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**Thermal Evolution of the Eastern Serranía del Interior Foreland Fold and Thrust
Belt, Northeastern Venezuela, Based on Apatite Fission Track Analyses**

by

Brian David Locke

A THESIS SUBMITTED
IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE

Master of Arts

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ABSTRACT

Thermal evolution of the eastern Serranía del Interior foreland fold and thrust belt, northeastern Venezuela, based on apatite fission track analyses

by

Brian Locke

Apatite fission track data show a gradual decrease in age (~30 Ma to ~15 Ma) from north to the south in the eastern Serranía del Interior, northeastern Venezuela. Based on a previous study, a model for the tectonic evolution of the eastern Serranía is proposed in which two stages of deformation occurred. Stage 1 (45 Ma –20 Ma) involves the internal deformation of fault blocks. Stage 2 (20 Ma – 12 Ma) involves envelopment thrusting, doubling the thickness of the thrust sheet. Shortening within the Serranía del Interior ceased at 12 Ma. In stage 1, cooling and exhumation rates were 5.8 °C/km and 0.26 km/my, respectively, and in stage 2, cooling and exhumation rates were 4.25 °C/km and 0.2 km/my, respectively. The deformation of the Serranía prior to the collision of the Caribbean plate with South America is probably related to the convergence of the North and South American plates.

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PREFACE

This thesis has been written in a non-traditional format. The main body of the thesis is written as a scientific paper that will be submitted for publication in a GSA Special Paper entitled "Caribbean / South American plate interactions, Venezuela", edited by Dr. Hans Avé Lallemant and Dr. Virginia Sisson. Additional background information and research is found in the appendices.

Thermal evolution of the eastern Serranía del Interior foreland fold and thrust belt, northeastern Venezuela, based on apatite fission-track analyses

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ABSTRACT

The eastern Serranía del Interior foreland fold and thrust belt in eastern Venezuela consists of many south vergent thrust faults that juxtapose deformed Cretaceous and Paleogene passive margin formations with less deformed Neogene active margin formations. Apatite fission track data show a gradual decrease in age from north to south from ~30 Ma to ~15 Ma. Based on a previous study (Hung, 1997) in which a total shortening of 115 km in the Serranía is estimated, a two-stage model for the tectonic evolution of the eastern Serranía del Interior is presented here. Stage 1 (45 Ma – 20 Ma) involves the internal deformation of fault blocks by folding and imbricate thrusting in an in-sequence piggy-back style propagating toward the south. Stage 2 (20 Ma – 12 Ma) involves envelopment thrusting that doubled the thickness of the thrust sheet. Shortening within the Serranía del Interior ceased at 12 Ma. Stage 1 had a cooling rate of 5.8 °C/km and an exhumation rate of 0.26 km/my from 30 Ma to 20 Ma. Stage 2 had a cooling rate of 4.25 °C/km and an exhumation rate of 0.2 km/my from 20 Ma to the Present. The deformation of the Serranía prior to the collision of the Caribbean plate with South America is probably related to the convergence of the North and South American plates which has been relatively constant since 50 Ma.

INTRODUCTION

The boundary between the South American and Caribbean plates in northern Venezuela is a wide diffuse zone of deformation resulting from a diachronous transcontractional collision and subduction of the Caribbean plate beneath the South American plate (for more details see Appendix A), (Avé Lallemant, 1997; Pindell, 1993; 1998). The northern margin of Venezuela was deformed as the Caribbean plate traveled to the east-southeast with respect to the South American plate. Deformation began in western Venezuela during the Eocene and decreased in age to the east. Consequently, the

Leeward Antilles terrane and accretionary complex (Villa de Cura, Paracotos, Caucagua-El Tinanco and the Cordillera del la Costa) was obducted diachronously onto the northern margin of Venezuela. Before obduction, this margin was a Cretaceous to Tertiary passive margin. The collision resulted in the Caribbean Mountain system and the Serranía del Interior fold and thrust belt.

The Cariaco basin separates the eastern Serranía del Interior and the Araya-Paria peninsulas from the central Serranía del Interior and Caribbean Mountain system. Erlich and Barrett (1990) believe movement along the right-stepping, right-lateral San Sebastian - El Pilar fault system created the pull-apart Cariaco basin.

The eastern Serranía del Interior is a south-vergent foreland fold and thrust belt (Fig.1. in Ostos et al., Chapter 2, this volume) with heavily deformed Cretaceous and Paleogene strata and less deformed Neogene sedimentary rocks (e.g., Case et al., 1984; Di Croce, 1995). In eastern Venezuela, the east-west trending El Pilar fault separates the Caribbean Mountain system to the north from the eastern Serranía del Interior to the south.

Apatite fission track data in the central Serranía del Interior (in the state of Guárico) (Pérez et al., 1998) suggested that two cooling events had occurred. The first was a previously recognized Late Oligocene to Early Miocene event that occurred in the western and central portion of the central Serranía del Interior. The second Middle Eocene event, previously unrecognized, is in the eastern part of the central Serranía del Interior. Three explanations are possible for the Middle Eocene cooling event. The first explanation is that the population of measured apatite grains may not have been completely reset and therefore may retain protolith history. Partially reset grains will suggest a cooling event older than completely reset grains. The second explanation is

that two grain populations with different annealing properties were counted in the same sample. Grains more resistant to annealing would suggest an older cooling age, while, grains least resistant to annealing would suggest a younger age. Mixing grain populations with different annealing properties would give an erroneous cooling age. The third explanation is that the grain population does record an Eocene event, possibly associated with convergence between the North and South American plates prior to the emplacement of the Caribbean plate.

Using GPS velocity data, Dixon and Mao (1997) estimate that the North and South American plates are converging at present. The pole of rotation lies within the Atlantic Ocean at a latitude approximately equivalent to Margarita Island (Figure 5). Rates of shortening increase from east to west from 2 mm/yr to 8 mm/yr. The rate of shortening at the eastern Serranía del Interior is estimated to be 3.5 mm/yr. Dixon and Mao (1997) show their pole of rotation and deformation rates are very similar to the Nuvel –1 prediction of DeMets et al. (1990) and four stage poles spanning the last 50 million years calculated by Müller and Smith (1993). The similarities between long term average deformation rates and the stability of pole position suggest that the plate motions have been steady for the last ~50 m.y. (e.g., Dixon and Mao, 1997). This implies that deformation in the eastern portion of the Caribbean / South American plate boundary may have occurred prior to the passage of the Caribbean plate. The Eocene apatite fission track cooling event may be the result of this North and South American convergence. The purpose of the present study was to use apatite fission track data to test the results found by Perez (2001) and to constrain a model for the tectonic evolution of the eastern Serranía del Interior.

STRATIGRAPHIC AND STRUCTURAL SETTING

Regional Geology

The field area within the eastern Serranía del Interior (Figure 1 in Avé Lallemant and Sission, 2001, this volume; Preface; and Figure 1 and 2) is bounded to the north by the east-west trending El Pilar right-lateral, strike-slip fault; to the south and east by the 070° trending subsurface Piritá fault; and to the west by the Úrica fault (e.g., Case et al., 1984; Chevalier et al., 1995). The Serranía del Interior is a south to southeast verging fold belt with major folds and thrust faults trending northeast to east and strike-slip faults trending northwest-southeast (e.g., Case et al., 1984; Chevalier et al., 1995). Younger Tertiary and Upper Cretaceous rocks are exposed in the west and southwest, while older Cretaceous rocks, closer to the core of the structure, are exposed to the north and the east.

Stratigraphy

Stratigraphic work in the eastern Serranía del Interior was performed by Liddle (1928), Hedberg (1937, 1950), Hedberg and Pyre (1944), Rod and Maync (1954), Vierbuchen (1984), Yoris (1985; 1988; 1992), Chevalier (1993), Chevalier et al. (1995) and Ostos et al. (2001, this volume; Chapter 2), (for more details see Appendix B). Summary information regarding the stratigraphic units is compiled under the Venezuelan Stratigraphic code (<http://www.pdv.com/lexico>).

The stratigraphy of the eastern Serranía del Interior can be subdivided into five groups; 1) Sucre Group (Neocomian - Albian), 2) Guayuta Group (Cenomanian – Campanian), 3) Santa Anita Group (Campanian – Middle Eocene), 4) Merecure Group (Lower Oligocene – Early Miocene), and 5) Neogene to Recent deposits (Figure 1).

Placed in a plate tectonic setting, the upper Jurassic to Eocene – Miocene rock units were deposited on a passive margin in basins formed by the subsidence associated with the rifting and breakup of Pangea during the Triassic to Late Jurassic. The Miocene to Present rock units were deposited on an active margin during the contraction between the Caribbean and South American plates as older rocks were uplifted, eroded and redeposited. During the passive margin phase, the Sucre, Guayuta, Santa Anita Groups and the Los Jabillos and Areo Formations of the Merecure Group were deposited with sediment input predominately from the south. During the active margin phase, the Naricual Formation of the Merecure Group and Neogene to recent sediments were deposited as the Serranía del Interior was uplifted and eroded. Sediment input was from the north and south (Erllich and Barret, 1990; Erickson and Pindell, 1993; Di Croce, 1995; Ostos et al. 2001, this volume, Chapter 2; Yoris, 2000 personal communication). It is possible that the influence of an active margin began earlier during the Middle Eocene. The Middle Eocene Tinajitas Member of the Caratas Formation may have been deposited on the foredeep margin of northern Venezuela (Ostos et al., 2001, this volume, Chapter 2).

Structural Geology

Previous structural work performed in the eastern Serranía del Interior includes Rod (1956), Rosales (1973), Rossi (1985), Carnevali (1988), Chevalier (1993), Roure et al. (1994), Chevalier et al. (1995), Di Croce (1995), Martinez (1995), Avé Lallemant (1997), Hung (1997), and Ysaccis (1997), (for more details see Appendix C). Additionally, geologic maps were made by Creole Petroleum Company (1962) and the República de Venezuela, Ministerio de Minas E Hidrocarburos (1976).

Folds in the eastern Serranía del Interior trend east-west to southwest-northeast with degrees of tightness ranging from isoclinal to gentle and open. Fold axes trend approximately 070° - 100° and plunge slightly to the southwest (Vierbuchen, 1984; Chevalier et al., 1995; Di Croce, 1995). Axial planes strike east-west to northeast-southwest and generally dip to the north. Some north-vergent folds and thrust faults have been described (e.g., Avé Lallemant, 1997). Axial plane dip angles vary from horizontal along the coast to vertical toward the south.

Major thrust and strike-slip fault systems exist within the eastern Serranía del Interior. The Pirital thrust fault is a major tectonic feature in the subsurface of the field area. Roure et al. (1994) proposes that the Pirital thrust fault has 20 to 30 km of horizontal displacement and 4 to 5 km of vertical displacement. The Pirital thrust fault may have 42 km of displacement (Pindell, 2000, personal communication). The Pirital thrust emplacement occurred during the Middle Miocene with a decollement surface within the syndepositional Carapita Formation shales.

Right-lateral, northwest-southeast trending strike-slip fault systems within the eastern Serranía del Interior include from west to east the Úrica and San Francisco faults dividing the eastern Serranía del Interior from west to east into the Bergantín and Caripe blocks (Roure et al., 1994; Chevalier et al., 1995). Dextral offset on the Úrica and San Francisco fault may be no greater than 35 km and 25 km, respectively (Salvador and Stainforth, 1968; Rosales, 1972; Munro and Smith, 1984; Rossi, 1985).

One of the biggest discrepancies among authors discussing the structure of the eastern Serranía del Interior is their interpretation of deep structures and basement faulting (Rosales, 1973; Rossi, 1985; Roure et al., 1994; Chevalier et al., 1995; Martinez 1995, Hung, 1997). The thickness and amount of deformation of rock units underlying

the Lower Cretaceous are unknown (Hung, 1997; Ysaccis, 1997). Hung (1997) used seismic reflection data to interpret a cross section through the Caripe block of the eastern Serranía del Interior using six different hypotheses of basement involvement. Model estimates for the shortening within the eastern Serranía del Interior range from 9 % (16 km) to 66 % (115 km). Recent seismic data indicates that complex thrust structures exist beneath the eastern Serranía del Interior and that 115 km of shortening may be the best estimate (Avé Lallemant, 2000, personal communication).

APATITE FISSION-TRACK AGES

A fission track is a zone of damage within a crystal (i.e. apatite, zircon) formed by the spontaneous fission of ^{238}U (Blythe et al., 1998), (for more details see Appendix D). During fission, two equally charged particles accelerate away from each other creating a linear zone of defects within the crystal called a fission track.

Fission tracks are relatively stable at low temperatures. Induced fission tracks in apatite have an initial mean length of $\sim 16\text{ }\mu\text{m}$. When fission tracks experience higher temperatures, they begin to shorten and disappear due to annealing. Annealing rates vary with fission track orientation (Green and Durrani, 1977; Donelick, 1991) and $\text{Cl}/(\text{Cl}+\text{F})$ content of the apatite (Green et al., 1986; Crowley et al., 1990). Apatite fission tracks anneal at temperatures between $60\text{ }^{\circ}\text{C}$ and $110\text{ }^{\circ}\text{C}$, the so-called partial annealing zone (PAZ) (Gleadow and Duddy, 1981; Gleadow et al., 1983). Track-length distributions are used to evaluate the cooling history of the sample within the PAZ.

Fission track densities are used to determine a grain's cooling age. The formation of fission tracks is dependent on the grain's concentration of Uranium and the age of when the grain passed through the PAZ. By measuring the amount of Uranium and the

number of natural tracks formed within a grain, a cooling age of the grain can be calculated.

Apatite grains are etched with acids to view fission tracks. The chemical composition of a grain controls its solubility. By measuring solubility, grain populations with different chemical compositions can be distinguished. The parameter used to quantify solubility is called D_{par} and it is the measurement of the maximum length of fission track etch pits parallel to the crystallographic c -axis (Burtner et al., 1994; Donelick 1993, 1995).

Experimental Techniques

Samples of sedimentary rocks were collected for apatite fission track analysis from the eastern Serranía del Interior during the spring of 1999 and 2000. Table 1 lists the location, lithology, and depositional age of the 20 samples analyzed. Apatite grains were separated from rock samples using conventional heavy liquid and magnetic separation techniques (Carlson et al., 1999; Locke, 2001).

The standard fission track age equation (Hurford and Green, 1982) was used with a weighted mean zeta calibration (Fleisher and Hart, 1972; Hurford and Green, 1983) factor based on Durango apatite standards. All measurements were done by the author.

Results

Fission track results are summarized in Table 2 and sample locations are depicted in Figure 2. Basic counting data is available in Locke (2001), (for more details see Appendix E). D_{par} measurements were not useful in identifying different grain

populations because no correlation between grain age and Dpar length was observed. Therefore, apatite fission track data were interpreted using the techniques of Brandon et al., (1998) to statistically separate the grains into minimum and older age populations. To deal with multiple populations, peak-fitting methods (Galbraith, 1988; Galbraith and Green, 1990; Brandon and Vance, 1992, Galbraith and Laslett, 1993; Brandon et al., 1998) were used to attempt to isolate different annealing resistant populations to obtain the age of the youngest population. The age of the youngest population of grains is called the minimum age of the fission track distribution (Galbraith and Laslett, 1993). The minimum age corresponds to the age of grains with the least resistance to annealing. These grains will be the first to reset at the lowest temperatures within the PAZ and the last grains to begin to record a cooling event. Grains more resistant to annealing (i.e., older grain ages) will survive higher temperatures within the PAZ and may even retain protolith information when the grain is not completely reset.

Interpretation of Multiple Populations

Of the 20 samples analyzed, four samples contained insufficient apatite to give a reliable age and were not used in the interpretation of data (samples BL-99-23, BL-00-31, BL-00-48, and BL-00-92 each had one grain of apatite). Samples BL-99-19a, BL-00-23 and BL-00-32 statistically have one age population, while the remainder of analyzed samples statistically have multiple age populations.

Two samples (BL-99-2 and BL-00-72) have three age populations while the rest of the samples have two age populations. In sample BL-00-72, two grains composed the third age population (189.2 Ma) and may reflect protolith age. The third age population

of sample BL-99-2 statistically contains only 0.1 grains and probably does not reflect a true geologic event, but more likely a poor quality grain. For ease of discussion, the second oldest age population is hereby referred to as the older age.

For most samples, the minimum age is based on the majority grains within the sample. However, in five samples (BL-99-2, BL-99-5, BL-99-16, BL-00-21, and BL-00-38) the minimum age is based on a minority of grains within the sample. For example, in BL-99-2 the minimum age is based on 5.6 grains while the older age is based on 32.3 grains. The minimum age of samples based on a minority of grains is much younger than the minimum age of other samples. However, the older age of the youngest samples is similar to the minimum age of the other samples. For example, samples BL-99-2 and BL-99-5 have minimum ages of 3.4 Ma and 4.9 Ma, and older ages of 23.5 Ma and 18.7 Ma respectively, while adjacent samples BL-99-6 and BL-99-9 have minimum ages of 28.5 Ma and 21.8 Ma respectively.

These very young minimum ages may 1) be based on less annealing resistant fluorapatite grains and reflect a recent cooling event that weakly overprints an older event or 2) be a product of sample preparation and measurement procedures and poor grain quality and quantity. The youngest minimum ages may be based on fluorapatite grains while the older ages and minimum ages of other samples may be based on chlorine rich apatite grains. If the second case is true, the youngest minimum ages do not reflect a recent cooling event. Individual apatite grains were severely corroded and dissolved. Secondary porosity is intense in most of the rocks in the eastern Serranía del Interior. Additionally, numerous inclusions were microscopically observed within grains.

The grain age may be incorrect and too young if, 1) the Uranium concentration is overestimated or 2) the spontaneous fission track count is underestimated. Uranium-rich inclusions or adjacent Uranium-bearing minerals, such as zircon, could increase the number of induced fission tracks counted, reducing the grain age. Corrosion or dissolution may remove a portion of a grain that contains fission tracks or make a fission track difficult to see, lowering the number of measured spontaneous tracks and reducing the grain age. Therefore, the youngest ages based on minority of grains are not used in the construction of the tectonic model.

The majority of samples were taken from the Lower Cretaceous Barranquin Formation (Ostos et al., 2001, this volume, Chapter 2). Most of the sample ages used were reset, except for samples BL-00-23 and BL-00-38. The latter two have ages older than their depositional age indicating that they retain unreset or partially reset protolith information. Unfortunately, the stratigraphy of these samples is not exactly defined. Sample BL-00-38 was collected from either the Caratas Formation (Middle Eocene) or the Los Jabillos Formation (Lower Oligocene). Sample BL-00-23 was collected from the San Antonio Formation (Santonian), San Juan Formation (Maastrichtian), or Caratas Formation (Middle Eocene). The stratigraphy of the unreset samples is younger than most of the other samples. It is possible that these samples have not been buried deep enough for completely resetting the fission track age.

GEOLOGIC INTERPRETATION OF APATITE FISSION TRACK RESULTS

Fission track ages have been projected onto a northwest-southeast trending transect and depicted in Figure 3. The five unlabeled (open square) ages are the youngest

ages based on a minority of grains. The solid squares represent ages based on the majority of grains. Each sample with a young age (open square) has a corresponding older age (solid square). A least square fit line has been drawn through the ages based on the majority of grains. The best fit line shows that apatite fission track ages generally get younger to the south. Sample BL-99-18 has been omitted in the construction of the best-fit line; it contains only five grains of apatite and of those five grains there are two distinct populations. The older population (102.4 Ma) is based on two grains and the younger population (13.1 Ma) is based on three grains. The small number of grains in each population is probably not a statistically accurate reflection of the samples true fission track age and therefore has been omitted.

Geothermal gradients. Based on numerous well logs, the present day geothermal gradient within the eastern Serranía del Interior is 23 °C/km (A. Aleman, 2000, personal communication). The surface temperature is assumed to be 25 °C. Using the geothermal gradient and surface temperature, the PAZ (60 °C and 110 °C) occurs at a depth of 1.5 km to 3.7 km. All reset samples indicate that the rocks reached temperature in excess of 110 °C (3.7 km depth). Hung (1997) estimates that the Barranquin Formation was buried to a depth of approximately 5 km or 139 °C, well above the effective closure temperature. In order to begin retaining fission tracks, these rocks needed to have been brought upwards to an effective closure temperature of 110 °C (3.7 km) by eroding 1.3 km of overburden.

Sequence of thrusting. In order to shorten the undeformed beds of the eastern Serranía del Interior to its current deformed state, it is important to understand the

sequence of faulting in the eastern Serranía del Interior. Using seismic reflection data, both Roure et al. (1994) and Hung (1997) suggested that the eastern Serranía del Interior underwent two stages of deformation. The early stage is in-sequence with piggy-back thrusts. The shales of the Carapita Formation had high pore pressure and contain dewatering and compaction features such as mud diapirs which indicate that they would make a good decollement surface (Roure et al., 1994). Deformation probably began in the north during the deposition of the Naricual Formation (late Oligocene) and continued to the south during the deposition of the Carapita Formation (Miocene). The early stage of deformation essentially doubled the thickness of the thrust sheet and created the complex structure within the eastern Serranía del Interior. The late stage deformation resulted in out-of-sequence faulting by reactivating older thrust faults such as the Pirital fault.

