocene-Pleistocene contractional event that involves the molasse in the foreland fold belt. Works could represent either a family of antithetic faults related to the right-lateral fault groups (R'; Petit, 1989) possibly generated in a younger event (Pliocene) and could be related to restraining bends between EW-trending, left-stepping, en-echelon, right-lateral strike-slip faults.

There is no field evidence suggesting relative timing of N1, N2 and N3 fault data. The N1 normal faults might have formed by NW-SE to E-W extension, parallel to the megascopic fold axes and the trend of the thrust faults. These structures may have formed

Figure 79. Summary of timing of deformation for the Western Serranía del Interior.

in the outer hinges of the megascopic folds, possibly during the latest NW-SE contractional event in the Neogene. The N2 normal faults have NW-SE trends that are compatible with a) NW-SE contractional event during the emplacement of the nappes or with b) bounding faults of pull-apart basins between EW-trending dextral, right stepping, en-echelon, strike-slip faults. Several megascopic pull-apart basins occur in the area, e.g. the Cariaco basin (see Ysaccis, 1997) in which such normal faults have been recognized.

The N3 normal faults trend approximately NS. They could have been formed during the Pliocene NS uplift event. Likewise, these structures could have formed by plate-boundary parallel extension. This extension may be related to oblique plate convergence along a curved plate boundary (Avé Lallemant and Guth, 1990).

The ESE-WNW-trending thrust faults in the San José de Güaribe area (Fig. 77) are not compatible with NNW-SSE contraction. However, they may be compatible with restraining bends between two EW-striking left-stepping right lateral strike-slip faults.

Integrated geological transects

An attempt to merge the geological information obtained from field work along the four studied transects and along the depth-converted 2D seismic lines was made to assess the structural geometry of both allochthonous and autochthonous stratigraphic units and to postulate a tectonic evolution for the area (Figs. 80 to 83). On the first three integrated transects the structural relationships are shown between the allochthonous blueschists of the Villa de Cura nappes, the allochthonous-parautochthonous sequences of the Western Serranía del Interior and the autochthonous sequences of the Guárico

Figure 80. Integrated geological cross section using seismic line G2 and geological cross section from the Platillón-Tiznados transect.
Legend as in Figure 13.

foredeep (Figs. 80 to 82). The last transect does not show the contact of the Villa de Cura nappes and the “Piedmont belt” (Fig. 83). The structural contact between the western Serranía del Interior and the Guárico foredeep occurs along the Guárico frontal thrust (Figs. 80 to 83). The Villa de Cura nappes are interpreted as a klippe based on gravimetric and magnetic models (Bosch and Rodriguez, 1992). They are in structural contact with the Western Serranía del Interior along the Cantagallo thrust (Figs. 7, 23, 31, 43). In the integrated Tiznados-Platillón transect, the “Piedmont belt” overrides the autochthonous sequences of the perisutural Guárico foredeep, forming a triangle-zone in the vicinity of the San Francisco de Tiznados village (Fig. 80).

The general structure consists of south-vergent hinterland-dipping imbricates that merge to a sole thrust or decollement along the basinal Oligocene horizon, deforming the western Serranía del Interior and the Guárico foredeep (Figs. 80 to 83). This detachment level probably ramps down farther north since Cretaceous sequences are included in the deformation (“Piedmont belt”).

Surface expression of this decoupling level is found in the “Belt of thrust faults” or Chacual complex where Cretaceous and Tertiary rocks are intensely deformed (Fig. 83). In summary, deformation and strain are more intense in the north, within the Cretaceous-Paleogene rocks of the “Piedmont belt,” suggesting a north-south strain gradient. This intense deformation could have taken place in the Middle Eocene, prior to the final Neogene emplacement of the nappes to the south. Minor faults formed during the Cretaceous and were later reactivated during the inception of the basal foredeep unconformity due to flexure of the South American continental crust during the emplacement of the nappes. The “Piedmont belt” is projected to extend beneath the Villa

Figure 81. Integrated geological cross section using seismic line G4 and geological cross section from the Camataguita-Valle Morin transect.. Legend as in figure 13

de Cura nappes and in turn the Cretaceous-Paleogene basinal deposits are interpreted to extend beneath both the “Piedmont belt” and the Villa de Cura nappes. Some Neogene reverse faults are observed in the Camatagüita-Valle Morín integrated transect, affecting the Pre-Cretaceous, Cretaceous and Paleogene rocks of the Guárico basin. On the basis of the four integrated seismic transects and the E-W trending seismic line, a hypothetical NS-trending cross section was constructed through the Caribbean-South American plate boundary zone (Fig. 84) that included interpretation of previous work in offshore Venezuela by Bijou-Duval et al. (1983), in the Cordillera de la Costa and Villa de Cura belts by Ostos (1990) and in the Villa de Cura nappes by Smith et al. (1999). Figure 84 shows a southward-dipping Neogene subduction zone in the north, where the Caribbean is subducting beneath the South America plate, and a northward dipping Paleogene subduction zone in the south, where the allochthons were obducted onto South America continental crust. These terranes are detached along deep decollement levels and can be considered as an orogenic float as defined by Oldow et al. (1989, 1990). The allochthonous terranes are from north to south: (1) Cretaceous-Oligocene (K-OL) in the Venezuela basin; (2) Neogene (N) sediments in the Los Roques trough, Curaçao ridge and Venezuela; (3) Crystalline basement of the Bonaire Basin (Mz-T) that includes the Leeward islands; (4) Eocene-Miocene (E-M) and Miocene-Pliocene sediments (M-P) in the Bonaire basin; (5) Obducted Mesozoic metasediments and Paleozoic metaigneous rocks of the Caracas Group in the Cordillera de la Costa Belt (Mz) and in the Cretaceous Villa de Cura nappe (VDC); (6) Platform and basinal parautochthonous sedimentary rocks of the Serranía del Interior (K-T)p; (7) Tertiary autochthonous sequences (foredeep

Figure 82. Integrated geological cross section using seismic line G5 and geological cross section from the Altagracia de Orituco transect. Legend as in figure 13

deposits) above decollement level in the Guárico basin (T); and (8) autochthonous Cretaceous-Tertiary sequences in the Guárico basin (K-T).

Reconstruction and balancing of the integrated Caribbean-South America geological cross section uses a combination of line length and area conservation that although not unique is consistent with the geology and its structural style (e.g., Dalstrom, 1969, Suppe, 1983). The datum utilized for this restoration is the level OB (Oligocene ~32 Ma). Pinning the Caribbean-South America geological cross section to the south, in the Guárico basin, the calculated minimum shortening obtained from its reconstruction is about 200 km since Oligocene time (32 Ma). A minimum calculated strain rate would be 0.6cm/yr.

Figure 83. Integrated geological cross section using seismic line G6 and geological cross section from the San José de Guaribe transect. Legend as in Figure 13.

Figure 84. Regional north-south cross section across the Caribbean-South American plate boundary zone sl

ate boundary zone showing an orogenic float as defined by Oldow et. al (1990)

VOLUME III

*Tectonic and thermal history of the western Serranía del Interior foreland fold
and thrust belt and Guárico basin, north-central Venezuela: Implications of new
apatite fission-track analysis and seismic interpretation*

by

Jaime Pérez De Armas

APPENDIX 5

APATITE FISSION-TRACK THERMOCHRONOLOGY

Introduction. Apatite, $\text{Ca}_5(\text{PO}_4)_3 (\text{F}, \text{Cl}, \text{OH})$, occur in igneous, metamorphic and sedimentary rocks as accessory minerals. Apatite grains are generally small ($< 300 \mu\text{m}$) and represent less than 1% of the rock volume. Apatite crystallizes in the 6/m-hexagonal dipyramidal crystal class. It has a hardness of 5 on the Moh scale, making it likely to endure weathering, transport and sedimentation (Fig. 1). Specific gravity of apatite varies from 3.15 g/cc to 3.20 g/cc. The proportion of F^- , Cl^- and OH^- anions vary the chemical composition, forming three end members: fluorapatite, chloroapatite and hydroxiapatite. Trace elements, especially Uranium, can also be incorporated in the apatite crystal lattice.

Uranium ($Z=92$) occurs in apatite as a trace element (1-200 ppm). The two most common isotopes of the element Uranium are ^{238}U and ^{235}U . These two isotopes occur in nature in a fixed ratio ($^{238}\text{U}/^{235}\text{U}$: 137.88; Steiger and Jager, 1977). Isotope ^{238}U undergoes two very distinct nuclear decay processes: (1) alpha-decay (decay constant $1.55125 \times 10^{-10} \text{ year}^{-1}$) and (2) spontaneous nuclear fission (decay constant 7.5×10^{-17}). It is important to note that the ratio of alpha-decay to spontaneous nuclear fission of ^{238}U nuclei is 2.0×10^6 . That means that for every 2.0×10^6 ^{238}U nuclei that undergo alpha-particle decay only one nucleus undergoes spontaneous nuclear fission.

The liquid-drop model of nuclear fission (Bohr and Wheeler, 1939; Freidlander, 1981) is the most accepted mechanism by which a ^{238}U nucleus splits into two, rarely three, nuclear fragments. As the ^{238}U nucleus vibrates 10^{12} times per second, there is a

chance for it to vibrate into an unstable configuration causing the nucleus to split into two fragments and generating fission tracks, in the present case, within apatite.

Fission-tracks are linear damage zones caused by the natural fission of the isotope ^{238}U in natural glasses and accessory minerals (e.g., apatite, zircon and sphene). It is assumed that all tracks are formed by the natural fission of the isotope ^{238}U . Price and Walker (1963) argue that the contribution of fission tracks from ^{235}U , ^{232}Th , and their daughter products are negligible, since their concentrations are small compared to that of the ^{238}U isotope. Moreover, ^{235}U and ^{232}Th half-lives for nuclear fission greatly exceed the ^{238}U half-life (Andriessen, 1995).

Fission tracks are randomly oriented, essentially straight trails of crystallographic damage with a limited length. The most accepted hypothesis of how tracks form is the “ion explosion spike” of Fleischer et al. (1975). Natural fission of unstable isotopes produces two positive, heavy and highly charged fragments of nuclei that recoil in opposite directions due to Coulomb repulsion. As the fission nuclei fragments pass through the crystal lattice, they strip electrons from the nearby atoms creating a positively charged region. Positively charged ions repel each other strongly forming a metastable defect or a region of vacant lattice loci within the crystal (Fleischer, 1975). Therefore, each track is the by-product of a uranium nuclear fission event (Fig. 2).

Fission tracks do not remain in metastable condition through time. Numerous controlled experiments show that once a track forms it can undergo measurable changes in length, even at room temperature. One of the most important characteristics of an apatite crystal is that it can heal itself, reverting back to its original track-free state by a process known as fission track annealing. Fleischer et al. (1965) argued that temperature,

Figure 1. Apatite crystallizes in the 6/m-hexagonal dipyramidal crystal class.

www.brocku.ca/earthsciences/people/gfinn/minerals/apatite.htm

not pressure, is the only important variable in controlling fission track annealing. Thermal annealing rates of fission tracks in apatite are strongly controlled by their chemical composition, but the overall relationship between temperature and composition remains unclear (Carlson, 1990; Carlson et al., 1999).

Fission-tracks form and accumulate through time at a fairly constant rate and their density in a single crystal or glass is dependent only on ^{238}U concentration and time (Fig. 3). The fission-track/ ^{238}U concentration ratio in a single grain is related to the time in which the fission tracks accumulated. Concentration of the isotope ^{238}U in apatite crystals cannot be measured directly. A process known as neutron activation makes it possible to calculate the concentration of ^{235}U in apatite crystals. By exposing an apatite sample to thermal neutrons present at the core of a nuclear fission reactor, induced fission occurs mainly in the ^{235}U isotopes. This happens because such an isotope has a 214.8 times larger cross-section for thermal neutron capture ($580 \times 10^{-24} \text{ cm}^2$) than that of ^{238}U ($2.7 \times 10^{-24} \text{ cm}^2$).

Apatite fission-track thermochronology. Apatite fission-track (AFT) analysis and modeling can yield important thermochronometric data, which can constrain several variables associated with low-temperature ($\sim 110^\circ\text{C}$) geological events occurring at shallow levels in the earth crust such as basin subsidence, sedimentary provenance and mountain-building processes (Fig. 4) (e.g., Gallagher et al., 1998). Depth of burial, peak burial temperature and timing of peak burial temperature can be assessed, as well as cooling events associated with uplift, exhumation and erosion of *buried* rocks (e.g., Andriessen, 1995). The technique has been in use since the early 1960s, but relatively recently advances have been made to aid understanding of fission track annealing such as

Figure 2. The ion spike mechanism of fission track formation. After a fission decay event, the nucleus is divided into two halves, repulsing each other and passing through the crystal lattice. Each half strips electrons from nearby atoms. The ions so created repulse each other creating a crystallographic damage. After Fleischer et al. (1975).

its relationship with temperature and chemistry (Naeser and Faul, 1969; Laslett et al., 1987; Carlson et al., 1999; Donelick et al., 1999; Ketcham et al., 1999) and the derivation of time-temperature paths when combined with track length data (e.g., Green et al., 1989). In this study, detrital AFT data yield new information that helps in interpreting the history of the accretionary wedge obducted onto the Guyana craton.

Apatite fission-track length analysis

As pointed out previously, fission tracks are formed at a constant rate. Thus, each track experiences a fragment of the thermal history of the rock. Each track records the maximum temperature at which it was exposed at a certain period in time. Therefore, the distribution of track length data is an integration of the complete thermal history of a sample that cooled below the temperatures at which fission tracks are retained (Crowley, 1986; Green et al., 1989).

Irreversible thermal annealing or reduction of length due to an increase in temperature of fission tracks occurs at temperatures between 20°C and 150°C (Gleadow and Lovering, 1977; Gleadow and Lovering, 1978; Green et al., 1986; Donelick et al., 1990). Some authors argue about the existence of a Partial Annealing Zone (PAZ) to be between 60°C and 110°C as an effective closure temperature (e.g., Green et al., 1986), but experimental work demonstrates that annealing can occur even at room temperature (23°C; Donelick, 1990). Instead of being a drawback in the technique itself, this characteristic of fission tracks can provide better insight information of low-temperature thermal histories (Willet, 1997).

Figure 3. Transmission electron microscope view of damage caused by fission tracks in mica. After Price and Walker (1963).

Latent fission tracks are not optically visible unless they are properly etched with acids under controlled conditions (Fleischer et al., 1965). The mean etchable length of typical, confined fission-tracks in unannealed volcanic rocks is 14.5 to $15.5 \pm 1 \mu\text{m}$ (Gleadow, 1986), although the mean etchable length of induced fission tracks can exceed $16 \mu\text{m}$. This difference in length is accounted for by thermal annealing of natural tracks at the shallowest levels of the crust or at the surface (Fig. 5), during extensive geologic periods, at temperatures as low as 21°C (Vrolijk et al., 1992). Moreover, Donelick (1990) suggested that significant annealing of thermally induced fission tracks can occur at room temperature (23°C) at laboratory time scale.

Green et al. (1986) suggest that annealing is a two step process: first, tracks shorten from their tips inward at low degrees of partial track annealing; second, fission tracks create non-etchable gaps at higher degrees of annealing. This notion seems to be supported by Paul and Fitzgerald (1992) who suggests that at an atomic level track annealing begins by shortening from the track ends and it is immediately followed by generation of gaps related to microstructure restoration.

Temperature most strongly affects the track stability through time. At high temperatures less time is needed for the tracks to anneal. All fission tracks can be annealed at temperatures greater than 110°C at geological times (10-100 m.y.). Thermal histories, peak burial temperatures, time of peak burial, nature of cooling and estimates of expected vitrinite reflectance values of rocks can be assessed by the integrated history that a fission track population experiences through time (Green et al., 1989; Burtner et al., 1994; Donelick et al., 1999).

Figure 4. Apatite fission-track (AFT) analysis and modeling can yield important thermochronometric data, which can constrain several variables associated with low-temperature ($\sim 110^{\circ}\text{C}$) geological events occurring at shallow levels in the earth crust such as basin subsidence, sedimentary provenance and mountain-building processes (e.g., Gallagher et al., 1998). Depth of burial, peak burial temperature and timing of peak burial temperature can be assessed, as well as cooling events associated with uplift, exhumation and erosion of buried rocks (e.g., Andriessen, 1995).

Much debate and proposed models have been derived in trying to explain the fission track annealing process. Mathematical relationships that describe fission-track annealing in apatite are the result of controlled experiments extrapolated to geological times (Green et al., 1986; Donelick et al., 1999; Ketcham et al., 1999). Early experimental work by Fleischer et al. (1965), and Naeser and Faul (1969) assume first order kinetics as an explanation for the physics of fission track annealing. First order kinetics, in the sense of this study, is the decrease in track density and length with time during isothermal annealing and can be described by a single exponential equation, as follows:

$$t = \exp (k E_a / R T) \quad \text{or} \quad \ln (t) = k E_a / R T$$

where

After Fleischer et al. (1975.)

t = Time (Ma)

k = Constant of proportionality (dimensionless)

E_a = Activation energy

R = Gas constant

T = Temperature (°K)

In the above equation, fission track annealing is a function of a single activation energy at all temperatures and there is a linear relationship between the logarithm of annealing time and the inverse value of the absolute temperature (Arrhenius behavior).

Figure 5. Temperature-time conditions for fission-tracks to be preserved for a Mid-Atlantic ocean-bottom basaltic glass sample. Solid dots are T-t conditions for the tracks to be unaffected. Open dots are conditions where tracks are either absent or reduced. After Fleischer et al. (1975.)

t = Time (Ma)

The radiation damage can be repaired or annealed as temperature increases. The activation energies in the annealing process are typical for the diffusive motion of atoms in solids (Fleischer, 1998; Fleischer et al., 1975).

Crowley (1991) described annealing processes in apatite as a first order kinetic equation, where it is characterized by a monotonic decrease in etched track length with increasing temperature. However, Green et al. (1989) suggest that first order kinetics cannot explain fission track annealing in apatite and that more sophisticated models should be developed to explain such phenomenon, but they fail to suggest any viable method. Empirical relationships of Laslett et al. (1987) and recently of Donelick et al. (1999) seem to explain annealing behavior. The empirical relationship of Laslett et al. (1987) fit the annealing data of Green et al. (1986). It displays also a fanning Arrhenius model where track reduction is dependent on time and temperature:

$$\{(1-r^{2.7})/2.7\}^{0.35} - 1 = 0.35 (-4.87 + 0.000168T [\ln(t) + 28.12])$$

Where r (mean track length reduction) = l/l_0

Donelick et al. (1999) fit an empirical equation to experimental data on the highly annealing-resistant Tioga apatite following an Arrhenius array, using it to define lines of constant annealing. This relationship is as follows:

$$\{[1 - (l/l_0)^{4.1615}] / 4.16615\}^{0.675508} - 1 / 0.675508 = -1.66965 + 2.41755e^{-5} \{[\ln(t) + 12.4864] / [(1/T) - 8.43004e^{-4}]\}.$$

Figure 6. Etch pit figure in apatite. Etch pits have a dimension along the apatite C-axis D_{par} and perpendicular to it, D_{per} . The size of an etch pit is related to the chemistry of the apatite crystal. After Donelick (1994).

The reduced fission track length of a less resistant apatite with the same thermal history is given by:

$$R_{lr} = [(R_{mr} - R_{mro}) / (1 - R_{mro})]^K$$

where

l/l_0 = mean track length reduction

t = time (seconds)

T = temperature ($^{\circ}\text{K}$)

R_{lr} = Reduced length of less resistant apatite

R_{mr} = Reduced length of the more resistant Tioga apatite

R_{mro} and K are fixed parameters.

These two relationships are the core of the algorithm used by Ketcham et al. (1999) for modeling apatite fission track ages and lengths.

In addition, Carlson et al. (1999) determined the importance of apatite chemistry as a constraining parameter in apatite annealing rates. Multikinetetic models such as proposed by Ketcham et al. (1999) include both track length and age determinations.

As pointed out earlier, there are three end members of apatite depending upon which anion is predominant in the crystal lattice. Near end-member Fluorapatite tend to anneal faster and at lower temperatures than Chloroapatite while Hydroxiapatite anneal

much faster than either of these (Donelick et al., 1999). It is important to acknowledge that not all apatite in nature are end members, especially in rocks like sandstones where there could be a wide variety of apatite from different sources, therefore complicating the extraction of thermal histories.

The orientation of tracks also plays an important role in thermal annealing; tracks parallel to the crystallographic c-axis of apatite are more resistant to shortening or annealing than those perpendiculars to it (Crowley et al., 1991; Donelick et al., 1991). Donelick et al. (1990) also observed that the mean etchable length of thermally neutron induced fission tracks parallel to c-axis (l_c) is greater than the mean length perpendicular to c (l_a) and that the rate of reduction of l_a is twice that for l_c at 23°C. Donelick et al. (1991) argues that the radius of an ellipse represents the mean etchable thermally neutron-induced fission-track length at any angle to the crystallographic c-axis. This is reliable as long as $l_a \geq 8.4 \mu\text{m}$.

Laboratory controlled experiments on thermal annealing of fission tracks in apatite suggest that as temperature increases the mean length is reduced and the length distribution broadens, even faster below a length reduction factor (l/l_0) of ~0.65 (Green et al., 1986) as a result of the etchable length anisotropy (Donelick et al., 1999).

Figure 7. Relationship between etched apatite surface and confined tracks. Only horizontal Track-in-Track (TINT) was measured in this study for apatite length data. After Donelick et al. (1999).

Apatite fission-track age

By assuming that all background tracks are daughter products of the spontaneous fission of ^{238}U and by knowing the amount of U present in a sample, Price and Walker (1962) found that the track density in the mica is a function of its geological age. Ages obtained by the fission-track methodology are generally younger than ages obtained using other radiometric techniques such as Ar/Ar, K/Ar or U/Pb.

Using an exponential law for the decay of radioactive elements or isotopes, it is possible to derive a fission track age equation (Friedlander et al., 1991; Donelick Analytical course notes, 1998; also in Locke, 2001). The basic equation is as follows:

$$[^{238}\text{U}] = [^{238}\text{U}]_0 \exp(-\lambda_D t) \quad (\text{a})$$

At time t , the number of decay events by virtue of isotope ^{238}U decay per volume can be written as:

$$[\text{D}] = [^{238}\text{U}]_0 - [^{238}\text{U}]. \quad (\text{b})$$

Combining equations (a) and (b) yields:

$$[\text{D}] = [^{238}\text{U}] (\exp(\lambda_D t) - 1). \quad (\text{c})$$

The fraction of spontaneous fission events is then:

Figure 8. Apatite fission track lengths are measured using the crystallographic axis as a reference. Three points are used for this purpose: the two ends of the confined fission track that yields the length and the third one along the C-axis. The inclination angle is then calculated from the above measurements. After Donelick et al. (1999).

$$[D_f] / [D] = \lambda_f / \lambda_D \quad (d)$$

Therefore, (C) and (D) yield:

$$[D_f] = \lambda_f / \lambda_D [^{238}\text{U}] \{ \exp (\lambda_D t) - 1 \}. \quad (e)$$

Solving for time t in (e) one can obtain an absolute fission track age given the actual concentration of ^{238}U :

$$t = 1/\lambda_D * \ln [\lambda_D/\lambda_f] * (D_f/^{238}\text{U} + 1)] \quad (f)$$

where

$[^{238}\text{U}]_0$ = Concentration of ^{238}U atoms at $t=0$ (atoms/cc)

$[^{238}\text{U}]$ = Present day concentration of ^{238}U atoms at $t=t$ (atoms/cc)

λ_α = ^{238}U alpha decay constant (1.55125×10^{-4} nuclei / m.y.)

λ_f = ^{238}U fission decay constant (8.46×10^{-11} nuclei / m.y.)

$\lambda_D = \lambda_\alpha + \lambda_f$

t = time (m.y.)

$[D]$ = Daughter product or fission decay events per unit volume (atoms/cc).

For an apatite grain, the number of natural fission tracks that intersects its polished and etched surface is called fission track density. The spontaneous fission track density relationship can be written as:

$$\rho_s = [D_f] R^{238} \eta^{238} \quad (g)$$

where

ρ_s = Spontaneous fission track density in apatite (tracks/cm²)

R^{238} = Mean total length of the natural fission track in apatite (cm/track)

η^{238} = Etching efficiency of natural fission tracks in apatite (dimensionless)

Solving (g) for $[D_f]$:

$$[D_f] = \rho_s / (R^{238} \eta^{238}). \quad (h)$$

The amount of induced fission tracks registered in an external detector adjacent to the same apatite grain can be written as:

$$\rho_i = [^{235}\text{U}] R^{235} \eta^{235} \sigma g \phi \quad (i)$$

where

ρ_i = Induced fission track density in external detector (tracks/cm²)

$[^{235}\text{U}]$ = Present day ²³⁵U concentration (atoms/cc)

R^{235} = Mean total length of the natural fission track in apatite (cm/track)

η^{235} = Etching efficiency of natural fission tracks in apatite (dimensionless)

σ = Thermal-neutron capture cross-section for ²³⁵U = 580.2 x 10

g = geometry factor; 1 for 4 π geometry and 0.5 for 2 π geometry

ϕ = Thermal neutron fluence from the irradiation (neutrons/ cm²)

From the Steiger and Jager (1977) equation, concentration of ^{235}U can be written as:

$$[^{235}\text{U}] = [^{238}\text{U}] I \quad (j)$$

where $I=1/137.88$

(j) in (i) yields:

$$\rho_i = [^{238}\text{U}] I R^{235} \eta^{235} \sigma \phi g. \quad (k)$$

Solving (k) for $[^{238}\text{U}]$

$$[^{238}\text{U}] = \rho_i / R^{235} \eta^{235} \sigma \phi g I. \quad (l)$$

Combining equations (h) and (l) in (f) we can rewrite the fission track age equation as:

$$t = 1/\lambda_D * \ln [(\lambda_D/\lambda_t) * (\rho_s R^{235} \eta^{235} \sigma \phi g I \phi / \rho_i R^{238} \eta^{238}) + 1]. \quad (m)$$

In the above equation it can be considered that $R^{235} = R^{238}$ and $\eta^{235} = \eta^{238}$.

Therefore, the final apatite fission track age equation can be rewritten as:

$$t = 1/\lambda_D * \ln [(\lambda_D/\lambda_f) * (\rho_s \sigma_g I \phi / \rho_i) + 1]. \quad (n)$$

Zeta calibration factor

In equation (n), the term $\sigma\phi$ stands for the number of induced fission reactions by thermal neutrons per atom of ^{235}U . In equation (n) all variables and constants are controlled except for ϕ (Thermal neutron fluence from the irradiation, in neutrons/ cm^2) and for λ_f (^{238}U fission decay constant). Unfortunately, experiments differ in determining an accurate value for λ_f , which can vary between 7.0×10^{-17} and $8.5 \times 10^{-17} \text{ yr}^{-1}$ (Issler, 1989). In order to circumvent the first problem, two pieces of CN-1 glass and external detectors attached to them are irradiated with thermal neutrons along with the samples in the reactor (see also sample preparation below). Such glasses contain a fixed amount of uranium. The number of induced fission tracks present in the micas or external detectors attached to the CN-1 glasses is proportional to the neutron fluence ϕ , the irradiation. Therefore, this new term, neutron dosimeter fission track density in the mica, ρ_d , is measurable and can be added to equation (n):

$$\phi = k \rho_d \quad (o)$$

where

ϕ = Thermal neutron fluence from the irradiation (neutrons/ cm^2)

ρ_d = Neutron dosimeter fission track density in external detector (tracks/ cm^2)

k = Constant of proportionality.

Hurford and Green (1983) established the use of a calibration factor, zeta calibration factor, ξ , in equation (n). This ξ calibration factor is dependent upon irradiation configuration, a particular dosimeter glass (CN-1 in this study) and the operator or analyst. It is calculated using known fission track age standards. Measuring the spontaneous and induced fission track densities of a standard with known fission track age is all that it is needed to obtain a zeta calibration factor ξ . This is accomplished as follows:

$$\xi = \{ \exp(t_{std} \lambda_D) - 1 \} * \{ (\rho_i / \rho_s)_{std} / g \lambda_D \rho_d \}. \quad (p)$$

In (p)

t_{std} = Fission track standard age

$\rho_{s_{std}}$ = Spontaneous track density in standard

$\rho_{i_{std}}$ = Induced track density in standard.

ρ_d = Neutron dosimeter fission track density in external detector (tracks/cm²).

In the present work, standards of Fish Canyon Tuff apatite and Durango de Mercado apatite were irradiated along with the samples. An amount of three calibrations for Fish Canyon Tuff and Durango de Mercado apatite yielded ξ weighted mean value factors of 114.8 ± 11.7 and 140.0 ± 10.7 respectively. These two combined values yielded a weighted mean value of $\xi = 128.5 \pm 7.9$. This ξ factor is the number used by the author, Jaime G. Perez, for obtaining all fission track ages for the samples in this study.

When substituting equations (o) and (p) in equation (n), we have a final fission track age equation dependent only on reliable a constant, λ_D and measurable parameters:

$$t = 1/\lambda_D * \ln \{ [\xi \lambda_D \rho_d (\rho_s / \rho_i) + 1] \}. \quad (q)$$

Fission track age reduction

Fission track ages are directly related to the density of natural tracks that intersect a polished and etched surface of an apatite crystal. Therefore, thermal annealing of spontaneous fission tracks has direct impact on its density within a given crystal. Reduction of fission track age is not only proportional to mean track length reduction but also to other parameters like crystallographic anisotropy and tendency to etch longer tracks (Willet, 1997). The following equations relate track density reduction as a function of mean track length reduction as proposed by Green (1988):

$$\rho / \rho_0 = l / l_0, \quad \text{when } l / l_0 > 0.65$$

$$\rho / \rho_0 = 2.862 l / l_0 - 1.2104, \quad \text{when } 0.423 < l / l_0 < 0.65$$

$$\rho / \rho_0 = 0 \quad \text{when } l / l_0 < 0.423$$

where

ρ = Mean track density

ρ_0 = Original track density

l_0 = Original mean track length

l = Mean track length.

Apatite fission-track sample preparation.

Heavy mineral separation. Samples for apatite fission-track analysis are processed and taken to very fine sand grain size first using a jaw-crusher and then, a grinding machine. Afterwards, the rock sample is sieved using a 300 μ nylon-mesh cloth (#60) and washed to remove all clay particles. In a fume hood, the remaining sample is mixed and stirred with acetone to remove all the water content from it and dried using a lamp. Once it is completely dry, the sample is spread out on bond paper and a magnet wrapped on tissue paper is used to remove all possible ferromagnetic material.

Once the above procedures have taken place, samples are ready for heavy mineral separation. First, the conventional procedure is to use Tribromomethane or bromoform ($\rho=2.89$ gr/cc) for heavy mineral separation in a fume hood. The latter procedure has been replaced lately by less toxic, water-based solutions like Lithium-Metastungstate, $\rho=3.0$ gr/cc. The heavy mineral fraction is processed in a Franz magnetic separator at 0.25 Amperes to remove as much magnetic particles as possible. Diiodomethane (MEI, $\rho=3.3$ gr/cc) is later used to separate apatite ($\rho=3.11$ gr/cc) from heavier accessory minerals (zircons, sphene, tourmaline). The sample fraction that floats in MEI is where apatite crystals should be found. This fraction is then processed in the Franz magnetic separator, first at 1.0 Amps and then at 2.0 Amps.

Panning of samples dumped in Pyrex dishes filled with ethanol separates even more apatite from other accessory minerals based on its density differences. Mineral separate is checked under a microscope and apatite crystals are picked with a dropper.

Mounting. Samples are split into two mounts, one for age and one for length measurement and are laid out on a cookie pan side by side. Previously, inside-square-cut rubber washers are put on top of the cookie pan, “framing” the sample. An epoxy resin is prepared, poured on top of the samples and both are stirred to maximize the homogeneity of distribution of the potential apatite crystals. Later, the cookie pan is taken to a furnace or oven and is heated for one hour at 100°C. Samples are later labeled and are ready for polishing.

Polishing. Samples are polished, first by using 600 grit wet sandpaper to expose the surface and a portion of the interior of the apatite grains. This procedure should be done carefully as apatite crystals could be totally removed from the sample. To avoid the latter, samples should be checked under a microscope to verify that sufficient apatite are well exposed. Specimens are then further polished by using 3µm grit Aluminum Oxide powder following by using 0.3µm Micropolish II grit on gyratory figures. When polishing, samples should be checked several times with a microscope to assess the quality of the surface and the exposure of the apatite crystals.

Preparation of samples for fission-track age analysis

Etching. Etching is a procedure that allows otherwise undetectable fission tracks in apatite to be enhanced and made optically visible when seen under a microscope. To accomplish this, polished samples are immersed for 20 seconds at 21°C in a 5.5 N solution of HNO₃. Subsequently they are rinsed thoroughly with water and dried at room temperature.

Preparation of irradiation package. In the present study, fission track analysis has been performed using the external detector method. Low uranium content, almost fission-track

free Brazil muscovite, is peeled into several slices, submerged in acetone and put into an oven, remove all water from its surface. Then, mica is cut in squares to almost fit the size of the samples to be analyzed and adhered to the polished side of the latter.

Samples are packaged in pairs facing each other with their polished surfaces, wrapped, and separated from the others in plastic foam. The tower-like sample setting has also on its top and bottom pieces of commercial dosimeter glasses CN-1 (Corning Glass, Number 1; Dr. Jan Schreurs, Corning Glass Works, New York) with respective attached mica sheets. These glasses are dosed with a known amount of the isotope ^{235}U and are used for calibration purposes. Also, for calibration purposes, prepared samples of known apatite fission-track ages should be analyzed. Fish Canyon Tuff apatite (fission track age= 21.7 Ma.) and Durango de Mercado apatite (fission track age: 30.1 Ma) were studied for obtaining a Z calibration number, an essential parameter in the fission-track age equation. All the samples of this project were irradiated at Texas A&M Nuclear Reactor.

After their return from the reactor, micas are detached from the samples and etched under a fume hood with a 48% HF solution at 21°C for 14 minutes. Afterwards micas are dipped and agitated in water, then submerged in acetone and dried at room temperature. Before separating the micas from their corresponding samples, three small holes are poked on both mica and epoxy resin, two on one side and a third on the opposing side, forming a triangle. The latter procedure allows generating a reference frame for locating the apatite crystals in samples and its correspondent induced tracks on micas.

Sample slide preparation. Samples are separated from the micas and mounted mirroring each other on a slide and numbered. Top and bottom micas from CN-1 corning glasses are mounted on a separate slide and are calibrated.

Preparation of samples for fission-track length analysis

The number of measurable and self-contained natural fission tracks in apatite crystals is very low (tracks which do not cross-cut the polished surface of an apatite grain showing its total length). Donelick and Miller (1991) developed a methodology used in this work that could yield a 20-fold increase of measurable fission tracks in apatite crystals. The methodology is described below.

Irradiation. A separate set of polished and non-etched mount samples is displayed on a cardboard surface (fiche) with the facing polished surface facing upward. These samples are then irradiated with approximately 10^7 tracks/cm² fission fragments from a 50 μ C source of the isotope ²⁵²Cf (activity as of July 1996) for 48 hours in a vacuum chamber. Exposing such samples to particle bombardment from a highly radioactive source generates preferably oriented induced tracks or pathways that penetrate deeply within the exposed apatite crystals.

Etching. Mounts were immersed in 5.5M NHO₃ for 20 seconds at 21 °C. Etching allows the solution to reach non-etch, self-contained fission tracks reached by the preferably oriented induced fission tracks from the radioactive ²⁵²Cf isotope.

Apatite fission-track measurements

Apatite fission-track measurements--density of tracks on micas and apatite grains, track lengths and etched pit dimensions--were carried out using a calibrated digitizing table. Calibration of the digitizing table was performed using a 600-lines/mm diffraction grating.

A cursor with an attached LED point source allowed performing measurements on the tablet. The digitizing tablet is interfaced with a personal computer for subsequent and pertinent calculations. A projection tube affixed to a microscope allowed positioning the cursor and the LED point source.

An Olympus microscope was used to perform all measurements in transmitted and reflective light (12.5X oculars, 1.25X projection tube, 100X dry objective). A Mitutoyo system served to calibrate a reference frame (X, Y coordinates) on the slide mount and was adapted to both computer and microscope to locate any individual apatite grain on the mount and its correspondent induced tracks on micas. The author of the present study, Jaime Perez, performed all apatite fission track measurements under the supervision of Dr. Raymond Donelick.

Fission track density

A fission track age for any individual apatite grain is obtained by optically measuring both the density of natural tracks (ρ , number of tracks per unit area) that intersect the polished and etched surface of a given crystal and the density of induced tracks ρ_i on mica for the same grain. As discussed previously on the apatite fission track age equation, the ρ/ρ_i ratio is used to calculate the concentration of the isotope ^{235}U . The

Steiger and Jager (1977) isotope ratio, $^{238}\text{U}/^{235}\text{U}=137.88$, is then used to calculate the concentration of isotope ^{238}U in the apatite host crystal.

Etched pit dimensions

Etch pits are hexagonal features formed at the intersection of a fission track with the polished surface of an apatite grain (Fig. 6). The dimensions of etch pits seem to be controlled mainly by chemical composition of apatite grains (Donelick, 1993). Apatite crystals with high concentration of F anions tend to have smaller etch pits dimensions ($<1.75\mu\text{m}$) than the chlorine-rich counterparts ($>1.75\mu\text{m}$). Dimensions of etch pits, i.e. diameter parallel (D_{par}) and perpendicular (D_{per}) to crystallographic c-axis, were measured on every single grain. Mean values of diameter parallel to apatite grain c-axis are used to classify fission track ages into different kinetic classes (Donelick, 1993; Carlson et al., 1999; Ketcham et al., 1999) and it is an important feature taken into account when modeling the data.

Track length

The density of self-confined tracks within apatite crystals, for example tracks that never intersect the surface of the polished section of the crystal, can be greatly improved by exposing the sample to a source of the radioactive isotope ^{252}Cf , as it was described above.

There are three distinctive types of self-confined tracks observed in apatite: TINTs (track-in-track), TINCLEs (track-in-cleavage) and TINDEFs (track-in-defects) (Fig. 7). Fission tracks that intersect the etched surface are avenues for the acid to reach and etch TINTs. Cleavage or fractures and crystallographic defects that intersect the polished and etched surface of the crystal allow the etchant to percolate and etch self-confined tracks (Donelick et al., 1999).

Prior to measuring track length in a sample, the track length in apatite from the Fish Canyon Tuff ($14.91 \pm 0.15 \mu\text{m}$) and Durango de Mercado ($15.03 \pm 0.15 \mu\text{m}$) is measured for calibration purposes.

For measuring track length, three points are selected using the LED digitizer: one point at each tip of the self-contained, nearly horizontal track and a third chosen along the crystallographic c-axis of the apatite crystal (Fig. 8).

Solely confined and horizontal TINT's were measured. Precision of a single fission track length measurement is $\pm 0.20 \mu\text{m}$ and is ± 2.0 degrees for a fission-track angle to the crystallographic c-axis.

Apatite Fission Track Data Analysis and Interpretation.

In this study, AFTSolve (Ketcham et al., 2000) was the algorithm used to generate forward thermal histories of the studied samples based that incorporates apatite fission track calibration experiments performed by Donelick (1999) and Carlson (1999). These experiments include a wide compositional spectrum of apatite with different kinetics or annealing response to temperature. AFTSolve allows the user to group populations of apatite crystals in kinetic classes based on etch pit dimensions (Donelick, R., 1993, U.S. Patent Number 5,267,274; and Donelick, R., 1995, Australian Patent Number 658,800).

There is a strong correlation between apatite grain composition and etch figure diameter parallel to crystallographic c-axis that makes it possible to group apatite in kinetic and compositional classes (i.e. Burtner et al., 1994). Likewise, AFTSolve includes several laboratory-derived calibrations that predict fission track response to either heating or cooling (i.e. Donelick et al., 1999).

AFTSolve generates 10,000 thermal histories for a given sample time-temperature paths by performing a MonteCarlo simulation. The thermal history of a sample is a combination of three different segments: provenance, burial and exhumation. The first segment is linear cooling and includes non-reset pre-depositional fission tracks, ending at the stratigraphic age of deposition. The burial segment, monotonically heating, begins at time of deposition and ends at time of peak burial temperature. It could be calibrated against independent geological and geochemical data, i.e. stratigraphy age and vitrinite reflectance or burial histories. Lastly, the exhumation segment, linear cooling, begins at time of peak burial and ends at present-day temperature. Time-Temperature paths converge to a range of possible solutions given the age and length data. The range includes 1) i.e. acceptable fit (green band) when model fission track data fit measured fission track data with a level of confidence (Kolmogorov-Smirnov test [K-S] and Age Goodness-of-Fit) of 0.05 or greater; 2) good fit (red band) when model fission track data fit measured fission track data with a level of confidence (K-S test and Age Goodness-of-Fit) of 0.50 or greater; and 3) best fit (black line).

AFTSolve gives an estimate of the vitrinite reflectance or maturity of the rock following the EasyRo method of Sweeney and Burnham (1990). Quality of output and its interpretation are dependent on the quality of age and track length measurements,

accuracy of stratigraphy age of sample and independent geochemical studies. A pooled fission-track age is based on a statistical procedure that assumes that a population of apatite crystals within a sample underwent the same thermal history and has the same kinetics. The age of the oldest fission track denotes the earliest-formed track population in a simulation that is not fully annealed by model's end. It marks the earliest time constrained by the fission-track data. If it post-dates the onset of final cooling as set by model constraints, it indicates that the peak reheating temperature is not constrained by the AFT data. Conversely, if it predates the provenance age then it indicates that the fission-track data may contain an inherited (pre-depositional) component.

Depth of burial (z) and uplift rate (U_r) were calculated only in the Camatagüita-Valle Morín and San José de Guaribe transects. The former follows this relationship:

$$z = (T_{\text{max}} - 25^{\circ}\text{C})/G,$$

where z = maximum burial depth, T_{max} = peak burial temperature and G = geothermal gradient, assuming a present day temperature of 25°C . Two geothermal gradients of $27^{\circ}\text{C} / \text{km}$ and $39^{\circ}\text{C} / \text{km}$, the latter value estimated in the Yucal-Placer field (Daal and Lander, 1993) were used in the calculations. It is assumed that the geothermal gradient has been constant since the emplacement of the tectonic slivers in the Neogene, since there is no data regarding paleogradients in the area.

The uplift rate (U_r) follows this relationship:

$$U_r = z / t_c,$$

where U_r = uplift rate, z = burial depth and t_c = timing of cooling event.

As it was discussed above, the timing of the cooling event is not given by the oldest track but by the model constraints. If the oldest track is younger than the re-heating time constraint, then t_c should be the time of this constraint, because it is the time at which T_{max} was reached. Conversely, if the oldest track is younger than the re-heating time constraint, then the peak temperature is basically unconstrained. In this case, T_{max} should be the temperature at the time given by the oldest track, not the time of the re-heating constraint.

Apatite Fission Track Analysis in northern South America

Previous works

Kohn et al., (1984) and Shagam et al. (1984) carried out apatite fission-track studies in eastern Colombia and western Venezuela, in regards to the uplift, exhumation and cooling of the northern South American mountain ranges. Kohn et al. (1984) suggested that uplift in the Venezuelan Andes occurred from Oligocene to Late Miocene followed by rapid uplift in Plio-Pleistocene time. Shagam et al. (1984) observed that cooling ages were the result of Late Oligocene to Middle Pliocene uplift and erosion in western Venezuela (Sierra de Perijá and Toas Island) and eastern Colombia (Santander Massif). This Late Oligocene event has been correlated with the northward tectonic

escape of the Maracaibo-Santa Marta block, the inception of the Andean orogeny (Pindell, 1988), and the development of pull-apart basins along the Venezuelan margin.

In north-central Venezuela, Kohn et al. (1984) analyzed fission-tracks in zircons as well, in samples from the Caribbean Mountain system (Peña de Mora Gneiss and the Choroní-Tovar Granites). These authors obtained cooling ages that pooled around 19.7 ± 2.1 Ma. Likewise, Avé Lallemant and Sisson (1993) reported zircon fission-track ages of 20 Ma and apatite fission-track ages of 16 and 115 Ma for the Choroní and Peña de Mora Gneiss. New published data by Sisson et al. (2002) show apatite fission track ages from the augen-gneiss of the Cordillera de la Costa belt, Guaremal granite and Choroní granite of 16.3 ± 1.6 Ma, 15.0 ± 1.4 Ma and 14.1 ± 1.6 Ma respectively

In the Eastern Serranía del Interior, Locke (2001) interprets an age gradient from north to south: 30 Ma in the north to 15 Ma in the south (Late Oligocene to Middle Miocene). In addition, Locke (2001) proposes two major cooling events or stages within the eastern Serranía del Interior: (1) a stage between 45 and 20 Ma (Middle Eocene to Early Miocene) involving internal deformation of parautochthonous blocks and (2) a second stage between 20 Ma to 12 Ma (Early Miocene- Middle Miocene) involving envelopment thrusting.

One of the principal problems in dealing with the interpretation of apatite fission tracks in north-central Venezuela is the high present-day temperature observed in the area, especially in the Yucal-Placer field, nearby the Altagracia de Orituco village. Another uncertainty is knowing when such high geothermal gradient was onset. In the Yucal-Placer field, geochemical analysis on cores from several wells from the Tertiary Roblecito, La Pascua Formations and the Cretaceous La Cruz, as well as Infante and

Guavinita units show that the amorphous marine, amorphous and coaly kerogen are overmature with vitrinite reflectance varying from 1.90 % to 2.46 %. This type of organic matter in such thermal condition would only yield thermal-derived dry gas (Aymard et al., 1985).

Geothermal gradient will affect estimates of rock maturity, depth of rock burial, maximum estimated paleo-altitude of mountain ranges and amount of eroded material. For high geothermal values such as that observed in the Yucal-Placer field of 56 °C / km (Daal and Lander, 1993), depth of burial of rock, possible maximum altitude of paleo-mountain range and amount of eroded material are equivalent and vary from 2 to 3 km. These values could be interpreted as minimum values given the high geothermal gradient. Another problem with this interpretation is that the geothermal gradient has been extrapolated to the entire study area. This may not be true since it could vary geographically and through geological time. There could be, at least, two speculative and different explanations for the existence of high geothermal gradients in north-central Venezuela: 1) the area did not reach thermal equilibrium since the Pangea breakup and subsequent opening of the Proto-Caribbean sea in Triassic-Jurassic times and/or 2) the beginning of low angle subduction of the Caribbean plate beneath the South America Plate during the Neogene, as suggested by Van der Hilst and Mann (1994), could be causing not only the thickening of the lithosphere but the generation of thermal anomalies in the surface, due to the heating of the subducting slab. Northern South America does not exhibit the presence of volcanic activity as it is expected in subduction zones. However, Early and Middle Miocene alkali basalt intrusives found in the Falcón basin in western Venezuela (Neal and Audemard, 1988) and Pliocene felsic plutons found north

of the El Pilar fault in the Paria peninsula, eastern Venezuela (Schubert and Sifontes, 1983) show to some degree that a very incipient volcanic activity has taken place along the northern margin of South America during Neogene and Pliocene time and that high geothermal gradients could well be the effect of very young melting of a subducting Caribbean slab beneath the South American margin. Onset of high geothermal gradients in northern Venezuela is still unclear (Van Decar et al., 2003).

Apatite Fission Track Analysis in the Western Serranía del Interior and Guárico Basin, North Central Venezuela

Sampling

A total of 30 samples were collected for apatite fission track analysis along four regional transects, totaling 120 samples, in the Western Serranía del Interior foreland fold and thrust belt and the Guárico sub-basin, in north-central Venezuela. The regional transects are from west to east: 1) Platillón-Tiznados, 2) Camatagüita-Valle Morín, 3) Altagracia de Orituco and 4) San José de Güaribe (Fig. 9).

The samples of the Altagracia de Orituco area are still pending for future analysis. Of the 90 remaining samples, 56 yielded enough apatite to obtain fission-track ages. Of the latter group, only 37 samples had enough good quality track lengths for apatite fission-track modeling.

Stratigraphic ages for the units of the Serranía were obtained from previous published reports (e.g., González de Juana et al., 1980).

Sampling was carried out along the unroofed sedimentary cover that includes allochthonous, parautochthonous and autochthonous terranes that made up the Western

Serranía del Interior foreland fold and thrust belt and its associated foredeep, the Guárico basin (Fig. 9); These belts are from north to south: 1) allochthonous-parautochthonous carbonates and siliciclastic marine Cretaceous-Tertiary units (Querecual, Garrapata and Guárico Formations) of the Piedmont belt; 2) parautochthonous-autochthonous carbonates and siliciclastic marine to continental Cretaceous and Tertiary units (Querecual, Naricual, Quebradón and Quiamare Formations) of the Belt of Thrust Fault (Chacual Complex); 3) parautochthonous-autochthonous siliciclastic marine to continental Tertiary units (Naricual, Quebradón and Quiamare Formations) of the Belt of overturned beds; and 4) parautochthonous-autochthonous siliciclastic marine to continental Tertiary units (Quebradón, Quiamare and its time equivalent Chaguaramas Formations) of the Belt of gently-dipping beds.

Figure 9. Map of tectonic belts in the north-central Caribbean Mountain system as defined by Menéndez (1966), Peirson (1965), Bell (1968), and Beck (1978). The dashed areas represent the studied transects: (1) Platillón-Tiznados, (2) Valle Morin-Camatagua, (3) Altagracia de Orituco, and (4) San José de Guaribe.

Results of present study

One hundred and twenty samples were collected: 30 in each of the four transects. The samples of the Altagracia de Orituco area are still pending for future analysis. Of the 90 remaining samples, 56 yielded enough apatite to obtain fission-track ages. Of the latter group, only 37 samples had enough good quality track lengths for apatite fission-track modeling. Table 2 shows a summary of the apatite fission-track ages. Table 3 summarizes apatite fission-track length data for all apatite grains. A summary of thermal histories and implications of the AFT data for 37 samples is presented in Table 3. Pooled AFT ages, oldest track ages and calculated vitrinite reflectance for four selected samples are shown in Figs. 10 and 11. All Time-temperature histories as well as forward models for the remaining samples are at the end of this appendix.

Stratigraphic ages for the units of the Serranía were obtained from previous published reports (e.g., González de Juana et al., 1980).

Platillón–Tiznados transect. In the Platillón-Tiznados area (Fig. 12), siliciclastic samples yielded enough apatite for fission-track age analysis (PFT-37 to PFT-65). No mounts for AFT length analysis were prepared. Therefore, no estimates of peak burial temperatures, time of peak burial and depth of burial could be assessed.

In the Platillón-Tiznados area, pooled AFT ages obtained in samples of the Mucaria, Garrapata and Guárico Formations in the “Piedmont belt” (allochthonous-parautochthonous terranes) range from 26.5 ± 4.8 to 13 ± 2.4 Ma (Late Oligocene to Middle Miocene; Table 3, PFT-37 to PFT-49). These ages are younger than the stratigraphic ages of the sampled units (Tables 1 and 2), suggesting a cooling event associated with mountain building processes that started in the area in the Late

Figure 10. Modeling of apatite fission-track data for samples PFT-6 and PFT-8 in the Camatagüita-Valle Morin transect, suggesting a relatively rapid cooling that initiated at 25.1 ± 4.8 Ma (Late Oligocene and 17.1 ± 2.6 Ma (Early Miocene), respectively. These ages correspond to the time of generation and preservation of the first fission-tracks once the sample cooled and reached temperatures below ~ 100 °C.

Oligocene; i.e., the emplacement the Serranía del Interior nappes onto the South American autochthonous terranes. In the “Piedmont belt” along this transect, there is an apparent cooling age gradient (Fig. 12); near the Cantagallo fault, within the Garrapata Formation, AFT ages are mainly Late Oligocene with two Middle Miocene ages (PFT-37 and 43). To the south, samples from the Mucaria and Guárico Formations yielded AFT ages of 13.0 ± 2.4 Ma and 16.7 ± 3.7 Ma, respectively.

AFT ages from the Galera Member of the Quebradón and Quiamare Formations in the “Belt of overturned beds” (autochthonous- parautochthonous terrane) are as old as or older than their estimated stratigraphic age (PFT-53, 55 and 61), suggesting influence from the provenance, in this case Eocene-Oligocene (Tables 1 and 3).

Camatagüita-Valle Morín transect. In the “Piedmont belt” of the Camatagüita-Valle Morín transect (Fig. 13), samples collected from the Cretaceous-Tertiary units (Garrapata-Guárico Formations) clearly show reset AFT ages (stratigraphic age is greater than the fission-track age; Tables 1 and 3). Pooled AFT ages range from 21.3 ± 2.8 to 14.5 ± 2.2 Ma (Early to Middle Miocene; PFT-6 to PFT 25). Modeling of AFT data and track length using AFTSolve suggests that the time of the cooling event ranges from Late Oligocene to Middle Miocene where peak temperatures reached well above ~ 110 °C, enough to reset all previous/older cooling events (Figs. 10, 13 and Table 3).

Estimates of vitrinite reflectance or EasyRo calculated by AFTSolve, following Sweeney and Burnham (1990) suggest that all samples are mature to overmature ($>0.65 \pm 0.01\%$ in all study samples). No independent vitrinite reflectance analysis was undertaken in the samples to constrain such estimates. Estimates of cooling rates for the samples range

Figure 11. Modeling of apatite fission-track data for samples GU-1 and GU-8 in the San José de Guaribe transect, suggest cooling that initiated at 55.8 ± 5.5 Ma (Paleocene-Eocene) and 43.7 ± 5.2 Ma (Early to Middle Eocene) respectively.

from 4 to 8 °C / my, with values clustering between 7 and 8 °C / my for four samples and 4 and 5 °C / my for three samples.

The best temperature of burial calculated from the modeling algorithm AFTSolve provides an estimate of maximum depth of burial given a particular geothermal gradient. Table 4 shows such estimates for modeled samples of the track-reset Cretaceous-Tertiary Garrapata and Guárico Formations, assuming two geothermal gradients of 27°C / km and 39°C / km as estimated for the Yucal-Placer field (Daal and Lander, 1993).

Results suggest that depth of burial for the samples range from 3 km to 5 km for a geothermal gradient of 27 °C / km and from 2 to 4 km when the geothermal gradient is 39 °C / km. These depths of burial values may be equivalent to the thickness of the sedimentary section eroded since the onset of the deformation. Thus, erosion may have removed up to 5 km of sediment.

A summary of calculated uplift rates for samples from the Garrapata and Guárico Formations is shown in Table 5. Uplift rates vary from 0.11 to 0.30 mm/yr for a geothermal gradient of 27 °C / km and from 0.08 to 0.21 mm/yr for a geothermal gradient of 39°C / km. One sample collected in the Neogene Galera Member of the Quebradón Formation in the “Belt of overturned beds” yields an apatite fission-track age (PFT-2, 81.9 ± 6.6 Ma) that is older than its stratigraphic age (Table 3). This AFT age suggests that burial, subsidence and subsequent heating of this sample was not enough to anneal completely any previous thermal events. The latter age is influenced by the provenance. No evident age-gradient is observed from north to south along the Camatagüita-Valle Morín transect. Almost all ages are similar within a small statistical error.

Figure 12. Geological map of the Platillón-Tiznados transect showing (1) the structural contact between the Villa de Cura nappes and the "Piedmont belt" in the Western Serranía del Interior and (2) sample location and fission-track pooled age data (± 1 sigma). Modified after Creole Petroleum Corporation (1961a and c). Topography from Cartografía Nacional de Venezuela 1:25,000. UTM grid. Legend as in Figure 13.

San José de Guaribe transect. AFT data in samples collected along the San José de Guaribe transect show cooling ages that are older than those of the previously studied transects but still younger than the stratigraphic ages (Figs. 14, 11 and Table 3). They do not seem to fit previous models for the interaction of the Caribbean-South American plates in northern Venezuela and the subsequent mountain building process. Samples collected along the “Piedmont belt” in the siliciclastic units Guárico Formation and in a unit lithologically similar to the Garrapata Formation yield pooled AFT ages that range from 44.1 ± 5.4 Ma to 16.2 ± 2.9 Ma (Early Eocene to Middle Miocene (GU-1 to GU-11; Table 1 and 3). Thermal histories for 24 out of 26 studied samples have K-S tests and Age GOF of 0.5 or greater indicating a high level of confidence. Time of cooling events for the Garrapata and the Guárico Formations obtained from the models is ~ 45 Ma.

The Venezuelan geological literature (e.g., Gonzalez de Juana et al., 1980) suggests that the age of the Guárico Formation ranges from Late Cretaceous to Early Eocene. However, Erlich and Barret (1992) suggest that the formation is as young as Late Paleocene. Thus, the stratigraphic age of the samples may be older than the cooling events. Table 4 shows paleodepth or burial depth estimates for modeled samples of the track-reset Cretaceous-Tertiary Garrapata and Guárico Formations assuming two geothermal gradients, $27^{\circ}\text{C} / \text{km}$ and $39^{\circ}\text{C} / \text{km}$, as estimated for the Yucal-Placer field (Daal and Lander, 1993). As in the Camatagüita-Valle Morín transect, the geothermal gradient is assumed constant since the emplacement of the tectonic slivers in the Neogene. As in the Camatagüita-Valle Morín transect, results suggest that depth of burial for the samples range from 3 km to 5 km for a geothermal gradient of $27^{\circ}\text{C} / \text{km}$ and from 2 to 4 km for a geothermal gradient of $39^{\circ}\text{C} / \text{km}$. Depth of burial values may be

Figure 13. Geological map of the Valle Morín-Camatagüita transect showing (1) the structural contact between the Villa de Cura nappes and the "Piedmont belt" in the Western Serranía del Interior and (2) sample location, fission-track pooled and modeled age data (± 1 sigma). Modified after Bell (1968). Topography from Cartografía Nacional de Venezuela 1:25,000. UTM grid. Legend as in Figure 13.

equivalent to the thickness of the sedimentary section eroded since the onset of the deformation. Thus, the maximum thickness of sedimentary rocks removed by erosion could be as high as 5 km. Uplift rates vary from 0.07 to 0.13 mm/yr for a geothermal gradient of 27 °C / km and from 0.05 to 0.09 mm/yr for a geothermal gradient of 39 °C / km. These calculated uplift rates are small because the time of the cooling events (Eocene) is considered in the calculations.

Samples of the Neogene Naricual, Quebradón and Quiamare Formations collected along the “Belt of thrusts faults,” “Belt of overturned beds,” and “Belt of gently dipping beds,” yield AFT ages influenced by provenance, since their stratigraphic ages are younger than their estimated cooling ages. The provenance of these rocks might have had many sources varying from the Guyana craton in the south to the emerging mountain range to the north. Samples from the Naricual Formation yielded both Paleozoic and Eocene AFT cooling ages (Tables 1 and 3). Thus, the sampled sedimentary rocks of the Neogene Naricual, Quebradón and Quiamare Formations involved in the “Belt of thrust faults,” “Belt of overturned beds,” and “Belt of gently dipping beds” (Guárico Basin) never reached temperatures higher than 110-150 °C, temperatures necessary to completely obliterate evidence of former thermal events. Therefore, for thermal gradients 27 °C / km and 39 °C / km, the maximum depth of burial varies between 2 to 4 km and 1 to 3 km, respectively

Figure 14. Geological map of the San José de Guaribe transect showing (1) the structural contact between the Villa de Cura nappes and the "Piedmont belt" in the Western Serranía del Interior and (2) sample location, fission-track pooled and modeled age data (± 1 sigma). Modified after Creole Petroleum Corporation (1961d). Topography from Cartografía Nacional de Venezuela 1:25,000. UTM grid. Legend as in Figure 13.

(Table 4). AFTSolve analysis indicates that for the model to converge to an acceptable or good time-temperature path solution, the non-reset samples of the “Belt of thrust faults,” “Belt of overturned beds,” and “Belt of gently dipping beds” should have had an approximate timing of cooling events at ~15 Ma. Pooled AFT ages and oldest track ages suggest a north-south cooling-age gradient within the “Piedmont belt” of the San José de Guaribe section (Fig. 14). Pooled AFT ages range from Middle Eocene in the north to Late Oligocene in the south. Likewise, oldest track ages range from Middle Eocene in the north to Late Oligocene in the south. This suggests that the uplift, cooling and exhumation of the accretionary wedge occurred in the Middle Eocene. Thus, the emplacement of a southward-vergent folded foreland belt may have started in the Middle Eocene.

As previously mentioned, Locke (2001) suggested that in eastern Serranía del Interior there is a Middle Eocene-Early Miocene north-south AFT cooling age gradient. Although Locke (2001) sampled units that differ in age and depositional environment from those analyzed in this work, it is interesting to note that there is a younging of events from west to east and from north to south beginning in San José de Guaribe and continuing to Locke’s (2001) regional transect in the eastern Serranía del Interior. The Middle Eocene-Late Oligocene pooled AFT north-south age gradient in the “Piedmont belt” of the Guaribe transect compares well to the Middle Eocene-Early Miocene pooled AFT north-south age gradient in Locke’s (2001) regional transect.

TABLE 2. SUMMARY OF APATITE FISSION-TRACK LENGTH DATA

Sample ID	Sample ID	Sample Location	Trails	Mean Length (µm)	Standard Deviation (µm)	0.1 µm	0.2 µm	0.3 µm	0.4 µm	0.5 µm	0.6 µm	0.7 µm	0.8 µm	0.9 µm	1.0 µm	1.1 µm	1.2 µm	1.3 µm	1.4 µm	1.5 µm	1.6 µm	1.7 µm	1.8 µm	1.9 µm	2.0 µm
1	PFT-02	CAM	13	13.49 ± 0.53	1.84	2.22	0.53																		
2	PFT-06	CAM	5	13.08 ± 0.68	1.76	2.18	0.57																		
3	PFT-09	CAM	5																						
4	PFT-12	CAM	3	14.43 ± 0.88	1.26	2.36	0.74																		
5	PFT-13	CAM	7	13.23 ± 1.32	3.23	2.01	0.56																		
6	PFT-15	CAM	7																						
7	PFT-16	CAM	7	11.22 ± 0.89	4.26	1.71	0.59																		
8	PFT-17	CAM	53	12.64 ± 0.64	3.79	2.1	0.63																		
9	PFT-18	CAM	5	13.2 ± 0.63	1.26	1.8	0.55																		
10	PFT-20	CAM	5																						
11	PFT-21	CAM	29	12.29 ± 0.61	3.24	2.08	0.62																		
12	PFT-23	CAM	12	13.53 ± 1.2	3.98	2.25	0.46																		
13	PFT-25	CAM	12	13.53 ± 1.2	3.98	2.25	0.46																		
14	PFT-26	CAM	27	12.84 ± 0.49	2.49	1.81	0.45																		
15	PFT-27	CAM	64	11.81 ± 0.36	3	2.04	0.42																		
16	PFT-28	PTZ																							
17	PFT-30	PTZ																							
18	PFT-42	PTZ																							
19	PFT-43	PTZ																							
20	PFT-44	PTZ																							
21	PFT-45	PTZ																							
22	PFT-46	PTZ																							
23	PFT-47	PTZ																							
24	PFT-48	PTZ																							
25	PFT-49	PTZ																							
26	PFT-55	PTZ																							
27	PFT-61	PTZ																							
28	PFT-65	PTZ																							
29	OU-01	SJO	102	11.77 ± 0.31	3.13	2.05	0.74																		
30	OU-02	SJO	107	11.85 ± 0.32	3.15	2.05	0.74																		
31	OU-03	SJO	101	13.36 ± 0.32	2.03	2.23	0.87																		
32	OU-04	SJO	17	9.48 ± 0.9	3.59	1.81	0.45																		
33	OU-06	SJO	103	11.89 ± 0.3	3.05	1.82	0.65																		
34	OU-07	SJO	90	11.87 ± 0.29	2.84	1.81	0.69																		
35	OU-08	SJO	80	10.96 ± 0.35	3.1	1.81	0.44																		
36	OU-09	SJO	105	12.04 ± 0.27	2.72	1.64	0.47																		
37	OU-10	SJO	107	11.71 ± 0.28	2.85	1.64	0.44																		
38	OU-11	SJO	58	11.82 ± 0.37	2.82	1.59	0.45																		
39	OU-12	SJO	29	10.04 ± 0.43	2.26	1.73	0.47																		
40	OU-13	SJO	10	9.19 ± 0.63	1.9	1.77	0.3																		
41	OU-14	SJO	97	9.93 ± 0.19	1.66	1.66	0.41																		
42	OU-15	SJO																							
43	OU-16	SJO																							
44	OU-17	SJO	8	10.04 ± 0.95	2.5	1.5	0.42																		
45	OU-18	SJO	64	10.82 ± 0.37	2.84	1.72	0.5																		
46	OU-19	SJO	44	10.87 ± 0.32	2.07	1.67	0.4																		
47	OU-20	SJO	30	10.22 ± 0.56	2.99	1.8	0.46																		
48	OU-21	SJO	6	8.62 ± 0.64	1.44	1.53	0.39																		
49	OU-22	SJO	14	10.22 ± 0.3	2.03	1.73	0.47																		
50	OU-23	SJO	54	10.82 ± 0.3	1.75	1.66	0.47																		
51	OU-24	SJO	6	9.53 ± 1.11	2.48	1.72	0.47																		
52	OU-25	SJO	10	10.51 ± 0.69	2.05	1.76	0.42																		
53	OU-26	SJO	1	9.85 ± 1.39	0.34																				
54	OU-27	SJO	2	9.4 ± 2.95																					
55	OU-28	SJO																							
56	OU-29	SJO	22	10.4 ± 0.5	2.27	1.85	0.43																		

Table 2. Summary of the apatite fission-track length data for all apatite grains combined

Discussion of the AFT study

Fission-track data generated and analyzed in this study suggest that an important mountain building process was active in north-central Venezuela from, at least, the Late Oligocene time and throughout the Neogene. Middle Miocene AFT ages are related to the final obduction of the Lara and the Western Serranía del Interior nappes. The Cordillera de la Costa belt was rising and eroding as well, as indicated by several Middle Miocene AFT ages (Avé Lallemant and Sisson, 1993). It is possible that the final obduction of the allochthonous nappes onto continental South America in the Middle Miocene is related to a flip in subduction polarity from a north- to south-dipping. The stratigraphic record and structural analysis of this study suggest that the mountain building process did not stop during the Middle Miocene. Instead, it continued possibly until the Plio-Pleistocene, as the Early-Late Miocene Quiamare Formation is included in the Serranía del Interior foreland fold and thrust belt and as the Guárico basin was tilted to the east marking the inception of a foredeep in northeastern South America.

The Late Oligocene-Middle Miocene signatures observed in the apatite grains (Pérez de Armas, 1998; Pérez de Armas, 2005) suggest that the Roblecito foredeep was involved in the deformation during the Late Oligocene cooling event. The Oligocene time of peak burial, peak burial temperature and depth of burial of the allochthonous-parautochthonous accretionary wedge (Querecual, Garrapata and Guárico Formations) in the Camatagüita-Valle Morín area and possibly the Platillón-Tiznados area can be associated with the arrival of the Villa de Cura nappes in north-central Venezuela. Clearly, AFT data from the Villa de Cura nappes are needed to support this statement.

TABLE 3. SUMMARY OF APATITE FISSION-TRACK THERMAL HISTORY

Sample Number	Formation	Age (My)	Transect	Surface Temperature (°C)	Timing of Peak Temperature (Ma)	Timing of Cooling Events	Timing of Cooling Events*	Peak Burial Temperature	Cooling Rate °C/My	EasyRo (% Reflectance)
PFT-6	Garrapata	86	CAM	25	25.0	25.1±4.8	25.1	125-172°C; best = 134°C	4.3	>0.85±0.02
PFT-8	Guárico	63	CAM	25	17.4	17.1±2.6	17.1	117-180°C; best = 146°C	7.1	>0.78±0.01
PFT-12	Guárico	63	CAM	25	12.8	13.2±1.8	13.2	102-179 °C; best = 127°C	7.7	>0.67±0.01
PFT-13	Guárico	63	CAM	25	15.0	16.8±1.0	16.8	105-184°C; best = 120°C	5.7	>0.70±0.01
PFT-17	Guárico	63	CAM	25	26.0	25.1±3.8	25.1	97-187°C; best = 115°C	3.6	>0.65±0.01
PFT-19	Guárico	63	CAM	25	20.0	17.0±4.2	17.0	104-187°C; best = 164°C	8.2	>0.65±0.01
PFT-20	Guárico	63	CAM	25	24.0	21.1±3.6	21.1	94-184°C; best = 162°C	6.5	>0.65±0.01
PFT-23	Guárico	63	CAM	25	21.0	19.7±1.2	19.7	106-183°C; best = 117°C	4.7	>0.70±0.01
PFT-25	Guárico	63	CAM	25	16.7	16.5±1.0	16.5	103-186°C; best = 136°C	6.7	>0.68±0.01
PFT-28	Roblecito	32	CAM	25	29.0	33.0±4.2	33.0	108-160°C; best = 124°C	3.0	>0.77±0.01
PFT-29	Guárico	63	CAM	25	23.0	21.8±2.2	21.8	123-147°C; best = 128°C	4.7	>0.77±0.01
GU-1	Garrapata	86	SIG	25	45.0	55.8±5.5	55.8	119-130°C; best = 128°C	1.8	>0.80±0.01
GU-2	Guárico	63	SIG	25	59.0	59.2±5.8	59.2	120-142°C; best = 129°C	1.8	>0.79±0.01
GU-3	Guárico	63	SIG	25	43.0	43.7±3.8	43.7	127-169°C; best = 139°C	2.6	>0.82±0.01
GU-4	Guárico	63	SIG	25	58.0	55.5±1.1	55.5	91-183°C; best = 107°C	1.5	>0.83±0.01
GU-5	Guárico	63	SIG	25	42.0	39.3±7.6	39.3	143-167°C; best = 102°C	3.5	>1.43±0.01
GU-6	Guárico	63	SIG	25	56.0	47.8±7.4	47.8	86-168°C; best = 144°C	2.5	>1.00±0.02
GU-7	Guárico	63	SIG	25	54.0	49.3±7.4	49.3	94-151°C; best = 144°C	2.4	>1.00±0.02
GU-8	Guárico	63	SIG	25	48.0	45.6±5.2	45.6	100-156°C; best = 106°C	1.8	>0.64±0.01
GU-9	Guárico	63	SIG	25	45.0	35.1±5.2	35.1	98-175°C; best = 102°C	2.2	>0.64±0.00
GU-10	Guárico	63	SIG	25	28.0	25.0±4.4	25.0	101-135°C; best = 106°C	3.4	>0.63±0.00
GU-11	Guárico	63	SIG	25	40.0	37.7±7.4	37.7	96-173°C; best = 107°C	2.1	>0.75±0.02
GU-13	Naricual	23	SIG	25	14.8	354.0±60	354.0	99-118°C; best = 93°C	0.2	>0.63±0.01
GU-14	Naricual	23	SIG	25	14.5	543.0±72	543.0	59-110°C; best = 90°C	0.1	>0.75±0.02
GU-15	Naricual	23	SIG	25	14.5	315.0±26	315.0	91-108°C; best = 93°C	0.2	>0.63±0.01
GU-17	Quebradón	20	SIG	25	14.5	52.1±6.1	52.1	90-130°C; best = 108°C	1.6	>0.78±0.01
GU-18	Quebradón	20	SIG	25	14.5	44.4±4.2	44.4	102-122°C; best = 104°C	1.8	>0.78±0.01
GU-19	Quebradón	20	SIG	25	14.5	49.4±5.8	49.4	93-113°C; best = 104°C	1.6	>0.69±0.01
GU-20	Quilamare	20	SIG	25	14.5	65.6±4.8	65.6	101-127°C; best = 104°C	1.2	>0.69±0.01
GU-21	Quilamare	20	SIG	25	14.5	141±23	141.0	105-131°C; best = 124°C	0.7	>0.80±0.01
GU-22	Quilamare	20	SIG	25	14.5	104±16	104.0	81-99°C; best = 81°C	0.5	>0.63±0.01
GU-23	Quilamare	20	SIG	25	14.5	43.5±9	43.5	72-112°C; best = 97°C	1.7	>0.64±0.01
GU-24	Quilamare	20	SIG	25	14.5	289±43.9	289.0	72-105°C; best = 98°C	0.3	>0.65±0.01
GU-25	Quilamare	20	SIG	25	14.5	153±14.1	153.0	81-108°C; best = 96°C	0.5	>0.65±0.01
GU-26	Quilamare	20	SIG	25	14.5	38.6±11.2	38.6	54-120°C; best = 109°C	2.2	>0.68±0.01
GU-28	Quilamare	20	SIG	25	14.5	31.4±4.4	31.4	104-125°C; best = 120°C	3.0	>0.69±0.01
GU-29	Quilamare	20	SIG	25	14.5	91±11	91.0	101-117°C; best = 104°C	0.9	>0.69±0.01

Table 3. Summary of thermal history of apatite fission-track data for selected samples. Timing of peak temperature, timing of cooling events, peak burial temperature and estimated Easy Ro (% reflectance) obtained by modeling apatite fission-track age and length data in AFTSolve.