Eastern Serranía evolution model. Pindell (1998) attempted to reconstruct the Serranía del Interior to its original undeformed state in three steps working backward in time. The first step is to remove approximately 20 km of right-lateral offset along the El Pilar fault and related strike-slip faults. The second step is to move the Serranía del Interior to the northwest by restoring 40 km to 50 km of thrusting on the Pirital thrust fault and similar faults south of the Pirital fault. The third step is to reconstruct approximately 40 km along the folds and thrusts of the Serranía del interior to their undeformed state. The amount of shortening (80 km) in this model is slightly less than within the Serranía del Interior, however, Pindell (2000, personal communication) currently suggests shortening within the Serranía del Interior to be 100 to 150 km.

Based on a shortening rate of 3.5 mm/yr, it would take 33 m.y. to shorten the eastern Serranía del Interior by 115 km. With shortening ceasing at 12 Ma, the initiation of deformation within the eastern Serranía del Interior began at about 45 Ma (Middle Eocene). This time corresponds to the deposition of the Tinajitas Member of the Caratas Formation.

Fission track ages, within the field area, in the eastern Serranía del Interior range from 30 Ma to 20 Ma. The tectonic model will reconstruct the Serranía del Interior evolution from 45 Ma to the present at 30 Ma, 25 Ma, 20 Ma, and 12 Ma. Figure 4 depicts the evolution of the eastern Serranía del Interior using a representative northwest-southeast trending cross-section. The original locations of the 30 Ma, 25 Ma, and 20 Ma fission track contours are shown as black dots. The effective closure temperature (110 °C, 3.7 km) has been superimposed on the cross-section with a dashed line. The irregular line represents the erosional surface. To simplify the model, each fission track contour is located within one fault block. Within the individual fault block, internal deformation (faulting and folding) will thicken the block as shortening is accommodated. Slight displacement along the main fault will also occur.

Beginning at 45 Ma and initiating shortening at a rate of 3.5 mm/yr, 52.5 km of shortening was accumulated by 30 Ma. Some time between 45 MA to 30 Ma, Point A was uplifted from approximately 5 km depth. Erosion of 1.3 km caused the temperature at Point A to decrease to the effective closure temperature (110 °C), at this point (30 Ma), apatite at Point A began to record fission tracks within the PAZ. From 30 Ma to 25 Ma, Block B was activated in an in-sequence piggy-back style, accumulating an additional 17.5 km of shortening. Uplift and deformation within Fault Block A was minimal. In a

similar manner as Point A, Point B was uplifted to 3.7 km after 1.3 km of erosion and began recording apatite fission tracks at 25 Ma. With continued shortening (87.5 km), uplift and erosion, Point C recorded fission tracks at 20 Ma. At 20 Ma, the second stage of deformation began with the emplacement of a long undeformed thrust sheet by the Pirital envelopment thrust fault. Reasons for the change in deformation style may include; 1) a change in the tectonic regime as the Caribbean plate interacts directly with the Serranía del Interior, 2) a decrease in the slope of the accretionary wedge which has sufficiently reduced the overburden to allow envelopment thrusting to occur, or 3) a pinch out of low strength horizons hindering the propagation of additional in-sequence thrust faults. Roure et al. (1994) suggests that the Pirital thrust fault became active during the mid Miocene. The Pirital envelopment fault accumulated 27.5 km of shortening. Pindell et al. (1998) estimate 40 km of shortening along the Pirital thrust fault. The envelopment thrusting doubled the thickness of the thrust sheet, and increased uplift and erosion until Point A, B, and C reached their present day elevation.

From 12 Ma to the Present, strike-slip motion occurred along the El Pilar and associated faults. It is not apparent that motion along the San Francisco fault is enough to offset the apatite fission track age contours.

Cooling and Exhumation Rates

Based on this model, the cooling history of each deformation stage can be described independently. For Stage 1, the cooling history (and exhumation rate) from 30 Ma – 25 Ma and 25 Ma – 20 Ma is the same. In each 5 m.y. segment, a cooling from 139

°C to 110 °C occurred, indicating a cooling rate of 5.8 °C/m.y, (exhumation rate of 0.26 km/m.y.) for each fault block during deformation and erosion.

Assuming a constant exhumation rate from 20 Ma to the present, the cooling history of the second stage can be determined. From 20 Ma to the Present, Points A, B, and C were cooled from 110 °C to surface temperatures of 25 °C yielding a cooling rate of 4.25 °C/m.y. Using the average elevation of the samples, (300 m), the exhumation rate from 20 Ma to the Present is 0.2 km/my. The cooling and exhumation rates of Stage 2 are lower than Stage 1 because cooling in Stage 2 occurred over a greater period of time.

Role of North and South American Convergence

Modeled deformation of the eastern Serranía del Interior began at 45 Ma. At this time, the location of the Caribbean plate foredeep axis intersected the northern margin of Venezuela in the Lake Maracaibo area (Pindell et al., 1998). The peripheral bulge was located near Caracas. The eastward advancing Caribbean plate is not close enough to deform the Serranía; therefore, another reason for the deformation must be sought. The next obvious explanation for the deformation is the convergence between the North and South American plates (Figure 5). Dixon and Mao (1997) estimated that this contraction has been occurring at a steady rate since about 50 Ma. Pindell et al. (1998) estimates that convergence began during the Maastrichtian. With North and South American plate convergence, proto-Caribbean oceanic lithosphere might have been subducted beneath South American continental lithosphere. Pindell et al. (1991; 1998) refer to the subduction zone as the “Proto-Caribbean underthrust zone.” Pindell (1998)

estimates 70 km of convergence by Middle Eocene time in eastern Venezuela. The Caribbean plate consumed the Proto-Caribbean seaway during its eastward movement causing deformation near plate boundaries. As the Caribbean plate advanced toward the Serranía del Interior (~35 Ma), increasing amounts of shortening were taken up by the northern boundary of the Caribbean plate (i.e., Puerto Rico trench). The result was a cessation of shortening within the Serranía del Interior in response to North America and South America plate convergence.

CONCLUSIONS

Apatite fission track data from the eastern Serranía del Interior show a gradual decrease in age from north to the south ranging from ~30 Ma to ~15 Ma. Based on cross-sections by Hung (1997), a model for the tectonic evolution of the eastern Serranía del Interior suggests two stages of deformation. Assuming 115 km of total shortening at a rate of 3.5 mm/yr, deformation within the Serranía began at ~45 Ma. Stage 1 (45 Ma – 20 Ma) involved the internal deformation of fault blocks by folding and imbricate thrusting in an in-sequence piggy-back style that advanced towards the south. Rocks were progressively uplifted and eroded, from north to south, until they were brought into the PAZ (110 °C). The amount of shortening during Stage 1 is 87.5 km. Stage 2 (20 Ma – 12 Ma) involved envelopment thrusting that doubled the thickness of the thrust sheet. The amount of shortening during Stage 2 was 27.5 km. Erosion continued to the Present, when the rocks were brought to the surface. Shortening within the Serranía del Interior ceased at 12 Ma. Assuming a geothermal gradient of 23 °C/km, Stage 1 had a cooling rate of 5.8 °C/km and an exhumation rate of 0.26 km/my from 30 Ma to 20 Ma. Stage 2 had a cooling rate of 4.25 °C/km and an exhumation rate of 0.2 km/my from 20 Ma to the

Present. The cooling and exhumation rates of Stage 2 are lower than Stage 1 because cooling during Stage 2 occurred over a greater period of time. The deformation of the Serranía prior to the collision of the Caribbean Plate with South America is probably related to the convergence of the North and South American plates which has been relatively stable since 50 Ma.

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(for additional references see Appendix F).

TABLE 1. DETAILS OF OUTCROP SAMPLES

Sample	Latitude (N)	Longitude (W)	Elevation (m)	Lithology	Unit	Stratigraphic Division	Stratigraphic Age (Ma)
BL-99-2	10° 19' 10"	63° 57' 50"	200	sandstone	Barranquín (Taquaruno)	Aptian	113 - 124
BL-99-5	10° 19' 40"	63° 57' 90"	200	sandstone	Barranquín (Taquaruno)	Aptian	113 - 124
BL-99-6	10° 19' 40"	63° 57' 90"	200	sandstone	Barranquín (Taquaruno)	Aptian	113 - 124
BL-99-9	10° 19' 42"	63° 58' 32"	120	sandstone	Barranquín (Taquaruno)	Aptian	113 - 124
BL-99-16	10° 20' 80"	64° 06' 87"	80	sandstone	Barranquín (Taquaruno)	Aptian	113 - 124
BL-99-18	10° 21' 20"	64° 06' 23"	80	sandstone	Barranquín (Taquaruno)	Aptian	113 - 124
BL-99-19a	10° 09' 92"	63° 50' 01"	800	sandstone	Barranquín (Taquaruno)	Aptian	113 - 124
BL-99-23	10° 06' 77"	63° 44' 17"	100	sandstone	San Juan	Maastriichtian	65 - 74
BL-99-31	9° 59' 68"	64° 22' 88"	220	sandstone	San Juan	Maastriichtian	65 - 74
BL-00-21	10° 26' 58"	63° 52' 77"	5	sandstone	Barranquín (Taquaruno)	Aptian	113 - 124
BL-00-23	10° 27' 10"	63° 17' 21"	200	sandstone	San Antonio/San Juan/Catacas?	Santonian/Maastriichtian/Mid Eocene ?	87-83/65-74/50-39?
BL-00-25	10° 27' 73"	63° 38' 02"	320	sandstone	Barranquín (Taquaruno)	Aptian	113 - 124
BL-00-31	10° 23' 16"	63° 42' 30"	400	sandstone	Barranquín (Taquaruno)	Aptian	113 - 124
BL-00-32	10° 23' 05"	63° 43' 52"	400	sandstone	Barranquín (Taquaruno)	Aptian	113 - 124
BL-00-38	10° 03' 91"	63° 28' 24"	800	sandstone	Catacas/Los Jabillos?	Mid Eocene/Early Oligocene	50-39/35-29
BL-00-44	10° 02' 06"	63° 28' 60"	560	sandstone	Barranquín (Taquaruno)	Aptian	113 - 124
BL-00-48	10° 00' 15"	63° 29' 52"	400	sandstone	Barranquín (Taquaruno)	Aptian	113 - 124
BL-00-72	10° 22' 85"	64° 15' 18"	80	sandstone	Barranquín (Venado)	Barremian	131 - 124
BL-00-81	9° 55' 54"	64° 04' 91"	520	sandstone	San Juan	Maastriichtian	65 - 74
BL-00-92	10° 24' 56"	63° 29' 45"	600	sandstone	Barranquín (Pucall/Taquaruno?)	Aptian	113 - 124

TABLE 2. APATITE FISSION TRACK RESULTS

Sample	χ^2 and F tests (%)		Minimum age			Age of second oldest peak			Age of third oldest peak		
	$P(\chi^2)$	$P(F)$	Age	63% C.I.	n_f	Age	63% C.I.	N_f	Age	63% C.I.	N_f
BL-99-2	0	0	3.4	-1.2	5.6	23.5	-2.3	22.3	26.6	-17.3	0.1
BL-99-5	1	0	4.9	-2.1	8.1	18.7	-2.6	26.9	N.D.	N.D.	N.D.
BL-99-6	0	0	28.5	-3.0	22.3	277.5	-171.8	0.7	N.D.	N.D.	N.D.
BL-99-9	0	0	21.8	-3.5	17.3	152.2	-45	1.7	N.D.	N.D.	N.D.
BL-99-16	0	0	8.3	-2.1	6.6	32.8	-4.6	15.4	N.D.	N.D.	N.D.
BL-99-18	0	3	13.1	-3.0	3	102.4	-11.4	2.0	N.D.	N.D.	N.D.
BL-99-19a	13	12.3	12.9	-1.5	32	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
BL-99-23	I.A.	I.A.	95.3	-14.1	1	I.A.	I.A.	I.A.	I.A.	I.A.	I.A.
BL-99-31	0	0	23.5	-3.7	7.1	80	-15.9	2.9	N.D.	N.D.	N.D.
BL-00-21	0	1.2	6.3	-1.7	3	34.8	-6.1	4	N.D.	N.D.	N.D.
BL-00-23	12	24	105.4	-12.4	7	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
BL-00-25	0	0	22.2	-2.3	41.9	118	-37.5	2.1	N.D.	N.D.	N.D.
BL-00-31	I.A.	I.A.	11.8	-3	1	I.A.	I.A.	I.A.	I.A.	I.A.	I.A.
BL-00-32	51	6.9	24.6	-2.9	22	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
BL-00-38	0	0	27.8	-6.1	3	161.2	-14.8	21	N.D.	N.D.	N.D.
BL-00-44	0	0	16.6	-2.2	15.8	121.9	-29.3	1.2	N.D.	N.D.	N.D.
BL-00-48	I.A.	I.A.	44.9	-17.7	1	I.A.	I.A.	I.A.	I.A.	I.A.	I.A.
BL-00-72	0	0	11.8	-1.9	8.5	27.4	-4	7.5	189.2	-42.7	2.0
BL-00-81	1	0	19.1	-2.3	15.3	97.7	-50.5	0.7	N.D.	N.D.	N.D.
BL-00-92	I.A.	I.A.	196.7	-100.5	1	I.A.	I.A.	I.A.	I.A.	I.A.	I.A.

Notes: $P(\chi^2) = \chi^2$ probability for concordance of grain ages. $P(F)$ = probability that the improvement of fit associated with inclusion of an older peak in peak-fit model could be due to random change alone. $P(F) > 5\%$ is considered to indicate a concordant single-peak distribution. N_f = number of grains in peak. The sum of N_f is forced to equal the total number of grains. N.D. = not determined. I.A. = insufficient apatite. The tectonic model is based on the ages in bold.

Figure 1. Index Map A) Map of the Caribbean Plate. Black box is location of B. B) Simplified geologic map of the eastern Serranía del Interior. Based map from Ministerio de Minas E Hidrocarburos Venezuela (1976).

Figure 2. Map of the eastern Serranía del Interior showing major faults and the location of apatite fission track samples. Ages used in the tectonic model are in bold. Black line represents transect on which fission track ages are project in Figure 3.

Figure 3. Graph of apatite fission track ages projected on black line in Figure 2. Open unlabeled squares represent fission track minimum ages based on a minority of grains. Solid squares represent fission tracks based on minimum ages or older ages based on a majority of grains.

Figure 4. Tectonic model of the evolution of the eastern Serranía del Interior based on apatite fission track data.

Figure 5. Late Eocene paleogeography of the northern margin of South America showing location of the Caribbean Plate with respect to the south American Plate (from Pindell et al., 1998) and relative plate motions between North and South American plates (from Dixon and Mao, 1997).

APPENDIX

APPENDIX A. TECTONIC SETTING OF THE EASTERN SERRANÍA DEL INTERIOR

Current Caribbean Plate Boundaries

The current Caribbean plate boundaries are defined by seismicity and geological criteria, such as the distribution of active volcanoes, sea floor trenches, sea floor spreading centers, and transform faults (e.g., Case et al., 1984; Russo and Speed, 1992, 1994). The eastern and western boundaries of the Caribbean plate are defined by subduction zones while the northern and southern boundaries are broad transcontractional zones of fault-bounded blocks dominated by strike-slip motion.

The western boundary of the Caribbean plate is the Panama–Costa Rica trench. The Cocos plate is subducting beneath the Caribbean plate and Panama–Costa Rica arc in an east-dipping subduction zone (e.g., Pindell and Barret, 1990). A line from the Caribbean-Cocos-North America triple junction to the Caribbean-South American-Nazca triple junction defines the western boundary of the Caribbean plate in the west. The eastern boundary of the Caribbean plate is the Lesser Antilles trench, with the Atlantic plate subducting beneath the Caribbean plate in a west-dipping subduction zone (e.g., Case et al., 1984). The northern boundary of the Caribbean plate extends from central Guatemala to the Puerto Rico trench and from west to east is represented by the Motagua Polochic fault zone, the Swan Island and Oriente transform faults of the Cayman trough, the Greater Antilles arc and the Puerto Rico trench (Mann et al., 1990; Draper et al., 1994). The plate motion at the northern boundary is predominately left lateral strike-slip

with local minor extension (e.g., Cayman Trough) and local minor contraction (e.g. Puerto Rico Trench). The southern boundary extends from Colombia to Trinidad and from west to east is represented by the north Panama deformation belt, the south Caribbean deformation belt, and the Boconó-San Sebastian-El Pilar strike-slip fault system (e.g., Schubert, 1984; Bellizzia et al., 1990; Mann et al., 1990). The plate motion at the southern boundary is predominately right-lateral strike-slip with some local extension (Cariaco Basin) and local contraction (Serranía del Interior). Coeval thrusting and strike-slip faulting within the Serranía del Interior and along the El Pilar fault, respectively, indicate that the displacement is partitioned (Avé Lallemant, 1996, 1997).

Current Caribbean Plate Motions

Using Global Positioning System measurements at sites in the Dominican Republic, Puerto Rico, Cuba, and Grand Turk, Dixon et al. (1998) determined that the Caribbean plate, in the vicinity of southern Dominican Republic, is moving eastward at a rate of 21 ± 1 mm/yr with respect to North America. Additionally, using a pole of rotation in the central Atlantic, Dixon and Mao (1997) show that the North and South American plates are converging at a rate of 2 mm/yr at a point just to the east of the Lesser Antilles, with an increasing rate of convergence westward up to 8 mm/yr. Extension up to 1mm/yr east of the pole of rotation at a point near the North American-African- South American plate triple junction is also predicted.

Caribbean plate tectonic evolution

Caribbean plate origin. The origin and evolution of the Caribbean plate is much debated due to the plate's tectonic complexity. Seismic refraction measurements indicate that the western portion of the Caribbean plate is thicker (10 - 25 km) than oceanic crust typically formed at sea floor spreading centers (6 km), (e.g., Fox and Heezen, 1975; Case et al., 1990), while the eastern portion of the Caribbean plate has a normal ocean crust thickness (Donnelly, 1994). The Caribbean plate is believed to have been formed over a hot spot within the Pacific plate which resulted in the emplacement of massive basalt flows (seismic horizon B''), allowing the Caribbean plate to achieve its current thickness, (e.g., Burke et al., 1978; Burke, 1988; Pindell et al., 1988; Pindell, 1993).

Presently, two families of plate tectonic models are proposed for the origin of the Caribbean plate, (e.g., Pindell, 1993, 1998; Meschede and Frisch, 1998). The "Pacific model" proposes a Late Mesozoic origin of the Caribbean oceanic crust in the Pacific region with subsequent northeast and eastward drift between North America and South America to its present location, (e.g., Pindell, 1993, 1998). An alternative model proposes the Caribbean crust formed west of its present location, but still between North America and South America, (e.g., Meschede and Frisch, 1998). These models converge towards the beginning of the Cenozoic. The "Pacific model" is currently the more accepted because it better deals with space problems.

Paleotectonic evolution of the northern margin of the South American craton.

Three major plate motion stages control the evolution of the northern edge of the South American craton (e.g., Pindell, 1993; Pindell and Barret, 1990; Erlich and Barret, 1990). The first stage, from early Jurassic to Cretaceous (190 Ma to about 120 Ma), shows northwest-southeast divergence (Figures A1 and A2). The second stage, from Cretaceous to Eocene (120 Ma to 49 Ma), shows negligible relative plate motions between North

Figure A1. Paleogeography, Valanginian ~130 Ma. Sea floor spreading in a northwest/southeast direction creates a Proto-Caribbean seaway and a passive margin allowing for the deposition of the Barranquin Formation. Dark gray is continental terrans and light gray is island arc terrane. After Burke (1988) and Pindell (1993).

Figure A2. Paleogeography, Barremian/Early Aptian ~120 Ma. Sea floor spreading continues in a northwest/southeast direction. The deposition of the El Cantil Formation occurs. After Pindell (1993).

America and South America while the polarity of a subduction zone, extending from Guatemala to Columbia, flipped at approximately 115 to 120 Ma prior to the emplacement of the Caribbean plate (Figures A3 – A7). Granitic intrusions in Margarita Island with U –Pb zircon dates of 114 – 105 Ma (Stöckhert et al., 1995) are thought to be emplaced during the flip in the subduction zone. The last stage, from Eocene to the Present (49 Ma to 0 Ma), consists of slow north-south convergence of the North and South American plates during the eastward migration of the Caribbean plate (Figure A8). Three tectonic settings can be differentiated from the plate motion stages: 1) a rifting phase associated with the breakup of Pangea during Triassic to Late Jurassic time, 2) a passive margin phase during Late Jurassic to Eocene-Miocene time, and 3) an active margin phase of transcontraction and diachronous formation of a foredeep from Early to Middle Eocene in the west, to Late Oligocene to Middle Miocene in eastern Venezuela and Trinidad (e.g., Erlich and Barret, 1990; Erickson and Pindell, 1993; Di Croce, 1995).