On-going contraction between the North and South American plates and their westward motion with respect to the Caribbean plate caused the subsequent south-directed tectonic transport of the nappes of the western Serranía del Interior in the Miocene. This is the time of the inception of the foredeep in eastern Venezuela (Hung, 1997).

The cooling ages obtained in rocks of the “Piedmont belt” in the eastern-most section of the San José de Guaribe transect do not follow the same pattern observed in the western transects and also do not fit with recent models proposed for the Caribbean-South America plate boundary (e.g., Pindell et al., 1998). AFT ages were not reset during the Miocene and there is a north-south apatite fission-track cooling age gradient from Middle Eocene to Late Oligocene. One possible explanation for these Eocene cooling ages is that in eastern Venezuela deformation began during the Middle Eocene due to North and South American plate convergence (Pindell, 1997; Pindell et al., 1998). Therefore, it is possible that eastern Venezuela was no longer a passive margin at that early time. Convergence between North and South America started during the Paleocene and by Middle Eocene time shortening could have been about 70 km (e.g., Pindell, 1997). Pindell (1997) and Pindell et al., (1998) suggest that contraction between the North and South American plates could have deformed the Proto-Caribbean crust. A subduction zone may have formed already in the Eocene causing subsequent early uplift of the Cordillera de la Costa and possibly of the northern Serranía as early as Early Paleocene.

The recognition of deformation in eastern Venezuela since the Paleogene does not preclude the generation of a roughly N-S oriented forearc basin in northwestern Venezuela as a result of the interaction of the Caribbean and South American plates. Therefore, it is possible that there was an evolving south-vergent foreland fold and thrust

TABLE 4. DEPTH OF BURIAL

Sample Number	Formation	Transect	Surface Temperature (°C)	Peak Burial Temperature from AFTSolve modeling (°C)	Depth of Burial Geothermal Gradient of 27 °C / Km	Depth of Burial Geothermal Gradient of 39 °C / Km	EasyRo (% Reflectance)
PFT-6	Garrapala	CAM	25	134	4	3	>0.85 ± 0.01%
PFT-8	Guárico	CAM	25	146	4	3	>0.78 ± 0.01%
PFT-12	Guárico	CAM	25	127	4	3	>0.67 ± 0.01%
PFT-13	Guárico	CAM	25	120	4	2	>0.70 ± 0.01%
PFT-17	Guárico	CAM	25	115	3	2	>0.65 ± 0.01%
PFT-19	Guárico	CAM	25	164	5	4	>0.65 ± 0.01%
PFT-20	Guárico	CAM	25	164	5	4	>0.65 ± 0.01%
PFT-23	Guárico	CAM	25	117	3	2	>0.70 ± 0.01%
PFT-25	Guárico	CAM	25	136	4	3	>0.68 ± 0.01%
PFT-28	Guárico	CAM	25	124	4	3	>0.77 ± 0.01%
PFT-29	Guárico	CAM	25	128	4	3	>0.67 ± 0.01%
GU-1	Garrapala	SJG	25	128	4	3	>0.80 ± 0.01%
GU-2	Garrapala	SJG	25	129	4	3	>0.79 ± 0.01%
GU-3	Guárico	SJG	25	139	4	3	>0.82 ± 0.01%
GU-4	Guárico	SJG	25	107	3	2	>0.63 ± 0.01%
GU-5	Guárico	SJG	25	162	5	4	>1.43 ± 0.01%
GU-6	Guárico	SJG	25	144	4	3	>1.00 ± 0.02%
GU-7	Guárico	SJG	25	144	4	3	>1.00 ± 0.02%
GU-8	Guárico	SJG	25	106	3	2	>0.64 ± 0.01%
GU-9	Guárico	SJG	25	102	3	2	>0.64 ± 0.00%
GU-10	Guárico	SJG	25	109	3	2	>0.63 ± 0.00%
GU-11	Guárico	SJG	25	106	3	2	>0.63 ± 0.00%
GU-13	Naricual	SJG	25	107	3	2	>0.75 ± 0.02%
GU-14	Naricual	SJG	25	90	2	2	>0.75 ± 0.02%
GU-15	Naricual	SJG	25	93	3	2	>0.63 ± 0.01%
GU-17	Quebradón	SJG	25	108	3	2	>0.78 ± 0.01%
GU-18	Quebradón	SJG	25	104	3	2	>0.69 ± 0.01%
GU-19	Quebradón	SJG	25	104	3	2	>0.69 ± 0.01%
GU-20	Quiamare	SJG	25	104	3	2	>0.69 ± 0.01%
GU-21	Quiamare	SJG	25	124	4	3	>0.80 ± 0.01%
GU-22	Quiamare	SJG	25	81	2	1	>0.63 ± 0.01%
GU-23	Quiamare	SJG	25	97	3	2	>0.64 ± 0.01%
GU-24	Quiamare	SJG	25	98	3	2	>0.65 ± 0.01%
GU-25	Quiamare	SJG	25	96	3	2	>0.65 ± 0.01%
GU-26	Quiamare	SJG	25	109	3	2	>0.68 ± 0.01%
GU-28	Quiamare	SJG	25	120	4	2	>0.69 ± 0.01%
GU-29	Quiamare	SJG	25	104	3	2	>0.69 ± 0.01%

Table 4. Calculation of depth of burial given Peak Burial Temperatures calculated from AFTSolve and possible geothermal gradients, for samples in the Camatagüita-Valle Morín and San José de Guaribe transects.

belt and associated foredeep along northern Venezuela during most of the Paleogene (Lugo and Mann, 1995).

Alternatively, AFT ages in the Garrapata and Guárico Formations along the San José de Guaribe transect may reflect the influence of provenance. Non-reset AFT age values may suggest that the cooling event represents a thermal event of the provenance rock, possibly caused by the emplacement of the Lara nappes in western Venezuela. However, a question still lingers as to how these cooling ages were preserved in the rocks within the Piedmont zone in the San José de Guaribe transect while the same rock types to the west, in the Camatagua-Valle Morín and Platillón-Tiznados transects, underwent burial causing the previous thermal events to be reset.

TABLE 5. UPLIFT RATES

Sample Number	Formation	Transect	Time of cooling event (Ma)	Time of cooling event (Ma) Only central value	Depth of Burial (Geothermal Gradient of 27 °C / Km)	Uplift Rate mm /yr (Geothermal Gradient of 27 °C / Km)	Depth of Burial (Geothermal Gradient of 39 °C / Km)	Uplift Rate mm /yr (Geothermal Gradient of 39 °C / Km)
PFT-6	Garripala	CAM	25.1±4.8	25.1	4	0.16	3	0.11
PFT-8	Guárico	CAM	17.1±2.6	17.1	4	0.26	3	0.18
PFT-12	Guárico	CAM	13.2±1.8	13.2	4	0.29	3	0.20
PFT-13	Guárico	CAM	16.8±1.0	16.8	4	0.21	2	0.14
PFT-17	Guárico	CAM	25.1±3.8	25.1	3	0.13	2	0.09
PFT-19	Guárico	CAM	17.0±4.2	17	5	0.30	4	0.21
PFT-20	Guárico	CAM	21.1±3.6	21.1	5	0.24	4	0.17
PFT-23	Guárico	CAM	19.0±1.2	19	3	0.18	2	0.12
PFT-25	Guárico	CAM	16.5±1.0	16.5	4	0.25	3	0.17
PFT-28	Guárico	CAM	33.0±4.2	33	4	0.11	3	0.08
PFT-29	Guárico	CAM	21.8±2.2	21.8	4	0.17	3	0.12
GU-1	Garripala	SJG	55.8 ±5.5	55.8	4	0.13	3	0.05
GU-2	Garripala	SJG	59.2±5.8	59.2	4	0.07	3	0.05
GU-3	Guárico	SJG	43.7±3.8	43.7	4	0.10	3	0.07
GU-4	Guárico	SJG	55.5±1.1	55.5	3	0.05	2	0.04
GU-5	Guárico	SJG	39.3±7.6	39.3	5	0.13	4	0.09
GU-6	Guárico	SJG	47.8±7.4	47.8	4	0.09	3	0.06
GU-7	Guárico	SJG	49.3±7.4	49.3	4	0.09	3	0.06
GU-8	Guárico	SJG	45.6±5.2	45.6	3	0.07	2	0.05
GU-9	Guárico	SJG	35.1±5.2	35.1	3	0.08	2	0.06
GU-10	Guárico	SJG	25.0±4.4	25	3	0.12	2	0.09
GU-11	Guárico	SJG	37.7±7.4	37.7	3	0.08	2	0.06

Table 5. Calculation of uplift rates given depth of burial and timing of cooling events calculated from AFTSolve and possible geothermal gradients, for samples in the Camatagüita-Valle Morfín and San José de Guaribe transects.

Apatite fission track measurements, Time-temperature history and forward models for all samples

KNOWN PARAMETERS AND ASSUMPTIONS

Sample Number	GU-1
Present Day Temperature	25 °C
Stratigraphic Unit	Garrapata Formation
Stratigraphic Age	86.5 Ma for modeling
Timing of Peak Temperature	45 Ma

IMPLICATIONS OF THE FISSION TRACK DATA

Timing of Cooling Events (Ma)	55.8±5.5 Ma (oldest track)
Peak of Burial Temperature (°C)	119-130°C; best =128°C
EasyRo (% reflectance)	>0.80±0.01%

KNOWN PARAMETERS AND ASSUMPTIONS

Sample Number	GU-2
Present Day Temperature	25 °C
Stratigraphic Unit	Garrapata Formation
Stratigraphic Age	86.5 Ma for modeling
Timing of Peak Temperature	59 Ma

IMPLICATIONS OF THE FISSION TRACK DATA

Timing of Cooling Events (Ma)	59.2±5.8 Ma (oldest track)
Peak of Burial Temperature (°C)	120-142°C; best =129°C
EasyRo (% reflectance)	>0.79±0.01%

KNOWN PARAMETERS AND ASSUMPTIONS

Sample Number	GU-3
Present Day Temperature	25 °C
Stratigraphic Unit	Guárico Formation
Stratigraphic Age	74.5≥ St_age ≤52 Ma; 63 Ma for modeling
Timing of Peak Temperature	43 Ma

IMPLICATIONS OF THE FISSION TRACK DATA

Timing of Cooling Events (Ma)	43.7±3.8 Ma (oldest track)
Peak of Burial Temperature (°C)	127-169°C; best =139°C
EasyRo (% reflectance)	>0.82±0.01%

KNOWN PARAMETERS AND ASSUMPTIONS

Sample Number	GU-4
Present Day Temperature	25 °C
Stratigraphic Unit	Guárico Formation
Stratigraphic Age	$74.5 \geq \text{St_age} \leq 52 \text{ Ma}$; 63 Ma for modeling
Timing of Peak Temperature	58 Ma

IMPLICATIONS OF THE FISSION TRACK DATA

Timing of Cooling Events (Ma)	$55.5 \pm 11 \text{ Ma}$ (oldest track)
Peak of Burial Temperature (°C)	91-183°C; best = 107°C
EasyRo (% reflectance)	$>0.63 \pm 0.01\%$

KNOWN PARAMETERS AND ASSUMPTIONS

Sample Number	GU-5
Present Day Temperature	25 °C
Stratigraphic Unit	Guárico Formation
Stratigraphic Age	74.5 ≥ St_age ≤ 52 Ma; 63 Ma for modeling
Timing of Peak Temperature	42 Ma

IMPLICATIONS OF THE FISSION TRACK DATA

Timing of Cooling Events (Ma)	39.3±7.6 Ma (oldest track)
Peak of Burial Temperature (°C)	143-167°C; best = 162°C
EasyRo (% reflectance)	>1.43±0.01%

KNOWN PARAMETERS AND ASSUMPTIONS

Sample Number	GU-6
Present Day Temperature	25 °C
Stratigraphic Unit	Guárico Formation
Stratigraphic Age	74.5± St_age ≤52 Ma; 63 Ma for modeling
Timing of Peak Temperature	56 Ma

IMPLICATIONS OF THE FISSION TRACK DATA

Timing of Cooling Events (Ma)	47.8±7.4 Ma (oldest track)
Peak of Burial Temperature (°C)	86-168°C; best =144°C
EasyRo (% reflectance)	>1.00±0.02%

KNOWN PARAMETERS AND ASSUMPTIONS

Sample Number	GU-7
Present Day Temperature	25 °C
Stratigraphic Unit	Guárico Formation
Stratigraphic Age	74.5≥ St_age ≤52 Ma; 63 Ma for modeling
Timing of Peak Temperature	54 Ma

IMPLICATIONS OF THE FISSION TRACK DATA

Timing of Cooling Events (Ma)	49.3±7.4 Ma (oldest track)
Peak of Burial Temperature (°C)	94-151°C; best =144°C
EasyRo (% reflectance)	>1.00±0.02%

KNOWN PARAMETERS AND ASSUMPTIONS

Sample Number	GU-8
Present Day Temperature	25 °C
Stratigraphic Unit	Guárico Formation
Stratigraphic Age	$74.5 \geq \text{St_age} \leq 52 \text{ Ma}$; 63 Ma for modeling
Timing of Peak Temperature	48 Ma

IMPLICATIONS OF THE FISSION TRACK DATA

Timing of Cooling Events (Ma)	$45.6 \pm 5.2 \text{ Ma}$ (oldest track)
Peak of Burial Temperature (°C)	100-156°C; best = 106°C
EasyRo (% reflectance)	$>0.64 \pm 0.01\%$

Sample Number	GU-9
Present Day Temperature	25 °C
Stratigraphic Unit	Guárico Formation; 63 Ma for modeling
Stratigraphic Age	$74.5 \geq \text{St_age} \leq 52 \text{ Ma}$
Timing of Peak Temperature	45 Ma

Timing of Cooling Events (Ma)	35.1±5.2 Ma (oldest track)
Peak of Burial Temperature (°C)	98-175°C; best =102°C
EasyRo (% reflectance)	>0.64±0.00%

KNOWN PARAMETERS AND ASSUMPTIONS

Sample Number	GU-10
Present Day Temperature	25 °C
Stratigraphic Unit	Guárico Formation
Stratigraphic Age	74.5 ≥ St_age ≤ 52 Ma; 63 Ma for modeling
Timing of Peak Temperature	28 Ma

IMPLICATIONS OF THE FISSION TRACK DATA

Timing of Cooling Events (Ma)	25.0 ± 4.4 Ma (oldest track)
Peak of Burial Temperature (°C)	101-135°C; best = 109°C
EasyRo (% reflectance)	>0.63 ± 0.00%

KNOWN PARAMETERS AND ASSUMPTIONS

Sample Number	GU-11
Present Day Temperature	25 °C
Stratigraphic Unit	Guárico Formation
Stratigraphic Age	74.5≥ St_age ≤52 Ma; 63 Ma for modeling
Timing of Peak Temperature	40 Ma

IMPLICATIONS OF THE FISSION TRACK DATA

Timing of Cooling Events (Ma)	37.7±7.4 Ma (oldest track)
Peak of Burial Temperature (°C)	96-173°C; best =106°C
EasyRo (% reflectance)	>0.63±0.00%

KNOWN PARAMETERS AND ASSUMPTIONS

Sample Number	GU-13
Present Day Temperature	25 °C
Stratigraphic Unit	Naricual Formation
Stratigraphic Age	23.70 Ma ≥ St_age ≤ 21.80 Ma; 23 Ma for modeling
Timing of Peak Temperature	14.8 Ma (modeled)

IMPLICATIONS OF THE FISSION TRACK DATA

Timing of Cooling Events (Ma)	354.0±60 Ma (oldest track)
Peak of Burial Temperature (°C)	99-119°C; best = 107°C (modeled at 14.8 Ma)
EasyRo (% reflectance)	>0.75±0.02% (modeled at 14.8 Ma)

KNOWN PARAMETERS AND ASSUMPTIONS

Sample Number	GU-14
Present Day Temperature	25 °C
Stratigraphic Unit	Naricual Formation
Stratigraphic Age	23.70 Ma ≥ St_age ≤ 21.80 Ma; 23 Ma for modeling
Timing of Peak Temperature	14.5 Ma (modeled)

IMPLICATIONS OF THE FISSION TRACK DATA

Timing of Cooling Events (Ma)	543.0±72 Ma (oldest track)
Peak of Burial Temperature (°C)	59-110°C; best =90°C (modeled at 14.5 Ma)
EasyRo (% reflectance)	>0.75±0.02% (modeled at 14.5 Ma)

KNOWN PARAMETERS AND ASSUMPTIONS

Sample Number	GU-15
Present Day Temperature	25 °C
Stratigraphic Unit	Naricual Formation
Stratigraphic Age	23.70 Ma ≥ St_age ≤ 21.80 Ma; 23 Ma for modeling
Timing of Peak Temperature	14.5 Ma (modeled)

IMPLICATIONS OF THE FISSION TRACK DATA

Timing of Cooling Events (Ma)	315.0±26 Ma (oldest track)
Peak of Burial Temperature (°C)	91-108°C; best = 93°C (modeled at 14.5 Ma)
EasyRo (% reflectance)	>0.63±0.01% (modeled at 14.5 Ma)

KNOWN PARAMETERS AND ASSUMPTIONS

Sample Number	GU-17
Present Day Temperature	25 °C
Stratigraphic Unit	Quebradón Formation
Stratigraphic Age	23.30 Ma $\geq$ St_age $\leq$ 10.4 Ma; 20 Ma for modeling
Timing of Peak Temperature	14.5 Ma (modeled)

IMPLICATIONS OF THE FISSION TRACK DATA

Timing of Cooling Events (Ma)	52.1 $\pm$ 6.1 Ma (oldest track)
Peak of Burial Temperature (°C)	90-130°C; best = 108°C (modeled at 14.5 Ma)
EasyRo (% reflectance)	>0.78 $\pm$ 0.01% (modeled at 14.5 Ma)

KNOWN PARAMETERS AND ASSUMPTIONS

Sample Number	GU-18
Present Day Temperature	25 °C
Stratigraphic Unit	Quebradón Formation
Stratigraphic Age	23.30 Ma $\geq$ St_age $\leq$ 10.4 Ma; 20 Ma for modeling
Timing of Peak Temperature	14.5 Ma (modeled)

IMPLICATIONS OF THE FISSION TRACK DATA

Timing of Cooling Events (Ma)	44.4 ± 4.2 Ma (oldest track)
Peak of Burial Temperature (°C)	102-122°C; best = 104°C (modeled at 14.5 Ma)
EasyRo (% reflectance)	>0.78 ± 0.01% (modeled at 14.5 Ma)

KNOWN PARAMETERS AND ASSUMPTIONS

Sample Number	GU-19
Present Day Temperature	25 °C
Stratigraphic Unit	Quebradón Formation
Stratigraphic Age	23.30 Ma ≥ St_age ≤ 10.4 Ma; 20 Ma for modeling
Timing of Peak Temperature	14.5 Ma (modeled)

IMPLICATIONS OF THE FISSION TRACK DATA

Timing of Cooling Events (Ma)	49.4 ± 5.8 Ma (oldest track)
Peak of Burial Temperature (°C)	93-113°C; best = 104°C (modeled at 14.5 Ma)
EasyRo (% reflectance)	>0.69 ± 0.01% (modeled at 14.5 Ma)

KNOWN PARAMETERS AND ASSUMPTIONS

Sample Number	GU-20
Present Day Temperature	25 °C
Stratigraphic Unit	Quiamare Formation
Stratigraphic Age	21.5 Ma ≥ St_age ≤ 10.4 Ma; 20 Ma for modeling
Timing of Peak Temperature	14.5 Ma (modeled)

IMPLICATIONS OF THE FISSION TRACK DATA

Timing of Cooling Events (Ma)	65.6 ± 48 Ma (oldest track)
Peak of Burial Temperature (°C)	101-127°C; best = 104°C (modeled at 14.5 Ma)
EasyRo (% reflectance)	>0.69 ± 0.01% (modeled at 14.5 Ma)

KNOWN PARAMETERS AND ASSUMPTIONS

Sample Number	GU-21
Present Day Temperature	25 °C
Stratigraphic Unit	Quiamare Formation
Stratigraphic Age	$21.5 \text{ Ma} \geq \text{St_age} \leq 10.4 \text{ Ma}$; 20 Ma for modeling
Timing of Peak Temperature	14.5 Ma (modeled)

IMPLICATIONS OF THE FISSION TRACK DATA

Timing of Cooling Events (Ma)	141 ± 23 Ma (oldest track)
Peak of Burial Temperature (°C)	$105\text{--}131^\circ\text{C}$; best = 124°C (modeled at 14.5 Ma)
EasyRo (% reflectance)	$>0.80 \pm 0.01\%$ (modeled at 14.5 Ma)

KNOWN PARAMETERS AND ASSUMPTIONS

Sample Number	GU-22
Present Day Temperature	25 °C
Stratigraphic Unit	Quiamare Formation
Stratigraphic Age	21.5 Ma ≥ St_age ≤ 10.4 Ma; 20 Ma for modeling
Timing of Peak Temperature	14.5 Ma (modeled)

IMPLICATIONS OF THE FISSION TRACK DATA

Timing of Cooling Events (Ma)	104 ± 16 Ma (oldest track)
Peak of Burial Temperature (°C)	81-99 °C; best = 81 °C (modeled at 14.5 Ma)
EasyRo (% reflectance)	> 0.63 ± 0.01% (modeled at 14.5 Ma)

KNOWN PARAMETERS AND ASSUMPTIONS

Sample Number	GU-23
Present Day Temperature	25 °C
Stratigraphic Unit	Quiamare Formation
Stratigraphic Age	21.5 Ma ≥ St_age ≤ 10.4 Ma; 20 Ma for modeling
Timing of Peak Temperature	14.5 Ma (modeled)

IMPLICATIONS OF THE FISSION TRACK DATA

Timing of Cooling Events (Ma)	43.5±9 Ma (oldest track)
Peak of Burial Temperature (°C)	87-112°C; best = 97°C (modeled at 14.5 Ma)
EasyRo (% reflectance)	>0.64±0.01% (modeled at 14.5 Ma)

KNOWN PARAMETERS AND ASSUMPTIONS

Sample Number	GU-24
Present Day Temperature	25 °C
Stratigraphic Unit	Quiamare Formation
Stratigraphic Age	21.5 Ma ≥ St_age ≤ 10.4 Ma; 20 Ma for modeling
Timing of Peak Temperature	14.5 Ma (modeled)

IMPLICATIONS OF THE FISSION TRACK DATA

Timing of Cooling Events (Ma)	289±43.9 Ma (oldest track)
Peak of Burial Temperature (°C)	72-105°C; best =98°C (modeled at 14.5 Ma)
EasyRo (% reflectance)	>0.65±0.01% (modeled at 14.5 Ma)

KNOWN PARAMETERS AND ASSUMPTIONS

Sample Number	GU-25
Present Day Temperature	25 °C
Stratigraphic Unit	Quiamare Formation
Stratigraphic Age	21.5 Ma ≥ St_age ≤ 10.4 Ma; 20 Ma for modeling
Timing of Peak Temperature	14.5 Ma (modeled)

IMPLICATIONS OF THE FISSION TRACK DATA

Timing of Cooling Events (Ma)	153 ± 14.1 Ma (oldest track)
Peak of Burial Temperature (°C)	81-108°C; best = 96°C (modeled at 14.5 Ma)
EasyRo (% reflectance)	>0.65 ± 0.01% (modeled at 14.5 Ma)

KNOWN PARAMETERS AND ASSUMPTIONS

Sample Number	GU-26
Present Day Temperature	25 °C
Stratigraphic Unit	Quiamare Formation
Stratigraphic Age	21.5 Ma ≥ St_age ≤ 10.4 Ma; 20 Ma for modeling
Timing of Peak Temperature	14.5 Ma (modeled)

IMPLICATIONS OF THE FISSION TRACK DATA

Timing of Cooling Events (Ma)	38.6 ± 11.2 Ma (oldest track)
Peak of Burial Temperature (°C)	54-120°C; best = 109°C (modeled at 14.5 Ma)
EasyRo (% reflectance)	>0.68 ± 0.01% (modeled at 14.5 Ma)

KNOWN PARAMETERS AND ASSUMPTIONS

Sample Number	GU-28
Present Day Temperature	25 °C
Stratigraphic Unit	Quiamare Formation
Stratigraphic Age	21.5 Ma ≥ St_age ≤ 10.4 Ma; 20 Ma for modeling
Timing of Peak Temperature	14.5 Ma (modeled)

IMPLICATIONS OF THE FISSION TRACK DATA

Timing of Cooling Events (Ma)	31.4±4.4 Ma (oldest track)
Peak of Burial Temperature (°C)	104-125°C; best = 120°C (modeled at 14.5 Ma)
EasyRo (% reflectance)	>0.69±0.01% (modeled at 14.5 Ma)

KNOWN PARAMETERS AND ASSUMPTIONS

Sample Number	PFT-6
Present Day Temperature	25 °C
Stratigraphic Unit	Garrapata Formation
Stratigraphic Age	86.5 Ma for modeling
Timing of Peak Temperature	25 Ma

IMPLICATIONS OF THE FISSION TRACK DATA

Timing of Cooling Events (Ma)	25.1±4.8 Ma (oldest track)
Approximate Cooling Rate	4.5 °C / My
Peak of Burial Temperature (°C)	125-172°C; best =134°C
EasyRo (% reflectance)	>0.85±0.02%

KNOWN PARAMETERS AND ASSUMPTIONS

Sample Number	PFT-8
Present Day Temperature	25 °C
Stratigraphic Unit	Guárico Formation
Stratigraphic Age	$74.5 \geq \text{St_age} \leq 52 \text{ Ma}$; 63 Ma
Timing of Peak Temperature	17.4 Ma

IMPLICATIONS OF THE FISSION TRACK DATA

Timing of Cooling Events (Ma)	$17.1 \pm 2.6 \text{ Ma}$ (oldest track)
Approximate Cooling Rate	7 °C / My
Peak of Burial Temperature (°C)	117-190°C; best = 146°C
EasyRo (% reflectance)	$>0.78 \pm 0.01\%$

KNOWN PARAMETERS AND ASSUMPTIONS

Sample Number	PFT-12
Present Day Temperature	25 °C
Stratigraphic Unit	Guárico Formation
Stratigraphic age	74.5 ≥ St_age ≤ 52 Ma; 63 Ma for modeling
Timing of Peak Temperature	12.8 Ma

IMPLICATIONS OF THE FISSION TRACK DATA

Timing of Cooling Events (Ma)	13.2±1.8 Ma (oldest track)
Approximate Cooling Rate	7.7 °C / My
Peak of Burial Temperature (°C)	102-179 °C; best = 127°C
EasyRo (% reflectance)	>0.67±0.01%

KNOWN PARAMETERS AND ASSUMPTIONS

Sample Number	PFT-13
Present Day Temperature	25 °C
Stratigraphic Unit	Guárico Formation
Stratigraphic age	$74.5 \geq \text{St_age} \leq 52 \text{ Ma}$; 63 Ma for modeling
Timing of Peak Temperature	15 Ma

IMPLICATIONS OF THE FISSION TRACK DATA

Timing of Cooling Events (Ma)	$16.8 \pm 10 \text{ Ma}$ (oldest track)
Approximate Cooling Rate	$5.6 \text{ }^{\circ}\text{C} / \text{My}$
Peak of Burial Temperature (°C)	$105\text{--}184^{\circ}\text{C}$; best = 120°C
EasyRo (% reflectance)	$>0.70 \pm 0.01\%$

KNOWN PARAMETERS AND ASSUMPTIONS

Sample Number	PFT-17
Present Day Temperature	25 °C
Stratigraphic Unit	Guárico Formation
Stratigraphic age	74.5 ≥ St_age ≤ 52 Ma; 63 Ma for modeling
Timing of Peak Temperature	26 Ma

IMPLICATIONS OF THE FISSION TRACK DATA

Timing of Cooling Events (Ma)	25.1 ± 3.8 Ma (oldest track)
Approximate Cooling Rate	3.6 °C / My
Peak of Burial Temperature (°C)	97-187°C; best = 115°C
EasyRo (% reflectance)	>0.65 ± 0.01%

KNOWN PARAMETERS AND ASSUMPTIONS

Sample Number	PFT-19
Present Day Temperature	25 °C
Stratigraphic Unit	Guárico Formation
Stratigraphic Age	74.5 ≥ St_age ≤ 52 Ma; 63 Ma for modeling
Timing of Peak Temperature	20 Ma

IMPLICATIONS OF THE FISSION TRACK DATA

Timing of Cooling Events (Ma)	17.0±4.2 Ma (oldest track)
Approximate Cooling Rate	8.1 °C / My
Peak of Burial Temperature (°C)	104-187°C; best = 164°C
EasyRo (% reflectance)	>0.65±0.01%

KNOWN PARAMETERS AND ASSUMPTIONS

Sample Number	PFT-20
Present Day Temperature	25 °C
Stratigraphic Unit	Guárico Formation
Stratigraphic Age	74.5 ≥ St_age ≤ 52 Ma; 63 Ma for modeling
Timing of Peak Temperature	24 Ma

IMPLICATIONS OF THE FISSION TRACK DATA

Timing of Cooling Events (Ma)	21.1±3.6 Ma (oldest track)
Approximate Cooling Rate	6.5 °C / My
Peak of Burial Temperature (°C)	94-184°C; best = 162°C
EasyRo (% reflectance)	>0.65±0.01%

KNOWN PARAMETERS AND ASSUMPTIONS

Sample Number	PFT-23
Present Day Temperature	25 °C
Stratigraphic Unit	Guárico Formation
Stratigraphic Age	74.5 ≥ St _{age} ≤ 52 Ma; 63 Ma for modeling
Timing of Peak Temperature	21 Ma

IMPLICATIONS OF THE FISSION TRACK DATA

Timing of Cooling Events (Ma)	19.7±1.2 Ma (oldest track)
Approximate Cooling Rate	4.7 °C / My
Peak of Burial Temperature (°C)	106-183°C; best = 117°C
EasyRo (% reflectance)	>0.70±0.01%

KNOWN PARAMETERS AND ASSUMPTIONS

Sample Number	PFT-25
Present Day Temperature	25 °C
Stratigraphic Unit	Guárico Formation
Stratigraphic Age	74.5 ≥ St_age ≤ 52 Ma; 63 Ma for modeling
Timing of Peak Temperature	16.7 Ma

IMPLICATIONS OF THE FISSION TRACK DATA

Timing of Cooling Events (Ma)	16.5 ± 1 Ma (oldest track)
Approximate Cooling Rate	7 °C / My
Peak of Burial Temperature (°C)	103-198°C; best = 136°C
EasyRo (% reflectance)	>0.68 ± 0.01%

KNOWN PARAMETERS AND ASSUMPTIONS

Sample Number	PFT-28
Present Day Temperature	25 °C
Stratigraphic Unit	Roblecito Formation
Stratigraphic Age	35 Ma ≥ St_age ≤ 23.8 Ma; 32 for modeling
Timing of Peak Temperature	29.0 Ma

IMPLICATIONS OF THE FISSION TRACK DATA

Timing of Cooling Events (Ma)	33.0±4.2 Ma (oldest track)
Approximate Cooling Rate	3 °C / My
Peak of Burial Temperature (°C)	108-160°C; best =124°C
EasyRo (% reflectance)	>0.77±0.01%

KNOWN PARAMETERS AND ASSUMPTIONS

Sample Number	PFT-29
Present Day Temperature	25 °C
Stratigraphic Unit	Guárico Formation
Stratigraphic Age	74.5 Ma ≥ St_age ≤ 52 Ma; 63 Ma for modeling
Timing of Peak Temperature	23.0 Ma

IMPLICATIONS OF THE FISSION TRACK DATA

Timing of Cooling Events (Ma)	21.8±2.2 Ma (oldest track)
Approximate Cooling Rate	4.9 °C / My
Peak of Burial Temperature (°C)	123-147°C; best = 128°C
EasyRo (% reflectance)	>0.77±0.01%

APATITE FISSION-TRACK
AGE DATA

GU-01

Etch	Grain Number Figures	Natural Dpar Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
	1	2	7	25	90.82	73.05	4
4	1.68	0.40					
	2	10	28	20	113.33	42.37	20
4	1.58	0.37					
	3	8	20	56	126.80	53.65	5
4	2.19	0.87					
	4	2	30	35	21.31	15.62	12
1	3.50	1.31					
	5	14	132	80	33.86	9.76	24
4	1.54	0.44					
	6	2	25	80	25.56	18.85	5
4	2.14	0.66					
	7	10	112	90	28.52	9.59	18
4	2.93	1.28					
	8	7	29	100	76.81	32.71	4
4	2.33	0.83					
	9	3	45	100	21.31	12.78	7
1	2.14	0.70					
	10	6	71	50	27.00	11.60	21
4	2.93	1.21					
	11	7	94	100	23.80	9.44	14
4	2.33	0.97					
	12	8	56	80	45.57	17.47	10
4	2.77	0.87					
	13	15	100	54	47.84	13.59	27
4	1.48	0.44					
	14	6	37	40	51.70	22.99	13
1	2.68	1.02					
	15	11	112	100	31.36	10.11	16
4	3.04	1.18					
	16	6	22	45	86.72	40.32	7
4	2.36	0.55					
	17	12	61	80	62.67	20.19	11
4	3.25	1.29					
	18	3	17	24	56.25	35.40	10
2	1.62	0.42					
	19	3	6	15	158.11	112.25	6
3	1.36	0.46					
	20	4	16	54	79.54	44.75	4
4	2.73	0.75					
	21	4	14	28	90.82	51.81	7
4	3.42	1.19					
	22	3	22	42	43.51	26.92	8
3	2.14	0.56					
	23	3	39	36	24.58	14.81	16
4	2.33	0.84					
	24	4	51	81	25.06	13.11	9
4	1.56	0.33					
	25	6	23	80	82.98	38.40	4
4	1.91	0.45					

	26	2	18	32	35.47	26.54	8
1	2.58	1.39					
	27	4	32	40	39.89	21.31	12
3	2.59	1.22					
	28	2	21	28	30.42	22.59	11
3	2.54	1.22					
	29	8	43	50	59.29	23.14	12
4	2.89	1.07					
	30	4	37	100	34.52	18.30	5
4	2.19	0.66					
	31	1	18	100	17.76	18.28	3
3	2.98	1.31					
	32	3	43	100	22.30	13.39	6
3	1.79	0.54					
	33	0	84	100	0.00	3.84	12
3	1.60	0.35					
	34	3	22	28	43.51	26.92	11
3	2.89	0.98					
	35	3	83	80	11.56	6.83	15
4	2.08	0.72					
	36	6	21	42	90.82	42.44	7
2	3.18	0.97					
	37	4	168	49	7.62	3.88	50
4	1.50	0.34					
	38	4	24	70	53.14	28.89	5
4	1.91	0.77					

Mean Dpar = 2.33
 Mean Dper = 0.81
 Chi-squared = 87.221
 Chi-squared prob= 0.000
 Pooled Age (Ma) = 36.3+/- 3.5
 Mean Age (Ma) = 50.7+/- 6.6
 W.Mean Age (Ma) = 17.4+/- 2.2
 Median Age (Ma) = 41.7- 4.1+ 8.6

GU-02

Etch	Grain Number Figures	Natural Dpar Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
	1	2	12	24	52.96	40.59	7
2	1.82	0.75					
	2	3	38	100	25.14	15.16	6
4	1.60	0.52					
	3	8	72	56	35.35	13.37	19
4	3.53	1.17					
	4	2	27	18	23.59	17.35	22
4	1.15	0.39					
	5	9	54	50	52.96	19.36	16
4	3.04	1.03					
	6	11	77	100	45.42	14.92	11
4	3.24	1.10					

	7	9	45	45	63.50	23.53	15
4	3.24	1.06					
	8	9	65	30	44.03	15.91	32
4	1.34	0.44					
	9	8	80	20	31.83	11.97	58
4	1.58	0.36					
	10	11	92	70	38.03	12.37	19
4	3.38	1.31					
	11	3	17	49	56.06	35.28	5
4	1.59	0.55					
	12	4	10	70	126.37	75.19	2
4	1.64	0.46					
	13	6	37	50	51.53	22.91	11
4	3.09	1.24					
	14	3	24	30	39.76	24.48	12
3	1.62	0.39					
	15	6	33	40	57.75	25.89	12
4	2.85	1.04					
	16	7	12	20	183.47	88.03	9
4	1.54	0.40					
	17	2	20	21	31.83	23.69	14
2	2.06	0.92					
	18	1	20	40	15.93	16.36	7
3	2.42	1.28					
	19	6	88	25	21.72	9.27	51
4	1.57	0.47					
	20	1	10	24	31.83	33.44	6
3	2.01	0.66					
	21	1	16	25	19.91	20.56	9
1	2.13	0.42					
	22	0	8	49	0.00	42.25	2
4	1.61	0.32					
	23	3	21	25	45.42	28.18	12
4	3.24	0.95					
	24	2	27	24	23.59	17.35	16
4	3.22	1.17					
	25	8	50	21	50.85	19.63	35
4	1.56	0.49					
	26	3	22	49	43.36	26.83	7
4	1.95	0.65					
	27	1	11	25	28.94	30.28	6
4	1.41	0.41					
	28	4	9	70	140.26	84.76	2
4	1.66	0.45					
	29	9	67	90	42.72	15.41	11
4	3.02	1.08					
	30	6	51	63	37.43	16.33	12
4	1.58	0.47					
	31	2	17	50	37.43	28.08	5
4	1.34	0.38					
	32	4	43	30	29.61	15.59	21
4	1.94	0.38					
	33	6	56	70	34.09	14.80	12
4	3.19	1.30					
	34	7	14	49	157.58	73.63	4
4	1.54	0.48					

	35	7	30	36	74.02	31.42	12
4	2.65	1.04					
	36	7	84	80	26.53	10.57	15
4	1.53	0.38					
	37	4	54	80	23.59	12.32	10
3	3.10	1.10					
	38	3	39	100	24.50	14.76	6
4	2.18	0.90					

Mean Dpar = 2.19
 Mean Dper = 0.73
 Chi-squared = 48.107
 Chi-squared prob= 0.104
 Pooled Age (Ma) = 41.2+/- 4.1
 Mean Age (Ma) = 49.3+/- 7.2
 W.Mean Age (Ma) = 33.9+/- 3.6
 Median Age (Ma) = 37.7- 2.7+ 3.7

GU-03

Etch	Grain Number	Natural Dpar Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
Figures							
	1	1	25	36	12.71	12.98	10
2	2.06	0.43					
	2	5	45	27	35.23	16.76	24
3	1.89	0.41					
	3	3	13	18	72.96	46.96	11
2	2.67	1.35					
	4	8	71	70	35.73	13.52	15
4	2.93	0.71					
	5	4	29	80	43.71	23.48	5
3	2.25	0.79					
	6	1	32	35	9.93	10.10	13
1	1.96	0.65					
	7	0	41	49	0.00	7.86	12
0	0.00	0.00					
	8	1	1	80	310.37	439.38	0
1	3.61	1.24					
	9	2	7	40	90.21	72.56	3
2	1.71	0.29					
	10	1	4	15	79.01	88.47	4
2	3.64	1.28					
	11	3	8	70	118.15	80.34	2
1	1.82	0.49					
	12	2	20	21	31.72	23.61	14
1	3.55	1.10					
	13	0	5	25	0.00	69.44	3
1	2.37	0.20					
	14	3	18	30	52.78	33.08	9
4	2.55	0.68					
	15	0	17	35	0.00	19.25	7
2	1.86	0.21					

	16	2	67	36	9.48	6.83	27
3	1.72	0.28					
	17	3	23	50	41.34	25.51	7
3	3.40	1.32					
	18	4	44	100	28.84	15.17	6
3	2.56	0.76					
	19	5	36	35	44.01	21.19	15
2	3.20	0.83					
	20	7	56	63	39.62	16.08	13
4	3.38	0.72					
	21	4	22	24	57.55	31.50	13
4	2.96	1.02					
	22	3	19	21	50.01	31.23	13
2	2.94	0.81					
	23	12	113	80	33.68	10.45	21
4	3.21	1.11					
	24	4	52	60	24.41	12.76	13
2	1.75	0.18					
	25	3	30	36	31.72	19.31	12
4	3.23	0.81					
	26	8	18	100	139.79	60.06	3
4	1.64	0.28					
	27	19	159	24	37.88	9.51	97
4	2.09	0.21					
	28	0	5	100	0.00	69.44	1
3	1.52	0.11					
	29	0	9	70	0.00	37.21	2
1	1.87	0.20					
	30	5	49	100	32.36	15.33	7
3	3.40	1.22					
	31	12	62	100	61.25	19.70	9
4	3.61	1.59					
	32	5	46	81	34.47	16.38	8
4	2.80	0.78					
	33	78	631	200	39.19	5.32	46
4	1.68	0.37					
	34	6	27	36	70.27	32.03	11
4	1.49	0.27					
	35	7	49	90	45.26	18.51	8
4	2.82	0.71					
	36	0	4	60	0.00	88.47	1
3	1.30	0.12					
	37	9	67	36	42.57	15.35	27
4	2.53	0.73					
	38	16	106	100	47.82	13.18	15
4	1.85	0.36					
	39	5	32	70	49.49	24.01	7
4	4.42	0.87					
	40	8	39	50	64.90	25.52	11
4	1.94	0.38					
	41	2	20	21	31.72	23.61	14
1	3.31	1.09					
	42	13	78	100	52.78	16.16	11
4	1.63	0.32					
	43	4	55	100	23.08	12.04	8
3	3.34	0.85					

	44	1	35	20	9.08	9.23	26
1	1.94	0.09					
	45	3	37	36	25.73	15.53	15
4	3.61	1.06					
	46	4	54	56	23.51	12.27	14
2	1.68	0.35					
	47	12	83	35	45.81	14.44	35
4	2.06	0.15					
	48	9	98	32	29.14	10.32	45
4	1.79	0.23					
	49	4	12	100	105.13	61.06	2
4	1.61	0.11					
	50	1	15	100	21.16	21.90	2
4	1.97	0.32					
	51	4	42	28	30.21	15.92	22
4	1.81	0.24					
	52	19	146	100	41.25	10.40	21
4	1.66	0.20					
	53	4	10	28	125.95	74.94	5
4	4.33	1.11					
	54	5	37	100	42.83	20.59	5
4	2.69	0.70					
	55	0	20	60	0.00	16.30	5
4	1.88	0.32					
	56	2	10	25	63.28	49.18	6
1	1.96	0.45					
	57	11	113	80	30.88	9.95	21
4	1.97	0.15					
	58	0	3	50	0.00	121.57	1
1	1.88	0.37					

Mean Dpar = 2.44
 Mean Dper = 0.60
 Chi-squared = 67.155
 Chi-squared prob= 0.168
 Pooled Age (Ma) = 38.1+/- 3.2
 Mean Age (Ma) = 45.3+/- 7.0
 W.Mean Age (Ma) = 29.3+/- 2.7
 Median Age (Ma) = 36.8- 2.6+ 3.1

GU-04

	Grain	Natural	Induced	Quads	FT Age	1 sigma	Uranium
Etch	Dpar	Dper					
Number	Tracks	Tracks	(dmnls)	(Ma)	(Ma)	(ppm)	
Figures	(microns)	(microns)					
	1	1	15	10	21.09	21.82	22
1	2.63	0.16					
	2	11	67	36	51.82	17.18	27
4	1.74	0.17					
	3	6	52	64	36.46	15.89	12
4	1.99	0.33					
	4	9	100	50	28.46	10.07	29
4	1.78	0.20					

	5	5	49	25	32.25	15.28	29
4	2.60	0.39					
	6	2	30	15	21.09	15.46	29
4	2.03	0.24					
	7	1	11	3	28.74	30.08	54
2	1.86	0.37					
	8	2	10	20	63.07	49.02	7
2	1.57	0.27					
	9	0	2	30	0.00	191.96	1
1	2.29	0.79					

Mean Dpar = 2.05
 Mean Dper = 0.32
 Chi-squared = 3.491
 Chi-squared prob= 0.900
 Pooled Age (Ma) = 34.8+/- 6.4
 Mean Age (Ma) = 31.5+/- 6.8
 W.Mean Age (Ma) = 31.7+/- 6.1
 Median Age (Ma) = 28.7- 4.0+ 4.0

GU-05

Etch	Grain Number Figures	Natural Dpar Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
	1	0	22	9	0.00	14.69	36
4	1.69	0.53					
	2	0	20	12	0.00	16.19	24
1	1.61	0.57					
	3	3	9	15	104.42	69.93	9
4	2.11	0.56					
	4	0	18	12	0.00	18.04	22
1	1.28	0.56					
	5	14	55	50	79.89	24.45	16
4	1.65	0.38					
	6	1	4	9	78.47	87.88	7
1	2.24	1.40					
	7	1	5	15	62.85	68.97	5
2	3.01	1.18					
	8	0	8	16	0.00	41.82	7
1	1.49	0.42					
	9	0	14	14	0.00	23.35	15
1	1.16	0.51					
	10	6	31	12	60.84	27.41	38
4	2.04	0.48					
	11	8	78	30	32.31	12.17	38
4	2.49	0.88					
	12	4	47	12	26.82	14.07	58
4	1.83	0.43					
	13	7	76	15	29.02	11.61	74
4	1.93	0.79					
	14	4	18	24	69.80	38.84	11
4	1.84	0.60					

	15	4	15	25	83.67	47.38	9
4	2.55	0.99					
	16	0	7	20	0.00	48.15	5
0	0.00	0.00					
	17	4	11	24	113.83	66.85	7
3	2.44	0.86					
	18	5	10	8	156.00	86.02	18
4	1.64	0.50					
	19	0	15	16	0.00	21.75	14
2	1.44	0.49					
	20	1	7	15	44.96	48.15	7
2	1.44	0.45					
	21	1	18	18	17.52	18.04	15
4	2.37	0.94					
	22	2	7	14	89.60	72.07	7
3	1.41	0.67					
	23	3	61	25	15.51	9.23	36
4	2.64	1.03					
	24	1	28	16	11.27	11.49	26
2	1.22	0.41					
	25	1	3	15	104.42	120.75	3
1	1.51	0.56					
	26	2	11	16	57.16	44.09	10
2	2.61	0.83					
	27	2	26	12	24.25	17.86	32
1	2.42	0.49					
	28	1	14	16	22.52	23.35	13
4	1.56	0.59					
	29	1	22	24	14.34	14.69	13
4	1.70	0.48					
	30	1	7	12	44.96	48.15	9
1	1.30	0.50					
	31	1	2	10	156.00	191.32	3
1	2.13	1.37					
	32	2	17	9	37.05	27.79	28
3	1.53	0.51					
	33	0	11	12	0.00	29.97	13
1	1.47	0.58					
	34	2	19	14	33.16	24.74	20
2	1.84	0.63					
	35	7	118	36	18.71	7.37	48
4	1.80	0.57					
	36	3	9	14	104.42	69.93	9
4	1.56	0.49					
	37	2	20	25	31.50	23.45	12
4	2.90	1.14					

Mean Dpar = 1.88
 Mean Dper = 0.68
 Chi-squared = 61.408
 Chi-squared prob= 0.005
 Pooled Age (Ma) = 34.3+/- 4.3
 Mean Age (Ma) = 46.8+/- 8.0
 W.Mean Age (Ma) = 21.2+/- 3.4
 Median Age (Ma) = 32.3- 4.4+ 11.4

GU-06

Etch	Grain Number Figures	Natural Dpar Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
	1	2	31	49	22.85	16.73	8
2	3.78	1.49					
	2	1	6	12	58.86	63.69	7
3	2.57	0.54					
	3	0	2	12	0.00	214.61	2
1	1.67	0.43					
	4	8	84	21	33.70	12.65	52
4	1.98	0.58					
	5	0	5	15	0.00	77.43	4
3	1.67	0.32					
	6	8	70	28	40.42	15.30	33
4	1.69	0.11					
	7	0	6	40	0.00	63.69	2
3	5.29	1.39					
	8	4	54	16	26.23	13.69	44
4	1.90	0.46					
	9	10	11	25	314.72	138.95	6
4	1.90	0.28					
	10	0	1	15	0.00	488.91	1
0	0.00	0.00					
	11	0	1	16	0.00	488.91	1
0	0.00	0.00					
	12	1	9	9	39.30	41.50	13
2	1.85	0.20					
	13	1	10	12	35.38	37.18	11
2	1.63	0.45					
	14	0	5	15	0.00	77.43	4
3	2.79	0.66					
	15	1	7	18	50.49	54.07	5
1	2.37	0.95					
	16	4	11	15	127.74	75.02	10
3	2.78	0.55					
	17	2	15	16	47.13	35.61	12
2	0.83	0.31					
	18	1	5	16	70.57	77.43	4
1	1.18	0.16					
	19	3	13	30	81.36	52.37	6
3	1.14	0.18					
	20	3	14	24	75.58	48.32	8
4	1.70	0.37					
	21	0	5	28	0.00	77.43	2
0	0.00	0.00					
	22	5	28	9	63.04	30.87	41
4	1.88	0.21					
	23	2	22	28	32.17	23.85	10
2	1.99	0.79					
	24	0	1	16	0.00	488.91	1
0	0.00	0.00					
	25	1	9	18	39.30	41.50	7
1	4.02	0.79					

	26	0	8	24	0.00	46.96	4
1	2.51	0.20					
	27	1	2	25	174.99	214.61	1
4	1.46	0.14					
	28	31	239	60	45.85	9.22	52
4	1.57	0.17					
	29	1	10	18	35.38	37.18	7
1	1.15	0.23					
	30	0	6	36	0.00	63.69	2
0	0.00	0.00					
	31	0	14	24	0.00	26.23	8
0	0.00	0.00					
	32	1	1	16	345.36	488.91	1
4	1.67	0.47					
	33	1	10	25	35.38	37.18	5
1	1.86	0.35					
	34	8	89	9	31.81	11.91	129
4	1.91	0.50					
	35	1	4	8	88.09	98.65	7
1	1.47	0.27					
	36	1	10	9	35.38	37.18	15
4	2.00	0.64					

Mean Dpar = 2.07
 Mean Dper = 0.47
 Chi-squared = 50.063
 Chi-squared prob= 0.048
 Pooled Age (Ma) = 44.1+/- 5.4
 Mean Age (Ma) = 54.7+/- 13.9
 W.Mean Age (Ma) = 36.4+/- 4.9
 Median Age (Ma) = 35.4- 8.9+ 6.4

GU-07

Etch	Grain Dpar Number Figures	Natural Dper Tracks (microns)	Induced Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
	1	0	12	24	0.00	31.11	6
1	1.10	0.17					
	2	0	4	35	0.00	99.78	1
0	0.00	0.00					
	3	2	7	16	101.73	81.82	6
1	2.47	0.49					
	4	3	110	30	9.78	5.76	47
0	0.00	0.00					
	5	4	49	30	29.23	15.31	21
3	2.08	0.33					
	6	1	4	28	89.10	99.78	2
3	1.40	0.31					
	7	7	105	42	23.88	9.44	32
3	1.70	0.23					
	8	2	8	8	89.10	70.67	13
4	1.86	0.29					

Mean Dpar = 1.77
 Mean Dper = 0.30
 Chi-squared = 12.963
 Chi-squared prob= 0.073
 Pooled Age (Ma) = 22.8+/- 5.6
 Mean Age (Ma) = 43.0+/- 16.6
 W.Mean Age (Ma) = 15.5+/- 4.7
 Median Age (Ma) = 26.6- 12.1+ 35.0

GU-08

Etch	Grain Dpar Number Figures	Natural Dper Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
	1	0	10	100	0.00	37.53	1
3	1.93	0.63					
	2	0	6	100	0.00	64.30	1
0	0.00	0.00					
	3	1	5	30	71.24	78.18	2
4	1.54	0.45					
	4	0	20	40	0.00	18.36	6
2	2.54	0.66					
	5	0	1	16	0.00	493.49	1
0	0.00	0.00					
	6	1	41	30	8.73	8.85	18
4	1.49	0.40					
	7	1	8	16	44.62	47.41	6
4	1.39	0.28					
	8	9	125	42	25.74	9.03	39
4	1.66	0.26					
	9	2	13	14	54.87	41.82	12
4	1.55	0.37					
	10	4	15	16	94.82	53.70	12
4	1.49	0.24					
	11	23	157	150	52.26	12.13	14
4	1.72	0.18					
	12	1	16	40	22.35	23.08	5
1	2.50	0.71					
	13	0	1	15	0.00	493.49	1
3	1.65	0.11					
	14	7	71	24	35.22	14.13	38
4	1.82	0.32					
	15	0	1	20	0.00	493.49	1
3	1.49	0.25					
	16	0	1	50	0.00	493.49	0
3	1.43	0.19					
	17	1	2	9	176.66	216.65	3
2	1.78	0.20					
	18	0	15	9	0.00	24.66	22
1	1.87	0.39					
	19	1	20	64	17.89	18.36	4
4	1.47	0.32					
	20	2	9	45	79.11	62.05	3
2	1.48	0.20					

	21	9	97	160	33.15	11.74	8
4	2.28	0.43					
	22	4	14	50	101.54	57.93	4
4	1.53	0.23					
	23	0	4	12	0.00	99.59	4
1	1.06	0.33					
	24	0	3	36	0.00	136.82	1
4	1.55	0.22					
	25	4	28	40	50.97	27.44	9
4	1.77	0.25					
	26	2	6	18	118.31	96.89	4
3	2.01	0.30					
	27	1	10	28	35.72	37.53	5
3	1.77	0.21					
	28	2	21	40	34.02	25.27	7
4	1.44	0.13					
	29	5	56	50	31.90	15.03	15
4	1.56	0.22					
	30	0	2	21	0.00	216.65	1
0	0.00	0.00					
	31	1	15	30	23.84	24.66	6
1	1.94	0.24					
	32	2	12	24	59.43	45.54	6
4	1.46	0.18					
	33	2	12	40	59.43	45.54	4
3	1.44	0.16					
	34	1	5	12	71.24	78.18	5
1	2.26	0.45					
	35	10	142	20	25.18	8.39	92
4	1.98	0.25					
	36	2	14	40	50.97	38.66	5
4	1.55	0.23					
	37	2	21	42	34.02	25.27	6
2	2.18	0.67					
	38	1	64	10	5.59	5.65	83
2	2.48	0.80					
	39	1	73	16	4.90	4.95	59
1	1.99	0.14					
	40	0	2	64	0.00	216.65	0
2	2.76	1.09					
	41	6	41	25	52.21	23.06	21
3	1.19	0.35					

Mean Dpar = 1.76
 Mean Dper = 0.34
 Chi-squared = 43.283
 Chi-squared prob= 0.333
 Pooled Age (Ma) = 32.7+/- 3.9
 Mean Age (Ma) = 36.1+/- 6.6
 W.Mean Age (Ma) = 17.7+/- 2.7
 Median Age (Ma) = 31.9- 7.5+ 4.8

GU-09

Grain	Natural	Induced	Quads	FT Age	1 sigma	Uranium
Etch	Dpar	Dper				

Figures	Number (microns)	Tracks (microns)	Tracks (microns)	(dmnls)	(Ma)	(Ma)	(ppm)
	1	4	104	16	13.74	7.05	84
4	1.99	0.54					
	2	0	27	36	0.00	13.50	10
4	1.53	0.55					
	3	2	25	18	28.54	21.05	18
4	1.84	0.48					
	4	5	60	50	29.72	13.96	16
3	2.26	0.73					
	5	1	74	16	4.83	4.87	60
1	1.73	0.91					
	6	7	141	40	17.72	6.95	46
4	1.76	0.44					
	7	0	15	30	0.00	24.62	6
3	1.41	0.54					
	8	1	10	24	35.65	37.46	5
2	2.14	0.70					
	9	1	12	9	29.72	31.00	17
4	1.80	0.56					
	10	1	16	20	22.31	23.04	10
3	2.14	0.56					
	11	11	69	18	56.74	18.77	50
4	1.76	0.41					
	12	0	8	16	0.00	47.32	6
1	2.66	1.09					
	13	1	17	16	21.00	21.65	14
3	1.78	0.43					
	14	1	73	15	4.90	4.94	63
2	2.51	0.71					
	15	2	15	24	47.49	35.88	8
3	2.23	0.40					
	16	0	3	28	0.00	136.56	1
1	1.48	0.76					
	17	2	22	18	32.42	24.03	16
4	1.58	0.50					
	18	2	24	36	29.72	21.96	9
3	1.46	0.39					
	19	1	6	9	59.31	64.17	9
3	1.99	0.44					
	20	0	3	21	0.00	136.56	2
0	0.00	0.00					
	21	7	21	21	118.08	52.08	13
4	1.92	0.53					
	22	5	111	30	16.08	7.42	48
3	1.55	0.49					
	23	3	15	16	71.11	45.20	12
4	1.82	0.42					

Mean Dpar = 1.88
 Mean Dper = 0.57
 Chi-squared = 43.307
 Chi-squared prob= 0.004
 Pooled Age (Ma) = 23.4+/- 3.5
 Mean Age (Ma) = 27.8+/- 6.3
 W.Mean Age (Ma) = 12.3+/- 2.5

Median Age (Ma) = 22.3- 5.5+ 3.7

GU-10

Etch	Grain Dpar Number Figures	Natural Dper Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
	1	1	58	12	6.15	6.21	63
4	1.37	0.40					
	2	2	15	36	47.40	35.81	5
4	1.62	0.42					
	3	1	19	16	18.75	19.28	15
4	1.62	0.39					
	4	4	164	18	8.70	4.44	118
4	1.49	0.37					
	5	4	60	12	23.75	12.35	65
4	1.67	0.47					
	6	5	13	18	135.80	71.98	9
4	1.46	0.37					
	7	3	109	20	9.81	5.78	71
2	1.99	0.47					
	8	2	32	42	22.26	16.29	10
1	3.36	1.07					
	9	0	43	9	0.00	8.41	62
0	0.00	0.00					
	10	5	182	64	9.80	4.48	37
4	1.62	0.47					
	11	10	117	28	30.43	10.21	54
4	1.82	0.47					

Mean Dpar = 1.80
 Mean Dper = 0.49
 Chi-squared = 37.018
 Chi-squared prob= 0.000
 Pooled Age (Ma) = 16.2+/- 2.9
 Mean Age (Ma) = 28.5+/- 12.3
 W.Mean Age (Ma) = 10.5+/- 2.3
 Median Age (Ma) = 18.8- 4.5+ 3.9

GU-11

Etch	Grain Dpar Number Figures	Natural Dper Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
	1	1	7	9	50.68	54.27	10
2	1.31	0.43					
	2	4	146	40	9.75	4.98	48
4	1.58	0.46					
	3	0	4	30	0.00	99.02	2
1	1.87	0.73					

	4	2	1	36	675.62	828.58	0
4	1.72	0.45					
	5	2	10	16	70.84	55.06	8
4	1.67	0.38					
	6	2	43	9	16.54	12.01	62
2	1.42	0.45					
	7	0	5	25	0.00	77.73	3
3	1.42	0.48					
	8	1	5	16	70.84	77.73	4
3	1.74	0.45					
	9	1	3	30	117.64	136.04	1
4	1.53	0.51					
	10	0	6	16	0.00	63.93	5
4	1.65	0.39					
	11	2	30	35	23.70	17.37	11
4	1.51	0.42					
	12	1	11	16	32.30	33.79	9
1	1.45	0.43					
	13	3	2	16	513.24	469.65	2
2	1.53	0.38					
	14	7	90	44	27.64	10.99	27
4	1.51	0.43					
	15	0	1	16	0.00	490.74	1
1	1.36	0.40					
	16	1	7	16	50.68	54.27	6
4	1.39	0.44					
	17	0	25	30	0.00	14.54	11
4	1.70	0.48					
	18	1	8	30	44.37	47.14	3
4	1.99	0.72					
	19	2	18	16	39.45	29.51	15
4	1.32	0.35					

Mean Dpar = 1.56
 Mean Dper = 0.46
 Chi-squared = 54.261
 Chi-squared prob= 0.000
 Pooled Age (Ma) = 25.3+/- 5.0
 Mean Age (Ma) = 94.2+/- 45.1
 W.Mean Age (Ma) = 14.6+/- 3.9
 Median Age (Ma) = 32.3- 9.6+ 9.9

GU-12

Etch	Grain Number Figures	Natural Dpar Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
	1	5	66	24	26.87	12.58	36
3	1.45	0.35					
	2	1	23	16	15.44	15.80	19
4	1.74	0.39					
	3	1	6	10	58.97	63.81	8
4	1.65	0.53					

	4	1	16	15	22.18	22.90	14
1	1.89	0.84					
	Mean Dpar = 1.68 Mean Dper = 0.53 Chi-squared = 0.919 Chi-squared prob= 0.821 Pooled Age (Ma) = 25.6+/- 9.5 Mean Age (Ma) = 30.9+/- 11.4 W.Mean Age (Ma) = 23.1+/- 9.0 Median Age (Ma) = 24.5- 4.9+ 15.7						

GU-13

Etch	Grain Number	Natural Dpar Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
	1	19	15	10	400.97	140.82	21
4	1.77	0.34					
	2	1	1	6	318.61	451.03	2
3	2.19	0.53					
	3	27	33	21	261.84	69.95	22
4	2.00	0.18					
	4	1	13	12	25.08	26.07	15
1	3.06	0.91					
	5	25	10	6	768.81	291.78	24
4	1.64	0.22					
	6	2	25	18	26.08	19.23	20
2	1.80	0.18					
	Mean Dpar = 2.08 Mean Dper = 0.39 Chi-squared = 35.138 Chi-squared prob= 0.000 Pooled Age (Ma) = 247.7+/- 41.2 Mean Age (Ma) = 305.2+/-129.7 W.Mean Age (Ma) = 43.4+/- 15.2 Median Age (Ma) = 290.2-175.1+ 73.4						

GU-14

Etch	Grain Number	Natural Dpar Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
	1	13	26	30	161.80	55.91	12
4	1.73	0.42					
	2	3	9	9	108.32	72.54	14
2	2.24	0.22					
	3	74	53	30	442.02	84.35	25
4	2.12	0.31					

	4	0	4	4	0.00	91.16	14
1	1.62	0.20					
	5	0	20	9	0.00	16.80	31
1	1.19	0.41					
	6	55	16	10	1038.17	302.17	23
4	1.88	0.29					

Mean Dpar = 1.80
 Mean Dper = 0.31
 Chi-squared = 55.384
 Chi-squared prob= 0.000
 Pooled Age (Ma) = 360.9+/- 49.4
 Mean Age (Ma) = 302.3+/-190.6
 W.Mean Age (Ma) = 35.0+/- 15.3
 Median Age (Ma) = 135.1- 89.5+203.5

GU-15

Etch	Grain Number	Natural Dpar Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
Figures							
	1	2	8	20	81.67	64.78	6
2	2.02	0.45					
	2	3	5	25	194.31	142.44	3
2	2.97	0.33					
	3	16	24	6	215.54	70.90	56
4	2.20	0.23					
	4	7	43	56	53.30	21.99	11
4	1.93	0.37					
	5	0	8	9	0.00	43.53	13
1	1.28	0.20					
	6	8	6	6	424.10	230.62	14
4	2.08	0.48					
	7	11	23	16	155.35	57.80	20
4	2.34	0.39					
	8	10	33	40	98.87	36.24	12
4	1.91	0.26					
	9	10	15	24	215.54	89.05	9
4	1.93	0.23					
	10	30	37	70	261.21	66.28	7
4	1.88	0.15					
	11	5	12	24	135.55	72.67	7
4	2.12	0.36					
	12	79	61	30	412.32	75.00	29
4	1.98	0.15					
	13	13	5	24	802.69	425.47	3
3	1.79	0.41					
	14	1	5	6	65.42	71.79	12
1	0.94	0.43					
	15	59	61	60	310.40	60.01	14
4	2.08	0.36					
	16	10	43	24	76.01	27.12	25
4	1.94	0.42					

	17	10	8	6	398.40	190.66	19
4	1.49	0.25					
	18	29	127	18	74.64	16.08	100
4	1.89	0.20					
	19	70	96	30	235.38	39.90	45
4	1.81	0.37					
	20	33	55	14	194.31	44.53	55
4	2.34	0.16					
	21	13	34	25	124.50	41.36	19
4	1.93	0.35					
	22	12	25	21	155.91	55.64	17
4	1.92	0.43					
	23	10	25	25	130.19	49.41	14
4	1.53	0.30					
	24	7	14	8	162.33	75.85	25
4	1.78	0.32					
	25	89	117	70	245.36	37.87	24
4	1.96	0.45					
	26	9	31	70	94.75	36.38	6
4	2.10	0.38					
	27	41	23	30	560.94	150.42	11
4	1.80	0.17					
	28	64	164	100	127.04	20.39	23
4	1.93	0.31					
	29	38	53	60	231.52	51.36	12
4	1.88	0.36					
	30	79	182	40	141.15	21.03	64
4	2.20	0.52					
	31	11	14	40	253.28	103.31	5
4	1.52	0.34					

Mean Dpar = 1.92
 Mean Dper = 0.33
 Chi-squared = 146.904
 Chi-squared prob= 0.000
 Pooled Age (Ma) = 186.0+/- 14.5
 Mean Age (Ma) = 216.0+/- 34.3
 W.Mean Age (Ma) = 125.1+/- 10.4
 Median Age (Ma) = 162.3- 13.7+ 23.5

GU-16

	Grain	Natural	Induced	Quads	FT Age	1 sigma	Uranium
Etch	Dpar	Dper					
Number	Tracks	Tracks	(dmnls)	(Ma)	(Ma)	(ppm)	
Figures	(microns)	(microns)					
	1	1	6	6	54.74	59.23	14
2	2.41	0.17					
	2	2	8	10	81.94	64.99	11
2	1.93	0.46					
	3	0	7	4	0.00	50.28	25
3	1.47	0.22					
	4	1	30	4	10.99	11.19	105
2	1.17	0.31					

	5	0	3	18	0.00	126.08	2
1	2.26	0.88					
	6	1	7	24	46.95	50.28	4
4	1.51	0.20					
	7	0	2	6	0.00	199.72	5
3	2.07	0.36					
	8	2	10	9	65.64	51.01	16
1	1.36	0.14					
	9	1	12	4	27.43	28.60	42
1	1.84	0.18					
	10	1	1	6	321.69	455.40	2
4	2.41	0.55					
	11	2	33	12	19.96	14.59	39
2	1.20	0.14					
	12	5	23	2	71.31	35.48	162
4	1.94	0.16					
	13	2	3	9	216.23	197.87	5
3	1.19	0.26					
	14	0	1	36	0.00	455.40	0
2	1.39	0.31					
	15	2	4	2	162.85	141.41	28
2	1.77	0.16					
	16	4	24	6	54.74	29.77	56
3	1.81	0.24					

Mean Dpar = 1.73
 Mean Dper = 0.30
 Chi-squared = 16.396
 Chi-squared prob= 0.356
 Pooled Age (Ma) = 45.3+/- 10.3
 Mean Age (Ma) = 71.5+/- 24.1
 W.Mean Age (Ma) = 24.2+/- 7.6
 Median Age (Ma) = 50.8- 17.4+ 9.9

GU-17

Etch	Grain Number	Natural Dpar Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
Figures							
	1	0	6	8	0.00	59.42	11
1	2.51	0.23					
	2	1	3	12	109.38	126.49	4
3	1.42	0.18					
	3	2	16	6	41.23	31.04	37
2	2.27	0.35					
	4	1	5	28	65.85	72.26	3
4	1.62	0.40					
	5	0	51	24	0.00	6.56	30
4	1.71	0.19					
	6	1	7	12	47.10	50.44	8
1	1.33	0.41					
	7	2	7	9	93.87	75.50	11
4	2.97	0.22					

	8	7	55	12	41.98	17.06	64
4	1.50	0.33					
	9	1	11	9	30.01	31.41	17
1	2.23	0.49					
	10	2	6	12	109.38	89.58	7
4	1.61	0.21					
	11	5	71	24	23.26	10.86	41
2	1.64	0.24					
	12	1	7	8	47.10	50.44	12
2	2.30	0.24					
	13	2	19	21	34.74	25.92	13
1	2.30	0.53					
	14	1	5	18	65.85	72.26	4
3	2.43	0.57					
	15	8	47	16	56.08	21.74	41
4	1.35	0.34					
	16	3	16	24	61.75	39.05	9
4	2.72	0.85					
	17	3	24	21	41.23	25.39	16
4	2.30	0.56					
	18	0	8	15	0.00	43.81	7
2	3.18	0.22					
	19	2	27	35	24.47	18.00	11
4	1.71	0.21					
	20	3	13	25	75.92	48.87	7
3	2.08	0.25					
	21	0	1	24	0.00	456.85	1
3	2.41	0.29					
	22	0	4	24	0.00	92.06	2
2	2.01	0.23					
	23	12	50	42	78.94	25.87	17
4	1.58	0.43					
	24	3	76	20	13.05	7.73	53
2	2.01	0.23					
	25	4	44	25	30.01	15.79	25
4	1.99	0.24					
	26	1	51	15	6.49	6.56	48
2	1.81	0.27					
	27	0	7	20	0.00	50.44	5
0	0.00	0.00					
	28	0	4	12	0.00	92.06	5
4	1.68	0.36					
	29	16	146	40	36.17	9.80	51
4	1.87	0.20					
	30	0	17	15	0.00	20.04	16
2	2.38	0.43					
	31	21	114	18	60.67	14.91	89
4	1.68	0.34					
	32	1	5	16	65.85	72.26	4
4	2.58	0.34					
	33	5	43	18	38.37	18.29	33
4	2.09	0.36					

Mean Dpar = 2.04
 Mean Dper = 0.34
 Chi-squared = 38.999
 Chi-squared prob= 0.184

Pooled Age (Ma) = 36.9+/- 4.4
 Mean Age (Ma) = 39.4+/- 6.3
 W.Mean Age (Ma) = 20.0+/- 3.2
 Median Age (Ma) = 38.4- 8.4+ 6.1

GU-18

Etch	Grain Number Figures	Natural Dpar Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
	1	4	32	21	41.37	22.10	21
3	2.55	0.74					
	2	3	18	24	55.10	34.54	10
4	3.38	1.22					
	3	0	19	49	0.00	17.94	5
0	0.00	0.00					
	4	0	7	21	0.00	50.61	5
1	2.37	0.63					
	5	0	32	12	0.00	10.55	37
3	2.29	0.36					
	6	29	324	45	29.65	6.05	101
4	1.51	0.28					
	7	0	5	16	0.00	72.49	4
3	1.83	0.30					
	8	0	2	20	0.00	201.01	1
2	2.17	0.38					
	9	0	16	21	0.00	21.40	11
2	1.85	0.45					
	10	0	14	40	0.00	24.55	5
2	1.28	0.29					
	11	6	86	42	23.12	9.87	29
2	1.69	0.22					
	12	1	11	18	30.11	31.51	9
1	1.48	0.28					
	13	0	3	63	0.00	126.90	1
2	1.51	0.23					
	14	7	150	36	15.48	6.06	58
4	1.80	0.16					
	15	0	1	28	0.00	458.31	0
3	1.95	0.59					
	16	6	50	24	39.72	17.35	29
4	1.44	0.20					
	17	2	10	50	66.06	51.34	3
1	1.63	0.31					
	18	1	7	27	47.26	50.61	4
2	1.56	0.19					
	19	0	1	20	0.00	458.31	1
2	1.93	0.18					
	20	0	5	20	0.00	72.49	3
4	1.28	0.21					
	21	0	11	25	0.00	31.51	6
1	1.29	0.53					
	22	6	25	25	79.19	36.35	14
2	1.54	0.11					

	23	12	34	36	116.13	39.68	13
3	1.63	0.26					
	24	14	173	36	26.81	7.64	67
3	1.86	0.23					
	25	0	2	70	0.00	201.01	0
4	2.69	1.17					
	26	0	3	20	0.00	126.90	2
3	1.93	0.37					
	27	0	11	64	0.00	31.51	2
3	2.04	0.59					
	28	0	30	35	0.00	11.26	12
1	2.44	0.45					
	29	0	1	35	0.00	458.31	0
0	0.00	0.00					
	30	24	341	54	23.33	5.14	88
4	2.09	0.27					
	31	0	6	36	0.00	59.62	2
4	1.64	0.36					
	32	1	87	36	3.82	3.84	34
4	2.13	0.40					
	33	2	22	24	30.11	22.32	13
2	1.90	0.41					
	34	3	34	35	29.23	17.70	14
3	1.59	0.27					
	35	3	78	64	12.76	7.55	17
4	1.72	0.28					
	36	2	7	25	94.17	75.74	4
2	3.05	0.69					
	37	0	14	36	0.00	24.55	5
2	1.62	0.16					
	38	0	39	30	0.00	8.63	18
0	0.00	0.00					
	39	2	5	54	131.46	110.30	1
4	1.30	0.34					
	40	22	161	25	45.21	10.67	90
4	1.57	0.29					
	41	3	18	18	55.10	34.54	14
2	2.85	0.65					
	42	6	48	42	41.37	18.10	16
4	2.51	0.72					
	43	12	77	64	51.54	16.33	17
4	2.38	0.53					
	44	14	47	54	98.15	30.53	12
4	1.66	0.23					
	45	7	42	24	55.10	22.76	24
4	1.60	0.27					
	46	1	25	60	13.27	13.56	6
3	1.90	0.25					
	47	1	36	40	9.22	9.36	13
4	1.90	0.19					

Mean Dpar = 1.92
 Mean Dper = 0.39
 Chi-squared = 97.249
 Chi-squared prob= 0.000
 Pooled Age (Ma) = 29.6+/- 2.9
 Mean Age (Ma) = 27.0+/- 5.3

W.Mean Age (Ma) = 17.4+/- 2.1
 Median Age (Ma) = 13.3- 2.9+ 6.6

GU-19

Etch Figures	Grain Dpar Number (microns)	Natural Dper Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
1	1	1	5	16	66.28	72.72	4
1	2.29	0.37					
3	2	6	89	48	22.42	9.56	26
3	2.03	0.18					
3	3	4	6	30	218.32	141.61	3
3	1.87	0.22					
2	4	0	19	30	0.00	18.00	9
2	1.94	0.22					
2	5	1	30	48	11.09	11.30	9
2	2.49	0.29					
4	6	0	10	27	0.00	34.91	5
4	1.83	0.47					
3	7	0	5	35	0.00	72.72	2
3	2.17	0.36					
2	8	3	15	28	66.28	42.13	7
2	1.56	0.39					
3	9	0	3	25	0.00	127.31	2
3	1.78	0.34					
0	10	0	1	24	0.00	459.76	1
0	0.00	0.00					
0	11	0	3	18	0.00	127.31	2
0	0.00	0.00					
0	12	0	6	18	0.00	59.81	5
0	0.00	0.00					
1	13	1	1	12	324.77	459.76	1
1	3.72	1.10					
0	14	0	6	15	0.00	59.81	6
0	0.00	0.00					
2	15	1	49	10	6.79	6.88	68
2	2.18	0.41					
2	16	2	99	9	6.73	4.82	153
2	2.21	0.23					
1	17	2	18	54	36.90	27.61	5
1	2.26	0.37					
2	18	1	1	8	324.77	459.76	2
2	1.33	0.13					
2	19	3	37	40	26.95	16.27	13
2	2.02	0.16					
4	20	14	20	12	229.05	81.13	23
4	1.72	0.33					
2	21	4	6	15	218.32	141.61	6
2	1.06	0.06					
2	22	4	18	21	73.60	40.95	12
2	1.49	0.38					
3	23	1	32	50	10.40	10.58	9
3	2.55	0.34					

	24	2	34	16	19.56	14.29	30
1	1.72	0.24					
	25	2	9	32	73.60	57.72	4
4	1.63	0.33					
	26	2	9	80	73.60	57.72	2
4	1.87	0.46					
	27	8	124	21	21.45	7.94	82
4	1.42	0.25					
	28	8	58	100	45.78	17.51	8
2	1.67	0.48					
	29	11	157	21	23.30	7.41	104
4	2.05	0.32					
	30	0	5	16	0.00	72.72	4
1	2.02	0.65					
	31	2	35	30	19.01	13.87	16
2	1.28	0.39					
	32	6	19	14	104.34	49.31	19
4	1.76	0.49					
	33	0	5	18	0.00	72.72	4
1	1.47	0.20					
	34	2	3	18	218.32	199.78	2
1	1.89	0.40					
	35	0	2	20	0.00	201.66	1
3	2.83	0.44					
	36	0	2	6	0.00	201.66	5
1	2.08	0.33					
	37	1	7	10	47.41	50.77	10
1	1.95	0.64					
	38	1	3	9	110.09	127.31	5
2	1.68	0.49					
	39	1	19	20	17.51	18.00	13
2	1.03	0.40					
	40	0	7	42	0.00	50.77	2
0	0.00	0.00					
	41	1	10	60	33.22	34.91	2
1	1.64	0.43					
	42	4	6	30	218.32	141.61	3
2	2.21	0.90					
	43	0	4	16	0.00	92.66	3
0	0.00	0.00					
	44	17	127	80	44.43	11.82	22
4	1.85	0.23					

Mean Dpar = 1.91
 Mean Dper = 0.38
 Chi-squared = 128.746
 Chi-squared prob= 0.000
 Pooled Age (Ma) = 34.3+/- 4.0
 Mean Age (Ma) = 62.3+/- 14.5
 W.Mean Age (Ma) = 17.1+/- 2.7
 Median Age (Ma) = 21.9- 5.0+ 11.7

GU-20

Etch	Grain Dpar	Natural Dper	Induced	Quads	FT Age	1 sigma	Uranium
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Figures	Number (microns)	Tracks (microns)	Tracks (microns)	(dmnls)	(Ma)	(Ma)	(ppm)
	1	1	6	36	55.46	60.00	2
2	2.31	0.14					
	2	1	9	20	37.02	39.10	6
1	2.08	0.26					

Mean Dpar = 2.19
 Mean Dper = 0.20
 Chi-squared = 0.073
 Chi-squared prob= 0.787
 Pooled Age (Ma) = 44.4+/- 33.5
 Mean Age (Ma) = 46.2+/- 13.4
 W.Mean Age (Ma) = 42.5+/- 32.8
 Median Age (Ma) = 46.2- 13.7+ 13.7

GU-21

Etch Figures	Grain Number (microns)	Natural Dpar Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
	1	4	3	10	432.19	331.23	4
4	2.99	1.06					
	2	0	4	6	0.00	93.25	9
1	2.54	0.61					
	3	10	38	9	87.63	31.64	58
3	2.69	0.67					
	4	4	14	10	95.08	54.24	19
4	2.17	0.62					
	5	1	6	10	55.64	60.20	8
3	2.21	0.65					
	6	0	10	12	0.00	35.14	12
1	4.43	0.32					
	7	34	172	24	65.93	13.06	99
4	1.87	0.22					
	8	4	9	6	147.31	89.01	21
3	1.13	0.24					
	9	1	1	4	326.83	462.67	3
2	2.25	0.28					

Mean Dpar = 2.48
 Mean Dper = 0.52
 Chi-squared = 13.738
 Chi-squared prob= 0.089
 Pooled Age (Ma) = 75.2+/- 11.9
 Mean Age (Ma) = 136.0+/- 54.4
 W.Mean Age (Ma) = 64.1+/- 11.2
 Median Age (Ma) = 87.6- 16.8+ 31.3

GU-22

Etch	Grain Number Figures	Natural Dpar Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
	1	2	18	24	37.26	27.87	10
1	1.76	0.16					
	2	4	32	27	41.91	22.38	16
1	1.64	0.31					
	3	3	12	42	83.54	54.19	4
2	2.00	0.31					
	4	1	13	36	25.82	26.85	5
1	1.86	0.36					
	5	1	9	28	37.26	39.35	4
1	2.28	0.23					
	6	7	32	15	73.16	30.88	29
2	1.83	0.23					
	7	25	52	21	159.71	40.17	34
4	1.74	0.31					
	8	7	12	14	193.27	92.73	12
4	1.85	0.28					
	9	2	16	21	41.91	31.54	11
1	1.93	0.63					
	10	0	12	18	0.00	29.16	9
1	1.85	0.20					
	11	0	1	36	0.00	464.13	0
0	0.00	0.00					
	12	13	75	50	58.04	17.82	21
3	2.43	0.29					
	13	19	130	36	48.97	12.42	50
3	1.79	0.27					
	14	6	36	30	55.81	24.87	17
3	1.63	0.40					
	15	8	43	32	62.27	24.30	19
3	2.03	0.25					
	16	7	54	21	43.45	17.67	35
4	1.99	0.39					
	17	2	1	18	639.84	784.70	1
4	1.77	0.60					
	18	2	4	24	166.01	144.16	2
4	1.44	0.47					
	19	0	2	70	0.00	203.60	0
4	1.73	0.36					
	20	3	2	100	485.74	444.49	0
2	2.68	0.19					
	21	0	5	42	0.00	73.43	2
3	1.78	0.43					
	22	2	43	40	15.62	11.35	15
2	1.90	0.41					
	23	21	152	20	46.30	11.17	105
4	1.74	0.38					
	24	1	13	12	25.82	26.85	15
1	1.94	0.31					
	25	4	44	100	30.50	16.05	6
2	1.46	0.44					
	26	0	1	40	0.00	464.13	0
0	0.00	0.00					

0	27	0	4	12	0.00	93.55	5
	0.00	0.00					
1	28	1	6	6	55.81	60.39	14
	1.63	0.23					
1	29	0	12	14	0.00	29.16	12
	1.96	0.35					
4	30	3	13	16	77.15	49.66	11
	1.63	0.28					
2	31	2	9	8	74.31	58.28	16
	2.15	0.20					
0	32	0	2	18	0.00	203.60	2
	0.00	0.00					
0	33	0	14	12	0.00	24.87	16
	0.00	0.00					
1	34	1	2	16	166.01	203.60	2
	1.80	0.45					
4	35	1	1	9	327.86	464.13	2
	1.62	0.41					
2	36	4	30	15	44.69	23.96	28
	1.62	0.31					
1	37	2	31	30	21.66	15.86	14
	1.27	0.29					
4	38	4	20	24	66.92	36.90	11
	1.58	0.24					
0	39	0	4	20	0.00	93.55	3
	0.00	0.00					
2	40	1	20	36	16.79	17.24	8
	1.91	0.38					

Mean Dpar = 1.83
 Mean Dper = 0.33
 Chi-squared = 72.901
 Chi-squared prob= 0.001
 Pooled Age (Ma) = 54.2+/- 5.8
 Mean Age (Ma) = 81.9+/- 22.4
 W.Mean Age (Ma) = 38.0+/- 4.7
 Median Age (Ma) = 42.7- 8.3+ 7.4

GU-23

Etch	Grain Number	Natural Dpar Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
Figures							
1	1	1	9	24	37.38	39.48	5
	1.75	0.41					
4	2	7	167	24	14.13	5.52	96
	1.80	0.28					
4	3	10	142	6	23.72	7.90	325
	1.73	0.24					
1	4	5	64	25	26.31	12.33	35
	2.40	0.35					
1	5	1	22	18	15.32	15.69	17
	2.26	0.35					

	6	4	20	15	67.13	37.02	18
4	1.89	0.44					

Mean Dpar = 1.97
 Mean Dper = 0.34
 Chi-squared = 6.496
 Chi-squared prob= 0.261
 Pooled Age (Ma) = 22.2+/- 4.6
 Mean Age (Ma) = 30.7+/- 9.1
 W.Mean Age (Ma) = 18.9+/- 4.2
 Median Age (Ma) = 25.0- 6.4+ 8.2

GU-24

	Grain Etch	Natural Dpar	Induced Dper	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
	Number Figures	Tracks (microns)	Tracks (microns)				
	1	3	16	9	63.16	39.94	24
2	2.11	0.27					
	2	80	115	32	231.28	36.74	49
4	1.96	0.43					

Mean Dpar = 2.03
 Mean Dper = 0.35
 Chi-squared = 4.644
 Chi-squared prob= 0.031
 Pooled Age (Ma) = 211.0+/- 32.5
 Mean Age (Ma) = 147.8+/-120.6
 W.Mean Age (Ma) = 160.5+/- 27.6
 Median Age (Ma) = 147.2-124.6+124.6

GU-25

	Grain Etch	Natural Dpar	Induced Dper	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
	Number Figures	Tracks (microns)	Tracks (microns)				
	1	2	78	36	8.70	6.26	30
1	2.66	0.57					
	2	0	7	15	0.00	51.76	6
1	1.95	0.20					
	3	3	68	60	14.96	8.88	15
2	2.05	0.34					
	4	31	71	15	146.59	32.90	65
4	2.30	0.34					
	5	1	7	16	48.33	51.76	6
1	1.84	0.46					
	6	0	4	12	0.00	94.45	5
0	0.00	0.00					
	7	0	2	6	0.00	205.53	5
2	1.84	0.33					

	8	1	4	10	84.34	94.45	5
2	1.90	0.51					
	9	1	6	20	56.35	60.97	4
1	1.82	0.71					
	10	0	15	10	0.00	23.38	20
0	0.00	0.00					
	11	2	7	30	96.30	77.45	3
1	1.88	0.12					
	12	0	52	28	0.00	6.60	25
1	2.15	0.44					
	13	0	27	21	0.00	12.82	18
1	2.05	0.32					
	14	3	42	15	24.21	14.55	38
3	1.88	0.23					
	15	6	41	24	49.50	21.87	23
4	1.91	0.30					
	16	25	41	49	203.80	53.31	11
4	1.75	0.48					
	17	48	85	42	188.97	36.17	28
4	1.88	0.26					
	18	0	3	9	0.00	129.77	5
4	2.05	0.25					
	19	4	153	42	8.87	4.53	50
2	1.93	0.28					
	20	0	9	9	0.00	39.73	14
1	1.76	0.16					
	21	0	2	48	0.00	205.53	1
0	0.00	0.00					
	22	70	202	105	116.61	17.79	26
4	1.86	0.15					
	23	93	145	99	214.20	31.54	20
4	1.75	0.32					

Mean Dpar = 1.96
 Mean Dper = 0.34
 Chi-squared = 184.485
 Chi-squared prob= 0.000
 Pooled Age (Ma) = 91.3+/- 8.4
 Mean Age (Ma) = 55.2+/- 15.9
 W.Mean Age (Ma) = 16.4+/- 2.9
 Median Age (Ma) = 15.0- 4.7+ 23.8

GU-26

Etch	Grain Number Figures	Natural Dpar Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
	1	8	105	16	24.75	9.21	94
4	2.07	0.23					
	2	1	21	18	15.48	15.88	17
1	1.70	0.26					
	3	0	1	4	0.00	449.58	4
0	0.00	0.00					

	4	0	6	35	0.00	58.46	2
2	2.32	0.77					
	5	1	8	18	40.56	43.10	6
1	1.64	0.37					
	6	1	17	10	19.12	19.71	24
1	1.70	0.33					
	7	2	5	2	128.91	108.17	36
2	2.14	0.64					

Mean Dpar = 1.93
 Mean Dper = 0.43
 Chi-squared = 5.697
 Chi-squared prob= 0.458
 Pooled Age (Ma) = 25.9+/- 7.6
 Mean Age (Ma) = 32.8+/- 18.5
 W.Mean Age (Ma) = 22.6+/- 7.3
 Median Age (Ma) = 19.1- 6.9+ 8.2

GU-27

	Grain Etch Figures	Natural Dpar Number (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
	1	13	36	50	116.11	38.29	10
4	2.23	0.34					
	2	4	37	4	34.98	18.55	132
3	2.44	0.60					
	3	0	21	9	0.00	15.83	33
1	2.56	0.29					

Mean Dpar = 2.41
 Mean Dper = 0.41
 Chi-squared = 9.527
 Chi-squared prob= 0.009
 Pooled Age (Ma) = 58.4+/- 15.8
 Mean Age (Ma) = 50.5+/- 42.5
 W.Mean Age (Ma) = 24.1+/- 11.5
 Median Age (Ma) = 35.0- 18.3+ 42.5

GU-28

	Grain Etch Figures	Natural Dpar Number (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
	1	0	18	8	0.00	18.47	32
1	2.85	1.18					
	2	0	25	21	0.00	13.20	17
2	1.75	0.35					
	3	1	5	55	64.35	70.61	1
1	2.09	0.27					

	4	1	26	8	12.43	12.69	47
1	0.90	0.04					
	5	1	26	8	12.43	12.69	47
1	1.96	0.23					
	6	0	4	21	0.00	89.97	3
0	0.00	0.00					
	7	24	444	200	17.46	3.82	32
2	2.07	0.53					

Mean Dpar = 1.94
 Mean Dper = 0.43
 Chi-squared = 4.551
 Chi-squared prob= 0.602
 Pooled Age (Ma) = 15.9+/- 3.3
 Mean Age (Ma) = 15.3+/- 9.4
 W.Mean Age (Ma) = 15.3+/- 3.4
 Median Age (Ma) = 12.4- 7.5+ 1.5

GU-29

Etch	Grain Dpar Number Figures	Natural Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
	1	3	9	9	106.54	71.35	14
2	2.23	0.35					
	2	1	10	15	32.15	33.78	10
1	1.97	0.24					
	3	26	53	18	156.20	38.69	42
4	1.66	0.45					
	4	10	89	15	36.11	12.26	85
4	2.17	0.50					
	5	1	9	6	35.71	37.71	22
1	2.56	0.53					
	6	1	37	18	8.70	8.84	30
1	2.28	0.27					
	7	3	187	49	5.17	3.03	55
2	1.44	0.32					
	8	19	89	32	68.44	17.83	40
4	1.55	0.41					
	9	25	27	6	291.71	83.06	65
2	1.39	0.36					
	10	0	4	18	0.00	89.67	3
2	1.95	0.33					

Mean Dpar = 1.92
 Mean Dper = 0.38
 Chi-squared = 101.799
 Chi-squared prob= 0.000
 Pooled Age (Ma) = 55.6+/- 7.3
 Mean Age (Ma) = 74.7+/- 31.2
 W.Mean Age (Ma) = 10.2+/- 2.8
 Median Age (Ma) = 35.9- 13.4+ 34.9

PFT-02

Etch Figures	Grain Dpar Number (microns)	Natural Dper Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
1	1	3	15	64	53.41	33.95	4
1	1.89	0.26					
4	2	12	107	70	30.00	9.33	26
4	1.74	0.23					
1	3	0	8	24	0.00	35.52	6
1	1.84	0.23					
4	4	19	65	70	77.91	20.91	16
4	1.66	0.29					
4	5	7	34	30	54.97	23.08	20
4	1.57	0.23					
4	6	35	22	49	413.09	115.41	8
4	1.68	0.13					
4	7	50	70	64	188.75	36.94	19
4	1.62	0.26					
4	8	9	28	64	85.62	33.25	8
4	1.40	0.15					
4	9	25	72	40	92.44	22.25	31
4	1.67	0.22					
4	10	8	24	100	88.77	36.68	4
4	1.78	0.26					
4	11	57	124	50	122.10	21.02	43
4	1.99	0.30					
4	12	28	167	63	44.80	9.58	46
4	1.70	0.25					
4	13	105	193	64	144.26	19.74	52
4	1.90	0.29					
4	14	30	44	40	180.29	44.19	19
4	1.84	0.17					
4	15	37	153	24	64.52	12.51	110
4	1.56	0.25					
2	16	1	246	64	1.09	1.09	67
2	1.60	0.22					
4	17	13	45	32	77.00	24.73	24
4	1.57	0.22					
4	18	20	76	35	70.18	18.19	38
4	1.59	0.35					
4	19	13	150	60	23.20	6.87	43
4	1.57	0.25					
4	20	9	47	64	51.15	18.89	13
4	1.48	0.28					
4	21	48	24	100	515.16	132.87	4
4	1.55	0.19					
2	22	1	11	64	24.33	25.46	3
2	1.40	0.13					

Mean Dpar = 1.66
 Mean Dper = 0.23
 Chi-squared = 309.124
 Chi-squared prob= 0.000
 Pooled Age (Ma) = 81.9+/- 6.6

Mean Age (Ma) = 110.4+/- 29.2
 W.Mean Age (Ma) = 5.6+/- 1.1
 Median Age (Ma) = 73.6- 9.3+ 15.7

PFT-06

Etch Figures	Grain Dpar Number (microns)	Natural Dper Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
	1	0	6	64	0.00	48.38	2
2	1.81	0.39					
	2	5	62	64	21.68	10.17	17
4	2.55	0.39					
	3	1	5	40	53.62	58.84	2
4	1.29	0.33					
	4	1	12	45	22.40	23.36	5
4	2.15	0.37					
	5	0	9	35	0.00	31.52	4
4	1.57	0.24					
	6	1	13	30	20.68	21.50	7
2	2.13	0.35					
	7	0	7	64	0.00	41.07	2
3	2.03	0.52					
	8	1	8	45	33.57	35.67	3
3	1.73	0.24					
	9	2	5	64	106.80	89.62	1
2	1.86	0.36					
	10	2	11	72	48.77	37.61	3
3	1.71	0.36					
	11	1	23	64	11.70	11.97	6
4	1.64	0.23					
	12	0	10	60	0.00	28.23	3
4	1.86	0.30					
	13	0	11	64	0.00	25.56	3
1	1.30	0.24					
	14	1	5	28	53.62	58.84	3
1	1.59	0.31					
	15	0	11	40	0.00	25.56	5
3	1.26	0.26					
	16	1	12	54	22.40	23.36	4
1	2.12	0.74					
	17	1	6	60	44.72	48.38	2
3	1.78	0.19					
	18	0	7	36	0.00	41.07	3
4	2.10	0.55					
	19	1	18	45	14.94	15.38	7
1	2.10	0.29					
	20	0	7	45	0.00	41.07	3
4	1.59	0.29					
	21	1	6	60	44.72	48.38	2
4	1.64	0.33					
	22	0	4	60	0.00	74.98	1
4	1.65	0.35					

	23	1	31	80	8.68	8.84	7
2	3.46	0.83					
	24	0	5	49	0.00	58.84	2
0	0.00	0.00					
	25	1	8	49	33.57	35.67	3
2	2.17	0.53					
	26	0	13	60	0.00	21.50	4
4	2.02	0.38					
	27	1	4	56	66.96	74.98	1
1	1.85	0.39					
	28	1	9	80	29.85	31.52	2
2	1.98	0.44					
	29	0	7	35	0.00	41.07	3
0	0.00	0.00					
	30	0	7	64	0.00	41.07	2
3	1.47	0.29					
	31	0	9	100	0.00	31.52	2
2	1.63	0.29					
	32	0	11	60	0.00	25.56	3
0	0.00	0.00					
	33	0	9	80	0.00	31.52	2
4	3.16	1.55					
	34	0	16	49	0.00	17.36	6
4	1.72	0.47					
	35	0	4	36	0.00	74.98	2
0	0.00	0.00					
	36	0	4	36	0.00	74.98	2
1	1.23	0.31					
	37	3	24	56	33.57	20.67	7
3	2.23	0.44					
	38	3	18	90	44.72	28.03	3
3	1.90	0.42					
	39	1	8	40	33.57	35.67	3
2	1.53	0.33					
	40	0	13	60	0.00	21.50	4
0	0.00	0.00					
	41	1	29	56	9.28	9.45	9
2	1.56	0.58					

Mean Dpar = 1.87
 Mean Dper = 0.41
 Chi-squared = 31.912
 Chi-squared prob= 0.815
 Pooled Age (Ma) = 17.1+/- 3.4
 Mean Age (Ma) = 18.6+/- 4.0
 W.Mean Age (Ma) = 13.3+/- 3.6
 Median Age (Ma) = 8.7- 2.0+ 5.8

PFT-08

Etch	Grain Number Figures	Natural Dpar Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
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	1	1	23	100	11.74	12.02	4
4	1.76	0.38					
	2	0	5	64	0.00	59.08	1
0	0.00	0.00					
	3	0	5	24	0.00	59.08	4
1	2.32	0.24					
	4	0	7	64	0.00	41.23	2
2	2.09	0.36					
	5	2	83	100	6.51	4.68	14
4	1.64	0.32					
	6	1	16	100	16.87	17.43	3
3	1.68	0.43					
	7	2	46	100	11.74	8.51	8
3	1.68	0.25					
	8	0	1	100	0.00	374.87	0
0	0.00	0.00					
	9	10	143	60	18.88	6.29	41
4	1.47	0.24					
	10	0	7	100	0.00	41.23	1
0	0.00	0.00					
	11	0	10	64	0.00	28.34	3
4	2.09	0.25					
	12	0	4	64	0.00	75.28	1
4	1.56	0.21					
	13	4	73	100	14.79	7.66	13
4	1.80	0.33					
	14	3	93	64	8.71	5.14	25
3	1.58	0.17					
	15	0	12	64	0.00	23.45	3
4	1.48	0.44					
	16	1	45	50	6.00	6.08	15
1	1.74	0.26					
	17	0	11	100	0.00	25.67	2
0	0.00	0.00					
	18	0	6	64	0.00	48.58	2
2	2.06	0.16					
	19	0	52	80	0.00	5.26	11
1	1.71	0.09					
	20	2	15	100	35.94	27.15	3
3	2.38	0.62					
	21	2	41	70	13.17	9.58	10
4	1.49	0.29					
	22	0	17	100	0.00	16.37	3
4	1.87	0.54					
	23	0	7	50	0.00	41.23	2
0	0.00	0.00					
	24	3	9	64	89.48	59.92	2
4	1.65	0.48					
	25	0	3	64	0.00	103.48	1
0	0.00	0.00					
	26	1	5	49	53.84	59.08	2
4	2.34	0.58					
	27	3	14	80	57.67	36.87	3
4	2.04	0.37					
	28	0	9	60	0.00	31.64	3
0	0.00	0.00					

	29	2	16	50	33.70	25.37	5
2	2.15	0.20					
	30	0	8	60	0.00	35.81	2
3	2.29	0.24					
	31	0	6	25	0.00	48.58	4
0	0.00	0.00					
	32	1	24	100	11.25	11.51	4
3	1.55	0.28					
	33	3	13	40	62.08	39.96	6
4	1.54	0.28					
	34	2	9	64	59.79	46.90	2
3	2.18	0.63					
	35	1	18	100	15.00	15.44	3
2	1.51	0.56					
	36	1	20	100	13.50	13.86	3
4	2.02	0.34					
	37	1	12	100	22.49	23.45	2
4	1.92	0.27					
	38	0	17	60	0.00	16.37	5
3	2.34	0.41					
	39	1	14	60	19.28	19.99	4
1	2.00	0.33					
	40	1	13	90	20.76	21.58	2
1	1.44	0.37					
	41	1	11	70	24.53	25.67	3
2	2.04	0.45					
	42	3	18	100	44.90	28.14	3
4	2.44	0.56					
	43	1	25	100	10.80	11.04	4
4	1.84	0.55					

Mean Dpar = 1.88
 Mean Dper = 0.36
 Chi-squared = 48.185
 Chi-squared prob= 0.237
 Pooled Age (Ma) = 14.5+/- 2.2
 Mean Age (Ma) = 15.9+/- 3.5
 W.Mean Age (Ma) = 9.8+/- 2.0
 Median Age (Ma) = 10.8- 2.5+ 2.1

PFT-09

	Grain	Natural	Induced	Quads	FT Age	1 sigma	Uranium
Etch	Dpar	Dper					
Number	Tracks	Tracks	(dmnls)	(Ma)	(Ma)	(ppm)	
Figures	(microns)	(microns)					
	1	0	16	100	0.00	17.49	3
0	0.00	0.00					
	2	1	11	56	24.63	25.77	3
3	1.93	0.57					
	3	6	62	24	26.21	11.33	44
4	1.52	0.31					
	4	0	8	48	0.00	35.95	3
0	0.00	0.00					

	5	5	67	64	20.22	9.46	18
4	1.84	0.44					
	6	1	16	64	16.94	17.49	4
2	1.67	0.32					
	7	2	36	40	15.06	10.98	15
4	2.03	0.35					
	8	0	10	30	0.00	28.46	6
0	0.00	0.00					
	9	2	27	64	20.07	14.76	7
4	1.88	0.51					
	10	0	3	35	0.00	103.89	1
4	1.83	0.36					
	11	4	23	40	47.03	25.65	10
4	1.58	0.48					
	12	3	23	56	35.30	21.79	7
2	1.93	0.26					
	13	3	36	56	22.58	13.64	11
4	1.95	0.32					
	14	0	7	49	0.00	41.40	2
0	0.00	0.00					
	15	0	5	18	0.00	59.31	5
0	0.00	0.00					
	16	0	6	50	0.00	48.77	2
0	0.00	0.00					
	17	1	5	40	54.05	59.31	2
4	1.96	0.30					
	18	1	10	64	27.08	28.46	3
2	1.87	0.25					
	19	0	16	40	0.00	17.49	7
0	0.00	0.00					
	20	26	322	40	21.88	4.67	138
4	1.52	0.30					
	21	0	5	56	0.00	59.31	2
0	0.00	0.00					
	22	0	11	64	0.00	25.77	3
4	2.01	0.21					
	23	0	28	50	0.00	9.88	10
0	0.00	0.00					
	24	1	29	60	9.35	9.53	8
2	1.59	0.33					
	25	1	6	40	45.08	48.77	3
1	2.00	0.79					
	26	7	30	80	63.02	26.75	6
4	1.53	0.23					
	27	0	23	60	0.00	12.07	7
4	1.79	0.26					
	28	0	13	48	0.00	21.67	5
0	0.00	0.00					
	29	1	6	42	45.08	48.77	2
1	1.81	0.53					
	30	0	6	64	0.00	48.77	2
2	1.97	0.19					
	31	4	49	32	22.12	11.59	26
4	1.60	0.46					
	32	4	9	80	119.51	72.21	2
4	1.89	0.18					

	33	0	6	80	0.00	48.77	1
3	2.10	0.44					
	34	3	49	50	16.60	9.93	17
3	1.78	0.56					
	35	1	11	60	24.63	25.77	3
2	1.98	0.67					
	36	3	28	60	29.01	17.72	8
3	1.81	0.36					

Mean Dpar = 1.82
 Mean Dper = 0.38
 Chi-squared = 37.388
 Chi-squared prob= 0.360
 Pooled Age (Ma) = 21.3+/- 2.8
 Mean Age (Ma) = 19.6+/- 4.4
 W.Mean Age (Ma) = 17.4+/- 2.7
 Median Age (Ma) = 16.8- 4.2+ 2.5

PFT-12

Etch	Grain Number Figures	Natural Dpar Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
	1	1	7	35	38.96	41.73	3
1	1.32	0.45					
	2	1	2	64	135.35	165.99	1
1	2.30	0.44					
	3	8	107	50	20.42	7.60	36
4	1.92	0.42					
	4	4	91	18	12.01	6.18	86
4	1.97	0.23					
	5	0	8	40	0.00	36.24	3
0	0.00	0.00					
	6	1	60	48	4.56	4.60	21
4	1.86	0.35					
	7	0	17	100	0.00	16.57	3
0	0.00	0.00					
	8	0	13	25	0.00	21.84	9
0	0.00	0.00					
	9	0	6	40	0.00	49.16	3
0	0.00	0.00					
	10	4	97	64	11.27	5.79	26
4	1.59	0.23					
	11	4	135	49	8.10	4.14	47
4	1.51	0.26					
	12	0	116	100	0.00	2.37	20
2	1.96	0.40					
	13	1	22	100	12.42	12.73	4
4	1.97	0.18					
	14	0	60	64	0.00	4.60	16
2	1.62	0.37					
	15	0	7	36	0.00	41.73	3
2	4.32	0.43					

	16	2	44	70	12.42	9.02	11
2	1.55	0.12					
	17	4	73	40	14.97	7.75	31
4	1.56	0.16					
	18	0	17	40	0.00	16.57	7
4	1.53	0.22					
	19	1	24	48	11.39	11.65	8
4	1.38	0.25					
	20	2	38	50	14.38	10.47	13
2	1.09	0.31					
	21	4	153	60	7.15	3.65	43
4	1.69	0.19					
	22	6	73	60	22.45	9.64	21
4	2.03	0.47					
	23	0	3	64	0.00	104.72	1
0	0.00	0.00					
	24	0	6	64	0.00	49.16	2
0	0.00	0.00					
	25	1	40	40	6.84	6.93	17
3	1.51	0.09					
	26	11	140	70	21.46	6.86	34
4	1.53	0.26					
	27	6	117	100	14.01	5.93	20
4	1.71	0.20					
	28	7	42	48	45.43	18.77	15
3	2.06	0.46					

Mean Dpar = 1.82
 Mean Dper = 0.29
 Chi-squared = 41.716
 Chi-squared prob= 0.035
 Pooled Age (Ma) = 12.2+/- 1.7
 Mean Age (Ma) = 14.8+/- 5.2
 W.Mean Age (Ma) = 6.9+/- 1.3
 Median Age (Ma) = 9.7- 2.8+ 1.4

PFT-13

Etch	Grain Number Figures	Natural Dpar Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
	1	1	11	21	24.92	26.08	9
4	1.68	0.16					
	2	1	25	35	10.98	11.22	12
4	1.64	0.13					

Mean Dpar = 1.66
 Mean Dper = 0.14
 Chi-squared = 0.332
 Chi-squared prob= 0.565
 Pooled Age (Ma) = 15.2+/- 11.1
 Mean Age (Ma) = 18.0+/- 9.9
 W.Mean Age (Ma) = 13.2+/- 10.3
 Median Age (Ma) = 17.9- 10.3+ 10.3

PFT-15

Etch	Grain Number Figures	Natural Dpar Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
0	1	1	2	15	136.41	167.29	2
0	0.00	0.00					
0	2	0	4	64	0.00	76.78	1
0	0.00	0.00					
0	3	0	9	56	0.00	32.28	3
0	0.00	0.00					
0	4	0	17	40	0.00	16.70	7
0	0.00	0.00					
3	5	0	8	60	0.00	36.52	2
3	1.49	0.45					
4	6	5	38	50	36.18	17.36	13
4	1.43	0.09					
4	7	6	48	50	34.37	15.04	16
4	1.72	0.16					
4	8	2	32	35	17.21	12.59	15
4	1.86	0.26					
4	9	25	78	40	87.78	20.93	33
4	1.70	0.24					
4	10	2	75	24	7.35	5.29	53
4	1.41	0.07					
0	11	0	3	28	0.00	105.54	2
0	0.00	0.00					
0	12	0	11	40	0.00	26.18	5
0	0.00	0.00					
3	13	9	62	40	39.90	14.46	26
3	1.46	0.19					
0	14	0	4	48	0.00	76.78	1
0	0.00	0.00					

Mean Dpar = 1.58
 Mean Dper = 0.21
 Chi-squared = 32.737
 Chi-squared prob= 0.002
 Pooled Age (Ma) = 35.2+/- 5.7
 Mean Age (Ma) = 25.8+/- 11.5
 W.Mean Age (Ma) = 16.4+/- 4.1
 Median Age (Ma) = 3.7- 1.5+ 13.4

PFT-17

Etch	Grain Number Figures	Natural Dpar Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
0	1	1	18	40	15.36	15.81	8
0	0.00	0.00					

	2	3	8	24	102.98	70.02	6
2	3.35	0.49					
	3	0	19	30	0.00	14.96	11
0	0.00	0.00					
	4	3	29	40	28.57	17.42	12
0	0.00	0.00					
	5	2	15	48	36.80	27.80	5
2	1.86	0.24					
	6	1	102	40	2.71	2.73	43
2	1.74	0.16					
	7	18	140	48	35.49	9.17	49
4	1.48	0.38					
	8	2	30	40	18.43	13.51	13
0	0.00	0.00					
	9	18	363	60	13.71	3.42	101
4	1.39	0.19					
	10	1	18	21	15.36	15.81	14
1	1.75	0.04					
	11	0	33	42	0.00	8.53	13
2	1.14	0.11					
	12	13	3	40	1100.09	708.07	1
4	1.54	0.15					
	13	0	23	50	0.00	12.31	8
2	1.52	0.22					
	14	0	9	24	0.00	32.40	6
0	0.00	0.00					
	15	0	33	48	0.00	8.53	12
0	0.00	0.00					

Mean Dpar = 1.75
 Mean Dper = 0.22
 Chi-squared = 169.094
 Chi-squared prob= 0.000
 Pooled Age (Ma) = 20.3+/- 3.0
 Mean Age (Ma) = 97.3+/- 81.4
 W.Mean Age (Ma) = 8.3+/- 1.9
 Median Age (Ma) = 15.4- 6.1+ 6.6

PFT-19

	Grain Etch Figures	Natural Dpar Number (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
	1	0	5	36	0.00	61.20	2
1	1.81	0.17					
	2	0	5	25	0.00	61.20	3
1	1.79	0.61					
	3	1	11	20	25.41	26.59	9
1	3.55	1.39					
	4	5	26	50	53.63	26.41	9
4	2.73	0.93					
	5	4	51	50	21.93	11.47	17
1	1.06	0.36					

	6	0	12	48	0.00	24.29	4
1	1.85	0.25					
	7	13	245	24	14.84	4.33	169
4	1.44	0.13					

Mean Dpar = 2.03
 Mean Dper = 0.55
 Chi-squared = 7.634
 Chi-squared prob= 0.266
 Pooled Age (Ma) = 18.1+/- 4.1
 Mean Age (Ma) = 16.6+/- 8.1
 W.Mean Age (Ma) = 16.2+/- 3.9
 Median Age (Ma) = 14.8- 9.0+ 5.3

PFT-20

Etch	Grain Number Figures	Natural Dpar Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
	1	0	1	30	0.00	389.56	1
3	1.40	0.27					
	2	9	42	35	59.97	22.35	20
4	1.82	0.39					
	3	7	27	6	72.48	31.08	74
4	1.46	0.28					
	4	1	12	21	23.39	24.39	9
4	0.94	0.27					
	5	2	20	18	28.05	20.88	18
1	2.79	0.28					
	6	3	40	30	21.05	12.67	22
2	1.33	0.11					
	7	7	229	70	8.59	3.34	54
4	1.63	0.47					
	8	16	254	40	17.69	4.69	105
3	1.21	0.18					
	9	1	22	12	12.77	13.08	30
1	1.77	0.20					

Mean Dpar = 1.59
 Mean Dper = 0.27
 Chi-squared = 26.517
 Chi-squared prob= 0.001
 Pooled Age (Ma) = 20.0+/- 3.3
 Mean Age (Ma) = 27.1+/- 8.6
 W.Mean Age (Ma) = 13.5+/- 2.6
 Median Age (Ma) = 21.1- 4.3+ 3.7

PFT-21

Etch	Grain Number Figures	Natural Dpar Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
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	1	2	20	50	28.16	20.96	7
1	2.04	0.11					
	2	9	33	64	76.52	29.18	8
4	1.35	0.15					
	3	2	74	48	7.62	5.48	25
0	0.00	0.00					
	4	0	41	64	0.00	6.98	11
2	1.45	0.23					
	5	4	24	100	46.87	25.49	4
1	1.82	0.18					
	6	6	148	64	11.43	4.82	38
2	1.94	0.32					
	7	0	6	100	0.00	50.71	1
3	1.85	0.30					
	8	2	24	64	23.48	17.34	6
2	1.57	0.26					
	9	6	111	60	15.24	6.46	30
3	1.72	0.16					
	10	0	98	64	0.00	2.90	25
0	0.00	0.00					
	11	6	215	100	7.87	3.30	35
4	1.69	0.45					
	12	0	22	70	0.00	13.13	5
2	1.16	0.25					
	13	1	241	70	1.17	1.18	57
2	1.34	0.29					
	14	1	22	64	12.82	13.13	6
2	1.59	0.42					
	15	2	13	64	43.27	32.98	3
4	1.51	0.32					
	16	3	19	40	44.41	27.73	8
1	1.51	0.20					
	17	1	91	40	3.10	3.12	37
1	2.06	0.37					
	18	1	71	64	3.97	4.01	18
2	1.65	0.37					
	19	2	53	64	10.64	7.69	14
4	1.35	0.24					
	20	4	106	48	10.64	5.46	36
2	1.78	0.25					
	21	1	21	64	13.43	13.77	5
2	1.43	0.23					
	22	0	130	60	0.00	2.18	36
0	0.00	0.00					
	23	0	54	40	0.00	5.28	22
4	1.27	0.31					
	24	0	72	100	0.00	3.95	12
3	2.25	0.41					
	25	0	47	100	0.00	6.08	8
2	1.34	0.51					
	26	14	24	100	162.57	55.63	4
4	1.51	0.18					
	27	0	27	60	0.00	10.66	7
0	0.00	0.00					
	28	1	49	64	5.76	5.83	13
0	0.00	0.00					

	29	0	46	60	0.00	6.21	13
0	0.00	0.00					
	30	1	27	50	10.44	10.66	9
1	1.22	0.04					
	31	1	36	100	7.83	7.96	6
0	0.00	0.00					
	32	2	8	64	70.17	55.66	2
2	1.89	0.29					
	33	4	47	70	23.97	12.58	11
1	2.00	0.14					
	34	1	45	36	6.27	6.35	21
0	0.00	0.00					
	35	1	39	12	7.23	7.34	53
4	1.41	0.20					
	36	1	10	6	28.16	29.59	27
3	1.25	0.15					
	37	2	50	20	11.28	8.16	41
4	1.40	0.14					
	38	7	84	27	23.48	9.35	51
3	1.08	0.24					
	39	1	63	24	4.48	4.52	43
4	1.14	0.16					
	40	1	10	6	28.16	29.59	27
2	1.80	0.16					
	41	0	6	21	0.00	50.71	5
2	1.18	0.25					
	42	1	23	16	12.26	12.55	24
2	1.25	0.19					
	43	2	4	35	139.59	121.21	2
2	1.08	0.08					
	44	2	12	48	46.87	35.92	4
4	1.04	0.12					
	45	1	9	4	31.28	33.03	37
4	1.28	0.06					
	46	5	32	12	43.95	21.32	44
4	1.16	0.17					
	47	1	13	15	21.67	22.53	14
4	1.23	0.11					
	48	3	41	14	20.62	12.40	48
2	0.76	0.13					
	49	2	10	14	56.20	43.68	12
2	1.13	0.13					
	50	4	23	20	48.90	26.67	19
3	1.40	0.05					
	51	2	28	9	20.13	14.79	51
4	1.31	0.15					
	52	6	38	24	44.41	19.71	26
4	1.05	0.14					
	53	7	52	12	37.88	15.44	71
4	1.45	0.15					
	54	4	21	15	53.53	29.40	23
3	1.36	0.08					
	55	2	9	16	62.41	48.95	9
4	1.52	0.26					
	56	2	36	49	15.66	11.42	12
2	1.41	0.21					

	57	11	49	16	63.05	21.41	50
4	1.51	0.15					
	58	4	36	16	31.28	16.61	37
4	1.68	0.17					
	59	4	21	24	53.53	29.40	14
4	1.77	0.43					
	60	17	211	24	22.70	5.90	145
4	1.01	0.15					
	61	1	57	40	4.95	5.00	23
3	1.31	0.21					
	62	12	157	28	21.54	6.59	92
4	1.08	0.08					

Mean Dpar = 1.45
 Mean Dper = 0.21
 Chi-squared = 246.895
 Chi-squared prob= 0.000
 Pooled Age (Ma) = 16.1+/- 1.6
 Mean Age (Ma) = 25.9+/- 4.3
 W.Mean Age (Ma) = 4.4+/- 0.8
 Median Age (Ma) = 15.4- 2.0+ 5.3

PFT-23

Etch	Grain Number Figures	Natural Dpar Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
	1	1	12	40	20.43	21.31	6
4	1.70	0.26					
	2	2	25	36	19.62	14.47	13
3	1.48	0.28					
	3	1	30	60	8.18	8.33	9
1	1.39	0.16					
	4	1	10	70	24.51	25.75	3
0	0.00	0.00					
	5	0	28	70	0.00	8.94	8
0	0.00	0.00					
	6	2	42	30	11.68	8.49	26
3	1.58	0.19					
	7	5	35	49	34.99	16.87	13
4	1.43	0.35					
	8	2	22	70	22.29	16.52	6
2	1.81	0.41					
	9	3	84	70	8.76	5.18	23
1	1.62	0.08					
	10	1	23	64	10.67	10.92	7
0	0.00	0.00					
	11	1	28	49	8.76	8.94	11
4	1.43	0.24					
	12	2	33	64	14.87	10.87	10
2	1.64	0.35					
	13	1	58	64	4.23	4.28	17
1	1.70	0.12					

	14	0	10	40	0.00	25.75	5
1	1.27	0.23					
	15	3	28	64	26.26	16.04	8
3	2.02	0.22					
	16	3	91	60	8.09	4.78	29
1	2.53	1.06					
	17	7	97	70	17.70	7.02	26
4	1.74	0.25					
	18	2	38	64	12.91	9.40	11
4	1.66	0.32					
	19	2	52	64	9.44	6.83	15
0	0.00	0.00					
	20	1	32	40	7.67	7.80	15
1	1.58	0.23					
	21	0	42	70	0.00	5.93	11
0	0.00	0.00					
	22	0	8	28	0.00	32.54	5
0	0.00	0.00					
	23	2	50	36	9.82	7.11	26
3	1.66	0.32					
	24	1	15	64	16.35	16.92	4
2	1.77	0.46					
	25	1	64	45	3.84	3.87	27
1	1.86	0.26					
	26	5	74	64	16.57	7.73	22
4	2.22	0.53					
	27	10	87	50	28.17	9.57	33
4	1.61	0.16					
	28	4	34	64	28.83	15.35	10
2	1.59	0.14					
	29	4	35	42	28.01	14.89	16
3	0.94	0.20					
	30	3	22	70	33.40	20.67	6
2	2.88	1.04					
	31	3	25	64	29.40	18.06	7
3	1.64	0.26					
	32	3	25	50	29.40	18.06	9
2	1.92	0.70					
	33	0	27	30	0.00	9.27	17
2	1.66	0.33					
	34	1	27	24	9.09	9.27	21
1	1.79	0.04					
	35	0	25	20	0.00	10.03	24
0	0.00	0.00					
	36	2	41	40	11.97	8.70	19
2	1.26	0.26					
	37	1	37	40	6.63	6.74	17
1	1.95	0.64					
	38	1	43	48	5.71	5.79	17
2	1.86	0.69					
	39	1	32	24	7.67	7.80	25
1	1.78	0.12					

Mean Dpar = 1.72
 Mean Dper = 0.34
 Chi-squared = 37.907
 Chi-squared prob= 0.474

Pooled Age (Ma) = 13.5+/- 1.8
 Mean Age (Ma) = 13.7+/- 1.9
 W.Mean Age (Ma) = 9.0+/- 1.4
 Median Age (Ma) = 10.7- 0.8+ 2.6

PFT-25

Etch	Grain Number Figures	Natural Dpar Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
	1	7	60	45	28.54	11.54	25
4	1.49	0.25					
	2	0	54	30	0.00	4.59	34
1	1.57	0.08					
	3	0	5	45	0.00	53.61	2
1	2.05	0.28					
	4	1	9	16	27.19	28.71	11
1	1.41	0.28					
	5	0	14	40	0.00	18.14	7
2	1.87	0.27					
	6	1	19	64	12.89	13.25	6
2	1.51	0.41					
	7	1	30	30	8.17	8.32	19
1	2.23	0.28					
	8	0	18	42	0.00	14.01	8
2	1.64	0.19					
	9	0	5	24	0.00	53.61	4
0	0.00	0.00					
	10	6	59	40	24.89	10.78	28
4	1.41	0.24					
	11	0	15	80	0.00	16.89	4
3	1.59	0.49					
	12	3	5	50	145.47	106.63	2
4	1.46	0.26					
	13	0	32	100	0.00	7.79	6
1	1.91	0.46					
	14	3	15	45	48.85	31.05	6
3	2.14	0.87					
	15	0	8	30	0.00	32.49	5
0	0.00	0.00					
	16	0	6	40	0.00	44.08	3
2	2.02	0.22					
	17	2	17	40	28.78	21.59	8
2	1.75	0.34					
	18	3	19	35	38.60	24.10	10
2	1.55	0.21					
	19	5	86	50	14.24	6.61	33
3	2.27	0.31					
	20	0	18	70	0.00	14.01	5
0	0.00	0.00					
	21	3	63	60	11.67	6.93	20
2	2.76	0.75					
	22	2	28	48	17.49	12.85	11
2	1.69	0.33					

	23	1	21	64	11.67	11.96	6
2	1.45	0.21					
	24	3	2	24	357.69	327.31	2
4	2.06	0.22					
	25	6	122	60	12.05	5.10	38
4	1.72	0.23					
	26	0	5	50	0.00	53.61	2
0	0.00	0.00					
	27	0	11	32	0.00	23.28	7
2	2.05	0.52					
	28	0	35	70	0.00	7.12	9
1	1.53	0.20					

Mean Dpar = 1.80
 Mean Dper = 0.33
 Chi-squared = 69.392
 Chi-squared prob= 0.000
 Pooled Age (Ma) = 14.7+/- 2.4
 Mean Age (Ma) = 28.5+/- 14.0
 W.Mean Age (Ma) = 8.6+/- 2.1
 Median Age (Ma) = 9.9- 2.8+ 4.6

PFT-28

	Grain Etch Number Figures	Natural Dpar Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
	1	11	12	42	220.60	93.14	5
4	1.37	0.33					
	2	5	12	50	101.21	54.25	5
4	1.46	0.30					
	3	5	46	60	26.56	12.62	15
4	2.26	0.67					
	4	2	13	42	37.56	28.62	6
3	1.76	0.17					
	5	3	34	56	21.57	13.06	12
2	1.38	0.14					
	6	1	42	64	5.83	5.91	12
2	1.36	0.22					
	7	10	110	90	22.22	7.47	23
4	1.81	0.33					
	8	0	17	100	0.00	14.83	3
3	1.45	0.28					
	9	0	9	42	0.00	28.67	4
0	0.00	0.00					
	10	6	93	80	15.78	6.72	22
4	1.53	0.38					
	11	14	157	48	21.79	6.23	62
4	1.70	0.32					
	12	1	12	54	20.37	21.24	4
1	2.73	0.21					
	13	3	14	28	52.25	33.41	9
3	1.32	0.30					

	14	5	14	100	86.85	45.58	3
3	1.39	0.08					
	15	3	47	80	15.61	9.35	11
3	1.70	0.42					
	16	0	20	64	0.00	12.56	6
0	0.00	0.00					
	17	6	16	40	91.16	44.02	8
4	1.79	0.41					
	18	4	32	100	30.53	16.31	6
2	1.59	0.15					
	19	1	12	70	20.37	21.24	3
1	1.26	0.20					
	20	0	5	64	0.00	53.52	1
0	0.00	0.00					
	21	3	34	100	21.57	13.06	6
4	1.46	0.23					
	22	1	71	35	3.45	3.48	38
1	1.45	0.04					
	23	0	5	24	0.00	53.52	4
0	0.00	0.00					
	24	0	7	28	0.00	37.35	5
0	0.00	0.00					
	25	4	28	42	34.88	18.77	13
3	1.83	0.34					

Mean Dpar = 1.63
 Mean Dper = 0.28
 Chi-squared = 82.847
 Chi-squared prob= 0.000
 Pooled Age (Ma) = 24.9+/- 3.2
 Mean Age (Ma) = 34.2+/- 10.2
 W.Mean Age (Ma) = 12.5+/- 2.2
 Median Age (Ma) = 21.6- 5.5+ 4.0

PFT-29

Etch	Grain Number Figures	Natural Dpar Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
	1	2	35	21	13.95	10.18	32
1	1.34	0.08					
	2	9	71	64	30.91	11.11	21
4	1.78	0.27					
	3	13	360	28	8.82	2.55	244
4	1.67	0.27					
	4	3	11	50	66.32	43.40	4
3	1.51	0.19					
	5	0	6	28	0.00	43.94	4
4	1.55	0.28					
	6	2	27	90	18.08	13.30	6
2	1.57	0.16					
	7	0	6	64	0.00	43.94	2
0	0.00	0.00					

	8	0	4	100	0.00	68.11	1
3	1.99	0.21					
	9	1	5	100	48.70	53.44	1
1	1.84	0.14					
	10	3	3	100	239.92	196.49	1
3	1.77	0.21					
	11	0	15	42	0.00	16.84	7
0	0.00	0.00					
	12	5	101	100	12.09	5.59	19
4	1.51	0.23					
	13	13	116	100	27.34	8.18	22
2	1.59	0.30					
	14	23	349	60	16.09	3.61	110
4	1.59	0.24					
	15	0	17	60	0.00	14.81	5
0	0.00	0.00					
	16	1	3	100	80.97	93.64	1
4	2.16	0.47					
	17	8	110	56	17.75	6.60	37
2	1.31	0.21					
	18	4	39	64	25.02	13.23	12
2	1.87	0.37					
	19	6	27	70	54.09	24.65	7
2	1.91	0.28					
	20	6	45	64	32.51	14.28	13
3	2.03	0.51					
	21	0	9	36	0.00	28.62	5
0	0.00	0.00					
	22	4	6	80	160.94	104.38	1
3	1.55	0.12					
	23	8	48	64	40.61	15.72	14
4	1.34	0.26					
	24	41	280	200	35.69	6.38	27
4	1.42	0.24					
	25	0	5	80	0.00	53.44	1
1	2.28	0.53					
	26	10	82	100	29.74	10.14	16
4	1.47	0.13					
	27	28	211	80	32.36	6.82	50
4	2.58	0.82					

Mean Dpar = 1.72
 Mean Dper = 0.28
 Chi-squared = 72.243
 Chi-squared prob= 0.000
 Pooled Age (Ma) = 23.3+/- 2.3
 Mean Age (Ma) = 36.9+/- 10.8
 W.Mean Age (Ma) = 16.8+/- 1.9
 Median Age (Ma) = 25.0- 6.0+ 3.8

PFT-37

Etch	Grain	Natural	Induced	Quads	FT Age	1 sigma	Uranium
	Dpar	Dper					
Number	Tracks	Tracks	(dmnls)	(Ma)	(Ma)	(ppm)	
Figures	(microns)	(microns)					

	1	11	98	50	27.21	8.82	37
4	1.72	0.27					
	2	1	16	100	15.17	15.66	3
4	1.45	0.40					
	3	2	25	60	19.41	14.31	8
3	1.36	0.31					
	4	2	40	48	12.14	8.83	16
1	2.78	0.12					
	5	2	10	100	48.40	37.62	2
2	2.34	0.72					
	6	17	268	64	15.39	3.97	80
4	1.84	0.22					
	7	0	8	30	0.00	32.19	5
0	0.00	0.00					
	8	5	5	64	238.47	151.57	1
1	1.75	0.34					
	9	0	5	64	0.00	53.11	1
0	0.00	0.00					
	10	0	9	20	0.00	28.44	9
0	0.00	0.00					
	11	0	3	42	0.00	93.06	1
0	0.00	0.00					
	12	1	6	40	40.36	43.67	3
1	1.26	0.28					
	13	1	54	36	4.50	4.55	29
1	1.37	0.18					
	14	1	21	28	11.56	11.85	14
1	2.11	0.23					
	15	0	21	100	0.00	11.85	4
3	1.54	0.52					
	16	2	46	100	10.55	7.65	9
4	1.54	0.42					

Mean Dpar = 1.76
 Mean Dper = 0.33
 Chi-squared = 41.613
 Chi-squared prob= 0.000
 Pooled Age (Ma) = 17.2+/- 2.9
 Mean Age (Ma) = 27.9+/- 15.3
 W.Mean Age (Ma) = 12.1+/- 2.4
 Median Age (Ma) = 11.8- 4.5+ 4.4

PFT-39

Etch	Grain Number Figures	Natural Dpar (microns)	Induced Dper (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
	1	2	4	50	120.15	104.33	2
2	1.91	0.36					
	2	0	2	24	0.00	147.35	2
4	1.76	0.41					
	3	1	16	78	15.14	15.64	4
4	1.68	0.32					

	4	2	16	54	30.25	22.77	6
4	2.08	0.57					
	5	1	4	40	60.36	67.59	2
2	2.23	0.53					
	6	1	12	50	20.18	21.04	5
2	1.92	0.10					
	7	1	15	49	16.15	16.71	6
2	1.19	0.19					
	8	0	3	12	0.00	92.92	5
1	1.79	0.20					

Mean Dpar = 1.82
 Mean Dper = 0.33
 Chi-squared = 5.413
 Chi-squared prob= 0.610
 Pooled Age (Ma) = 26.9+/- 10.2
 Mean Age (Ma) = 32.9+/- 15.4
 W.Mean Age (Ma) = 20.1+/- 9.1
 Median Age (Ma) = 18.2- 5.9+ 15.2

PFT-42

	Grain Etch Number Figures	Natural Dpar Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
	1	3	12	100	60.17	39.02	2
4	1.71	0.25					
	2	9	46	64	47.14	17.44	14
4	1.27	0.14					
	3	1	8	64	30.15	32.04	2
2	1.77	0.20					
	4	6	64	60	22.63	9.77	20
4	1.82	0.58					
	5	1	5	64	48.18	52.87	1
1	1.98	0.57					
	6	1	10	48	24.13	25.36	4
4	1.77	0.45					
	7	0	3	21	0.00	92.63	3
0	0.00	0.00					
	8	1	3	40	80.10	92.63	1
3	1.74	0.50					
	9	0	11	80	0.00	22.96	3
1	1.16	0.09					
	10	2	7	48	68.72	55.27	3
2	1.38	0.18					
	11	1	13	64	18.57	19.31	4
1	1.05	0.28					
	12	2	4	45	119.78	104.01	2
4	2.09	0.49					
	13	1	6	36	40.17	43.47	3
1	1.75	0.54					
	14	1	1	64	237.37	336.03	0
2	1.13	0.23					

	15	1	4	50	60.17	67.38	2
2	1.72	0.31					
	16	2	9	100	53.51	41.97	2
2	1.87	0.39					
	17	0	12	35	0.00	20.98	7
0	0.00	0.00					
	18	0	14	80	0.00	17.89	3
1	1.82	0.69					
	19	0	4	40	0.00	67.38	2
1	1.33	0.26					
	20	1	15	100	16.10	16.66	3
1	1.80	0.41					
	21	0	9	50	0.00	28.31	3
0	0.00	0.00					
	22	1	6	48	40.17	43.47	2
1	1.63	0.65					
	23	0	12	100	0.00	20.98	2
1	1.99	0.45					
	24	0	10	40	0.00	25.36	5
2	1.09	0.29					
	25	3	29	80	24.97	15.22	7
1	1.69	0.29					
	26	1	21	100	11.50	11.80	4
4	1.68	0.30					
	27	0	8	54	0.00	32.04	3
2	1.52	0.15					

Mean Dpar = 1.61
 Mean Dper = 0.36
 Chi-squared = 26.539
 Chi-squared prob= 0.434
 Pooled Age (Ma) = 26.5+/- 4.8
 Mean Age (Ma) = 37.4+/- 10.3
 W.Mean Age (Ma) = 18.5+/- 4.6
 Median Age (Ma) = 24.1- 7.0+ 7.8

PFT-43

Etch	Grain Number	Natural Dpar Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
Figures							
	1	2	9	24	53.43	41.90	7
1	1.96	0.42					
	2	0	5	64	0.00	52.78	2
3	1.49	0.30					
	3	3	29	40	24.93	15.20	14
4	1.70	0.48					
	4	1	14	64	17.22	17.86	4
1	1.34	0.26					
	5	1	14	50	17.22	17.86	5
1	2.09	0.68					
	6	0	13	28	0.00	19.28	9
1	1.44	0.41					

	7	0	7	35	0.00	36.84	4
0	0.00	0.00					
	8	0	3	28	0.00	92.49	2
0	0.00	0.00					
	9	0	12	60	0.00	20.95	4
1	1.82	0.49					
	10	1	9	100	26.77	28.27	2
1	1.83	0.54					
	11	2	51	40	9.46	6.85	25
2	1.44	0.14					
	12	0	4	36	0.00	67.27	2
0	0.00	0.00					
	13	1	24	42	10.05	10.28	11
3	1.78	0.20					
	14	9	125	50	17.36	6.09	48
4	1.73	0.36					
	15	1	5	32	48.10	52.78	3
1	2.10	0.56					
	16	7	73	54	23.11	9.26	26
2	1.45	0.25					
	17	0	2	35	0.00	146.67	1
2	0.62	0.06					
	18	1	7	28	34.40	36.84	5
1	1.75	0.37					

Mean Dpar = 1.64
 Mean Dper = 0.37
 Chi-squared = 9.145
 Chi-squared prob= 0.936
 Pooled Age (Ma) = 17.2+/- 3.5
 Mean Age (Ma) = 15.7+/- 4.2
 W.Mean Age (Ma) = 15.2+/- 3.5
 Median Age (Ma) = 13.6- 4.9+ 4.1

PFT-44

Etch	Grain Number	Natural Dpar Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
Figures							
	1	1	7	25	34.34	36.78	5
1	1.74	0.28					
	2	2	38	15	12.67	9.23	49
2	1.54	0.29					
	3	4	7	49	136.29	85.86	3
4	2.40	0.65					
	4	0	20	15	0.00	12.36	26
1	1.59	0.31					
	5	0	12	24	0.00	20.91	10
1	0.88	0.31					
	6	1	27	30	8.92	9.10	17
2	2.51	0.55					
	7	4	13	36	73.74	42.42	7
4	1.65	0.18					

	8	0	2	40	0.00	146.44	1
0	0.00	0.00					
	9	0	3	36	0.00	92.34	2
0	0.00	0.00					
	10	1	6	12	40.05	43.33	10
1	2.47	0.58					

Mean Dpar = 1.85
 Mean Dper = 0.39
 Chi-squared = 20.686
 Chi-squared prob= 0.014
 Pooled Age (Ma) = 23.2+/- 6.9
 Mean Age (Ma) = 30.7+/- 15.0
 W.Mean Age (Ma) = 10.4+/- 5.4
 Median Age (Ma) = 10.8- 5.3+ 14.5

PFT-45

Etch Figures	Grain Dpar Number (microns)	Natural Dper Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
	1	0	8	100	0.00	31.89	2
1	3.23	1.01					
	2	3	16	100	44.97	28.43	3
1	2.16	0.97					
	3	0	14	64	0.00	17.80	4
3	1.95	0.39					
	4	3	106	90	6.81	4.01	23
3	1.45	0.16					
	5	0	3	40	0.00	92.20	1
0	0.00	0.00					
	6	0	8	24	0.00	31.89	6
1	1.84	0.28					
	7	1	6	28	39.99	43.26	4
1	1.15	0.04					
	8	0	15	100	0.00	16.58	3
3	2.18	0.49					
	9	9	88	100	24.57	8.74	17
4	1.90	0.21					
	10	2	23	40	20.89	15.46	11
2	2.23	0.35					
	11	9	85	40	25.43	9.06	41
4	1.49	0.39					
	12	2	9	100	53.26	41.77	2
2	2.00	0.55					
	13	1	32	70	7.52	7.65	9
3	2.02	0.52					
	14	3	11	100	65.30	42.74	2
2	1.86	0.36					
	15	6	20	100	71.80	33.73	4
4	1.35	1.09					
	16	2	51	70	9.43	6.82	14
1	1.62	0.18					

	17	0	4	30	0.00	67.06	3
2	2.02	0.20					
	18	0	7	30	0.00	36.72	4
0	0.00	0.00					
	19	1	24	49	10.02	10.25	9
2	1.52	0.06					
	20	10	93	30	25.83	8.75	60
4	1.47	0.36					
	21	0	11	60	0.00	22.85	4
0	0.00	0.00					
	22	0	12	100	0.00	20.88	2
1	1.94	0.79					
	23	14	105	64	32.01	9.33	32
4	1.83	0.38					
	24	12	169	100	17.07	5.21	33
4	1.59	0.25					
	25	0	13	70	0.00	19.22	4
0	0.00	0.00					
	26	2	14	100	34.29	26.01	3
4	2.13	0.48					
	27	2	12	100	39.99	30.65	2
1	2.07	0.57					
	28	3	21	100	34.29	21.27	4
4	1.99	0.29					
	29	1	14	100	17.17	17.80	3
3	1.66	0.25					
	30	0	23	100	0.00	10.70	4
3	2.28	0.60					

Mean Dpar = 1.88
 Mean Dper = 0.43
 Chi-squared = 38.646
 Chi-squared prob= 0.109
 Pooled Age (Ma) = 20.3+/- 2.6
 Mean Age (Ma) = 19.4+/- 4.1
 W.Mean Age (Ma) = 14.1+/- 2.2
 Median Age (Ma) = 13.5- 3.7+ 5.7

PFT-47

Etch	Grain Number	Natural Dpar Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
Figures							
	1	0	28	60	0.00	8.74	9
0	0.00	0.00					
	2	0	15	30	0.00	16.55	10
2	1.39	0.26					
	3	2	16	15	29.97	22.55	21
2	1.79	0.12					
	4	0	10	35	0.00	25.20	6
0	0.00	0.00					
	5	3	23	16	31.27	19.29	28
3	1.57	0.24					

	6	0	34	24	0.00	7.18	27
0	0.00	0.00					
	7	0	9	42	0.00	28.14	4
0	0.00	0.00					
	8	0	10	15	0.00	25.20	13
0	0.00	0.00					
	9	2	28	64	17.14	12.59	8
1	1.70	0.11					
	10	1	10	24	23.98	25.20	8
1	1.78	0.54					
	11	1	6	21	39.92	43.20	6
1	2.39	0.42					
	12	1	11	28	21.81	22.82	8
1	1.81	0.16					
	13	1	12	25	19.99	20.85	9
1	2.57	0.56					
	14	0	14	42	0.00	17.78	6
0	0.00	0.00					
	15	0	13	24	0.00	19.19	10
2	1.61	0.18					
	16	3	21	40	34.24	21.24	10
3	2.02	0.54					
	17	1	31	40	7.75	7.89	15
1	1.52	0.42					
	18	4	23	30	41.65	22.72	15
3	1.47	0.29					
	19	1	10	32	23.98	25.20	6
1	1.46	0.16					
	20	3	51	40	14.12	8.44	25
2	1.48	0.19					
	21	1	65	64	3.70	3.73	20
1	2.07	0.48					
	22	1	17	49	14.12	14.56	7
2	1.79	0.27					
	23	0	9	36	0.00	28.14	5
0	0.00	0.00					
	24	1	32	64	7.50	7.64	10
2	1.96	0.16					
	25	2	19	30	25.24	18.83	12
1	1.44	0.11					
	26	2	12	34	39.92	30.60	7
2	1.48	0.26					
	27	4	37	90	25.92	13.74	8
3	1.62	0.11					
	28	0	8	32	0.00	31.84	5
1	2.37	0.28					
	29	1	16	40	15.00	15.49	8
1	1.45	0.29					
	30	0	13	42	0.00	19.19	6
1	2.08	0.35					
	31	0	16	60	0.00	15.49	5
0	0.00	0.00					
	32	0	8	64	0.00	31.84	2
1	1.57	0.29					
	33	0	20	100	0.00	12.32	4
0	0.00	0.00					

Mean Dpar = 1.77
 Mean Dper = 0.28
 Chi-squared = 32.499
 Chi-squared prob= 0.442
 Pooled Age (Ma) = 13.0+/- 2.4
 Mean Age (Ma) = 13.3+/- 2.7
 W.Mean Age (Ma) = 7.6+/- 2.2
 Median Age (Ma) = 7.7- 2.0+ 4.3

PFT-49

Etch	Grain Dpar Number Figures	Natural Dper Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
	1	0	23	32	0.00	10.67	14
3	1.82	0.34					
	2	0	10	45	0.00	25.16	4
0	0.00	0.00					
	3	1	10	50	23.95	25.16	4
1	1.42	0.04					
	4	5	66	42	18.15	8.50	30
4	1.37	0.33					
	5	0	1	64	0.00	333.46	0
2	1.69	0.18					
	6	4	34	62	28.16	14.99	11
3	1.79	0.30					
	7	3	21	18	34.18	21.21	23
2	1.68	0.27					
	8	8	97	36	19.76	7.37	52
4	1.91	0.22					
	9	1	10	40	23.95	25.16	5
2	1.59	0.26					
	10	0	71	40	0.00	3.41	34
0	0.00	0.00					
	11	2	1	45	462.80	567.57	0
3	2.19	0.22					

Mean Dpar = 1.72
 Mean Dper = 0.24
 Chi-squared = 28.010
 Chi-squared prob= 0.002
 Pooled Age (Ma) = 16.7+/- 3.7
 Mean Age (Ma) = 56.9+/- 44.5
 W.Mean Age (Ma) = 6.5+/- 2.7
 Median Age (Ma) = 19.8- 9.3+ 3.0

PFT-53

Etch	Grain Dpar Number Figures	Natural Dper Tracks (microns)	Induced Dper Tracks (microns)	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)
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	1	9	48	40	53.81	19.84	19
4	1.85	0.36					
	2	2	12	36	47.85	36.68	5
2	1.69	0.28					
	3	13	82	100	45.53	13.90	13
4	1.52	0.31					
	4	0	37	40	0.00	7.90	15
0	0.00	0.00					
	5	3	120	70	7.20	4.23	28
2	1.77	0.25					
	6	7	153	80	13.17	5.16	31
2	1.68	0.16					
	7	10	42	50	68.26	24.40	14
4	1.66	0.22					
	8	7	47	28	42.78	17.54	27
3	1.97	0.24					
	9	24	45	100	151.90	39.59	7
4	1.65	0.15					
	10	3	37	48	23.33	14.08	12
2	1.74	0.17					
	11	0	11	42	0.00	27.36	4
1	1.93	0.23					
	12	4	119	40	9.68	4.96	48
3	1.56	0.25					
	13	14	101	70	39.82	11.64	23
4	1.80	0.31					
	14	23	261	64	25.35	5.74	66
4	1.74	0.53					
	15	10	133	35	21.63	7.23	61
3	1.97	0.19					
	16	0	21	27	0.00	14.06	13
0	0.00	0.00					
	17	11	61	42	51.76	17.27	23
4	1.79	0.20					
	18	3	52	64	16.61	9.92	13
2	2.25	0.25					
	19	7	87	60	23.15	9.21	23
3	1.89	0.25					
	20	23	285	70	23.22	5.24	66
4	1.74	0.28					
	21	20	140	49	41.04	10.15	46
4	1.61	0.30					

Mean Dpar = 1.78
 Mean Dper = 0.26
 Chi-squared = 100.086
 Chi-squared prob= 0.000
 Pooled Age (Ma) = 29.3+/- 2.9
 Mean Age (Ma) = 33.7+/- 7.8
 W.Mean Age (Ma) = 18.3+/- 2.1
 Median Age (Ma) = 23.3- 3.4+ 7.4

PFT-55

	Grain	Natural	Induced	Quads	FT Age	1 sigma	Uranium
Etch	Dpar	Dper					

	Number Figures	Tracks (microns)	Tracks (microns)	(dmnls)	(Ma)	(Ma)	(ppm)
	1	2	14	16	41.02	31.12	14
1	1.19	0.17					
	2	5	30	60	47.83	23.30	8
4	1.83	0.13					

Mean Dpar = 1.51
 Mean Dper = 0.15
 Chi-squared = 0.030
 Chi-squared prob= 0.863
 Pooled Age (Ma) = 45.7+/- 18.8
 Mean Age (Ma) = 44.4+/- 5.6
 W.Mean Age (Ma) = 45.4+/- 18.7
 Median Age (Ma) = 44.4- 5.0+ 5.0

PFT-61

	Grain Etch	Natural Dpar	Induced Dper	Quads	FT Age	1 sigma	Uranium
	Number Figures	Tracks (microns)	Tracks (microns)	(dmnls)	(Ma)	(Ma)	(ppm)
	1	20	119	70	48.15	12.03	27
4	1.56	0.32					
	2	2	25	50	22.96	16.94	8
2	1.88	0.23					

Mean Dpar = 1.72
 Mean Dper = 0.28
 Chi-squared = 0.958
 Chi-squared prob= 0.328
 Pooled Age (Ma) = 43.8+/- 10.4
 Mean Age (Ma) = 35.6+/- 18.0
 W.Mean Age (Ma) = 40.0+/- 9.9
 Median Age (Ma) = 35.6- 18.7+ 18.7

PFT-65

	Grain Etch	Natural Dpar	Induced Dper	Quads	FT Age	1 sigma	Uranium
	Number Figures	Tracks (microns)	Tracks (microns)	(dmnls)	(Ma)	(Ma)	(ppm)
	1	39	369	60	30.27	5.45	99
4	2.30	0.29					
	2	15	133	24	32.30	9.03	90
4	1.76	0.18					
	3	20	248	80	23.11	5.57	50
4	2.03	0.15					

Mean Dpar = 2.03
 Mean Dper = 0.21
 Chi-squared = 1.164

Chi-squared prob= 0.559
Pooled Age (Ma) = 28.3+/- 3.9
Mean Age (Ma) = 28.6+/- 3.9
W.Mean Age (Ma) = 27.7+/- 3.8
Median Age (Ma) = 30.3- 3.8+ 1.1

***APATITE FISSION-TRACK
LENGTH DATA***

GU-01

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	1.39	4	1.68	0.47	61.92
2	5.52	4	0.94	0.38	48.16
3	10.10	4	1.49	0.44	32.73
4	12.17	4	1.77	0.34	4.67
5	13.89	4	2.64	1.21	71.84
6	15.54	4	2.11	0.55	60.79
7	5.94	4	2.11	0.55	62.63
8	6.05	4	1.40	0.38	15.03
9	15.23	4	1.64	0.48	72.35
10	12.39	4	1.64	0.48	72.34
11	14.45	4	1.64	0.48	61.62
12	12.80	4	1.64	0.48	7.73
13	8.72	4	1.64	0.48	38.54
14	6.59	4	1.74	0.53	66.05
15	10.30	4	1.45	0.46	70.61
16	8.80	4	1.45	0.46	9.62
17	2.20	4	1.14	0.38	65.40
18	2.48	4	1.86	0.63	71.77
19	12.53	4	1.96	0.79	82.38
20	9.91	4	1.71	0.29	59.92
21	11.16	4	2.27	0.86	61.69
22	13.10	4	2.48	0.86	63.65
23	14.14	4	2.93	1.21	81.83
24	11.61	4	1.68	0.78	55.95
25	14.41	4	1.54	0.38	50.99
26	15.66	4	2.05	0.52	2.92
27	14.74	4	2.77	1.17	60.80
28	13.60	4	2.17	1.20	36.28
29	11.74	4	1.90	1.25	76.73
30	13.55	4	1.90	1.25	22.71
31	9.03	4	1.90	1.25	39.21
32	11.34	4	2.24	0.89	67.22
33	13.80	4	1.48	0.41	52.99
34	13.48	4	1.48	0.41	68.56
35	11.30	4	1.48	0.41	79.95
36	12.76	4	1.31	0.41	51.63
37	11.50	4	2.17	0.82	76.89
38	9.09	4	2.10	0.74	55.82
39	14.67	4	3.03	1.27	61.05
40	10.90	4	3.03	1.27	37.65
41	13.69	4	3.03	1.27	80.47
42	14.33	4	3.03	1.27	22.27
43	13.16	4	3.03	1.27	26.41
44	12.81	4	2.08	0.60	44.72
45	12.64	4	3.06	0.80	67.68
46	11.30	4	3.06	0.80	23.20
47	13.33	4	3.06	0.80	71.18
48	8.67	4	3.06	0.80	62.29
49	13.88	4	2.31	0.56	75.65
50	10.61	4	1.43	0.44	42.10
51	11.86	4	2.10	0.88	74.28
52	13.09	4	1.97	0.85	50.99