In the Jurassic, sea floor spreading occurred between the North American and South American continents as Pangea began to breakup. This sea floor spreading resulted in the development of an extensive passive margin system and the formation of a seaway underlain by the Proto-Caribbean lithosphere (e.g., Pindell and Barret, 1990; Pindell, 1993). Basaltic rock in the Espino Graben dated 162 Ma are thought to be the result of this initial rifting (e.g., Feo-Codecido, 1984). In the Sierra de Perijá of northwestern Venezuela, continental sedimentary rocks and interbedded volcanic rocks of the La Quinta Formation have whole-rock K-Ar dates of 155 ± 5 m.y. and 146 ± 7 m.y. Similar rock ages and types are found from Mexico to Chile and suggest the depositional environment was related to convergent plate margin processes (Maze, 1984; Steinitz and Maze, 1984). After this initial rifting, the northern margin of the South American plate

Figure A3. Paleogeography, Late Albian ~100 Ma. Proto-Caribbean sea floor spreading ceases. Selected terranes of the Great Arc of the Caribbean (Burke, 1988) are noted. Two subduction zones are indicated due to disagreement of when polarity reversal occurred. The formation of the oceanic plateau basalt has begun. Deposition of the Chimana Formation occurs. After Pindell (1993); Stiles (2000).

Figure A4. Paleogeography, Turonian ~90 Ma. The Oceanic Plateau Basalt is still forming and has begun colliding with the Great Arc of the Caribbean. Deposition of the Querecual Formation is occurring. After Pindell (1993); Stiles (2000).

Figure A5. Paleogeography, Campanian ~76 Ma. North and South America are drifting westward relative to the Caribbean plate, while the Great Arc of the Caribbean is actively deforming. The Costa Rica-Panama arc forms. Deposition of the San Antonio Formation occurs. After Pindell (1993); Stiles (2000).

Figure A6. Paleogeography, Paleocene ~59 Ma. Three segments form in the Great Arc of the Caribbean. The Cayman trough begins to open and the collision of the Venezuelan nappes begins. Deposition of the Vidono Formation occurs. After Pindell (1993); Stiles (2000).

Figure A7. Paleogeography, Middle Eocene ~49 Ma. Collision of the Caribbean plate with the northern margin of the South American plates, with an advancing peripheral bulge, continues from west to east. Contraction between North and South American may begin to occur. The Grenada Basin begins to open. The Caribbean plate begins to collide with the Bahamas. The deposition of the Caratas Formation occurs. After Pindell (1993); Stiles (2000).

Figure A8. Paleogeography, Early Oligocene ~35 Ma. Caribbean plate moves in a southeast direction with respect to the South American plate. Allochthonous terranes are emplaced on the South American continent. Lesser Antilles and Aves Ridge are two distinct bodies. Cuba is no longer part of the Caribbean plate. Approximately 1000 km of offset in Cayman trough. The deposition of the Los Jabillos Formation occurs. After Pindell (1993); Stiles (2000).

thermally subsided creating a passive margin phase, which allowed for the deposition of a non-volcanic, terrestrial and marine sedimentary wedge 3 to 4 km thick (Figure A1 and A2; e.g., Di Croce, 1995). Until the middle Cretaceous, the western boundary zone of the North American and South American plates, and Proto-Caribbean seaway was a volcanic arc and east-dipping subduction zone (e.g., Pindell, 1993). At approximately 120 Ma, a large volume magmatic event created a flood basalt oceanic plateau (future Caribbean plate) which increased plate thickness to 15 - 30 km (Figure A3; e.g., Sinton, 1998). The relative buoyancy and resistance to subduction of the oceanic plateau caused a reversal in the subduction polarity from an east-dipping to a west-dipping subduction zone. The Farallon plate began consuming the Proto-Caribbean seaway. From the Paleocene to mid-Eocene (Figures A6 – A8), the relative northeast emplacement of the Caribbean plate between the North and South American plates occurred as a diachronous collision (older from west to east), between the Greater Antilles and the Bahamas. The North and South American plates traveled westward with respect to the relatively stationary Caribbean plate (e.g., Pindell, 1993). The termination of this collision caused a restructuring of the plate motions and resulted in a shift of the Caribbean plate motion from northeast to slightly southeast (e.g., Pindell, 1993).

Contraction between North and South America with a pole of rotation centered in the central Atlantic may have occurred for the last ~50 m.y. (e.g., Dixon and Mao, 1997). A diachronous, transcontractional deformation along the northern margin of the South American plate occurred as a result of the southeastward motion of the Caribbean plate with respect to South America (e.g., Pindell and Barret, 1990). The Leeward Antilles arc, along the southern boundary of the Caribbean plate, began to be rotated clockwise during

the late Cretaceous. The Leeward Antilles collision with northern Venezuela from the Early Eocene to Middle Miocene resulted in southeastward thrusting and foreland loading. As a result of the diachronous transcontraction, former Leeward Antilles terranes and associated foredeep rocks (Villa de Cura, Paracotos, Caucagua-El Tinanco and the Cordillera del la Costa) were emplaced over the former Cretaceous passive margin sequence, by thrusting and right-lateral strike-slip motion, forming the Caribbean Mountain system and Serranía del Interior fold and thrust belt. The formation of the Cariaco pull-apart basin was caused by the right-stepping, right-lateral San Sebastian - El Pilar fault system. This resulted in the separation of the eastern Serranía del Interior and the Araya-Paria Peninsulas from the Caribbean Mountain system in the late Oligocene-early Miocene (Figure A9; Erlich and Barret, 1990).

Geologic Setting of the Northeastern Margin of South America

The northcentral and northeastern boundary zone between the Caribbean and South American plates can be subdivided into three blocks from north to south: 1) the Leeward Antilles terrane, 2) the Caribbean Mountain system and, 3) central and eastern Serranía del Interior foreland fold and thrust belt. South of the eastern Serranía are the Monagas Foothills and the Maturín and Guárico sub-basins of the Eastern Venezuela Basin (e.g., Case et al., 1984; Bellizzia et al., 1990; Hung, 1997). The eastern Serranía del Interior is separated from the central Serranía del Interior by the Cariaco Basin, a pull apart basin formed by a right step in the Morón / El Pilar fault zone (e.g., Erlich and Barret, 1990). The El Pilar fault separates the Caribbean Mountain system from the eastern Serranía del Interior.

Figure A9. Late Eocene to early Miocene evolution of the Margarita Block and northeastern Venezuela. A) Late Eocene to early Oligocene: Allochthonous terranes (Villa de Cura, Cordillera del la Costa, Margarita Block) emplaced over autochthonous South America. B) Early Oligocene: Eastward motion of the Caribbean plate with respect to the South American plate results in the formation of the extensional Bonaire and Falcon basins. C) Late Oligocene to early Moicene: Shift in plate motions form right-stepping, en echlon faults, creating the Cariaco pull-apart basin. Contraction between the Caribbean and South American plates cause folding and thrusting in the Serrania del Interior (SDI). After Erlich and Barret, (1990).

Eastern Serranía del Interior

The eastern Serranía del Interior is bounded to the north by the east-west trending El Pilar strike-slip fault, to the south and east by the 070° trending Pirital thrust fault, and to the west by the Úrica fault (Figure A10; Case et al., 1984; Chevalier et al., 1995). The El Pilar right-lateral strike-slip fault extends east to west 700 km from the Cariaco Basin to northern Trinidad with offset estimates ranging from 40 to 125 km (Burke, et al., 1984; Mann et al., 1990). The Pirital fault has approximately 20 to 30 km of horizontal displacement and 4 to 5 km of vertical displacement (Roure et al., 1994).

Right-lateral, northwest-southeast trending tear fault systems include, from west to east, the Úrica and San Francisco. These faults divide the eastern Serranía del Interior from west to east into the Bergantín and Caripe blocks (Roure et al., 1994). The Úrica and San Francisco faults act as lateral ramps with dextral offset on the Úrica and San Francisco faults no greater than 25 km each (Roure et al., 1994; Di Croce, 1995). Based on seismic data, the Úrica fault does not connect directly to the basement (Roure et al., 1994). Thrusting in the Serranía del Interior and coeval strike-slip motion along the El Pilar fault and associated faults indicate strain partitioning is occurring at this plate boundary as a result of oblique convergence (Avé Lallemant, 1997).

Figure A10. Map of the eastern Serranía del Interior showing locations of faults and the Bergantín and Caripe fault blocks. See Figure 1 for legend. (Base map from Ministerio de Minas E Hidrocarburos Venezuela, 1976).

APPENDIX B. STRATIGRAPHY OF THE EASTERN SERRANÍA DEL INTERIOR

INTRODUCTION

The stratigraphy of the eastern Serranía del Interior is complex temporally and spatially. To add to the complexity, most of northeastern Venezuela is covered with vegetation and the rocks are weathered due to the tropical climate. The outcrop is very poor throughout the field area and is generally limited to road cuts and riverbeds. Initial stratigraphic work was performed by Hedberg (1937, 1950), Hedberg and Pyre (1944), with revisions by Rod and Maync (1954) and more recently by Vierbuchen (1984), Yoris (1985; 1988; 1992), Chevalier (1993; 1995), and Ostos et al. (2001). The generally accepted stratigraphy is shown in Figure B1. For brief descriptions of eastern Venezuelan stratigraphic units, see Appendix A of Di Croce (1995) and Hung (1997). Information regarding the stratigraphic units and summary information is compiled under the Venezuelan Stratigraphic code (<http://www.pdv.com/lexico>). Figure B2 depicts a cartoon showing the composite spatial and temporal relationships between sedimentary rocks of the passive margin sequence (Sucre Group to Merecure Group). Generally, during the passive margin sequence, deeper water sediments were deposited to the north.

EASTERN SERRANÍA DEL INTERIOR

The rocks of the eastern Serranía del Interior are composed of Cretaceous and Tertiary sedimentary rocks that were deposited on the northern flank of the Eastern Venezuela Basin (Figure 1 and Figure B1). The stratigraphy of the eastern Serranía del

Figure B1. Composite stratigraphic column of the eastern Serrania del Interior (From Chevalier, 1995; Hung, 1997).

Figure B2. Cartoon of spatial and temporal relationships between the Surce, Guayuta, Santa Anita, and Merecure Groups of the passive margin sequence. Approximate location of El Pilar fault is noted. Not to scale in thickness or time. (Based on Yoris, 2000, pers. comm.).

Interior can best be subdivided into five units; 1) Sucre Group, 2) Guayuta Group, 3) Santa Anita Group, 4) Merecure Group, and 5) Neogene to recent deposits.

Placed in a plate tectonic setting, the Late Jurassic to Eocene – Miocene rock units were deposited in basins caused by the subsidence associated with the rifting and breakup of Pangea during the Triassic to Late Jurassic. The Miocene to present rock units were deposited during the contraction between the Caribbean and South American plates as older rocks were uplifted, eroded and redeposited. The stratigraphic units record 1) the passive margin phase during Late Jurassic to Eocene-Miocene when the Sucre, Guayuta, Santa Anita Groups and the Los Jabillos and Areo formations of the Merecure Group were deposited in rifted basins (sediment input predominately from the south), and 2) an active margin phase of transcontraction and diachronous formation of a foredeep from Early to Middle Eocene in western Venezuela to Late Oligocene to Middle Miocene in eastern Venezuela and Trinidad depositing the Naricual Formation of the Merecure Group and Neogene to recent deposits, (dual sediment input from the north and south as the Serranía del Interior is uplifted and eroded); (Erlich and Barret, 1990; Erickson and Pindell, 1993; Di Croce, 1995; Ostos et al. 2001; Yoris, 2000 pers. comm.).

NEOCOMIAN – ALBIAN (SUCRE GROUP)

The Sucre Group, conformably underlying the Guayuta Group, represents a transgressive, continental to shallow water marine passive margin sequence and contains the oldest exposed strata in the eastern Serranía del Interior. The Sucre Group thickens toward the north exceeding several kilometers (Vierbuchen, 1984). The sediment source is the Guayana shield to the south. From the base upward, the Sucre Group consists of

the 1) Barranquin Formation (Venados, Morro Blanco, Picuda, and Taguarumo Members), 2) El Cantil Formation (the García Shale Member, El Mapurite Member, El Cantil Member, Guácharo Member, Punceres Member, and the Chimana Formation, and 3) the Valle Grande Formation (Vierbuchen, 1984; Yoris, 2000 pers. comm.; Ostos et al., 2001).

Neocomian – Aptian (Barranquin Formation)

Liddle (1928) and Hedberg (1950) were the first to carry out work on the Barranquin Formation. The Barranquin Formation is 1000 to 1400 meters thick and consists of micaceous and kaolinitic quartzitic sandstone interbedded with arenaceous shale and thin limestone beds. To the south, reflecting more terrestrial input, the Barranquin Formation consists mainly of sandstones, coals, and shales, and in the north, reflecting more marine input, consists mainly of limestones and bioclastic and calcareous pelities. Regressive and transgressive deltaic cycles, dominated by a fluvial setting, show channeling (Figure B3), large-scale cross-bedding (Figure B4), scouring, and bioturbation. The Barranquin Formation contains four members, from base upward: 1) the Venados (~375 m thick), 2) Morro Blanco (~230 m), 3) Picuda (~425 m), and, 4) Taguarumo (~660 m). The Venados Member was deposited in a fluvial environment with well-sorted beach sandstones containing small discontinuous beds of limestone. The Morro Blanco Member records a change to a marine environment with massive micritic fine gray limestone (Figure B5). The Picuda Member returns to a fluvial environment with thick deposits of sandstone and the Taguarumo Member is a prodelta, deltaic-marine environment, consisting of interbedded sand and shale with minor limestone beds (Figure B6). The Taguarumo reflects a tidal, highly bioturbated environment with high

Figure B3. Site Locality BL9913. Photograph (A) and line drawing (B) of an example of channeling in the Barranquin Formation showing key channeling features and cut crossbeds and beds. Site locality noted on Figure B9. Note hammer for scale. (Photograph by Brian Locke).

Figure B4. Site locality BL9911. Photograph (A) and line drawing (B) of an example of crossbeds within the Barranquin Formation. Heavy lines represent bedding planes, light lines represent crossbeds. Note hammer for scale. Site locality noted on Figure B9. (Photo by Brian Locke).

Figure B5. Site locality BL00MB. Photograph of Morro Blanco Member (Barranquin Formation), a massive micritic fine gray limestone. Site locality noted on Figure B9. (Photograph by Franklin Yoris).

Figure B6. Site locality BL0077. Photograph of the interbedded sand and shales of the Taguarumo Member (Barranquin Formation). Fold may be a syndepositional slump fold. Tree is approximately six feet in height. Site locality noted of Figure B9 (Photograph taken by James Jones).

evaporation rates; it coarsens, but does not shallow upward. The Barranquin shows thickening across normal faults indicating synsedimentary faulting and gravitational slumping during deposition (Figure B6).

Aptian (García Member)

The García Member (~100 m thick) is part of the El Cantil Formation and conformably overlies the Barranquin Formation and conformably underlies the El Cantil Member. The García Member is a maximum flooding surface with black and brown fossiliferous shales with some nodular limestones deposited in water depths approximately 200 meters. The García Member is fairly continuous and may be a possible source rock for hydrocarbons (Yoris, 2000, pers. comm.).

Late Aptian – Middle Albian (El Cantil Formation)

Original descriptions of the El Cantil Formation used type sections that were highly faulted with many sections miscorrelated (Hedberg, 1950; Rod and Maync, 1954). The base of the El Cantil Formation is the García Member shale. Today, El Cantil proper (~860 m thick), [or Borracha; Rod and Maync, (1954)] refers to three units, 1) a lower unit of glauconitic shale and alternating limestones, pelities, shales, and quartz clays; 2) a middle sandy sequence; and 3) an upper unit of limestone beds with individual limestone beds thickness up to 400 m. The third unit of the El Cantil is the resistant cliff-forming limestones exposed on the peaks of many of the mountains (Figure B7) within the eastern Serranía del Interior and also contains the famous Cueva del Guácharo. The El Cantil Formation was deposited in a shallow water and marginal marine environment. The El

East

West

Figure B7. Site locality BL0016. El Cantil Formation limestones exposed at an active quarry located south of Cumana. Quarry vehicle in bottom right for scale. Site locality noted on Figure B9. (Photograph taken by Brian Locke).

Cantil Formation also contains many sandy units that vary spatially and temporally.

Toward the terrestrial sediment source in the south, sand content in the El Cantil increases until it becomes a sandy limestone (Guácharo Member), and finally a terrestrial sandstone (El Mapurite Member) (Figure B2). Additionally, the uppermost unit of the El Cantil Formation becomes sandy and is separated into the Chimana and the Punceres members. The Chimana Member is a middle to upper Albian gray shale and limestone with a fine to coarse glauconitic sandstone representing an open marine shelf. The Punceres Member is the shallow water equivalents of the Guácharo Member.

Late Aptian – Albian (Valle Grande Formation)

The Valle Grande Formation is part of the El Cantil Formation and was deposited in a deepwater talus facies, possibly a lowstand slope fan. It contains reef talus and blocks of the El Cantil Member within a calcareous and silicic mudstone matrix.

CENOMANIAN – CAMPANIAN (GUAYUTA GROUP)

The Guayuta Group records an abrupt change from shallow oxygenated seas of the Sucre Group to deeper more stagnant conditions as extensive marine environments invaded from east to west inundating Venezuela (Vierbuchen, 1984; Ostos et al., 2001). The Guayuta Group is 600 to 1600 meters thick and consists of 1) the Querecual Formation of pelagic limestone and pyritic black shale with abundant concretions (Figure B8) and 2) the overlying San Antonio Formation of dark shale with finely laminated glauconitic limestone and calcareous shale. The Querecual Formation (Cenomanian – Santonian) is 600 to 800 meters thick, and represents the open marine, deep water, upper

Figure B8. Site locality BL00CG. Querecual Formation outcrop near the Cueva del Guarcharo. Site locality noted on Figure B9. (Photograph taken by Brian Locke).

Figure B9. Map of the eastern Serranía del Interior showing faults and stratigraphic site localities. See Figure 1 for legend. (Base map from Ministerio de Minas E Hidrocarburos Venezuela, 1976).

portion of the slope. The Querecual Formation is the main source rock for hydrocarbons in northeastern Venezuela. The San Antonio Formation (Santonian – Campanian) is 350 to 950 meters thick and was deposited in an outer shelf, lower slope facies and contains submarine fans. Anastomosing sandstone dikes are present within the San Antonio Formation.

CAMPANIAN – MIDDLE EOCENE (SANTA ANITA GROUP)

The lower-most strata of the Santa Anita Group are sandstones that are transitional with the underlying Guayuta Group. The upper contact is usually a major erosional unconformity dating from the Middle Eocene marking the first important interruption of the cycle of sedimentation that started with the Lower Cretaceous Sucre Group (Vierbuchen, 1984). The Santa Anita Group lithology consists of several hundred meters of quartzitic sandstone, dolomitic and calcareous sandstones and siltstones, gray shales, and glauconitic rocks and is divided into (from base upward) the 1) San Juan Formation (~520 m thick), 2) the Vidoño Formation (~200 to 305 m), and 3) the Caratas Formation and Tinajitas Member (~330 to 600m), (Vierbuchen, 1984). The San Juan Formation (Maastrichtian) is a fine- to coarse-grained, well-stratified sandstone, shale, and siltstone representing basin floor fan turbidites deposited in an outer shelf to deep-water environment. The Vidoño Formation (Paleocene) is a black, calcareous, glauconitic, and massive shale with minor beds of sandstone and calcareous siltstone deposited as a flooding surface during a lowstand systems tract with an open marine shelf to deep-water environment (Yoris, 2000 pers. comm). The Caratas Formation (Paleocene – Middle Eocene) is a resistant calcareous and dolomitic siltstone and glauconitic

sandstone deposited in a shallow to deepwater environment. The Tinajitas Member (upper Eocene) within the Caratas Formation is a foraminifera-coralline algal reef limestone which changes laterally to thin limestone beds overlain by an interbedded quartzitic and glauconitic sandstone, siltstone, and shale (Hedberg and Pyre, 1944). The sandy glauconitic and foraminiferal-rich carbonates of the Tinajitas Member may represent the beginning of the influence of the formation of the oblique collision and creation of an active margin, possibly associated with the bending of the lithosphere (Ostos et al., 2001).

LOWER OLIGOCENE – EARLY MIOCENE (MEREURE GROUP)

The Mereure Group consists of 1) Los Jabillos (~150 to 340 m thick), 2) Areo (~250 to 1200 m), and 3) Naricual (~1800 m) Formations and shows a transition from deltaic to shallow-marine environments. The Mereure Group was deposited within a foredeep. The Los Jabillos Formation is a resistant, thick-bedded, fine- to coarse-grained quartzitic sandstone deposited on a shallow water near-shore platform. The Areo Formation is a dark gray glauconitic shale with gray quartzitic sandstones and yellowish or reddish glauconitic ironstone concretions deposited in deep-waters. The Naricual Formation is a carbonaceous shale, sandy shale, and sandstone underlain by a coal-bearing package with massive quartzitic sandstone and shales. The Naricual Formation was deposited in a tectonically unstable shelf, shallow marine and coastal-fluvial environment with a high rate of sedimentation and turbidite facies. The Naricual Formation sediments indicate two source directions, one from the north and one from the

south, placing the deposition of the Naricual Formation between the advancing Caribbean Plate and the fold-and-thrust belt source (Ostos et al., 2001).