53	10.76	4	2.76	1.11	39.98
54	13.12	4	2.88	1.23	19.17
55	9.22	4	2.88	1.23	65.57
56	16.65	4	2.84	1.26	38.35
57	13.68	4	1.85	0.69	45.12
58	13.20	4	2.65	1.22	62.06
59	15.33	4	2.65	1.22	64.01
60	12.95	4	2.65	1.22	39.59
61	15.06	4	1.51	0.39	52.53
62	13.39	4	2.69	1.19	61.27
63	13.34	4	1.53	0.40	39.84
64	14.73	4	2.78	1.16	45.02
65	11.05	4	1.46	0.48	45.58
66	3.39	4	1.10	0.37	78.06
67	8.98	4	2.05	0.86	74.38
68	10.65	4	2.05	0.86	72.95
69	13.39	4	2.44	1.07	10.01
70	13.81	4	3.20	0.73	76.56
71	13.56	4	3.20	0.73	65.97
72	13.00	4	3.20	0.73	77.21
73	14.27	4	2.87	0.98	67.16
74	7.37	4	0.94	0.37	47.37
75	13.27	4	2.31	0.45	30.08
76	13.84	4	1.61	0.33	65.58
77	11.94	4	1.30	0.51	48.85
78	10.87	4	1.81	0.47	48.61
79	16.27	4	1.81	0.47	31.71
80	10.74	4	1.71	0.41	12.45
81	8.86	4	1.29	0.33	33.82
82	14.62	4	1.73	0.44	58.54
83	12.26	4	1.26	0.39	49.13
84	10.48	4	1.70	0.44	78.15
85	11.19	4	1.38	0.52	59.05
86	13.54	4	1.80	0.89	72.69
87	10.36	4	1.50	0.46	51.71
88	8.37	4	1.50	0.46	69.97
89	11.80	4	2.13	0.92	57.16
90	11.77	4	2.68	1.15	73.95
91	13.38	4	2.68	1.15	67.83
92	15.00	4	2.55	1.23	20.75
93	3.82	4	1.28	0.42	43.33
94	11.27	4	1.50	0.45	20.16
95	8.61	4	1.50	0.45	67.98
96	14.06	4	1.43	0.41	59.95
97	12.23	4	2.01	0.84	26.36
98	14.29	4	2.01	0.84	33.98
99	14.31	4	2.73	1.19	38.41
100	15.35	4	1.74	0.45	39.69
101	13.96	4	1.50	0.83	22.31
102	14.89	4	1.50	0.83	16.16

Mean Dpar = 2.05
 Mean Dper = 0.74
 Mean length (um) = 11.77 +/- 0.31
 Std. Dev. (um) = 3.13
 Skewness = -1.31
 Kurtosis = 1.62

GU-02

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	4.61	4	3.16	1.06	33.44
2	11.30	4	3.16	1.06	37.64
3	13.63	4	1.26	0.35	40.65
4	2.53	4	1.55	0.52	67.93
5	15.39	4	3.12	0.98	71.43
6	12.19	4	3.12	0.98	38.19
7	13.63	4	1.47	0.89	50.83
8	13.19	4	1.47	0.89	64.01
9	12.14	4	1.47	0.89	69.46
10	14.93	4	0.88	0.43	50.19
11	13.38	4	2.79	1.26	70.87
12	7.37	4	2.79	1.26	24.36
13	2.62	4	1.23	0.39	16.91
14	12.07	4	2.38	1.16	50.80
15	13.14	4	1.56	1.00	10.07
16	8.66	4	2.02	0.87	60.56
17	12.86	4	0.92	0.42	59.26
18	2.91	4	0.92	0.42	43.03
19	14.59	4	1.09	0.36	56.06
20	8.73	4	1.47	0.41	12.10
21	12.05	4	1.35	0.42	70.41
22	4.00	4	1.41	0.32	28.64
23	4.72	4	1.41	0.32	74.45
24	15.34	4	1.26	0.58	13.95
25	9.25	4	1.29	0.49	12.53
26	12.74	4	1.29	0.49	45.77
27	10.84	4	1.90	0.47	72.96
28	14.03	4	1.90	0.47	46.74
29	11.24	4	1.90	0.47	52.92
30	14.39	4	1.74	0.60	56.61
31	12.34	4	1.74	0.60	59.09
32	13.58	4	1.74	0.60	14.78
33	6.21	4	1.57	0.34	26.25
34	14.28	4	2.72	0.93	57.19
35	14.04	4	2.72	0.93	51.43
36	11.32	4	1.27	0.38	45.79
37	8.78	4	2.06	1.28	40.23
38	14.83	4	1.56	0.33	35.17
39	13.86	4	2.52	1.08	77.78
40	14.06	4	2.85	1.01	64.47
41	12.97	4	2.85	1.01	68.67
42	13.19	4	2.85	1.01	12.80
43	14.61	4	2.83	1.13	43.49
44	10.25	4	1.96	0.94	74.89
45	13.92	4	2.60	0.98	20.16
46	12.10	4	2.39	1.08	58.24
47	14.75	4	3.45	1.46	22.38
48	10.87	4	1.12	0.35	68.27
49	14.32	4	1.49	0.35	38.09
50	12.92	4	1.49	0.35	25.82

51	14.28	4	1.49	0.35	49.94
52	10.72	4	1.49	0.35	7.21
53	12.63	4	1.38	0.41	73.58
54	15.65	4	2.27	0.90	19.37
55	10.71	4	2.27	0.90	69.88
56	12.73	4	2.77	1.31	42.31
57	10.98	4	1.66	0.51	60.10
58	12.16	4	1.66	0.51	66.91
59	12.73	4	1.66	0.51	66.12
60	13.17	4	1.66	0.51	26.77
61	9.55	4	1.66	0.51	64.62
62	10.96	4	1.66	0.51	73.27
63	10.35	4	1.66	0.51	63.59
64	11.56	4	1.59	0.41	67.40
65	11.72	4	1.59	0.41	51.99
66	13.31	4	1.59	0.41	67.34
67	12.37	4	1.16	0.46	48.97
68	13.21	4	1.06	0.30	77.02
69	13.01	4	0.93	0.39	24.73
70	14.05	4	0.93	0.39	32.45
71	10.64	4	0.93	0.39	47.14
72	15.55	4	0.93	0.39	69.33
73	13.30	4	2.03	0.66	68.26
74	13.65	4	3.17	0.83	71.81
75	11.90	4	3.17	0.83	69.87
76	14.58	4	3.17	0.83	33.83
77	15.67	4	2.55	1.64	17.56
78	12.51	4	2.55	1.64	32.43
79	13.74	4	2.55	1.64	53.53
80	4.40	4	1.33	0.43	37.30
81	9.01	4	1.62	0.34	66.01
82	7.34	4	1.62	0.34	47.07
83	14.46	4	3.12	1.12	56.24
84	13.86	4	2.58	1.21	68.22
85	14.38	4	2.58	1.21	20.80
86	15.21	4	2.58	1.21	22.16
87	11.94	4	2.58	1.21	54.40
88	11.90	4	1.37	0.42	55.88
89	13.20	4	3.14	0.96	50.88
90	10.51	4	3.14	0.96	26.91
91	4.68	4	3.14	0.96	38.69
92	12.71	4	2.99	1.08	63.22
93	13.33	4	2.99	1.08	63.34
94	4.55	4	1.45	0.42	36.43
95	16.51	4	2.72	1.08	19.31
96	14.19	4	2.72	1.08	58.09
97	12.69	4	2.72	1.08	39.51
98	12.63	4	2.89	1.24	83.99
99	12.43	4	1.54	0.42	33.33
100	12.71	4	1.50	0.35	8.55

Mean Dpar = 2.01
 Mean Dper = 0.74
 Mean length (um) = 11.82 +/- 0.32
 Std. Dev. (um) = 3.16
 Skewness = -1.39
 Kurtosis = 1.33

GU-03

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	10.27	4	2.49	1.08	4.34
2	14.88	4	2.49	1.08	79.96
3	14.41	4	2.49	1.08	37.20
4	14.88	4	2.49	1.08	70.74
5	13.17	4	2.49	1.08	66.20
6	15.72	4	2.79	1.25	49.61
7	13.09	4	1.18	0.44	46.59
8	14.35	4	2.48	0.54	60.53
9	8.54	4	0.99	0.35	61.70
10	14.71	4	2.69	0.80	50.64
11	12.52	4	2.69	0.80	49.17
12	14.29	4	2.69	0.80	5.01
13	13.10	4	2.53	0.89	40.77
14	13.05	4	2.62	1.01	52.30
15	14.91	4	1.37	0.43	44.25
16	12.97	4	1.47	0.41	51.34
17	15.12	4	3.30	0.96	72.97
18	13.27	4	0.98	0.40	14.27
19	13.85	4	2.78	1.27	77.67
20	13.68	4	2.78	1.27	63.41
21	13.40	4	2.78	1.27	49.78
22	14.89	4	2.58	1.03	85.07
23	11.57	4	2.58	1.03	60.69
24	14.85	4	2.50	0.97	80.44
25	9.03	4	2.50	0.97	39.65
26	13.24	4	2.50	0.97	46.97
27	14.77	4	2.50	0.97	39.76
28	12.43	4	1.39	0.34	24.27
29	13.58	4	1.39	0.34	72.03
30	13.37	4	1.39	0.34	50.70
31	9.35	4	1.39	0.34	87.51
32	15.00	4	2.08	1.06	56.65
33	10.86	4	1.46	0.43	51.63
34	13.80	4	1.46	0.43	51.32
35	14.82	4	2.46	0.78	21.79
36	6.39	4	1.26	0.45	52.19
37	5.46	4	1.26	0.45	56.16
38	14.95	4	2.23	0.48	42.43
39	13.63	4	1.30	0.53	60.29
40	13.95	4	2.29	0.75	58.99
41	9.64	4	1.33	0.35	60.69
42	14.40	4	2.53	1.51	58.98
43	15.96	4	2.40	1.11	58.94
44	15.25	4	2.40	1.11	63.84
45	16.20	4	2.40	1.11	29.74
46	13.38	4	2.40	1.11	57.38
47	14.39	4	2.40	1.11	37.86
48	13.13	4	2.40	1.11	72.22
49	14.31	4	2.40	1.11	59.82
50	13.92	4	2.40	1.11	59.18

51	14.84	4	2.40	1.11	54.92
52	14.05	4	2.40	1.11	31.07
53	15.20	4	2.40	1.11	68.49
54	13.83	4	2.40	1.11	71.78
55	14.08	4	2.40	1.11	60.77
56	15.18	4	2.40	1.11	69.87
57	16.18	4	2.40	1.11	72.88
58	14.52	4	2.40	1.11	64.85
59	14.50	4	2.40	1.11	44.24
60	13.38	4	2.40	1.11	81.50
61	14.35	4	2.40	1.11	5.38
62	12.66	4	2.40	1.11	72.43
63	14.01	4	2.40	1.11	55.88
64	13.96	4	2.40	1.11	17.56
65	15.98	4	2.70	0.70	51.93
66	14.91	4	2.70	0.70	35.29
67	10.50	4	2.70	0.70	68.32
68	13.46	4	2.70	0.70	64.58
69	14.28	4	2.70	0.70	61.85
70	13.64	4	2.98	0.97	62.57
71	9.10	4	2.98	0.97	34.56
72	16.39	4	2.98	0.97	69.14
73	13.90	4	1.61	0.41	51.28
74	12.47	4	1.61	0.41	20.57
75	11.30	4	1.61	0.41	39.31
76	11.10	4	1.61	0.41	80.18
77	12.49	4	1.61	0.41	84.92
78	12.24	4	1.61	0.41	47.89
79	13.56	4	1.61	0.41	72.21
80	12.65	4	1.61	0.41	60.47
81	13.92	4	1.61	0.41	52.83
82	9.24	4	2.26	1.29	45.91
83	15.48	4	2.34	0.93	69.86
84	14.24	4	2.34	0.93	54.12
85	12.16	4	2.32	1.08	87.48
86	14.91	4	2.83	1.57	51.04
87	14.05	4	2.83	1.57	40.31
88	14.42	4	2.83	1.57	74.39
89	13.75	4	2.83	1.57	64.70
90	16.45	4	2.71	1.63	38.49
91	11.68	4	1.29	0.37	22.28
92	12.89	4	1.29	0.37	81.77
93	9.76	4	1.29	0.37	52.10
94	14.52	4	1.29	0.37	77.95
95	12.49	4	1.29	0.37	52.80
96	12.34	4	2.92	1.06	60.60
97	15.80	4	2.92	1.06	47.64
98	10.77	4	2.92	1.06	74.55
99	13.75	4	2.67	1.14	45.48
100	13.54	4	2.67	1.14	83.06
101	12.39	4	2.67	1.14	39.48

Mean Dpar = 2.23
 Mean Dper = 0.87
 Mean length (um) = 13.35+/- 0.20
 Std. Dev. (um) = 2.03
 Skewness = -1.39

Kurtosis = 2.36

GU-04

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	8.75	4	1.57	0.40	41.12
2	3.93	4	1.57	0.40	69.68
3	4.99	4	1.57	0.40	49.07
4	10.98	4	1.70	0.51	46.68
5	12.20	4	1.70	0.51	64.84
6	10.73	4	1.70	0.51	61.15
7	14.46	4	1.70	0.51	34.53
8	10.49	4	1.70	0.51	56.21
9	9.21	4	1.70	0.51	74.39
10	5.90	4	1.37	0.39	37.14
11	10.59	4	1.40	0.37	59.75
12	14.48	4	1.40	0.37	23.18
13	2.50	4	1.40	0.37	64.05
14	11.96	4	1.72	0.47	63.32
15	13.45	4	1.72	0.47	64.77
16	9.87	4	1.72	0.47	33.53
17	6.74	4	1.72	0.47	42.90

Mean Dpar = 1.61
 Mean Dper = 0.45
 Mean length (um)= 9.48+/- 0.90
 Std. Dev. (um)= 3.59
 Skewness = -0.40
 Kurtosis = -1.03

GU-05

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	14.13	4	2.49	1.09	25.05
2	8.69	4	3.12	0.93	54.23
3	5.11	4	3.12	0.93	57.03
4	12.76	4	1.29	0.27	82.81
5	9.27	4	2.88	1.21	51.21
6	14.32	4	2.57	0.95	46.50
7	15.32	4	1.80	0.43	84.12
8	15.19	4	1.80	0.43	11.14
9	13.09	4	2.37	0.94	54.02
10	10.14	4	1.35	0.46	42.78
11	15.46	4	2.62	1.05	53.27
12	13.13	4	2.04	0.74	74.45
13	13.93	4	1.37	0.37	62.90
14	11.67	4	1.37	0.37	47.37
15	3.20	4	1.80	0.48	73.93
16	9.87	4	1.80	0.48	32.23
17	13.54	4	2.52	0.89	78.23
18	10.01	4	1.65	0.29	76.67

19	14.10	4	1.65	0.29	34.72
20	10.48	4	1.65	0.29	21.41
21	10.04	4	1.65	0.29	47.70
22	14.31	4	1.13	0.38	62.13
23	13.12	4	1.14	0.78	72.42
24	13.41	4	1.14	0.78	39.12
25	11.34	4	1.63	0.35	52.10
26	5.28	4	1.32	0.47	12.87
27	14.85	4	1.93	0.77	26.50
28	13.83	4	1.63	0.46	50.39
29	14.10	4	1.53	0.50	63.73
30	15.00	4	3.16	1.22	69.78
31	12.28	4	0.99	0.44	16.67
32	14.66	4	2.63	1.17	38.86
33	11.20	4	1.84	0.49	13.81
34	14.50	4	1.90	0.77	7.21
35	5.80	4	3.06	1.02	84.80
36	11.76	4	1.46	0.59	38.91
37	15.12	4	2.23	1.15	55.42
38	8.91	4	2.31	1.21	71.97
39	15.37	4	1.48	0.47	67.04
40	9.55	4	1.48	0.47	24.22
41	11.28	4	1.48	0.47	62.42
42	13.22	4	2.11	0.85	45.86
43	13.96	4	1.26	0.39	8.24
44	12.24	4	2.77	0.88	80.53
45	11.19	4	1.68	0.38	23.59
46	10.13	4	1.85	0.55	42.18
47	13.64	4	2.10	0.96	21.71
48	13.29	4	2.44	0.55	81.13
49	11.18	4	1.05	0.32	19.08
50	15.54	4	3.27	0.87	35.37
51	9.79	4	1.12	0.34	19.67
52	12.57	4	1.98	0.65	61.14
53	9.02	4	1.98	0.65	34.73
54	2.93	4	1.18	0.37	66.84
55	2.45	4	1.18	0.37	73.26
56	14.96	4	2.72	0.87	43.82
57	12.73	4	1.52	0.36	39.47
58	13.53	4	2.11	0.66	72.70
59	10.71	4	2.17	0.39	70.44
60	10.80	4	2.12	0.86	33.32
61	14.40	4	1.66	0.70	6.02
62	14.11	4	2.87	0.80	55.85
63	12.80	4	1.03	0.33	75.82
64	13.59	4	1.03	0.33	28.30
65	14.27	4	2.11	0.69	64.04
66	4.54	4	2.44	1.12	41.80
67	10.64	4	1.99	0.48	74.90
68	5.73	4	2.68	0.76	51.32
69	15.32	4	3.45	1.07	62.04
70	10.98	4	2.06	0.45	57.37
71	13.97	4	1.33	0.65	70.25
72	13.15	4	1.83	0.58	46.15
73	7.97	4	1.63	0.51	51.58
74	10.72	4	3.14	1.18	18.06
75	6.45	4	1.57	0.50	40.16

76	5.19	4	1.59	0.48	78.74
77	15.92	4	3.68	1.25	46.16
78	13.82	4	1.84	0.41	64.41
79	9.50	4	1.19	0.70	33.84
80	12.25	4	3.09	0.98	77.98
81	11.71	4	1.05	0.46	61.80
82	11.72	4	1.60	0.78	47.87
83	9.79	4	1.78	0.50	78.86
84	11.43	4	1.31	0.58	71.75
85	13.43	4	1.36	0.39	24.13
86	13.06	4	1.41	0.33	77.59
87	12.97	4	1.41	0.33	49.98
88	12.34	4	1.45	0.66	56.87
89	8.76	4	1.49	0.44	48.03
90	11.72	4	1.69	0.47	58.17
91	11.85	4	1.57	0.86	84.05
92	13.02	4	2.06	0.86	28.06
93	15.26	4	3.28	1.15	79.93
94	13.87	4	1.44	0.44	38.20
95	11.44	4	1.79	0.50	74.97
96	14.74	4	1.36	0.39	28.90
97	9.77	4	2.27	0.83	64.31
98	6.90	4	2.05	0.68	64.26
99	14.54	4	3.17	1.28	72.42
100	8.88	4	1.60	0.66	43.53
101	14.42	4	1.76	0.77	30.08
102	11.26	4	1.03	0.44	69.03
103	13.22	4	2.41	0.87	76.98

Mean Dpar = 1.92
 Mean Dper = 0.65
 Mean length (um) = 11.69+/- 0.30
 Std. Dev. (um) = 3.06
 Skewness = -1.09
 Kurtosis = 0.72

GU-06

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	13.40	4	2.98	0.96	30.53
2	14.29	4	2.00	0.83	57.18
3	9.40	4	1.60	0.48	77.25
4	9.44	4	1.72	0.71	69.81
5	6.30	4	1.81	0.49	61.62
6	14.70	4	2.53	1.03	63.50
7	12.87	4	2.46	0.63	26.41
8	13.74	4	1.52	0.45	76.04
9	13.34	4	1.58	0.36	5.39
10	9.39	4	1.58	0.36	12.20
11	3.82	4	1.37	0.40	36.74
12	10.75	4	3.13	1.07	46.89
13	10.63	4	1.74	0.44	53.00
14	7.08	4	1.37	0.48	51.15
15	14.16	4	1.95	0.32	68.38

16	11.77	4	1.40	0.37	85.94
17	11.32	4	2.43	0.60	51.07
18	13.22	4	2.43	0.60	30.34
19	10.79	4	2.43	0.60	73.12
20	11.71	4	2.43	0.60	42.34
21	9.98	4	1.97	0.84	14.20
22	12.30	4	2.15	0.95	27.48
23	12.86	4	1.84	0.78	32.53
24	13.92	4	2.24	0.64	40.75
25	14.16	4	2.07	0.38	38.59
26	12.44	4	2.07	0.38	20.04
27	13.51	4	2.03	0.60	73.90
28	13.33	3	1.64	0.51	12.94
29	13.18	4	3.02	0.97	60.76
30	12.76	4	3.02	0.97	18.83
31	17.35	4	1.98	0.39	53.19
32	12.13	4	1.22	0.43	79.34
33	13.32	4	1.61	0.45	75.42
34	13.65	4	1.61	0.45	84.42
35	13.81	4	2.08	0.53	35.51
36	12.09	4	2.08	0.53	60.87
37	13.87	4	2.27	0.91	32.56
38	8.92	4	2.27	0.91	42.10
39	12.92	4	2.15	0.75	41.41
40	10.70	4	2.00	0.62	54.56
41	15.18	4	2.00	0.62	38.06
42	12.26	4	2.00	0.62	11.72
43	11.94	4	2.00	0.62	27.15
44	4.96	4	2.28	0.47	24.59
45	3.78	4	2.09	0.73	74.27
46	12.08	4	2.09	0.86	77.06
47	13.77	4	2.09	0.86	63.57
48	3.78	4	1.23	0.44	69.93
49	13.29	4	2.62	1.09	79.77
50	12.44	4	1.79	0.47	75.78
51	12.98	4	1.34	0.42	73.96
52	13.73	4	1.37	0.37	72.75
53	15.77	4	2.33	0.89	43.58
54	12.67	4	2.14	0.61	18.95
55	9.53	4	2.45	1.14	35.83
56	14.72	4	1.33	0.38	44.39
57	14.10	4	1.84	0.57	56.75
58	10.70	4	1.30	0.38	62.87
59	13.96	4	1.74	0.41	11.95
60	9.25	4	1.74	0.41	80.18
61	13.01	4	0.97	0.49	56.52
62	13.94	4	1.55	0.32	50.77
63	11.79	4	1.55	0.32	42.64
64	10.24	4	1.55	0.32	41.69
65	8.73	4	1.39	0.52	44.21
66	4.46	4	1.32	0.63	40.45
67	13.80	4	1.29	0.36	6.78
68	12.47	4	2.79	0.91	59.39
69	9.61	4	1.73	0.53	62.51
70	15.17	4	1.74	0.62	38.74
71	14.74	4	1.72	0.51	52.43
72	7.83	4	2.28	0.96	61.91

73	13.97	4	2.02	0.93	55.64
74	13.71	4	1.78	0.59	27.74
75	13.36	4	2.10	0.43	29.49
76	13.88	4	2.10	0.43	37.93
77	13.73	4	2.22	0.40	50.87
78	6.48	4	0.89	0.45	70.38
79	13.19	4	1.89	0.50	66.07
80	7.16	4	1.76	0.70	62.90
81	9.66	4	1.93	0.70	50.98
82	14.33	4	2.02	0.68	69.24
83	13.90	4	2.46	0.74	64.46
84	16.11	4	2.35	0.93	63.76
85	12.60	4	1.37	0.43	66.23
86	9.22	4	1.97	0.70	44.98
87	13.41	4	0.69	0.33	62.76
88	13.94	4	2.71	0.69	83.20
89	15.19	4	2.71	0.69	61.12
90	13.37	4	1.49	0.46	86.64
91	12.24	4	1.28	0.48	84.47
92	14.14	4	1.77	0.43	30.12
93	11.33	4	1.36	0.39	56.73
94	14.41	4	1.18	0.46	39.77
95	10.49	4	2.44	0.58	8.42
96	6.86	4	1.54	0.40	52.36
97	9.87	4	1.82	0.52	43.92
98	13.80	4	1.82	0.52	57.84
99	11.96	4	1.99	0.55	37.35
100	8.95	4	1.58	0.43	37.36

Mean Dpar = 1.91
 Mean Dper = 0.59
 Mean length (um) = 11.87+/- 0.29
 Std. Dev. (um) = 2.84
 Skewness = -1.11
 Kurtosis = 0.83

GU-07

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	14.14	4	1.22	0.44	32.87
2	14.49	4	1.22	0.44	31.29
3	5.68	4	1.27	0.33	6.57
4	12.11	4	1.27	0.42	11.56
5	12.88	4	0.83	0.24	64.47
6	2.24	4	1.79	0.56	77.50
7	3.37	4	1.79	0.56	48.25
8	10.90	4	1.53	0.33	9.06
9	10.17	4	2.68	0.68	59.88
10	11.61	4	1.79	0.64	89.53
11	14.00	4	1.79	0.64	41.92
12	11.62	4	1.41	0.33	54.81
13	14.77	4	1.98	0.35	48.76
14	12.10	4	1.50	0.45	4.90
15	13.58	4	1.32	0.45	47.09

16	13.42	4	1.32	0.45	12.14
17	10.03	4	1.32	0.45	30.30
18	11.54	4	1.32	0.45	74.83
19	7.67	4	1.44	0.33	14.43
20	11.89	4	1.42	0.37	31.20
21	8.44	4	1.42	0.37	32.90
22	13.51	4	1.25	0.45	40.58
23	7.69	4	1.62	0.40	73.53
24	10.15	4	1.62	0.40	77.95
25	12.37	4	1.62	0.40	44.76
26	13.08	4	1.67	0.39	55.74
27	11.66	4	1.67	0.39	49.74
28	2.47	4	1.13	0.35	44.64
29	13.62	4	1.39	0.44	44.41
30	10.00	4	1.39	0.44	34.26
31	10.10	4	1.39	0.44	68.19
32	9.76	4	1.39	0.44	72.26
33	9.54	4	1.25	0.36	43.98
34	15.55	4	1.25	0.36	34.47
35	14.10	4	2.15	0.56	29.01
36	15.75	4	1.45	0.44	8.71
37	6.91	4	1.04	0.62	59.01
38	13.75	4	1.93	0.65	69.72
39	12.63	4	1.93	0.65	29.25
40	14.11	4	1.41	0.46	7.65
41	3.44	4	1.51	0.46	77.79
42	11.33	4	1.61	0.73	82.37
43	12.39	4	1.66	0.49	82.05
44	10.79	4	1.66	0.49	45.79
45	11.94	4	1.99	0.35	54.54
46	10.12	4	1.47	0.40	54.45
47	11.74	4	1.47	0.40	44.25
48	9.68	4	1.47	0.40	81.70
49	5.62	4	1.24	0.38	67.32
50	12.50	4	1.63	0.45	65.90
51	12.47	4	1.63	0.25	75.63
52	12.72	4	1.88	0.32	58.54
53	12.17	4	1.23	0.31	19.76
54	13.53	4	1.23	0.31	59.40
55	13.79	4	0.80	0.35	71.99
56	6.78	4	1.45	0.37	68.32
57	5.98	4	1.45	0.37	31.26
58	16.23	4	1.72	0.37	66.54
59	12.51	4	0.95	0.36	78.25
60	11.70	4	1.40	0.48	19.29
61	7.89	4	1.40	0.48	77.15
62	8.61	4	1.36	0.34	48.03
63	11.20	4	1.87	0.42	59.02
64	9.92	4	1.44	0.35	72.71
65	8.33	4	0.99	0.39	56.37
66	11.72	4	1.45	0.41	6.58
67	8.88	4	1.68	0.45	45.12
68	4.54	4	1.61	0.35	54.87
69	12.54	2	1.21	0.42	82.00
70	12.69	4	1.74	0.42	41.44
71	10.00	4	1.74	0.42	43.01
72	10.28	4	1.09	0.38	22.97

73	11.83	4	1.28	0.53	65.09
74	13.06	4	1.30	0.39	64.34
75	14.76	4	2.52	0.74	81.55
76	8.53	4	2.52	0.74	25.54
77	13.26	4	1.32	0.31	13.96
78	12.54	4	1.61	0.48	62.17
79	12.75	4	1.39	0.45	55.51
80	14.40	4	1.39	0.45	76.36

Mean Dpar = 1.51
 Mean Dper = 0.44
 Mean length (um) = 10.98+/- 0.35
 Std. Dev. (um) = 3.10
 Skewness = -0.96
 Kurtosis = 0.52

GU-08

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	6.88	4	1.27	0.35	63.10
2	11.13	4	1.33	0.40	32.25
3	12.07	4	1.77	0.46	89.92
4	11.27	4	2.01	0.36	39.83
5	3.12	4	2.09	0.46	62.09
6	12.80	4	1.92	0.45	52.82
7	9.87	4	1.24	0.54	70.19
8	11.05	4	1.60	0.37	28.43
9	14.70	4	1.35	0.44	19.08
10	4.80	4	1.68	0.75	86.16
11	14.16	4	2.26	0.94	70.33
12	14.55	4	1.43	0.31	75.97
13	14.57	4	1.43	0.31	23.32
14	14.16	4	1.63	0.38	78.73
15	11.58	4	1.64	0.41	51.12
16	14.13	4	1.64	0.41	54.69
17	14.02	4	1.64	0.41	63.65
18	14.13	4	1.64	0.41	75.47
19	14.01	4	1.67	0.35	30.01
20	12.38	4	1.67	0.35	74.58
21	10.39	4	1.66	0.41	54.01
22	9.20	4	1.11	0.32	70.35
23	14.30	4	2.02	0.59	61.47
24	14.65	4	2.02	0.59	59.23
25	10.74	4	1.50	0.37	30.67
26	12.40	4	1.16	0.56	37.43
27	13.79	4	1.58	0.56	52.83
28	13.58	4	1.58	0.56	57.91
29	14.07	4	1.58	0.56	3.74
30	9.75	4	1.19	0.45	82.32
31	13.88	4	1.28	0.43	25.16
32	12.41	4	1.66	0.45	20.08
33	13.77	4	1.59	0.44	61.14
34	5.10	4	1.65	0.58	5.27
35	12.98	4	1.53	0.29	58.77

36	12.68	4	1.53	0.29	42.81
37	7.26	4	1.50	0.39	7.64
38	14.53	4	1.54	0.36	68.79
39	12.95	4	1.54	0.36	60.17
40	14.35	4	2.09	0.88	53.64
41	13.32	4	1.51	0.46	51.63
42	14.71	4	1.86	0.76	29.99
43	4.35	4	1.60	0.43	75.93
44	12.95	4	1.54	0.55	57.51
45	11.15	4	1.73	0.35	23.20
46	13.30	4	1.76	0.42	39.65
47	13.18	4	1.33	0.41	81.99
48	14.40	4	2.04	0.75	64.30
49	12.93	4	1.66	0.38	38.78
50	13.62	4	1.66	0.38	69.71
51	12.89	4	1.66	0.38	29.16
52	15.39	4	1.66	0.38	14.47
53	14.28	4	1.66	0.38	43.38
54	14.72	4	1.66	0.38	48.30
55	6.30	4	1.66	0.38	48.01
56	9.66	4	1.66	0.38	47.16
57	6.60	4	1.66	0.38	71.58
58	8.48	4	1.66	0.38	84.78
59	11.18	4	1.21	0.36	4.58
60	10.88	4	1.50	0.46	33.75
61	13.68	4	2.02	0.56	68.20
62	13.57	4	2.02	0.56	34.08
63	11.90	4	2.10	0.54	43.55
64	11.82	4	1.71	0.38	67.91
65	13.61	4	2.03	0.65	31.85
66	11.58	4	1.58	0.31	49.24
67	14.00	4	2.20	0.65	52.31
68	15.20	4	1.85	0.35	27.98
69	13.51	4	1.73	0.31	7.38
70	12.35	4	1.73	0.31	49.63
71	13.43	4	1.71	0.40	84.11
72	12.65	4	1.50	0.43	73.36
73	11.74	4	1.87	0.52	74.10
74	15.77	4	1.30	0.40	74.42
75	13.37	4	1.37	0.36	84.37
76	12.37	4	1.68	0.38	89.01
77	12.36	4	1.36	0.35	50.49
78	11.73	4	1.49	0.34	73.13
79	6.96	4	2.03	0.70	72.68
80	12.67	4	1.71	0.72	60.09
81	11.80	4	1.71	0.72	74.28
82	12.00	4	1.76	0.76	46.13
83	8.45	4	1.62	0.40	74.27
84	10.55	4	1.97	0.62	47.60
85	15.34	4	1.97	0.62	66.53
86	10.15	4	1.97	0.62	72.90
87	6.73	4	1.85	0.44	48.10
88	13.54	4	1.97	0.59	50.28
89	6.32	4	1.57	0.34	9.96
90	15.09	4	1.68	0.45	50.70
91	13.46	4	1.42	0.37	78.06
92	12.12	2	1.55	0.35	69.12

93	9.90	4	1.52	0.42	76.66
94	12.17	4	1.86	0.40	37.49
95	15.05	4	1.54	0.35	59.26
96	14.92	4	2.58	0.77	80.80
97	12.71	4	1.83	0.70	24.63
98	11.46	4	0.88	0.39	57.94
99	14.79	4	2.23	0.37	86.89
100	10.96	4	2.29	0.90	68.71

Mean Dpar = 1.68
 Mean Dper = 0.47
 Mean length (um) = 12.04+/- 0.27
 Std. Dev. (um) = 2.72
 Skewness = -1.27
 Kurtosis = 1.11

GU-09

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	14.32	4	1.78	0.73	79.06
2	14.22	4	1.78	0.73	84.00
3	12.69	4	1.78	0.73	54.63
4	12.44	4	1.78	0.73	24.62
5	13.02	4	1.78	0.73	65.69
6	12.62	4	1.78	0.73	28.98
7	12.45	4	1.63	0.40	40.21
8	12.96	4	1.63	0.40	69.12
9	6.63	4	1.63	0.40	75.25
10	14.52	4	0.91	0.33	37.03
11	13.37	4	0.91	0.33	67.07
12	13.01	4	1.36	0.41	38.54
13	11.80	4	1.36	0.41	28.26
14	10.72	4	1.88	0.45	18.01
15	9.96	4	1.85	0.44	47.36
16	13.59	4	1.60	0.28	49.27
17	11.50	4	1.60	0.28	54.81
18	10.22	4	1.16	0.31	54.34

Mean Dpar = 1.57
 Mean Dper = 0.49
 Mean length (um) = 12.22+/- 0.47
 Std. Dev. (um) = 1.92
 Skewness = -1.29
 Kurtosis = 1.51

GU-10

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	13.19	4	1.46	0.40	57.76
2	13.64	4	1.69	0.54	39.90
3	8.32	4	1.98	0.75	42.93

4	7.88	4	1.78	0.52	49.05
5	10.71	4	1.85	0.36	16.60
6	10.21	4	1.73	0.45	89.51
7	8.60	4	1.79	0.43	28.48
8	13.28	4	1.58	0.33	70.63
9	15.12	4	2.78	0.89	70.99
10	6.26	4	1.49	0.41	10.04
11	13.20	4	1.51	0.46	62.81
12	14.30	4	1.90	0.37	81.03
13	14.09	4	1.90	0.37	35.39
14	12.65	4	1.90	0.37	10.52
15	11.80	4	1.46	0.40	52.71
16	11.28	4	1.45	0.44	69.12
17	16.66	4	1.45	0.44	81.32
18	13.79	4	1.45	0.44	52.89
19	9.27	4	1.15	0.29	57.73
20	14.45	4	1.73	0.38	55.56
21	10.41	4	1.73	0.38	71.15
22	13.20	4	1.73	0.38	56.57
23	13.96	4	1.73	0.38	36.11
24	12.48	4	1.53	0.30	71.26
25	13.27	4	1.36	0.37	77.89
26	12.89	4	1.82	0.54	49.61
27	12.99	4	1.82	0.54	42.93
28	15.63	4	1.82	0.54	54.83
29	13.13	4	1.54	0.39	54.73
30	7.61	4	1.46	0.42	55.71
31	12.73	4	1.19	0.40	60.34
32	2.78	4	1.16	0.44	73.05
33	12.16	4	1.67	0.37	62.54
34	13.54	4	1.67	0.37	42.51
35	9.79	4	1.67	0.37	38.73
36	13.53	4	1.51	0.33	67.72
37	13.75	4	1.70	0.38	54.47
38	5.12	4	1.70	0.38	57.15
39	9.31	4	1.58	0.36	56.49
40	4.35	4	1.85	0.65	79.68
41	5.65	4	1.30	0.31	65.85
42	10.39	4	1.82	0.56	63.80
43	12.14	4	1.48	0.35	64.34
44	13.47	4	1.62	0.37	58.36
45	12.71	4	1.08	0.28	22.65
46	8.78	4	1.69	0.30	37.64
47	12.71	4	1.61	0.45	76.76
48	9.87	4	1.49	0.40	63.86
49	12.09	4	1.75	0.77	67.42
50	12.46	4	1.83	0.37	76.34
51	14.61	4	1.39	0.37	79.55
52	13.63	4	1.39	0.37	77.51
53	14.32	4	1.37	0.35	33.82
54	13.25	4	1.81	0.37	80.58
55	12.79	4	1.44	0.43	24.84
56	16.33	4	1.87	0.86	53.15
57	12.50	4	1.53	0.38	64.65
58	5.34	4	1.61	0.29	87.34
59	6.63	4	1.66	0.40	54.33
60	14.60	4	1.45	0.52	67.82

61	14.62	4	1.52	0.52	43.26
62	4.53	4	2.69	0.78	61.92
63	11.50	4	1.49	0.42	48.93
64	9.23	4	1.69	0.48	57.40
65	8.72	4	1.62	0.34	60.30
66	9.57	4	1.39	0.40	49.09
67	12.24	4	1.84	0.28	27.26
68	9.52	4	2.09	0.74	71.20
69	12.10	4	1.50	0.45	14.11
70	13.20	4	1.69	0.33	70.30
71	11.55	4	1.69	0.33	53.61
72	13.79	4	1.61	0.38	76.23
73	13.71	4	1.35	0.41	61.10
74	14.24	4	1.69	0.35	72.41
75	15.74	4	1.69	0.35	24.84
76	12.11	4	1.67	0.20	7.90
77	6.07	4	1.92	0.30	45.18
78	14.09	4	1.81	0.55	76.16
79	13.33	4	1.46	0.49	57.87
80	14.49	4	1.79	0.42	26.49
81	12.26	4	1.86	0.41	30.88
82	8.02	4	1.03	0.34	71.28
83	13.72	4	1.15	0.65	59.00
84	11.75	4	1.15	0.65	49.28
85	13.81	4	1.81	0.33	15.82
86	12.31	4	1.81	0.33	79.96
87	13.51	4	1.93	0.76	32.19
88	11.54	4	1.59	0.31	27.13
89	10.30	4	1.74	0.45	36.47
90	10.09	4	2.11	0.52	66.14
91	12.26	4	1.34	0.30	77.48
92	6.76	4	1.29	0.36	24.19
93	15.01	4	1.64	0.36	33.22
94	6.58	4	1.64	0.36	34.04
95	9.26	4	1.85	0.38	71.18
96	13.42	4	1.73	0.84	35.83
97	12.30	4	1.62	0.33	64.36
98	15.33	4	2.21	0.74	32.11
99	14.17	4	1.70	0.38	55.07
100	11.68	4	1.70	0.38	44.16
101	14.73	4	1.70	0.38	35.59
102	14.05	4	1.57	0.40	69.54
103	11.24	4	1.57	0.40	84.63
104	9.97	4	1.30	0.36	76.03
105	12.42	4	1.18	0.38	36.88
106	13.07	4	2.49	0.87	34.22
107	13.78	4	1.43	0.39	83.70

Mean Dpar = 1.64
 Mean Dper = 0.44
 Mean length (um) = 11.71 +/- 0.28
 Std. Dev. (um) = 2.88
 Skewness = -0.98
 Kurtosis = 0.37

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	11.14	4	1.79	0.35	75.05
2	6.11	4	1.98	0.45	75.29
3	12.78	4	1.72	0.44	16.63
4	12.07	4	1.72	0.44	72.45
5	11.88	4	1.72	0.44	34.63
6	10.86	4	1.37	0.35	74.94
7	13.74	4	1.58	0.38	56.86
8	7.29	4	1.21	0.32	7.51
9	5.76	4	0.94	0.33	55.39
10	13.79	4	1.38	0.32	19.78
11	4.34	4	1.23	0.34	68.29
12	9.45	4	1.80	0.57	54.61
13	8.78	4	1.81	0.41	12.25
14	15.26	4	1.54	0.48	16.98
15	12.84	4	1.76	0.48	83.84
16	12.86	4	1.75	0.43	10.10
17	11.74	4	1.75	0.43	45.36
18	12.01	4	1.52	0.42	63.88
19	14.83	4	1.33	0.39	68.12
20	11.18	4	1.45	0.47	65.20
21	8.31	4	1.15	0.38	36.12
22	14.46	4	1.64	0.72	85.25
23	13.92	4	1.64	0.72	35.92
24	13.18	4	1.40	0.39	79.12
25	12.27	4	1.75	0.48	35.46
26	11.74	4	1.64	0.42	67.48
27	10.64	4	1.75	0.44	83.76
28	12.88	4	2.27	0.80	16.08
29	14.11	4	1.12	0.41	85.69
30	12.99	4	1.57	0.36	58.36
31	15.57	4	1.60	0.53	39.71
32	8.66	4	1.41	0.47	86.06
33	14.41	4	2.19	0.69	36.04
34	13.80	4	2.19	0.69	52.97
35	9.55	4	1.56	0.33	87.98
36	10.49	4	1.46	0.61	67.12
37	7.39	4	1.15	0.35	72.40
38	13.02	4	1.57	0.49	30.99
39	13.66	4	1.57	0.49	70.20
40	13.59	4	2.26	0.44	28.46
41	13.65	4	1.55	0.42	38.78
42	11.57	4	1.31	0.37	4.32
43	8.45	4	1.26	0.42	44.33
44	12.85	4	1.36	0.40	75.08
45	13.67	4	1.36	0.40	71.56
46	12.12	4	1.52	0.35	62.29
47	15.30	4	1.60	0.51	13.03
48	14.24	4	2.01	0.50	46.14
49	13.45	4	1.55	0.52	38.24
50	4.36	4	1.69	0.38	89.97
51	12.11	4	1.58	0.34	32.71
52	6.33	4	1.78	0.65	83.22
53	11.48	4	1.53	0.44	63.30

54	13.44	4	1.76	0.58	41.39
55	13.21	4	1.55	0.36	50.77
56	7.29	4	1.62	0.43	59.95
57	12.93	4	1.00	0.47	15.69
58	14.07	4	2.02	0.36	54.94

Mean Dpar = 1.59
 Mean Dper = 0.45
 Mean length (um) = 11.62+/- 0.37
 Std. Dev. (um) = 2.82
 Skewness = -0.97
 Kurtosis = 0.02

GU-12

no confined tracks observed

GU-13

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	12.33	4	1.78	0.41	41.49
2	12.27	4	1.78	0.41	35.28
3	5.47	4	1.78	0.41	27.53
4	10.29	4	1.78	0.41	29.14
5	8.45	4	1.78	0.41	22.62
6	12.88	4	1.52	0.40	58.06
7	9.42	4	1.13	0.45	68.42
8	7.99	4	1.13	0.45	68.19
9	9.19	4	1.13	0.45	17.66
10	9.11	4	1.46	0.43	72.77
11	8.37	4	1.46	0.43	22.18
12	3.48	4	1.46	0.43	58.27
13	9.54	4	1.46	0.43	70.18
14	10.55	4	2.18	0.53	21.58
15	13.04	4	1.77	0.66	3.97
16	13.93	4	1.77	0.66	29.38
17	11.19	4	1.46	0.37	46.96
18	9.40	4	1.86	0.62	66.48
19	12.14	4	1.86	0.62	27.46
20	9.82	4	1.86	0.62	43.94
21	9.56	4	1.86	0.62	67.34
22	10.34	4	1.86	0.62	65.91
23	12.14	4	1.86	0.62	74.58
24	12.42	4	2.10	0.30	45.79
25	9.19	4	2.10	0.30	32.74
26	9.45	4	2.10	0.30	64.51
27	10.25	4	1.92	0.38	31.57
28	11.24	4	1.92	0.38	40.71
29	7.82	4	1.92	0.38	84.16

Mean Dpar = 1.73
 Mean Dper = 0.47
 Mean length (um) = 10.04+/- 0.43

Std. Dev. (um)= 2.26
 Skewness = -0.73
 Kurtosis = 0.80

GU-14

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	8.11	4	1.77	0.30	54.86
2	7.85	4	1.77	0.30	68.53
3	10.01	4	1.77	0.30	37.02
4	12.15	4	1.77	0.30	69.92
5	10.36	4	1.77	0.30	50.84
6	9.44	4	1.77	0.30	35.48
7	11.64	4	1.77	0.30	36.67
8	6.75	4	1.77	0.30	54.89
9	6.58	4	1.77	0.30	44.89
10	9.04	4	1.77	0.30	48.64

Mean Dpar = 1.77
 Mean Dper = 0.30
 Mean length (um)= 9.19+/- 0.63
 Std. Dev. (um)= 1.90
 Skewness = 0.09
 Kurtosis = -1.47

GU-15

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	14.84	4	1.76	0.35	55.69
2	11.67	4	1.76	0.35	65.17
3	9.99	4	1.76	0.35	68.24
4	9.98	4	1.64	0.34	65.56
5	13.23	4	1.80	0.40	64.33
6	11.28	4	1.96	0.41	61.98
7	10.60	4	1.96	0.41	33.90
8	9.43	4	1.96	0.41	60.82
9	9.61	4	1.84	0.38	71.16
10	10.48	4	1.84	0.38	44.67
11	9.06	4	1.84	0.38	61.62
12	7.83	4	1.63	0.46	56.58
13	7.56	4	1.61	0.46	35.47
14	12.41	4	1.61	0.46	76.39
15	11.21	4	1.61	0.46	24.76
16	10.33	4	1.66	0.33	69.38
17	12.35	4	1.66	0.33	57.52
18	13.89	4	1.66	0.33	72.69
19	9.99	4	1.66	0.33	71.13
20	9.56	4	1.66	0.33	70.24
21	9.44	4	1.66	0.33	35.26
22	9.96	4	1.66	0.33	67.10
23	11.57	4	1.66	0.33	79.39

24	9.69	4	1.66	0.33	26.98
25	7.20	4	1.66	0.33	53.31
26	9.88	4	1.71	0.41	57.98
27	10.41	4	1.71	0.41	58.65
28	12.56	4	1.71	0.41	71.37
29	12.02	4	1.71	0.41	25.68
30	9.74	4	1.71	0.41	41.73
31	7.57	4	1.71	0.41	74.00
32	12.36	4	1.71	0.41	66.40
33	11.51	4	1.71	0.41	59.39
34	9.29	4	1.77	0.51	68.06
35	9.41	4	1.39	0.42	78.53
36	9.41	4	1.62	0.41	29.70
37	9.32	4	1.62	0.41	61.44
38	10.61	4	1.62	0.41	63.64
39	9.52	4	1.62	0.41	55.13
40	11.17	4	1.62	0.41	56.42
41	10.98	4	1.62	0.41	11.82
42	9.27	4	1.62	0.41	21.15
43	8.36	4	1.62	0.41	20.04
44	10.56	4	1.38	0.33	59.20
45	8.55	4	1.38	0.33	84.74
46	6.70	4	1.38	0.33	72.12
47	15.15	4	1.52	0.36	67.55
48	9.03	4	1.52	0.36	39.75
49	9.82	4	1.52	0.36	29.93
50	11.22	4	1.52	0.36	26.55
51	10.55	4	1.64	0.41	65.78
52	8.21	4	1.64	0.41	55.36
53	11.89	4	1.64	0.41	39.59
54	7.24	4	1.64	0.41	58.03
55	10.03	4	1.64	0.41	74.15
56	9.13	4	1.64	0.41	89.73
57	10.22	4	1.64	0.41	69.01
58	7.62	4	1.64	0.41	52.07
59	8.16	4	1.64	0.41	34.74
60	9.19	4	1.64	0.41	68.23
61	8.97	4	1.32	0.42	60.29
62	9.40	4	1.67	0.33	75.40
63	12.01	4	1.67	0.33	79.83
64	9.36	4	1.67	0.33	19.44
65	9.47	4	1.25	0.38	45.41
66	9.44	4	1.25	0.38	70.97
67	12.89	4	1.72	0.40	16.61
68	12.59	4	1.72	0.40	56.90
69	11.11	4	1.72	0.40	46.12
70	7.40	4	1.72	0.40	24.96
71	9.92	4	1.66	0.34	26.13
72	2.69	4	1.66	0.34	62.57
73	11.49	4	1.71	0.48	31.94
74	12.30	4	1.71	0.48	28.91
75	10.31	4	1.71	0.48	53.64
76	9.20	4	1.71	0.48	72.39
77	9.44	4	1.71	0.48	54.41
78	5.32	4	1.71	0.48	67.76
79	9.06	4	1.71	0.48	43.61
80	9.33	4	1.71	0.48	82.08

81	9.79	4	1.71	0.48	33.98
82	7.97	4	1.71	0.48	60.57
83	10.83	4	1.71	0.48	29.63
84	10.30	4	1.71	0.48	34.04
85	11.53	4	1.71	0.48	68.07
86	7.80	4	1.71	0.48	47.26
87	8.31	4	1.71	0.48	57.66
88	10.12	4	1.71	0.48	57.89
89	8.09	4	1.71	0.48	62.07
90	8.74	4	1.71	0.48	67.51
91	8.09	4	1.71	0.48	62.07
92	9.37	4	1.71	0.48	52.72
93	10.32	4	1.71	0.48	24.90
94	10.37	4	1.39	0.49	30.53
95	10.95	4	1.62	0.35	67.46
96	8.87	4	1.62	0.35	65.24
97	10.45	4	1.62	0.35	17.02

Mean Dpar = 1.66
 Mean Dper = 0.41
 Mean length (um) = 9.93+/- 0.19
 Std. Dev. (um) = 1.86
 Skewness = -0.22
 Kurtosis = 2.01

GU-16

no confined tracks observed

GU-17

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	11.20	4	1.46	0.36	80.68
2	10.98	4	2.01	0.50	62.71
3	6.33	1	1.35	0.48	15.68
4	11.57	4	1.06	0.34	44.83
5	11.06	4	1.48	0.41	40.07
6	12.13	4	1.48	0.41	78.24
7	5.74	4	1.48	0.41	51.10
8	11.29	4	1.64	0.41	55.21

Mean Dpar = 1.50
 Mean Dper = 0.42
 Mean length (um) = 10.04+/- 0.95
 Std. Dev. (um) = 2.50
 Skewness = -0.90
 Kurtosis = -1.21

GU-18

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
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1	13.60	4	1.66	0.60	20.74
2	10.48	4	1.58	0.29	33.77
3	13.27	4	1.60	0.46	55.08
4	12.33	4	2.02	0.93	51.78
5	2.14	4	1.68	0.43	61.63
6	12.19	4	1.30	0.31	28.61
7	10.54	4	1.39	0.41	84.24
8	4.72	4	1.46	0.41	41.86
9	9.16	4	1.73	0.80	55.04
10	3.92	4	1.73	0.80	16.33
11	11.67	4	2.48	0.61	50.69
12	6.46	4	1.48	0.35	50.76
13	14.11	4	1.41	0.36	37.44
14	7.34	4	1.50	0.36	45.16
15	13.97	4	1.93	0.54	77.22
16	12.57	4	1.93	0.54	41.95
17	12.19	4	1.93	0.54	47.25
18	10.32	4	1.93	0.54	44.53
19	12.63	4	1.36	0.40	49.89
20	6.39	4	1.33	0.34	81.27
21	5.47	4	1.86	0.64	38.20
22	9.51	4	1.86	0.64	23.13
23	14.12	4	3.06	1.22	62.86
24	14.87	4	3.06	1.22	67.78
25	9.73	4	1.43	0.37	45.95
26	7.80	4	1.43	0.37	87.12
27	10.93	4	1.34	0.30	28.93
28	11.86	4	1.55	0.45	20.97
29	10.16	4	1.55	0.45	37.82
30	10.88	4	1.55	0.45	26.37
31	13.96	4	1.96	0.48	60.46
32	14.61	4	1.80	0.31	57.53
33	13.43	4	1.79	0.54	38.10
34	9.49	4	3.24	1.19	72.30
35	7.13	4	1.39	0.42	46.92
36	13.26	4	2.05	0.46	67.54
37	6.65	4	2.05	0.46	64.38
38	12.37	4	2.05	0.46	70.03
39	11.09	4	2.05	0.46	31.91
40	11.82	4	2.05	0.46	33.68
41	13.38	4	2.05	0.46	18.59
42	12.93	4	2.16	0.52	74.20
43	11.73	4	1.19	0.38	57.59
44	12.00	4	1.19	0.38	8.31
45	14.08	4	1.19	0.38	30.41
46	13.88	4	1.95	0.93	33.75
47	13.41	4	1.60	0.37	73.09
48	10.57	4	1.64	0.35	36.23
49	9.75	4	1.64	0.35	85.96
50	11.30	4	0.86	0.38	42.13
51	8.79	4	0.86	0.38	33.81
52	10.71	4	1.31	0.38	69.78
53	7.56	4	1.33	0.44	76.09
54	9.24	4	1.59	0.34	88.60
55	14.67	4	2.08	0.84	21.83
56	12.12	4	2.08	0.84	20.90

57	7.39	4	1.28	0.44	49.08
58	9.32	4	1.55	0.39	73.89
59	10.66	4	1.55	0.39	28.92
60	6.16	4	1.55	0.39	64.46
61	12.52	4	1.98	0.39	65.08
62	14.46	4	1.98	0.39	18.63
63	12.92	4	1.98	0.39	31.77
64	13.88	4	0.93	0.38	71.63

Mean Dpar = 1.72
 Mean Dper = 0.50
 Mean length (um) = 10.82+/- 0.37
 Std. Dev. (um) = 2.94
 Skewness = -0.81
 Kurtosis = -0.01

GU-19

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	13.58	4	1.61	0.35	59.10
2	12.94	4	1.54	0.42	73.83
3	12.24	4	1.54	0.42	42.69
4	9.04	4	1.83	0.44	68.50
5	11.63	4	1.83	0.44	15.82
6	9.27	4	1.83	0.44	53.14
7	11.54	4	1.83	0.44	51.96
8	7.78	4	1.83	0.44	63.32
9	6.87	4	1.83	0.44	60.70
10	10.21	4	1.83	0.44	29.13
11	10.54	4	1.78	0.41	48.74
12	14.36	4	1.75	0.34	78.20
13	10.00	4	1.75	0.34	20.64
14	10.91	4	1.28	0.32	44.31
15	11.16	4	1.60	0.34	32.54
16	11.93	4	1.60	0.34	23.47
17	12.26	4	2.19	0.61	75.39
18	8.98	4	2.19	0.61	34.24
19	7.62	4	1.60	0.37	55.63
20	9.00	4	1.60	0.37	60.06
21	4.56	4	1.60	0.37	84.22
22	11.82	4	1.60	0.37	13.82
23	11.83	4	1.85	0.37	45.08
24	10.68	4	1.85	0.37	42.99
25	13.83	4	1.85	0.37	49.59
26	11.23	4	1.85	0.37	75.49
27	8.40	4	1.85	0.37	53.68
28	9.62	4	1.74	0.40	35.97
29	12.57	4	1.74	0.40	65.61
30	10.90	4	1.74	0.40	28.34
31	9.50	4	2.01	0.40	33.92
32	11.73	4	1.36	0.36	36.26
33	10.84	4	1.36	0.36	69.70
34	13.81	4	1.36	0.36	73.99
35	12.01	4	1.36	0.36	52.20

36	12.98	4	1.36	0.36	66.69
37	14.06	4	1.36	0.36	69.06
38	13.52	4	1.56	0.37	63.94
39	10.40	4	1.56	0.37	66.28
40	12.69	4	1.56	0.37	31.92
41	10.02	4	1.72	0.52	64.34
42	12.78	4	1.76	0.44	81.49
43	11.30	4	1.48	0.34	57.54
44	9.67	4	1.23	0.39	63.25

Mean Dpar = 1.67
 Mean Dper = 0.40
 Mean length (um) = 10.97+/- 0.32
 Std. Dev. (um) = 2.07
 Skewness = -0.68
 Kurtosis = 0.47

GU-20

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dper (microns)	Angle to c-axis (degrees)
1	12.02	4	1.62	0.38	52.67
2	9.82	4	1.53	0.32	71.21
3	10.92	4	1.75	0.52	43.38
4	12.91	4	1.75	0.52	64.42
5	6.93	4	1.76	0.34	71.51
6	11.06	4	1.76	0.34	46.72
7	5.77	4	1.93	0.76	73.19
8	11.15	4	2.94	1.16	22.49
9	7.85	4	1.71	0.39	70.49
10	11.91	4	2.59	1.02	42.32
11	11.37	4	1.86	0.41	54.18
12	6.59	4	2.00	0.58	55.90
13	4.95	4	1.81	0.61	70.37
14	3.18	4	1.51	0.37	19.48
15	16.17	4	2.66	0.63	44.92
16	10.58	4	1.51	0.47	48.70
17	10.58	4	1.53	0.33	64.91
18	12.74	4	1.70	0.31	50.58
19	8.90	4	1.70	0.31	76.32
20	11.32	4	1.70	0.31	73.52
21	15.07	4	1.70	0.31	28.24
22	9.38	4	1.70	0.31	35.51
23	10.86	4	1.70	0.31	64.81
24	11.73	4	1.70	0.31	67.11
25	6.21	4	1.70	0.31	79.53
26	9.36	4	1.70	0.31	38.39
27	10.90	4	1.45	0.56	70.21
28	10.41	4	1.73	0.38	81.14
29	15.36	4	1.73	0.38	47.95
30	10.52	4	1.69	0.54	75.35

Mean Dpar = 1.80
 Mean Dper = 0.46
 Mean length (um) = 10.22+/- 0.56

Std. Dev. (um)= 2.99
 Skewness = -0.29
 Kurtosis = -0.15

GU-21

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	9.21	4	2.01	0.36	63.83
2	9.44	4	1.38	0.39	28.04
3	6.86	4	1.38	0.39	73.33
4	6.73	4	1.38	0.39	57.77
5	10.01	4	1.52	0.40	70.48
6	9.49	4	1.52	0.40	40.94

Mean Dpar = 1.53
 Mean Dper = 0.39
 Mean length (um)= 8.62+/- 0.64
 Std. Dev. (um)= 1.44
 Skewness = -0.46
 Kurtosis = -1.94

GU-22

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	13.10	4	1.16	0.41	51.14
2	10.86	4	1.16	0.41	44.66
3	11.89	4	1.32	0.28	53.21
4	10.48	4	1.32	0.28	81.90
5	10.56	4	1.25	0.39	53.03
6	10.32	4	1.25	0.39	21.86
7	10.50	4	1.25	0.39	44.55
8	11.24	4	1.25	0.39	44.19
9	9.92	4	1.25	0.39	68.38
10	9.93	4	1.25	0.39	66.34
11	10.46	4	1.52	0.38	23.22
12	11.96	4	1.16	0.42	69.76
13	10.94	4	1.16	0.42	57.59
14	10.96	4	1.16	0.42	70.64
15	11.36	4	1.68	0.36	50.11
16	13.26	4	1.68	0.36	65.62
17	10.96	4	1.07	0.37	61.19
18	10.49	4	1.45	0.43	46.17
19	11.38	4	1.45	0.43	64.76
20	13.58	4	1.61	0.40	61.08
21	9.23	4	1.46	0.41	61.41
22	11.70	4	1.43	0.36	48.89
23	10.23	4	1.43	0.36	67.04
24	11.59	4	1.43	0.36	26.85
25	11.59	4	1.43	0.36	79.94
26	14.45	4	1.43	0.36	79.79
27	10.52	4	1.43	0.36	44.31

28	8.71	4	1.43	0.36	31.55
29	9.62	4	1.45	0.42	74.46
30	10.53	4	1.79	0.32	62.49
31	11.46	4	1.79	0.32	43.90
32	9.82	4	1.43	0.53	38.82
33	14.16	4	1.38	0.36	61.07
34	10.15	4	1.38	0.36	68.12
35	6.37	4	1.38	0.36	24.51
36	9.61	4	1.68	0.44	64.85
37	9.13	4	1.40	0.39	24.22
38	12.65	4	1.36	0.45	74.54
39	9.24	4	1.44	0.42	41.14
40	11.76	4	1.63	0.51	89.76
41	10.57	4	1.63	0.51	68.41
42	14.18	4	1.67	0.39	77.22
43	10.99	4	1.33	0.36	35.99
44	10.82	4	1.33	0.36	48.43
45	9.05	4	1.33	0.36	45.94
46	10.61	4	1.33	0.36	28.60
47	13.19	4	1.33	0.36	46.34
48	8.86	4	1.33	0.36	34.90
49	13.84	4	1.60	0.45	46.57
50	10.04	4	1.38	0.37	56.55
51	7.98	4	1.38	0.37	71.81
52	8.81	4	1.51	0.36	55.60
53	9.82	4	1.41	0.38	36.41
54	12.31	4	1.41	0.38	79.57
55	10.75	4	1.15	0.48	29.09
56	10.43	4	1.15	0.48	79.39
57	11.53	4	1.15	0.48	27.35
58	12.35	4	1.58	0.47	71.42
59	13.36	4	1.79	0.35	21.30
60	10.58	4	1.45	0.43	74.05
61	10.95	4	1.36	0.46	67.64
62	8.31	4	1.76	0.34	57.93
63	9.52	4	1.76	0.34	53.49
64	8.17	4	1.33	0.36	31.23
65	10.54	4	1.74	0.69	62.40
66	13.59	4	1.17	0.29	71.36
67	11.87	4	1.63	0.32	58.83
68	13.10	4	1.30	0.29	76.14
69	13.26	4	1.60	0.39	57.73
70	14.05	4	1.60	0.39	65.99
71	10.29	4	1.60	0.39	76.64
72	9.41	4	1.60	0.39	22.21
73	10.14	4	1.60	0.39	72.78
74	10.82	4	1.60	0.39	22.72
75	11.95	4	1.52	0.44	79.17
76	0.99	4	1.52	0.44	35.53
77	11.49	4	1.06	0.46	20.61
78	14.25	4	1.06	0.46	82.61
79	12.95	4	1.06	0.46	24.92
80	7.81	4	0.94	0.41	32.21
81	14.19	4	1.43	0.33	34.08
82	9.34	4	1.24	0.42	58.22
83	7.16	4	1.24	0.42	48.90
84	11.11	4	1.67	0.32	72.24

85	11.03	4	1.67	0.48	72.51
86	11.52	4	1.67	0.48	39.18
87	12.05	4	1.67	0.48	21.56
88	10.65	4	1.67	0.48	70.58
89	11.44	4	1.67	0.48	23.62
90	9.83	4	1.67	0.48	78.95
91	11.41	4	1.90	0.37	72.24
92	12.62	4	1.29	0.38	60.27
93	8.35	4	1.45	0.46	75.50
94	11.16	4	1.45	0.46	54.42
95	11.14	4	0.97	0.41	60.22
96	10.42	4	0.97	0.41	32.29
97	10.26	4	0.97	0.41	80.18
98	9.52	4	1.58	0.37	81.60
99	13.07	4	1.22	0.40	45.52
100	12.43	4	1.70	0.46	39.22
101	13.53	4	1.96	0.33	71.43
102	13.73	4	1.31	0.41	51.99
103	11.37	4	1.31	0.41	70.91
104	11.95	4	1.59	0.39	30.74
105	2.75	4	1.57	0.34	57.65
106	11.96	4	1.73	0.57	41.17
107	10.56	4	1.79	0.46	47.13
108	12.63	4	1.36	0.42	54.59
109	9.97	4	1.59	0.48	66.41
110	10.74	4	1.77	0.34	77.45
111	10.66	4	1.77	0.34	69.06
112	10.71	4	0.96	0.38	87.71
113	13.45	4	1.34	0.33	62.64
114	10.08	4	1.34	0.33	83.15

Mean Dpar = 1.43
 Mean Dper = 0.40
 Mean length (um) = 10.90+/- 0.19
 Std. Dev. (um) = 2.03
 Skewness = -1.44
 Kurtosis = 5.43

GU-23

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	10.41	4	1.08	0.40	22.28
2	10.80	4	1.08	0.40	25.51
3	11.22	4	1.68	0.39	26.64
4	12.53	4	1.72	0.48	69.14
5	11.49	4	1.72	0.48	40.04
6	13.27	4	1.72	0.48	15.14
7	9.62	4	1.72	0.48	71.96
8	8.59	4	1.72	0.48	71.38
9	9.06	4	1.77	0.55	48.27
10	11.46	4	1.77	0.55	25.42
11	10.21	4	1.77	0.55	59.98
12	10.15	4	1.77	0.55	77.34
13	12.41	4	1.77	0.55	19.89

14	9.49	4	1.77	0.55	31.92
15	13.76	4	1.77	0.55	40.43
16	11.82	4	1.77	0.55	69.60
17	9.20	4	1.77	0.55	36.15
18	9.66	4	1.77	0.55	75.35
19	9.05	4	1.77	0.55	73.12
20	9.16	4	1.77	0.55	45.13
21	9.42	4	1.77	0.55	53.63
22	9.02	4	1.77	0.55	84.29
23	12.18	4	1.77	0.55	19.54
24	10.80	4	1.63	0.38	65.59
25	10.54	4	1.63	0.38	67.25
26	13.74	4	1.53	0.38	45.68
27	13.46	4	1.53	0.38	28.60
28	11.56	4	1.78	0.39	59.27
29	10.77	4	1.78	0.39	53.91
30	9.56	4	1.78	0.39	77.27
31	10.13	4	1.78	0.39	40.32
32	9.23	4	1.78	0.39	46.75
33	7.81	4	1.55	0.37	72.91
34	6.02	4	1.62	0.37	54.54

Mean Dpar = 1.69
 Mean Dper = 0.47
 Mean length (um) = 10.52+/- 0.30
 Std. Dev. (um) = 1.75
 Skewness = -0.00
 Kurtosis = -0.18

GU-24

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	9.82	4	1.77	0.57	71.33
2	8.41	4	1.77	0.57	66.82
3	6.15	4	1.71	0.39	38.03
4	9.24	4	1.71	0.39	70.22
5	13.66	4	1.86	0.40	39.02
6	10.51	4	1.52	0.50	30.68

Mean Dpar = 1.72
 Mean Dper = 0.47
 Mean length (um) = 9.63+/- 1.11
 Std. Dev. (um) = 2.48
 Skewness = 0.24
 Kurtosis = -1.19

GU-25

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	5.87	4	2.08	0.48	45.71
2	12.29	4	1.89	0.36	54.93

3	9.27	4	0.93	0.23	47.97
4	11.21	4	0.93	0.23	69.11
5	10.06	4	1.26	0.31	6.01
6	13.13	4	2.04	0.58	31.05
7	12.32	4	2.12	0.51	11.27
8	10.30	4	2.12	0.51	67.81
9	11.50	4	2.12	0.51	36.09
10	10.12	4	2.12	0.51	40.46

Mean Dpar = 1.76
 Mean Dper = 0.42
 Mean length (um) = 10.61 +/- 0.69
 Std. Dev. (um) = 2.06
 Skewness = -0.94
 Kurtosis = 0.14

GU-26

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	9.85	4	1.39	0.34	31.53

Mean Dpar = 1.39
 Mean Dper = 0.34
 Mean length (um) = 9.85
 Std. Dev. (um) = n.a.
 Skewness = n.a.
 Kurtosis = n.a.