NEOGENE TO RECENT DEPOSITS

The Neogene deposits are not as widespread as older deposits. The limited distribution of Neogene deposits within the eastern Serranía del Interior reflect mountain-building episodes associated with the collision of the Caribbean and South American plates. The Eastern Venezuela basin resulted from this collision. In eastern Venezuela, to the south, the Carapita Formation records deeper water environments. The Carapita Formation is a turbidite unit of gray to black calcareous and microfossiliferous shales and thin beds of fine-grained sandstone. Further to the north are shallower water deposits of the Quiamare Formation. The Quiamare Formation was deposited in many different environments including lagoonal, fluvial channels, and alluvial fans (Hedberg and Pyre, 1944). Along the northern coast of the eastern Serranía del Interior, the Quiamare Formation is a boulder conglomerate (alluvial fan). The Quiamare is overlain by the fluvial-deltaic to shallow marine Las Piedras Formation, (Hedberg and Pyre, 1944). The alluvial and deltaic fans of the Mesa Formation of Pleistocene age ends the sedimentary cycle. Some 2 Ma Pliocene beach sediments are located at the tops of the 1.6 km high mountains indicating a quick regional uplift. Additional recent sediments outcrops behind Cumaná are tightly folded indicating very recent deformation (Yoris, 2000, pers. comm.).

APPENDIX C. STRUCTURAL STYLES OF THE EASTERN SERRANÍA DEL INTERIOR

Introduction

The primary purpose of this thesis is to use apatite fission track data to constrain a model for the tectonic evolution of the eastern Serranía del Interior. In an effort to improve the model, structural data (orientation of bedding planes, faults, and folds) within the eastern Serranía del Interior were measured during the 1999 and 2000 field seasons to determine styles of deformation and fault and fold vergence. The structural data of local geology were compared to expected structural orientations caused by plate tectonic motions and interactions.

Bedding planes were measured and plotted on Pi-diagrams (Rowland and Duebendorfer, 1994) to determine the orientation of fold axes (assuming cylindrical folding). Additionally, bedding planes and sedimentary features such as cross bedding, ripple marks, bioturbation, and mud cracks were used to determine, where possible, stratigraphic tops in each outcrop (Boggs, 1987). Determining stratigraphic top at each outcrop was often difficult. Fault data such as fault plane orientation, slickenside striation orientation, and type of offset was recorded to determine the kinematics of the fault. The type of offset along faults was determined using brittle features such as Riedel shear orientations, vein orientations, offset bedding, and groove features (Petit, 1987). The orientation of fold axes, axial planes, and vergence were recorded to determine styles of folding within the eastern Serranía del Interior.

Measured structural data supplimented previous work performed in the eastern Serranía del Interior which includes Rod (1956), Rosales (1983), Rossi (1985), Carnevali

(1988), Chevalier (1993), Roure et al. (1994), Chevalier et al. (1995), Di Croce (1995), Martinez (1995), Hung (1997), and Ysaccis (1997). Additionally, geologic maps were used made by Creole Petroleum Company (1962) and the República de Venezuela, Ministerio de Minas E Hidrocarburos (1976).

Eastern Serranía del Interior

The field area within the eastern Serranía del Interior is bounded to the north by the east-west trending El Pilar right-lateral, strike-slip fault, to the south and east by the 070° trending Pirital thrust, and to the west by the Úrica fault (Figure C1; Hung, 1997; Case et al., 1984; Chevalier, 1995).

Structure

The Serranía del Interior is a southeast verging folded belt with major folds and thrust faults trending northeast to east and tear faults trending northwest-southeast, (Case et al., 1984; Chevalier, 1995). South vergent imbricate and duplex thrust faults juxtapose Cretaceous and Paleogene formations with less deformed Neogene formations (Case et al., 1984; Di Croce, 1995; Hung, 1997). Younger Tertiary and Upper Cretaceous rocks are exposed in the west and southwest, while older Cretaceous rocks, closer to the core of the structure, are exposed to the north and the east.

Folding. Folds in the eastern Serranía del Interior trend east-west to southwest-northeast with degrees of tightness ranging from isoclinal to gentle and open. Axial axes trend approximately 070° - 080° and plunge slightly to the southwest (Vierbuchen, 1984; Chevalier, 1995; Di Croce, 1995). The lengths of the axial traces are approximately 70

Figure C1. Map of the eastern Serranía del Interior showing major faults and Pi-diagrams from the Bergantín and Caripe fault blocks. The Pi-diagrams are equal-area, lower hemisphere projections plotting poles to the bedding planes. The poles to bedding in the Bergantín fault block are lying in a great circle girdle with the pole of the fold axis plunging 8° to N83W. The poles to bedding in the Caripe fault block also lay in a great circle girdle with the pole of the fold axis plunging 2° to S80W. See Figure 1 for legend. Fault teeth on thrust faults point toward the hanging wall. Stereonet program from Allmendinger (1988) and base map from Ministerio de Minas E Hidrocarburos, Venezuela (1976).

km with fold wavelengths of 5 km (Hung, 1997). Axial planes throughout the field area have a strike between 63° - 105° and generally dip north (Figure C2). There are two sets of axial plane dip measurements observed in the field data, 1) a shallow dipping set, and 2) a steep to vertical dipping set (Figure C2). Shallow, north-dipping (0° to 57°) axial planes were observed along the coast near Cumaná. Steeply north-dipping (65° - 90°) axial planes were observed throughout the remainder of the field area. The distinction of axial plane orientations may be the result of increased deformation to the north and northwest, tilting the axial planes to shallow and even horizontal dips. The shallower north dipping axial planes to the north also indicate a south vergent fold style.

Figure C1 shows major faults and Pi-diagrams for the Bergantín and Caripe fault blocks. Pi-diagrams are equal-area, lower hemisphere projections of poles to the bedding planes. The poles to bedding planes lie on a great circle (Rowland and Duebendorfer, 1994). The pole to that great circle is the fold axis of the beds. The poles to bedding in the Bergantín fault block are lying in a great circle girdle with the pole of the fold axis plunging 8° to N83W. The poles to bedding in the Caripe fault block also lie in a great circle girdle with the pole of the fold axis plunging 2° to S80W. The plotting program used is Stereonet v. 4.9.6 by Allmendinger (1988). The difference in fold axis orientations is small, however, it may reflect a slight counterclockwise rotation of the Caripe fault block caused by recent right-lateral movement along the San Francisco fault.

Recumbent, chevron, and kink folds were observed in the field and are shown in Figures C3 – C6. Many outcrops were vertical faces, making it difficult to obtain measurements that reflect the entire outcrop. Figure C3 shows a recumbent fold in the Barranquin Formation at Site locality BL0071, near Cumaná. Stratigraphic top was

Figure C2. Map of the eastern Serranía del Interior showing axial plane orientations and specific site localities. Site localities indicated with a circle have low angle axial planes, site localities indicated with a rectangle have high angle axial planes, and site localities indicated with a triangle are additional figure site localities. See Figure 1 for legend. Stereonet program from Allmendinger (1988) and base map from Ministerio de Minas E Hidrocarburos Venezuela (1976).

Figure C3. Site locality BL0071 showing recumbent fold in the Barranquin Formation. Site locality noted on Figure D6. (photograph taken by James Jones)

NE

SW

Figure C4. Site locality BL0068 showing chevron style folding. Stratigraphic up is interpreted to be to the northeast indicating that this is a north vergent back fold. Site locality noted on figure D6. (Photograph taken by James Jones).

Figure C5. Site locality BL0035 showing kink style folds. A) photograph of kink style folds with vertical axial planes, B) line drawing of bedding (solid lines) and axial planes (dashed line), C) lower hemisphere projection of bedding surfaces. Site locality note on Figure D6. (photo taken by Brian Locke).

5C)

Pt-Diagram of poles to bedding (dots).
 Trend and plunge of fold axis - $90^{\circ} 0^{\circ}$
 Best fit of Great Circle - $0^{\circ} 90^{\circ}$. $N = 9$

Figure C6. Site locality BL005. A) Photography of deformed Taguarumo Member (Barranquin Formation) showing an anticline with thrust faults. Note smaller fold syncline between the two thrust faults interpreted as drag fold. B) line drawing of photograph showing key structural features and bedding surfaces. Site locality noted on Figure C2. (Photo taken by Brian Locke).

determined to be right side up based on cross bedding. Vergence is towards the south with an almost horizontal axial plane. Figure C4 shows a chevron style fold with a low angle axial plane (dipping $\sim 15^\circ$ to the southwest) in the Morro Blanco Member (Site locality BL0068), east of Cumaná, along the coast. Based on cross bedding and ripple marks, stratigraphic top is to the northeast indicating that this may be a north vergent back fold. Figure C5 A) and B) show kink style folds in the Querecual Formation with vertical axial planes striking east-west (Site locality BL0035). Figure C5 C) is an equal area, lower hemisphere Pi-diagram projection depicting poles to bedding (dots). The poles to bedding lie on a great circle girdle with the pole of the fold axis plunging 0° to N90E. Figure C6 depicts thrust-faulted folds in the Barranquin. A small synform fold is present between the two thrust faults. This synform had been interpreted to be a drag fold caused by movement along the thrust faults.

Faulting

The eastern Serranía del Interior contains three systems of faults: thrust, strike-slip, and normal faults. On many fault surfaces more than one slickenside striation orientation was observed indicating that many of the faults record different motion directions throughout their existence. Often the slickenside striation orientations do not readily reflect the current expected movement along a fault based on offset bedding planes. Figure C7 depicts stereonet projections of thrust, strike-slip, and normal faults with strike measurements and Figure C8 depicts stereonet projections of additional thrust, strike-slip, and normal faults without strike measurements.

Figure C7. Equal-area, lower hemisphere projections of measured fault plane and fault slip vectors (left) and fault plane solutions (right). Thrust faults) Site locality BL0038 located at the San Francisco fault. These faults trend east-west (not the expected northeast-southwest regional trend). These faults reflect thrusting occurring on the locally east-west trending San Francisco fault. Strike-slip faults) Site localities BL005, BL006, BL008, BL0024, BL0034, and BL0074 showing conjugate strike-slip faults with the northwest-southeast orientation similar the Úrica and San Francisco strike-slip fault orientations. Normal faults) Site locality BL0066 showing normal faults with a similar orientation as pull apart basin normal faults. Site localities are noted on Figure C2. (Stereonet program Fault Kinematics v.3.8a, Allmendinger et al., 1988).

N = 5

P

Thrust faults

N = 7

P

Strike-slip faults

N = 5

P

Normal faults

Figure C7

Figure C8. Equal-area, lower hemisphere projections of fault plane data with no measurable slickenside striations. Apparent offset was determined by relationships between offset bedding planes. Thrust faults) Site localities BL005, BL0076, BL0079, and BL0091. The thrust faults show an east-west trend and a slightly northwest-southeast trend. The northwest-southeast trend may represent back thrusting. Strike-slip faults) Site localities BL0034, BL0049, and BL0050. The strike-slip faults may show two orientations, one similar to Figure C7 (northwest-southeast) reflecting strike-slip faulting similar to the Úrica and San Francisco faults and the other showing an east-west orientation similar to the right-lateral El Pilar faults. Normal faults). The normal faults show similar orientations to Figure C7 which may reflect pull apart extension. Site localities noted on Figure C2. (Stereonet program, Allmendinger, 1988).

Figure C8 **Thrust faults N = 5** **Strike-slip faults N = 5** **Normal faults N = 5**

Thrust Faulting. The subsurface Pirital thrust fault forms the southern boundary of the field area within the eastern Serranía del Interior. The Pirital thrust fault is part of a thrust complex which consists of the Pirital, Quiriquire, and Warm Springs faults. Within the field area, only the Pirital thrust fault is present. The Quiriquire and Warm Springs faults occur further to the east, offshore, and in Trinidad (Hung, 1997). Roure et al. (1994) proposes that the Pirital thrust fault has 20 to 30 km of horizontal displacement and 4 to 5 km of vertical displacement (Roure et al., 1994). The Pirital thrust fault has 42 km of displacement (Pindell, 2000, pers. comm.). The Pirital thrust emplacement occurred during the Middle Miocene with a decollement surface within the syndepositional Carapita Formation shales. The Pirital thrust fault was reactivated during the Pliocene-Pleistocene (Roure et al., 1994).

Figure C7 depicts thrust fault data with P and T fault plane solutions for site locality BL0038. The orientation of the trends of thrust faults are east-west, whereas the expected trend of thrust faults is northeast-southwest. These thrust faults may reflect thrusting on the San Francisco fault which trends east-west at site locality BL0038. Figure C8 depicts similar east-west trending thrust faults. Measured thrust faults trend more east-west than would be expected by previous authors work. This may be the result of 1) an insufficient number of measured faults, 2) a high number of measured anomalous faults, 3) a true reflection of thrust fault orientation possibly reflecting shortening along curved east-west strike-slip faults, shortening caused by north-south convergence of North and South American plates, or a clockwise rotation of previously northeast-southwest trending thrust faults. Figure C9 depicts a south vergent low angle axial plane fold with a north dipping south vergent thrust fault.

Figure C9. Site locality BL0076. A) photograph of fold with low angle axial plane with a thrust fault truncating one limb, B) line drawing of thrust fault and fold, (photo taken by Brian Locke).

Strike-slip Faulting. Right-lateral, northwest-southeast trending strike-slip fault systems within the eastern Serranía del Interior include from west to east the Úrica and San Francisco faults dividing the eastern Serranía del Interior from west to east into the Bergantín and Caripe blocks (Roure et al., 1994; Chevalier, 1995). Dextral offset on the Úrica and San Francisco fault may be no greater than 35 km and 25 km, respectively (Salvador and Stainforth, 1968; Rosales, 1972; Munro and Smith, 1984; Rossi, 1985). The Úrica fault of late Miocene to Pliocene age has 8-10 km of Pliocene offset with its last activity after the formation of the eastern Serranía del Interior (Chevalier, 1995). The mapped San Francisco fault begins with a trend of 130° and is nearly vertical in Cumanacoa, probably as one side of a pull-apart basin which creates the valley in which Cumanacoa is located, and curves to the east merging with the Pirital thrust complex, until it trends east-west. The northern end of the San Francisco fault may curve to the northwest forming the Río Manzanares valley (Figure C2). The Río Manzanares valley makes a 90° turn and may flow along the edge of a fault block. Estimates of the displacement along the San Francisco fault ranges from 18 km to 30 to 40 km (Rod, 1956; Chevalier, 1995). The San Francisco fault has been interpreted to have a normal component of offset by Rossi (1985), Chevalier (1995) and Hung (1997). Figure C7 and C8 depict strike-slip fault data which may show three orientations of strike-slip faulting, 1) an orientation similar to the northwest-southeast strike-slip faults, 2) an orientation conjugate to the northwest-southeast strike-slip faults, and 3) an orientation similar to the east-west El Pilar fault.

The El Pilar right-lateral strike-slip fault extends east to west 700 km from the Cariaco Basin to northern Trinidad with offset estimates ranging from 40 to 125 km (Schubert, 1984; Roure et al., 1994; Di Croce, 1995). The western termination of the El

Pilar with the Moron fault is a right-step creating the Cariaco pull-apart basin. The eastern termination of the El Pilar is not well defined. The El Pilar fault zone tip may end in Paria and propagate at about 1 cm/yr (Speed, 1985) or it may continue into the Northern Range of Trinidad with offsets ranging from 5–10 km (Robertson and Burke, 1989; Algar and Pindell, 1993). The minor amount of offset in Trinidad indicates that the El Pilar fault is not a significant fault in the Caribbean/South American plate boundary zone (Algar and Pindell, 1993). Hung (1997) merges the El Pilar into a Carapita Formation decollement surface (to be discussed below) creating a transpressional orogenic float (Oldow et al., 1990) of the eastern Serranía del Interior.

Normal Faulting. Normal faults were observed along the coast. Faults generally trend north-south to northwest-southeast expressing east-west to northeast-southwest extension (Figure C7 and C8). The similarities of measured normal fault orientation with Cariaco basin faulting indicate that the normal faults may be related to pull apart basin formation. Figure C10 is a photograph, line drawing, and measurements of an outcrop with normal faults.

Basement Involvement

One of the biggest discrepancies among authors discussing the structure of the eastern Serranía del Interior is their interpretation of deep structures and basement faulting (Rosales, 1973; Rossi, 1985; Roure et al., 1994; Chevalier, 1995; Martinez 1995, Hung, 1997). The thickness and amount of deformation of rock units underlying the lower Cretaceous are unknown (Hung, 1997; Ysaccis, 1997). Numerous structural cross-sections through the eastern Serranía have been proposed by previous authors and discussed in detail by Hung (1997). Figure C11 depicts a northeast-southwest trending

Figure C10. Site locality BL0074 showing normal faults. A) photograph of Taguarumo Member (Barranquin Formation) showing normal faults. B) line drawing of normal faults and sandstone beds (stippled fill). Site locality noted on Figure D6. (photo by Brian Locke).

10 C)

Bedding

Faults

Figure C10 C) Equal-area lower hemisphere projections of bedding and poles to bedding (upper projection) and fault planes (lower projection) at site locality BL0074.

Figure C11. Cross-section through the Bergantin block of the eastern Serranía del Interior. Line location depicted on Figure C13 (In Hung 1997; from Roure et al., 1994, and Passalacqua et al., (1995).

cross-section through the Bergantín block of the eastern Serranía del Interior (Roure et al., 1994). Hung (1997) used seismic reflection data to reinterpret a cross section through the Caripe block of the eastern Serranía del Interior using six different hypotheses of basement involvement. Model estimates for the shortening within the eastern Serranía del Interior range from 9 % (16 km) to 66 % (115 km). The style of deformation of these models (from lowest to greatest shortening) vary from 1) basement-involved deformation (9%), 2) basement involved deformation only beneath the Serranía del Interior with sediment involved deformation in the foothills (20%), 3) a Paleozoic sediment wedge (21%), 4) graben inversion (21%), 5) imbricates with multiple decollements (63%), and 6) complex duplex structures repeating the Cretaceous – Oligocene passive margin sequence beneath the eastern Serranía del Interior (66%) (Figure C12; Table 5.1 and Plates 3 – 9 in Hung, 1997). Recent seismic data indicates that complex duplex structures may exist beneath the eastern Serranía del Interior and that the cross section with the maximum amount of shortening (66%, 115 km) may be the most likely cross section (Avé Lallemant, 2000, pers. comm.).

Figure C12. Cross-section through the Caripe block of the eastern Serranía del Interior with 66% (115km) shortening. Line location depicted on Figure C13 (from Hung, 1997).

Figure C13. Map of the eastern Serranía del Interior showing the cross-section locations of Figures C11 and C12.

APPENDIX D. FISSION-TRACK METHODOLOGY AND EQUATION DERIVATIONS

Apatite Fission Track Formation

Fission track analysis is a relatively new method to determine the cooling age and thermal history of a rock. Fission track analysis can be performed on apatite, zircon, and man-made glass, however, the dependence of fission track formation on age and thermal history is best understood in apatite. A fission track is a zone of damage within a crystal or glass formed by the natural fission of ^{238}U or the induced fission of ^{235}U (Blythe et al., 1998). As depicted in Figure D1, when a ^{238}U nucleus spontaneously fissions, two charged particles of approximately equal size, each one-half the size of the original nucleus, are formed. These charged particles accelerate away from each other by Coulomb repulsion. As the charged particles travel through the crystal lattice, they strip electrons from other nearby atoms. These atoms become ions themselves and again, by Coulomb repulsion, force the ions to distance themselves from each other forming a defect or track. Relaxation of the stress field surrounding the path of the original particle causes elastic strain of the crystal lattice (Fleischer et al., 1975; Donelick, 1994). Etching with acids make these tracks visible with an optical microscope. For an overview of background work done on fission tracks see Faure (1986).

At low temperatures, fission tracks in apatite are relatively stable, but with increasing temperature, fission tracks will shorten and eventually disappear completely. This process is called annealing. The temperatures at which fission tracks will anneal are dependant on many factors, including rate of cooling, (Gleadow and Duddy, 1981;

Figure D1. The ion spike mechanism of fission track formation. A) illustration depicts one half of a nucleus passing through the crystal lattice after a fission decay event. The nucleus strips electrons from nearby atoms making them ions. B) Coulomb repulsion of ions creates crystallographic damage. C) relaxation of stress field surrounding the original path of the nucleus causes elastic strain in the crystal lattice and the formation of a fission track. After Fleischer et al. (1975)

Gleadow et al., 1983), orientation of the track to the crystallographic *c* axis (Figure D2; Green and Durrani, 1977; Donelick, 1991; Donelick et al., 1999), and chemical composition of the grain itself (Green et al., 1986; Crowley et al., 1990; Carlson et al., 1999). At cooling rates of 1° to 100°C/m.y., apatite fission track annealing occurs between 60° and 110°C (Gleadow and Duddy, 1981; Gleadow et al., 1983). With respect to the orientation of the track to the crystallographic *c* axis, tracks perpendicular to the crystallographic *c* axis anneal quicker than those tracks which are parallel to the crystallographic *c* axis (Figure D2; Green and Durrani, 1977; Donelick, 1991; Donelick et al., 1999). With respect to the grain composition, the Cl/(Cl+F) content of the apatite grain affects the annealing properties of the grains where the apatite grains with the highest Cl content are more resistant to annealing than grains with a higher F content. These three factors affect the annealing rate, making modeling thermal histories a multikinetic problem (Green et al., 1988; Ketcham et al., 1999)

This range of temperatures (60° to 110°C) over which annealing occurs is the Partial Annealing Zone (PAZ), (Gleadow and Fitzgerald, 1987; Wagner et al., 1989). The initial mean length of an induced fission track is approximately 16 µm. Above the higher temperature limit of the PAZ, fission will continue to occur, however, the fission will not form a track because the grain will immediately anneal. As the grain passes through the PAZ, the fission tracks will be recorded and will begin decreasing in length as annealing occurs. Some tracks may even anneal completely. Fission tracks that occur at temperatures lower than the lower limit of the PAZ will undergo very little annealing. Induced, unannealed, fission tracks are almost always longer than naturally occurring

Figure D2. Apatite fission track length c-axis projection model relating the length of a fission track at any angle to the c-axis to its corrected parallel to c-axis (l_c) length. Note: the kink in the plot shows that with progressive annealing, tracks perpendicular (l_a) to the c-axis anneal much faster than tracks parallel to the c-axis. After Donelick et al., (1999).

fission tracks, indicating that some level of annealing occurs below the lower limit of the PAZ.

Fission track densities are used to determine the grains cooling age, while fission track length distributions are used to model the cooling history of the grain. The fission track age is dependent on the number of times a 2-dimensional surface is intersected by fission tracks. Statistically, the longer the track, the higher the chance of an intersection, the higher the fission track density and the older the sample; and vice-versa, the shorter the track, the lower the chance of an intersection, the lower the fission track density and the younger the sample. Regarding fission track length, samples may have fission track histograms that are uni-, bi-, or multi- modal in length. The fission track length distribution reflects the time the sample spent and the rate at which the sample passed through the PAZ. Track lengths can be used to determine the cooling history of the sample and the geologic meaning of the track age (Gleadow et al., 1986; Ketcham et al., 1999).

Fission Track General Sample Preparation

Preparation and analysis of the apatites are discussed in Donelick et al. (1999) and Carlson et al. (1999). Conventional heavy liquid and magnetic separation methods were used to separate individual apatite grains. To measure and model fission tracks, two types of mounts were made, 1) a fission track age mount and 2) a fission track length

mount. The fission track age mount is used to determine the cooling age of the grain, while the fission track length mount is used to model the thermal history of the grain.

Whole rock samples were pulverized in a jaw-crusher and sieved through a #60 mesh (300 μm openings). The grains that passed through the sieve were washed with water to remove clay-sized particles. The sample was then mixed with acetone and warmed beneath a heat lamp to remove excess water, dry the sample, and reduce the possibility of oxidation. After drying, the sample was separated using either Tribromomethane (bromoform; density = 2.89 gm cm^{-3}) or Lithium Metatungstate (density = 3.0 gm cm^{-3}) and Diiodomethane (MEI; density = 3.3 gm cm^{-3}). The heavy fraction from the Bromoform and Lithium Metatungstate separation and the light fraction from the MEI separation was then sent through a Frantz Model L-1 magnetic separator at 1.8 Amps, (tilt 10° , angle 15°). The non-magnetic fraction consisting, hopefully, of some apatite grains was immersed in epoxy resin that was cured at 80°C for 2 hours. After the epoxy resin cured, each grain mount was polished with 600 grit wet sheet sandpaper, and 3 μm grit Aluminum Oxide powder then 0.3 μm grit Micropolish II Deagglomerated Alpha Alumina on a polishing wheel to expose internal grain surfaces. Sample quantities determined the numbers of mounts made for each sample, but at least two mounts of each sample were prepared; one for track length and one for track age measurements.

Fission Track Age Mount Preparation. The fission track age mounts were immersed in 5.5N NHO_3 for 20 seconds at 21°C to etch and record spontaneous,

naturally occurring fission tracks with the apatite grains. A thin low-uranium muscovite mica sheet that was placed in immediate contact with the polished and etched grains covered each age mount. The mica sheet, when irradiated in contact with the apatite grain, will record the number of induced fission track events occurring within the apatite grain caused by irradiation as induced fission fragments travel from the grain to the mica. For standardization and zeta calibration determination, similar mica sheets were placed in immediate contact with two small chips of ^{235}U -doped glass (CN-1 glass) and two mounts of Durango apatite. The age determination mounts were stacked on each other to create a package to be irradiated with the ^{235}U -doped glass “sandwiches” placed on the top and bottom of the package. The package was irradiated for 45 minutes in site D-9 at the Washington State University Nuclear Reactor. The reactor was operating at 1 MW power output, yielding an axial average thermal neutron flux of $2.61 \times 10^{12} \text{ N/cm}^2\text{-sec}$ (Washington State University, 1991), and a thermal-neutron fluence of approximately $7.05 \times 10^{15} \text{ N/cm}^2$. Following neutron irradiation, the short-lived radionuclides were allowed to decay to background levels. The mica sheets were removed from the apatite grain mounts and the CN-1 glass and immersed in 49% hydrofluoric acid (HF) for 17 minutes at 21°C to reveal induced fission tracks resulting from the induced fission of ^{235}U in the adjacent apatite grains and CN-1 glass. The induced fission track densities observed for an apatite grain and CN-1 glass were used to calculate the ^{238}U concentration in the apatite grain.

Fission Track Length Mount Preparation. The fission track length mounts are used to measure fission track length distributions which may provide information useful

to model the time-temperature path of a grain. Typically, the number of natural fission tracks with measurable track lengths is very low. In order to increase the number of natural measurable track lengths, the track length mounts are irradiated with a radioactive ^{252}Cf source. The ^{252}Cf radioactive source bombards the mount with radioactive particles that act like little drills and bore into the grains. The mounts will then be etched to reveal etched track lengths. The etchant is able to use these bore holes to penetrate deeper into the grain and reveal more fission tracks, thereby enhance the measurability of natural fission track length distributions (Figure D3). Donelick and Miller (1991) demonstrated that this method could yield a 20-fold increase in the number of available fission tracks for length measurement.

The track length mounts were irradiated with approximately 10^7 tracks/cm² fission fragments from a 50 μCi (activity as of July, 1996) ^{252}Cf source in a vacuum chamber. Mounts were irradiated for either approximately 12 hours at 4.8 cm from the source or approximately 51 hours at 8.2 cm from the source. Following irradiation, the short-lived radionuclides were allowed to decay to background levels. The mounts were then immersed in 5.5M HNO_3 for 20 seconds at 21°C before they were measured.

Apatite Fission Track Measurement

Fission tracks of individual apatite grains were measured using the external detector method of analysis. Natural fission tracks form as a result of the spontaneous nuclear fission of ^{238}U within an apatite grain. Using a modified version of the radioactive decay equation, the fission-track age of an apatite grain is calculated using the

Figure D3. Transmitted light photomicrographs taken at 1562.5x magnification of two apatite crystals from the same sample that exhibit low natural fission-track densities.

(a) not irradiated with ^{252}Cf fission fragments (arrow indicates a natural fission track).

(b) irradiated with approximately 5×10^6 tracks/cm² ^{252}Cf fission fragments (arrow indicates a natural fission track totally confined within the crystal for which a track length can be measured and which was etched via a ^{252}Cf fission fragment track). From Donelick Analytical (2000).

ratio of the number of fission tracks present in the grain to the amount of ^{238}U present in the grain. It is very difficult to directly measure the ^{238}U concentration in small apatite grains; however, it is relatively easy to measure the ^{235}U concentration in a grain using thermal-neutron activation analysis. The ^{238}U concentration in an apatite grain is calculated from the ^{235}U concentration using the constant ratio of $^{238}\text{U}/^{235}\text{U}$ observed in nature (137.88 by convention; Steiger and Jäger, 1977).

The total etched length of a natural fission track is a strong indicator of the integrated thermal history that the track has experienced. Fission tracks form continuously through time at a rate determined by the concentration of ^{238}U in the host apatite grain. Therefore, the distribution of fission-track lengths in an apatite contains abundant information about the time-temperature path experienced by the apatite, particularly the cooling history since the time of peak temperature.

Fission Track Age and Length Measurement Apparatus and Parameters

To determine the fission track cooling age, densities of naturally occurring fission tracks were measured on apatite grains and induced fission track densities were measured on areas of the mica sheets corresponding to those apatite grains. To model the cooling history, individual track lengths, angles to the crystallographic c axis, and etch pit dimensions were measured.

All measurements were made using a digitizing tablet interfaced with a personal computer. An LED light attached to a digitizing cursor aided the positioning of the

cursor within the optical field of view. The digitizer surface was calibrated for length measurement using a 600 lines/mm diffraction grating. Tracks were measured in transmitted and reflective light at 1562.5x magnification (12.5x oculars, 1.25x projection tube, 100x dry objective) using a Nikon Optiphot-2 microscope. All measurements were performed by Brian Locke (BDL) using a single analytical system. The length of each fission-track and its angle to the crystallographic *c* axis were computed from three digitized points per track, one point at each end of the track and one point along the crystallography *c* axis from the second point (Figure D4). Track length measurements were made only on horizontal, confined Track-IN-Track (TINT) fission tracks (Figure D5). TINT tracks are tracks that intersect another track exposed at the grain surface. The etchant travels into the TINT via the surface track. The precision of each track length and angle to the crystallographic *c* axis is approximately $\pm 0.2\mu\text{m}$ and 2° , respectively. (Donelick, 1991; Donelick et al., 1999). The etch pit dimensions were computed using four points, one point at each end of the pit parallel to the crystallography *c* axis and two points measuring the width perpendicular to the crystallography *c* axis (Figure D6).

The fission track age measurements were made by counting the number of naturally occurring tracks which intersected the surface of the age mount (ρ_s) and counting the number of induced fission tracks on the mica sheets over the same area (ρ_i) to which the apatite grain was juxtaposed. The ratio of the spontaneous track density over the induced track density is used to determine the ^{238}U concentration, whereas a high ρ_s indicates either an old grain or a high Uranium concentration, the ρ_i is used to distinguish

Figure D4. Measurement points (black dots) of fission track length (l_i) and inclination angle (θ_i) to the crystallographic c axis. After Donelick et al., (1999).

Figure D5. Illustration of relationship between etched surface and confined tracks. Confined tracks can be etched via fractures, cleavage, or inclusions. Only horizontal Track-in-Track (TINT) tracks were measured in this study. After Gleadow et al., (1984).

the difference. A high ρ_I would indicate a high Uranium concentration and a low ρ_I indicates an old grain.

Kinetic Classification of each Apatite Grain

Apatite fission track ages and total etched fission track lengths are strongly correlated with the solubility of their host apatite grain in samples that have experienced significant residence time at temperatures above approximately 70°C (see Burtner et al., 1994; Donelick, 1993, 1995; Donelick et al., 1999). Using the techniques of Donelick (1999), the parameter used to quantify solubility is termed Dpar (Figure D6). Dpar refers to the maximum length of fission track etch pits parallel to the crystallographic c-axis at their intersection with the polished and etched apatite surface. Dper refers to the maximum diameter of fission track etch pits perpendicular to the crystallographic c-axis at their intersection with the polished and etched apatite surface.

The Dpar parameter reflects the different annealing properties of individual grains and can, therefore, be used to determine different grain populations; i.e., grains that are more resistant to annealing versus grains less resistant. These grain populations can then be separated and modeled individually, obtaining a better understanding of the time-temperature path of the grain, instead of a general average of different grain populations.

Fission tracks in apatite grains exhibiting the smallest Dpar values usually anneal more quickly than fission tracks in apatite grains having larger Dpar values (Figure D7).

Figure D6. Illustration of an etch pit figure in apatite. A) Illustrated microscopic view of a mounted and etched apatite grain with four etch pits. B) Enlarged view of etch pit: dpar is diameter parallel to the c-axis, dper is diameter perpendicular to c-axis. After Donelick (1994).

Figure D7. Reflected light photomicrographs taken at 1562.5x magnification of two apatite crystals that exhibit very different D_{par} values. Both apatite crystals were etched in 5.5N HNO_3 for 20.0 seconds (± 0.5 seconds) at 21°C ($\pm 1^\circ\text{C}$).

(a) $D_{\text{par}}=1.83\ \mu\text{m}$ (apatite from Durango, Mexico ([F]=3.33 wt.%, [Cl]=0.43 wt.%).

(b) $D_{\text{par}}=4.99\ \mu\text{m}$ (apatite from Bamble, Norway ([F]=0.08 wt.%, [Cl]=6.37 wt.%). From Donelick Analytical, (2000).

For example, in an apatite grain having a Dpar value near 1.50 μm (a typical fluorine-rich apatite), fission tracks generally do not survive geological heating above about 100°C.

On the other hand, in an apatite grain having a Dpar value near 3.00 μm (a typical chlorine-rich apatite), fission tracks may survive geological heating above 150°C (Carlson et al., 1999).

For each apatite grain from which fission-track data were measured, between one and four etch pit diameters were measured and an arithmetic mean Dpar value was calculated from these individual values.

Results and Interpretation of Data

Fission track results are summarized in Table 2 and sample locations are depicted in Figure 2. Basic counting data is available in Appendix E. Dpar measurements were not useful in identifying different grain populations because no correlation between age and Dpar length was observed. Therefore, apatite fission track data were interpreted using the techniques of Brandon et al., (1998). The Chi-square (χ^2) test was used to discriminate between concordant and discordant grain age distributions. Samples are concordant when $P(\chi^2) > 5\%$ and discordant when $P(\chi^2) < 5\%$. A discordant sample implies that the variance of the ages may reflect multiple grain populations with different compositions or other annealing dependant parameters (Brandon et al., 1998). The issue of concordance is important because a single homogeneous population with similar annealing properties is needed to determine an accurate grain age as well as to

correctly interpret fission track ages using apatite fission track length data (Green et al., 1989; Carlson et al., 1990, Ketcham et al., 1999).

Heterogeneous annealing populations (disconcordant populations) have been shown to be a very common feature in detrital samples (O'Sullivan and Parrish, 1995). To deal with disconcordant populations, peak-fitting methods (Galbraith, 1988; Galbraith and Green, 1990; Brandon and Vance, 1992, Galbraith and Laslett, 1993; Brandon et al., 1998) can be used to attempt to isolate different annealing resistant populations to obtain the youngest group of concordant grain ages. The age of the youngest group of concordant grains is called the minimum age of the fission track distribution (Galbraith and Laslett, 1993). The minimum age corresponds to the age of grains with the least resistance to annealing. These grains will be the first to reset at the lowest temperatures within the partial annealing zone and the last grains to begin to record a cooling event, thereby, these grains will record the most recent cooling event of any of the grain populations. Grains more resistant to annealing (i.e., older grain ages) will survive higher temperatures within the partial annealing zone and may even retain protolith information when the grain is not completely reset.

Binomial peak-fit methods of Galbraith (1988) and Galbraith and Green (1990) and programs (available at <http://www.love.geology.yale.edu/~brandon>) described in Brandon et al. (1998) were used to estimate minimum and older ages in the grain age distribution. These programs include ZETAAGE (version 4.7) which calculates fission track ages according to Brandon (1992) and confidence intervals according to Sneyd (1984); BINOMFIT (version 1.8), which is an implementation of the binomial peak fit algorithm of Galbraith (1988); and CHI2COMP (version 1.1), which compares χ^2 values

and degrees of freedom of different grain peak models to determine if the addition of a new peak might be due to random change alone (F Test, see Brandon, 1992).

The analysis of fission track data relies on track length data to interpret the geologic implications of fission track ages. Track length analysis assumes that all the apatites have the same annealing properties (are concordant) which is generally not the case in the analyzed samples. As a result, more traditional concepts of the partial annealing zone and effective closure temperature must be relied upon. A brief review of published literature on fission track annealing, the partial annealing zone and effective closure temperature is discussed in Brandon et al. (1998). For ease of discussion and interpretation, the partial annealing zone is assumed to be between 60 °C and 110 °C (effective closure temperature) for apatite (Gleadow and Fitzgerald, 1987; Wagner et al., 1989; Green et al., 1986).

Fission Track Age Equation

The decay of ^{238}U in natural materials occurs by 1) spontaneous fission of ^{238}U , creating fission tracks and 2) alpha emission, resulting in ^{206}Pb through a series of intermediate isotopes (Fleischer et al., 1975; Friedlander et al., 1981). Described by Donelick (1994; pers.comm., 2000), and Issler (1989), derivation of the fission track age equation is described below.

Beginning with the exponential law for the decay of a radioactive species (Friedlander et al., 1981):

$$[^{238}\text{U}] = [^{238}\text{U}]_0 \exp(-\lambda_D t) \quad (1)$$

where;

$[^{238}\text{U}]_0$ = initial number of ^{238}U atoms per unit volume at $t=0$ (atoms cm^{-3})

$[^{238}\text{U}]$ = present number of ^{238}U atoms per unit volume at $t=t$ (atoms cm^{-3})

λ_α = alpha decay constant for $^{238}\text{U} = 1.55125 \times 10^{-4}$ (nuclei million year $^{-1}$)

λ_f = fission decay constant for $^{238}\text{U} = \text{approx. } 8.46 \times 10^{-11}$ (nuclei million year $^{-1}$)

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

t = time (million year)

The number of decay events that occurred in time t by decay of ^{238}U per volume is given by:

$$[D] = [^{238}\text{U}]_0 - [^{238}\text{U}] \quad (2)$$

where;

$[D]$ = number of decay events per unit volume (decay atoms cm^{-3}).

Solving equation 1 in terms of $[^{238}\text{U}]_0$ yields,

$$[^{238}\text{U}]_0 = [^{238}\text{U}] \exp(\lambda_D t) \quad (3)$$

and substituting equation (3) into equation (2) gives

$$[D] = [^{238}\text{U}] \{ \exp(\lambda_D t) - 1 \} \quad (4)$$

Remembering that ^{238}U decays by both spontaneous fission and alpha emission, the fraction of spontaneous fission decay can be written:

$$[D_f]/[D] = \lambda_f / \lambda_D \quad (5)$$

where ;

$[D_f]$ = number of fission events per unit volume (decayed atoms cm^{-3}).

Combining equations 4 and 5 solves for the total number of fission track events per unit volume after time t

$$[D_f] = \lambda_f / \lambda_D [^{238}\text{U}] \{ \exp(\lambda_D t) - 1 \} \quad (6)$$

and solving for time (t) yields the absolute fission track age in terms of present day concentrations of ^{238}U and fission tracks:

$$t = 1/\lambda_D * \ln[(\lambda_D / \lambda_f) (D_f / ^{238}\text{U}) + 1] \quad (7)$$

where;

t = absolute fission track age (year).

As an aside to be incorporated below, fission tracks are metastable features and may anneal or disappear as the system tends toward the lowest free energy state.

Therefore, the number of retained fission tracks per unit volume can be expressed as:

$$[D_f]_r = f_r[D_f] \quad (8)$$

where;

$[D_f]_r$ = number of fission tracks retained per unit volume (decayed atoms cm^{-3})

f_r = fraction of fission tracks retained.

Absolute Fission Track Age Using Measurable Parameters. The absolute fission track age depends on two physical constants, λ_D and λ_f and two variable parameters D_f and ^{238}U . By assuming λ_D and λ_f are constant, D_f and ^{238}U concentrations are all that need to be determined to obtain an absolute fission track age.

An equation expressing D_f in terms of a measurable quantity is needed. Fission track measurements are confined to 1- and 2- dimensional parameters. D_f can be described in these dimensions by using the mean fission track length (R^{238}) and the

number of tracks crossing a random plane of a unit area (ρ_s) in the volume of interest as (Fleischer et al. 1975; Laslett et al. 1982;1984):

$$D_f = \rho_s / f_r R^{238} r^{238} g_s \quad (9)$$

where;

ρ_s = spontaneous fission track density (decayed atoms cm^{-2})

R^{238} = mean etchable spontaneous fission track length (cm)

r^{238} = spontaneous fission track etching efficiency

g_s = geometry factor for spontaneous track density measurement.

An equation expressing [^{238}U] in terms of measurable quantities is also needed. It is easier to measure [^{235}U] by neutron activation techniques and use the $^{238}\text{U} / ^{235}\text{U}$ accepted conventional constant of 137.88 (Steiger and Jäger, 1977) to determine [^{238}U]. The number of ^{235}U atoms per unit volume for induced fissioning of ^{235}U by neutron activation is given by Fleischer et al., (1975):

$$[^{235}\text{U}] = \rho_i / \sigma \phi R^{235} r^{235} g_i \quad (10)$$

where;

$[^{235}\text{U}]$ = number of ^{235}U atoms per unit volume (atoms cm^{-3})

ρ_i = induced fission track density (decayed atoms cm⁻²)

σ = ²³⁵U thermal neutron cross-section (cm² neutron⁻¹)

ϕ = thermal neutron fluence (neutrons cm⁻²)

R^{235} = mean etchable induced fission track length (cm)

r^{235} = induced fission track etching efficiency

g_i = geometry factor for induced track density measurement.