GU-27

no confined tracks observed

GU-28

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	7.32	4	1.06	0.42	11.17
2	11.49	4	2.44	1.45	66.45

Mean Dpar = 1.75
 Mean Dper = 0.94
 Mean length (um) = 9.40 +/- 2.95
 Std. Dev. (um) = 2.95
 Skewness = 0.00
 Kurtosis = -2.75

GU-29

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
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1	8.86	4	1.95	0.50	58.52
2	3.41	4	1.95	0.50	78.63
3	8.35	4	1.60	0.44	54.27
4	12.14	4	1.87	0.48	41.85
5	13.77	4	1.87	0.48	50.06
6	9.37	4	1.87	0.48	76.29
7	14.18	4	1.87	0.48	27.81
8	11.95	4	1.87	0.48	26.76
9	9.66	4	1.87	0.48	63.84
10	10.72	4	1.87	0.48	69.93
11	12.27	4	1.87	0.48	15.66
12	9.41	4	1.69	0.51	54.25
13	10.47	4	1.69	0.51	63.93
14	9.30	4	1.69	0.51	10.49
15	10.12	4	1.92	0.31	63.00
16	10.69	4	1.92	0.31	57.02
17	10.37	4	1.92	0.31	33.98
18	7.45	4	1.92	0.31	38.13
19	7.46	4	1.92	0.31	80.60
20	10.09	4	1.87	0.33	55.80
21	9.99	4	1.87	0.33	36.28
22	10.05	4	1.87	0.33	49.83

Mean Dpar = 1.85
 Mean Dper = 0.43
 Mean length (um) = 10.00 +/- 0.50
 Std. Dev. (um) = 2.27
 Skewness = -0.66
 Kurtosis = 1.36

PFT-02

no confined tracks observed

PFT-06

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	11.62	1	2.45	0.58	81.72
2	16.26	4	2.04	0.51	66.74
3	14.29	4	2.59	0.24	70.00
4	11.43	4	1.36	0.31	10.01
5	12.54	4	2.18	0.55	69.24
6	15.84	4	2.41	0.33	64.49
7	11.33	4	1.06	0.31	51.19
8	16.23	4	3.30	1.46	64.10
9	12.57	4	3.30	1.46	70.46
10	14.17	4	2.21	0.58	55.20
11	12.73	4	1.48	0.55	44.15
12	11.79	4	2.48	0.69	76.57
13	14.55	4	2.03	0.68	61.07

Mean Dpar = 2.22

Mean Dper = 0.63
 Mean length (um) = 13.49+/- 0.53
 Std. Dev. (um) = 1.84
 Skewness = 0.31
 Kurtosis = -1.59

PFT-08

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	12.12	4	2.77	1.01	65.93
2	14.28	4	2.56	0.66	74.18
3	13.85	4	1.85	0.39	51.87
4	14.73	4	1.85	0.39	47.81
5	10.49	4	1.85	0.39	36.41

Mean Dpar = 2.18
 Mean Dper = 0.57
 Mean length (um) = 13.09+/- 0.88
 Std. Dev. (um) = 1.76
 Skewness = -0.44
 Kurtosis = -1.82

PFT-09

no confined tracks observed

PFT-12

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	14.61	4	2.52	0.95	80.76
2	15.58	4	2.52	0.95	74.10
3	13.09	4	2.12	0.33	13.43

Mean Dpar = 2.39
 Mean Dper = 0.74
 Mean length (um) = 14.43+/- 0.89
 Std. Dev. (um) = 1.26
 Skewness = -0.14
 Kurtosis = -2.33

PFT-13

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	15.18	4	2.07	0.35	56.02
2	15.80	4	2.07	0.35	70.03
3	14.80	4	1.97	0.40	15.41
4	14.83	4	1.97	0.40	15.20

5	14.53	4	2.14	0.26	59.64
6	7.15	4	1.97	0.35	69.02
7	10.34	4	1.85	0.43	82.80

Mean Dpar = 2.01
 Mean Dper = 0.36
 Mean length (um) = 13.23+/- 1.32
 Std. Dev. (um) = 3.23
 Skewness = -0.91
 Kurtosis = -1.01

PFT-15

no confined tracks observed

PFT-17

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	13.37	4	1.88	0.44	66.31
2	13.77	4	1.63	0.36	46.57
3	6.51	4	1.63	0.36	68.03

Mean Dpar = 1.71
 Mean Dper = 0.39
 Mean length (um) = 11.22+/- 2.89
 Std. Dev. (um) = 4.08
 Skewness = -0.38
 Kurtosis = -2.33

PFT-19

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	13.72	4	2.51	0.51	44.84
2	12.99	4	2.51	0.51	79.92
3	9.15	4	2.51	0.51	56.07
4	14.33	4	1.99	0.83	40.52
5	10.96	4	1.59	0.33	41.59
6	14.52	4	2.44	0.61	31.10
7	12.40	4	2.44	0.61	56.92
8	12.98	4	1.95	0.80	67.85
9	15.08	4	2.60	0.97	72.42
10	13.75	4	2.14	0.75	34.38
11	16.54	2	2.49	0.75	41.43
12	14.37	2	2.49	0.75	21.98
13	15.47	2	2.49	0.75	68.20
14	7.21	4	2.09	0.68	43.69
15	16.43	4	2.09	0.68	48.05
16	11.25	4	2.09	0.68	50.25
17	4.91	4	2.14	0.64	75.20
18	15.68	4	1.94	0.61	44.26

19	15.15	4	1.99	0.48	61.17
20	8.88	4	1.99	0.48	57.10
21	12.52	4	2.74	0.60	66.38
22	15.01	4	2.74	0.60	64.72
23	15.33	4	2.74	0.60	68.78
24	14.50	4	2.74	0.60	59.24
25	13.85	4	2.74	0.60	63.01
26	5.71	4	2.74	0.60	54.99
27	12.47	4	2.74	0.60	48.10
28	16.43	4	2.11	0.70	28.40
29	12.55	4	2.11	0.70	30.20
30	13.07	4	1.82	0.50	52.17
31	11.44	4	2.43	0.57	26.26
32	14.00	4	1.75	0.41	52.77
33	4.46	4	2.18	0.70	87.75

Mean Dpar = 2.30
 Mean Dper = 0.63
 Mean length (um) = 12.64 +/- 0.58
 Std. Dev. (um) = 3.27
 Skewness = -1.12
 Kurtosis = 0.34

PFT-20

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	14.20	4	2.17	0.92	78.47
2	13.64	4	1.71	0.46	70.95
3	12.68	4	1.71	0.46	49.03
4	14.24	4	1.71	0.46	49.40
5	11.24	4	1.71	0.46	32.67

Mean Dpar = 1.80
 Mean Dper = 0.55
 Mean length (um) = 13.20 +/- 0.63
 Std. Dev. (um) = 1.26
 Skewness = -0.54
 Kurtosis = -1.66

PFT-21

no confined tracks observed

PFT-23

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	9.01	4	1.84	0.35	59.42
2	14.25	4	2.12	0.40	27.58
3	13.46	4	2.12	0.40	62.94
4	14.04	4	2.12	0.40	66.77

5	12.61	4	1.79	0.43	56.63
6	14.63	4	2.37	0.74	64.61
7	14.14	4	2.37	0.74	82.52
8	14.54	4	1.30	0.46	61.22
9	12.54	4	1.30	0.46	58.64
10	8.01	4	2.09	0.69	64.37
11	13.39	4	2.13	0.27	12.70
12	11.50	4	1.81	0.34	72.09
13	2.36	4	1.81	0.34	34.82
14	13.64	4	1.99	0.41	52.98
15	15.58	4	1.72	0.31	69.58
16	13.79	4	2.68	0.48	70.98
17	14.30	4	2.68	0.48	27.30
18	7.67	4	2.68	0.48	48.98
19	15.39	4	2.16	0.90	18.38
20	14.76	4	2.16	0.90	38.36
21	14.50	4	2.16	0.90	3.69
22	10.85	4	2.16	0.90	51.31
23	14.70	4	1.77	0.46	78.10
24	13.76	4	1.61	0.42	30.84
25	5.08	4	1.76	0.31	11.03
26	10.33	4	2.11	0.87	43.78
27	14.98	4	2.36	0.43	24.62
28	13.00	4	1.94	0.23	89.48
29	9.54	4	2.51	0.53	62.97

Mean Dpar = 2.06
 Mean Dper = 0.52
 Mean length (um) = 12.29+/- 0.61
 Std. Dev. (um) = 3.24
 Skewness = -1.43
 Kurtosis = 1.34

PFT-25

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	14.12	4	3.26	0.56	69.25
2	16.07	4	3.26	0.56	81.75
3	1.77	4	3.26	0.56	38.60
4	14.78	4	1.67	0.24	64.81
5	13.40	4	1.90	0.41	67.79
6	15.08	4	1.68	0.25	35.60
7	13.52	4	1.79	0.34	54.08
8	15.52	4	2.22	0.45	53.71
9	12.37	4	2.06	0.73	72.46
10	17.94	4	1.95	0.64	75.00
11	14.19	4	1.70	0.50	70.88
12	13.56	4	2.31	0.25	71.62

Mean Dpar = 2.25
 Mean Dper = 0.46
 Mean length (um) = 13.53+/- 1.20
 Std. Dev. (um) = 3.98
 Skewness = -2.00

Kurtosis = 3.49

PFT-28

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	15.02	4	1.47	0.40	66.20
2	14.79	4	1.47	0.40	13.77
3	10.13	4	1.47	0.40	38.35
4	14.44	4	1.96	0.62	80.92
5	13.42	4	1.96	0.62	53.42
6	7.48	4	1.96	0.62	62.59
7	12.73	4	1.96	0.62	67.07
8	9.24	4	1.96	0.62	60.60
9	13.70	4	1.96	0.62	66.26
10	14.15	4	2.08	0.35	67.19
11	13.57	4	2.04	0.29	2.88
12	12.97	4	1.18	0.17	55.44
13	9.94	4	1.18	0.17	42.34
14	15.37	4	2.25	0.73	22.72
15	13.75	4	2.25	0.73	22.78
16	13.71	4	1.61	0.54	51.27
17	14.74	4	1.61	0.54	64.67
18	13.42	4	1.79	0.17	46.60
19	13.49	4	1.79	0.17	69.44
20	16.14	4	1.79	0.17	8.37
21	13.56	4	2.16	0.69	61.38
22	11.82	4	1.51	0.38	41.05
23	5.13	4	1.65	0.30	54.88
24	14.33	1	1.85	0.51	12.51
25	13.05	1	1.85	0.51	41.75
26	14.02	4	2.00	0.39	69.48
27	13.76	4	2.00	0.39	52.69

Mean Dpar = 1.81
 Mean Dper = 0.45
 Mean length (um) = 12.88 +/- 0.49
 Std. Dev. (um) = 2.49
 Skewness = -1.53
 Kurtosis = 1.85

PFT-29

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	5.31	4	2.01	0.56	45.95
2	14.69	4	2.32	0.41	56.66
3	14.90	4	2.09	0.36	22.57
4	12.74	4	2.10	0.32	22.62
5	12.40	4	2.13	0.53	48.66
6	12.19	4	2.13	0.53	63.80
7	5.80	4	1.54	0.26	49.21
8	13.61	4	1.88	0.39	89.66

9	13.95	4	1.88	0.39	45.44
10	16.27	4	1.88	0.39	43.02
11	11.92	4	1.88	0.39	32.47
12	11.81	4	1.88	0.39	36.18
13	5.19	4	2.00	0.43	53.60
14	4.91	4	2.00	0.43	43.09
15	15.08	4	2.37	0.37	24.14
16	7.76	4	2.37	0.37	76.84
17	14.47	4	2.72	1.15	67.14
18	14.93	4	2.72	1.15	6.99
19	13.61	4	2.81	0.41	83.07
20	10.74	4	2.81	0.41	55.03
21	13.02	4	2.81	0.41	85.52
22	13.88	4	2.81	0.41	78.11
23	12.95	4	1.72	0.42	47.74
24	13.63	4	1.72	0.42	46.24
25	12.39	4	1.72	0.42	89.31
26	11.25	4	1.72	0.42	71.43
27	8.78	4	1.81	0.25	25.77
28	6.52	4	1.76	0.44	21.74
29	15.16	4	1.84	0.35	25.89
30	12.57	4	1.90	0.34	71.43
31	9.55	4	1.66	0.26	29.84
32	15.68	4	1.66	0.26	37.44
33	14.62	4	1.66	0.26	45.94
34	15.70	4	2.19	0.39	33.57
35	4.54	4	1.79	0.28	68.05
36	14.17	4	2.05	0.38	59.11
37	11.96	4	2.05	0.38	69.70
38	9.76	4	2.05	0.38	71.60
39	7.17	4	1.70	0.30	59.82
40	10.60	4	1.73	0.34	39.12
41	13.24	4	1.91	0.60	23.16
42	15.04	4	1.40	0.17	37.63
43	14.09	4	2.14	0.34	56.99
44	12.65	4	1.72	0.38	51.50
45	10.25	4	1.72	0.38	69.09
46	12.68	4	1.67	0.54	34.42
47	12.37	4	2.02	0.29	69.23
48	8.80	4	2.02	0.29	62.18
49	12.66	4	2.02	0.29	62.69
50	8.66	4	2.02	0.29	75.53
51	7.03	4	1.89	0.60	51.55
52	14.22	4	2.09	0.37	64.19
53	16.12	4	2.09	0.37	52.13
54	13.92	4	1.82	0.45	42.74
55	11.43	4	1.82	0.45	42.33
56	9.95	4	2.91	0.72	56.60
57	13.57	4	1.85	0.23	66.41
58	14.03	4	2.87	0.84	13.45
59	13.18	4	2.87	0.84	25.90
60	10.85	4	2.87	0.84	67.76
61	10.03	4	1.62	0.45	40.61
62	12.38	4	1.87	0.29	68.56
63	10.77	4	1.90	0.23	75.10
64	11.53	4	1.74	0.12	41.07

Mean Dpar = 2.04
Mean Dper = 0.42
Mean length (um) = 11.81+/- 0.38
Std. Dev. (um) = 3.00
Skewness = -0.82
Kurtosis = -0.18

PFT-37

no confined tracks observed

PFT-39

no confined tracks observed

PFT-42

no confined tracks observed

PFT-43

no confined tracks observed

PFT-44

no confined tracks observed

PFT-45

no confined tracks observed

PFT-47

no confined tracks observed

PFT-49

no confined tracks observed

PFT-53

no confined tracks observed

PFT-55

no confined tracks observed

PFT-61

no confined tracks observed

PFT-65

no confined tracks observed

VOLUME IV

***Tectonic and thermal history of the western Serranía del Interior foreland fold
and thrust belt and Guárico basin, north-central Venezuela: Implications of new
apatite fission-track analysis and seismic interpretation***

by

Jaime Pérez De Armas

APATITE FISSION-TRACK
FORWARD MODELS

Model specs and results for AFTSOLVE.EXE, version 0.8, 6/14/98

GU-01

TIME-TEMPERATURE PATH

1
Time (Ma) Temperature (deg C)
0.000 20.000
KINETIC PARAMETERS
model: Ketcham et al. in review
kinParUsed: Etch Pit Length
Initial track length model: Use kinetic parameter
L0 vs. kpar line defs:
0.2830 15.6300
0.2060 16.1700
0.5440 16.1800
0.4040 16.5700
0.0000 16.1800
0.0000 16.5700
0.1382 16.2880
0.1732 16.4950
Single L0 value:
16.30

Dividers:

4

1.20

1.85

2.32

3.30

Model	Calc	Kin Par
1	0	1.04
2	1	1.53
3	0	2.08
4	1	2.79
5	0	3.46

MODEL RESULTS

pctPerTimeStep

1.00

41

length	pdf2	cdf2	pdf4	cdf4
0.0	0.00000	0.00000	0.00000	0.00000
0.5	0.00000	0.00000	0.00000	0.00000
1.0	0.00000	0.00000	0.00000	0.00000
1.5	0.00000	0.00000	0.00000	0.00000
2.0	0.00000	0.00000	0.00000	0.00000
2.5	0.00056	0.00014	0.00226	0.00056
3.0	0.00086	0.00050	0.00295	0.00187
3.5	0.00130	0.00104	0.00378	0.00355
4.0	0.00198	0.00186	0.00473	0.00568
4.5	0.00301	0.00310	0.00582	0.00831
5.0	0.00456	0.00499	0.00703	0.01153
5.5	0.00684	0.00784	0.00837	0.01538
6.0	0.01013	0.01209	0.00983	0.01992
6.5	0.01469	0.01829	0.01143	0.02524

7.0	0.02072	0.02715	0.01320	0.03140
7.5	0.02829	0.03940	0.01520	0.03850
8.0	0.03723	0.05578	0.01755	0.04669
8.5	0.04708	0.07686	0.02048	0.05619
9.0	0.05707	0.10289	0.02448	0.06743
9.5	0.06637	0.13375	0.03055	0.08119
10.0	0.07440	0.16895	0.04033	0.09891
10.5	0.08130	0.20787	0.05578	0.12293
11.0	0.08831	0.25028	0.07809	0.15640
11.5	0.09790	0.29683	0.10615	0.20246
12.0	0.11331	0.34964	0.13620	0.26305
12.5	0.13689	0.41219	0.16365	0.33801
13.0	0.16701	0.48816	0.18555	0.42531
13.5	0.19510	0.57869	0.20065	0.52186
14.0	0.20724	0.67928	0.20640	0.62363
14.5	0.19244	0.77920	0.19748	0.72460
15.0	0.15214	0.86534	0.16997	0.81646
15.5	0.10066	0.92854	0.12754	0.89084
16.0	0.05512	0.96749	0.08150	0.94310
16.5	0.02480	0.98747	0.04367	0.97439
17.0	0.00912	0.99594	0.01943	0.99017
17.5	0.00273	0.99891	0.00713	0.99681
18.0	0.00066	0.99976	0.00215	0.99913
18.5	0.00013	0.99996	0.00053	0.99980
19.0	0.00002	0.99999	0.00011	0.99996
19.5	0.00000	1.00000	0.00002	0.99999
20.0	0.00000	1.00000	0.00000	1.00000

DATA

Stratigraphic information

NumDefs	age1	age2
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2	60.50	86.50
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Garrapata Formation

Track length file and data

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102

length	proj len	kinPar
1.3900	7.3103	1.6800
5.5200	10.8835	0.9400
10.1000	11.4758	1.4900
12.1700	12.2000	1.7700
13.8900	15.1296	2.6400
15.5400	16.1563	2.1100
5.9400	11.6416	2.1100
6.0500	8.3720	1.4000
15.2300	16.0236	1.6400
12.3900	14.1421	1.6400
14.4500	15.4072	1.6400
12.8000	12.8657	1.6400
8.7200	10.9765	1.6400
6.5900	11.9128	1.7400
10.3000	12.7444	1.4500
8.8000	9.1669	1.4500
2.2000	9.3806	1.1400
2.4800	9.9913	1.8600
12.5300	14.3084	1.9600
9.9100	12.2856	1.7100

11.1600	13.1618	2.2700
13.1000	14.5082	2.4800
14.1400	15.3522	2.9300
11.6100	13.3451	1.6800
14.4100	15.2345	1.5400
15.6600	15.6633	2.0500
14.7400	15.5991	2.7700
13.6000	14.3155	2.1700
11.7400	13.7576	1.9000
13.5500	13.9167	1.9000
9.0300	11.0515	1.9000
11.3400	13.3801	2.2400
13.8000	14.8257	1.4800
13.4800	14.8257	1.4800
11.3000	13.4957	1.4800
12.7600	14.0537	1.3100
11.5000	13.6020	2.1700
9.0900	11.8343	2.1000
14.6700	15.5527	3.0300
10.9000	12.2763	3.0300
13.6900	15.0540	3.0300
14.3300	14.6045	3.0300
13.1600	13.6798	3.0300
12.8100	13.9245	2.0800
12.6400	14.2527	3.0600
11.3000	11.9874	3.0600
13.3300	14.7522	3.0600
8.6700	12.0409	3.0600
13.8800	15.1517	2.3100
10.6100	12.2321	1.4300
11.8600	13.8132	2.1000
13.0900	14.2770	1.9700
10.7600	12.2621	2.7600
13.1200	13.4350	2.8800
9.2200	12.2020	2.8800
16.6500	16.8206	2.8400
13.6800	14.5845	1.8500
13.2000	14.5531	2.6500
15.3300	16.0365	2.6500
12.9500	13.8931	2.6500
15.0600	15.7311	1.5100
13.3900	14.6715	2.6900
13.3400	14.2013	1.5300
14.7300	15.3779	2.7800
11.0500	12.6666	1.4600
3.3900	11.0935	1.1000
8.9800	12.4725	2.0500
10.6500	13.0048	2.0500
13.3900	13.4793	2.4400
13.8100	15.1111	3.2000
13.5600	14.8499	3.2000
13.0000	14.5852	3.2000
14.2700	15.3422	2.8700
7.3700	11.2491	0.9400
13.2700	13.8796	2.3100
13.8400	15.0347	1.6100

11.9400 13.3994 1.3000
 10.8700 12.6345 1.8100
 16.2700 16.4524 1.8100
 10.7400 11.0348 1.7100
 8.8600 10.7087 1.2900
 14.6200 15.4892 1.7300
 12.2600 13.6363 1.2600
 10.4800 12.9484 1.7000
 11.1900 13.1268 1.3800
 13.5400 14.9049 1.8000
 10.3600 12.3734 1.5000
 8.3700 12.2839 1.5000
 11.8000 13.5028 2.1300
 11.7700 13.7511 2.6800
 13.3800 14.7500 2.6800
 15.0000 15.1874 2.5500
 3.8200 9.9059 1.2800
 11.2700 11.8318 1.5000
 8.6100 12.2364 1.5000
 14.0600 15.1161 1.4300
 12.2300 12.8906 2.0100
 14.2900 14.8214 2.0100
 14.3100 14.9298 2.7300
 15.3500 15.7818 1.7400
 13.9600 14.2727 1.5000
 14.8900 15.0162 1.5000
 123643

Age file and data

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38

ns	ni	kinPar	age	ageErr
2	7	1.68	90.82	73.05
10	28	1.58	113.33	42.37
8	20	2.19	126.80	53.65
2	30	3.50	21.31	15.62
14	132	1.54	33.86	9.76
2	25	2.14	25.56	18.85
10	112	2.93	28.52	9.59
7	29	2.33	76.81	32.71
3	45	2.14	21.31	12.78
6	71	2.93	27.00	11.60
7	94	2.33	23.80	9.44
8	56	2.77	45.57	17.47
15	100	1.48	47.84	13.59
6	37	2.68	51.70	22.99
11	112	3.04	31.36	10.11
6	22	2.36	86.72	40.32
12	61	3.25	62.67	20.19
3	17	1.62	56.25	35.40
3	6	1.36	158.11	112.25
4	16	2.73	79.54	44.75
4	14	3.42	90.82	51.81
3	22	2.14	43.51	26.92
3	39	2.33	24.58	14.81
4	51	1.56	25.06	13.11
6	23	1.91	82.98	38.40

2	18	2.58	35.47	26.54
4	32	2.59	39.89	21.31
2	21	2.54	30.42	22.59
8	43	2.89	59.29	23.14
4	37	2.19	34.52	18.30
1	18	2.98	17.76	18.28
3	43	1.79	22.30	13.39
0	84	1.60	0.00	3.84
3	22	2.89	43.51	26.92
3	83	2.08	11.56	6.83
6	21	3.18	90.82	42.44
4	168	1.50	7.62	3.88
4	24	1.91	53.14	28.89

245873

Display specs

maxTime	maxTemp	maxFreq	maxLength
100.00	200.00	0.50	20.00

projectToC	showFit	calcEasyRo	usedCf
0	1	1	1

Max age for kinetic plots

270.36

Inverse model constraints

Num constraints

4

Time (Ma)	Upper (deg C)	Lower (deg C)
0.000	20.000	20.000
39.871	166.492	25.131
64.952	25.131	25.131
99.678	198.953	198.953

Inverse model specs

Monte Carlo

Enforce Max Heating	Enforce Max Cooling	Monotonic	Watch It Go
0	0	1	1

Max Heat Rate	Max Cool Rate
10.0	10.0

Num Paths	Num Paths Run	Divs per seg
10000	10000	2

Time-temperature paths

Num Acceptable	Num Good
3	0

13

Temperature (deg C)

Time (Ma)	Best fit	Min Acc	Max Acc
0.000	20.000	20.000	20.000
9.968	49.587	49.587	71.188
19.936	91.733	89.610	92.192
29.904	93.344	93.344	104.657
39.871	161.502	161.502	166.406
46.141	159.717	151.708	160.974
52.412	152.810	25.633	152.810
58.682	48.161	25.345	67.440
64.952	25.131	25.131	25.131
73.633	47.961	47.961	124.211
82.315	123.524	123.524	134.096
90.997	140.107	140.107	182.184
99.678	198.953	198.953	198.953

Easy Ro Results

calc	equalAcc	meanAcc	sdAcc	equalGood	meanGood	sdGood
1	0	1.26	0.01	1	0.00	0.00

15335427

Model specs and results for AFTSOLVE.EXE, version 0.8, 6/14/98

GU-02***TIME-TEMPERATURE PATH***

1
Time (Ma) Temperature (deg C)
0.000 20.000
KINETIC PARAMETERS
model: Ketcham et al. in review
kinParUsed: Etch Pit Length
Initial track length model: Use kinetic parameter
L0 vs. kpar line defs:
0.2830 15.6300
0.2060 16.1700
0.5440 16.1800
0.4040 16.5700
0.0000 16.1800
0.0000 16.5700
0.1382 16.2880
0.1732 16.4950
Single L0 value:
16.30

Dividers:

2

0.79

3.61

Model	Calc	Kin Par
-------	------	---------

1	0	0.40
---	---	------

2	1	2.21
---	---	------

3	0	4.30
---	---	------

MODEL RESULTS

pctPerTimeStep

1.00

41

length	pdf2	cdf2
0.0	0.00000	0.00000
0.5	0.00000	0.00000
1.0	0.00000	0.00000
1.5	0.00000	0.00000
2.0	0.00000	0.00000
2.5	0.00168	0.00042
3.0	0.00233	0.00142
3.5	0.00318	0.00280
4.0	0.00428	0.00466
4.5	0.00567	0.00715
5.0	0.00742	0.01042
5.5	0.00960	0.01468
6.0	0.01226	0.02015
6.5	0.01549	0.02708

7.0	0.01935	0.03579
7.5	0.02394	0.04662
8.0	0.02940	0.05995
8.5	0.03599	0.07630
9.0	0.04424	0.09636
9.5	0.05518	0.12121
10.0	0.07032	0.15258
10.5	0.09120	0.19296
11.0	0.11798	0.24525
11.5	0.14775	0.31169
12.0	0.17438	0.39222
12.5	0.19111	0.48359
13.0	0.19439	0.57997
13.5	0.18513	0.67485
14.0	0.16611	0.76266
14.5	0.13922	0.83899
15.0	0.10635	0.90038
15.5	0.07180	0.94492
16.0	0.04170	0.97330
16.5	0.02043	0.98883
17.0	0.00833	0.99602
17.5	0.00281	0.99880
18.0	0.00078	0.99970
18.5	0.00018	0.99994
19.0	0.00003	0.99999
19.5	0.00001	1.00000
20.0	0.00000	1.00000

DATA

Stratigraphic information

NumDefs age1 age2

2 64.50 86.50

Garrapata Formation

Track length file and data

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100

length	proj len	kinPar
4.6100	9.6608	3.1600
11.3000	12.5739	3.1600
13.6300	14.4454	1.2600
2.5300	9.9328	1.5500
15.3900	16.1249	3.1200
12.1900	13.2674	3.1200
13.6300	14.6637	1.4700
13.1900	14.5745	1.4700
12.1400	13.9431	1.4700
14.9300	15.6055	0.8800
13.3800	14.7821	2.7900
7.3700	9.7551	2.7900
2.6200	7.3103	1.2300
12.0700	13.5428	2.3800
13.1400	13.2381	1.5600
8.6600	11.9761	2.0200
12.8600	14.2748	0.9200
2.9100	9.1789	0.9200
14.5900	15.4371	1.0900
8.7300	9.2653	1.4700

12.0500	13.8953	1.3500
4.0000	8.9427	1.4100
4.7200	11.7283	1.4100
15.3400	15.4179	1.2600
9.2500	9.7227	1.2900
12.7400	13.8995	1.2900
10.8400	13.1297	1.9000
14.0300	14.8799	1.9000
11.2400	13.0148	1.9000
14.3900	15.3030	1.7400
12.3400	13.9138	1.7400
13.5800	13.7533	1.7400
6.2100	9.6470	1.5700
14.2800	15.2331	2.7200
14.0400	14.9719	2.7200
11.3200	12.8664	1.2700
8.7800	11.0784	2.0600
14.8300	15.2887	1.5600
13.8600	15.1510	2.5200
14.0600	15.1717	2.8500
12.9700	14.4860	2.8500
13.1900	13.3409	2.8500
14.6100	15.2609	2.8300
10.2500	12.7665	1.9600
13.9200	14.1878	2.6000
12.1000	13.7319	2.3900
14.7500	14.9862	3.4500
10.8700	13.0847	1.1200
14.3200	14.9313	1.4900
12.9200	13.4565	1.4900
14.2800	15.1225	1.4900
10.7200	10.8301	1.4900
12.6300	14.3127	1.3800
15.6500	15.7711	2.2700
10.7100	13.0034	2.2700
12.7300	13.8004	2.7700
10.9800	13.0077	1.6600
12.1600	13.9217	1.6600
12.7300	14.2927	1.6600
13.1700	13.6990	1.6600
9.5500	12.1930	1.6600
10.9600	13.2117	1.6600
10.3500	12.6573	1.6600
11.5600	13.5292	1.5900
11.7200	13.3259	1.5900
13.3100	14.6979	1.5900
12.3700	13.7112	1.1600
13.2100	14.7208	1.0600
13.0100	13.5007	0.9300
14.0500	14.5888	0.9300
10.6400	12.4269	0.9300
15.5500	16.2206	0.9300
13.3000	14.7015	2.0300
13.6500	14.9705	3.1700
11.9000	13.7889	3.1700
14.5800	15.0576	3.1700

15.6700 15.7703 2.5500
 12.5100 13.3302 2.5500
 13.7400 14.7921 2.5500
 4.4000 9.8364 1.3300
 9.0100 12.2013 1.6200
 7.3400 11.2298 1.6200
 14.4600 15.3472 3.1200
 13.8600 15.0768 2.5800
 14.3800 14.6202 2.5800
 15.2100 15.4007 2.5800
 11.9400 13.5385 2.5800
 11.9000 13.5442 1.3700
 13.2000 14.3533 3.1400
 10.5100 11.5157 3.1400
 4.6800 10.0532 3.1400
 12.7100 14.2370 2.9900
 13.3300 14.6601 2.9900
 4.5500 9.8467 1.4500
 16.5100 16.5752 2.7200
 14.1900 15.1817 2.7200
 12.6900 13.6912 2.7200
 12.6300 14.3797 2.8900
 12.4300 13.2959 1.5400
 12.7100 12.7922 1.5000
 121218

Age file and data

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38

ns	ni	kinPar	age	ageErr
2	12	1.82	52.96	40.59
3	38	1.60	25.14	15.16
8	72	3.53	35.35	13.37
2	27	1.15	23.59	17.35
9	54	3.04	52.96	19.36
11	77	3.24	45.42	14.92
9	45	3.24	63.50	23.53
9	65	1.34	44.03	15.91
8	80	1.58	31.83	11.97
11	92	3.38	38.03	12.37
3	17	1.59	56.06	35.28
4	10	1.64	126.37	75.19
6	37	3.09	51.53	22.91
3	24	1.62	39.76	24.48
6	33	2.85	57.75	25.89
7	12	1.54	183.47	88.03
2	20	2.06	31.83	23.69
1	20	2.42	15.93	16.36
6	88	1.57	21.72	9.27
1	10	2.01	31.83	33.44
1	16	2.13	19.91	20.56
0	8	1.61	0.00	42.25
3	21	3.24	45.42	28.18
2	27	3.22	23.59	17.35
8	50	1.56	50.85	19.63
3	22	1.95	43.36	26.83
1	11	1.41	28.94	30.28

4	9	1.66	140.26	84.76
9	67	3.02	42.72	15.41
6	51	1.58	37.43	16.33
2	17	1.34	37.43	28.08
4	43	1.94	29.61	15.59
6	56	3.19	34.09	14.80
7	14	1.54	157.58	73.63
7	30	2.65	74.02	31.42
7	84	1.53	26.53	10.57
4	54	3.10	23.59	12.32
3	39	2.18	24.50	14.76

239724

Display specs

maxTime	maxTemp	maxFreq	maxLength
100.00	200.00	0.50	20.00

projectToC	showFit	calcEasyRo	usedCf
0	1	1	1

Max age for kinetic plots

270.36

Inverse model constraints

Num constraints

5

Time (Ma)	Upper (deg C)	Lower (deg C)
0.000	20.000	20.000
59.164	167.539	25.131
86.334	25.131	25.131
99.357	197.906	197.906
148.071	197.906	197.906

Inverse model specs

Monte Carlo

Enforce Max Heating	Enforce Max Cooling	Monotonic	Watch It Go
0	0	1	0

Max Heat Rate	Max Cool Rate
10.0	10.0

Num Paths	Num Paths Run	Divs per seg
10000	10000	2

Time-temperature paths

Num Acceptable	Num Good
311	21

17

Time (Ma)	Best fit	Min Acc	Max Acc	Min Good	Max Good
0.000	20.000	20.000	20.000	20.000	20.000
14.791	76.017	29.764	86.751	55.963	79.133
29.582	79.264	48.139	111.296	76.707	99.970
44.373	108.795	80.587	141.999	99.102	118.701
59.164	129.039	117.630	167.272	120.004	141.642
65.957	124.583	45.142	162.177	49.685	135.649
72.749	103.783	25.561	160.079	29.789	122.605
79.542	100.316	25.224	143.721	25.811	100.316
86.334	25.131	25.131	25.131	25.131	25.131
89.590	95.986	25.134	178.854	26.272	178.854
92.846	169.937	25.153	196.112	35.790	185.460
96.101	177.421	33.234	197.885	66.868	196.409
99.357	197.906	197.906	197.906	197.906	197.906
111.535	197.906	197.906	197.906	197.906	197.906

123.714 197.906 197.906 197.906 197.906 197.906
 135.892 197.906 197.906 197.906 197.906 197.906
 148.071 197.906 197.906 197.906 197.906 197.906

Easy Ro Results

calc	equalAcc	meanAcc	sdAcc	equalGood	meanGood	sdGood
1	0	0.79	0.01	0	0.79	0.00

41156919

Model specs and results for AFTSOLVE.EXE, version 1.2

GU-03

TIME-TEMPERATURE PATH

1
 Time (Ma) Temperature (deg C)
 0.000 20.000
KINETIC PARAMETERS
 model: Ketcham et al. 1999
 kinParUsed: Etch Pit Length
 Initial track length model: Use kinetic parameter
 L0 vs. kpar line defs:
 0.2830 15.6300
 0.2050 16.1000
 0.5440 16.1800
 0.4070 16.4900
 0.0000 16.1800
 0.0000 16.5700
 0.1382 16.2880
 0.1732 16.4950

Single L0 value:

16.30

Standard length reduction:

0.893000

Age calculation to use for data: Pooled

Dividers:

2

0.84

3.48

Model	Calc	Kin Par
-------	------	---------

1	0	0.00
---	---	------

2	1	2.19
---	---	------

3	0	3.99
---	---	------

MODEL RESULTS

pctPerTimeStep

1.00

41

length	pdf2	cdf2
0.0	0.00000	0.00000
0.5	0.00000	0.00000
1.0	0.00000	0.00000
1.5	0.00000	0.00000
2.0	0.00000	0.00000
2.5	0.00000	0.00000
3.0	0.00000	0.00000
3.5	0.00000	0.00000

4.0	0.00000	0.00000
4.5	0.00000	0.00000
5.0	0.00000	0.00000
5.5	0.00000	0.00000
6.0	0.00000	0.00000
6.5	0.00000	0.00000
7.0	0.00001	0.00000
7.5	0.00003	0.00001
8.0	0.00013	0.00005
8.5	0.00043	0.00019
9.0	0.00110	0.00058
9.5	0.00240	0.00145
10.0	0.00469	0.00323
10.5	0.00851	0.00652
11.0	0.01453	0.01228
11.5	0.02350	0.02179
12.0	0.03642	0.03677
12.5	0.05583	0.05983
13.0	0.08953	0.09617
13.5	0.15211	0.15658
14.0	0.25014	0.25715
14.5	0.35056	0.40732
15.0	0.38382	0.59092
15.5	0.31528	0.76570
16.0	0.19131	0.89234
16.5	0.08498	0.96141
17.0	0.02731	0.98949
17.5	0.00625	0.99788
18.0	0.00100	0.99969
18.5	0.00011	0.99997
19.0	0.00001	1.00000
19.5	0.00000	1.00000
20.0	0.00000	1.00000

DATA

Stratigraphic information

NumDefs	age1	age2
2	52.00	74.50

Guárico Formation

Track length file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\AIME\AFT\FTDD\FTDDUGPSAMPLES\L\LGU3B1.A1G
101

length	proj len	kinPar
10.2700	10.3285	2.4900
14.8800	15.7682	2.4900
14.4100	14.9769	2.4900
14.8800	15.7261	2.4900
13.1700	14.5938	2.4900
15.7200	16.1285	2.7900
13.0900	14.1978	1.1800
14.3500	15.2951	2.4800
8.5400	12.0333	0.9900
14.7100	15.4186	2.6900
12.5200	13.8596	2.6900
14.2900	14.3069	2.6900
13.1000	14.0622	2.5300
13.0500	14.2927	2.6200

14.9100	15.4749	1.3700
12.9700	14.2178	1.4700
15.1200	15.8902	3.3000
13.2700	13.4593	0.9800
13.8500	15.1203	2.7800
13.6800	14.8892	2.7800
13.4000	14.4839	2.7800
14.8900	15.7860	2.5800
11.5700	13.4786	2.5800
14.8500	15.7511	2.5000
9.0300	11.1754	2.5000
13.2400	14.3127	2.5000
14.7700	15.3009	2.5000
12.4300	13.0212	1.3900
13.5800	14.9134	1.3900
13.3700	14.4810	1.3900
9.3500	12.8829	1.3900
15.0000	15.6904	2.0800
10.8600	12.8029	1.4600
13.8000	14.7914	1.4600
14.8200	15.0347	2.4600
6.3900	11.4467	1.2600
5.4600	11.4625	1.2600
14.9500	15.4792	2.2300
13.6300	14.8164	1.3000
13.9500	15.0105	2.2900
9.6400	12.2478	1.3300
14.4000	15.3108	2.5300
15.9600	16.3604	2.4000
15.2500	15.9187	2.4000
16.2000	16.3411	2.4000
13.3800	14.6073	2.4000
14.3900	14.9734	2.4000
13.1300	14.6323	2.4000
14.3100	15.2609	2.4000
13.9200	14.9933	2.4000
14.8400	15.5627	2.4000
14.0500	14.5595	2.4000
15.2000	15.9166	2.4000
13.8300	15.0690	2.4000
14.0800	15.1196	2.4000
15.1800	15.9116	2.4000
16.1800	16.5588	2.4000
14.5200	15.4507	2.4000
14.5000	15.1710	2.4000
13.3800	14.8478	2.4000
14.3500	14.3690	2.4000
12.6600	14.3391	2.4000
14.0100	15.0076	2.4000
13.9600	14.1735	2.4000
15.9800	16.3319	2.7000
14.9100	15.3380	2.7000
10.5000	12.9335	2.7000
13.4600	14.7607	2.7000
14.2800	15.2638	2.7000
13.6400	14.8528	2.9800

9.1000 10.9906 2.9800
 16.3900 16.6836 2.9800
 13.9000 14.8599 1.6100
 12.4700 12.9242 1.6100
 11.3000 12.7094 1.6100
 11.1000 13.4358 1.6100
 12.4900 14.3119 1.6100
 12.2400 13.6341 1.6100
 13.5600 14.9020 1.6100
 12.6500 14.1757 1.6100
 13.9200 14.8999 1.6100
 9.2400 11.5593 2.2600
 15.4800 16.1035 2.3400
 14.2400 15.1396 2.3400
 12.1600 14.1150 2.3200
 14.9100 15.5656 2.8300
 14.0500 14.7622 2.8300
 14.4200 15.4571 2.8300
 13.7500 14.9498 2.8300
 16.4500 16.6030 2.7100
 11.6800 12.3198 1.2900
 12.8900 14.5467 1.2900
 9.7600 12.0994 1.2900
 14.5200 15.5377 1.2900
 12.4900 13.9224 1.2900
 12.3400 13.9759 2.9200
 15.8000 16.1699 2.9200
 10.7700 13.1832 2.9200
 13.7500 14.6459 2.6700
 13.5400 14.9512 2.6700
 12.3900 13.5035 2.6700

141041

Age file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\JAIME\AFT\FTDD\FTDD\UGP\SAMPLES\A\AGU3A1.AIG

58

ns	ni	kinPar	age	ageErr
1	25	2.06	12.71	12.98
5	45	1.89	35.23	16.76
3	13	2.67	72.96	46.96
8	71	2.93	35.73	13.52
4	29	2.25	43.71	23.48
1	32	1.96	9.93	10.10
0	41	0.00	0.00	7.86
1	1	3.61	310.37	439.38
2	7	1.71	90.21	72.56
1	4	3.64	79.01	88.47
3	8	1.82	118.15	80.34
2	20	3.55	31.72	23.61
0	5	2.37	0.00	69.44
3	18	2.55	52.78	33.08
0	17	1.86	0.00	19.25
2	67	1.72	9.48	6.83
3	23	3.40	41.34	25.51
4	44	2.56	28.84	15.17
5	36	3.20	44.01	21.19
7	56	3.38	39.62	16.08

4	22	2.96	57.55	31.50
3	19	2.94	50.01	31.23
12	113	3.21	33.68	10.45
4	52	1.75	24.41	12.76
3	30	3.23	31.72	19.31
8	18	1.64	139.79	60.06
19	159	2.09	37.88	9.51
0	5	1.52	0.00	69.44
0	9	1.87	0.00	37.21
5	49	3.40	32.36	15.33
12	62	3.61	61.25	19.70
5	46	2.80	34.47	16.38
78	631	1.68	39.19	5.32
6	27	1.49	70.27	32.03
7	49	2.82	45.26	18.51
0	4	1.30	0.00	88.47
9	67	2.53	42.57	15.35
16	106	1.85	47.82	13.18
5	32	4.42	49.49	24.01
8	39	1.94	64.90	25.52
2	20	3.31	31.72	23.61
13	78	1.63	52.78	16.16
4	55	3.34	23.08	12.04
1	35	1.94	9.08	9.23
3	37	3.61	25.73	15.53
4	54	1.68	23.51	12.27
12	83	2.06	45.81	14.44
9	98	1.79	29.14	10.32
4	12	1.61	105.13	61.06
1	15	1.97	21.16	21.90
4	42	1.81	30.21	15.92
19	146	1.66	41.25	10.40
4	10	4.33	125.95	74.94
5	37	2.69	42.83	20.59
0	20	1.88	0.00	16.30
2	10	1.96	63.28	49.18
11	113	1.97	30.88	9.95
0	3	1.88	0.00	121.57

376782

DISPLAY AND PARAMETER SPECIFICATIONS

maxTime	maxTemp	maxFreq	maxLength
100.00	200.00	0.50	20.00

projectToC	showFit	calcEasyRo	usedCf
1	1	1	1

Max age for kinetic plots
749.75

Inverse model constraints

Num constraints
4

Time (Ma)	Upper (deg C)	Lower (deg C)
0.000	20.000	20.000
43.408	170.681	25.131
64.952	25.131	25.131
99.035	196.859	196.859

Inverse model specs

Monte Carlo

```

Enforce Max Heating      Enforce Max Cooling      Monotonic      Watch It Go
0      0      1      0
Max Heat Rate      Max Cool Rate
10.0      10.0
Num Paths      Num Paths Run      Divs per seg
10000      10000      2
Time-temperature paths
Num Acceptable      Num Good
610      107
13
      Temperature (deg C)
Time (Ma)      Best fit      Min Acc      Max Acc      Min Good      Max Good
0.000      20.000      20.000      20.000      20.000      20.000
10.852      51.676      20.017      63.574      20.112      58.267
21.704      53.760      21.541      95.387      46.175      76.772
32.556      86.948      43.495      125.508      64.005      117.657
43.408      138.791      118.384      170.015      126.275      169.471
48.794      94.741      30.515      167.681      30.515      160.207
54.180      73.989      25.997      165.004      26.332      156.628
59.566      38.547      25.157      139.273      25.377      129.058
64.952      25.131      25.131      25.131      25.131      25.131
73.473      26.714      25.190      182.206      25.218      147.539
81.993      27.011      25.723      196.530      25.768      193.598
90.514      122.536      27.962      196.852      48.521      196.658
99.035      196.859      196.859      196.859      196.859      196.859
Easy Ro Results
calc      equalAcc      meanAcc      sdAcc      equalGood      meanGood      sdGood
1      0      0.82      0.01      0      0.82      0.01
22544994

```

Model specs and results for AFTSOLVE.EXE, version 1.2

GU-04

TIME-TEMPERATURE PATH

```

1
Time (Ma)      Temperature (deg C)
0.000      20.000
KINETIC PARAMETERS
model: Ketcham et al. 1999
kinParUsed: Etch Pit Length
Initial track length model: Use kinetic parameter
L0 vs. kpar line defs:
0.2830      15.6300
0.2050      16.1000
0.5440      16.1800
0.4070      16.4900
0.0000      16.1800
0.0000      16.5700
0.1382      16.2880
0.1732      16.4950
Single L0 value:
16.30

```

Standard length reduction:

0.893000

Age calculation to use for data: Pooled

Dividers:

2

1.24

2.83

Model	Calc	Kin Par
1	0	0.62
2	1	2.00
3	0	3.92

MODEL RESULTS

pctPerTimeStep

1.00

41

length	pdf2	cdf2
0.0	0.00000	0.00000
0.5	0.00000	0.00000
1.0	0.00000	0.00000
1.5	0.00000	0.00000
2.0	0.00000	0.00000
2.5	0.00000	0.00000
3.0	0.00000	0.00000
3.5	0.00000	0.00000
4.0	0.00000	0.00000
4.5	0.00000	0.00000
5.0	0.00000	0.00000
5.5	0.00000	0.00000
6.0	0.00000	0.00000
6.5	0.00000	0.00000
7.0	0.00000	0.00000
7.5	0.00001	0.00000
8.0	0.00008	0.00002
8.5	0.00070	0.00022
9.0	0.00450	0.00152
9.5	0.02036	0.00773
10.0	0.06347	0.02869
10.5	0.13692	0.07879
11.0	0.21145	0.16588
11.5	0.24888	0.28096
12.0	0.24170	0.40361
12.5	0.20623	0.51559
13.0	0.16056	0.60729
13.5	0.12348	0.67830
14.0	0.10957	0.73657
14.5	0.11601	0.79296
15.0	0.12241	0.85257
15.5	0.10827	0.91024
16.0	0.07317	0.95560
16.5	0.03602	0.98290
17.0	0.01257	0.99504
17.5	0.00306	0.99895
18.0	0.00051	0.99984
18.5	0.00006	0.99998
19.0	0.00000	1.00000
19.5	0.00000	1.00000

20.0 0.00000 1.00000

DATA

Stratigraphic information

NumDefs age1 age2

2 52.00 74.50

Guárico Formation

Track length file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\JAIME\AFT\FTDD\FTDD\UGP\SAMPLES\L\LGU4B1.A1G
17

length proj len kinPar

8.7500 11.1631 1.5700

3.9300 11.5520 1.5700

4.9900 11.1300 1.5700

10.9800 12.7365 1.7000

12.2000 13.9545 1.7000

10.7300 12.9492 1.7000

14.4600 14.9648 1.7000

10.4900 12.6823 1.7000

9.2100 12.4959 1.7000

5.9000 10.7162 1.3700

10.5900 12.8293 1.4000

14.4800 14.7565 1.4000

2.5000 10.9827 1.4000

11.9600 13.7768 1.7200

13.4500 14.7572 1.7200

9.8700 11.4636 1.7200

6.7400 11.0846 1.7200

11970

Age file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\JAIME\AFT\FTDD\FTDD\UGP\SAMPLES\A\AGU4A1.A1G
9

ns ni kinPar age ageErr

1 15 2.63 21.09 21.82

11 67 1.74 51.82 17.18

6 52 1.99 36.46 15.89

9 100 1.78 28.46 10.07

5 49 2.60 32.25 15.28

2 30 2.03 21.09 15.46

1 11 1.86 28.74 30.08

2 10 1.57 63.07 49.02

0 2 2.29 0.00 191.96

23481

DISPLAY AND PARAMETER SPECIFICATIONS

maxTime maxTemp maxFreqmaxLength

100.00 200.00 0.50 20.00

projectToC showFit calcEasyRo usedCf

1 1 1 1

Max age for kinetic plots

191.96

Inverse model constraints

Num constraints

4

Time (Ma) Upper (deg C) Lower (deg C)

0.000 20.000 20.000

45.338 174.869 25.131

64.952 25.131 25.131

98.071 194.764 194.764

Inverse model specs

Monte Carlo

Enforce Max Heating Enforce Max Cooling Monotonic Watch It Go

0 0 1 0

Max Heat Rate Max Cool Rate

10.0 10.0

Num Paths Num Paths Run Divs per seg

10000 10000 2

Time-temperature paths

Num Acceptable Num Good

271 18

13

Temperature (deg C)

Time (Ma) Best fit Min Acc Max Acc Min Good Max Good

0.000 20.000 20.000 20.000 20.000 20.000

11.334 95.564 21.025 100.267 64.223 97.170

22.669 97.702 65.550 107.006 93.798 103.367

34.003 98.423 83.796 127.159 98.423 105.775

45.338 98.429 96.839 172.941 98.429 117.939

50.241 96.717 34.487 172.449 42.792 107.550

55.145 80.901 25.231 166.229 27.823 102.373

60.048 74.432 25.155 133.811 26.541 85.727

64.952 25.131 25.131 25.131 25.131 25.131

73.232 153.232 25.156 187.202 25.473 177.205

81.511 157.220 25.441 194.303 32.692 188.160

89.791 184.179 42.948 194.731 66.765 193.459

98.071 194.764 194.764 194.764 194.764 194.764

Easy Ro Results

calc equalAcc meanAcc sdAcc equalGood meanGood sdGood

1 0 0.73 0.01 0 0.72 0.01

22544655

Model specs and results for AFTSOLVE.EXE, version 1.2

GU-05

TIME-TEMPERATURE PATH

1

Time (Ma) Temperature (deg C)

0.000 20.000

KINETIC PARAMETERS

model: Ketcham et al. 1999

kinParUsed: Etch Pit Length

Initial track length model: Use kinetic parameter

L0 vs. kpar line defs:

0.2830 15.6300

0.2060 16.1700

0.5440 16.1800

0.4040 16.5700

0.0000 16.1800

0.0000 16.5700

0.1382 16.2880

0.1732 16.4950

Single L0 value:

16.30

Standard length reduction:

0.893000

Age calculation to use for data: Pooled

Dividers:

4

0.90

1.78

2.12

3.73

Model	Calc	Kin Par
1	0	0.00
2	1	1.39
3	0	1.95
4	1	2.91
5	0	4.37

MODEL RESULTS

pctPerTimeStep

1.00

41

length	pdf2	cdf2	pdf4	cdf4
0.0	0.00000	0.00000	0.00000	0.00000
0.5	0.00000	0.00000	0.00000	0.00000
1.0	0.00000	0.00000	0.00000	0.00000
1.5	0.00000	0.00000	0.00000	0.00000
2.0	0.00000	0.00000	0.00000	0.00000
2.5	0.00000	0.00000	0.00000	0.00000
3.0	0.00000	0.00000	0.00000	0.00000
3.5	0.00000	0.00000	0.00000	0.00000
4.0	0.00000	0.00000	0.00000	0.00000
4.5	0.00000	0.00000	0.00000	0.00000
5.0	0.00000	0.00000	0.00000	0.00000
5.5	0.00000	0.00000	0.00000	0.00000
6.0	0.00000	0.00000	0.00000	0.00000
6.5	0.00000	0.00000	0.00000	0.00000
7.0	0.00000	0.00000	0.00001	0.00000
7.5	0.00002	0.00000	0.00017	0.00005
8.0	0.00010	0.00003	0.00113	0.00037
8.5	0.00049	0.00018	0.00548	0.00202
9.0	0.00188	0.00078	0.01829	0.00797
9.5	0.00592	0.00273	0.04171	0.02297
10.0	0.01571	0.00813	0.06488	0.04962
10.5	0.03550	0.02094	0.06923	0.08314
11.0	0.06820	0.04686	0.05193	0.11344
11.5	0.11133	0.09174	0.03058	0.13406
12.0	0.15459	0.15822	0.02371	0.14764
12.5	0.18437	0.24296	0.04462	0.16472
13.0	0.19625	0.33812	0.10648	0.20249
13.5	0.20168	0.43760	0.20266	0.27977
14.0	0.21372	0.54145	0.28579	0.40189
14.5	0.22773	0.65181	0.30799	0.55033
15.0	0.22182	0.76420	0.27295	0.69557
15.5	0.17897	0.86440	0.21145	0.81667
16.0	0.11099	0.93689	0.14157	0.90493

16.5	0.05032	0.97722	0.07654	0.95945
17.0	0.01617	0.99384	0.03129	0.98641
17.5	0.00361	0.99879	0.00927	0.99655
18.0	0.00056	0.99983	0.00195	0.99936
18.5	0.00006	0.99998	0.00029	0.99991
19.0	0.00000	1.00000	0.00003	0.99999
19.5	0.00000	1.00000	0.00000	1.00000
20.0	0.00000	1.00000	0.00000	1.00000

DATA

Stratigraphic information

NumDefs	age1	age2
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2	52.00	74.50
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Guárico Formation

Track length file and data

c:\docume~1\jperez\mydocu~1\jaime\lft\ftdd\jgp\samples\l\lgu5bl.alg
103

length	proj len	kinPar
--------	----------	--------

14.1300	14.4867	2.4900
8.6900	11.7311	3.1200
5.1100	11.1713	3.1200
12.7600	14.4596	1.2900
9.2700	11.6615	2.8800
14.3200	15.0925	2.5700
15.3200	16.1242	1.8000
15.1900	15.2452	1.8000
13.0900	14.3383	2.3700
10.1400	11.9224	1.3500
15.4600	16.0308	2.6200
13.1300	14.6494	2.0400
13.9300	15.0647	1.3700
11.6700	13.1653	1.3700
3.2000	10.8092	1.8000
9.8700	11.2831	1.8000
13.5400	14.9448	2.5200
10.0100	12.6288	1.6500
14.1000	14.6815	1.6500
10.4800	11.2253	1.6500
10.0400	12.0273	1.6500
14.3100	15.3166	1.1300
13.1200	14.6252	1.1400
13.4100	14.2370	1.1400
11.3400	13.0626	1.6300
5.2800	7.7468	1.3200
14.8500	15.1489	1.9300
13.8300	14.8007	1.6300
14.1000	15.1903	1.5300
15.0000	15.8545	3.1600
12.2800	12.5960	0.9900
14.6600	15.2174	2.6300
11.2000	11.5093	1.8400
14.5000	14.5317	1.9000
5.8000	12.5111	3.0600
11.7600	12.9649	1.4600
15.1200	15.8082	2.2300
8.9100	12.3913	2.3100
15.3700	16.0850	1.4800

9.5500	10.6360	1.4800
11.2800	13.2567	1.4800
13.2200	14.2570	2.1100
13.9600	14.0108	1.2600
12.2400	14.1107	2.7700
11.1900	11.9124	1.6800
10.1300	11.8932	1.8500
13.6400	13.9716	2.1000
13.2900	14.7964	2.4400
11.1800	11.7077	1.0500
15.5400	15.8774	3.2700
9.7900	10.5732	1.1200
12.5700	14.1079	1.9800
9.0200	10.7937	1.9800
2.9300	10.3300	1.1800
2.4500	9.9954	1.1800
14.9600	15.5356	2.7200
12.7300	13.7204	1.5200
13.5300	14.8984	2.1100
10.7100	13.0112	2.1700
10.8000	12.0266	2.1200
14.4000	14.4232	1.6600
14.1100	15.0932	2.8700
12.8000	14.4439	1.0300
13.5900	14.0993	1.0300
14.2700	15.3101	2.1100
4.5400	10.1847	2.4400
10.6400	13.0212	1.9900
5.7300	11.0963	2.6800
15.3200	16.0136	3.4500
10.9800	12.9463	2.0600
13.9700	15.1696	1.3300
13.1500	14.2121	1.8300
7.9700	11.5328	1.6300
10.7200	11.2660	3.1400
6.4500	10.6894	1.5700
5.1900	12.0684	1.5900
15.9200	16.3040	3.6800
13.8200	15.0076	1.8400
9.5000	11.0905	1.1900
12.2500	14.1007	3.0900
11.7100	13.5349	1.0500
11.7200	13.2153	1.6000
9.7900	12.6440	1.7800
11.4300	13.5021	1.3100
13.4300	13.8489	1.3600
13.0600	14.6266	1.4100
12.9700	14.1685	1.4100
12.3400	13.8703	1.4500
8.7600	11.4681	1.4900
11.7200	13.4700	1.6900
11.8500	13.8739	1.5700
13.0200	13.6106	2.0600
15.2600	16.0757	3.2800
13.8700	14.5767	1.4400
11.4400	13.5449	1.7900

14.7400 15.0975 1.3600
 9.7700 12.2870 2.2700
 6.9000 11.8970 2.0500
 14.5400 15.5656 3.1700
 8.8800 11.2636 1.6000
 14.4200 14.8471 1.7600
 11.2600 13.3537 1.0300
 13.2200 14.7272 2.4100
 123953

Age file and data

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 37

ns	ni	kinPar	age	ageErr
0	22	1.69	0.00	14.69
0	20	1.61	0.00	16.19
3	9	2.11	104.42	69.93
0	18	1.28	0.00	18.04
14	55	1.65	79.89	24.45
1	4	2.24	78.47	87.88
1	5	3.01	62.85	68.97
0	8	1.49	0.00	41.82
0	14	1.16	0.00	23.35
6	31	2.04	60.84	27.41
8	78	2.49	32.31	12.17
4	47	1.83	26.82	14.07
7	76	1.93	29.02	11.61
4	18	1.84	69.80	38.84
4	15	2.55	83.67	47.38
0	7	0.00	0.00	48.15
4	11	2.44	113.83	66.85
5	10	1.64	156.00	86.02
0	15	1.44	0.00	21.75
1	7	1.44	44.96	48.15
1	18	2.37	17.52	18.04
2	7	1.41	89.60	72.07
3	61	2.64	15.51	9.23
1	28	1.22	11.27	11.49
1	3	1.51	104.42	120.75
2	11	2.61	57.16	44.09
2	26	2.42	24.25	17.86
1	14	1.56	22.52	23.35
1	22	1.70	14.34	14.69
1	7	1.30	44.96	48.15
1	2	2.13	156.00	191.32
2	17	1.53	37.05	27.79
0	11	1.47	0.00	29.97
2	19	1.84	33.16	24.74
7	118	1.80	18.71	7.37
3	9	1.56	104.42	69.93
2	20	2.90	31.50	23.45

227071

DISPLAY AND PARAMETER SPECIFICATIONS

maxTime	maxTemp	maxFreq	maxLength
100.00	200.00	0.50	20.00
projectToC	showFit	calcEasyRo	usedCf
1	1	1	1

Max age for kinetic plots

347.32

Inverse model constraints

Num constraints

5

Time (Ma) Upper (deg C) Lower (deg C)

0.000 20.000 20.000

34.727 165.445 25.131

42.122 167.539 25.131

64.952 25.131 25.131

99.357 196.859 196.859

Inverse model specs

Monte Carlo

Enforce Max Heating Enforce Max Cooling Monotonic Watch It Go

0 0 1 0

Max Heat Rate Max Cool Rate

10.0 10.0

Num Paths Num Paths Run Divs per seg

10000 10000 2

Time-temperature paths

Num Acceptable Num Good

60 0

17

Temperature (deg C)

Time (Ma) Best fit Min AccMax Acc

0.000 20.000 20.000 20.000

8.682 60.113 45.827 86.881

17.363 85.438 58.308 94.984

26.045 89.671 82.536 103.712

34.727 95.507 84.701 164.184

36.576 97.558 88.637 164.991

38.424 104.589 94.858 165.578

40.273 118.516 111.436 165.677

42.122 161.857 143.298 167.340

47.830 154.935 82.375 163.645

53.537 123.125 26.352 155.406

59.245 38.815 25.293 148.873

64.952 25.131 25.131 25.131

73.553 108.580 25.971 189.404

82.154 127.297 27.280 196.094

90.756 190.965 28.947 196.832

99.357 196.859 196.859 196.859

Easy Ro Results

calc equalAcc meanAcc sdAcc equalGood meanGood sdGood

1 0 1.43 0.01 1 0.00 0.00

49676348

Model specs and results for AFTSOLVE.EXE, version 0.8, 6/14/98

GU-06

TIME-TEMPERATURE PATH

```

1
Time (Ma)      Temperature (deg C)
0.000  20.000
KINETIC PARAMETERS
model: Ketcham et al. in review
kinParUsed: Etch Pit Length
Initial track length model: Use kinetic parameter
L0 vs. kpar line defs:
0.2830  15.6300
0.2060  16.1700
0.5440  16.1800
0.4040  16.5700
0.0000  16.1800
0.0000  16.5700
0.1382  16.2880
0.1732  16.4950
Single L0 value:
16.30
Dividers:
3
0.49
1.76
3.28
Model  Calc    Kin Par
1      0      0.00
2      1      1.21
3      1      2.45
4      0      4.54
MODEL RESULTS
pctPerTimeStep
1.00
41
length  pdf2    cdf2    pdf3    cdf3
0.0     0.00000 0.00000 0.00000 0.00000
0.5     0.00000 0.00000 0.00000 0.00000
1.0     0.00000 0.00000 0.00000 0.00000
1.5     0.00000 0.00000 0.00000 0.00000
2.0     0.00000 0.00000 0.00000 0.00000
2.5     0.00051 0.00013 0.00743 0.00186
3.0     0.00073 0.00044 0.00926 0.00603
3.5     0.00103 0.00088 0.01126 0.01116
4.0     0.00147 0.00150 0.01336 0.01732
4.5     0.00209 0.00239 0.01549 0.02453
5.0     0.00301 0.00366 0.01755 0.03279
5.5     0.00441 0.00552 0.01948 0.04205
6.0     0.00662 0.00828 0.02123 0.05223
6.5     0.01012 0.01246 0.02277 0.06323
7.0     0.01559 0.01889 0.02414 0.07496
7.5     0.02391 0.02876 0.02544 0.08736
8.0     0.03594 0.04373 0.02688 0.10044
8.5     0.05229 0.06578 0.02890 0.11438
9.0     0.07290 0.09708 0.03237 0.12970
9.5     0.09669 0.13948 0.03894 0.14753
10.0    0.12129 0.19397 0.05116 0.17005
10.5    0.14327 0.26011 0.07181 0.20079
11.0    0.15909 0.33570 0.10205 0.24426

```

11.5	0.16660	0.41712	0.13887	0.30449
12.0	0.16655	0.50041	0.17427	0.38277
12.5	0.16231	0.58262	0.19825	0.47590
13.0	0.15721	0.66250	0.20425	0.57653
13.5	0.15097	0.73955	0.19259	0.67574
14.0	0.13912	0.81207	0.16844	0.76600
14.5	0.11735	0.87619	0.13728	0.84243
15.0	0.08684	0.92723	0.10301	0.90250
15.5	0.05471	0.96262	0.06940	0.94561
16.0	0.02879	0.98349	0.04082	0.97316
16.5	0.01250	0.99382	0.02048	0.98849
17.0	0.00445	0.99806	0.00863	0.99576
17.5	0.00129	0.99949	0.00302	0.99868
18.0	0.00030	0.99989	0.00087	0.99965
18.5	0.00006	0.99998	0.00021	0.99992
19.0	0.00001	1.00000	0.00004	0.99999
19.5	0.00000	1.00000	0.00001	1.00000
20.0	0.00000	1.00000	0.00000	1.00000

DATA

Stratigraphic information

NumDefs	age1	age2
2	52.00	74.50

Guárico Formation

Track length file and data

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100

length	proj	len	kinPar
13.4000	14.0001	2.9800	
14.2900	15.2395	2.0000	
9.4000	12.5820	1.6000	
9.4400	12.3562	1.7200	
6.3000	11.6808	1.8100	
14.7000	15.5991	2.5300	
12.8700	13.4322	2.4600	
13.7400	15.0618	1.5200	
13.3400	13.3673	1.5800	
9.3900	9.8226	1.5800	
3.8200	9.4797	1.3700	
10.7500	12.4961	3.1300	
10.6300	12.5953	1.7400	
7.0800	11.3792	1.3700	
14.1600	15.2794	1.9500	
11.7700	13.8282	1.4000	
11.3200	13.0212	2.4300	
13.2200	13.8453	2.4300	
10.7900	13.0990	2.4300	
11.7100	13.0412	2.4300	
9.9800	10.4391	1.9700	
12.3000	12.9891	2.1500	
12.8600	13.6156	1.8400	
13.9200	14.6730	2.2400	
14.1600	14.8150	2.0700	
12.4400	12.8507	2.0700	
13.5100	14.8949	2.0300	
13.3300	13.4771	1.6400	
13.1800	14.5196	3.0200	

12.7600	13.0990	3.0200
17.3500	17.4178	1.9800
12.1300	14.0315	1.2200
13.3200	14.7821	1.6100
13.6500	15.0419	1.6100
13.8100	14.4653	2.0800
12.0900	13.7754	2.0800
13.8700	14.4425	2.2700
8.9200	11.1947	2.2700
12.9200	13.9202	2.1500
10.7000	12.6852	2.0000
15.1800	15.6212	2.0000
12.2600	12.4297	2.0000
11.9400	12.6787	2.0000
4.9600	9.0611	2.2800
3.7800	11.2436	2.0900
12.0800	13.9823	2.0900
13.7700	14.9634	2.0900
3.7800	11.0901	1.2300
13.2900	14.7900	2.6200
12.4400	14.2071	1.7900
12.9800	14.5467	1.3400
13.7300	15.0312	1.3700
15.7700	16.1613	2.3300
12.6700	13.0219	2.1400
9.5300	11.2039	2.4500
14.7200	15.3601	1.3300
14.1000	15.0996	1.8400
10.7000	12.8764	1.3000
13.9600	14.0629	1.7400
9.2500	12.6626	1.7400
13.0100	14.3298	0.9700
13.9400	14.8877	1.5500
11.7900	13.1097	1.5500
10.2400	11.9524	1.5500
8.7300	11.2808	1.3900
4.4600	10.0670	1.3200
13.8000	13.8368	1.2900
12.4700	14.0087	2.7900
9.6100	12.1443	1.7300
15.1700	15.6234	1.7400
14.7400	15.4964	1.7200
7.8300	11.9376	2.2800
13.9700	14.9912	2.0200
13.7100	14.1871	1.7800
13.3600	13.9381	2.1000
13.8800	14.5781	2.1000
13.7300	14.7372	2.2200
6.4800	12.0581	0.8900
13.1900	14.6016	1.8900
7.1600	11.8853	1.7600
9.6600	11.8732	1.9300
14.3300	15.4015	2.0200
13.9000	15.0625	2.4600
16.1100	16.5716	2.3500
12.6000	14.2071	1.3700

9.2200 11.3724 1.9700
 13.4100 14.7065 0.6900
 13.9400 15.2267 2.7100
 15.1900 15.9152 2.7100
 13.3700 14.8656 1.4900
 12.2400 14.1286 1.2800
 14.1400 14.6109 1.7700
 11.3300 13.1703 1.3600
 14.4100 15.0361 1.1800
 10.4900 10.6488 2.4400
 6.8600 11.3951 1.5400
 9.8700 11.7762 1.8200
 13.8000 14.9049 1.8200
 11.9600 13.0640 1.9900
 8.9500 10.9366 1.5800
 121113

Age file and data

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36

ns	ni	kinPar	age	ageErr
2	31	3.78	22.85	16.73
1	6	2.57	58.86	63.69
0	2	1.67	0.00	214.61
8	84	1.98	33.70	12.65
0	5	1.67	0.00	77.43
8	70	1.69	40.42	15.30
0	6	5.29	0.00	63.69
4	54	1.90	26.23	13.69
10	11	1.90	314.72	138.95
0	1	0.00	0.00	488.91
0	1	0.00	0.00	488.91
1	9	1.85	39.30	41.50
1	10	1.63	35.38	37.18
0	5	2.79	0.00	77.43
1	7	2.37	50.49	54.07
4	11	2.78	127.74	75.02
2	15	0.83	47.13	35.61
1	5	1.18	70.57	77.43
3	13	1.14	81.36	52.37
3	14	1.70	75.58	48.32
0	5	0.00	0.00	77.43
5	28	1.88	63.04	30.87
2	22	1.99	32.17	23.85
0	1	0.00	0.00	488.91
1	9	4.02	39.30	41.50
0	8	2.51	0.00	46.96
1	2	1.46	174.99	214.61
31	239	1.57	45.85	9.22
1	10	1.15	35.38	37.18
0	6	0.00	0.00	63.69
0	14	0.00	0.00	26.23
1	1	1.67	345.36	488.91
1	10	1.86	35.38	37.18
8	89	1.91	31.81	11.91
1	4	1.47	88.09	98.65
1	10	2.00	35.38	37.18

281480

Display specs

maxTime	maxTemp	maxFreq	maxLength
---------	---------	---------	-----------

100.00	200.00	0.50	20.00
--------	--------	------	-------

projectToC	showFit	calcEasyRo	usedCf
------------	---------	------------	--------

0	1	1	1
---	---	---	---

Max age for kinetic plots

347.32

Inverse model constraints

Num constraints

4

Time (Ma)	Upper (deg C)	Lower (deg C)
-----------	---------------	---------------

0.000	20.000	20.000
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55.949	168.586	25.131
--------	---------	--------

64.952	25.131	25.131
--------	--------	--------

99.035	196.859	196.859
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Inverse model specs

Monte Carlo

Enforce Max Heating	Enforce Max Cooling	Monotonic	Watch It Go
---------------------	---------------------	-----------	-------------

0	0	1	1
---	---	---	---

Max Heat Rate	Max Cool Rate
---------------	---------------

10.0	10.0
------	------

Num Paths	Num Paths Run	Divs per seg
-----------	---------------	--------------

10000	10000	2
-------	-------	---

Time-temperature paths

Num Acceptable Num Good

61	0
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13

Temperature (deg C)

Time (Ma)	Best fit	Min Acc	Max Acc
-----------	----------	---------	---------

0.000	20.000	20.000	20.000
-------	--------	--------	--------

13.987	75.997	21.340	82.348
--------	--------	--------	--------

27.974	81.934	68.656	89.807
--------	--------	--------	--------

41.961	85.837	79.508	99.163
--------	--------	--------	--------

55.949	144.965	86.133	167.961
--------	---------	--------	---------

58.199	139.694	49.930	162.198
--------	---------	--------	---------

60.450	113.000	26.762	143.585
--------	---------	--------	---------

62.701	73.329	25.264	124.759
--------	--------	--------	---------

64.952	25.131	25.131	25.131
--------	--------	--------	--------

73.473	144.594	25.840	170.050
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81.994	186.297	30.484	195.527
--------	---------	--------	---------

90.514	189.006	82.627	196.219
--------	---------	--------	---------

99.035	196.859	196.859	196.859
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Easy Ro Results

calc	equalAcc	meanAcc	sdAcc	equalGood	meanGood	sdGood
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1	0	0.96	0.01	1	0.00	0.00
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15335485

Model specs and results for AFTSOLVE.EXE, version 0.8, 6/14/98

GU-07**TIME-TEMPERATURE PATH**

1
Time (Ma) Temperature (deg C)
0.000 20.000
KINETIC PARAMETERS
model: Ketcham et al. in review
kinParUsed: Etch Pit Length
Initial track length model: Use kinetic parameter
L0 vs. kpar line defs:
0.2830 15.6300
0.2060 16.1700
0.5440 16.1800
0.4040 16.5700
0.0000 16.1800
0.0000 16.5700
0.1382 16.2880
0.1732 16.4950
Single L0 value:
16.30
Dividers:
2
0.69
2.25
Model Calc Kin Par
1 0 0.00
2 1 1.48
3 0 2.58
MODEL RESULTS
pctPerTimeStep
1.00
41
length pdf2 cdf2
0.0 0.00000 0.00000
0.5 0.00000 0.00000
1.0 0.00000 0.00000
1.5 0.00000 0.00000
2.0 0.00000 0.00000
2.5 0.00333 0.00083
3.0 0.00466 0.00283
3.5 0.00639 0.00559
4.0 0.00862 0.00934
4.5 0.01145 0.01436
5.0 0.01497 0.02097
5.5 0.01931 0.02954
6.0 0.02455 0.04050
6.5 0.03082 0.05434
7.0 0.03821 0.07160
7.5 0.04682 0.09286
8.0 0.05674 0.11875
8.5 0.06800 0.14993
9.0 0.08055 0.18707
9.5 0.09413 0.23074
10.0 0.10818 0.28132
10.5 0.12164 0.33877
11.0 0.13296 0.40242
11.5 0.14057 0.47080
12.0 0.14379 0.54189

12.5	0.14347	0.61371
13.0	0.14115	0.68486
13.5	0.13672	0.75433
14.0	0.12721	0.82031
14.5	0.10913	0.87940
15.0	0.08284	0.92739
15.5	0.05394	0.96158
16.0	0.02950	0.98244
16.5	0.01338	0.99316
17.0	0.00499	0.99776
17.5	0.00152	0.99938
18.0	0.00038	0.99986
18.5	0.00008	0.99997
19.0	0.00001	1.00000
19.5	0.00000	1.00000
20.0	0.00000	1.00000

DATA

Stratigraphic information

NumDefs	age1	age2
---------	------	------

2	52.00	74.50
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Guárico Formation

Track length file and data

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80

length	proj len	kinPar
14.1400	14.6730	1.2200
14.4900	14.9313	1.2200
5.6800	7.3104	1.2700
12.1100	12.2835	1.2700
12.8800	14.3704	0.8300
2.2400	9.8013	1.7900
3.3700	9.8818	1.7900
10.9000	11.0591	1.5300
10.1700	12.4583	2.6800
11.6100	13.7304	1.7900
14.0000	14.7600	1.7900
11.6200	13.3252	1.4100
14.7700	15.4664	1.9800
12.1000	12.1336	1.5000
13.5800	14.5517	1.3200
13.4200	13.5471	1.3200
10.0300	11.3095	1.3200
11.5400	13.6091	1.3200
7.6700	8.7396	1.4400
11.8900	12.7908	1.4200
8.4400	10.5923	1.4200
13.5100	14.3512	1.2500
7.6900	12.3424	1.6200
10.1500	12.7323	1.6200
12.3700	13.5999	1.6200
13.0800	14.3640	1.6700
11.6600	13.2246	1.6700
2.4700	8.7630	1.1300
13.6200	14.5239	1.3900
10.0000	11.4715	1.3900
10.1000	12.5753	1.3900

9.7600 12.4491 1.3900
 9.5400 11.5493 1.2500
 15.5500 15.8738 1.2500
 14.1000 14.5510 2.1500
 15.7500 15.7753 1.4500
 6.9100 11.6897 1.0400
 13.7500 15.0176 1.9300
 12.6300 13.3230 1.9300
 14.1100 14.1514 1.4100
 3.4400 11.1238 1.5100
 11.3300 13.5292 1.6100
 12.3900 14.2156 1.6600
 10.7900 12.4882 1.6600
 11.9400 13.5414 1.9900
 10.1200 12.2870 1.4700
 11.7400 13.1225 1.4700
 9.6800 12.7211 1.4700
 5.6200 11.7483 1.2400
 12.5000 14.1350 1.6300
 12.4700 14.2256 1.6300
 12.7200 14.1650 1.8800
 12.1700 12.6017 1.2300
 13.5300 14.7408 1.2300
 13.7900 15.0647 0.8000
 6.7800 12.0319 1.4500
 5.9800 9.9865 1.4500
 16.2800 16.7015 1.7200
 12.5100 14.2720 0.9500
 11.7000 12.1700 1.4000
 7.8900 12.4863 1.4000
 8.6100 11.4508 1.3600
 11.2000 13.1332 1.8700
 9.9200 12.5246 1.4400
 8.3300 11.7792 0.9900
 11.7200 11.7869 1.4500
 8.8800 11.3428 1.6800
 4.5400 10.8615 1.6100
 12.5400 14.3134 1.2100
 12.6900 13.7461 1.7400
 10.0000 11.8325 1.7400
 10.2800 11.1404 1.0900
 11.8300 13.6734 1.2800
 13.0600 14.4910 1.3000
 14.7600 15.7546 2.5200
 8.5300 10.0594 2.5200
 13.2600 13.4329 1.3200
 12.5400 14.1050 1.6100
 12.7500 14.1286 1.3900
 14.4000 15.4971 1.3900

85445

Age file and data

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8

ns	ni	kinPar	age	ageErr
0	12	1.10	0.00	31.11
0	4	0.00	0.00	99.78

2	7	2.47	101.73	81.82
3	110	0.00	9.78	5.76
4	49	2.08	29.23	15.31
1	4	1.40	89.10	99.78
7	105	1.70	23.88	9.44
2	8	1.86	89.10	70.67

31460

Display specs

maxTime	maxTemp	maxFreq	maxLength
100.00	200.00	0.50	20.00
projectToC	showFit	calcEasyRo	usedCf
0	1	1	1