Using the conventional ²³⁸U / ²³⁵U value and solving for [²³⁸U] gets:

$$[^{238}\text{U}] = 137.88\rho_i/\sigma\phi R^{235}r^{235}g_i \quad (11)$$

By combining equations (9) and (11) with equation (7), the absolute fission track age in terms of measurable parameters and constants is:

$$t = 1/\lambda_D \ln\{ (1/f_r) (\lambda_D / \lambda_f) (\rho_s/\rho_i) (R^{235}/R^{238}) (r^{235}/r^{238}) (g_i/g_s) (\sigma\phi/137.88)] + 1 \} \quad (12)$$

Apparent Fission Track Age. The absolute fission track age, equation (12), requires the determination of the total number of fission events that have occurred in the unit volume of interest. However, because 1- and 2- dimensional measurements are made and fission track lengths reduce and can completely anneal after formation, the absolute age of the sample realistically cannot be determined. Instead, the apparent fission track age is determined. The apparent fission track age is made using only standard track density measurements and does not depend on track lengths.

The derivation of the apparent fission track age in terms of measurable parameters and constants is simple and begins with equation (12). By assuming that R^{235}/R^{238} and r^{235}/r^{238} equal 1, the terms R^{235} , R^{238} , r^{235} , r^{238} and $1/f_r$ can be removed leaving behind:

$$t = 1/\lambda_D \ln \{ \lambda_D / \lambda_f \rho_s / \rho_i g_i / g_s \sigma \phi / 137.88 \} + 1 \} \quad (13)$$

The assumption that R^{235}/R^{238} equals 1 seems reasonable because the initial track lengths produced by ^{238}U and ^{235}U should be the same due to similarities in fission decay energies and fission fragment mass distributions. The assumption that r^{235}/r^{238} also equals 1 is reasonable because the etching efficiencies are close enough to 1 for the accuracy of the fission track technique (Donelick, pers.comm., 2000).

Zeta Calibration Equation

Fission track ages were calculated using the modified version of the radioactive decay equation that includes the zeta calibration factor. The values for the constants λ_D , σ , and $^{238}\text{U} / ^{235}\text{U}$ are agreed upon, however the determination of the thermal-neutron fluence, ϕ , and the fission decay constant, λ_f have been a notorious problem for fission trackers. To avoid these problems Fleischer and Hart (1972) and Hurford and Green (1982) suggested using a zeta calibration factor obtained using standards of known fission track age. As previously mentioned in the sample preparation methodology, two pieces of CN-1 glass were irradiated with the samples. The number of induced fission events recorded on the mica sheets adjacent to the CN-1 glass is measured and is proportional to

the neutron fluence. The measurable neutron dosimeter fission track density is proportional to the difficult to measure thermal-neutron fluence value:

$$\phi = C\rho_d \quad (14)$$

where;

ϕ = neutron dosimeter fission track density (tracks cm⁻²)

C = a constant of proportionality (dimensionless, value close to 1)

ρ_d = the neutron dosimeter fission track density in the mica (tracks cm⁻²)

Substituting equation (14) into equation (13) and introducing the zeta calibration factor yields:

$$t = 1/\lambda_D \{ [\zeta g_i/g_s \lambda_D \rho_d \rho_s/\rho_i] + 1 \} \quad (15)$$

where;

ζ = calibration constant specific to a particular dosimeter glass, a particular irradiation configuration, and a particular analyst.

The ζ can be determined by measuring the spontaneous and induced fission track densities for a fission track age standard of known age:

$$\zeta = \{ \exp(t_{\text{std}} \lambda_D) - 1 \} \{ g_s / g_i (\rho_i / \rho_s)_{\text{std}} 1 / \lambda_D \rho_d \} \quad (16)$$

where;

t_{std} = the known age of the fission track age standard (Ma)

$\rho_{s \text{ std}}$ = spontaneous track density in the fission track age standard (tracks cm^{-2})

$\rho_{i \text{ std}}$ = induced track density in the fission track age standard (tracks cm^{-2}).

Operators establish their own zeta calibration factor. A zeta calibration factor of 114 ± 9.3 (one standard deviation) for Brian D. Locke was determined using apatite from Durango de Mercado (Mexico) as calibration standards.

APPENDIX E

APATITE FISSION TRACK DATA

Table E1. Summary of the apatite fission-track age data for all apatite grains combined.

Client Sample ID	DA Sample ID	ρ_e (10^6 tracks cm^{-2})	N_e (tracks)	ρ_e (10^6 tracks cm^{-2})	N_e (tracks)	ρ_e (10^6 tracks cm^{-2})	N_e (tracks)	ρ_e (10^6 tracks cm^{-2})	N_e (tracks)	N_d (tracks)	Grains (detritals)	Q (dmbs)	D_{par} (μm)	D_{per} (μm)	Pooled FTAge (Ma)	Mean FTAge (Ma)	Median FTAge (Ma)
Durango																	
DR(01first)	DR-01	0.151	99	0.936	612	3.694	4315	11	0.053	1.90	0.68				34.143.6	36.988.1	26.4 1.6- 8.3+
DR(01second)	DR-01	0.113	81	0.869	625	3.700	4315	11	0.765	1.88	0.72				27.443.9	28.243.7	29.1 3.7- 1.6+
Serranía del Interior																	
BL-99-19a	SER-01	0.149	124	2.439	2026	3.706	4315	32	0.127	1.79	0.65				13.041.6	12.341.9	11.6 1.5- 2.3+
BL-99-2	SER-02	0.192	211	2.089	2290	3.712	4315	38	0.080	1.81	0.66				19.642.1	23.843.7	23.4 2.8- 1.8+
BL-99-5	SER-03	0.171	135	2.404	1894	3.718	4315	35	0.049	1.86	0.66				15.341.8	16.142.7	14.7 2.4- 1.5+
BL-99-16	SER-04	0.174	120	1.678	1159	3.724	4315	22	0.080	1.79	0.66				22.042.8	29.946.4	25.6 5.0- 4.7+
BL-99-32	SER-05	no grain ages															
BL-99-9	SER-06	0.246	79	1.808	581	3.730	4315	19	0.080	1.83	0.65				29.042.2	33.241.5	21.3 2.3- 3.5+
BL-99-7	SER-11	no grain ages															
BL-99-20	SER-14	no grain ages															
BL-99-23	SER-15	3.299	76	7.378	170	3.764	4315	1	n.a.	2.08	0.69				95.6415.4		
BL-99-6	SER-16	0.368	204	2.738	1516	3.773	4315	23	0.080	1.89	0.69				29.043.2	37.9413.0	26.9 6.1- 5.5+
BL-99-31	SER-19	0.459	99	3.099	649	3.782	4315	10	0.080	1.75	0.71				32.944.5	43.5416.4	26.9 3.6- 14.5+
BL-99-18	SER-20	0.755	226	2.447	733	3.795	4315	5	0.080	2.09	0.78				66.647.5	46.0425.6	18.1 7.9- 57.5+
BL-00-21	270-02	0.670	60	7.109	637	3.350	4183	7	0.080	1.74	0.59				18.042.9	34.6417.8	20.2 6.3- 9.6+
BL-00-23	270-03	1.056	173	1.910	313	3.373	4183	7	0.121	1.81	0.65				106.413	119.230	115 12- 26+
BL-00-25	270-04	0.342	269	2.832	2229	3.389	4183	44	0.080	1.84	0.65				23.442.5	28.944.8	23.5 2.1- 2.4+
BL-00-31	270-05	0.188	13	3.096	214	3.407	4183	1	n.a.	2.11	0.66				11.843.5		
BL-00-32	270-06	0.373	127	2.961	1008	3.429	4183	22	0.507	1.90	0.75				24.743.1	27.244.9	25.2 2.7- 3.0+
BL-00-38	270-07	0.848	728	1.171	1005	3.446	4183	24	0.080	1.89	0.79				141.414	159.422	159 15- 8+
BL-00-44	270-08	0.393	112	3.750	1068	3.457	4183	17	0.080	2.00	0.79				20.742.7	26.547.7	21.4 3.5- 2.5+
BL-00-48	270-09	0.122	5	0.537	22	3.475	4183	1	n.a.	1.61	0.89				45.1422.6		
BL-00-72	270-15	0.597	170	5.242	1493	3.497	4183	18	0.080	1.87	0.79				22.842.6	39.0413.5	20.5 3.3- 5.7+

BL-00-81	270-18	0.503	119	5.165	1223	3.520	4183	16	0.007	1.98	0.82	196225	280280	18.4	2.9	4.1+
BL-00-92	270-23	0.260	4	0.260	4	3.542	4183	1	n.a.	2.12	0.85	2002142				

Table E2. Summary of the apatite fission-track length data for all apatite grains combined.

Client Sample ID	DA Sample ID	Tracks	Mean Length (μm)	Standard Deviation (μm)	Dpar (μm)	Dper (μm)	0-1 (μm)	1-2 (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)
Entrapage																										
DR(dx1)	DR-01	39	13.74 $\pm$ 0.24	1.49	1.66	0.58	-	-	-	-	-	-	-	-	-	-	1	4	10	5	10	8	-	-	1	-
DR(dx2)	DR-01	27	14.57 $\pm$ 0.20	1.02	1.92	0.71	-	-	-	-	-	-	-	-	-	-	-	-	1	8	10	6	1	1	-	-
DR(dx1)	DR-01	105	14.76 $\pm$ 0.16	1.60	1.95	0.71	-	1	-	-	-	-	-	-	-	-	-	-	3	14	37	38	10	2	-	-
Traps																										
TI100(1)	TI-01	101	15.44 $\pm$ 0.21	2.07	2.41	0.87	-	-	-	-	-	-	-	1	2	-	2	1	6	4	14	26	28	15	1	-
TI100(2)	TI-01	101	15.54 $\pm$ 0.16	1.58	2.43	0.88	-	-	-	-	-	-	-	-	-	1	-	1	2	12	19	28	18	18	-	1
TI171(1)	TI-01	101	13.34 $\pm$ 0.11	1.06	2.34	0.90	-	-	-	-	-	-	-	-	1	2	-	2	27	44	22	3	-	-	-	-
Fish Canyon Tuff																										
FC(dx1)	FC-01	104	14.72 $\pm$ 0.12	1.21	2.08	0.68	-	-	-	-	-	-	-	-	-	-	1	1	9	13	33	33	13	1	-	-
FC(dx2)	FC-01	103	15.15 $\pm$ 0.10	1.03	2.46	1.03	-	-	-	-	-	-	-	-	-	-	-	1	2	6	40	34	16	2	-	-
Serrania del Interior																										
BL-99-19a	SER-01	37	13.45 $\pm$ 0.27	1.64	2.11	0.82	-	-	-	-	-	-	-	-	-	-	3	6	5	5	12	4	2	-	-	-
BL-99-2	SER-02	70	12.98 $\pm$ 0.32	2.64	2.15	0.79	-	-	-	-	1	1	1	4	-	3	1	4	13	16	8	14	4	-	-	-
BL-99-5	SER-03	80	13.45 $\pm$ 0.21	1.86	1.99	0.71	-	-	-	-	1	-	-	1	-	1	2	8	14	13	26	13	1	-	-	-
BL-99-16	SER-04	21	12.36 $\pm$ 0.49	2.19	1.93	0.77	-	-	-	-	-	-	-	1	1	1	3	2	4	4	3	2	-	-	-	-
BL-99-32	SER-05	no track lengths																								
BL-99-9	SER-08	23	11.02 $\pm$ 0.99	4.64	1.68	0.68	-	4	-	-	-	-	-	-	1	-	1	3	4	3	6	1	-	-	-	-
BL-99-7	SER-11	no track lengths																								
BL-99-29	SER-14	no track lengths																								
BL-99-23	SER-15	1	16.49		2.15	0.78	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BL-99-6	SER-16	49	13.33 $\pm$ 0.24	1.66	2.12	0.75	-	-	-	-	-	-	-	-	1	1	4	2	11	10	13	5	2	-	-	-
BL-99-31	SER-19	3	11.64 $\pm$ 1.07	1.52	1.54	0.59	-	-	-	-	-	-	-	-	-	-	1	1	-	1	-	-	-	-	-	-
BL-99-18	SER-20	42	14.22 $\pm$ 0.18	1.17	2.04	0.91	-	-	-	-	-	-	-	-	-	-	-	1	6	7	20	5	3	-	-	-
BL-00-21	270-02	13	12.65 $\pm$ 0.39	1.34	1.55	0.57	-	-	-	-	-	-	-	-	-	-	1	3	5	2	1	1	-	-	-	-
BL-00-23	270-03	2	10.83 $\pm$ 2.90	2.90	2.09	0.74	-	-	-	-	-	-	-	-	1	-	-	-	1	-	-	-	-	-	-	-

BL-00-25	270-04	33	12.1140.73	4.14	1.56	0.61	-	2	2	-	-	-	-	-	-	-	2	2	8	5	7	3	1	1	-
BL-00-31	270-05	39	12.8340.29	1.79	1.68	0.58	-	-	-	-	1	-	-	-	-	-	2	2	5	10	8	7	4	-	-
BL-00-32	270-06	76	13.8840.34	2.94	2.03	0.88	-	-	-	1	1	-	-	-	-	1	2	-	4	9	17	25	11	3	1
BL-00-38	270-07	16	11.5640.37	1.45	1.70	0.65	-	-	-	-	-	-	-	-	-	1	1	3	5	4	2	-	-	-	
BL-00-44	270-08	24	14.0440.35	1.69	1.91	0.74	-	-	-	-	-	-	-	-	-	-	1	1	1	1	7	6	4	3	-
BL-00-48	270-09	no track knolls																							
BL-00-72	270-15	20	14.1340.31	1.34	1.92	0.77	-	-	-	-	-	-	-	-	-	-	-	1	4	3	6	5	-	1	-
BL-00-81	270-18	7	13.0640.45	1.10	2.01	0.88	-	-	-	-	-	-	-	-	-	-	-	-	3	2	1	1	-	-	-
BL-00-92	270-23	45	14.2740.20	1.34	2.02	0.85	-	-	-	-	-	-	-	-	-	-	1	2	6	7	13	2	1	-	-

Apatite Fission-Track Length Data

DR-01 (first)

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	12.64	4	1.77	0.50	44.85
2	12.83	4	1.10	0.59	36.36
3	13.95	4	1.82	0.66	84.85
4	11.13	4	1.86	0.65	68.99
5	14.12	4	2.17	0.56	83.23
6	14.90	4	2.14	0.65	88.57
7	11.27	4	2.33	0.72	11.88
8	12.55	4	1.31	0.47	11.67
9	12.99	4	1.31	0.47	15.54
10	14.79	4	1.31	0.47	39.68
11	12.69	4	1.35	0.43	43.64
12	13.80	4	1.35	0.43	33.60
13	15.45	4	1.35	0.43	41.67
14	14.69	4	1.35	0.43	7.51
15	12.06	4	1.35	0.43	5.51
16	14.90	4	1.20	0.65	29.88
17	15.39	4	1.36	0.48	19.19
18	12.62	4	1.36	0.48	12.56
19	14.48	4	1.49	0.69	47.46
20	13.17	4	1.56	0.66	59.44
21	12.80	4	1.56	0.66	56.74
22	14.61	4	1.94	0.50	76.73
23	14.59	4	1.91	0.51	81.69
24	14.03	4	2.37	0.78	79.61
25	11.06	4	2.37	0.75	5.46
26	10.88	4	1.67	0.69	50.95
27	11.73	4	2.06	0.73	33.65
28	13.66	4	1.54	0.85	14.68
29	12.75	4	1.72	0.43	56.16
30	15.77	4	2.14	0.61	61.02
31	15.30	4	1.00	0.60	43.28
32	12.47	4	1.68	0.51	62.20
33	14.26	4	1.53	0.69	10.37
34	15.38	4	1.92	0.59	53.83
35	13.70	4	1.68	0.56	82.26
36	15.27	4	1.82	0.66	70.61
37	17.11	4	2.32	0.60	35.78
38	15.01	4	1.26	0.73	73.11
39	15.06	4	1.60	0.52	2.86

Mean Dpar = 1.66
 Mean Dper = 0.58
 Mean length (um) = 13.74 +/- 0.24
 Std. Dev. (um) = 1.49
 Skewness = -0.15
 Kurtosis = -0.76

DR-01 (second)

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	15.67	4	2.11	0.74	52.32
2	17.24	4	2.30	0.67	34.38
3	15.79	4	1.87	0.57	70.29
4	15.08	4	1.62	0.71	6.03
5	14.90	4	2.15	0.67	73.61
6	12.43	4	2.15	0.67	59.53
7	16.17	4	2.30	0.67	66.47
8	13.42	4	2.25	0.71	68.91
9	14.49	4	1.68	0.84	19.38
10	13.96	4	2.24	0.82	56.95
11	13.31	4	2.16	0.87	56.40
12	13.88	4	2.44	0.71	82.82
13	13.89	4	2.11	0.81	77.31
14	15.12	4	1.98	0.62	76.97

15	14.91	4	2.15	0.72	84.10
16	15.48	4	2.28	0.81	75.52
17	14.09	4	1.56	0.72	52.03
18	14.94	4	1.56	0.72	52.53
19	15.25	4	1.52	0.67	47.91
20	14.41	4	1.52	0.67	9.77
21	13.60	4	1.52	0.67	70.16
22	14.72	4	1.52	0.67	35.05
23	14.34	4	1.52	0.67	43.33
24	14.70	4	1.52	0.67	18.38
25	13.29	4	1.52	0.67	12.37
26	13.66	4	2.41	0.83	86.31
27	14.75	4	1.95	0.69	85.58

Mean Dpar = 1.92
 Mean Dper = 0.71
 Mean length (um) = 14.57 +/- 0.20
 Std. Dev. (um) = 1.02
 Skewness = 0.33
 Kurtosis = 0.12

DR-01 (third)

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	15.49	4	2.03	0.63	81.05
2	14.00	4	2.03	0.63	43.09
3	15.22	4	1.63	0.71	34.04
4	15.62	4	1.63	0.71	70.85
5	15.82	4	1.63	0.71	44.41
6	15.40	4	1.63	0.71	66.78
7	14.81	4	1.63	0.71	43.29
8	16.36	4	1.63	0.71	34.91
9	14.68	4	1.63	0.71	71.68
10	16.32	4	1.63	0.71	48.58
11	13.38	4	1.63	0.71	61.01
12	13.40	4	1.63	0.71	76.78
13	15.92	4	1.63	0.71	60.14
14	14.15	4	1.63	0.71	72.16
15	13.08	4	1.63	0.71	59.58
16	12.41	4	1.63	0.71	88.06
17	14.63	4	1.63	0.71	60.89
18	15.47	4	1.63	0.71	23.23
19	12.11	4	1.63	0.71	77.64
20	13.98	4	1.63	0.71	40.19
21	14.82	4	1.63	0.71	52.01
22	15.95	4	1.63	0.71	21.95
23	13.83	4	1.63	0.71	55.31
24	14.72	4	1.63	0.71	32.32
25	14.97	4	1.63	0.71	55.65
26	14.32	4	1.63	0.71	82.15
27	14.15	4	1.89	0.72	58.68
28	13.37	4	1.89	0.72	82.76
29	14.30	4	1.89	0.72	55.48
30	15.75	4	1.89	0.72	7.17
31	15.27	4	1.89	0.72	98.31
32	14.26	4	1.89	0.72	23.56
33	14.30	4	1.89	0.72	50.19
34	15.06	4	1.89	0.72	59.32
35	15.18	4	1.89	0.72	23.43
36	17.12	4	1.89	0.72	42.04
37	13.30	4	1.89	0.72	65.47
38	15.23	4	2.00	0.59	52.76
39	14.42	4	2.00	0.59	81.62
40	14.43	4	2.00	0.59	74.79
41	16.25	4	2.00	0.59	41.25
42	14.80	4	2.15	0.77	70.36
43	14.91	4	2.15	0.77	54.04
44	14.01	4	2.15	0.77	33.64
45	13.64	4	2.15	0.77	44.91
46	15.60	4	2.15	0.77	89.28
47	14.72	4	2.15	0.77	77.28
48	15.75	4	2.15	0.77	72.32
49	15.47	4	2.15	0.77	61.69
50	13.91	4	2.15	0.77	70.60
51	16.03	4	2.15	0.77	53.52
52	14.13	4	2.15	0.77	85.17
53	15.37	4	2.15	0.77	48.66
54	15.06	4	2.15	0.77	78.29