Max age for kinetic plots

188.88

Inverse model constraints

Num constraints

4

Time (Ma)	Upper (deg C)	Lower (deg C)
0.000	20.000	20.000
44.051	173.822	25.131
64.952	24.084	24.084
99.678	197.906	197.906

Inverse model specs

Monte Carlo

Enforce Max Heating	Enforce Max Cooling	Monotonic	Watch It Go
0	0	1	0
Max Heat Rate	Max Cool Rate		
10.0	10.0		
Num Paths	Num Paths Run	Divs per seg	
10000	10000	2	

Time-temperature paths

Time (Ma)	Temperature (deg C)	Best fit	Min Acc	Max Acc	Min Good	Max Good
0.000	20.000	20.000	20.000	20.000	20.000	
11.013	73.003	20.161	93.821	71.681	83.429	
22.026	84.073	45.205	97.538	81.269	90.664	
33.039	91.321	62.999	136.502	86.311	96.407	
44.051	94.314	84.426	172.843	93.968	150.767	
49.277	94.260	30.559	167.485	53.058	123.511	
54.502	94.090	24.131	164.321	38.844	115.053	
59.727	41.486	24.091	135.776	26.563	89.999	
64.952	24.084	24.084	24.084	24.084	24.084	
73.633	55.980	24.086	194.264	24.086	161.029	
82.315	114.109	24.179	196.897	24.179	194.491	
90.996	165.309	29.093	197.901	59.689	197.265	
99.678	197.906	197.906	197.906	197.906	197.906	

Easy Ro Results

calc	equalAcc	meanAcc	sdAcc	equalGood	meanGood	sdGood
1	0	0.61	0.02	0	0.62	0.00

41156893

Model specs and results for AFTSOLVE.EXE, version 0.8, 6/14/98

GU-08

TIME-TEMPERATURE PATH

1
Time (Ma) Temperature (deg C)
0.000 20.000
KINETIC PARAMETERS
model: Ketcham et al. in review
kinParUsed: Etch Pit Length
Initial track length model: Use kinetic parameter
L0 vs. kpar line defs:
0.2830 15.6300
0.2060 16.1700
0.5440 16.1800
0.4040 16.5700
0.0000 16.1800
0.0000 16.5700
0.1382 16.2880
0.1732 16.4950

Single L0 value:

16.30

Dividers:

2

0.84

2.85

Model	Calc	Kin Par
-------	------	---------

1	0	0.00
---	---	------

2	1	1.82
---	---	------

3	0	3.93
---	---	------

MODEL RESULTS

pctPerTimeStep

1.00

41

length	pdf2	cdf2
0.0	0.00000	0.00000
0.5	0.00000	0.00000
1.0	0.00000	0.00000
1.5	0.00000	0.00000
2.0	0.00000	0.00000
2.5	0.00142	0.00036
3.0	0.00203	0.00122
3.5	0.00283	0.00243
4.0	0.00388	0.00411
4.5	0.00523	0.00639
5.0	0.00691	0.00942
5.5	0.00898	0.01340
6.0	0.01145	0.01851
6.5	0.01436	0.02496
7.0	0.01770	0.03297
7.5	0.02149	0.04277
8.0	0.02577	0.05458
8.5	0.03074	0.06871
9.0	0.03683	0.08561

9.5	0.04495	0.10605
10.0	0.05679	0.13149
10.5	0.07461	0.16433
11.0	0.10025	0.20805
11.5	0.13307	0.26638
12.0	0.16817	0.34169
12.5	0.19730	0.43306
13.0	0.21267	0.53555
13.5	0.21048	0.64134
14.0	0.19123	0.74176
14.5	0.15811	0.82910
15.0	0.11676	0.89781
15.5	0.07522	0.94581
16.0	0.04136	0.97495
16.5	0.01908	0.99006
17.0	0.00730	0.99666
17.5	0.00230	0.99905
18.0	0.00059	0.99978
18.5	0.00012	0.99996
19.0	0.00002	0.99999
19.5	0.00000	1.00000
20.0	0.00000	1.00000

DATA

Stratigraphic information

NumDefs	age1	age2
2	52.00	74.50

Guárico Formation

Track length file and data

c:\docume~1\jperez\mydocu~1\jaime\lft\ftdd\ftdd\jgp\samples\Ugu8b1.a1g
100

length	proj len	kinPar
6.8800	11.8481	1.2700
11.1300	12.2342	1.3300
12.0700	14.0280	1.7700
11.2700	12.6309	2.0100
3.1200	10.3224	2.0900
12.8000	14.1086	1.9200
9.8700	12.4561	1.2400
11.0500	12.0109	1.6000
14.7000	14.8835	1.3500
4.8000	12.2419	1.6800
14.1600	15.2966	2.2600
14.5500	15.5941	1.4300
14.5700	14.8414	1.4300
14.1600	15.3522	1.6300
11.5800	13.2046	1.6400
14.1300	15.0904	1.6400
14.0200	15.1353	1.6400
14.1300	15.3144	1.6400
14.0100	14.4982	1.6700
12.3800	14.1571	1.6700
10.3900	12.4590	1.6600
9.2000	12.3583	1.1100
14.3000	15.3016	2.0200
14.6500	15.5185	2.0200
10.7400	11.8661	1.5000

12.4000	13.4051	1.1600
13.7900	14.8157	1.5800
13.5800	14.7522	1.5800
14.0700	14.0801	1.5800
9.7500	12.7404	1.1900
13.8800	14.2698	1.2800
12.4100	12.8257	1.6600
13.7700	14.9313	1.5900
5.1000	7.3104	1.6500
12.9800	14.3490	1.5300
12.6800	13.7768	1.5300
7.2600	7.8177	1.5000
14.5300	15.5313	1.5400
12.9500	14.3519	1.5400
14.3500	15.2316	2.0900
13.3200	14.4554	1.5100
14.7100	15.0925	1.8600
4.3500	11.6188	1.6000
12.9500	14.3062	1.5400
11.1500	11.8625	1.7300
13.3000	14.1657	1.7600
13.1800	14.7286	1.3300
14.4000	15.4015	2.0400
12.9300	13.8553	1.6600
13.6200	14.9305	1.6600
12.8900	13.5357	1.6600
15.3900	15.4714	1.6600
14.2800	15.0048	1.6600
14.7200	15.4221	1.6600
6.3000	11.0756	1.6600
9.6600	11.7469	1.6600
6.6000	12.1249	1.6600
8.4800	12.7762	1.6600
11.1800	11.2196	1.2100
10.8800	12.1051	1.5000
13.6800	14.9555	2.0200
13.5700	14.2349	2.0200
11.9000	13.2189	2.1000
11.8200	13.7090	1.7100
13.6100	14.2099	2.0300
11.5800	13.1539	1.5800
14.0000	14.9584	2.2000
15.2000	15.4807	1.8500
13.5100	13.5578	1.7300
12.3500	13.7133	1.7300
13.4300	14.8984	1.7100
12.6500	14.3234	1.5000
11.7400	13.7326	1.8700
15.7700	16.3911	1.3000
13.3700	14.8606	1.3700
12.3700	14.2213	1.6800
12.3600	13.7419	1.3600
11.7300	13.7155	1.4900
6.9600	12.2219	2.0300
12.6700	14.1585	1.7100
11.8000	13.7740	1.7100

12.0000 13.3680 1.7600
 8.4500 12.4340 1.6200
 10.5500 12.3784 1.9700
 15.3400 16.0614 1.9700
 10.1500 12.6773 1.9700
 6.7300 11.1706 1.8500
 13.5400 14.5874 1.9700
 6.3200 7.6911 1.5700
 15.0900 15.7304 1.6800
 13.4600 14.8913 1.4200
 12.1200 13.9252 1.5500
 9.9000 12.5855 1.5200
 12.1700 13.2296 1.8600
 15.0500 15.7996 1.5400
 14.9200 15.8567 2.5800
 12.7100 13.2388 1.8300
 11.4600 13.2866 0.8800
 14.7900 15.7853 2.2300
 10.9600 13.1511 2.2900
 123600

Age file and data

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41

ns	ni	kinPar	age	ageErr
0	10	1.93	0.00	37.53
0	6	0.00	0.00	64.30
1	5	1.54	71.24	78.18
0	20	2.54	0.00	18.36
0	1	0.00	0.00	493.49
1	41	1.49	8.73	8.85
1	8	1.39	44.62	47.41
9	125	1.66	25.74	9.03
2	13	1.55	54.87	41.82
4	15	1.49	94.82	53.70
23	157	1.72	52.26	12.13
1	16	2.50	22.35	23.08
0	1	1.65	0.00	493.49
7	71	1.82	35.22	14.13
0	1	1.49	0.00	493.49
0	1	1.43	0.00	493.49
1	2	1.78	176.66	216.65
0	15	1.87	0.00	24.66
1	20	1.47	17.89	18.36
2	9	1.48	79.11	62.05
9	97	2.28	33.15	11.74
4	14	1.53	101.54	57.93
0	4	1.06	0.00	99.59
0	3	1.55	0.00	136.82
4	28	1.77	50.97	27.44
2	6	2.01	118.31	96.89
1	10	1.77	35.72	37.53
2	21	1.44	34.02	25.27
5	56	1.56	31.90	15.03
0	2	0.00	0.00	216.65
1	15	1.94	23.84	24.66
2	12	1.46	59.43	45.54

2	12	1.44	59.43	45.54
1	5	2.26	71.24	78.18
10	142	1.98	25.18	8.39
2	14	1.55	50.97	38.66
2	21	2.18	34.02	25.27
1	64	2.48	5.59	5.65
1	73	1.99	4.90	4.95
0	2	2.76	0.00	216.65
6	41	1.19	52.21	23.06

192900

Display specs

maxTime	maxTemp	maxFreq	maxLength
100.00	200.00	0.50	20.00

projectToC showFit calcEasyRo usedCf

0	1	1	1
---	---	---	---

Max age for kinetic plots

188.88

Inverse model constraints

Num constraints

4

Time (Ma)	Upper (deg C)	Lower (deg C)
0.000	20.000	20.000
48.553	165.445	25.131
64.952	25.131	25.131
99.035	197.906	197.906

Inverse model specs

Monte Carlo

Enforce Max Heating	Enforce Max Cooling	Monotonic	Watch It Go
0	0	1	0

Max Heat Rate Max Cool Rate

10.0	10.0
------	------

Num Paths Num Paths Run Divs per seg

10000	10000	2
-------	-------	---

Time-temperature paths

Num Acceptable	Num Good
570	68

13

Temperature (deg C)					
Time (Ma)	Best fit	Min Acc	Max Acc	Min Good	Max Good
0.000	20.000	20.000	20.000	20.000	20.000
12.138	65.196	23.747	82.979	47.725	71.878
24.277	68.409	51.045	99.044	68.229	90.500
36.415	99.343	69.525	149.826	84.702	104.848
48.553	105.732	96.021	165.406	99.550	155.859
52.653	100.757	28.329	162.461	45.228	142.922
56.753	96.990	25.140	156.690	25.372	120.282
60.852	50.630	25.132	138.698	25.263	101.080
64.952	25.131	25.131	25.131	25.131	25.131
73.473	91.319	25.146	192.553	25.168	180.869
81.993	110.452	25.349	197.884	31.027	195.612
90.514	183.396	43.561	197.893	72.051	197.827
99.035	197.906	197.906	197.906	197.906	197.906

Easy Ro Results

calc	equalAcc	meanAcc	sdAcc	equalGood	meanGood	sdGood
1	0	0.64	0.00	0	0.64	0.00

41157178

Model specs and results for AFTSOLVE.EXE, version 0.8, 6/14/98

GU-09

TIME-TEMPERATURE PATH

1

Time (Ma) Temperature (deg C)

0.000 20.000

KINETIC PARAMETERS

model: Ketcham et al. in review

kinParUsed: Etch Pit Length

Initial track length model: Use kinetic parameter

L0 vs. kpar line defs:

0.2830 15.6300

0.2060 16.1700

0.5440 16.1800

0.4040 16.5700

0.0000 16.1800

0.0000 16.5700

0.1382 16.2880

0.1732 16.4950

Single L0 value:

16.30

Dividers:

2

0.77

3.00

Model	Calc	Kin Par
-------	------	---------

1	0	0.00
---	---	------

2	1	1.79
---	---	------

3	0	4.00
---	---	------

MODEL RESULTS

pctPerTimeStep

1.00

41

length	pdf2	cdf2
0.0	0.00000	0.00000
0.5	0.00000	0.00000
1.0	0.00000	0.00000
1.5	0.00000	0.00000
2.0	0.00000	0.00000
2.5	0.00203	0.00051
3.0	0.00286	0.00173
3.5	0.00396	0.00343
4.0	0.00540	0.00577
4.5	0.00725	0.00893
5.0	0.00960	0.01315
5.5	0.01254	0.01868
6.0	0.01615	0.02585
6.5	0.02053	0.03502
7.0	0.02574	0.04659
7.5	0.03181	0.06098

8.0	0.03876	0.07862
8.5	0.04655	0.09995
9.0	0.05518	0.12538
9.5	0.06475	0.15536
10.0	0.07550	0.19042
10.5	0.08779	0.23124
11.0	0.10190	0.27866
11.5	0.11783	0.33359
12.0	0.13520	0.39685
12.5	0.15313	0.46893
13.0	0.16967	0.54964
13.5	0.18062	0.63721
14.0	0.17953	0.72725
14.5	0.16114	0.81241
15.0	0.12666	0.88436
15.5	0.08509	0.93730
16.0	0.04802	0.97058
16.5	0.02250	0.98821
17.0	0.00869	0.99601
17.5	0.00275	0.99887
18.0	0.00071	0.99973
18.5	0.00015	0.99995
19.0	0.00003	0.99999
19.5	0.00000	1.00000
20.0	0.00000	1.00000

DATA

Stratigraphic information

NumDefs	age1	age2
2	52.00	74.50

Guárico Formation

Track length file and data

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18

length	proj len	kinPar
14.3200	15.4585	1.7800
14.2200	15.4107	1.7800
12.6900	14.0686	1.7800
12.4400	13.0069	1.7800
13.0200	14.4818	1.7800
12.6200	13.3059	1.7800
12.4500	13.5285	1.6300
12.9600	14.4846	1.6300
6.6300	12.2681	1.6300
14.5200	15.0711	0.9100
13.3700	14.7350	0.9100
13.0100	13.9110	1.3600
11.8000	12.6067	1.3600
10.7200	11.2632	1.8800
9.9600	11.9602	1.8500
13.5900	14.6038	1.6000
11.5000	13.2424	1.6000
10.2200	12.3520	1.1600

17442

Age file and data

c:\docume~1\jperez\mydocu~1\jaime\aft\ftdd\ftdd\jgp\samples\l\lgu9a1.a1g
23

ns	ni	kinPar	age	ageErr
4	104	1.99	13.74	7.05
0	27	1.53	0.00	13.50
2	25	1.84	28.54	21.05
5	60	2.26	29.72	13.96
1	74	1.73	4.83	4.87
7	141	1.76	17.72	6.95
0	15	1.41	0.00	24.62
1	10	2.14	35.65	37.46
1	12	1.80	29.72	31.00
1	16	2.14	22.31	23.04
11	69	1.76	56.74	18.77
0	8	2.66	0.00	47.32
1	17	1.78	21.00	21.65
1	73	2.51	4.90	4.94
2	15	2.23	47.49	35.88
0	3	1.48	0.00	136.56
2	22	1.58	32.42	24.03
2	24	1.46	29.72	21.96
1	6	1.99	59.31	64.17
0	3	0.00	0.00	136.56
7	21	1.92	118.08	52.08
5	111	1.55	16.08	7.42
3	15	1.82	71.11	45.20

68376

Display specs

maxTime	maxTemp	maxFreq	maxLength
100.00	200.00	0.50	20.00
projectToC	showFit	calcEasyRo	usedCf
0	1	1	1

Max age for kinetic plots

200.00

Inverse model constraints

Num constraints

4

Time (Ma)	Upper (deg C)	Lower (deg C)
-----------	---------------	---------------

0.000 20.000 20.000

45.016 175.916 25.131

64.952 25.131 25.131

99.357 196.859 196.859

Inverse model specs

Monte Carlo

Enforce Max Heating	Enforce Max Cooling	Monotonic	Watch It Go
---------------------	---------------------	-----------	-------------

0 0 1 0

Max Heat Rate Max Cool Rate

10.0 10.0

Num Paths	Num Paths Run	Divs per seg
-----------	---------------	--------------

10000 10000 2

Time-temperature paths

Num Acceptable Num Good

1263 156

13

Temperature (deg C)

Time (Ma)	Best fit	Min Acc	Max Acc	Min Good	Max Good
-----------	----------	---------	---------	----------	----------

0.000 20.000 20.000 20.000 20.000 20.000

11.254 67.594 20.033 94.159 46.563 82.466

22.508 93.380 56.371 133.971 72.345 100.732
 33.762 102.406 83.181 174.031 96.492 167.801
 45.016 102.552 95.247 175.513 97.794 174.714
 50.000 97.898 27.743 175.284 32.857 168.664
 54.984 97.214 25.374 169.243 25.734 155.299
 59.968 55.555 25.133 158.231 25.173 140.037
 64.952 25.131 25.131 25.131 25.131 25.131
 73.553 78.476 25.146 195.180 25.185 193.744
 82.154 122.139 25.842 196.773 25.842 196.773
 90.756 151.336 33.499 196.856 37.263 196.848
 99.357 196.859 196.859 196.859 196.859 196.859

Easy Ro Results

calc	equalAcc	meanAcc	sdAcc	equalGood	meanGood	sdGood
1	0	0.64	0.00	0	0.64	0.00

41157871

Model specs and results for AFTSOLVE.EXE, version 0.8, 6/14/98

GU-10

TIME-TEMPERATURE PATH

1
 Time (Ma) Temperature (deg C)
 0.000 20.000
KINETIC PARAMETERS
 model: Ketcham et al. in review
 kinParUsed: Etch Pit Length
 Initial track length model: Use kinetic parameter
 L0 vs. kpar line defs:
 0.2830 15.6300
 0.2060 16.1700
 0.5440 16.1800
 0.4040 16.5700
 0.0000 16.1800
 0.0000 16.5700
 0.1382 16.2880
 0.1732 16.4950
 Single L0 value:
 16.30
 Dividers:
 2
 0.94
 2.30

Model	Calc	Kin Par
1	0	0.00
2	1	1.62
3	0	2.92

MODEL RESULTS
 pctPerTimeStep
 1.00
 41

length	pdf2	cdf2
0.0	0.00000	0.00000

0.5	0.00000	0.00000
1.0	0.00000	0.00000
1.5	0.00000	0.00000
2.0	0.00000	0.00000
2.5	0.00230	0.00058
3.0	0.00313	0.00193
3.5	0.00419	0.00376
4.0	0.00555	0.00620
4.5	0.00727	0.00940
5.0	0.00946	0.01358
5.5	0.01219	0.01900
6.0	0.01561	0.02595
6.5	0.01985	0.03481
7.0	0.02508	0.04604
7.5	0.03149	0.06019
8.0	0.03922	0.07786
8.5	0.04841	0.09977
9.0	0.05913	0.12665
9.5	0.07136	0.15928
10.0	0.08506	0.19838
10.5	0.10005	0.24466
11.0	0.11584	0.29863
11.5	0.13149	0.36046
12.0	0.14579	0.42978
12.5	0.15772	0.50566
13.0	0.16639	0.58669
13.5	0.16986	0.67075
14.0	0.16412	0.75425
14.5	0.14513	0.83156
15.0	0.11347	0.89621
15.5	0.07624	0.94364
16.0	0.04314	0.97349
16.5	0.02029	0.98934
17.0	0.00786	0.99638
17.5	0.00249	0.99897
18.0	0.00065	0.99976
18.5	0.00014	0.99995
19.0	0.00002	0.99999
19.5	0.00000	1.00000
20.0	0.00000	1.00000

DATA

Stratigraphic information

NumDefs	age1	age2
2	52.00	74.50

Guárico Formation

Track length file and data

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107

length	proj len	kinPar
13.1900	14.4775	1.4600
13.6400	14.4354	1.6900
8.3200	11.1644	1.9800
7.8800	11.4061	1.7800
10.7100	11.1897	1.8500
10.2100	12.9393	1.7300
8.6000	10.3025	1.7900

13.2800	14.7136	1.5800
15.1200	15.9423	2.7800
6.2600	7.6835	1.4900
13.2000	14.5645	1.5100
14.3000	15.4535	1.9000
14.0900	14.6887	1.9000
12.6500	12.7736	1.9000
11.8000	13.4001	1.4600
11.2800	13.3687	1.4500
16.6600	16.9911	1.4500
13.7900	14.8171	1.4500
9.2700	11.9245	1.1500
14.4500	15.3308	1.7300
10.4100	12.8243	1.7300
13.2000	14.4639	1.7300
13.9600	14.6002	1.7300
12.4800	14.1899	1.5300
13.2700	14.7657	1.3600
12.8900	14.1022	1.8200
12.9900	14.0130	1.8200
15.6300	16.1692	1.8200
13.1300	14.3804	1.5400
7.6100	11.6615	1.4600
12.7300	14.2035	1.1900
2.7800	10.3830	1.1600
12.1600	13.8532	1.6700
13.5400	14.4204	1.6700
9.7900	11.5150	1.6700
13.5300	14.8499	1.5100
13.7500	14.8157	1.7000
5.1200	11.1803	1.7000
9.3100	11.8805	1.5800
4.3500	11.7579	1.8500
5.6500	11.6980	1.3000
10.3900	12.6880	1.8200
12.1400	13.8696	1.4800
13.4700	14.6822	1.6200
12.7100	13.1746	1.0800
8.7800	10.9317	1.6900
12.7100	14.3919	1.6100
9.8700	12.3441	1.4900
12.0900	13.8824	1.7500
12.4600	14.2249	1.8300
14.6100	15.6498	1.3900
13.6300	14.9990	1.3900
14.3200	14.8428	1.3700
13.2500	14.7679	1.8100
12.7900	13.3138	1.4400
16.3300	16.6665	1.8700
12.5000	14.1164	1.5300
5.3400	12.5249	1.6100
6.6300	11.4398	1.6600
14.6000	15.5706	1.4500
14.6200	15.2645	1.5200
4.5300	11.1617	2.6900
11.5000	13.0883	1.4900

9.2300 11.9087 1.6900
 8.7200 11.9720 1.6200
 9.5700 11.7512 1.3900
 12.2400 12.9313 1.8400
 9.5200 12.4044 2.0900
 12.1000 12.3491 1.5000
 13.2000 14.6573 1.6900
 11.5500 13.2474 1.6900
 13.7900 15.0961 1.6100
 13.7100 14.8899 1.3500
 14.2400 15.3665 1.6900
 15.7400 15.9159 1.6900
 12.1100 12.1950 1.6700
 6.0700 10.8773 1.9200
 14.0900 15.2923 1.8100
 13.3300 14.5767 1.4600
 14.4900 14.8335 1.7900
 12.2600 13.0762 1.8600
 8.0200 12.2970 1.0300
 13.7200 14.8663 1.1500
 11.7500 13.2759 1.1500
 13.8100 13.9916 1.8100
 12.3100 14.1528 1.8100
 13.5100 14.1364 1.9300
 11.5400 12.3498 1.5900
 10.3000 11.7869 1.7400
 10.0900 12.5332 2.1100
 12.2600 14.1029 1.3400
 6.7600 9.6050 1.2900
 15.0100 15.4036 1.6400
 6.5800 10.3355 1.6400
 9.2600 12.3885 1.8500
 13.4200 14.1600 1.7300
 12.3000 13.9773 1.6200
 15.3300 15.6555 2.2100
 14.1700 15.1246 1.7000
 11.6800 13.0762 1.7000
 14.7300 15.2138 1.7000
 14.0500 15.2167 1.5700
 11.2400 13.4814 1.5700
 9.9700 12.5960 1.3000
 12.4200 13.4029 1.1800
 13.0700 13.8353 2.4900
 13.7800 15.1246 1.4300
 130002

Age file and data

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11

ns	ni	kinPar	age	ageErr
1	58	1.37	6.15	6.21
2	15	1.62	47.40	35.81
1	19	1.62	18.75	19.28
4	164	1.49	8.70	4.44
4	60	1.67	23.75	12.35
5	13	1.46	135.80	71.98
3	109	1.99	9.81	5.78

```

2      32      3.36  22.26  16.29
0      43      0.00   0.00   8.41
5     182      1.62   9.80   4.48
10    117      1.82  30.43  10.21
28876
Display specs
maxTime      maxTemp      maxFreqmaxLength
100.00 200.00   0.50   20.00
projectToC    showFit calcEasyRo    usedCf
0      1      1      1
Max age for kinetic plots
200.00
Inverse model constraints
Num constraints
4
Time (Ma)      Upper (deg C)  Lower (deg C)
0.000 20.000 20.000
27.974 172.775 25.131
64.952 25.131 25.131
99.035 196.859 196.859
Inverse model specs
Monte Carlo
Enforce Max Heating  Enforce Max Cooling  Monotonic  Watch It Go
0      0      1      0
Max Heat Rate  Max Cool Rate
10.0  10.0
Num Paths      Num Paths Run  Divs per seg
10000 10000 2
Time-temperature paths
Num Acceptable Num Good
319  4
13
      Temperature (deg C)
Time (Ma)      Best fit  Min AccMax Acc      Min Good      Max Good
0.000 20.000 20.000 20.000 20.000 20.000
6.994 70.386 33.350 94.354 66.667 77.769
13.987 88.820 66.023 105.433 87.097 90.985
20.981 99.720 81.690 161.113 92.115 103.624
27.974 108.508 93.995 172.287 101.449 134.940
37.219 103.404 25.388 166.404 82.182 103.404
46.463 100.638 25.303 165.249 30.202 100.638
55.708 42.323 25.196 143.934 26.880 42.323
64.952 25.131 25.131 25.131 25.131 25.131
73.473 47.306 25.308 186.563 47.306 93.420
81.993 81.890 26.342 196.140 65.166 112.277
90.514 135.280 35.881 196.729 88.102 158.347
99.035 196.859 196.859 196.859 196.859 196.859
Easy Ro Results
calc      equalAcc      meanAcc      sdAcc  equalGood      meanGood      sdGood
1      0      0.63  0.00  0      0.63  0.00
41156927

```

GU-11**TIME-TEMPERATURE PATH**

1
 Time (Ma) Temperature (deg C)
 0.000 20.000
 KINETIC PARAMETERS
 model: Ketcham et al. in review
 kinParUsed: Etch Pit Length
 Initial track length model: Use kinetic parameter
 L0 vs. kpar line defs:
 0.2830 15.6300
 0.2060 16.1700
 0.5440 16.1800
 0.4040 16.5700
 0.0000 16.1800
 0.0000 16.5700
 0.1382 16.2880
 0.1732 16.4950
 Single L0 value:
 16.30
 Dividers:

2
 0.86
 2.40

Model	Calc	Kin Par
1	0	0.43
2	1	1.60
3	0	3.70

MODEL RESULTS

pctPerTimeStep

1.00
 41

length	pdf2	cdf2
0.0	0.00000	0.00000
0.5	0.00000	0.00000
1.0	0.00000	0.00000
1.5	0.00000	0.00000
2.0	0.00000	0.00000
2.5	0.00117	0.00029
3.0	0.00172	0.00101
3.5	0.00250	0.00207
4.0	0.00358	0.00359
4.5	0.00505	0.00575
5.0	0.00704	0.00877
5.5	0.00972	0.01296
6.0	0.01328	0.01871
6.5	0.01799	0.02653
7.0	0.02413	0.03706
7.5	0.03195	0.05108
8.0	0.04161	0.06947
8.5	0.05310	0.09314
9.0	0.06611	0.12295
9.5	0.08007	0.15949
10.0	0.09433	0.20309

10.5	0.10832	0.25375
11.0	0.12171	0.31126
11.5	0.13438	0.37528
12.0	0.14623	0.44543
12.5	0.15690	0.52122
13.0	0.16520	0.60174
13.5	0.16816	0.68508
14.0	0.16107	0.76739
14.5	0.14028	0.84272
15.0	0.10750	0.90467
15.5	0.07059	0.94919
16.0	0.03897	0.97658
16.5	0.01787	0.99079
17.0	0.00674	0.99694
17.5	0.00208	0.99915
18.0	0.00053	0.99980
18.5	0.00011	0.99996
19.0	0.00002	0.99999
19.5	0.00000	1.00000
20.0	0.00000	1.00000

DATA

Stratigraphic information

NumDefs	age1	age2
2	52.00	74.50

Guárico Formation

Track length file and data

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58

length proj len kinPar

11.1400	13.3494	1.7900
6.1100	12.1737	1.9800
12.7800	13.0526	1.7200
12.0700	13.9324	1.7200
11.8800	12.9078	1.7200
10.8600	13.1653	1.3700
13.7400	14.8478	1.5800
7.2900	7.8269	1.2100
5.7600	11.2911	0.9400
13.7900	14.0601	1.3800
4.3400	11.3297	1.2300
9.4500	11.8404	1.8000
8.7800	9.3153	1.8100
15.2600	15.3765	1.5400
12.8400	14.5153	1.7600
12.8600	12.9677	1.7500
11.7400	13.1568	1.7500
12.0100	13.7740	1.5200
14.8300	15.7282	1.3300
11.1800	13.2403	1.4500
8.3100	10.7789	1.1500
14.4600	15.5691	1.6400
13.9200	14.5638	1.6400
13.1800	14.7144	1.4000
12.2700	13.2403	1.7500
11.7400	13.6498	1.6400
10.6400	13.0890	1.7500

12.8800 13.1297 2.2700
 14.1100 15.3430 1.1200
 12.9900 14.3490 1.5700
 15.5700 15.9580 1.6000
 8.6600 12.8230 1.4100
 14.4100 14.9619 2.1900
 13.8000 14.8257 2.1900
 9.5500 12.8946 1.5600
 10.4900 12.8150 1.4600
 7.3900 12.2688 1.1500
 13.0200 13.6990 1.5700
 13.6600 14.9619 1.5700
 13.5900 14.1036 2.2600
 13.6500 14.4168 1.5500
 11.5700 11.6006 1.3100
 8.4500 11.2526 1.2600
 12.8500 14.4703 1.3600
 13.6700 14.9812 1.3600
 12.1200 13.8218 1.5200
 15.3000 15.3701 1.6000
 14.2400 15.0262 2.0100
 13.4500 14.2463 1.5500
 4.3600 12.1937 1.6900
 12.1100 13.0198 1.5800
 6.3300 12.5400 1.7800
 11.4800 13.4072 1.5300
 13.4400 14.3169 1.7600
 13.2100 14.3583 1.5500
 7.2900 11.7882 1.6200
 12.9300 13.1661 1.0000
 14.0700 15.0511 2.0200

62743

Age file and data

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ns	ni	kinPar	age	ageErr
1	7	1.31	50.68	54.27
4	146	1.58	9.75	4.98
0	4	1.87	0.00	99.02
2	1	1.72	675.62	828.58
2	10	1.67	70.84	55.06
2	43	1.42	16.54	12.01
0	5	1.42	0.00	77.73
1	5	1.74	70.84	77.73
1	3	1.53	117.64	136.04
0	6	1.65	0.00	63.93
2	30	1.51	23.70	17.37
1	11	1.45	32.30	33.79
3	2	1.53	513.24	469.65
7	90	1.51	27.64	10.99
0	1	1.36	0.00	490.74
1	7	1.39	50.68	54.27
0	25	1.70	0.00	14.54
1	8	1.99	44.37	47.14
2	18	1.32	39.45	29.51

266136

Display specs
 maxTime maxTemp maxFreqmaxLength
 100.00 200.00 0.50 20.00
 projectToC showFit calcEasyRo usedCf
 0 1 1 1
 Max age for kinetic plots
 200.00
 Inverse model constraints
 Num constraints
 4
 Time (Ma) Upper (deg C) Lower (deg C)
 0.000 20.000 20.000
 39.871 174.869 25.131
 64.952 25.131 25.131
 98.714 196.859 196.859
 Inverse model specs
 Monte Carlo
 Enforce Max Heating Enforce Max Cooling Monotonic Watch It Go
 0 0 1 1
 Max Heat Rate Max Cool Rate
 10.0 10.0
 Num Paths Num Paths Run Divs per seg
 10000 10000 2
 Time-temperature paths
 Num Acceptable Num Good
 689 48
 13
 Temperature (deg C)
 Time (Ma) Best fit Min AccMax Acc Min Good Max Good
 0.000 20.000 20.000 20.000 20.000 20.000
 9.968 65.483 21.173 91.447 57.712 79.745
 19.936 86.257 38.153 108.713 72.486 92.818
 29.903 91.248 71.134 166.364 88.864 104.834
 39.871 105.516 93.118 174.650 95.881 172.922
 46.141 70.349 27.809 173.371 36.061 169.928
 52.412 55.476 25.170 169.174 25.170 165.008
 58.682 50.841 25.137 154.391 25.137 154.391
 64.952 25.131 25.131 25.131 25.131 25.131
 73.392 98.679 25.133 185.596 25.959 185.596
 81.833 109.694 25.133 196.348 26.119 193.430
 90.273 171.649 31.023 196.855 66.350 196.624
 98.714 196.859 196.859 196.859 196.859 196.859
 Easy Ro Results
 calc equalAcc meanAcc sdAcc equalGood meanGood sdGood
 1 0 0.63 0.00 0 0.62 0.00
 41157297

Model specs and results for AFTSOLVE.EXE, version 1.2

GU-13

TIME-TEMPERATURE PATH

1

Time (Ma) Temperature (deg C)
 0.000 20.000
 KINETIC PARAMETERS
 model: Ketcham et al. 1999
 kinParUsed: Etch Pit Length
 Initial track length model: Use kinetic parameter
 L0 vs. kpar line defs:
 0.2830 15.6300
 0.2050 16.1000
 0.5440 16.1800
 0.4070 16.4900
 0.0000 16.1800
 0.0000 16.5700
 0.1382 16.2880
 0.1732 16.4950
 Single L0 value:
 16.30
 Standard length reduction:
 0.893000
 Age calculation to use for data: Pooled
 Dividers:
 2
 0.88
 3.20

Model	Calc	Kin Par
1	0	0.44
2	1	2.09
3	0	4.10

 MODEL RESULTS
 pctPerTimeStep
 1.00
 41

length	pdf2	cdf2
0.0	0.00000	0.00000
0.5	0.00000	0.00000
1.0	0.00000	0.00000
1.5	0.00000	0.00000
2.0	0.00000	0.00000
2.5	0.00000	0.00000
3.0	0.00000	0.00000
3.5	0.00000	0.00000
4.0	0.00000	0.00000
4.5	0.00000	0.00000
5.0	0.00000	0.00000
5.5	0.00000	0.00000
6.0	0.00000	0.00000
6.5	0.00000	0.00000
7.0	0.00000	0.00000
7.5	0.00002	0.00001
8.0	0.00006	0.00003
8.5	0.00018	0.00009
9.0	0.00048	0.00025
9.5	0.00112	0.00065
10.0	0.00414	0.00197
10.5	0.01863	0.00766
11.0	0.07732	0.03165

11.5	0.22629	0.10755
12.0	0.42936	0.27146
12.5	0.51654	0.50794
13.0	0.39267	0.73524
13.5	0.19121	0.88121
14.0	0.06495	0.94525
14.5	0.02343	0.96735
15.0	0.01685	0.97742
15.5	0.01566	0.98555
16.0	0.01174	0.99240
16.5	0.00630	0.99691
17.0	0.00233	0.99907
17.5	0.00059	0.99980
18.0	0.00010	0.99997
18.5	0.00001	1.00000
19.0	0.00000	1.00000
19.5	0.00000	1.00000
20.0	0.00000	1.00000

DATA

Stratigraphic information

NumDefs	age1	age2
2	21.80	23.70

Naricual Formation

Track length file and data

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29

length	proj len	kinPar
12.3300	13.5200	1.7800
12.2700	13.2795	1.7800
5.4700	10.1324	1.7800
10.2900	11.5528	1.7800
8.4500	9.8997	1.7800
12.8800	14.2863	1.5200
9.4200	12.3273	1.1300
7.9900	12.2020	1.1300
9.1900	10.0973	1.1300
9.1100	12.4402	1.4600
8.3700	9.8197	1.4600
3.4800	11.1314	1.4600
9.5400	12.3906	1.4600
10.5500	11.3702	2.1800
13.0400	13.0576	1.7700
13.9300	14.4211	1.7700
11.1900	12.8878	1.4600
9.4000	12.2639	1.8600
12.1400	12.9006	1.8600
9.8200	11.8653	1.8600
9.5600	12.3305	1.8600
10.3400	12.7929	1.8600
12.1400	14.0344	1.8600
12.4200	13.7048	2.1000
9.1900	10.9613	2.1000
9.4500	12.2093	2.1000
10.2500	11.6399	1.9200
11.2400	12.7173	1.9200
7.8200	12.6949	1.9200

23687

Age file and data

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6

ns	ni	kinPar	age	ageErr
19	15	1.77	400.97	140.82
1	1	2.19	318.61	451.03
27	33	2.00	261.84	69.95
1	13	3.06	25.08	26.07
25	10	1.64	768.81	291.78
2	25	1.80	26.08	19.23

228936

DISPLAY AND PARAMETER SPECIFICATIONS

maxTime	maxTemp	maxFreq	maxLength
400.00	200.00	0.50	20.00
projectToC	showFit	calcEasyRo	usedCf
1	1	1	1

Max age for kinetic plots

1060.58

Inverse model constraints

Num constraints

4

Time (Ma)	Upper (deg C)	Lower (deg C)
0.000	20.000	20.000
14.791	182.199	25.131
20.579	25.131	25.131
396.141	195.812	195.812

Inverse model specs

Monte Carlo

Enforce Max Heating	Enforce Max Cooling	Monotonic	Watch It Go
0	0	1	0

Max Heat Rate Max Cool Rate

10.0 10.0

Num Paths Num Paths Run Divs per seg

10000 10000 2

Time-temperature paths

Num Acceptable Num Good

202 22

13

Temperature (deg C)

Time (Ma)	Best fit	Min Acc	Max Acc	Min Good	Max Good
0.000	20.000	20.000	20.000	20.000	20.000
3.698	33.917	20.082	91.118	20.536	65.228
7.395	80.280	20.111	104.509	20.545	99.953
11.093	100.229	31.707	107.996	41.283	101.125
14.791	107.273	92.141	126.091	99.234	118.866
16.238	86.925	31.130	112.515	57.362	108.879
17.685	77.740	25.264	106.110	28.258	106.110
19.132	69.146	25.211	98.146	25.861	94.623
20.579	25.131	25.131	25.131	25.131	25.131
114.469	27.765	25.132	80.637	25.545	58.180
208.360	40.651	25.180	97.616	26.663	68.076
302.251	41.641	28.027	195.383	28.027	93.838
396.141	195.812	195.812	195.812	195.812	195.812

Easy Ro Results

calc	equalAcc	meanAcc	sdAcc	equalGood	meanGood	sdGood
------	----------	---------	-------	-----------	----------	--------

1 0 0.75 0.01 0 0.75 0.01
 23199946

Model specs and results for AFTSOLVE.EXE, version 1.2

GU-14

TIME-TEMPERATURE PATH

1
 Time (Ma) Temperature (deg C)
 0.000 20.000
 KINETIC PARAMETERS
 model: Ketcham et al. 1999
 kinParUsed: Etch Pit Length
 Initial track length model: Use kinetic parameter
 L0 vs. kpar line defs:
 0.2830 15.6300
 0.2050 16.1000
 0.5440 16.1800
 0.4070 16.4900
 0.0000 16.1800
 0.0000 16.5700
 0.1382 16.2880
 0.1732 16.4950
 Single L0 value:
 16.30
 Standard length reduction:
 0.893000
 Age calculation to use for data: Pooled
 Dividers:

2
 1.01
 2.68

Model	Calc	Kin Par
1	0	0.50
2	1	1.72
3	0	3.84

MODEL RESULTS

pctPerTimeStep
 1.00
 41

length	pdf2	cdf2
0.0	0.00000	0.00000
0.5	0.00000	0.00000
1.0	0.00000	0.00000
1.5	0.00000	0.00000
2.0	0.00000	0.00000
2.5	0.00000	0.00000
3.0	0.00000	0.00000
3.5	0.00000	0.00000
4.0	0.00000	0.00000
4.5	0.00000	0.00000
5.0	0.00000	0.00000

5.5	0.00000	0.00000
6.0	0.00000	0.00000
6.5	0.00000	0.00000
7.0	0.00000	0.00000
7.5	0.00001	0.00000
8.0	0.00003	0.00001
8.5	0.00011	0.00004
9.0	0.00033	0.00015
9.5	0.00145	0.00060
10.0	0.00769	0.00288
10.5	0.03859	0.01445
11.0	0.13993	0.05908
11.5	0.33317	0.17736
12.0	0.50563	0.38706
12.5	0.48444	0.63458
13.0	0.29309	0.82896
13.5	0.11449	0.93085
14.0	0.03350	0.96785
14.5	0.01379	0.97967
15.0	0.01161	0.98602
15.5	0.01030	0.99150
16.0	0.00701	0.99582
16.5	0.00340	0.99843
17.0	0.00114	0.99956
17.5	0.00026	0.99991
18.0	0.00004	0.99999
18.5	0.00000	1.00000
19.0	0.00000	1.00000
19.5	0.00000	1.00000
20.0	0.00000	1.00000

DATA

Stratigraphic information

NumDefs	age1	age2
---------	------	------

2	21.80	23.70
---	-------	-------

Naricual Formation

Track length file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\AIME\AFT\FTDD\FTDDUGPSAMPLES\LLGU14B1.A1G
10

length	proj len	kinPar
--------	----------	--------

8.1100	11.7386	1.7700
7.8500	12.1985	1.7700
10.0100	11.7162	1.7700
12.1500	13.9916	1.7700
10.3600	12.4511	1.7700
9.4400	11.2603	1.7700
11.6400	12.8600	1.7700
6.7500	11.5954	1.7700
6.5800	11.1610	1.7700
9.0400	11.5548	1.7700

6538

Age file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\AIME\AFT\FTDD\FTDDUGPSAMPLES\AAGU14A1.A1G
6

ns	ni	kinPar	age	ageErr
13	26	1.73	161.80	55.91
3	9	2.24	108.32	72.54

74	53	2.12	442.02	84.35
0	4	1.62	0.00	91.16
0	20	1.19	0.00	16.80
55	16	1.88	1038.17	302.17

240953

DISPLAY AND PARAMETER SPECIFICATIONS

maxTime	maxTemp	maxFreq	maxLength
600.00	200.00	0.50	20.00
projectToC	showFit	calcEasyRo	usedCf
1	1	1	1

Max age for kinetic plots

1060.58

Inverse model constraints

Num constraints

5

Time (Ma)	Upper (deg C)	Lower (deg C)
0.000	20.000	20.000
14.148	173.822	25.131
23.151	25.131	25.131
339.550	186.387	25.131
596.141	198.953	198.953

Inverse model specs

Monte Carlo

Enforce Max Heating	Enforce Max Cooling	Monotonic	Watch It Go
0	0	1	0

Max Heat Rate Max Cool Rate

10.0 10.0

Num Paths	Num Paths Run	Divs per seg
10000	10000	2

Time-temperature paths

Num Acceptable	Num Good
179	1
17	

Temperature (deg C)					
Time (Ma)	Best fit	Min Acc	Max Acc	Min Good	Max Good
0.000	20.000	20.000	20.000	20.000	20.000
3.537	37.345	20.057	79.861	37.345	37.345
7.074	71.459	20.311	89.032	71.459	71.459
10.611	88.953	22.051	94.427	88.953	88.953
14.148	90.238	59.018	110.752	90.238	90.238
16.399	89.539	37.160	96.726	89.539	89.539
18.650	88.926	25.171	93.108	88.926	88.926
20.900	48.878	25.156	79.933	48.878	48.878
23.151	25.131	25.131	25.131	25.131	25.131
102.251	30.080	25.145	67.171	30.080	30.080
181.350	37.174	25.152	68.881	37.174	37.174
260.450	37.257	25.350	74.866	37.257	37.257
339.550	43.263	25.350	83.098	43.263	43.263
403.698	51.022	35.152	183.868	51.022	51.022
467.846	51.198	35.746	198.561	51.198	51.198
531.994	85.877	56.852	198.841	85.877	85.877
596.141	198.953	198.953	198.953	198.953	198.953

Easy Ro Results

calc	equalAcc	meanAcc	sdAcc	equalGood	meanGood	sdGood
1	0	0.62	0.01	0	0.63	0.00

23199923

Model specs and results for AFTSOLVE.EXE, version 1.2

GU-15

TIME-TEMPERATURE PATH

1
 Time (Ma) Temperature (deg C)
 0.000 20.000
KINETIC PARAMETERS
 model: Ketcham et al. 1999
 kinParUsed: Etch Pit Length
 Initial track length model: Use kinetic parameter
 L0 vs. kpar line defs:
 0.2830 15.6300
 0.2050 16.1000
 0.5440 16.1800
 0.4070 16.4900
 0.0000 16.1800
 0.0000 16.5700
 0.1382 16.2880
 0.1732 16.4950
 Single L0 value:
 16.30
 Standard length reduction:
 0.893000
 Age calculation to use for data: Pooled
 Dividers:

2
 1.03
 2.04

Model	Calc	Kin Par
1	0	0.94
2	1	1.64
3	0	2.53

MODEL RESULTS

pctPerTimeStep
 1.00
 41

length	pdf2	cdf2
0.0	0.00000	0.00000
0.5	0.00000	0.00000
1.0	0.00000	0.00000
1.5	0.00000	0.00000
2.0	0.00000	0.00000
2.5	0.00000	0.00000
3.0	0.00000	0.00000
3.5	0.00000	0.00000
4.0	0.00000	0.00000
4.5	0.00000	0.00000
5.0	0.00000	0.00000
5.5	0.00000	0.00000
6.0	0.00000	0.00000

6.5	0.00000	0.00000
7.0	0.00000	0.00000
7.5	0.00000	0.00000
8.0	0.00002	0.00001
8.5	0.00011	0.00004
9.0	0.00037	0.00016
9.5	0.00175	0.00069
10.0	0.00925	0.00344
10.5	0.04478	0.01695
11.0	0.15421	0.06669
11.5	0.34612	0.19178
12.0	0.49343	0.40166
12.5	0.44353	0.63590
13.0	0.25214	0.80982
13.5	0.09433	0.89644
14.0	0.03177	0.92796
14.5	0.02443	0.94201
15.0	0.03129	0.95594
15.5	0.03250	0.97189
16.0	0.02359	0.98592
16.5	0.01160	0.99471
17.0	0.00381	0.99857
17.5	0.00083	0.99973
18.0	0.00012	0.99996
18.5	0.00001	1.00000
19.0	0.00000	1.00000
19.5	0.00000	1.00000
20.0	0.00000	1.00000

DATA

Stratigraphic information

NumDefs	age1	age2
---------	------	------

2	21.80	23.70
---	-------	-------

Naricual Formation

Track length file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\VAIME\AFT\FTDD\FTDDUGP\SAMPLES\LLGU15B1.AIG
97

length	proj len	kinPar
--------	----------	--------

14.8400	15.5713	1.7600
11.6700	13.6213	1.7600
9.9900	12.6131	1.7600
9.9800	12.5610	1.6400
13.2300	14.6095	1.8000
11.2800	13.3166	1.9600
10.6000	11.9952	1.9600
9.4300	12.1186	1.9600
9.6100	12.4250	1.8400
10.4800	12.3327	1.8400
9.0600	12.0739	1.8400
7.8300	11.7786	1.6300
7.5600	10.7589	1.6100
12.4100	14.2178	1.6100
11.2100	12.0459	1.6100
10.3300	12.8428	1.6600
12.3500	13.9259	1.6600
13.8900	15.1139	1.6600
9.9900	12.6566	1.6600

9.5600	12.3934	1.6600
9.4400	11.2503	1.6600
9.9600	12.5760	1.6600
11.5700	13.7197	1.6600
9.6900	11.0091	1.6600
7.2000	11.5858	1.6600
9.8800	12.3355	1.7100
10.4100	12.6894	1.7100
12.5600	14.2656	1.7100
12.0200	12.7358	1.7100
9.7400	11.7284	1.7100
7.5700	12.3431	1.7100
12.3600	14.0793	1.7100
11.5100	13.4144	1.7100
9.2900	12.3073	1.7700
9.4100	12.6281	1.3900
9.4100	10.9563	1.6200
9.3200	12.0870	1.6200
10.6100	12.9220	1.6200
9.5200	12.0323	1.6200
11.1700	13.1282	1.6200
10.9800	11.2646	1.6200
9.2700	10.3741	1.6200
8.3600	9.6728	1.6200
10.5600	12.7979	1.3800
8.5500	12.7658	1.3800
6.7000	12.1758	1.3800
15.1500	15.8788	1.5200
9.0300	11.1797	1.5200
9.8200	11.2539	1.5200
11.2200	12.1343	1.5200
10.5500	12.9228	1.6400
8.2100	11.7675	1.6400
11.8900	13.1425	1.6400
7.2400	11.7703	1.6400
10.0300	12.7201	1.6400
9.1300	12.9497	1.6400
10.2200	12.7686	1.6400
7.6200	11.5789	1.6400
8.1600	10.7541	1.6400
9.1900	12.3052	1.6400
8.9700	12.0188	1.3200
9.4000	12.5373	1.6700
12.0100	13.9944	1.6700
9.3600	10.3349	1.6700
9.4700	11.6898	1.2500
9.4400	12.4078	1.2500
12.8900	13.1711	1.7200
12.5900	14.0729	1.7200
11.1100	12.8072	1.7200
7.4000	10.0140	1.7200
9.9200	11.1297	1.6600
2.6900	11.0137	1.6600
11.4900	12.5689	1.7100
12.3000	13.0819	1.7100
10.3100	12.4982	1.7100

9.2000 12.4354 1.7100
 9.4400 11.9617 1.7100
 5.3200 11.8137 1.7100
 9.0600 11.3566 1.7100
 9.3300 12.7245 1.7100
 9.7900 11.4294 1.7100
 7.9700 11.9403 1.7100
 10.8300 11.9745 1.7100
 10.3000 11.7883 1.7100
 11.5300 13.5763 1.7100
 7.8000 11.3889 1.7100
 8.3100 11.8653 1.7100
 10.1200 12.4861 1.7100
 8.0900 12.0051 1.7100
 8.7400 12.2474 1.7100
 8.0900 12.0051 1.7100
 9.3700 11.8675 1.7100
 10.3200 11.3630 1.7100
 10.3700 11.6777 1.3900
 10.9500 13.2024 1.6200
 8.8700 12.1827 1.6200
 10.4500 11.0520 1.6200

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Age file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\JAIME\AFT\FTDD\FTDD\GFP\SAMPLES\A\AGU15A1.A1G

31

ns	ni	kinPar	age	ageErr
2	8	2.02	81.67	64.78
3	5	2.97	194.31	142.44
16	24	2.20	215.54	70.90
7	43	1.93	53.30	21.99
0	8	1.28	0.00	43.53
8	6	2.08	424.10	230.62
11	23	2.34	155.35	57.80
10	33	1.91	98.87	36.24
10	15	1.93	215.54	89.05
30	37	1.88	261.21	66.28
5	12	2.12	135.55	72.67
79	61	1.98	412.32	75.00
13	5	1.79	802.69	425.47
1	5	0.94	65.42	71.79
59	61	2.08	310.40	60.01
10	43	1.94	76.01	27.12
10	8	1.49	398.40	190.66
29	127	1.89	74.64	16.08
70	96	1.81	235.38	39.90
33	55	2.34	194.31	44.53
13	34	1.93	124.50	41.36
12	25	1.92	155.91	55.64
10	25	1.53	130.19	49.41
7	14	1.78	162.33	75.85
89	117	1.96	245.36	37.87
9	31	2.10	94.75	36.38
41	23	1.80	560.94	150.42
64	164	1.93	127.04	20.39
38	53	1.88	231.52	51.36

```

79      182      2.20  141.15  21.03
11      14       1.52  253.28 103.31
1104919
DISPLAY AND PARAMETER SPECIFICATIONS
maxTime      maxTemp      maxFreqmaxLength
400.00 200.00  0.50   20.00
projectToC    showFit calcEasyRo    usedCf
1         1         1         1
Max age for kinetic plots
1060.58
Inverse model constraints
Num constraints
5
Time (Ma)      Upper (deg C)  Lower (deg C)
0.000 20.000 20.000
14.148 185.340 0.000
23.151 25.131 25.131
216.077 185.340 25.131
397.428 196.859 196.859
Inverse model specs
Monte Carlo
Enforce Max Heating      Enforce Max Cooling      Monotonic      Watch It Go
0         0         1         0
Max Heat Rate      Max Cool Rate
10.0      10.0
Num Paths      Num Paths Run      Divs per seg
10000 10000 2
Time-temperature paths
Num Acceptable Num Good
76      13
17
      Temperature (deg C)
Time (Ma)      Best fit Min AccMax Acc      Min Good      Max Good
0.000 20.000 20.000 20.000 20.000 20.000
3.537 20.962 20.190 81.419 20.303 62.397
7.074 21.926 20.718 88.785 20.718 79.981
10.611 51.634 35.906 92.343 41.461 91.866
14.148 92.876 85.534 110.541 91.488 107.987
16.399 92.465 34.619 95.807 56.114 92.465
18.649 92.118 26.029 94.317 29.499 92.118
20.900 89.380 25.156 89.380 25.290 89.380
23.151 25.131 25.131 25.131 25.131 25.131
71.383 28.386 25.131 62.098 25.132 39.036
119.614 28.642 25.135 62.385 25.211 59.313
167.846 36.736 25.317 72.550 25.317 60.354
216.077 37.301 25.339 82.061 25.339 81.543
261.415 46.194 26.792 142.743 26.792 86.560
306.752 87.894 30.923 196.852 78.420 165.111
352.090 193.634 74.599 196.858 120.661 193.683
397.428 196.859 196.859 196.859 196.859 196.859
Easy Ro Results
calc      equalAcc      meanAcc      sdAcc      equalGood      meanGood      sdGood
1         0         0.63      0.01 0         0.63      0.01
30801996

```

Model specs and results for AFTSOLVE.EXE, version 1.2

GU-17

TIME-TEMPERATURE PATH

1
Time (Ma) Temperature (deg C)
0.000 20.000
KINETIC PARAMETERS
model: Ketcham et al. 1999
kinParUsed: Etch Pit Length
Initial track length model: Use kinetic parameter
L0 vs. kpar line defs:
0.2830 15.6300
0.2050 16.1000
0.5440 16.1800
0.4070 16.4900
0.0000 16.1800
0.0000 16.5700
0.1382 16.2880
0.1732 16.4950
Single L0 value:
16.30
Standard length reduction:
0.893000
Age calculation to use for data: Pooled
Dividers:

2
0.90
3.30
Model Calc Kin Par
1 0 0.00
2 1 2.12
3 0 4.15

MODEL RESULTS

pctPerTimeStep

1.00
41
length pdf2 cdf2
0.0 0.00000 0.00000
0.5 0.00000 0.00000
1.0 0.00000 0.00000
1.5 0.00000 0.00000
2.0 0.00000 0.00000
2.5 0.00000 0.00000
3.0 0.00000 0.00000
3.5 0.00000 0.00000
4.0 0.00000 0.00000
4.5 0.00000 0.00000
5.0 0.00000 0.00000
5.5 0.00000 0.00000
6.0 0.00000 0.00000
6.5 0.00000 0.00000
7.0 0.00001 0.00000

7.5	0.00005	0.00002
8.0	0.00019	0.00008
8.5	0.00062	0.00028
9.0	0.00164	0.00085
9.5	0.00372	0.00219
10.0	0.00770	0.00504
10.5	0.01578	0.01091
11.0	0.03667	0.02403
11.5	0.09327	0.05651
12.0	0.20460	0.13098
12.5	0.32506	0.26339
13.0	0.35684	0.43387
13.5	0.28936	0.59542
14.0	0.21079	0.72046
14.5	0.16282	0.81386
15.0	0.12418	0.88561
15.5	0.08414	0.93769
16.0	0.04876	0.97091
16.5	0.02299	0.98885
17.0	0.00824	0.99666
17.5	0.00213	0.99925
18.0	0.00039	0.99988
18.5	0.00005	0.99999
19.0	0.00000	1.00000
19.5	0.00000	1.00000
20.0	0.00000	1.00000

DATA

Stratigraphic information

NumDefs	age1	age2
---------	------	------

2	10.40	23.30
---	-------	-------

Quebradón Formation

Track length file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\JAIME\AFT\FTDD\FTDDUGPSAMPLES\1\LGU17B1.A1G
8

length	proj len	kinPar
--------	----------	--------

11.2000	13.5000	1.4600
---------	---------	--------

10.9800	13.1389	2.0100
---------	---------	--------

6.3300	9.1045	1.3500
--------	--------	--------

11.5700	13.0833	1.0600
---------	---------	--------

11.0600	12.5674	1.4800
---------	---------	--------

12.1300	14.0579	1.4800
---------	---------	--------

5.7400	11.3180	1.4800
--------	---------	--------

11.2900	13.1782	1.6400
---------	---------	--------

5741

Age file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\JAIME\AFT\FTDD\FTDDUGPSAMPLES\1\AGU17A1.A1G
33

ns	ni	kinPar	age	ageErr
0	6	2.51	0.00	59.42
1	3	1.42	109.38	126.49
2	16	2.27	41.23	31.04
1	5	1.62	65.85	72.26
0	51	1.71	0.00	6.56
1	7	1.33	47.10	50.44
2	7	2.97	93.87	75.50
7	55	1.50	41.98	17.06

1	11	2.23	30.01	31.41
2	6	1.61	109.38	89.58
5	71	1.64	23.26	10.86
1	7	2.30	47.10	50.44
2	19	2.30	34.74	25.92
1	5	2.43	65.85	72.26
8	47	1.35	56.08	21.74
3	16	2.72	61.75	39.05
3	24	2.30	41.23	25.39
0	8	3.18	0.00	43.81
2	27	1.71	24.47	18.00
3	13	2.08	75.92	48.87
0	1	2.41	0.00	456.85
0	4	2.01	0.00	92.06
12	50	1.58	78.94	25.87
3	76	2.01	13.05	7.73
4	44	1.99	30.01	15.79
1	51	1.81	6.49	6.56
0	7	0.00	0.00	50.44
0	4	1.68	0.00	92.06
16	146	1.87	36.17	9.80
0	17	2.38	0.00	20.04
21	114	1.68	60.67	14.91
1	5	2.58	65.85	72.26
5	43	2.09	38.37	18.29

158643

DISPLAY AND PARAMETER SPECIFICATIONS

maxTime	maxTemp	maxFreq	maxLength
---------	---------	---------	-----------

80.00	200.00	0.50	20.00
-------	--------	------	-------

projectToC	showFit	calcEasyRo	usedCf
------------	---------	------------	--------

1	1	1	1
---	---	---	---

Max age for kinetic plots

1060.58

Inverse model constraints

Num constraints

5

Time (Ma)	Upper (deg C)	Lower (deg C)
-----------	---------------	---------------

0.000	20.000	20.000
-------	--------	--------

14.148	180.105	25.131
--------	---------	--------

20.064	25.131	25.131
--------	--------	--------

45.016	185.340	25.131
--------	---------	--------

79.743	197.906	197.906
--------	---------	---------

Inverse model specs

Monte Carlo

Enforce Max Heating	Enforce Max Cooling	Monotonic	Watch It Go
---------------------	---------------------	-----------	-------------

0	0	1	0
---	---	---	---

Max Heat Rate	Max Cool Rate
---------------	---------------

10.0	10.0
------	------

Num Paths	Num Paths Run	Divs per seg
-----------	---------------	--------------

10000	10000	2
-------	-------	---

Time-temperature paths

Num Acceptable	Num Good
----------------	----------

1452	260
------	-----

17

Temperature (deg C)

Time (Ma)	Best fit	Min Acc	Max Acc	Min Good	Max Good
-----------	----------	---------	---------	----------	----------

0.000	20.000	20.000	20.000	20.000	20.000
3.537	70.398	20.004	100.851	20.128	89.813
7.074	72.413	20.016	109.355	20.368	101.033
10.611	76.121	23.268	116.729	23.268	107.422
14.148	107.505	28.832	130.854	90.112	129.594
15.627	101.944	27.450	123.157	27.450	119.162
17.106	51.040	25.152	117.389	25.294	112.362
18.585	50.751	25.136	108.474	25.136	99.880
20.064	25.131	25.131	25.131	25.131	25.131
26.302	57.064	25.133	106.836	25.158	96.942
32.540	62.395	25.148	135.613	25.658	106.187
38.778	85.203	25.218	179.211	26.461	113.431
45.016	112.629	25.812	185.164	26.699	169.612
53.698	136.307	28.793	196.287	33.878	191.284
62.379	148.403	37.413	197.855	109.701	197.734
71.061	175.574	42.730	197.880	130.928	197.849
79.743	197.906	197.906	197.906	197.906	197.906

Easy Ro Results

calc	equalAcc	meanAcc	sdAcc	equalGood	meanGood	sdGood
1	0	0.78	0.01	0	0.78	0.01

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Model specs and results for AFTSOLVE.EXE, version 1.2

GU-18

TIME-TEMPERATURE PATH

1

Time (Ma)	Temperature (deg C)
0.000	20.000

KINETIC PARAMETERS

model: Ketcham et al. 1999

kinParUsed: Etch Pit Length

Initial track length model: Use kinetic parameter

L0 vs. kpar line defs:

0.2830	15.6300
0.2050	16.1000
0.5440	16.1800
0.4070	16.4900
0.0000	16.1800
0.0000	16.5700
0.1382	16.2880
0.1732	16.4950

Single L0 value:

16.30

Standard length reduction:

0.893000

Age calculation to use for data: Pooled

Dividers:

2

0.77

3.52

Model	Calc	Kin Par
-------	------	---------

1	0	0.00
2	1	2.12
3	0	4.26

MODEL RESULTS

pctPerTimeStep

1.00

41

length	pdf2	cdf2
0.0	0.00000	0.00000
0.5	0.00000	0.00000
1.0	0.00000	0.00000
1.5	0.00000	0.00000
2.0	0.00000	0.00000
2.5	0.00000	0.00000
3.0	0.00000	0.00000
3.5	0.00000	0.00000
4.0	0.00000	0.00000
4.5	0.00000	0.00000
5.0	0.00000	0.00000
5.5	0.00000	0.00000
6.0	0.00000	0.00000
6.5	0.00000	0.00000
7.0	0.00000	0.00000
7.5	0.00003	0.00001
8.0	0.00015	0.00005
8.5	0.00058	0.00024
9.0	0.00177	0.00082
9.5	0.00443	0.00237
10.0	0.01066	0.00614
10.5	0.02721	0.01561
11.0	0.07356	0.04080
11.5	0.17227	0.10226
12.0	0.29598	0.21932
12.5	0.34984	0.38077
13.0	0.28883	0.54044
13.5	0.18821	0.65970
14.0	0.12889	0.73897
14.5	0.11553	0.80008
15.0	0.11555	0.85785
15.5	0.10231	0.91231
16.0	0.07088	0.95561
16.5	0.03617	0.98237
17.0	0.01316	0.99470
17.5	0.00335	0.99883
18.0	0.00059	0.99981
18.5	0.00007	0.99998
19.0	0.00001	1.00000
19.5	0.00000	1.00000
20.0	0.00000	1.00000

DATA

Stratigraphic information

NumDefs	age1	age2
2	10.40	23.30

Quebradón Formation

Track length file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\AIME\AFT\FTDD\FTDDJGPSAMPLES\L\GU18B1.A1G

64
length proj len kinPar
13.6000 13.9224 1.6600
10.4800 11.9039 1.5800
13.2700 14.4946 1.6000
12.3300 13.7911 2.0200
2.1400 10.8044 1.6800
12.1900 12.9834 1.3000
10.5400 13.1125 1.3900
4.7200 10.8023 1.4600
9.1600 11.8350 1.7300
3.9200 9.3696 1.7300
11.6700 13.3180 2.4800
6.4600 11.3978 1.4800
14.1100 14.7479 1.4100
7.3400 11.2498 1.5000
13.9700 15.1924 1.9300
12.5700 13.7069 1.9300
12.1900 13.5827 1.9300
10.3200 12.2200 1.9300
12.6300 13.9523 1.3600
6.3900 12.4161 1.3300
5.4700 10.7266 1.8600
9.5100 10.6652 1.8600
14.1200 15.1703 3.0600
14.8700 15.7004 3.0600
9.7300 11.8789 1.4300
7.8000 12.8051 1.4300
10.9300 12.0180 1.3400
11.8600 12.4169 1.5500
10.1600 11.8532 1.5500
10.8800 11.8625 1.5500
13.9600 15.0361 1.9600
14.6100 15.4357 1.8000
13.4300 14.2413 1.7900
9.4900 12.4512 3.2400
7.1300 11.3097 1.3900
13.2600 14.6673 2.0500
6.6500 11.9197 2.0500
12.3700 14.1314 2.0500
11.0900 12.2678 2.0500
11.8200 12.8842 2.0500
13.3800 13.6698 2.0500
12.9300 14.5239 2.1600
11.7300 13.5200 1.1900
12.0000 12.1072 1.1900
14.0800 14.5695 1.1900
13.8800 14.4846 1.9500
13.4100 14.8150 1.6000
10.5700 12.0730 1.6400
9.7500 12.8478 1.6400
11.3000 12.8079 0.8600
8.7900 10.7501 0.8600
10.7100 13.0861 1.3100
7.5600 12.4078 1.3300
9.2400 12.9145 1.5900

14.6700 14.9006 2.0800
 12.1200 12.6352 2.0800
 7.3900 11.4302 1.2800
 9.3200 12.4884 1.5500
 10.6600 11.8154 1.5500
 6.1600 11.8522 1.5500
 12.5200 14.1628 1.9800
 14.4600 14.6530 1.9800
 12.9200 13.6691 1.9800
 13.8800 15.0989 0.9300

64648

Age file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\JAIME\AFT\FTDD\FTDD\JGP\SAMPLES\A\AGU18A1.A1G

47

ns	ni	kinPar	age	ageErr
4	32	2.55	41.37	22.10
3	18	3.38	55.10	34.54
0	19	0.00	0.00	17.94
0	7	2.37	0.00	50.61
0	32	2.29	0.00	10.55
29	324	1.51	29.65	6.05
0	5	1.83	0.00	72.49
0	2	2.17	0.00	201.01
0	16	1.85	0.00	21.40
0	14	1.28	0.00	24.55
6	86	1.69	23.12	9.87
1	11	1.48	30.11	31.51
0	3	1.51	0.00	126.90
7	150	1.80	15.48	6.06
0	1	1.95	0.00	458.31
6	50	1.44	39.72	17.35
2	10	1.63	66.06	51.34
1	7	1.56	47.26	50.61
0	1	1.93	0.00	458.31
0	5	1.28	0.00	72.49
0	11	1.29	0.00	31.51
6	25	1.54	79.19	36.35
12	34	1.63	116.13	39.68
14	173	1.86	26.81	7.64
0	2	2.69	0.00	201.01
0	3	1.93	0.00	126.90
0	11	2.04	0.00	31.51
0	30	2.44	0.00	11.26
0	1	0.00	0.00	458.31
24	341	2.09	23.33	5.14
0	6	1.64	0.00	59.62
1	87	2.13	3.82	3.84
2	22	1.90	30.11	22.32
3	34	1.59	29.23	17.70
3	78	1.72	12.76	7.55
2	7	3.05	94.17	75.74
0	14	1.62	0.00	24.55
0	39	0.00	0.00	8.63
2	5	1.30	131.46	110.30
22	161	1.57	45.21	10.67
3	18	2.85	55.10	34.54

6	48	2.51	41.37	18.10
12	77	2.38	51.54	16.33
14	47	1.66	98.15	30.53
7	42	1.60	55.10	22.76
1	25	1.90	13.27	13.56
1	36	1.90	9.22	9.36

168106

DISPLAY AND PARAMETER SPECIFICATIONS

maxTime	maxTemp	maxFreq	maxLength
80.00	200.00	0.50	20.00
projectToC	showFit	calcEasyRo	usedCf
1	1	1	1

Max age for kinetic plots

1060.58

Inverse model constraints

Num constraints

5

Time (Ma)	Upper (deg C)	Lower (deg C)
0.000	20.000	20.000
14.405	182.199	25.131
20.064	25.131	25.131
36.013	183.246	25.131
79.228	197.906	197.906

Inverse model specs

Monte Carlo

Enforce Max Heating	Enforce Max Cooling	Monotonic	Watch It Go
0	1	1	

Max Heat Rate	Max Cool Rate
10.0	10.0

Num Paths	Num Paths Run	Divs per seg
10000	10000	2

Time-temperature paths

Num Acceptable	Num Good
383	35

17

Temperature (deg C)					
Time (Ma)	Best fit	Min Acc	Max Acc	Min Good	Max Good
0.000	20.000	20.000	20.000	20.000	20.000
3.601	54.406	21.246	56.009	39.559	55.971
7.203	86.556	39.989	92.022	68.440	91.524
10.804	103.507	68.476	110.932	82.685	106.733
14.405	104.322	94.045	125.800	102.241	121.960
15.820	101.013	32.615	118.996	35.304	109.239
17.235	74.205	25.794	112.794	27.122	102.631
18.650	29.159	25.142	107.290	25.158	94.471
20.064	25.131	25.131	25.131	25.131	25.131
24.051	32.571	25.140	65.001	25.194	62.272
28.039	62.056	25.254	104.851	25.484	97.440
32.026	84.836	25.540	134.211	26.705	103.594
36.013	104.432	25.587	169.437	34.231	120.208
46.817	138.384	60.747	193.044	111.194	180.655
57.621	153.336	106.280	197.869	116.757	196.666
68.424	185.033	130.797	197.905	139.677	197.191
79.228	197.906	197.906	197.906	197.906	197.906

Easy Ro Results

calc	equalAcc	meanAcc	sdAcc	equalGood	meanGood	sdGood
------	----------	---------	-------	-----------	----------	--------

1 0 0.78 0.01 0 0.78 0.01
23200127

Model specs and results for AFTSOLVE.EXE, version 1.2

GU-19

TIME-TEMPERATURE PATH

1
Time (Ma) Temperature (deg C)
0.000 20.000
KINETIC PARAMETERS
model: Ketcham et al. 1999
kinParUsed: Etch Pit Length
Initial track length model: Use kinetic parameter
L0 vs. kpar line defs:
0.2830 15.6300
0.2050 16.1000
0.5440 16.1800
0.4070 16.4900
0.0000 16.1800
0.0000 16.5700
0.1382 16.2880
0.1732 16.4950
Single L0 value:
16.30
Standard length reduction:
0.893000
Age calculation to use for data: Pooled
Dividers:

2
1.16
2.66
Model Calc Kin Par
1 0 0.53
2 1 1.89
3 0 3.27

MODEL RESULTS

pctPerTimeStep
1.00
41
length pdf2 cdf2
0.0 0.00000 0.00000
0.5 0.00000 0.00000
1.0 0.00000 0.00000
1.5 0.00000 0.00000
2.0 0.00000 0.00000
2.5 0.00000 0.00000
3.0 0.00000 0.00000
3.5 0.00000 0.00000
4.0 0.00000 0.00000
4.5 0.00000 0.00000
5.0 0.00000 0.00000
5.5 0.00000 0.00000

6.0	0.00000	0.00000
6.5	0.00000	0.00000
7.0	0.00000	0.00000
7.5	0.00002	0.00001
8.0	0.00007	0.00003
8.5	0.00021	0.00010
9.0	0.00053	0.00029
9.5	0.00148	0.00079
10.0	0.00496	0.00240
10.5	0.02042	0.00874
11.0	0.07499	0.03259
11.5	0.19569	0.10026
12.0	0.33708	0.23346
12.5	0.38115	0.41302
13.0	0.29646	0.58242
13.5	0.18351	0.70241
14.0	0.12084	0.77849
14.5	0.10336	0.83455
15.0	0.09884	0.88510
15.5	0.08427	0.93088
16.0	0.05623	0.96600
16.5	0.02754	0.98694
17.0	0.00958	0.99622
17.5	0.00232	0.99920
18.0	0.00039	0.99988
18.5	0.00004	0.99999
19.0	0.00000	1.00000
19.5	0.00000	1.00000
20.0	0.00000	1.00000

DATA

Stratigraphic information

NumDefs	age1	age2
2	10.40	23.30

Quebradón Formation

Track length file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\AIME\AFT\FTDD\FTDD\GP\SAMPLES\L\LGU19B1.AIG

44

length	proj len	kinPar
13.5800	14.7664	1.6100
12.9400	14.5267	1.5400
12.2400	13.4907	1.5400
9.0400	12.3025	1.8300
11.6300	12.0109	1.8300
9.2700	11.8168	1.8300
11.5400	13.2631	1.8300
7.7800	12.0175	1.8300
6.8700	11.8219	1.8300
10.2100	11.4936	1.8300
10.5400	12.5061	1.7800
14.3600	15.4393	1.7500
10.0000	10.8900	1.7500
10.9100	12.6117	1.2800
11.1600	12.3462	1.6000
11.9300	12.5753	1.6000
12.2600	14.1164	2.1900
8.9800	10.8957	2.1900

7.6200 11.7207 1.6000
 9.0000 12.0133 1.6000
 4.5600 12.0925 1.6000
 11.8200 12.1065 1.6000
 11.8300 13.2717 1.8500
 10.6800 12.4090 1.8500
 13.8300 14.7814 1.8500
 11.2300 13.4779 1.8500
 8.4000 11.7180 1.8500
 9.6200 11.4044 1.7400
 12.5700 14.2021 1.7400
 10.9000 11.9688 1.7400
 9.5000 11.2282 2.0100
 11.7300 12.9113 1.3600
 10.8400 13.1668 1.3600
 13.8100 15.0725 1.3600
 12.0100 13.5849 1.3600
 12.9800 14.4782 1.3600
 14.0600 15.1924 1.3600
 13.5200 14.7921 1.5600
 10.4000 12.8371 1.5600
 12.6900 13.4928 1.5600
 10.0200 12.5632 1.7200
 12.7800 14.4775 1.7600
 11.3000 13.2388 1.4800
 9.6700 12.3220 1.2300

42181

Age file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\VAIME\AFT\FTDD\FTDD\GPSAMPLES\A\AGU19A1.A1G

44

ns	ni	kinPar	age	ageErr
1	5	2.29	66.28	72.72
6	89	2.03	22.42	9.56
4	6	1.87	218.32	141.61
0	19	1.94	0.00	18.00
1	30	2.49	11.09	11.30
0	10	1.83	0.00	34.91
0	5	2.17	0.00	72.72
3	15	1.56	66.28	42.13
0	3	1.78	0.00	127.31
0	1	0.00	0.00	459.76
0	3	0.00	0.00	127.31
0	6	0.00	0.00	59.81
1	1	3.72	324.77	459.76
0	6	0.00	0.00	59.81
1	49	2.18	6.79	6.88
2	99	2.21	6.73	4.82
2	18	2.26	36.90	27.61
1	1	1.33	324.77	459.76
3	37	2.02	26.95	16.27
14	20	1.72	229.05	81.13
4	6	1.06	218.32	141.61
4	18	1.49	73.60	40.95
1	32	2.55	10.40	10.58
2	34	1.72	19.56	14.29
2	9	1.63	73.60	57.72

2	9	1.87	73.60	57.72
8	124	1.42	21.45	7.94
8	58	1.67	45.78	17.51
11	157	2.05	23.30	7.41
0	5	2.02	0.00	72.72
2	35	1.28	19.01	13.87
6	19	1.76	104.34	49.31
0	5	1.47	0.00	72.72
2	3	1.89	218.32	199.78
0	2	2.83	0.00	201.66
0	2	2.08	0.00	201.66
1	7	1.95	47.41	50.77
1	3	1.68	110.09	127.31
1	19	1.03	17.51	18.00
0	7	0.00	0.00	50.77
1	10	1.64	33.22	34.91
4	6	2.21	218.32	141.61
0	4	0.00	0.00	92.66
17	127	1.85	44.43	11.82

430447

DISPLAY AND PARAMETER SPECIFICATIONS

maxTime	maxTemp	maxFreq	maxLength
80.00	200.00	0.50	20.00
projectToC	showFit	calcEasyRo	usedCf
1	1	1	1

Max age for kinetic plots
1060.58

Inverse model constraints

Num constraints
5

Time (Ma)	Upper (deg C)	Lower (deg C)
0.000	20.000	20.000
14.405	175.916	25.131
20.064	25.131	25.131
39.871	173.822	25.131
79.743	198.953	198.953

Inverse model specs

Monte Carlo

Enforce Max Heating	Enforce Max Cooling	Monotonic	Watch It Go
0	1	1	0

Max Heat Rate Max Cool Rate
10.0 10.0

Num Paths	Num Paths Run	Divs per seg
10000	10000	2

Time-temperature paths

Num Acceptable	Num Good
508	67

17

Temperature (deg C)					
Time (Ma)	Best fit	Min Acc	Max Acc	Min Good	Max Good
0.000	20.000	20.000	20.000	20.000	20.000
3.601	54.131	20.130	56.013	25.463	55.978
7.203	84.947	28.716	92.020	50.130	91.989
10.804	90.772	61.222	103.724	75.170	98.127
14.405	103.996	87.480	116.464	92.523	113.323
15.820	70.940	28.811	111.229	34.251	103.587

17.235 63.728 25.473 103.519 26.024 99.546
 18.650 32.597 25.239 99.138 25.330 81.814
 20.064 25.131 25.131 25.131 25.131 25.131
 25.016 26.174 25.136 73.318 25.149 69.832
 29.968 37.462 25.167 103.798 25.182 98.133
 34.920 42.357 25.208 125.971 25.208 101.246
 39.871 47.820 25.598 172.225 25.598 105.911
 49.839 130.668 30.272 186.966 74.127 147.121
 59.807 192.510 32.663 198.940 104.895 198.940
 69.775 194.389 107.507 198.951 114.135 198.950
 79.743 198.953 198.953 198.953 198.953 198.953

Easy Ro Results

calc	equalAcc	meanAcc	sdAcc	equalGood	meanGood	sdGood
1	0	0.69	0.01	0	0.69	0.01

23200252

Model specs and results for AFTSOLVE.EXE, version 1.2

GU-20

TIME-TEMPERATURE PATH

1

Time (Ma) Temperature (deg C)

0.000 20.000

KINETIC PARAMETERS

model: Ketcham et al. 1999

kinParUsed: Etch Pit Length

Initial track length model: Use kinetic parameter

L0 vs. kpar line defs:

0.2830 15.6300

0.2050 16.1000

0.5440 16.1800

0.4070 16.4900

0.0000 16.1800

0.0000 16.5700

0.1382 16.2880

0.1732 16.4950

Single L0 value:

16.30

Standard length reduction:

0.893000

Age calculation to use for data: Pooled

Dividers:

2

1.27

3.05

Model	Calc	Kin Par
1	0	0.63
2	1	2.20
3	0	4.02

MODEL RESULTS

pctPerTimeStep

1.00


```

41
length pdf2 cdf2
0.0 0.00000 0.00000
0.5 0.00000 0.00000
1.0 0.00000 0.00000
1.5 0.00000 0.00000
2.0 0.00000 0.00000
2.5 0.00000 0.00000
3.0 0.00000 0.00000
3.5 0.00000 0.00000
4.0 0.00000 0.00000
4.5 0.00000 0.00000
5.0 0.00000 0.00000
5.5 0.00000 0.00000
6.0 0.00000 0.00000
6.5 0.00000 0.00000
7.0 0.00001 0.00000
7.5 0.00005 0.00002
8.0 0.00019 0.00008
8.5 0.00060 0.00027
9.0 0.00158 0.00082
9.5 0.00367 0.00213
10.0 0.00823 0.00511
10.5 0.01985 0.01213
11.0 0.05424 0.03065
11.5 0.14145 0.07957
12.0 0.28518 0.18623
12.5 0.39834 0.35711
13.0 0.37384 0.55016
13.5 0.24491 0.70484
14.0 0.13442 0.79968
14.5 0.09037 0.85588
15.0 0.08151 0.89884
15.5 0.07192 0.93720
16.0 0.05061 0.96784
16.5 0.02627 0.98706
17.0 0.00972 0.99605
17.5 0.00252 0.99911
18.0 0.00045 0.99986
18.5 0.00006 0.99998
19.0 0.00000 1.00000
19.5 0.00000 1.00000
20.0 0.00000 1.00000

```

DATA

Stratigraphic information

```

NumDefs      age1      age2
2          10.40    21.50

```

Quiamare Formation

Track length file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\JAIME\AFT\FTDD\FTDDUGP\SAMPLES\L\LGU20B1.A1G

30

```

length proj len kinPar
12.0200 13.6027 1.6200
9.8200 12.5524 1.5300
10.9200 12.5874 1.7500
12.9100 14.4040 1.7500

```

6.9300 12.1875 1.7600
 11.0600 12.7922 1.7600
 5.7700 12.0601 1.9300
 11.1500 11.8946 2.9400
 7.8500 12.2619 1.7100
 11.9100 13.2445 2.5900
 11.3700 13.2060 1.8600
 6.5900 11.6133 2.0000
 4.9500 11.8157 1.8100
 3.1800 9.6064 1.5100
 16.1700 16.4246 2.6600
 10.5800 12.5310 1.5100
 10.5800 12.9263 1.5300
 12.7400 14.0437 1.7000
 8.9000 12.5324 1.7000
 11.3200 13.5135 1.7000
 15.0700 15.3579 1.7000
 9.3800 11.2218 1.7000
 10.8600 13.1011 1.7000
 11.7300 13.6891 1.7000
 6.2100 12.3300 1.7000
 9.3600 11.3374 1.7000
 10.9000 13.2110 1.4500
 10.4100 13.0169 1.7300
 15.3600 15.8524 1.7300
 10.5200 13.0369 1.6900

25024

Age file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\AIME\AFT\FTDD\FTDD\UGP\SAMPLES\A\AGU20A1.A1G

2

ns	ni	kinPar	age	ageErr
1	6	2.31	55.46	60.00
1	9	2.08	37.02	39.10

6136

DISPLAY AND PARAMETER SPECIFICATIONS

maxTime	maxTemp	maxFreq	maxLength
80.00	200.00	0.50	20.00
projectToC	showFit	calcEasyRo	usedCf
1	1	1	1

Max age for kinetic plots

1060.58

Inverse model constraints

Num constraints

5

Time (Ma)	Upper (deg C)	Lower (deg C)
0.000	20.000	20.000
14.148	180.105	25.131
19.035	25.131	25.131
50.161	184.293	25.131
79.228	196.859	196.859

Inverse model specs

Monte Carlo

Enforce Max Heating	Enforce Max Cooling	Monotonic	Watch It Go
0	1	1	

Max Heat Rate Max Cool Rate

10.0 10.0

Num Paths Num Paths Run Divs per seg

10000 10000 2

Time-temperature paths

Num Acceptable Num Good

1444 515

17

Temperature (deg C)

Time (Ma)	Best fit	Min Acc	Max Acc	Min Good	Max Good
0.000	20.000	20.000	20.000	20.000	20.000
3.537	51.844	20.421	55.369	21.074	55.369
7.074	85.108	38.201	90.738	40.457	90.738
10.611	104.153	71.198	119.120	73.705	111.284
14.148	104.194	92.116	135.086	100.734	126.872
15.370	92.485	25.871	126.146	28.216	118.044
16.592	88.449	25.282	123.652	25.586	113.201
17.814	76.636	25.139	117.451	25.139	104.218
19.035	25.131	25.131	25.131	25.131	25.131
26.817	38.487	25.133	102.485	25.133	93.038
34.598	49.879	25.164	179.235	25.176	121.404
42.379	79.398	25.165	180.994	25.568	149.199
50.161	98.675	25.519	183.889	25.918	183.760
57.428	113.066	27.685	194.808	27.685	194.016
64.695	134.455	51.528	196.856	51.528	196.790
71.961	137.467	124.195	196.858	124.195	196.816
79.228	196.859	196.859	196.859	196.859	196.859

Easy Ro Results

calc	equalAcc	meanAcc	sdAcc	equalGood	meanGood	sdGood
1	0	0.82	0.01	0	0.82	0.01
23201188						

Model specs and results for AFTSOLVE.EXE, version 1.2

GU-21

TIME-TEMPERATURE PATH

1

Time (Ma) Temperature (deg C)

0.000 20.000

KINETIC PARAMETERS

model: Ketcham et al. 1999

kinParUsed: Etch Pit Length

Initial track length model: Use kinetic parameter

L0 vs. kpar line defs:

0.2830 15.6300

0.2050 16.1000

0.5440 16.1800

0.4070 16.4900

0.0000 16.1800

0.0000 16.5700

0.1382 16.2880

0.1732 16.4950

Single L0 value:

16.30

Standard length reduction:

0.893000

Age calculation to use for data: Pooled

Dividers:

2

1.18

3.11

Model	Calc	Kin Par
1	0	1.13
2	1	2.19
3	0	4.43

MODEL RESULTS

pctPerTimeStep

1.00

41

length	pdf2	cdf2
0.0	0.00000	0.00000
0.5	0.00000	0.00000
1.0	0.00000	0.00000
1.5	0.00000	0.00000
2.0	0.00000	0.00000
2.5	0.00000	0.00000
3.0	0.00000	0.00000
3.5	0.00000	0.00000
4.0	0.00000	0.00000
4.5	0.00000	0.00000
5.0	0.00000	0.00000
5.5	0.00000	0.00000
6.0	0.00000	0.00000
6.5	0.00000	0.00000
7.0	0.00000	0.00000
7.5	0.00002	0.00001
8.0	0.00010	0.00004
8.5	0.00041	0.00016
9.0	0.00131	0.00059
9.5	0.00480	0.00212
10.0	0.01890	0.00805
10.5	0.07063	0.03043
11.0	0.19684	0.09730
11.5	0.36752	0.23838
12.0	0.44415	0.44130
12.5	0.34645	0.63895
13.0	0.18161	0.77096
13.5	0.07894	0.83610
14.0	0.04996	0.86833
14.5	0.05256	0.89396
15.0	0.05868	0.92177
15.5	0.05548	0.95031
16.0	0.04027	0.97425
16.5	0.02118	0.98961
17.0	0.00781	0.99686
17.5	0.00199	0.99931
18.0	0.00034	0.99989
18.5	0.00004	0.99999
19.0	0.00000	1.00000

19.5 0.00000 1.00000

20.0 0.00000 1.00000

DATA

Stratigraphic information

NumDefs age1 age2

2 10.40 21.50

Quiamare Formation

Track length file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\VAIME\AFT\FTDD\FTDDUGPSAMPLES\L\LGU21B1.AIG
6

length proj len kinPar

9.2100 12.1620 2.0100

9.4400 10.8893 1.3800

6.8600 12.2357 1.3800

6.7300 11.7001 1.3800

10.0100 12.6602 1.5200

9.4900 11.5307 1.5200

3444

Age file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\VAIME\AFT\FTDD\FTDDUGPSAMPLES\A\AGU21A1.AIG
9

ns	ni	kinPar	age	ageErr
4	3	2.99	432.19	331.23
0	4	2.54	0.00	93.25
10	38	2.69	87.63	31.64
4	14	2.17	95.08	54.24
1	6	2.21	55.64	60.20
0	10	4.43	0.00	35.14
34	172	1.87	65.93	13.06
4	9	1.13	147.31	89.01
1	1	2.25	326.83	462.67

145465

DISPLAY AND PARAMETER SPECIFICATIONS

maxTime	maxTemp	maxFreq	maxLength
200.00	200.00	0.50	20.00

projectToC	showFit	calcEasyRo	usedCf
1	1	1	1

Max age for kinetic plots

1060.58

Inverse model constraints

Num constraints

5

Time (Ma)	Upper (deg C)	Lower (deg C)
0.000	20.000	20.000
14.791	183.246	25.131
20.579	25.131	25.131
88.746	183.246	25.131
197.428	198.953	198.953

Inverse model specs

Monte Carlo

Enforce Max Heating	Enforce Max Cooling	Monotonic	Watch It Go
0	1	0	

Max Heat Rate	Max Cool Rate
10.0	10.0

Num Paths	Num Paths Run	Divs per seg
10000	10000	2

Time-temperature paths

Num Acceptable Num Good

1132 201

17

Temperature (deg C)

Time (Ma)	Best fit	Min Acc	Max Acc	Min Good	Max Good
0.000	20.000	20.000	20.000	20.000	20.000
3.698	37.486	20.004	56.973	20.085	56.956
7.395	70.912	20.185	93.931	39.784	93.726
11.093	93.607	21.786	120.102	75.902	115.650
14.791	123.735	26.580	133.584	104.478	131.112
16.238	92.474	26.006	127.966	33.750	121.778
17.685	76.714	25.144	123.995	25.556	118.250
19.132	27.635	25.132	110.667	25.205	104.928
20.579	25.131	25.131	25.131	25.131	25.131
37.621	27.597	25.134	104.652	25.137	81.309
54.662	45.539	25.192	111.288	25.192	98.888
71.704	69.127	25.329	149.208	25.329	100.534
88.746	73.413	25.417	182.946	25.535	112.249
115.916	81.190	28.234	195.020	28.234	179.572
143.087	137.474	30.801	198.742	30.858	197.716
170.257	178.457	42.486	198.951	51.511	198.951
197.428	198.953	198.953	198.953	198.953	198.953

Easy Ro Results

calc	equalAcc	meanAcc	sdAcc	equalGood	meanGood	sdGood
1	0	0.80	0.01	0	0.80	0.01

24118380

Model specs and results for AFTSOLVE.EXE, version 1.2

GU-22***TIME-TEMPERATURE PATH***

1

Time (Ma) Temperature (deg C)

0.000 20.000

KINETIC PARAMETERS

model: Ketcham et al. 1999

kinParUsed: Etch Pit Length

Initial track length model: Use kinetic parameter

L0 vs. kpar line defs:

0.2830 15.6300

0.2050 16.1000

0.5440 16.1800

0.4070 16.4900

0.0000 16.1800

0.0000 16.5700

0.1382 16.2880

0.1732 16.4950

Single L0 value:

16.30

Standard length reduction:

0.893000

Age calculation to use for data: Pooled

Dividers:

2

0.77

2.36

Model	Calc	Kin Par
-------	------	---------

1	0	0.39
---	---	------

2	1	1.59
---	---	------

3	0	3.48
---	---	------

MODEL RESULTS

pctPerTimeStep

1.00

41

length	pdf2	cdf2
0.0	0.00000	0.00000
0.5	0.00000	0.00000
1.0	0.00000	0.00000
1.5	0.00000	0.00000
2.0	0.00000	0.00000
2.5	0.00000	0.00000
3.0	0.00000	0.00000
3.5	0.00000	0.00000
4.0	0.00000	0.00000
4.5	0.00000	0.00000
5.0	0.00000	0.00000
5.5	0.00000	0.00000
6.0	0.00000	0.00000
6.5	0.00000	0.00000
7.0	0.00001	0.00000
7.5	0.00006	0.00002
8.0	0.00027	0.00010
8.5	0.00093	0.00040
9.0	0.00266	0.00130
9.5	0.00662	0.00362
10.0	0.01512	0.00906
10.5	0.03324	0.02115
11.0	0.07027	0.04703
11.5	0.13801	0.09910
12.0	0.23983	0.19356
12.5	0.34730	0.34034
13.0	0.38903	0.52442
13.5	0.31707	0.70095
14.0	0.18841	0.82732
14.5	0.09651	0.89855
15.0	0.06039	0.93778
15.5	0.04539	0.96422
16.0	0.02931	0.98290
16.5	0.01382	0.99368
17.0	0.00454	0.99827
17.5	0.00102	0.99966
18.0	0.00016	0.99995
18.5	0.00002	1.00000
19.0	0.00000	1.00000
19.5	0.00000	1.00000
20.0	0.00000	1.00000

DATA

Stratigraphic information

NumDefs age1 age2

2 10.40 21.50

Quiamare Formation

Track length file and data

C:\DOCUME~1\UPEREZ\MYDOCU~1\JAIME\AFT\FTDD\FTDD\UGP\SAMPLES\LLGU22B1.A1G

114

length proj len kinPar

13.1000 14.3034 1.1600

10.8600 12.5896 1.1600

11.8900 13.5278 1.3200

10.4800 13.0647 1.3200

10.5600 12.6445 1.2500

10.3200 11.2039 1.2500

10.5000 12.3420 1.2500

11.2400 12.8343 1.2500

9.9200 12.5717 1.2500

9.9300 12.5439 1.2500

10.4600 11.3837 1.5200

11.9600 13.8703 1.1600

10.9400 13.0062 1.1600

10.9600 13.2545 1.1600

11.3600 13.0940 1.6800

13.2600 14.6444 1.6800

10.9600 13.0968 1.0700

10.4900 12.3898 1.4500

11.3800 13.4301 1.4500

13.5800 14.7943 1.6100

9.2300 12.0794 1.4600

11.7000 13.2902 1.4300

10.2300 12.7437 1.4300

11.5900 12.4376 1.4300

11.5900 13.7361 1.4300

14.4500 15.5013 1.4300

10.5200 12.3470 1.4300

8.7100 10.5839 1.4300

9.6200 12.5228 1.4500

10.5300 12.8486 1.7900

11.4600 12.9777 1.7900

9.8200 11.6634 1.4300

14.1600 15.1760 1.3800

10.1500 12.7116 1.3800

6.3700 9.9527 1.3800

9.6100 12.3163 1.6800

9.1300 10.4583 1.4000

12.6500 14.3519 1.3600

9.2400 11.3752 1.4400

11.7600 13.8717 1.6300

10.5700 12.9784 1.6300

14.1800 15.3230 1.6700

10.9900 12.3627 1.3300

10.8200 12.6830 1.3300

9.0500 11.4380 1.3300

10.6100 11.7626 1.3300

13.1900 14.2627 1.3300

8.8600	10.8493	1.3300
13.8400	14.7322	1.6000
10.0400	12.4019	1.3800
7.9800	12.3163	1.3800
8.8100	11.8295	1.5100
9.8200	11.5600	1.4100
12.3100	14.1778	1.4100
10.7500	11.8903	1.1500
10.4300	13.0169	1.1500
11.5300	12.4112	1.1500
12.3500	14.1343	1.5800
13.3600	13.7247	1.7900
10.5800	13.0597	1.4500
10.9500	13.2053	1.3600
8.3100	11.8756	1.7600
9.5200	11.9859	1.7600
8.1700	10.5235	1.3300
10.5400	12.8535	1.7400
13.5900	14.9141	1.1700
11.8700	13.6370	1.6300
13.1000	14.6444	1.3000
13.2600	14.5324	1.6000
14.0500	15.1574	1.6000
10.2900	12.9071	1.6000
9.4100	10.5389	1.6000
10.1400	12.7715	1.6000
10.8200	11.6406	1.6000
11.9500	13.9531	1.5200
0.9900	9.9555	1.5200
11.4900	12.0901	1.0600
14.2500	15.3872	1.0600
12.9500	13.4793	1.0600
7.8100	10.5703	0.9400
14.1900	14.7393	1.4300
9.3400	11.9995	1.2400
7.1600	11.3992	1.2400
11.1100	13.3680	1.6700
11.0300	13.3216	1.6700
11.5200	12.8621	1.6700
12.0500	12.6010	1.6700
10.6500	13.0597	1.6700
11.4400	12.1800	1.6700
9.8300	12.6605	1.6700
11.4100	13.5549	1.9000
12.6200	14.1528	1.2900
8.3500	12.4650	1.4500
11.1600	13.0740	1.4500
11.1400	13.1925	0.9700
10.4200	11.7947	0.9700
10.2600	12.9185	0.9700
9.5200	12.7197	1.5800
13.0700	14.1585	1.2200
12.4300	13.5250	1.7000
13.5300	14.8770	1.9600
13.7300	14.7543	1.3100
11.3700	13.5142	1.3100

11.9500 12.8742 1.5900
 2.7500 10.9166 1.5700
 11.9600 13.2438 1.7300
 10.5600 12.4683 1.7900
 12.6300 14.0544 1.3600
 9.9700 12.5696 1.5900
 10.7400 13.1925 1.7700
 10.6600 13.0448 1.7700
 10.7100 13.2267 0.9600
 13.4500 14.7301 1.3400
 10.0800 12.8257 1.3400
 127722

Age file and data

C:\DOCUME~1\JPerez\MYDOCU~1\JAIME\AFT\FTDD\FTDD\JGP\SAMPLES\A\AGU21A1.AIG
 9

ns	ni	kinPar	age	ageErr
4	3	2.99	432.19	331.23
0	4	2.54	0.00	93.25
10	38	2.69	87.63	31.64
4	14	2.17	95.08	54.24
1	6	2.21	55.64	60.20
0	10	4.43	0.00	35.14
34	172	1.87	65.93	13.06
4	9	1.13	147.31	89.01
1	1	2.25	326.83	462.67

145465

DISPLAY AND PARAMETER SPECIFICATIONS

maxTime	maxTemp	maxFreq	maxLength
200.00	200.00	0.50	20.00
projectToC	showFit	calcEasyRo	usedCf
1	1	1	1

Max age for kinetic plots

1060.58

Inverse model constraints

Num constraints

5

Time (Ma)	Upper (deg C)	Lower (deg C)
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0.000 20.000 20.000

14.791 184.293 25.131

21.865 25.131 25.131

80.386 185.340 24.084

198.714 197.906 197.906

Inverse model specs

Monte Carlo

Enforce Max Heating	Enforce Max Cooling	Monotonic	Watch It Go
---------------------	---------------------	-----------	-------------

0 1 1 1

Max Heat Rate	Max Cool Rate
---------------	---------------

10.0 10.0

Num Paths	Num Paths Run	Divs per seg
-----------	---------------	--------------

10000 10000 2

Time-temperature paths

Num Acceptable	Num Good
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261 44

17

Temperature (deg C)

Time (Ma)	Best fit	Min Acc	Max Acc	Min Good	Max Good
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0.000	20.000	20.000	20.000	20.000	20.000
3.698	43.627	20.012	56.921	20.719	56.476
7.395	79.779	20.094	86.964	23.325	82.722
11.093	80.520	48.279	89.682	59.190	88.172
14.791	80.534	79.115	102.901	80.534	98.839
16.559	64.456	29.586	95.240	33.938	92.612
18.328	58.749	25.322	90.844	26.236	88.463
20.096	33.176	25.293	84.309	25.461	67.394
21.865	25.131	25.131	25.131	25.131	25.131
36.495	32.546	25.132	80.832	25.297	62.302
51.125	77.071	25.170	88.397	26.381	77.071
65.756	79.891	25.349	137.351	29.972	86.230
80.386	80.235	25.467	181.143	30.537	93.881
109.968	99.702	32.757	195.833	88.245	183.933
139.550	102.573	81.204	197.638	88.536	197.638
169.132	175.382	96.188	197.895	122.698	197.704
198.714	197.906	197.906	197.906	197.906	197.906

Easy Ro Results

calc	equalAcc	meanAcc	sdAcc	equalGood	meanGood	sdGood
1	0	0.63	0.01	0	0.63	0.01

24117509

Model specs and results for AFTSOLVE.EXE, version 1.2

GU-23

TIME-TEMPERATURE PATH

1

Time (Ma)	Temperature (deg C)
0.000	20.000

KINETIC PARAMETERS
model: Ketcham et al. 1999
kinParUsed: Etch Pit Length
Initial track length model: Use kinetic parameter
L0 vs. kpar line defs:

0.2830	15.6300
0.2050	16.1000
0.5440	16.1800
0.4070	16.4900
0.0000	16.1800
0.0000	16.5700
0.1382	16.2880
0.1732	16.4950

Single L0 value:
16.30
Standard length reduction:
0.893000
Age calculation to use for data: Pooled
Dividers:
2
0.90
2.51

Model	Calc	Kin Par
1	0	0.45
2	1	1.74
3	0	3.76

MODEL RESULTS

pctPerTimeStep

1.00

41

length	pdf2	cdf2
0.0	0.00000	0.00000
0.5	0.00000	0.00000
1.0	0.00000	0.00000
1.5	0.00000	0.00000
2.0	0.00000	0.00000
2.5	0.00000	0.00000
3.0	0.00000	0.00000
3.5	0.00000	0.00000
4.0	0.00000	0.00000
4.5	0.00000	0.00000
5.0	0.00000	0.00000
5.5	0.00000	0.00000
6.0	0.00000	0.00000
6.5	0.00000	0.00000
7.0	0.00000	0.00000
7.5	0.00002	0.00000
8.0	0.00010	0.00003
8.5	0.00039	0.00016
9.0	0.00139	0.00060
9.5	0.00495	0.00219
10.0	0.01943	0.00828
10.5	0.06792	0.03012
11.0	0.17318	0.09040
11.5	0.29776	0.20813
12.0	0.34188	0.36804
12.5	0.27372	0.52194
13.0	0.17416	0.63391
13.5	0.11424	0.70601
14.0	0.09872	0.75925
14.5	0.10646	0.81054
15.0	0.11322	0.86546
15.5	0.09977	0.91871
16.0	0.06658	0.96029
16.5	0.03214	0.98497
17.0	0.01094	0.99574
17.5	0.00258	0.99912
18.0	0.00042	0.99987
18.5	0.00005	0.99999
19.0	0.00000	1.00000
19.5	0.00000	1.00000
20.0	0.00000	1.00000

DATA

Stratigraphic information

NumDefs	age1	age2
---------	------	------

2	10.40	21.50
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Quiamare Formation

Track length file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\VAIME\AFT\FTDD\FTDDUGPSAMPLES\LA\GU23B1.A1G
34

length	proj	len	kinPar
10.4100	11.2960	1.0800	
10.8000	11.7597	1.0800	
11.2200	12.1379	1.6800	
12.5300	14.2220	1.7200	
11.4900	12.8707	1.7200	
13.2700	13.4807	1.7200	
9.6200	12.4491	1.7200	
8.5900	12.3583	1.7200	
9.0600	11.5397	1.7700	
11.4600	12.2742	1.7700	
10.2100	12.5924	1.7700	
10.1500	12.8279	1.7700	
12.4100	12.8486	1.7700	
9.4900	11.1240	1.7700	
13.7600	14.5460	1.7700	
11.8200	13.7797	1.7700	
9.2000	11.1312	1.7700	
9.6600	12.5510	1.7700	
9.0500	12.4471	1.7700	
9.1600	11.4793	1.7700	
9.4200	11.9267	1.7700	
9.0200	12.7755	1.7700	
12.1800	12.6359	1.7700	
10.8000	13.0769	1.6300	
10.5400	12.9413	1.6300	
13.7400	14.6430	1.5300	
13.4600	14.0130	1.5300	
11.5600	13.4443	1.7800	
10.7700	12.8050	1.7800	
9.5600	12.6006	1.7800	
10.1300	11.9346	1.7800	
9.2300	11.5828	1.7800	
7.8100	12.3342	1.5500	
6.0200	11.4873	1.6200	

30064

Age file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\VAIME\AFT\FTDD\FTDDUGPSAMPLES\VA\GU23A1.A1G
6

ns	ni	kinPar	age	ageErr
1	9	1.75	37.38	39.48
7	167	1.80	14.13	5.52
10	142	1.73	23.72	7.90
5	64	2.40	26.31	12.33
1	22	2.26	15.32	15.69
4	20	1.89	67.13	37.02

13890

DISPLAY AND PARAMETER SPECIFICATIONS

maxTime	maxTemp	maxFreq	maxLength
80.00	200.00	0.50	20.00
projectToC	showFit	calcEasyRo	usedCf
1	1	1	1

Max age for kinetic plots

100.00

Inverse model constraints

Num constraints

6

Time (Ma) Upper (deg C) Lower (deg C)

0.000 20.000 20.000

13.891 184.293 25.131

20.579 25.131 25.131

40.900 185.340 24.084

78.199 196.859 196.859

79.486 197.906 197.906

Inverse model specs

Monte Carlo

Enforce Max Heating Enforce Max Cooling Monotonic Watch It Go

0 1 1 0

Max Heat Rate Max Cool Rate

10.0 10.0

Num Paths Num Paths Run Divs per seg

10000 10000 2

Time-temperature paths

Num Acceptable Num Good

153 0

21

Temperature (deg C)

Time (Ma) Best fit Min AccMax Acc

0.000 20.000 20.000 20.000

3.473 53.792 22.208 54.725

6.945 88.369 45.828 89.444

10.418 93.453 72.705 100.038

13.891 97.082 87.308 112.056

15.563 80.486 33.396 101.848

17.235 53.127 25.182 97.734

18.907 35.042 25.141 92.597

20.579 25.131 25.131 25.131

25.659 27.670 25.133 75.693

30.740 27.671 25.170 113.219

35.820 73.573 29.491 152.443

40.900 98.969 29.683 181.761

50.225 147.667 64.007 193.831

59.550 178.402 100.335 196.453

68.875 194.980 107.811 196.631

78.199 196.859 196.859 196.859

78.521 197.142 196.861 197.798

78.842 197.365 196.872 197.904

79.164 197.448 196.946 197.905

79.486 197.906 197.906 197.906

Easy Ro Results

calc equalAcc meanAcc sdAcc equalGood meanGood sdGood

1 0 0.64 0.00 1 0.00 0.00

23199897

Model specs and results for AFTSOLVE.EXE, version 1.2

GU-24

TIME-TEMPERATURE PATH

1

Time (Ma) Temperature (deg C)

0.000 20.000

KINETIC PARAMETERS

model: Ketcham et al. 1999

kinParUsed: Etch Pit Length

Initial track length model: Use kinetic parameter

L0 vs. kpar line defs:

0.2830 15.6300

0.2050 16.1000

0.5440 16.1800

0.4070 16.4900

0.0000 16.1800

0.0000 16.5700

0.1382 16.2880

0.1732 16.4950

Single L0 value:

16.30

Standard length reduction:

0.893000

Age calculation to use for data: Pooled

Dividers:

2

1.44

2.49

Model	Calc	Kin Par
1	0	0.72
2	1	1.81
3	0	3.74

MODEL RESULTS

pctPerTimeStep

1.00

41

length	pdf2	cdf2
0.0	0.00000	0.00000
0.5	0.00000	0.00000
1.0	0.00000	0.00000
1.5	0.00000	0.00000
2.0	0.00000	0.00000
2.5	0.00000	0.00000
3.0	0.00000	0.00000
3.5	0.00000	0.00000
4.0	0.00000	0.00000
4.5	0.00000	0.00000
5.0	0.00000	0.00000
5.5	0.00000	0.00000
6.0	0.00000	0.00000
6.5	0.00000	0.00000
7.0	0.00000	0.00000
7.5	0.00000	0.00000
8.0	0.00000	0.00000
8.5	0.00001	0.00001
9.0	0.00005	0.00002
9.5	0.00015	0.00007
10.0	0.00120	0.00041

10.5	0.00862	0.00287
11.0	0.04693	0.01676
11.5	0.16590	0.06997
12.0	0.36902	0.20370
12.5	0.51322	0.42426
13.0	0.44672	0.66424
13.5	0.24630	0.83750
14.0	0.09228	0.92214
14.5	0.03423	0.95377
15.0	0.02427	0.96840
15.5	0.02239	0.98006
16.0	0.01639	0.98976
16.5	0.00846	0.99597
17.0	0.00299	0.99883
17.5	0.00071	0.99976
18.0	0.00011	0.99996
18.5	0.00001	1.00000
19.0	0.00000	1.00000
19.5	0.00000	1.00000
20.0	0.00000	1.00000

DATA

Stratigraphic information

NumDefs	age1	age2
2	10.40	21.50

Quiamare Formation

Track length file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\JAIME\AFT\FTDD\FTDD\UGP\SAMPLES\L\LGU24B1.A1G
6

length	proj len	kinPar
9.8200	12.5539	1.7700
8.4100	12.1965	1.7700
6.1500	10.7858	1.7100
9.2400	12.3713	1.7100
13.6600	14.4382	1.8600
10.5100	11.7861	1.5200

3963

Age file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\JAIME\AFT\FTDD\FTDD\UGP\SAMPLES\A\AGU24A1.A1G
2

ns	ni	kinPar	age	ageErr
3	16	2.11	63.16	39.94
80	115	1.96	231.28	36.74

25545

DISPLAY AND PARAMETER SPECIFICATIONS

maxTime	maxTemp	maxFreq	maxLength
300.00	200.00	0.50	20.00

projectToC	showFit	calcEasyRo	usedCf
1	1	1	1

Max age for kinetic plots

400.00

Inverse model constraints

Num constraints

5

Time (Ma)	Upper (deg C)	Lower (deg C)
0.000	20.000	20.000
14.469	175.916	25.131


```

20.257 25.131 25.131
241.158 170.681 25.131
299.035 194.764 194.764
Inverse model specs
Monte Carlo
Enforce Max Heating      Enforce Max Cooling      Monotonic      Watch It Go
0          1          1          0
Max Heat Rate      Max Cool Rate
10.0      10.0
Num Paths      Num Paths Run      Divs per seg
10000      10000      2
Time-temperature paths
Num Acceptable      Num Good
1379      67
17
      Temperature (deg C)
Time (Ma)      Best fit      Min Acc      Max Acc      Min Good      Max Good
0.000      20.000      20.000      20.000      20.000      20.000
3.617      20.224      20.004      56.149      20.224      55.970
7.235      53.046      20.048      92.314      25.971      87.243
10.852      84.368      21.402      96.747      58.709      91.502
14.469      98.310      25.185      110.852      71.712      104.831
15.916      83.850      25.178      101.281      45.586      96.915
17.363      80.746      25.134      98.390      25.502      91.907
18.810      41.789      25.131      89.514      25.159      86.583
20.257      25.131      25.131      25.131      25.131      25.131
75.482      25.262      25.132      76.025      25.159      70.321
130.707      25.336      25.136      87.491      25.253      73.530
185.933      26.479      25.227      100.000      26.479      73.751
241.158      29.783      25.322      170.338      26.866      77.425
255.627      29.887      25.811      191.412      29.167      103.668
270.096      52.638      34.006      194.732      34.006      186.069
284.566      53.735      53.735      194.752      53.735      193.878
299.035      194.764      194.764      194.764      194.764      194.764
Easy Ro Results
calc      equalAcc      meanAcc      sdAcc      equalGood      meanGood      sdGood
1          0          0.65      0.01      0          0.65      0.01
24118627

```

Model specs and results for AFTSOLVE.EXE, version 1.2

GU-25

TIME-TEMPERATURE PATH

```

1
Time (Ma)      Temperature (deg C)
0.000      20.000
KINETIC PARAMETERS
model: Ketcham et al. 1999
kinParUsed: Etch Pit Length
Initial track length model: Use kinetic parameter
L0 vs. kpar line defs:

```

0.2830 15.6300

0.2050 16.1000

0.5440 16.1800

0.4070 16.4900

0.0000 16.1800

0.0000 16.5700

0.1382 16.2880

0.1732 16.4950

Single L0 value:

16.30

Standard length reduction:

0.893000

Age calculation to use for data: Pooled

Dividers:

2

0.75

2.75

Model	Calc	Kin Par
1	0	0.00
2	1	1.80
3	0	3.87

MODEL RESULTS

pctPerTimeStep

1.00

41

length	pdf2	cdf2
0.0	0.00000	0.00000
0.5	0.00000	0.00000
1.0	0.00000	0.00000
1.5	0.00000	0.00000
2.0	0.00000	0.00000
2.5	0.00000	0.00000
3.0	0.00000	0.00000
3.5	0.00000	0.00000
4.0	0.00000	0.00000
4.5	0.00000	0.00000
5.0	0.00000	0.00000
5.5	0.00000	0.00000
6.0	0.00000	0.00000
6.5	0.00000	0.00000
7.0	0.00000	0.00000
7.5	0.00000	0.00000
8.0	0.00002	0.00001
8.5	0.00011	0.00004
9.0	0.00041	0.00017
9.5	0.00112	0.00055
10.0	0.00313	0.00162
10.5	0.01103	0.00516
11.0	0.04538	0.01926
11.5	0.14984	0.06806
12.0	0.33356	0.18891
12.5	0.47701	0.39155
13.0	0.43568	0.61972
13.5	0.26152	0.79402
14.0	0.11722	0.88871
14.5	0.05717	0.93230

15.0	0.04091	0.95682
15.5	0.03182	0.97501
16.0	0.02030	0.98804
16.5	0.00962	0.99551
17.0	0.00325	0.99873
17.5	0.00077	0.99974
18.0	0.00013	0.99996
18.5	0.00001	1.00000
19.0	0.00000	1.00000
19.5	0.00000	1.00000
20.0	0.00000	1.00000

DATA

Stratigraphic information

NumDefs	age1	age2
---------	------	------

2	10.40	21.50
---	-------	-------

Quiamare Formation

Track length file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\AIME\AFT\FTDD\FTDDUGP\SAMPLES\LLGU25B1.AIG
10

length	proj len	kinPar
5.8700	11.1156	2.0800
12.2900	13.8339	1.8900
9.2700	11.6513	0.9300
11.2100	13.3901	0.9300
10.0600	10.1779	1.2600
13.1300	13.8146	2.0400
12.3200	12.4897	2.1200
10.3000	12.8000	2.1200
11.5000	12.7365	2.1200
10.1200	11.9331	2.1200

7884

Age file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\AIME\AFT\FTDD\FTDDUGP\SAMPLES\AAGU25A1.AIG
23

ns	ni	kinPar	age	ageErr
2	78	2.66	8.70	6.26
0	7	1.95	0.00	51.76
3	68	2.05	14.96	8.88
31	71	2.30	146.59	32.90
1	7	1.84	48.33	51.76
0	4	0.00	0.00	94.45
0	2	1.84	0.00	205.53
1	4	1.90	84.34	94.45
1	6	1.82	56.35	60.97
0	15	0.00	0.00	23.38
2	7	1.88	96.30	77.45
0	52	2.15	0.00	6.60
0	27	2.05	0.00	12.82
3	42	1.88	24.21	14.55
6	41	1.91	49.50	21.87
25	41	1.75	203.80	53.31
48	85	1.88	188.97	36.17
0	3	2.05	0.00	129.77
4	153	1.93	8.87	4.53
0	9	1.76	0.00	39.73
0	2	0.00	0.00	205.53

```

70      202      1.86  116.61  17.79
93      145      1.75  214.20  31.54
165162
DISPLAY AND PARAMETER SPECIFICATIONS
maxTime      maxTemp      maxFreqmaxLength
200.00 200.00  0.50   20.00
projectToC    showFit calcEasyRo    usedCf
1        1        1        1
Max age for kinetic plots
300.00
Inverse model constraints
Num constraints
6
Time (Ma)      Upper (deg C)  Lower (deg C)
0.000 20.000 20.000
14.791 181.152 24.084
21.222 25.131 25.131
108.039 178.010 25.131
198.714 196.859 196.859
298.071 198.953 198.953
Inverse model specs
Monte Carlo
Enforce Max Heating      Enforce Max Cooling      Monotonic      Watch It Go
0        1        1        0
Max Heat Rate      Max Cool Rate
10.0      10.0
Num Paths      Num Paths Run      Divs per seg
10000 10000 2
Time-temperature paths
Num Acceptable Num Good
750      138
21
      Temperature (deg C)
Time (Ma)      Best fit Min AccMax Acc      Min Good      Max Good
0.000 20.000 20.000 20.000 20.000 20.000
3.698 54.498 20.001 56.970 20.377 56.714
7.395 77.906 20.456 93.018 22.216 89.042
11.093 87.271 24.738 98.872 54.081 94.297
14.791 95.931 25.971 111.596 81.334 108.237
16.399 49.305 25.707 101.799 35.444 100.520
18.006 25.459 25.162 101.137 25.237 98.216
19.614 25.254 25.137 91.476 25.173 80.861
21.222 25.131 25.131 25.131 25.131 25.131
42.926 26.932 25.132 80.164 25.132 71.054
64.630 27.473 25.151 87.069 25.151 78.757
86.335 37.989 25.313 93.364 26.909 85.784
108.039 40.612 25.465 173.007 27.580 91.962
130.708 111.613 30.335 194.827 36.204 174.327
153.376 154.296 31.979 196.772 51.784 196.240
176.045 177.518 51.294 196.840 99.296 196.760
198.714 196.859 196.859 196.859 196.859 196.859
223.553 197.779 196.859 198.808 196.860 198.610
248.393 197.960 196.859 198.948 196.868 198.929
273.232 198.381 197.031 198.952 197.031 198.952
298.071 198.953 198.953 198.953 198.953 198.953
Easy Ro Results

```

calc	equalAcc	meanAcc	sdAcc	equalGood	meanGood	sdGood
1	0	0.65	0.01	0	0.65	0.01
24117998						

Model specs and results for AFTSOLVE.EXE, version 1.2

GU-26

TIME-TEMPERATURE PATH

1
Time (Ma) Temperature (deg C)
0.000 20.000
KINETIC PARAMETERS
model: Ketcham et al. 1999
kinParUsed: Etch Pit Length
Initial track length model: Use kinetic parameter
L0 vs. kpar line defs:
0.2830 15.6300
0.2050 16.1000
0.5440 16.1800
0.4070 16.4900
0.0000 16.1800
0.0000 16.5700
0.1382 16.2880
0.1732 16.4950
Single L0 value:
16.30
Standard length reduction:
0.893000
Age calculation to use for data: Pooled
Dividers:
2
1.24
2.64
Model Calc Kin Par
1 0 0.00
2 1 1.85
3 0 3.82
MODEL RESULTS
pctPerTimeStep
1.00
41
length pdf2 cdf2
0.0 0.00000 0.00000
0.5 0.00000 0.00000
1.0 0.00000 0.00000
1.5 0.00000 0.00000
2.0 0.00000 0.00000
2.5 0.00000 0.00000
3.0 0.00000 0.00000
3.5 0.00000 0.00000
4.0 0.00000 0.00000

4.5	0.00000	0.00000
5.0	0.00000	0.00000
5.5	0.00000	0.00000
6.0	0.00000	0.00000
6.5	0.00000	0.00000
7.0	0.00000	0.00000
7.5	0.00002	0.00001
8.0	0.00008	0.00003
8.5	0.00025	0.00011
9.0	0.00070	0.00035
9.5	0.00227	0.00109
10.0	0.00873	0.00384
10.5	0.03435	0.01461
11.0	0.10378	0.04915
11.5	0.21221	0.12814
12.0	0.28454	0.25233
12.5	0.25709	0.38774
13.0	0.18029	0.49708
13.5	0.13764	0.57657
14.0	0.13955	0.64587
14.5	0.15579	0.71970
15.0	0.16352	0.79953
15.5	0.14592	0.87689
16.0	0.10062	0.93852
16.5	0.05019	0.97623
17.0	0.01749	0.99315
17.5	0.00419	0.99857
18.0	0.00068	0.99979
18.5	0.00008	0.99998
19.0	0.00001	1.00000
19.5	0.00000	1.00000
20.0	0.00000	1.00000

DATA

Stratigraphic information

NumDefs	age1	age2
---------	------	------

2	10.40	21.50
---	-------	-------

Quiamare Formation

Track length file and data

C:\DOCUME~1\JPerez\MYDOCU~1\JAIME\AFT\FTDD\FTDD\JGP\SAMPLES\VL\GU26B1.A1G

1

length	proj len	kinPar
--------	----------	--------

9.8500	11.3545	1.3900
--------	---------	--------

594

Age file and data

C:\DOCUME~1\JPerez\MYDOCU~1\JAIME\AFT\FTDD\FTDD\JGP\SAMPLES\VA\GU26A1.A1G

7

ns	ni	kinPar	age	ageErr
8	105	2.07	24.75	9.21
1	21	1.70	15.48	15.88
0	1	0.00	0.00	449.58
0	6	2.32	0.00	58.46
1	8	1.64	40.56	43.10
1	17	1.70	19.12	19.71
2	5	2.14	128.91	108.17

20073

DISPLAY AND PARAMETER SPECIFICATIONS

```

maxTime      maxTemp      maxFreqmaxLength
60.00 200.00 0.50 20.00
projectToC    showFit calcEasyRo    usedCf
1          1          1          1
Max age for kinetic plots
300.00
Inverse model constraints
Num constraints
5
Time (Ma)      Upper (deg C)  Lower (deg C)
0.000 20.000 20.000
14.469 180.105 25.131
20.064 25.131 25.131
33.183 179.058 25.131
59.421 197.906 197.906
Inverse model specs
Monte Carlo
Enforce Max Heating  Enforce Max Cooling  Monotonic  Watch It Go
0          1          1          0
Max Heat Rate  Max Cool Rate
10.0 10.0
Num Paths      Num Paths Run  Divs per seg
10000 10000 2
Time-temperature paths
Num Acceptable Num Good
2119 844
17
      Temperature (deg C)
Time (Ma)  Best fit  Min AccMax Acc      Min Good      Max Good
0.000 20.000 20.000 20.000 20.000 20.000
3.617 36.858 20.011 56.165 20.031 56.163
7.235 72.426 20.087 92.311 22.916 92.251
10.852 82.656 21.206 111.814 45.631 104.484
14.469 109.285 25.566 134.669 53.601 119.473
15.868 82.145 25.332 129.276 27.423 110.694
17.267 37.009 25.137 128.805 25.281 109.908
18.665 33.123 25.134 127.272 25.153 97.098
20.064 25.131 25.131 25.131 25.131 25.131
23.344 25.559 25.131 57.928 25.133 57.926
26.623 26.979 25.136 90.721 25.136 90.716
29.903 55.445 25.333 123.487 25.333 123.487
33.183 72.988 25.340 156.271 25.792 156.271
39.742 134.685 30.043 194.189 30.228 193.593
46.302 196.278 66.717 197.855 66.990 197.855
52.861 197.301 132.312 197.903 132.312 197.887
59.421 197.906 197.906 197.906 197.906 197.906
Easy Ro Results
calc      equalAcc      meanAcc      sdAcc  equalGood      meanGood      sdGood
1          0          0.68 0.01 0 0.67 0.01
24119367

```

Model specs and results for AFTSOLVE.EXE, version 1.2

GU-28

TIME-TEMPERATURE PATH

1
 Time (Ma) Temperature (deg C)
 0.000 20.000
KINETIC PARAMETERS
 model: Ketcham et al. 1999
 kinParUsed: Etch Pit Length
 Initial track length model: Use kinetic parameter
 L0 vs. kpar line defs:
 0.2830 15.6300
 0.2050 16.1000
 0.5440 16.1800
 0.4070 16.4900
 0.0000 16.1800
 0.0000 16.5700
 0.1382 16.2880
 0.1732 16.4950
 Single L0 value:
 16.30
 Standard length reduction:
 0.893000
 Age calculation to use for data: Pooled
 Dividers:

2
 0.69
 2.90

Model	Calc	Kin Par
1	0	0.00
2	1	1.87
3	0	3.95

MODEL RESULTS

pctPerTimeStep
 1.00
 41

length	pdf2	cdf2
0.0	0.00000	0.00000
0.5	0.00000	0.00000
1.0	0.00000	0.00000
1.5	0.00000	0.00000
2.0	0.00000	0.00000
2.5	0.00000	0.00000
3.0	0.00000	0.00000
3.5	0.00000	0.00000
4.0	0.00000	0.00000
4.5	0.00000	0.00000
5.0	0.00000	0.00000
5.5	0.00000	0.00000
6.0	0.00000	0.00000
6.5	0.00000	0.00000
7.0	0.00000	0.00000
7.5	0.00004	0.00001
8.0	0.00045	0.00013
8.5	0.00283	0.00095
9.0	0.01293	0.00489

9.5	0.04078	0.01832
10.0	0.08661	0.05017
10.5	0.12295	0.10256
11.0	0.11904	0.16306
11.5	0.08682	0.21452
12.0	0.06561	0.25263
12.5	0.07541	0.28789
13.0	0.11275	0.33493
13.5	0.16497	0.40436
14.0	0.21447	0.49922
14.5	0.24420	0.61389
15.0	0.24067	0.73510
15.5	0.19688	0.84449
16.0	0.12609	0.92523
16.5	0.06008	0.97177
17.0	0.02056	0.99193
17.5	0.00494	0.99830
18.0	0.00082	0.99974
18.5	0.00009	0.99997
19.0	0.00001	1.00000
19.5	0.00000	1.00000
20.0	0.00000	1.00000

DATA

Stratigraphic information

NumDefs	age1	age2
2	10.40	21.50

Quiamare Formation

Track length file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\VAIME\AFT\FTDD\FTDDUGPSAMPLES\VLGU28C1.A1G

2

length	proj len	kinPar
7.3200	8.3621	1.0600
11.4900	13.5271	2.4400

1239

Age file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\VAIME\AFT\FTDD\FTDDUGPSAMPLES\AVAGU28B1.A1G

7

ns	ni	kinPar	age	ageErr
0	18	2.85	0.00	18.47
0	25	1.75	0.00	13.20
1	5	2.09	64.35	70.61
1	26	0.90	12.43	12.69
1	26	1.96	12.43	12.69
0	4	0.00	0.00	89.97
24	444	2.07	17.46	3.82

8269

DISPLAY AND PARAMETER SPECIFICATIONS

maxTime	maxTemp	maxFreq	maxLength
40.00	200.00	0.50	20.00

projectToC	showFit	calcEasyRo	usedCf
1	1	1	1

Max age for kinetic plots

100.00

Inverse model constraints

Num constraints

5

```

Time (Ma)      Upper (deg C)  Lower (deg C)
0.000  20.000  20.000
14.148 188.482 25.131
20.064 25.131 25.131
22.122 190.576 25.131
39.871 195.812 195.812
Inverse model specs
Monte Carlo
Enforce Max Heating  Enforce Max Cooling  Monotonic  Watch It Go
0      1      1      1
Max Heat Rate  Max Cool Rate
10.0  10.0
Num Paths      Num Paths Run  Divs per seg
10000 10000 2
Time-temperature paths
Num Acceptable Num Good
3163  392
17
      Temperature (deg C)
Time (Ma)  Best fit  Min Acc  Max Acc  Min Good  Max Good
0.000  20.000  20.000  20.000  20.000  20.000
3.537  53.372  20.363  55.369  20.363  55.369
7.074  75.758  38.826  90.738  43.418  90.738
10.611 88.294  72.344 121.138  78.150 108.405
14.148 119.910 96.679 156.039 104.356 124.665
15.627 90.862  28.570 153.874  31.560 118.179
17.106 51.654  25.132 151.771  25.822 113.185
18.585 50.140  25.132 142.897  25.142 111.064
20.064 25.131  25.131  25.131  25.131  25.131
20.579 30.273  25.131  30.275  25.132  30.274
21.093 35.389  25.132  35.419  25.170  35.416
21.608 37.310  25.168  40.557  25.269  40.538
22.122 38.050  25.232  45.702  25.433  45.682
26.559 77.578  62.809  89.696  63.308  89.696
30.997 114.216 107.067 133.947 107.144 133.947
35.434 152.910 151.439 177.067 151.452 177.067
39.871 195.812 195.812 195.812 195.812 195.812
Easy Ro Results
calc  equalAcc  meanAcc  sdAcc  equalGood  meanGood  sdGood
1      0      0.69  0.01  0      0.68  0.00
23202907

```

Model specs and results for AFTSOLVE.EXE, version 1.2

GU-29

TIME-TEMPERATURE PATH

```

1
Time (Ma)      Temperature (deg C)
0.000  20.000
KINETIC PARAMETERS
model: Ketcham et al. 1999

```

kinParUsed: Etch Pit Length
Initial track length model: Use kinetic parameter

L0 vs. kpar line defs:

0.2830 15.6300

0.2050 16.1000

0.5440 16.1800

0.4070 16.4900

0.0000 16.1800

0.0000 16.5700

0.1382 16.2880

0.1732 16.4950

Single L0 value:

16.30

Standard length reduction:

0.893000

Age calculation to use for data: Pooled

Dividers:

2

1.18

2.73

Model	Calc	Kin Par
1	0	0.59
2	1	1.97
3	0	3.86

MODEL RESULTS

pctPerTimeStep

1.00

41

length	pdf2	cdf2
0.0	0.00000	0.00000
0.5	0.00000	0.00000
1.0	0.00000	0.00000
1.5	0.00000	0.00000
2.0	0.00000	0.00000
2.5	0.00000	0.00000
3.0	0.00000	0.00000
3.5	0.00000	0.00000
4.0	0.00000	0.00000
4.5	0.00000	0.00000
5.0	0.00000	0.00000
5.5	0.00000	0.00000
6.0	0.00000	0.00000
6.5	0.00000	0.00000
7.0	0.00000	0.00000
7.5	0.00001	0.00000
8.0	0.00004	0.00002
8.5	0.00013	0.00006
9.0	0.00034	0.00018
9.5	0.00148	0.00063
10.0	0.00788	0.00297
10.5	0.03867	0.01461
11.0	0.13404	0.05779
11.5	0.30195	0.16679
12.0	0.43324	0.35058
12.5	0.39656	0.55803
13.0	0.23851	0.71680

13.5	0.10858	0.80357
14.0	0.06067	0.84588
14.5	0.06028	0.87612
15.0	0.06909	0.90846
15.5	0.06607	0.94225
16.0	0.04728	0.97059
16.5	0.02413	0.98844
17.0	0.00857	0.99662
17.5	0.00209	0.99928
18.0	0.00035	0.99989
18.5	0.00004	0.99999
19.0	0.00000	1.00000
19.5	0.00000	1.00000
20.0	0.00000	1.00000

DATA

Stratigraphic information

NumDefs	age1	age2
---------	------	------

2	10.40	21.50
---	-------	-------

Quiamare Formation

Track length file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\AIME\AFT\FTDD\FTDD\GPSAMPLES\1\LGU29D1.A1G
22

length	proj len	kinPar
8.8600	11.9452	1.9500
3.4100	11.6023	1.9500
8.3500	11.7372	1.6000
12.1400	13.3937	1.8700
13.7700	14.7479	1.8700
9.3700	12.5614	1.8700
14.1800	14.5938	1.8700
11.9500	12.7208	1.8700
9.6600	12.3277	1.8700
10.7200	13.0947	1.8700
12.2700	12.5788	1.8700
9.4100	11.9381	1.6900
10.4700	12.8386	1.6900
9.3000	9.7220	1.6900
10.1200	12.5995	1.9200
10.6900	12.8314	1.9200
10.3700	11.8347	1.9200
7.4500	10.9035	1.9200
7.4600	12.5400	1.9200
10.0900	12.4147	1.8700
9.9900	11.6706	1.8700
10.0500	12.2178	1.8700

17251

Age file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\AIME\AFT\FTDD\FTDD\GPSAMPLES\1\AGU29C1.A1G
10

ns	ni	kinPar	age	ageErr
3	9	2.23	106.54	71.35
1	10	1.97	32.15	33.78
26	53	1.66	156.20	38.69
10	89	2.17	36.11	12.26
1	9	2.56	35.71	37.71
1	37	2.28	8.70	8.84

3	187	1.44	5.17	3.03
19	89	1.55	68.44	17.83
25	27	1.39	291.71	83.06
0	4	1.95	0.00	89.67

81783

DISPLAY AND PARAMETER SPECIFICATIONS

maxTime	maxTemp	maxFreq	maxLength
100.00	200.00	0.50	20.00
projectToC	showFit	calcEasyRo	usedCf
1	1	1	1

Max age for kinetic plots

100.00

Inverse model constraints

Num constraints

5

Time (Ma)	Upper (deg C)	Lower (deg C)
0.000	20.000	20.000
14.148	188.482	25.131
20.579	25.131	25.131
64.952	190.576	25.131
98.714	197.906	197.906

Inverse model specs

Monte Carlo

Enforce Max Heating	Enforce Max Cooling	Monotonic	Watch It Go
0	1	1	0

Max Heat Rate

10.0

Max Cool Rate

10.0

Num Paths	Num Paths Run	Divs per seg
10000	10000	2

Time-temperature paths

Num Acceptable	Num Good
437	52
17	

	Temperature (deg C)				
Time (Ma)	Best fit	Min Acc	Max Acc	Min Good	Max Good
0.000	20.000	20.000	20.000	20.000	20.000
3.537	37.636	20.035	55.342	23.808	55.237
7.074	71.588	34.176	90.440	36.694	90.229
10.611	102.552	67.366	105.190	70.675	102.671
14.148	104.317	94.395	120.665	100.817	116.505
15.756	89.071	28.515	112.359	30.363	106.592
17.363	69.241	25.604	107.828	25.613	104.654
18.971	48.421	25.157	103.303	25.165	90.866
20.579	25.131	25.131	25.131	25.131	25.131
31.752	25.624	25.132	89.981	25.132	74.737
42.926	26.967	25.155	95.717	25.168	83.280
54.100	27.075	25.416	107.753	25.450	86.348
65.273	27.415	25.447	188.490	25.493	98.521
73.633	29.109	27.244	189.323	29.109	109.437
81.994	49.982	32.336	197.645	49.982	155.650
90.354	126.156	114.511	197.905	115.301	196.913
98.714	197.906	197.906	197.906	197.906	197.906

Easy Ro Results

calc	equalAcc	meanAcc	sdAcc	equalGood	meanGood	sdGood
1	0	0.72	0.01	0	0.72	0.01

23200181

Model specs and results for AFTSOLVE.EXE, version 1.2

PFT-06

TIME-TEMPERATURE PATH

1
 Time (Ma) Temperature (deg C)
 0.000 20.000
 KINETIC PARAMETERS
 model: Ketcham et al. 1999
 kinParUsed: Etch Pit Length
 Initial track length model: Use kinetic parameter
 L0 vs. kpar line defs:
 0.2830 15.6300
 0.2050 16.1000
 0.5440 16.1800
 0.4070 16.4900
 0.0000 16.1800
 0.0000 16.5700
 0.1382 16.2880
 0.1732 16.4950
 Single L0 value:
 16.30
 Standard length reduction:
 0.893000
 Age calculation to use for data: Pooled
 Dividers:

2
 0.84
 3.58

Model	Calc	Kin Par
1	0	0.00
2	1	2.26
3	0	4.29

MODEL RESULTS

pctPerTimeStep
 1.00
 41

length	pdf2	cdf2
0.0	0.00000	0.00000
0.5	0.00000	0.00000
1.0	0.00000	0.00000
1.5	0.00000	0.00000
2.0	0.00000	0.00000
2.5	0.00000	0.00000
3.0	0.00000	0.00000
3.5	0.00000	0.00000
4.0	0.00000	0.00000
4.5	0.00000	0.00000
5.0	0.00000	0.00000
5.5	0.00000	0.00000

6.0	0.00000	0.00000
6.5	0.00000	0.00000
7.0	0.00001	0.00000
7.5	0.00010	0.00003
8.0	0.00050	0.00018
8.5	0.00182	0.00076
9.0	0.00504	0.00248
9.5	0.01089	0.00646
10.0	0.01903	0.01394
10.5	0.02795	0.02568
11.0	0.03716	0.04196
11.5	0.04947	0.06361
12.0	0.06770	0.09290
12.5	0.08939	0.13218
13.0	0.10877	0.18172
13.5	0.12463	0.24006
14.0	0.14973	0.30865
14.5	0.20437	0.39718
15.0	0.28064	0.51843
15.5	0.31882	0.66829
16.0	0.26644	0.81461
16.5	0.15550	0.92009
17.0	0.06196	0.97446
17.5	0.01669	0.99412
18.0	0.00302	0.99905
18.5	0.00037	0.99989
19.0	0.00003	0.99999
19.5	0.00000	1.00000
20.0	0.00000	1.00000

DATA

Stratigraphic information

NumDefs	age1	age2
0	0.00	0.00

Track length file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\AIME\AFT\FTDD\FTDD\GPG\SAMPLES\LA\LPFT6B1.A1G
13

length	proj	len	kinPar
11.6200	13.7647	2.4500	
16.2600	16.5930	2.0400	
14.2900	15.3458	2.5900	
11.4300	11.6128	1.3600	
12.5400	14.2292	2.1800	
15.8400	16.3097	2.4100	
11.3300	13.1033	1.0600	
16.2300	16.5645	3.3000	
12.5700	14.2620	3.3000	
14.1700	15.1068	2.2100	
12.7300	13.8810	1.4800	
11.7900	13.8346	2.4800	
14.5500	15.4336	2.0300	

13638

Age file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\AIME\AFT\FTDD\FTDD\GPG\SAMPLES\LA\LPFT6A1.A2G
41

ns	ni	kinPar	age	ageErr
----	----	--------	-----	--------

0	6	1.81	0.00	48.38
5	62	2.55	21.68	10.17
1	5	1.29	53.62	58.84
1	12	2.15	22.40	23.36
0	9	1.57	0.00	31.52
1	13	2.13	20.68	21.50
0	7	2.03	0.00	41.07
1	8	1.73	33.57	35.67
2	5	1.86	106.80	89.62
2	11	1.71	48.77	37.61
1	23	1.64	11.70	11.97
0	10	1.86	0.00	28.23
0	11	1.30	0.00	25.56
1	5	1.59	53.62	58.84
0	11	1.26	0.00	25.56
1	12	2.12	22.40	23.36
1	6	1.78	44.72	48.38
0	7	2.10	0.00	41.07
1	18	2.10	14.94	15.38
0	7	1.59	0.00	41.07
1	6	1.64	44.72	48.38
0	4	1.65	0.00	74.98
1	31	3.46	8.68	8.84
0	5	0.00	0.00	58.84
1	8	2.17	33.57	35.67
0	13	2.02	0.00	21.50
1	4	1.85	66.96	74.98
1	9	1.98	29.85	31.52
0	7	0.00	0.00	41.07
0	7	1.47	0.00	41.07
0	9	1.63	0.00	31.52
0	11	0.00	0.00	25.56
0	9	3.16	0.00	31.52
0	16	1.72	0.00	17.36
0	4	0.00	0.00	74.98
0	4	1.23	0.00	74.98
3	24	2.23	33.57	20.67
3	18	1.90	44.72	28.03
1	8	1.53	33.57	35.67
0	13	0.00	0.00	21.50
1	29	1.56	9.28	9.45

91044

DISPLAY AND PARAMETER SPECIFICATIONS

maxTime	maxTemp	maxFreq	maxLength
150.00	200.00	0.50	20.00
projectToC	showFit	calcEasyRo	usedCf
1	1	1	1

Max age for kinetic plots
301.35

Inverse model constraints

Num constraints
5

Time (Ma)	Upper (deg C)	Lower (deg C)
0.000	20.000	20.000
25.080	171.728	21.990
86.334	25.131	25.131

146.624 196.859 196.859

194.212 193.717 193.717

Inverse model specs

Monte Carlo

Enforce Max Heating

Enforce Max Cooling

Monotonic

Watch It Go

0 0 1 0

Max Heat Rate Max Cool Rate

10.0 10.0

Num Paths

Num Paths Run

Divs per seg

10000 10000 2

Time-temperature paths

Num Acceptable Num Good

2440 740

17

Temperature (deg C)

Time (Ma)

Best fit

Min AccMax Acc

Min Good

Max Good

0.000 20.000 20.000 20.000 20.000 20.000

6.270 20.728 20.001 112.736 20.029 85.148

12.540 94.150 20.034 154.474 30.847 122.155

18.810 126.380 26.286 170.121 78.734 159.918

25.080 134.002 120.602 171.681 124.594 171.681

40.394 130.825 27.498 170.971 27.498 170.295

55.707 89.468 25.141 170.260 25.141 170.260

71.021 54.525 25.133 159.004 25.133 157.036

86.334 25.131 25.131 25.131 25.131 25.131

101.406 28.096 25.141 195.761 25.160 185.599

116.479 29.490 25.141 196.801 25.644 196.801

131.552 31.029 30.377 196.857 31.029 196.836

146.624 196.859 196.859 196.859 196.859 196.859

158.521 195.030 193.889 196.859 193.889 196.859

170.418 194.815 193.719 196.859 193.719 196.858

182.315 193.910 193.717 196.793 193.717 196.793

194.212 193.717 193.717 193.717 193.717 193.717

Easy Ro Results

calc equalAcc

meanAcc

sdAcc

equalGood

meanGood

sdGood

1 0 0.85 0.02 0 0.85 0.01

44960136

Model specs and results for AFTSOLVE.EXE, version 1.2

PFT-08***TIME-TEMPERATURE PATH***

1

Time (Ma)

Temperature (deg C)

0.000 20.000

KINETIC PARAMETERS

model: Ketcham et al. 1999

kinParUsed: Etch Pit Length

Initial track length model: Use kinetic parameter

L0 vs. kpar line defs:

0.2830 15.6300

0.2050 16.1000

0.5440 16.1800
 0.4070 16.4900
 0.0000 16.1800
 0.0000 16.5700
 0.1382 16.2880
 0.1732 16.4950
 Single L0 value:
 16.30
 Standard length reduction:
 0.893000
 Age calculation to use for data: Pooled
 Dividers:
 2
 1.33
 2.83

Model	Calc	Kin Par
1	0	0.00
2	1	2.11
3	0	3.92

 MODEL RESULTS
 pctPerTimeStep
 1.00
 41

length	pdf2	cdf2
0.0	0.00000	0.00000
0.5	0.00000	0.00000
1.0	0.00000	0.00000
1.5	0.00000	0.00000
2.0	0.00000	0.00000
2.5	0.00000	0.00000
3.0	0.00000	0.00000
3.5	0.00000	0.00000
4.0	0.00000	0.00000
4.5	0.00000	0.00000
5.0	0.00000	0.00000
5.5	0.00000	0.00000
6.0	0.00000	0.00000
6.5	0.00000	0.00000
7.0	0.00000	0.00000
7.5	0.00001	0.00000
8.0	0.00005	0.00002
8.5	0.00022	0.00009
9.0	0.00067	0.00031
9.5	0.00162	0.00088
10.0	0.00336	0.00213
10.5	0.00625	0.00453
11.0	0.01080	0.00879
11.5	0.01759	0.01588
12.0	0.02741	0.02713
12.5	0.04281	0.04469
13.0	0.07288	0.07361
13.5	0.13646	0.12595
14.0	0.24417	0.22111
14.5	0.35896	0.37189
15.0	0.40170	0.56206
15.5	0.33422	0.74603

16.0	0.20618	0.88114
16.5	0.09413	0.95621
17.0	0.03148	0.98761
17.5	0.00758	0.99738
18.0	0.00129	0.99959
18.5	0.00015	0.99996
19.0	0.00001	1.00000
19.5	0.00000	1.00000
20.0	0.00000	1.00000

DATA

Stratigraphic information

NumDefs	age1	age2
2	52.00	74.50

Guárico Formation

Track length file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\JAIME\AFT\FTDD\FTDD\UGP\SAMPLES\A\LPFT8B1.A1G
5

length	proj len	kinPar
12.1200	13.9195	2.7700
14.2800	15.3686	2.5600
13.8500	14.8357	1.8500
14.7300	15.3943	1.8500
10.4900	12.0237	1.8500

4728

Age file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\JAIME\AFT\FTDD\FTDD\UGP\SAMPLES\A\APFT8A1.A2G
43

ns	ni	kinPar	age	ageErr
1	23	1.76	11.74	12.02
0	5	0.00	0.00	59.08
0	5	2.32	0.00	59.08
0	7	2.09	0.00	41.23
2	83	1.64	6.51	4.68
1	16	1.68	16.87	17.43
2	46	1.68	11.74	8.51
0	1	0.00	0.00	374.87
10	143	1.47	18.88	6.29
0	7	0.00	0.00	41.23
0	10	2.09	0.00	28.34
0	4	1.56	0.00	75.28
4	73	1.80	14.79	7.66
3	93	1.58	8.71	5.14
0	12	1.48	0.00	23.45
1	45	1.74	6.00	6.08
0	11	0.00	0.00	25.67
0	6	2.06	0.00	48.58
0	52	1.71	0.00	5.26
2	15	2.38	35.94	27.15
2	41	1.49	13.17	9.58
0	17	1.87	0.00	16.37
0	7	0.00	0.00	41.23
3	9	1.65	89.48	59.92
0	3	0.00	0.00	103.48
1	5	2.34	53.84	59.08
3	14	2.04	57.67	36.87
0	9	0.00	0.00	31.64

2	16	2.15	33.70	25.37
0	8	2.29	0.00	35.81
0	6	0.00	0.00	48.58
1	24	1.55	11.25	11.51
3	13	1.54	62.08	39.96
2	9	2.18	59.79	46.90
1	18	1.51	15.00	15.44
1	20	2.02	13.50	13.86
1	12	1.92	22.49	23.45
0	17	2.34	0.00	16.37
1	14	2.00	19.28	19.99
1	13	1.44	20.76	21.58
1	11	2.04	24.53	25.67
3	18	2.44	44.90	28.14
1	25	1.84	10.80	11.04

80140

DISPLAY AND PARAMETER SPECIFICATIONS

maxTime	maxTemp	maxFreq	maxLength
---------	---------	---------	-----------

100.00	200.00	0.50	20.00
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projectToC	showFit	calcEasyRo	usedCf
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1	1	1	1
---	---	---	---

Max age for kinetic plots

374.87

Inverse model constraints

Num constraints

4

Time (Ma)	Upper (deg C)	Lower (deg C)
-----------	---------------	---------------

0.000	20.000	20.000
-------	--------	--------

17.363	190.576	25.131
--------	---------	--------

65.273	25.131	25.131
--------	--------	--------

99.035	196.859	196.859
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Inverse model specs

Monte Carlo

Enforce Max Heating	Enforce Max Cooling	Monotonic	Watch It Go
---------------------	---------------------	-----------	-------------

0	0	1	1
---	---	---	---

Max Heat Rate	Max Cool Rate
---------------	---------------

10.0	10.0
------	------

Num Paths	Num Paths Run	Divs per seg
-----------	---------------	--------------

10000	10000	2
-------	-------	---

Time-temperature paths

Num Acceptable	Num Good
----------------	----------

2585	1139
------	------

13

Temperature (deg C)

Time (Ma)	Best fit	Min Acc	Max Acc	Min Good	Max Good
-----------	----------	---------	---------	----------	----------

0.000	20.000	20.000	20.000	20.000	20.000
-------	--------	--------	--------	--------	--------

4.341	55.494	20.000	105.393	20.000	87.386
-------	--------	--------	---------	--------	--------