55	15.50	4	2.15	0.77	89.11
56	15.33	4	2.18	0.71	59.65
57	14.29	4	1.94	0.70	72.78
58	14.25	4	1.94	0.70	63.37
59	14.78	4	1.94	0.70	48.22
60	15.24	4	1.94	0.70	26.85
61	14.77	4	1.94	0.70	41.58
62	16.24	4	1.94	0.70	42.08
63	14.44	4	1.94	0.70	56.37
64	17.07	4	1.94	0.70	39.30
65	15.58	4	2.00	0.61	23.21
66	12.77	4	2.00	0.61	67.74
67	15.95	4	2.00	0.61	20.94
68	15.00	4	2.00	0.61	55.68
69	13.44	4	2.00	0.61	46.31
70	14.74	4	2.00	0.61	71.27
71	16.48	4	2.00	0.61	87.38
72	13.96	4	2.00	0.61	56.16
73	15.78	4	2.00	0.61	42.19
74	16.21	4	2.00	0.61	42.14
75	1.97	4	2.05	0.73	24.80
76	15.56	4	2.05	0.73	77.86
77	16.82	4	2.05	0.73	78.75
78	15.11	4	2.05	0.73	74.99
79	14.96	4	2.05	0.73	55.72
80	14.17	4	2.05	0.73	49.84
81	13.15	4	2.05	0.73	58.97
82	14.73	4	2.05	0.73	54.16
83	15.88	4	2.05	0.73	41.94
84	15.13	4	2.05	0.73	33.58
85	15.01	4	2.05	0.73	59.49
86	15.65	4	2.05	0.73	93.21
87	16.41	4	2.05	0.73	5.99
88	13.56	4	2.05	0.73	80.40
89	15.10	4	2.11	0.71	65.06
90	14.90	4	2.11	0.71	44.84
91	14.54	4	2.11	0.71	36.20
92	14.14	4	2.11	0.71	58.04
93	15.21	4	2.11	0.71	31.86
94	15.70	4	2.11	0.71	52.48
95	14.06	4	2.11	0.71	50.19
96	14.93	4	2.11	0.71	78.06
97	13.71	4	2.11	0.71	73.45
98	14.16	4	2.11	0.71	56.47
99	15.90	4	2.11	0.71	72.96
100	16.21	4	2.11	0.71	56.05
101	14.74	4	2.11	0.71	42.40
102	15.39	4	2.11	0.71	63.79
103	15.26	4	2.11	0.71	81.94
104	14.50	4	2.11	0.71	42.88
105	15.18	4	2.11	0.71	30.79

Mean Dpar = 1.95
 Mean Dper = 0.71
 Mean length (um) = 14.76 +/- 0.16
 Std. Dev. (um) = 1.60
 Skewness = -4.87
 Kurtosis = 36.74

TI-01 (H0 first)

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	17.60	4	2.58	0.78	72.96
2	16.19	4	2.58	0.78	44.60
3	16.68	4	2.58	0.78	33.06
4	7.68	4	2.58	0.78	60.65
5	8.64	4	2.58	0.78	76.60
6	16.92	4	2.87	0.96	85.20
7	16.75	4	2.87	0.96	62.67
8	15.29	4	2.36	0.66	57.63
9	16.82	4	2.36	0.66	55.78
10	17.40	4	2.90	0.73	44.60
11	12.43	4	2.21	0.88	61.42
12	15.48	4	2.21	0.88	51.42
13	12.76	4	2.21	0.88	59.31
14	8.23	4	2.21	0.88	41.07
15	16.04	4	2.21	0.88	33.08
16	16.79	4	2.21	0.88	67.29

17	16.61	4	2.69	0.97	81.24
18	14.74	4	2.69	0.97	73.54
19	14.12	4	2.69	0.97	50.58
20	16.58	4	2.41	1.05	48.37
21	17.18	4	2.41	1.05	75.83
22	14.36	4	2.41	1.05	59.89
23	15.34	4	2.41	1.05	86.91
24	15.87	4	2.41	1.05	76.25
25	14.85	4	2.41	1.05	39.03
26	17.58	4	2.33	0.78	53.13
27	15.37	4	2.33	0.78	70.86
28	15.70	4	2.33	0.78	51.87
29	15.48	4	2.33	0.78	8.92
30	15.83	4	2.33	0.78	42.49
31	12.27	4	2.33	0.78	38.14
32	10.89	4	2.33	0.78	62.05
33	16.54	4	2.33	0.78	61.17
34	15.68	4	2.33	0.78	58.66
35	15.72	4	2.33	0.78	74.28
36	17.63	4	2.30	0.84	57.75
37	14.50	4	2.30	0.84	18.38
38	13.35	4	2.30	0.84	72.67
39	15.57	4	2.30	0.84	49.08
40	14.52	4	2.30	0.84	34.42
41	15.69	4	2.30	0.84	52.06
42	15.93	4	2.30	0.84	75.73
43	18.08	4	2.30	0.84	55.68
44	15.14	4	2.54	0.76	6.12
45	13.33	4	2.54	0.76	62.26
46	16.74	4	2.54	0.76	25.77
47	12.45	4	2.54	0.76	51.24
48	14.68	4	2.54	0.76	4.13
49	16.40	4	2.33	0.74	76.56
50	16.71	4	2.33	0.74	25.39
51	10.63	4	2.33	0.74	0.00
52	16.97	4	2.33	0.74	40.95
53	14.52	4	2.43	0.88	82.89
54	15.63	4	2.43	0.88	55.95
55	16.83	4	2.43	0.88	57.92
56	21.10	4	2.40	0.99	40.49
57	17.62	4	2.40	0.99	72.26
58	15.44	4	2.40	0.99	19.90
59	14.77	4	2.40	0.99	85.48
60	17.90	4	2.40	0.99	66.98
61	12.88	4	2.40	0.99	17.65
62	15.28	4	2.40	0.99	27.21
63	17.24	4	2.40	0.99	47.54
64	15.31	4	2.40	0.99	56.95
65	15.10	4	2.40	0.99	70.32
66	16.36	4	2.40	0.99	70.06
67	15.89	4	2.40	0.99	51.05
68	15.97	4	2.40	0.99	58.06
69	17.17	4	2.40	0.99	48.25
70	16.29	4	2.49	0.83	82.68
71	14.63	4	2.49	0.83	43.98
72	16.61	4	2.49	0.83	38.17
73	16.01	4	2.49	0.83	71.93
74	16.11	4	2.49	0.83	62.80
75	17.20	4	2.32	0.86	57.50
76	16.01	4	2.32	0.86	66.91
77	17.11	4	2.32	0.86	62.75
78	17.07	4	2.32	0.86	63.99
79	16.50	4	2.84	0.90	33.75
80	15.67	4	2.84	0.90	42.14
81	15.05	4	2.84	0.90	30.94
82	16.09	4	2.84	0.90	75.15
83	12.76	4	2.84	0.90	40.81
84	17.54	4	2.49	0.89	75.71
85	14.82	4	2.49	0.89	81.93
86	13.38	4	2.49	0.89	41.68
87	14.91	4	2.49	0.89	80.21
88	14.84	4	2.12	0.88	39.23
89	16.74	4	2.12	0.88	65.19
90	11.77	4	2.12	0.88	54.57
91	15.34	4	2.12	0.88	74.98
92	16.31	4	2.24	0.82	57.73
93	17.82	4	2.24	0.82	66.80
94	17.71	4	2.24	0.82	52.74
95	13.77	4	2.24	0.82	62.93
96	16.57	4	2.24	0.82	51.76
97	15.62	4	2.24	0.82	79.37

98	16.51	4	2.24	0.82	55.03
99	15.64	4	2.24	0.82	48.96
100	16.65	4	2.24	0.82	80.15
101	14.65	4	2.24	0.82	64.87

Mean Dpar = 2.41
 Mean Dper = 0.87
 Mean length (um) = 15.44 +/- 0.21
 Std. Dev. (um) = 2.07
 Skewness = -1.37
 Kurtosis = 3.23

TI-01 (H0 second)

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to C-axis (degrees)
1	14.96	4	2.30	0.90	7.34
2	17.34	4	2.63	0.79	82.23
3	14.76	4	2.63	0.79	29.69
4	17.51	4	2.63	0.79	60.93
5	15.45	4	2.28	0.78	14.93
6	16.64	4	2.28	0.78	43.61
7	15.69	4	2.28	0.78	43.37
8	15.76	4	2.28	0.78	65.72
9	15.96	4	2.76	0.94	39.19
10	11.02	4	2.76	0.94	96.13
11	13.69	4	2.76	0.94	42.96
12	13.41	4	2.76	0.94	42.72
13	17.44	4	2.76	0.94	67.62
14	14.50	4	2.76	0.94	61.97
15	16.78	4	2.46	0.94	48.72
16	17.36	4	2.46	0.94	31.58
17	14.52	4	2.46	0.94	24.51
18	13.97	4	2.46	0.94	77.96
19	14.21	4	2.46	0.94	78.09
20	14.30	4	2.97	0.69	48.60
21	15.59	4	2.39	1.05	80.80
22	16.36	4	2.39	1.05	64.24
23	17.05	4	2.39	1.05	60.41
24	14.68	4	2.39	1.05	23.98
25	14.87	4	2.39	1.05	61.75
26	13.81	4	2.39	1.05	17.19
27	17.09	4	2.49	0.86	20.35
28	17.14	4	2.49	0.86	47.56
29	16.30	4	2.49	0.86	21.53
30	15.54	4	2.49	0.86	46.66
31	16.74	4	2.49	0.86	28.00
32	13.93	4	2.49	0.86	56.76
33	17.50	4	2.50	0.82	45.11
34	15.66	4	2.50	0.82	67.75
35	14.57	4	2.50	0.82	33.39
36	16.42	4	2.50	0.82	56.51
37	15.63	4	2.50	0.82	40.58
38	17.49	4	2.50	0.82	70.62
39	15.87	4	2.50	0.82	40.38
40	16.02	4	2.53	0.77	63.05
41	16.83	4	2.53	0.77	62.19
42	14.56	4	2.53	0.77	14.98
43	16.15	4	2.53	0.77	72.58
44	15.12	4	2.53	0.77	66.69
45	17.73	4	2.48	0.81	60.81
46	13.61	4	2.48	0.81	66.69
47	15.71	4	2.48	0.81	28.35
48	15.69	4	2.48	0.81	36.18
49	17.34	4	2.48	0.81	97.11
50	14.77	4	2.69	0.84	69.67
51	17.51	4	2.69	0.84	76.36
52	14.72	4	2.69	0.84	26.95
53	16.16	4	2.74	0.91	73.52
54	15.63	4	2.74	0.91	60.24
55	14.78	4	2.74	0.91	68.69
56	15.01	4	2.22	1.02	77.68
57	14.56	4	2.22	1.02	2.68
58	13.63	4	2.22	1.02	55.72
59	13.94	4	2.22	1.02	41.67
60	9.13	4	2.22	1.02	0.00
61	13.00	4	2.22	1.02	29.60
62	12.16	4	2.22	1.02	45.24
63	17.81	4	2.62	1.00	61.73

64	16.08	4	2.62	1.00	64.96
65	13.66	4	2.62	1.00	29.91
66	13.91	4	2.62	1.00	74.21
67	16.14	4	2.27	0.88	42.49
68	16.24	4	2.27	0.88	73.38
69	15.71	4	2.27	0.88	85.95
70	15.59	4	2.27	0.88	56.72
71	15.61	4	2.27	0.88	24.60
72	15.01	4	2.27	0.88	58.68
73	12.72	4	2.27	0.88	76.38
74	17.46	4	2.15	0.89	76.84
75	17.28	4	2.15	0.89	24.43
76	17.32	4	2.15	0.89	74.28
77	15.22	4	2.15	0.89	52.95
78	15.09	4	2.15	0.89	77.13
79	17.27	4	2.15	0.89	66.24
80	16.31	4	2.15	0.89	38.57
81	15.60	4	2.15	0.89	59.35
82	19.03	4	2.15	0.89	44.26
83	14.75	4	2.69	0.99	51.75
84	14.97	4	2.69	0.99	45.00
85	14.72	4	2.69	0.99	61.56
86	14.69	4	2.38	0.83	59.67
87	15.51	4	2.38	0.83	52.85
88	17.06	4	2.38	0.83	48.01
89	16.28	4	2.38	0.83	58.17
90	15.10	4	2.38	0.83	39.96
91	20.35	4	2.38	0.83	74.54
92	16.76	4	2.38	0.83	44.52
93	15.80	4	2.38	0.83	81.58
94	13.84	4	2.38	0.83	84.30
95	14.86	4	2.38	0.83	20.96
96	15.75	4	2.38	0.83	45.78
97	16.16	4	2.38	0.83	48.41
98	16.43	4	2.08	0.79	33.35
99	15.24	4	2.08	0.79	80.91
100	15.76	4	2.08	0.79	50.30
101	15.22	4	2.08	0.79	83.48

Mean Dpar = 2.43
 Mean Dper = 0.88
 Mean length (um) = 15.54 +/- 0.16
 Std. Dev. (um) = 1.58
 Skewness = -0.57
 Kurtosis = 2.36

TI-01 (H71)

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dper (microns)	Angle to c-axis (degrees)
1	12.04	4	2.33	0.73	66.56
2	13.59	4	2.33	0.73	78.13
3	12.91	4	2.33	0.73	83.80
4	13.93	4	2.33	0.73	29.16
5	13.78	4	2.24	0.97	79.59
6	13.46	4	2.24	0.97	64.25
7	13.59	4	2.24	0.97	32.03
8	12.33	4	2.24	0.97	41.68
9	12.86	4	2.24	0.97	23.54
10	12.12	4	2.24	0.97	3.70
11	13.71	4	2.40	0.85	43.80
12	12.83	4	2.40	0.85	36.56
13	12.06	4	2.40	0.85	83.90
14	13.72	4	2.40	0.85	34.31
15	14.63	4	2.22	0.88	54.22
16	14.48	4	2.22	0.88	49.65
17	13.28	4	2.22	0.88	14.23
18	9.95	4	2.22	0.88	54.47
19	12.95	4	2.22	0.88	44.96
20	13.12	4	2.30	0.80	48.83
21	12.12	4	2.30	0.80	59.22
22	14.57	4	2.30	0.80	59.37
23	13.83	4	2.30	0.80	40.73
24	12.53	4	2.29	0.82	69.99
25	15.11	4	2.29	0.82	50.64
26	14.48	4	2.39	1.00	46.07
27	15.14	4	2.30	1.09	31.95
28	13.05	4	2.30	1.09	62.29
29	13.81	4	2.30	1.09	66.46

30	13.91	4	2.35	0.96	34.50
31	14.18	4	2.22	0.99	61.36
32	13.07	4	2.22	0.99	24.07
33	9.47	4	2.22	0.99	71.58
34	13.63	4	2.52	1.05	81.45
35	9.80	4	2.52	1.05	49.92
36	13.78	4	2.52	1.05	54.28
37	13.72	4	2.14	0.94	13.62
38	12.44	4	2.14	0.94	61.67
39	12.34	4	2.14	0.94	78.12
40	12.62	4	2.14	0.94	52.03
41	12.32	4	2.33	0.92	57.59
42	13.09	4	2.33	0.92	61.80
43	12.61	4	2.35	1.00	50.33
44	14.33	4	2.15	0.71	61.45
45	14.37	4	2.15	0.71	61.00
46	12.15	4	2.15	0.71	77.15
47	12.80	4	2.15	0.71	92.86
48	13.29	4	2.30	0.68	87.96
49	14.83	4	2.30	0.68	57.73
50	14.81	4	2.30	0.68	26.49
51	13.47	4	2.30	0.68	61.34
52	11.52	4	2.30	0.68	61.89
53	14.30	4	2.30	0.68	40.65
54	13.74	4	2.30	0.68	75.57
55	13.45	4	2.30	0.68	52.23
56	13.82	4	2.45	0.87	47.81
57	13.29	4	2.45	0.87	75.06
58	12.89	4	2.45	0.87	59.30
59	14.05	4	2.45	0.87	76.42
60	13.25	4	2.45	0.87	75.87
61	13.00	4	2.45	0.87	93.05
62	13.19	4	2.45	0.87	49.45
63	13.47	4	2.45	0.87	74.32
64	13.80	4	2.33	0.92	97.29
65	14.02	4	2.33	0.92	62.07
66	12.16	4	2.33	0.92	92.25
67	12.37	4	2.33	0.92	53.54
68	14.22	4	2.33	0.92	59.86
69	14.49	4	2.29	0.86	84.16
70	13.14	4	2.29	0.86	79.97
71	14.48	4	2.37	0.97	68.42
72	13.76	4	2.37	0.97	64.81
73	14.39	4	2.37	0.97	85.71
74	13.23	4	2.40	1.04	96.05
75	12.87	4	2.40	1.04	51.01
76	13.59	4	1.97	0.88	96.32
77	13.61	4	2.52	0.98	43.94
78	13.95	4	2.52	0.98	54.46
79	13.00	4	2.52	0.98	58.04
80	14.57	4	2.52	0.98	32.44
81	12.98	4	2.53	1.07	54.17
82	13.57	4	2.53	1.07	36.81
83	13.20	4	2.24	1.01	90.41
84	14.45	4	2.24	1.01	37.87
85	15.00	4	2.24	1.01	43.60
86	11.36	4	2.24	1.01	76.27
87	13.76	4	2.23	0.92	98.85
88	12.99	4	2.48	0.89	62.84
89	13.47	4	2.52	0.91	81.32
90	12.97	4	2.52	0.91	63.19
91	12.86	4	2.52	0.91	98.14
92	13.65	4	2.44	0.91	46.79
93	13.32	4	2.44	0.91	88.31
94	13.96	4	2.44	0.91	57.92
95	14.21	4	2.44	0.91	62.46
96	14.56	4	2.44	0.91	42.36
97	12.38	4	2.50	0.96	41.66
98	14.12	4	2.50	0.96	52.92
99	14.15	4	2.50	0.96	69.87
100	13.55	4	2.50	0.96	52.50
101	12.74	4	2.50	0.96	77.25

Mean Dpar = 2.34
 Mean Dper = 0.90
 Mean length (um) = 13.34 +/- 0.11
 Std. Dev. (um) = 1.06
 Skewness = -1.44
 Kurtosis = 3.90

BL-99-19a

SER-01

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	13.67	4	1.83	0.84	50.83
2	10.21	4	1.83	0.84	53.18
3	15.02	4	2.17	0.70	53.42
4	10.96	4	2.17	0.70	35.65
5	11.70	4	2.35	0.90	68.19
6	14.86	4	1.96	0.66	16.06
7	14.30	4	1.96	0.66	34.07
8	14.18	4	2.10	0.82	64.36
9	14.04	4	2.10	0.82	53.25
10	12.74	4	2.10	0.82	50.08
11	14.67	4	2.26	0.92	50.13
12	11.86	4	2.26	0.92	53.07
13	11.08	4	2.15	0.79	76.07
14	11.24	4	2.15	0.79	81.34
15	10.37	4	1.69	0.80	52.61
16	14.99	4	2.23	0.62	61.73
17	13.48	4	2.44	1.04	68.85
18	16.08	4	2.27	0.95	15.14
19	13.30	4	2.27	0.95	21.40
20	14.14	4	2.27	0.95	44.31
21	14.69	4	2.27	0.95	31.14
22	13.96	4	2.22	0.93	71.47
23	12.72	4	2.22	0.93	45.35
24	14.10	4	2.22	0.93	53.25
25	13.94	4	2.33	1.02	45.67
26	12.78	4	2.33	1.02	60.55
27	11.05	4	2.03	0.87	65.78
28	15.29	4	2.49	0.66	51.42
29	12.21	4	1.88	0.85	86.77
30	11.90	4	1.79	0.59	62.24
31	15.18	4	1.29	0.63	25.08
32	14.16	4	2.07	0.81	36.85
33	15.56	4	2.07	0.81	64.97
34	14.03	4	2.07	0.81	58.53
35	16.42	4	2.10	0.65	75.74
36	14.47	4	2.10	0.65	50.62
37	12.24	4	1.85	0.74	39.96

Mean Dpar = 2.11
 Mean Dper = 0.82
 Mean length (um) = 13.45 +/- 0.27
 Std. Dev. (um) = 1.64
 Skewness = -0.32
 Kurtosis = -0.95

BL-99-2**SER-02**

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	14.86	4	2.16	0.87	51.29
2	15.40	4	1.98	0.74	55.51
3	13.06	4	2.35	0.81	79.95
4	13.39	4	2.35	0.81	77.52
5	12.13	4	2.35	0.81	57.22
6	12.14	4	2.19	0.75	62.56
7	16.25	4	2.59	0.78	44.89
8	12.48	4	2.31	0.82	37.80
9	15.62	4	2.39	0.82	48.46
10	14.41	4	2.10	0.53	53.01
11	15.39	4	1.81	0.68	58.92
12	13.48	4	2.58	0.90	55.03
13	6.80	4	2.58	0.90	52.99
14	15.22	4	2.04	0.70	64.09
15	5.96	4	1.56	0.47	84.00
16	12.27	4	2.00	0.97	68.61
17	4.73	4	1.78	0.61	89.18
18	15.24	4	1.95	0.76	47.20
19	13.63	4	2.18	0.92	29.17
20	7.01	4	1.99	0.80	60.33
21	13.47	4	1.73	0.69	72.68
22	11.47	4	2.00	0.89	68.29
23	12.53	4	1.96	0.90	85.16