8.682	56.219	20.003	120.770	20.003	108.458
-------	--------	--------	---------	--------	---------

13.023	81.622	21.229	189.466	21.229	125.747
--------	--------	--------	---------	--------	---------

17.363	146.096	114.383	190.542	117.851	190.500
--------	---------	---------	---------	---------	---------

29.341	123.993	27.723	189.189	29.563	189.147
--------	---------	--------	---------	--------	---------

41.318	120.066	25.208	188.481	25.208	188.481
--------	---------	--------	---------	--------	---------

53.296	73.514	25.138	184.954	25.192	184.954
--------	--------	--------	---------	--------	---------

65.273	25.131	25.131	25.131	25.131	25.131
--------	--------	--------	--------	--------	--------

73.714	79.782	25.141	194.571	25.141	194.571
--------	--------	--------	---------	--------	---------

82.154	143.166	25.240	196.838	25.819	196.829
--------	---------	--------	---------	--------	---------

90.595 165.059 32.119 196.855 32.119 196.848
 99.035 196.859 196.859 196.859 196.859 196.859

Easy Ro Results

calc	equalAcc	meanAcc	sdAcc	equalGood	meanGood	sdGood
1	0	0.78	0.01	0	0.78	0.01

36178457

Model specs and results for AFTSOLVE.EXE, version 1.2

PFT-12

TIME-TEMPERATURE PATH

1
 Time (Ma) Temperature (deg C)
 0.000 20.000
 KINETIC PARAMETERS
 model: Ketcham et al. 1999
 kinParUsed: Etch Pit Length
 Initial track length model: Use kinetic parameter
 L0 vs. kpar line defs:
 0.2830 15.6300
 0.2050 16.1000
 0.5440 16.1800
 0.4070 16.4900
 0.0000 16.1800
 0.0000 16.5700
 0.1382 16.2880
 0.1732 16.4950
 Single L0 value:
 16.30
 Standard length reduction:
 0.893000
 Age calculation to use for data: Pooled
 Dividers:

2
 0.86
 2.73

Model	Calc	Kin Par
1	0	0.00
2	1	1.81
3	0	4.32

MODEL RESULTS

pctPerTimeStep

1.00
 41

length	pdf2	cdf2
0.0	0.00000	0.00000
0.5	0.00000	0.00000
1.0	0.00000	0.00000
1.5	0.00000	0.00000
2.0	0.00000	0.00000
2.5	0.00000	0.00000
3.0	0.00000	0.00000

3.5	0.00000	0.00000
4.0	0.00000	0.00000
4.5	0.00000	0.00000
5.0	0.00000	0.00000
5.5	0.00000	0.00000
6.0	0.00000	0.00000
6.5	0.00000	0.00000
7.0	0.00000	0.00000
7.5	0.00003	0.00001
8.0	0.00011	0.00004
8.5	0.00032	0.00015
9.0	0.00064	0.00039
9.5	0.00093	0.00078
10.0	0.00126	0.00133
10.5	0.00217	0.00218
11.0	0.00425	0.00379
11.5	0.00774	0.00679
12.0	0.01256	0.01186
12.5	0.01904	0.01976
13.0	0.02926	0.03184
13.5	0.05253	0.05229
14.0	0.11424	0.09398
14.5	0.24152	0.18292
15.0	0.39848	0.34292
15.5	0.46383	0.55850
16.0	0.36721	0.76626
16.5	0.19518	0.90685
17.0	0.06934	0.97298
17.5	0.01645	0.99443
18.0	0.00261	0.99920
18.5	0.00028	0.99992
19.0	0.00002	0.99999
19.5	0.00000	1.00000
20.0	0.00000	1.00000

DATA

Stratigraphic information

NumDefs	age1	age2
---------	------	------

2	52.00	74.50
---	-------	-------

Guárico Formation

Track length file and data

C:\DOCUME~1\JPEREZ\MYDOCU~1\VAIME\AFT\FTDD\FTDDUGPSAMPLES\LLPFT12B1.A1G

3

length	proj len	kinPar
--------	----------	--------

14.6100	15.6034	2.5200
---------	---------	--------

15.5800	16.1842	2.5200
---------	---------	--------

13.0900	13.2709	2.1200
---------	---------	--------

3117

Age file and data

C:\DOCUME~1\JPEREZ\MYDOCU~1\VAIME\AFT\FTDD\FTDDUGPSAMPLES\VAAPFT12A1.A2G

28

ns	ni	kinPar	age	ageErr
1	7	1.32	38.96	41.73
1	2	2.30	135.35	165.99
8	107	1.92	20.42	7.60
4	91	1.97	12.01	6.18
0	8	0.00	0.00	36.24

1	60	1.86	4.56	4.60
0	17	0.00	0.00	16.57
0	13	0.00	0.00	21.84
0	6	0.00	0.00	49.16
4	97	1.59	11.27	5.79
4	135	1.51	8.10	4.14
0	116	1.96	0.00	2.37
1	22	1.97	12.42	12.73
0	60	1.62	0.00	4.60
0	7	4.32	0.00	41.73
2	44	1.55	12.42	9.02
4	73	1.56	14.97	7.75
0	17	1.53	0.00	16.57
1	24	1.38	11.39	11.65
2	38	1.09	14.38	10.47
4	153	1.69	7.15	3.65
6	73	2.03	22.45	9.64
0	3	0.00	0.00	104.72
0	6	0.00	0.00	49.16
1	40	1.51	6.84	6.93
11	140	1.53	21.46	6.86
6	117	1.71	14.01	5.93
7	42	2.06	45.43	18.77

44879

DISPLAY AND PARAMETER SPECIFICATIONS

maxTime	maxTemp	maxFreq	maxLength
100.00	200.00	0.50	20.00
projectToC	showFit	calcEasyRo	usedCf
1	1	1	1

Max age for kinetic plots
301.35

Inverse model constraints

Num constraints
4

Time (Ma)	Upper (deg C)	Lower (deg C)
0.000	20.000	20.000
12.862	179.058	25.131
64.952	25.131	25.131
97.749	193.717	193.717

Inverse model specs

Monte Carlo

Enforce Max Heating	Enforce Max Cooling	Monotonic	Watch It Go
0	0	1	0

Max Heat Rate Max Cool Rate
10.0 10.0

Num Paths	Num Paths Run	Divs per seg
10000	10000	2

Time-temperature paths

Num Acceptable	Num Good
2190	627

13

Time (Ma)	Best fit	Min Acc	Max Acc	Min Good	Max Good
0.000	20.000	20.000	20.000	20.000	20.000
3.215	22.842	20.001	93.279	20.001	54.480
6.431	25.266	20.041	103.702	20.041	101.494

9.646 28.489 22.305 135.525 22.305 109.094
 12.862 126.952 99.464 179.032 101.818 178.938
 25.884 105.205 29.231 178.551 29.231 175.056
 38.907 78.343 25.131 176.100 25.176 174.670
 51.929 49.220 25.131 156.854 25.132 149.450
 64.952 25.131 25.131 25.131 25.131 25.131
 73.151 122.092 25.144 189.489 25.148 186.206
 81.350 134.944 25.251 193.514 25.616 193.261
 89.550 187.446 30.658 193.700 34.040 193.661
 97.749 193.717 193.717 193.717 193.717 193.717

Easy Ro Results

calc	equalAcc	meanAcc	sdAcc	equalGood	meanGood	sdGood
1	0	0.67	0.01	0	0.67	0.01

29231246

Model specs and results for AFTSOLVE.EXE, version 1.2

PFT-13

TIME-TEMPERATURE PATH

1

Time (Ma) Temperature (deg C)

0.000 20.000

KINETIC PARAMETERS

model: Ketcham et al. 1999

kinParUsed: Etch Pit Length

Initial track length model: Use kinetic parameter

L0 vs. kpar line defs:

0.2830 15.6300

0.2050 16.1000

0.5440 16.1800

0.4070 16.4900

0.0000 16.1800

0.0000 16.5700

0.1382 16.2880

0.1732 16.4950

Single L0 value:

16.30

Standard length reduction:

0.893000

Age calculation to use for data: Pooled

Dividers:

2

1.39

2.32

Model	Calc	Kin Par
1	0	0.70
2	1	1.89
3	0	3.66

MODEL RESULTS

pctPerTimeStep

1.00

41

length	pdf2	cdf2
0.0	0.00000	0.00000
0.5	0.00000	0.00000
1.0	0.00000	0.00000
1.5	0.00000	0.00000
2.0	0.00000	0.00000
2.5	0.00000	0.00000
3.0	0.00000	0.00000
3.5	0.00000	0.00000
4.0	0.00000	0.00000
4.5	0.00000	0.00000
5.0	0.00000	0.00000
5.5	0.00000	0.00000
6.0	0.00000	0.00000
6.5	0.00000	0.00000
7.0	0.00000	0.00000
7.5	0.00004	0.00001
8.0	0.00021	0.00007
8.5	0.00076	0.00032
9.0	0.00194	0.00099
9.5	0.00370	0.00240
10.0	0.00588	0.00479
10.5	0.00824	0.00832
11.0	0.01036	0.01297
11.5	0.01290	0.01879
12.0	0.01807	0.02653
12.5	0.02718	0.03784
13.0	0.04127	0.05496
13.5	0.06783	0.08223
14.0	0.12813	0.13122
14.5	0.24310	0.22403
15.0	0.37970	0.37973
15.5	0.43373	0.58308
16.0	0.34422	0.77757
16.5	0.18577	0.91007
17.0	0.06752	0.97339
17.5	0.01645	0.99439
18.0	0.00268	0.99917
18.5	0.00029	0.99992
19.0	0.00002	0.99999
19.5	0.00000	1.00000
20.0	0.00000	1.00000

DATA

Stratigraphic information

NumDefs	age1	age2
2	52.00	74.50

Guárico Formation

Track length file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\JAIME\AFT\FTDD\FTDD\GPSAMPLES\1\LPFT13B1.A1G
7

length	proj len	kinPar
15.1800	15.8074	2.0700
15.8000	16.3083	2.0700
14.8000	14.9184	1.9700
14.8300	14.9434	1.9700
14.5300	15.4050	2.1400

7.1500 12.1359 1.9700
 10.3400 12.9834 1.8500
 6809

Age file and data

C:\DOCUME~1\JPerez\MYDOCU~1\JAIME\AFT\FTDD\FTDDJGPSAMPLES\A\APFT13A1.A2G

2

ns	ni	kinPar	age	ageErr
1	11	1.68	24.92	26.08
1	25	1.64	10.98	11.22

1946

DISPLAY AND PARAMETER SPECIFICATIONS

maxTime	maxTemp	maxFreq	maxLength
---------	---------	---------	-----------

100.00	200.00	0.50	20.00
--------	--------	------	-------

projectToC	showFit	calcEasyRo	usedCf
------------	---------	------------	--------

1	1	1	1
---	---	---	---

Max age for kinetic plots

301.35

Inverse model constraints

Num constraints

4

Time (Ma)	Upper (deg C)	Lower (deg C)
-----------	---------------	---------------

0.000	20.000	20.000
-------	--------	--------

15.113	184.293	25.131
--------	---------	--------

64.952	25.131	25.131
--------	--------	--------

98.071	197.906	197.906
--------	---------	---------

Inverse model specs

Monte Carlo

Enforce Max Heating	Enforce Max Cooling	Monotonic	Watch It Go
---------------------	---------------------	-----------	-------------

0	0	1	0
---	---	---	---

Max Heat Rate	Max Cool Rate
---------------	---------------

10.0	10.0
------	------

Num Paths	Num Paths Run	Divs per seg
-----------	---------------	--------------

10000	10000	2
-------	-------	---

Time-temperature paths

Num Acceptable	Num Good
----------------	----------

4875	2695
------	------

13

Temperature (deg C)

Time (Ma)	Best fit	Min Acc	Max Acc	Min Good	Max Good
-----------	----------	---------	---------	----------	----------

0.000	20.000	20.000	20.000	20.000	20.000
-------	--------	--------	--------	--------	--------

3.778	20.140	20.003	176.527	20.004	68.410
-------	--------	--------	---------	--------	--------

7.556	23.205	20.003	182.409	20.022	120.538
-------	--------	--------	---------	--------	---------

11.334	51.614	21.801	183.491	21.801	183.221
--------	--------	--------	---------	--------	---------

15.113	120.276	96.469	184.271	104.834	184.199
--------	---------	--------	---------	---------	---------

27.572	116.950	26.707	183.858	26.707	183.629
--------	---------	--------	---------	--------	---------

40.032	26.158	25.143	183.696	25.159	182.643
--------	--------	--------	---------	--------	---------

52.492	26.054	25.131	178.791	25.131	178.791
--------	--------	--------	---------	--------	---------

64.952	25.131	25.131	25.131	25.131	25.131
--------	--------	--------	--------	--------	--------

73.232	60.408	25.133	193.673	25.133	193.673
--------	--------	--------	---------	--------	---------

81.511	98.193	25.133	197.825	25.133	197.825
--------	--------	--------	---------	--------	---------

89.791	192.099	29.946	197.904	29.946	197.904
--------	---------	--------	---------	--------	---------

98.071	197.906	197.906	197.906	197.906	197.906
--------	---------	---------	---------	---------	---------

Easy Ro Results

calc	equalAcc	meanAcc	sdAcc	equalGood	meanGood	sdGood
------	----------	---------	-------	-----------	----------	--------

1	0	0.70	0.01	0	0.70	0.01
---	---	------	------	---	------	------

29233931

Model specs and results for AFTSOLVE.EXE, version 1.2

PFT-17

TIME-TEMPERATURE PATH

1
 Time (Ma) Temperature (deg C)
 0.000 20.000
 KINETIC PARAMETERS
 model: Ketcham et al. 1999
 kinParUsed: Etch Pit Length
 Initial track length model: Use kinetic parameter
 L0 vs. kpar line defs:
 0.2830 15.6300
 0.2050 16.1000
 0.5440 16.1800
 0.4070 16.4900
 0.0000 16.1800
 0.0000 16.5700
 0.1382 16.2880
 0.1732 16.4950
 Single L0 value:
 16.30
 Standard length reduction:
 0.893000
 Age calculation to use for data: Pooled
 Dividers:

2
 0.82
 2.51

Model	Calc	Kin Par
1	0	0.00
2	1	1.51
3	0	3.35

MODEL RESULTS

pctPerTimeStep
 1.00
 41

length	pdf2	cdf2
0.0	0.00000	0.00000
0.5	0.00000	0.00000
1.0	0.00000	0.00000
1.5	0.00000	0.00000
2.0	0.00000	0.00000
2.5	0.00000	0.00000
3.0	0.00000	0.00000
3.5	0.00000	0.00000
4.0	0.00000	0.00000
4.5	0.00000	0.00000
5.0	0.00000	0.00000
5.5	0.00000	0.00000
6.0	0.00000	0.00000

6.5	0.00000	0.00000
7.0	0.00000	0.00000
7.5	0.00002	0.00001
8.0	0.00014	0.00005
8.5	0.00057	0.00023
9.0	0.00170	0.00079
9.5	0.00393	0.00220
10.0	0.00791	0.00516
10.5	0.01470	0.01081
11.0	0.02542	0.02084
11.5	0.04049	0.03731
12.0	0.05968	0.06236
12.5	0.08413	0.09831
13.0	0.11959	0.14924
13.5	0.17555	0.22303
14.0	0.25331	0.33024
14.5	0.32619	0.47512
15.0	0.34331	0.64249
15.5	0.27805	0.79783
16.0	0.16653	0.90897
16.5	0.07171	0.96853
17.0	0.02176	0.99190
17.5	0.00459	0.99849
18.0	0.00066	0.99980
18.5	0.00007	0.99998
19.0	0.00000	1.00000
19.5	0.00000	1.00000
20.0	0.00000	1.00000

DATA

Stratigraphic information

NumDefs	age1	age2
2	52.00	74.50

Guárico Formation

Track length file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\AIME\AFT\FTDD\FTDDUGPSAMPLES\LPFT17B1.A1G
3

length	proj len	kinPar
--------	----------	--------

13.3700	14.7236	1.8800
---------	---------	--------

13.7700	14.6822	1.6300
---------	---------	--------

6.5100	12.0188	1.6300
--------	---------	--------

2329

Age file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\AIME\AFT\FTDD\FTDDUGPSAMPLES\APFT17A1.A2G
15

ns	ni	kinPar	age	ageErr
1	18	0.00	15.36	15.81
3	8	3.35	102.98	70.02
0	19	0.00	0.00	14.96
3	29	0.00	28.57	17.42
2	15	1.86	36.80	27.80
1	102	1.74	2.71	2.73
18	140	1.48	35.49	9.17
2	30	0.00	18.43	13.51
18	363	1.39	13.71	3.42
1	18	1.75	15.36	15.81
0	33	1.14	0.00	8.53

```

13      3      1.54 1100.09 708.07
0       23      1.52  0.00 12.31
0       9       0.00  0.00 32.40
0      33      0.00  0.00  8.53
234900
DISPLAY AND PARAMETER SPECIFICATIONS
maxTime      maxTemp      maxFreqmaxLength
100.00 200.00  0.50  20.00
projectToC    showFit calcEasyRo    usedCf
1         1         1         1
Max age for kinetic plots
301.35
Inverse model constraints
Num constraints
4
Time (Ma)      Upper (deg C)  Lower (deg C)
0.000 20.000 20.000
26.045 187.435 25.131
64.952 25.131 25.131
98.071 197.906 197.906
Inverse model specs
Monte Carlo
Enforce Max Heating      Enforce Max Cooling      Monotonic      Watch It Go
0         0         1         0
Max Heat Rate      Max Cool Rate
10.0      10.0
Num Paths      Num Paths Run      Divs per seg
10000 10000 2
Time-temperature paths
Num Acceptable Num Good
3236 1389
13
      Temperature (deg C)
Time (Ma)      Best fit Min AccMax Acc      Min Good      Max Good
0.000 20.000 20.000 20.000 20.000 20.000
6.511 45.303 20.000 90.886 20.008 84.006
13.023 64.487 20.021 103.214 20.021 95.653
19.534 94.574 23.842 185.872 29.627 122.450
26.045 114.584 93.708 187.426 97.424 187.396
35.772 76.711 32.450 187.085 32.805 186.437
45.498 47.763 25.198 185.653 25.199 182.601
55.225 43.737 25.137 174.398 25.158 172.692
64.952 25.131 25.131 25.131 25.131 25.131
73.232 31.083 25.157 188.986 25.159 188.147
81.511 157.263 25.206 197.800 25.271 197.685
89.791 158.701 33.381 197.902 33.381 197.902
98.071 197.906 197.906 197.906 197.906 197.906
Easy Ro Results
calc      equalAcc      meanAcc      sdAcc      equalGood      meanGood      sdGood
1         0         0.65      0.01      0         0.65      0.01
29756580

```

Model specs and results for AFTSOLVE.EXE, version 1.2

PFT-19

TIME-TEMPERATURE PATH

1

Time (Ma) Temperature (deg C)

0.000 20.000

KINETIC PARAMETERS

model: Ketcham et al. 1999

kinParUsed: Etch Pit Length

Initial track length model: Use kinetic parameter

L0 vs. kpar line defs:

0.2830 15.6300

0.2050 16.1000

0.5440 16.1800

0.4070 16.4900

0.0000 16.1800

0.0000 16.5700

0.1382 16.2880

0.1732 16.4950

Single L0 value:

16.30

Standard length reduction:

0.893000

Age calculation to use for data: Pooled

Dividers:

3

0.99

2.34

3.73

Model	Calc	Kin Par
1	0	0.49
2	1	1.62
3	1	2.99
4	0	4.37

MODEL RESULTS

pctPerTimeStep

1.00

41

length	pdf2	cdf2	pdf3	cdf3
0.0	0.00000	0.00000	0.00000	0.00000
0.5	0.00000	0.00000	0.00000	0.00000
1.0	0.00000	0.00000	0.00000	0.00000
1.5	0.00000	0.00000	0.00000	0.00000
2.0	0.00000	0.00000	0.00000	0.00000
2.5	0.00000	0.00000	0.00000	0.00000
3.0	0.00000	0.00000	0.00000	0.00000
3.5	0.00000	0.00000	0.00000	0.00000
4.0	0.00000	0.00000	0.00000	0.00000
4.5	0.00000	0.00000	0.00000	0.00000
5.0	0.00000	0.00000	0.00000	0.00000
5.5	0.00000	0.00000	0.00000	0.00000
6.0	0.00000	0.00000	0.00000	0.00000
6.5	0.00000	0.00000	0.00004	0.00001
7.0	0.00000	0.00000	0.00035	0.00011
7.5	0.00001	0.00000	0.00226	0.00076
8.0	0.00006	0.00002	0.00997	0.00382
8.5	0.00023	0.00010	0.03034	0.01389

9.0	0.00064	0.00031	0.06413	0.03751
9.5	0.00143	0.00083	0.09515	0.07733
10.0	0.00290	0.00191	0.10115	0.12641
10.5	0.00569	0.00406	0.08044	0.17180
11.0	0.01088	0.00820	0.05310	0.20519
11.5	0.02038	0.01602	0.03677	0.22766
12.0	0.03685	0.03033	0.03463	0.24551
12.5	0.06208	0.05506	0.04247	0.26478
13.0	0.09608	0.09460	0.05819	0.28995
13.5	0.14151	0.15400	0.08507	0.32576
14.0	0.20701	0.24113	0.12863	0.37919
14.5	0.29285	0.36609	0.18856	0.45849
15.0	0.36110	0.52958	0.24890	0.56785
15.5	0.34781	0.70681	0.27362	0.69848
16.0	0.24335	0.85460	0.23278	0.82508
16.5	0.11887	0.94515	0.14507	0.91954
17.0	0.03973	0.98481	0.06400	0.97181
17.5	0.00900	0.99699	0.01960	0.99271
18.0	0.00137	0.99958	0.00412	0.99864
18.5	0.00014	0.99996	0.00059	0.99982
19.0	0.00001	1.00000	0.00006	0.99998
19.5	0.00000	1.00000	0.00000	1.00000
20.0	0.00000	1.00000	0.00000	1.00000

DATA

Stratigraphic information

NumDefs	age1	age2
2	52.00	74.50

Guárico Formation

Track length file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\VAIME\AFT\FTDD\FTDDUGPSAMPLES\L\L\PFT19B1.A1G

33

length	proj len	kinPar
13.7200	14.6109	2.5100
12.9900	14.5995	2.5100
9.1500	11.8749	2.5100
14.3300	14.9784	1.9900
10.9600	12.5524	1.5900
14.5200	14.9462	2.4400
12.4000	13.9473	2.4400
12.9800	14.4925	1.9500
15.0800	15.8617	2.6000
13.7500	14.3968	2.1400
16.5400	16.6879	2.4900
14.3700	14.6359	2.4900
15.4700	16.0886	2.4900
7.2100	11.1679	2.0900
16.4300	16.6351	2.0900
11.2500	13.0241	2.0900
4.9100	11.9424	2.1400
15.6800	16.0507	1.9400
15.1500	15.8324	1.9900
8.8800	11.8935	1.9900
12.5200	14.1807	2.7400
15.0100	15.7682	2.7400
15.3300	16.0015	2.7400
14.5000	15.3808	2.7400

13.8500 14.9955 2.7400
 5.7100 11.4591 2.7400
 12.4700 13.7989 2.7400
 16.4300 16.5309 2.1100
 12.5500 13.3252 2.1100
 13.0700 14.3034 1.8200
 11.4400 12.2942 2.4300
 14.0000 14.9541 1.7500
 4.4600 12.1538 2.1800

36175

Age file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\VAIME\AFT\FTDD\FTDDUGP\SAMPLES\A\APFT19A1.A2G

7

ns	ni	kinPar	age	ageErr
0	5	1.81	0.00	61.20
0	5	1.79	0.00	61.20
1	11	3.55	25.41	26.59
5	26	2.73	53.63	26.41
4	51	1.06	21.93	11.47
0	12	1.85	0.00	24.29
13	245	1.44	14.84	4.33

8736

DISPLAY AND PARAMETER SPECIFICATIONS

maxTime	maxTemp	maxFreq	maxLength
100.00	200.00	0.50	20.00

projectToC	showFit	calcEasyRo
1	1	1

usedCf
1

Max age for kinetic plots

301.35

Inverse model constraints

Num constraints

4

Time (Ma)	Upper (deg C)	Lower (deg C)
0.000	20.000	20.000
20.257	187.435	24.084
64.952	25.131	25.131
98.392	194.764	194.764

0.000 20.000 20.000

20.257 187.435 24.084

64.952 25.131 25.131

98.392 194.764 194.764

Inverse model specs

Monte Carlo

Enforce Max Heating	Enforce Max Cooling	Monotonic	Watch It Go
0	0	1	0

0 0 1 0

Max Heat Rate	Max Cool Rate
10.0	10.0

10.0 10.0

Num Paths	Num Paths Run	Divs per seg
10000	10000	2

10000 10000 2

Time-temperature paths

Num Acceptable	Num Good
945	0

945 0

13

Temperature (deg C)

Time (Ma)	Best fit	Min Acc	Max Acc
0.000	20.000	20.000	20.000
5.064	27.439	20.010	98.359
10.129	65.219	20.219	182.161
15.193	99.347	36.519	186.594
20.257	164.312	104.366	187.433

0.000 20.000 20.000 20.000

5.064 27.439 20.010 98.359

10.129 65.219 20.219 182.161

15.193 99.347 36.519 186.594

20.257 164.312 104.366 187.433

31.431 157.716 35.442 186.822
 42.605 151.372 25.146 182.992
 53.778 107.673 25.138 177.308
 64.952 25.131 25.131 25.131
 73.312 25.835 25.149 189.974
 81.672 44.110 25.676 194.718
 90.032 105.519 28.053 194.752
 98.392 194.764 194.764 194.764

Easy Ro Results

calc	equalAcc	meanAcc	sdAcc	equalGood	meanGood	sdGood
1	0	1.52	0.02	1	0.00	0.00

29230001

Model specs and results for AFTSOLVE.EXE, version 1.2

PFT-20

TIME-TEMPERATURE PATH

1
 Time (Ma) Temperature (deg C)
 0.000 20.000
KINETIC PARAMETERS
 model: Ketcham et al. 1999
 kinParUsed: Etch Pit Length
 Initial track length model: Use kinetic parameter
 L0 vs. kpar line defs:
 0.2830 15.6300
 0.2050 16.1000
 0.5440 16.1800
 0.4070 16.4900
 0.0000 16.1800
 0.0000 16.5700
 0.1382 16.2880
 0.1732 16.4950
 Single L0 value:
 16.30
 Standard length reduction:
 0.893000
 Age calculation to use for data: Pooled
 Dividers:
 2
 0.75
 1.91

Model	Calc	Kin Par
1	0	0.38
2	1	1.38
3	0	2.48

MODEL RESULTS
 pctPerTimeStep
 1.00
 41

length	pdf2	cdf2
0.0	0.00000	0.00000

0.5	0.00000	0.00000
1.0	0.00000	0.00000
1.5	0.00000	0.00000
2.0	0.00000	0.00000
2.5	0.00000	0.00000
3.0	0.00000	0.00000
3.5	0.00000	0.00000
4.0	0.00000	0.00000
4.5	0.00000	0.00000
5.0	0.00000	0.00000
5.5	0.00000	0.00000
6.0	0.00000	0.00000
6.5	0.00000	0.00000
7.0	0.00000	0.00000
7.5	0.00001	0.00000
8.0	0.00006	0.00002
8.5	0.00020	0.00009
9.0	0.00049	0.00026
9.5	0.00104	0.00064
10.0	0.00207	0.00142
10.5	0.00397	0.00293
11.0	0.00722	0.00572
11.5	0.01247	0.01065
12.0	0.02147	0.01913
12.5	0.03967	0.03442
13.0	0.08103	0.06459
13.5	0.16423	0.12591
14.0	0.28623	0.23852
14.5	0.39261	0.40823
15.0	0.40638	0.60798
15.5	0.31122	0.78738
16.0	0.17423	0.90874
16.5	0.07044	0.96991
17.0	0.02026	0.99258
17.5	0.00408	0.99867
18.0	0.00057	0.99983
18.5	0.00005	0.99998
19.0	0.00000	1.00000
19.5	0.00000	1.00000
20.0	0.00000	1.00000

DATA

Stratigraphic information

NumDefs age1 age2

2 52.00 74.50

Guárico Formation

Track length file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\AIME\AFT\FTDD\FTDD\GPI\SAMPLES\L\LPFT20B1.A1G
5

length proj len kinPar

14.2000 15.3415 2.1700

13.6400 14.9420 1.7100

12.6800 13.9666 1.7100

14.2400 15.0683 1.7100

11.2400 12.4112 1.7100

4801

Age file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\JAIME\AFT\FTDD\FTDDUGP\SAMPLES\A\APFT20A1.A2G

9
 ns ni kinPar age ageErr
 0 1 1.40 0.00 389.56
 9 42 1.82 59.97 22.35
 7 27 1.46 72.48 31.08
 1 12 0.94 23.39 24.39
 2 20 2.79 28.05 20.88
 3 40 1.33 21.05 12.67
 7 229 1.63 8.59 3.34
 16 254 1.21 17.69 4.69
 1 22 1.77 12.77 13.08

20207

DISPLAY AND PARAMETER SPECIFICATIONS

maxTime maxTemp maxFreqmaxLength
 100.00 200.00 0.50 20.00
 projectToC showFit calcEasyRo usedCf
 1 1 1 1

Max age for kinetic plots

301.35

Inverse model constraints

Num constraints

4

Time (Ma) Upper (deg C) Lower (deg C)

0.000 20.000 20.000

24.437 184.293 25.131

65.273 25.131 25.131

98.714 198.953 198.953

Inverse model specs

Monte Carlo

Enforce Max Heating Enforce Max Cooling Monotonic Watch It Go

0 0 1 0

Max Heat Rate Max Cool Rate

10.0 10.0

Num Paths Num Paths Run Divs per seg

10000 10000 2

Time-temperature paths

Num Acceptable Num Good

3355 1524

13

Temperature (deg C)

Time (Ma) Best fit Min AccMax Acc Min Good Max Good

0.000 20.000 20.000 20.000 20.000 20.000

6.109 47.657 20.000 92.489 20.000 83.262

12.219 53.040 20.014 106.160 20.014 96.894

18.328 79.053 21.799 182.129 28.086 129.039

24.437 161.829 93.715 184.276 93.715 184.076

34.646 149.711 27.578 182.115 27.578 182.115

44.855 125.083 25.138 179.922 25.250 179.922

55.064 42.720 25.131 159.228 25.136 158.660

65.273 25.131 25.131 25.131 25.131 25.131

73.633 42.396 25.132 189.404 25.150 183.971

81.994 65.190 25.173 198.914 25.210 198.914

90.354 183.529 26.532 198.947 31.699 198.947

98.714 198.953 198.953 198.953 198.953 198.953

Easy Ro Results

calc	equalAcc	meanAcc	sdAcc	equalGood	meanGood	sdGood
1	0	0.65	0.01	0	0.65	0.01
34213147						

Model specs and results for AFTSOLVE.EXE, version 1.2

PFT-23

TIME-TEMPERATURE PATH

1
Time (Ma) Temperature (deg C)
0.000 20.000
KINETIC PARAMETERS
model: Ketcham et al. 1999
kinParUsed: Etch Pit Length
Initial track length model: Use kinetic parameter
L0 vs. kpar line defs:
0.2830 15.6300
0.2050 16.1000
0.5440 16.1800
0.4070 16.4900
0.0000 16.1800
0.0000 16.5700
0.1382 16.2880
0.1732 16.4950
Single L0 value:
16.30
Standard length reduction:
0.893000
Age calculation to use for data: Pooled
Dividers:

2
0.84
3.05
Model Calc Kin Par
1 0 0.00
2 1 1.91
3 0 4.02

MODEL RESULTS

pctPerTimeStep

1.00
41
length pdf2 cdf2
0.0 0.00000 0.00000
0.5 0.00000 0.00000
1.0 0.00000 0.00000
1.5 0.00000 0.00000
2.0 0.00000 0.00000
2.5 0.00000 0.00000
3.0 0.00000 0.00000
3.5 0.00000 0.00000
4.0 0.00000 0.00000
4.5 0.00000 0.00000

5.0	0.00000	0.00000
5.5	0.00000	0.00000
6.0	0.00000	0.00000
6.5	0.00000	0.00000
7.0	0.00002	0.00001
7.5	0.00011	0.00004
8.0	0.00045	0.00018
8.5	0.00145	0.00065
9.0	0.00367	0.00193
9.5	0.00777	0.00479
10.0	0.01435	0.01032
10.5	0.02416	0.01995
11.0	0.03816	0.03552
11.5	0.05674	0.05925
12.0	0.07953	0.09331
12.5	0.10756	0.14009
13.0	0.14381	0.20293
13.5	0.19013	0.28641
14.0	0.24244	0.39455
14.5	0.28509	0.52643
15.0	0.29185	0.67067
15.5	0.24458	0.80478
16.0	0.15858	0.90557
16.5	0.07602	0.96422
17.0	0.02610	0.98975
17.5	0.00628	0.99784
18.0	0.00105	0.99967
18.5	0.00012	0.99997
19.0	0.00001	1.00000
19.5	0.00000	1.00000
20.0	0.00000	1.00000

DATA

Stratigraphic information

NumDefs	age1	age2
2	52.00	64.50

Guárico Formation

Track length file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\AIME\AFT\FTDD\FTDD\JGPSAMPLES\L\LPFT23B1.A1G
29

length	proj len	kinPar
9.0100	11.9906	1.8400
14.2500	14.6480	2.1200
13.4600	14.7400	2.1200
14.0400	15.1589	2.1200
12.6100	14.0808	1.7900
14.6300	15.5199	2.3700
14.1400	15.3194	2.3700
14.5400	15.4286	1.3000
12.5400	14.0722	1.3000
8.0100	12.0767	2.0900
13.3900	13.5371	2.1300
11.5000	13.6099	1.8100
2.3600	10.1854	1.8100
13.6400	14.7094	1.9900
15.5800	16.1656	1.7200
13.7900	15.0369	2.6800

14.3000 14.6844 2.6800
 7.6700 11.4536 2.6800
 15.3900 15.5078 2.1600
 14.7600 15.2702 2.1600
 14.5000 14.5089 2.1600
 10.8500 12.7872 2.1600
 14.7000 15.6498 1.7700
 13.7600 14.3176 1.6100
 5.0800 8.6990 1.7600
 10.3300 12.2000 2.1100
 14.9800 15.2231 2.3600
 13.0000 14.6316 1.9400
 9.5400 12.2342 2.5100

30337

Age file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\AIME\AFT\FTDD\FTDD\UGP\SAMPLES\A\APFT23A1.A2G

39

ns	ni	kinPar	age	ageErr
1	12	1.70	20.43	21.31
2	25	1.48	19.62	14.47
1	30	1.39	8.18	8.33
1	10	0.00	24.51	25.75
0	28	0.00	0.00	8.94
2	42	1.58	11.68	8.49
5	35	1.43	34.99	16.87
2	22	1.81	22.29	16.52
3	84	1.62	8.76	5.18
1	23	0.00	10.67	10.92
1	28	1.43	8.76	8.94
2	33	1.64	14.87	10.87
1	58	1.70	4.23	4.28
0	10	1.27	0.00	25.75
3	28	2.02	26.26	16.04
3	91	2.53	8.09	4.78
7	97	1.74	17.70	7.02
2	38	1.66	12.91	9.40
2	52	0.00	9.44	6.83
1	32	1.58	7.67	7.80
0	42	0.00	0.00	5.93
0	8	0.00	0.00	32.54
2	50	1.66	9.82	7.11
1	15	1.77	16.35	16.92
1	64	1.86	3.84	3.87
5	74	2.22	16.57	7.73
10	87	1.61	28.17	9.57
4	34	1.59	28.83	15.35
4	35	0.94	28.01	14.89
3	22	2.88	33.40	20.67
3	25	1.64	29.40	18.06
3	25	1.92	29.40	18.06
0	27	1.66	0.00	9.27
1	27	1.79	9.09	9.27
0	25	0.00	0.00	10.03
2	41	1.26	11.97	8.70
1	37	1.95	6.63	6.74
1	43	1.86	5.71	5.79

```

1      32      1.78      7.67      7.80
53841
DISPLAY AND PARAMETER SPECIFICATIONS
maxTime      maxTemp      maxFreqmaxLength
100.00 200.00 0.50 20.00
projectToC      showFit calcEasyRo      usedCf
1      1      1      1
Max age for kinetic plots
301.35
Inverse model constraints
Num constraints
4
Time (Ma)      Upper (deg C)      Lower (deg C)
0.000 20.000 20.000
18.006 185.340 25.131
64.630 25.131 25.131
99.678 198.953 198.953
Inverse model specs
Monte Carlo
Enforce Max Heating      Enforce Max Cooling      Monotonic      Watch It Go
0      0      1      0
Max Heat Rate      Max Cool Rate
10.0      10.0
Num Paths      Num Paths Run      Divs per seg
10000 10000 2
Time-temperature paths
Num Acceptable Num Good
1852      201
13
      Temperature (deg C)
Time (Ma)      Best fit Min AccMax Acc      Min Good      Max Good
0.000 20.000 20.000 20.000 20.000 20.000
4.502 55.844 20.062 89.264 23.451 72.913
9.003 79.706 23.469 111.770 55.011 102.427
13.505 103.340 50.453 175.029 81.592 115.614
18.006 117.769 105.206 185.297 106.611 183.074
29.662 101.867 25.556 183.422 26.971 177.568
41.318 26.933 25.216 181.254 25.333 163.801
52.974 25.876 25.140 171.800 25.140 140.497
64.630 25.131 25.131 25.131 25.131 25.131
73.392 37.062 25.139 194.595 25.363 174.753
82.154 51.704 25.265 198.860 25.742 198.763
90.916 117.898 34.733 198.948 46.466 198.832
99.678 198.953 198.953 198.953 198.953 198.953
Easy Ro Results
calc      equalAcc      meanAcc      sdAcc      equalGood      meanGood      sdGood
1      0      0.70      0.01      0      0.70      0.01
29230908

```

Model specs and results for AFTSOLVE.EXE, version 1.2

PFT-25

TIME-TEMPERATURE PATH

Model specs and results for AFTSOLVE.EXE, version 0.8, 6/14/98

PFT-25

TIME-TEMPERATURE PATH

1

Time (Ma) Temperature (deg C)

0.000 20.000

KINETIC PARAMETERS

model: Ketcham et al. in review

kinParUsed: Etch Pit Length

Initial track length model: Use kinetic parameter

L0 vs. kpar line defs:

0.2830 15.6300

0.2060 16.1700

0.5440 16.1800

0.4040 16.5700

0.0000 16.1800

0.0000 16.5700

0.1382 16.2880

0.1732 16.4950

Single L0 value:

16.30

Dividers:

2

1.24

2.42

Model	Calc	Kin Par
1	0	0.00
2	1	1.86
3	0	3.01

MODEL RESULTS

pctPerTimeStep

1.00

41

length	pdf2	cdf2
0.0	0.00000	0.00000
0.5	0.00000	0.00000
1.0	0.00000	0.00000
1.5	0.00000	0.00000
2.0	0.00000	0.00000
2.5	0.00000	0.00000
3.0	0.00000	0.00000
3.5	0.00000	0.00000
4.0	0.00000	0.00000
4.5	0.00000	0.00000
5.0	0.00000	0.00000
5.5	0.00000	0.00000
6.0	0.00000	0.00000
6.5	0.00001	0.00000
7.0	0.00003	0.00001
7.5	0.00012	0.00005
8.0	0.00034	0.00016
8.5	0.00080	0.00045
9.0	0.00155	0.00104
9.5	0.00260	0.00207
10.0	0.00393	0.00370

10.5	0.00560	0.00609
11.0	0.00772	0.00942
11.5	0.01048	0.01397
12.0	0.01413	0.02012
12.5	0.01926	0.02847
13.0	0.02810	0.04031
13.5	0.04952	0.05971
14.0	0.10686	0.09881
14.5	0.22532	0.18185
15.0	0.37573	0.33212
15.5	0.45021	0.53860
16.0	0.37442	0.74476
16.5	0.21350	0.89174
17.0	0.08313	0.96589
17.5	0.02209	0.99220
18.0	0.00401	0.99873
18.5	0.00050	0.99985
19.0	0.00004	0.99999
19.5	0.00000	1.00000
20.0	0.00000	1.00000

DATA

Stratigraphic information

NumDefs	age1	age2
2	52.00	74.50

Guárico Formation

Track length file and data

c:\docume~1\jperez\mydocu~1\jaime\aft\ftdd\ftdd\jgp\samples\l\pft25b1.a1g
12

length	proj len	kinPar
14.1200	15.2609	3.2600
16.0700	16.6080	3.2600
1.7700	7.3103	3.2600
14.7800	15.6662	1.6700
13.4000	14.7636	1.9000
15.0800	15.5013	1.6800
13.5200	14.6451	1.7900
15.5200	16.0793	2.2200
12.3700	14.1300	2.0600
17.9400	17.8295	1.9500
14.1900	15.3215	1.7000
13.5600	14.9091	2.3100

12710

Age file and data

c:\docume~1\jperez\mydocu~1\jaime\aft\ftdd\ftdd\jgp\samples\l\apft25a1.a2g
28

ns	ni	kinPar	age	ageErr
7	60	1.49	28.54	11.54
0	54	1.57	0.00	4.59
0	5	2.05	0.00	53.61
1	9	1.41	27.19	28.71
0	14	1.87	0.00	18.14
1	19	1.51	12.89	13.25
1	30	2.23	8.17	8.32
0	18	1.64	0.00	14.01
0	5	0.00	0.00	53.61
6	59	1.41	24.89	10.78

0	15	1.59	0.00	16.89
3	5	1.46	145.47	106.63
0	32	1.91	0.00	7.79
3	15	2.14	48.85	31.05
0	8	0.00	0.00	32.49
0	6	2.02	0.00	44.08
2	17	1.75	28.78	21.59
3	19	1.55	38.60	24.10
5	86	2.27	14.24	6.61
0	18	0.00	0.00	14.01
3	63	2.76	11.67	6.93
2	28	1.69	17.49	12.85
1	21	1.45	11.67	11.96
3	2	2.06	357.69	327.31
6	122	1.72	12.05	5.10
0	5	0.00	0.00	53.61
0	11	2.05	0.00	23.28
0	35	1.53	0.00	7.12

109288

Display specs

maxTime	maxTemp	maxFreq	maxLength
100.00	200.00	0.50	20.00

projectToC showFit calcEasyRo usedCf

1	1	1	1
---	---	---	---

Max age for kinetic plots

400.00

Inverse model constraints

Num constraints

4

Time (Ma)	Upper (deg C)	Lower (deg C)
0.000	20.000	20.000
16.720	197.906	20.942
64.952	24.084	24.084
99.035	197.906	197.906

Inverse model specs

Monte Carlo

Enforce Max Heating	Enforce Max Cooling	Monotonic	Watch It Go
0	0	1	0

Max Heat Rate Max Cool Rate

10.0	10.0
------	------

Num Paths Num Paths Run Divs per seg

10000	10000	2
-------	-------	---

Time-temperature paths

Num Acceptable Num Good

2202	502
------	-----

13

Temperature (deg C)					
Time (Ma)	Best fit	Min Acc	Max Acc	Min Good	Max Good
0.000	20.000	20.000	20.000	20.000	20.000
4.180	21.800	20.000	70.581	20.006	47.138
8.360	24.438	20.028	100.764	20.044	59.081
12.540	28.516	21.989	181.000	21.989	98.792
16.720	136.922	103.294	197.906	109.088	197.481
28.778	99.015	24.542	196.989	32.125	186.143
40.836	95.445	24.113	190.601	24.568	186.134
52.894	44.810	24.089	184.509	24.152	167.663

64.952	24.084	24.084	24.084	24.084	24.084
73.473	50.154	24.085	191.909	24.085	186.993
81.994	109.402	24.119	197.828	24.665	196.719
90.514	195.034	30.877	197.893	30.877	197.770
99.035	197.906	197.906	197.906	197.906	197.906

Easy Ro Results

calc	equalAcc	meanAcc	sdAcc	equalGood	meanGood	sdGood
1	0	0.67	0.01	0	0.68	0.01

25692314

Model specs and results for AFTSOLVE.EXE, version 1.2

PFT-28**TIME-TEMPERATURE PATH**

1

Time (Ma) Temperature (deg C)

0.000 20.000

KINETIC PARAMETERS

model: Ketcham et al. 1999

kinParUsed: Etch Pit Length

Initial track length model: Use kinetic parameter

L0 vs. kpar line defs:

0.2830 15.6300

0.2050 16.1000

0.5440 16.1800

0.4070 16.4900

0.0000 16.1800

0.0000 16.5700

0.1382 16.2880

0.1732 16.4950

Single L0 value:

16.30

Standard length reduction:

0.893000

Age calculation to use for data: Pooled

Dividers:

2

1.01

2.92

Model	Calc	Kin Par
-------	------	---------

1	0	0.00
---	---	------

2	1	1.95
---	---	------

3	0	3.96
---	---	------

MODEL RESULTS

pctPerTimeStep

1.00

41

length	pdf2	cdf2
0.0	0.00000	0.00000
0.5	0.00000	0.00000
1.0	0.00000	0.00000
1.5	0.00000	0.00000
2.0	0.00000	0.00000
2.5	0.00000	0.00000

3.0	0.00000	0.00000
3.5	0.00000	0.00000
4.0	0.00000	0.00000
4.5	0.00000	0.00000
5.0	0.00000	0.00000
5.5	0.00000	0.00000
6.0	0.00000	0.00000
6.5	0.00000	0.00000
7.0	0.00003	0.00001
7.5	0.00017	0.00006
8.0	0.00058	0.00025
8.5	0.00149	0.00077
9.0	0.00292	0.00187
9.5	0.00456	0.00374
10.0	0.00619	0.00643
10.5	0.00825	0.01004
11.0	0.01187	0.01507
11.5	0.01849	0.02266
12.0	0.03063	0.03494
12.5	0.05646	0.05671
13.0	0.11473	0.09951
13.5	0.21851	0.18282
14.0	0.33367	0.32087
14.5	0.38584	0.50075
15.0	0.34230	0.68278
15.5	0.24133	0.82869
16.0	0.13663	0.92318
16.5	0.06021	0.97239
17.0	0.01969	0.99236
17.5	0.00460	0.99843
18.0	0.00075	0.99977
18.5	0.00008	0.99998
19.0	0.00001	1.00000
19.5	0.00000	1.00000
20.0	0.00000	1.00000

DATA

Stratigraphic information

NumDefs	age1	age2
2	23.80	35.00

Roblecito Formation

Track length file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\VAIME\AFT\FTDD\FTDDUGPSAMPLES\L\LPT28B1.A1G

27

length	proj len	kinPar
--------	----------	--------

15.0200	15.7860	1.4700
14.7900	14.8863	1.4700
10.1300	11.8546	1.4700
14.4400	15.4992	1.9600
13.4200	14.5667	1.9600
7.4800	11.9603	1.9600
12.7300	14.3234	1.9600
9.2400	12.0512	1.9600
13.7000	14.9348	1.9600
14.1500	15.2331	2.0800
13.5700	13.5777	2.0400
12.9700	14.2991	1.1800

9.9400 11.8853 1.1800
 15.3700 15.5420 2.2500
 13.7500 14.1057 2.2500
 13.7100 14.7279 1.6100
 14.7400 15.5920 1.6100
 13.4200 14.4325 1.7900
 13.4900 14.8335 1.7900
 16.1400 16.1549 1.7900
 13.5600 14.7850 2.1600
 11.8200 13.1397 1.5100
 5.1300 11.3641 1.6500
 14.3300 14.4297 1.8500
 13.0500 14.0508 1.8500
 14.0200 15.1703 2.0000
 13.7600 14.7871 2.0000

29520

Age file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\AIME\AFT\FTDD\FTDD\GPI\SAMPLES\A\APFT28A1.A2G
 25

ns	ni	kinPar	age	ageErr
11	12	1.37	220.60	93.14
5	12	1.46	101.21	54.25
5	46	2.26	26.56	12.62
2	13	1.76	37.56	28.62
3	34	1.38	21.57	13.06
1	42	1.36	5.83	5.91
10	110	1.81	22.22	7.47
0	17	1.45	0.00	14.83
0	9	0.00	0.00	28.67
6	93	1.53	15.78	6.72
14	157	1.70	21.79	6.23
1	12	2.73	20.37	21.24
3	14	1.32	52.25	33.41
5	14	1.39	86.85	45.58
3	47	1.70	15.61	9.35
0	20	0.00	0.00	12.56
6	16	1.79	91.16	44.02
4	32	1.59	30.53	16.31
1	12	1.26	20.37	21.24
0	5	0.00	0.00	53.52
3	34	1.46	21.57	13.06
1	71	1.45	3.45	3.48
0	5	0.00	0.00	53.52
0	7	0.00	0.00	37.35
4	28	1.83	34.88	18.77

101694

DISPLAY AND PARAMETER SPECIFICATIONS

maxTime	maxTemp	maxFreq	maxLength
80.00	200.00	0.50	20.00
projectToC	showFit	calcEasyRo	usedCf
1	1	1	1

Max age for kinetic plots

313.74

Inverse model constraints

Num constraints

5

```

Time (Ma)      Upper (deg C)  Lower (deg C)
0.000  20.000  20.000
29.068 175.916 25.131
34.984 25.131 25.131
59.421 196.859 196.859
79.228 197.906 197.906
Inverse model specs
Monte Carlo
Enforce Max Heating  Enforce Max Cooling  Monotonic  Watch It Go
0      0      1      0
Max Heat Rate  Max Cool Rate
10.0  10.0
Num Paths      Num Paths Run  Divs per seg
10000 10000 2
Time-temperature paths
Num Acceptable Num Good
1476  140
17
      Temperature (deg C)
Time (Ma)      Best fit  Min AccMax Acc      Min Good      Max Good
0.000  20.000  20.000  20.000  20.000  20.000
7.267  60.005  20.011  78.810  20.485  67.269
14.534 67.036  20.254 102.827 42.851  85.310
21.801 68.089  36.359 136.724 59.896 108.756
29.068 124.863 94.377 175.884 108.010 160.049
30.547 114.208 28.149 175.005 39.902 147.942
32.026 112.268 25.350 174.327 25.403 143.189
33.505 91.205  25.144 169.390 25.153 116.598
34.984 25.131  25.131  25.131  25.131  25.131
41.093 51.187  25.135 188.347 25.376 185.390
47.203 75.632  25.181 196.693 27.248 195.709
53.312 135.073 32.733 196.851 35.609 196.845
59.421 196.859 196.859 196.859 196.859 196.859
64.373 196.879 196.859 197.836 196.859 197.784
69.325 197.104 196.859 197.905 196.859 197.903
74.277 197.718 196.888 197.906 196.916 197.904
79.228 197.906 197.906 197.906 197.906 197.906
Easy Ro Results
calc  equalAcc      meanAcc      sdAcc  equalGood      meanGood      sdGood
1      0      0.72  0.01  0      0.72  0.01
42993092

```

Model specs and results for AFTSOLVE.EXE, version 1.2

PFT-29

TIME-TEMPERATURE PATH

1

Time (Ma) Temperature (deg C)

0.000 20.000

KINETIC PARAMETERS

model: Ketcham et al. 1999

kinParUsed: Etch Pit Length

Initial track length model: Use kinetic parameter

L0 vs. kpar line defs:

0.2830 15.6300

0.2050 16.1000

0.5440 16.1800

0.4070 16.4900

0.0000 16.1800

0.0000 16.5700

0.1382 16.2880

0.1732 16.4950

Single L0 value:

16.30

Standard length reduction:

0.893000

Age calculation to use for data: Pooled

Dividers:

4

1.16

1.70

1.78

3.00

Model	Calc	Kin Par
1	0	0.00
2	1	1.49
3	0	1.74
4	1	2.35
5	0	4.00

MODEL RESULTS

pctPerTimeStep

1.00

41

length	pdf2	cdf2	pdf4	cdf4
0.0	0.00000	0.00000	0.00000	0.00000
0.5	0.00000	0.00000	0.00000	0.00000
1.0	0.00000	0.00000	0.00000	0.00000
1.5	0.00000	0.00000	0.00000	0.00000
2.0	0.00000	0.00000	0.00000	0.00000
2.5	0.00000	0.00000	0.00000	0.00000
3.0	0.00000	0.00000	0.00000	0.00000
3.5	0.00000	0.00000	0.00000	0.00000
4.0	0.00000	0.00000	0.00000	0.00000
4.5	0.00000	0.00000	0.00000	0.00000
5.0	0.00000	0.00000	0.00000	0.00000
5.5	0.00000	0.00000	0.00000	0.00000
6.0	0.00000	0.00000	0.00000	0.00000
6.5	0.00000	0.00000	0.00002	0.00000
7.0	0.00001	0.00000	0.00019	0.00006
7.5	0.00003	0.00001	0.00119	0.00040
8.0	0.00010	0.00005	0.00512	0.00198
8.5	0.00025	0.00014	0.01553	0.00714
9.0	0.00057	0.00034	0.03393	0.01951
9.5	0.00129	0.00081	0.05525	0.04180
10.0	0.00282	0.00183	0.07047	0.07323
10.5	0.00556	0.00393	0.07463	0.10951
11.0	0.01005	0.00784	0.06913	0.14545
11.5	0.01711	0.01463	0.05866	0.17740
12.0	0.02830	0.02598	0.04957	0.20445
12.5	0.04824	0.04512	0.04854	0.22898
13.0	0.08986	0.07964	0.06187	0.25658

13.5	0.17208	0.14513	0.09976	0.29699
14.0	0.29123	0.26095	0.17326	0.36525
14.5	0.38972	0.43119	0.26650	0.47518
15.0	0.39309	0.62689	0.32034	0.62190
15.5	0.29483	0.79887	0.28539	0.77333
16.0	0.16374	0.91351	0.18528	0.89100
16.5	0.06674	0.97113	0.08720	0.95912
17.0	0.01963	0.99272	0.02960	0.98832
17.5	0.00408	0.99865	0.00718	0.99751
18.0	0.00059	0.99982	0.00123	0.99961
18.5	0.00006	0.99998	0.00015	0.99996
19.0	0.00000	1.00000	0.00001	1.00000
19.5	0.00000	1.00000	0.00000	1.00000
20.0	0.00000	1.00000	0.00000	1.00000

DATA

Stratigraphic information

NumDefs	age1	age2
2	52.00	74.50

Guárico Formation

Track length file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\VAIME\AFT\FTDD\FTDDUGPSAMPLES\LLPFT29B1.A1G
64

length	proj len	kinPar
5.3100	11.0536	2.0100
14.6900	15.4799	2.3200
14.9000	15.1189	2.0900
12.7400	13.2267	2.1000
12.4000	13.7640	2.1300
12.1900	13.9324	2.1300
5.8000	11.2519	1.5400
13.6100	15.0055	1.8800
13.9500	14.7900	1.8800
16.2700	16.4881	1.8800
11.9200	12.9156	1.8800
11.8100	12.9677	1.8800
5.1900	11.3283	2.0000
4.9100	10.8794	2.0000
15.0800	15.3037	2.3700
7.7600	12.4519	2.3700
14.4700	15.4386	2.7200
14.9300	14.9548	2.7200
13.6100	14.9948	2.8100
10.7400	12.8143	2.8100
13.0200	14.6387	2.8100
13.8800	15.1410	2.8100
12.9500	14.1250	1.7200
13.6300	14.5752	1.7200
12.3900	14.2577	1.7200
11.2500	13.4458	1.7200
8.7800	10.3106	1.8100
6.5200	9.7241	1.7600
15.1600	15.4000	1.8400
12.5700	14.2727	1.9000
9.5500	11.0605	1.6600
15.6800	15.9815	1.6600
14.6200	15.2866	1.6600

15.7000 15.9558 2.1900
 4.5400 11.6595 1.7900
 14.1700 15.1589 2.0500
 11.9600 13.8696 2.0500
 9.7600 12.5203 2.0500
 7.1700 11.8274 1.7000
 10.6000 12.2100 1.7300
 13.2400 13.6726 1.9100
 15.0400 15.4778 1.4000
 14.0900 15.0775 2.1400
 12.6500 14.0023 1.7200
 10.2500 12.7886 1.7200
 12.6800 13.5642 1.6700
 12.3700 14.1222 2.0200
 8.8000 12.0725 2.0200
 12.6600 14.2178 2.0200
 8.6600 12.4911 2.0200
 7.0300 11.4963 1.8900
 14.2200 15.2495 2.0900
 16.1200 16.4325 2.0900
 13.9200 14.7144 1.8200
 11.4300 12.9056 1.8200
 9.9500 12.3455 2.9100
 13.5700 14.8528 1.8500
 14.0300 14.1585 2.8700
 13.1800 13.7026 2.8700
 10.8500 13.1439 2.8700
 10.0300 11.8782 1.6200
 12.3800 14.1200 1.8700
 10.7700 13.1889 1.9000
 11.5300 12.9342 1.7400

71575

Age file and data

C:\DOCUME~1\PEREZ\MYDOCU~1\AIME\AFT\FTDD\FTDD\GPs\SAMPLES\A\APFT29A1.A2G

27

ns	ni	kinPar	age	ageErr
2	35	1.34	13.95	10.18
9	71	1.78	30.91	11.11
13	360	1.67	8.82	2.55
3	11	1.51	66.32	43.40
0	6	1.55	0.00	43.94
2	27	1.57	18.08	13.30
0	6	0.00	0.00	43.94
0	4	1.99	0.00	68.11
1	5	1.84	48.70	53.44
3	3	1.77	239.92	196.49
0	15	0.00	0.00	16.84
5	101	1.51	12.09	5.59
13	116	1.59	27.34	8.18
23	349	1.59	16.09	3.61
0	17	0.00	0.00	14.81
1	3	2.16	80.97	93.64
8	110	1.31	17.75	6.60
4	39	1.87	25.02	13.23
6	27	1.91	54.09	24.65
6	45	2.03	32.51	14.28

0	9	0.00	0.00	28.62
4	6	1.55	160.94	104.38
8	48	1.34	40.61	15.72
41	280	1.42	35.69	6.38
0	5	2.28	0.00	53.44
10	82	1.47	29.74	10.14
28	211	2.58	32.36	6.82

123000

DISPLAY AND PARAMETER SPECIFICATIONS

maxTime	maxTemp	maxFreq	maxLength
100.00	200.00	0.50	20.00
projectToC	showFit	calcEasyRo	usedCf
1	1	1	1

Max age for kinetic plots
301.35

Inverse model constraints

Num constraints
4

Time (Ma)	Upper (deg C)	Lower (deg C)
0.000	20.000	20.000
22.508	176.963	25.131
64.952	25.131	25.131
99.035	196.859	196.859

Inverse model specs

Monte Carlo

Enforce Max Heating	Enforce Max Cooling	Monotonic	Watch It Go
0	0	1	0

Max Heat Rate Max Cool Rate
10.0 10.0

Num Paths	Num Paths Run	Divs per seg
10000	10000	2

Time-temperature paths

Num Acceptable	Num Good
62	0

13

Temperature (deg C)

Time (Ma)	Best fit	Min Acc	Max Acc
0.000	20.000	20.000	20.000
5.627	50.877	20.358	77.656
11.254	52.786	39.905	86.234
16.881	74.653	41.483	107.873
22.508	128.620	122.996	147.296
33.119	124.706	50.350	133.227
43.730	123.950	26.947	130.019
54.341	113.691	25.154	113.691
64.952	25.131	25.131	25.131
73.473	180.911	25.904	185.021
81.994	194.715	26.446	196.625
90.514	196.358	37.383	196.788
99.035	196.859	196.859	196.859

Easy Ro Results

calc	equalAcc	meanAcc	sdAcc	equalGood	meanGood	sdGood
1	0	0.90	0.01	1	0.00	0.00

29229118

APPENDIX 6

TECTONIC MODEL AND CONCLUSIONS

Discussion

According to most plate tectonic models for the Proto-Caribbean and Caribbean lithosphere (e.g., Pindell et al., 1998; Pindell et al., 2005), the North and South American plates rifted apart during Jurassic and Lower Cretaceous time as a result of the break-up of the super continent Pangea (Bartok, 1993). Upper Jurassic and Lower Cretaceous sediments were deposited on the passive continental margin of South America. In Paleocene-Eocene time North and South America started to converge again. As a result of this convergence, the northern margin of South America evolved from a passive margin to a foredeep as suggested by Pindell et al. (1998).

Beck (1978) suggested on the basis of sedimentary structures that the Serranía del Interior fold and thrust belt and the Guárico basin underwent two phases of contraction: first in the Eocene and subsequently in the Miocene. The Eocene cooling ages derived from the AFT data in the eastern part of this study area (San José de Guaribe) are consistent with Beck's model and with the N-S convergence. New $^{40}\text{Ar}/^{39}\text{Ar}$ ages record exhumation of the Cordillera de la Costa belt in the Eocene as well (Sisson et al., 2005). The Cretaceous/Paleogene sedimentary rocks were probably incorporated in a Proto-Caribbean accretionary wedge and deformed in the Eocene as the consequence of North American and South American plates converging again and not as a consequence of Caribbean-South America plate interaction (Fig. 1). The Cretaceous /

Figure 1. Tectonic model for north central Venezuela. This cartoon shows how an Eocene apatite fission-track age can be preserved. Fission tracks form continuously within a uranium-238-bearing host crystal (e.g. apatite). All fission tracks within a detrital apatite at temperatures well above ~110 °C will anneal. As soon as there is a geological event (e.g., generation of a perisutural foreland fold and thrust belt), the apatite fission-tracks in the rocks that are uplifted and cooled below ~110 °C will be preserved and therefore will time the thrusting event. Subsequent younger events can be preserved in this very same manner. However, the loading of an allochthonous terrane on top of the hinterland portion of the belt (i.e. the one preserving an Eocene cooling event) could cause the preserved Eocene cooling ages to anneal at temperatures above ~110 °C.

Paleogene rocks of the “Piedmont belt” in the north are more intensely deformed than the rocks in the south. The deformation that affected the younger rock sequences started in the Neogene and continued through the Plio-Pleistocene.

The Cretaceous and Paleogene rocks in the western part of the study area were uplifted, eroded and exhumed and they went through the AFT annealing temperature of 110 °C in the Late Oligocene through the Middle Miocene (Fig. 2). Initiation of mountain building occurred in Late Oligocene, west of the site of its final emplacement that occurred in the Middle Miocene. This is the time that the Leeward Antilles and the allochthonous Caribbean terranes collided with South America (e.g., Pindell et al., 2005). The final obduction of the allochthonous nappes onto continental South America in Middle Miocene time marks the flip in the polarity of the subduction from a north-dipping Paleogene subduction to a south-dipping Benioff subduction zone (e.g., Fig. 9 of Avé Lallemant, 1997). Likewise, the inception of the basal foredeep unconformity in the eastern Venezuela basin occurred in Early Miocene. An Early to Middle Miocene tectonic event is recorded as well, offshore of north-central Venezuela. Here, Paleogene extensional structures north of the Margarita-Los Testigos high, La Tortuga, La Blanquilla basins and Cubagua sub-basin were inverted (Ysaccis, 1997). Biological evidence suggests that major divergence in marine species of stingrays occurred in northern South America as a result of physiographical isolation during the Miocene (Lovejoy et al., 1998). Fresh-water stingray species can be observed in the Platillon and Tiznados Rivers today.

Any pre-Oligocene fission tracks in the Cretaceous-Paleogene rocks from the Platillón-Tiznados and Camatagüita-Valle Morín transects were completely annealed

Figure 2. a) The Villa de Cura nappe formed in an island arc environment (red) while the Cordillera de la Costa and Caucagua-El Tinaco, Loma de Hierro belts (blue) represent ProtoCaribbean passive margin rocks, Paleozoic and older basement and assemblages of oceanic affinities, probably accreted on the northwest corner of South America as early as Cretaceous time (Campanian), b) During the Late Paleocene, the island arc derived Villa de Cura nappe (red) is tectonically moving towards the south along arc-parallel strike slip faults, overriding the Cordillera de la Costa and Caucagua-El Tinaco, Loma de Hierro belts (blue). In turn, the latter belts are being exhumed and loaded onto the Guyana craton. After Pindell and Keenan (2005)

prior to the Late Oligocene-Middle Miocene events. Only in the San José de Guaribe area were AFT ages not reset. Here, the rocks in the Paleogene accretionary wedge did not get hot enough for the fission tracks to be completely annealed. The accretionary wedge may have formed as the result of N-S convergence of the Americas. Pindell et al., (1998) suggested that a sutural basin might have formed along the margin of central and eastern Venezuela prior to the emplacement of the nappes. The collision of the Leeward Antilles volcanic arc caused the Villa de Cura nappes to be obducted and thrust to the south. Final emplacement of the nappes uplifted the entire northern margin resetting the apatite thermochronometer and resulting in the Middle Miocene ages observed in the Cordillera de la Costa belt. More AFT data of rocks along the Villa de Cura nappes are needed to better constrain its cooling history and to corroborate the hypothesis that the final obduction of this allochthonous terrane occurred in the Middle Miocene (Fig. 2). The thrust faults along which the allochthonous belts (inclusive of the Villa de Cura nappes) were emplaced can be considered as out-of sequence or envelopment thrusts, but, of course, there is considerable time between the two events.

As noted before, during Early to Middle Miocene metamorphic rocks of the accretionary wedge, specifically in the Cordillera de la Costa belt, experienced cooling below $\sim 110^{\circ}\text{C}$ (Sisson et al., 2005). Likewise, Middle Miocene AFT age data are widespread in the study area, in particular in the “Piedmont belt”. Presence of blueschists along the Venezuelan coast and in the Villa de Cura nappes (Klippe; Avé Lallemant and Sisson, 1993) and the antiformal structure of the Cordillera de la Costa rock suite (Ostos, 1990) suggest also that regional uplift occurred during the Pliocene-Pleistocene. All these arguments suggest that a regional tectonic pulse or rebound took

Figure 3. a) During Middle Eocene, the Villa de Cura nappe (red) and the Cordillera de la Costa and Caucagua-El Tinaco, Loma de Hierro belts (blue) possibly locked as a tectonic unit are loaded onto the Guyana craton. A foredeep formed along the northern Venezuela margin as a direct consequence of Caribbean-South America transpression and North America-South America contraction, b) In Early Oligocene time, the Caribbean plate is due east. The inception of the basal foredeep unconformity in the Guarico basin occurred as early as Late Eocene-Early Oligocene time as the allochthonous nappes are accreted to the south. After Pindell and Keenan (2005)

place in the Middle Miocene to Recent times, due to the interaction of the Caribbean and South American plates.

SUMMARY AND CONCLUSIONS

The E-W trending Caribbean – South American plate boundary zone in north-central Venezuela consists from north to south of several E-W trending belts: North Caribbean deformed belt, Leeward Antilles volcanic island arc, a zone of Neogene extension, Caribbean Mountain system and the Guárico foreland basin. The Caribbean Mountain system consists of several belts of which the Serranía del Interior foreland fold and thrust belt is the most southerly one. The Serranía is divided into four belts, the most northerly of which is the “Piedmont belt,” tectonically underlying the Villa de Cura blueschist nappes (klippe). The present study involves only the Serranía and the Guárico foreland basin.

Cenozoic deformation and thermal histories of the Serranía del Interior foreland fold and thrust belt in north-central Venezuela were studied by applying structural analysis, interpretation of seismic lines and apatite fission-track (AFT) analysis. Four north-south trending transects were investigated. They are from west to east: (1) Platillón-Tiznados, (2) Valle Morín-Camatagüita, (3) Altagracia de Orituco and (4) San José de Guaribe. Analysis of regional 2D seismic lines and field data suggests that the South American plate in north-central Venezuela underwent several phases of deformation:

(1) *NW-SE extension*. Extension and the opening of the Espino graben in the southernmost portion of the Guárico basin occurred in Triassic-Jurassic time. The graben-

Figure 4. a) By Early Miocene, the Villa de Cura nappe (red) has been disrupted and is represented by the Leeward Antilles and its southernmost portion in north-central Venezuela, b) In Late Miocene-Pliocene northern Venezuela was uplifted and eroded, exposing the Cordillera de la Costa, Cauagua-El Tinaco and Loma de Hierro belts (blue) leaving the Villa de Cura nappe in the area as a klippe. After Pindell and Keenan (2005)

bounding faults displace sedimentary and metamorphic Paleozoic rocks and Precambrian crystalline basement of the Guyana shield. The graben may extend beneath the eastern Serranía del Interior to the east and to the Apure and Colombia Llanos in the west.

(2) *Passive margin*. In the Cretaceous, a north-facing passive margin formed that subsequently subsided due to cooling (e.g., Pindell, 1993). This is the time of sea level rise, transgression and encroachment of the proto-Caribbean seas onto continental South America.

(3) *Contraction I*. In the Paleocene-Eocene, the North and South American plates started to converge in NW-SE direction. The trend of the plate boundary zone was E-W, thus, convergence was highly oblique. This caused displacement partitioning in the most northerly allochthonous terranes of the Caribbean Mountains (Avé Lallemant, 1997). Thrusting and folding were the result of N-S shortening related to the boundary-normal component of convergence and the boundary-parallel component was expressed by displacements along EW-trending right-lateral strike-slip faults and shear zones. However, the deformation structures in the Serranía del Interior fold and thrust belt formed only by NS shortening. The La Victoria fault zone, north of the Serranía del Interior, may be the most southerly structure along which major strike-slip displacements have occurred.

As contraction was highly right-oblique, collision of the Leeward Antilles arc with South America was strongly diachronous: it happened in Paleocene and Eocene time in the west (Lara nappes), in the Oligocene and Miocene in the Western Serranía del Interior of north-central Venezuela and in the Eastern Serranía del Interior, during

Miocene, Pliocene and Pleistocene. The AFT ages in the Western Serranía as presented here, support the model of diachronous collision.

During the Middle Miocene, a major regional event occurred that caused the inverted basins in the Venezuelan platform and resulted in uplift of the entire area. It is possible that the final obduction of the allochthonous nappes onto continental South America in Middle Miocene was caused by the change in the polarity of the subduction from a north-dipping in the Paleogene to a south-dipping in the Neogene.

(4) Foredeep. Late Eocene-Early Oligocene inception of the basal foredeep unconformity in the study area was coeval with extension in the Guárico basin. Normal faults in the autochthonous terranes of the South American plate were either reactivated older faults or they were newly formed. They extend well south into the basin and may have formed during early stages of the development of the foredeep, in response to the loading of the Lara nappes on the Guyana shield and on the peneplaned Paleozoic folded belt.

During the contractional phase, the Guárico basin was decoupled along marine shales of the Roblecito Formation. From this sole thrust or detachment level, south-vergent thrust imbricates emerged crosscutting Oligocene-Miocene sedimentary sequences of the Roblecito and Chaguaramas foredeep. Several small triangle zones developed within the basin. AFT show that for most of the area the onset of uplift and cooling was in Late Oligocene-Middle Miocene.

(5) Guárico basin. The Guárico basin was tilted to the east during a regional tectonic uplift that occurred in Pliocene-Pleistocene times. This caused the uplift and peneplanation of the Guárico basin. Field data support the hypothesis that during this

time contractional tectonics occurred as the Miocene molasse was incorporated into the mountain range. Minor Neogene and younger extension is observed throughout the basin, affecting Oligocene sedimentary sequences as well (Figs. 18 to 20). The available seismic data do not constrain the orientation of the extensional structures. Even so, based on analysis of 2D seismic data, Blanco et al., (1988) and Daal and Lander (1993) suggest that these normal faults are NE-SW trending.

A NNE-SSW trending 2D composite seismic line through the Guárico basin shows the Pliocene-Pleistocene uplift and exhumation of the Guárico basin deposits (Fig. 12). The latter deposits are much thinner in the east and they are overlain by very thick sequences of the Chaguaramas Formation and lateral equivalents.

(6) *Contraction II.* One of the most stunning results of the AFT analysis is the age of many samples from the easternmost transect (San José de Guaribe). This age is Paleogene and is younger than the stratigraphic age suggesting that deformation had already begun in north-central Venezuela prior to the arrival of the Leeward volcanic island arc and the emplacement of the Serranía del Interior thrust sheets. Convergence of the North and South American plates in the Eocene may have been the driving force that generated the foreland basin in central-eastern Venezuela, involving the passive margin in the deformation since the Middle Eocene.

(7) *Villa de Cura.* Within the “Piedmont belt” and beneath it and the Villa de Cura nappes, the seismic resolution is quite poor allowing for two contrasting structural interpretations: klippe, or imbricate thrust sheet (Figs. 8 and 9). Two of the interpreted 2D seismic lines cross the contact of the “Piedmont belt” with the Villa de Cura Group (Figs. 8 and 9), but the lines cannot resolve the question. Modeling of gravimetric and

magnetic data suggests that the Villa de Cura nappes are very thin (between 1 and 2 km thick; Figs. 3 and 4 of Bosch and Rodriguez, 1992) and, thus, may better be described as klippe. Projection of the proximal passive margin and its basement suggests that the interpreted Cretaceous sequence and probably the Lower Oligocene units may extend northward beneath the Serranía and the Villa de Cura nappes.

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