24	13.92	4	1.96	0.90	85.68
25	12.63	4	1.96	0.90	77.52
26	13.62	4	1.98	0.73	96.27
27	13.56	4	1.98	0.73	37.28
28	16.12	4	1.98	0.73	23.82
29	14.43	4	1.98	0.73	30.28
30	15.19	4	1.65	0.65	76.93
31	12.62	4	2.13	0.67	78.75
32	7.70	4	2.13	0.67	29.07
33	13.15	4	2.13	0.67	46.79
34	13.22	4	2.13	0.67	67.94
35	12.39	4	2.13	0.67	49.73
36	9.12	4	2.13	0.67	70.23
37	7.90	4	2.13	0.67	68.94
38	14.68	4	2.62	0.79	44.21
39	11.48	4	2.29	0.80	47.22
40	9.91	4	1.61	0.69	88.97
41	9.99	4	1.61	0.69	64.39
42	7.29	4	1.61	0.69	36.95
43	12.09	4	1.85	0.59	79.99
44	15.34	4	1.98	0.70	34.08
45	15.36	4	2.60	1.03	35.03
46	16.53	4	2.60	1.03	38.44
47	15.38	4	2.60	1.03	50.06
48	12.50	4	1.80	0.85	60.04
49	15.64	4	2.02	0.69	52.99
50	15.43	4	2.02	0.69	49.03
51	14.54	4	3.47	1.04	70.48
52	13.90	4	3.47	1.04	59.15
53	11.77	4	2.63	1.18	56.35
54	14.54	4	2.64	1.02	99.89
55	13.00	4	1.66	0.75	88.07
56	14.33	4	2.15	0.78	99.51
57	16.09	4	3.64	1.52	82.13
58	15.62	4	3.64	1.52	0.86
59	15.80	4	2.43	0.94	85.63
60	13.81	4	2.28	0.92	81.17
61	15.32	4	2.30	0.90	89.05
62	12.43	4	1.84	0.48	79.70
63	11.70	4	1.84	0.48	8.25
64	12.63	4	1.88	0.61	52.90
65	14.95	4	1.63	0.91	88.86
66	13.40	4	1.77	0.67	96.90
67	13.96	4	1.91	0.69	44.39
68	12.70	4	1.60	0.74	89.05
69	10.67	4	1.28	0.65	67.93
70	13.42	4	2.03	0.66	77.56

Mean Dpar = 2.15
 Mean Dper = 0.79
 Mean length (um) = 12.98 +/- 0.32
 Std. Dev. (um) = 2.64
 Skewness = -1.22
 Kurtosis = 1.04

BL-99-5

SER-03

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	14.05	4	2.17	0.71	50.73
2	14.08	4	1.73	0.70	70.44
3	12.21	4	1.86	0.74	89.73
4	13.50	4	1.86	0.74	60.50
5	13.85	4	2.20	0.73	62.71
6	14.31	4	2.20	0.73	57.42
7	14.67	4	2.20	0.69	62.86
8	12.83	4	2.22	0.69	31.34
9	15.56	4	2.22	0.69	56.53
10	15.59	4	1.38	0.74	48.67
11	13.54	4	1.79	0.72	75.59
12	12.53	4	1.79	0.72	82.78
13	12.22	4	1.87	0.62	20.68
14	14.94	4	1.97	0.77	46.60
15	14.77	4	1.89	0.68	44.97
16	11.21	4	1.89	0.68	82.67
17	12.48	4	2.07	0.73	37.98
18	14.02	4	1.87	0.66	85.97
19	12.30	4	1.87	0.66	6.34

20	16.17	4	1.21	0.67	68.16
21	13.60	4	2.00	0.76	87.33
22	14.01	4	2.00	0.76	46.73
23	13.21	4	1.93	0.72	30.04
24	14.24	4	2.28	0.61	60.97
25	15.44	4	2.05	0.85	22.58
26	11.83	4	2.64	0.91	50.50
27	14.64	4	1.55	0.58	86.16
28	15.35	4	1.55	0.58	24.60
29	13.58	4	2.56	0.71	69.56
30	14.78	4	1.88	0.79	70.10
31	14.50	4	1.88	0.79	86.91
32	14.03	4	1.87	0.72	40.32
33	14.96	4	1.87	0.72	66.03
34	12.85	4	1.80	0.60	84.95
35	14.26	4	2.24	0.55	75.49
36	14.17	4	2.18	0.79	37.91
37	13.65	4	2.17	0.84	1.70
38	12.88	4	2.17	0.84	66.07
39	13.41	4	2.17	0.84	79.31
40	15.96	4	2.10	0.73	31.24
41	15.45	4	2.10	0.73	75.81
42	14.22	4	2.12	0.76	63.04
43	14.19	4	2.23	0.63	67.46
44	7.80	4	1.86	0.55	59.54
45	12.28	4	1.96	0.65	36.57
46	11.34	4	2.40	0.74	80.69
47	11.24	4	2.40	0.74	29.33
48	14.06	4	1.81	0.62	84.93
49	4.75	4	2.25	0.81	35.45
50	12.84	4	2.25	0.91	39.06
51	13.92	4	2.25	0.91	41.32
52	15.19	4	2.25	0.81	71.24
53	11.20	4	1.54	0.63	87.43
54	10.39	4	1.81	0.49	48.93
55	15.40	4	2.18	0.69	67.76
56	9.42	4	2.05	0.71	45.25
57	13.47	4	2.02	0.72	66.12
58	10.86	4	2.02	0.72	33.18
59	13.23	4	1.75	0.70	55.68
60	13.60	4	2.00	0.64	76.44
61	14.95	4	2.90	0.88	33.89
62	14.12	4	1.14	0.70	67.13
63	12.37	4	1.30	0.77	36.18
64	12.48	4	2.00	0.56	70.92
65	14.76	4	2.12	0.97	67.61
66	14.87	4	2.12	0.97	60.63
67	11.76	4	1.59	0.66	81.44
68	15.22	4	2.05	0.62	41.93
69	15.43	4	1.84	0.50	42.08
70	12.04	4	1.72	0.61	86.64
71	15.24	4	2.18	0.85	70.44
72	14.24	4	2.18	0.85	59.33
73	11.23	4	1.88	0.77	55.37
74	11.42	4	1.84	0.77	65.24
75	13.37	4	2.10	0.71	58.94
76	14.27	4	1.98	0.61	54.21
77	15.07	4	1.98	0.61	66.35
78	14.65	4	1.93	0.62	55.74
79	15.29	4	1.93	0.62	39.63
80	12.29	4	1.93	0.62	78.60

Mean Dpar = 1.99
 Mean Dper = 0.71
 Mean length (um) = 13.45 +/- 0.21
 Std. Dev. (um) = 1.86
 Skewness = -1.72
 Kurtosis = 4.96

BL-99-16**SER-04**

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	13.04	4	2.05	0.74	59.07
2	14.94	4	2.05	0.74	43.57
3	10.70	4	2.02	0.71	24.34
4	14.86	4	1.89	0.66	31.47
5	13.23	4	1.79	0.76	57.22

6	15.58	4	1.81	0.78	69.06
7	10.32	4	2.05	0.83	67.19
8	12.25	4	1.96	0.93	69.62
9	15.10	4	2.07	0.91	47.56
10	12.90	4	1.98	0.71	89.30
11	8.43	4	1.98	0.71	70.19
12	7.85	4	1.98	0.71	52.13
13	13.42	4	1.96	0.71	79.97
14	13.96	4	1.96	0.71	68.19
15	12.20	4	1.96	0.71	8.63
16	10.82	4	1.53	0.78	67.72
17	9.96	4	1.96	0.68	71.58
18	11.96	4	2.03	0.85	63.28
19	14.96	4	1.84	0.97	50.52
20	12.01	4	1.90	0.89	68.06
21	11.01	4	1.95	0.58	61.43

Mean Dpar = 1.93
 Mean Dper = 0.77
 Mean length (um) = 12.36 +/- 0.49
 Std. Dev. (um) = 2.19
 Skewness = -0.34
 Kurtosis = -0.88

BL-99-32

SER-05

no confined tracks observed

BL-99-9

SER-08

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dper (microns)	Angle to c-axis (degrees)
1	11.73	4	1.61	0.60	66.77
2	11.25	4	1.56	0.59	80.52
3	9.93	4	1.44	0.70	7.54
4	14.00	4	2.14	0.71	67.44
5	14.04	4	1.54	0.65	59.70
6	12.94	4	1.54	0.65	78.18
7	10.07	4	1.55	0.62	3.42
8	13.94	4	1.55	0.62	52.45
9	11.96	4	1.67	0.70	50.19
10	15.60	4	1.95	0.65	19.50
11	14.87	4	1.85	0.57	53.14
12	12.14	4	1.46	0.52	66.19
13	14.40	4	1.54	0.71	69.85
14	12.50	4	1.54	0.71	88.16
15	12.75	4	1.80	0.63	67.26
16	14.17	4	1.78	0.82	66.64
17	1.68	0	0.00	0.00	26.76
18	1.64	0	0.00	0.00	19.16
19	1.82	0	0.00	0.00	20.15
20	1.59	0	0.00	0.00	36.37
21	13.02	0	0.00	0.00	26.65
22	14.68	0	0.00	0.00	27.18
23	13.73	4	2.07	0.76	36.86

Mean Dpar = 1.68
 Mean Dper = 0.68
 Mean length (um) = 11.02 +/- 0.99
 Std. Dev. (um) = 4.64
 Skewness = -1.25
 Kurtosis = -0.02

BL-99-7

SER-11

no confined tracks observed

BL-99-29

SER-14

no confined tracks observed

BL-99-23**SER-15**

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	16.49	4	2.15	0.78	44.04

Mean Dpar = 2.15
 Mean Dper = 0.78
 Mean length (um) = 16.49
 Std. Dev. (um) = n.a.
 Skewness = n.a.
 Kurtosis = n.a.

BL-99-6**SER-16**

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	12.36	4	1.62	0.58	48.73
2	13.12	4	1.62	0.58	55.96
3	12.92	4	2.18	0.82	51.35
4	12.63	4	2.18	0.82	24.73
5	14.01	4	2.18	0.82	61.41
6	13.42	4	2.18	0.82	13.66
7	12.52	4	2.18	0.82	57.21
8	15.01	4	2.18	0.82	35.38
9	15.53	4	2.18	0.82	24.72
10	14.19	4	2.18	0.82	24.33
11	13.41	4	2.18	0.82	81.08
12	15.12	4	2.11	0.79	71.79
13	14.34	4	2.11	0.79	46.12
14	13.58	4	2.11	0.79	32.47
15	14.84	4	2.11	0.79	61.61
16	14.38	4	2.11	0.79	79.44
17	15.15	4	1.79	0.64	56.74
18	13.46	4	1.90	0.61	44.90
19	12.91	4	2.21	0.59	43.69
20	14.06	4	2.10	0.68	67.51
21	13.98	4	2.10	0.68	72.48
22	15.22	4	2.16	1.00	74.37
23	11.40	4	2.16	1.00	44.51
24	14.82	4	1.88	0.68	49.24
25	9.88	4	1.81	0.72	25.51
26	16.54	4	2.41	1.03	65.69
27	13.95	4	2.41	1.03	35.88
28	12.73	4	2.08	0.69	46.81
29	12.54	4	2.08	0.69	59.69
30	14.01	4	2.08	0.69	76.38
31	13.20	4	2.08	0.69	1.10
32	8.56	4	2.08	0.69	47.64
33	10.44	4	2.08	0.69	52.10
34	10.42	4	2.08	0.69	46.96
35	11.49	4	2.08	0.69	0.00
36	10.61	4	2.08	0.69	0.00
37	14.31	4	2.32	0.74	77.46
38	13.09	4	2.32	0.74	67.77
39	14.97	4	2.32	0.74	76.46
40	14.02	4	2.32	0.74	73.49
41	13.87	4	2.32	0.74	13.89
42	14.58	4	2.32	0.74	2.89
43	12.86	4	2.32	0.74	74.95
44	12.35	4	2.32	0.74	47.55
45	12.41	4	2.32	0.74	80.65
46	16.25	4	2.24	0.65	63.71
47	12.90	4	2.24	0.65	66.72
48	14.30	4	2.08	0.61	63.73
49	10.54	4	1.34	0.67	50.62

Mean Dpar = 2.12
 Mean Dper = 0.75
 Mean length (um) = 13.33 +/- 0.24
 Std. Dev. (um) = 1.66
 Skewness = -0.65
 Kurtosis = 0.24

BL-99-31**SER-19**

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	13.21	4	1.87	0.62	79.33
2	10.18	4	1.37	0.58	65.02
3	11.54	4	1.37	0.58	46.44

Mean Dpar = 1.54
Mean Dper = 0.59
Mean length (um) = 11.64 +/- 1.07
Std. Dev. (um) = 1.52
Skewness = 0.07
Kurtosis = -2.33

BL-99-18**SER-20**

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	14.69	4	1.95	0.88	62.05
2	14.19	4	1.95	0.88	31.34
3	14.51	4	1.95	0.88	34.78
4	14.20	4	1.95	0.88	21.56
5	14.33	4	1.95	0.88	87.27
6	14.79	4	1.95	0.88	16.12
7	16.02	4	1.95	0.88	88.90
8	16.35	4	1.95	0.88	31.52
9	12.26	4	1.95	0.88	43.71
10	12.23	4	1.95	0.88	76.00
11	14.17	4	1.95	0.88	54.78
12	14.55	4	1.95	0.88	84.71
13	14.04	4	1.95	0.88	82.40
14	14.65	4	1.95	0.88	12.40
15	12.26	4	1.95	0.88	65.73
16	14.11	4	1.95	0.88	68.05
17	14.65	4	1.95	0.88	66.27
18	14.89	4	1.95	0.88	35.94
19	13.24	4	1.95	0.88	44.03
20	12.38	4	1.95	0.88	70.25
21	15.50	4	1.95	0.88	82.74
22	14.33	4	1.95	0.88	35.21
23	12.94	4	1.95	0.88	78.86
24	14.88	4	1.95	0.88	52.99
25	15.41	4	2.17	0.96	63.34
26	13.48	4	2.17	0.96	85.35
27	12.16	4	2.17	0.96	57.63
28	14.24	4	2.17	0.96	35.53
29	14.31	4	2.17	0.96	64.25
30	15.96	4	2.17	0.96	85.86
31	13.66	4	2.17	0.96	59.74
32	13.66	4	2.17	0.96	89.27
33	14.91	4	2.17	0.96	94.17
34	14.14	4	2.17	0.96	61.31
35	16.88	4	2.17	0.96	48.92
36	13.64	4	2.17	0.96	42.50
37	14.73	4	2.17	0.96	39.58
38	13.90	4	2.17	0.96	48.62
39	15.41	4	2.17	0.96	56.72
40	13.28	4	2.17	0.96	49.29
41	15.50	4	2.17	0.96	63.76
42	11.93	4	2.17	0.96	85.48

Mean Dpar = 2.04
Mean Dper = 0.91
Mean length (um) = 14.22 +/- 0.18
Std. Dev. (um) = 1.17
Skewness = -0.10
Kurtosis = -0.39

FC-01

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	14.72	4	2.08	0.58	42.52
2	14.49	4	2.08	0.58	81.41
3	14.80	4	2.08	0.58	56.17
4	15.47	4	2.08	0.58	11.58
5	16.37	4	2.08	0.58	84.18
6	14.76	4	2.08	0.58	23.86
7	15.28	4	2.04	0.85	43.73
8	14.89	4	2.04	0.85	63.31
9	17.25	4	2.04	0.85	30.43
10	14.37	4	2.04	0.85	60.18
11	14.39	4	2.14	0.82	29.03
12	13.98	4	2.14	0.82	23.37
13	14.52	4	2.34	0.90	28.65
14	14.62	4	2.10	0.86	42.26
15	15.30	4	2.10	0.86	45.73
16	15.32	4	2.41	0.58	73.57
17	15.31	4	2.41	0.58	47.62
18	14.58	4	2.41	0.58	66.74
19	14.45	4	1.95	0.79	66.52
20	16.05	4	1.95	0.79	17.88
21	15.01	4	2.34	0.54	84.03
22	15.00	4	2.34	0.54	27.87
23	12.59	4	2.34	0.54	62.56
24	15.97	4	2.30	0.65	38.41
25	13.68	4	2.30	0.65	59.00
26	15.23	4	2.18	0.83	50.20
27	11.76	4	2.45	0.57	71.08
28	15.60	4	2.45	0.57	72.71
29	16.56	4	1.99	0.77	52.80
30	15.80	4	1.77	0.74	77.56
31	14.26	4	1.77	0.74	69.90
32	15.08	4	1.77	0.74	61.52
33	13.60	4	1.77	0.74	57.55
34	15.66	4	1.79	0.57	55.87
35	15.92	4	1.79	0.57	85.07
36	15.76	4	1.79	0.57	3.44
37	15.39	4	1.94	0.62	82.32
38	15.39	4	2.15	0.57	75.94
39	13.43	4	2.15	0.57	24.65
40	16.31	4	2.15	0.57	37.64
41	15.80	4	2.26	0.80	43.86
42	14.65	4	2.26	0.80	84.49
43	15.25	4	2.26	0.80	42.34
44	16.17	4	2.16	0.83	40.68
45	14.41	4	2.16	0.83	47.04
46	16.21	4	2.21	0.70	59.32
47	15.12	4	2.21	0.70	68.22
48	14.99	4	2.08	0.74	85.81
49	16.37	4	1.98	0.73	65.02
50	12.65	4	1.76	0.44	81.08
51	13.68	4	1.76	0.44	28.76
52	14.95	4	1.98	0.71	65.97
53	14.90	4	1.98	0.71	14.13
54	14.86	4	1.98	0.71	82.82

55	15.09	4	1.98	0.71	50.66
56	13.09	4	1.98	0.71	48.11
57	12.72	4	1.98	0.71	77.65
58	14.84	4	2.16	0.87	89.25
59	14.38	4	2.04	0.83	10.51
60	14.74	4	2.00	0.50	85.86
61	12.54	4	2.00	0.50	28.47
62	16.49	4	2.00	0.50	49.93
63	14.46	4	2.11	0.62	66.66
64	13.78	4	2.11	0.62	24.99
65	15.08	4	2.08	0.60	81.09
66	16.40	4	2.08	0.60	45.30
67	14.30	4	1.87	0.73	21.15
68	16.91	4	1.87	0.73	21.59
69	12.57	4	1.87	0.73	60.96
70	14.72	4	2.06	0.94	20.03
71	13.75	4	2.06	0.94	76.27
72	15.85	4	2.39	0.62	85.69
73	15.66	4	2.39	0.62	40.69
74	12.14	4	2.39	0.62	87.31
75	14.18	4	2.15	0.56	76.17
76	15.56	4	2.15	0.56	67.26
77	15.84	4	1.91	0.83	56.91
78	15.28	4	2.14	0.75	11.81
79	14.23	4	1.82	0.68	76.54
80	15.43	4	1.82	0.68	43.43
81	15.08	4	1.82	0.68	33.12
82	15.66	4	1.34	0.43	19.53
83	14.40	4	2.35	0.67	72.67
84	14.40	4	2.35	0.67	44.11
85	13.09	4	2.35	0.67	57.81
86	13.72	4	2.24	0.80	29.94
87	14.54	4	2.24	0.80	77.50
88	16.56	4	2.23	0.72	55.18
89	12.99	4	2.23	0.72	24.40
90	14.90	4	2.20	0.85	60.47
91	10.81	4	2.20	0.85	53.53
92	12.30	4	2.20	0.85	71.42
93	16.48	4	2.05	0.59	76.51
94	14.13	4	2.05	0.59	71.21
95	15.27	4	1.91	0.75	57.12
96	13.55	4	1.91	0.75	32.45
97	15.01	4	1.91	0.75	2.11
98	12.23	4	1.91	0.75	32.66
99	13.14	4	2.12	0.51	45.31
100	15.20	4	2.12	0.51	25.41
101	14.25	4	2.12	0.51	52.17
102	14.78	4	2.12	0.51	85.47
103	16.13	4	2.12	0.51	51.27
104	13.49	4	2.12	0.51	25.17

Mean Dpar = 2.08
 Mean Dper = 0.68
 Mean length (um) = 14.72+/- 0.12
 Std. Dev. (um) = 1.21
 Skewness = -0.62
 Kurtosis = 0.28

FC-01

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	14.31	4	2.54	1.08	72.23
2	14.99	4	2.54	1.08	46.91
3	15.45	4	2.54	1.08	81.57
4	14.00	4	2.29	0.88	89.95
5	14.98	4	2.29	0.88	0.03
6	14.24	4	2.55	1.02	66.26
7	15.12	4	2.55	1.02	18.82
8	17.01	4	2.55	1.02	29.29
9	14.38	4	2.55	1.02	81.87
10	15.89	4	2.55	1.02	69.67
11	15.68	4	2.55	1.02	68.98
12	15.11	4	2.48	1.02	89.04
13	14.85	4	2.48	1.02	82.73
14	14.60	4	2.48	1.02	82.57
15	15.17	4	2.48	1.02	86.26
16	15.58	4	2.48	1.02	77.96
17	14.14	4	2.48	1.02	84.22
18	13.89	4	2.48	1.02	54.74
19	14.31	4	2.62	0.99	43.28
20	14.40	4	2.53	1.11	67.21
21	12.99	4	2.53	1.11	37.07
22	12.25	4	2.53	1.11	83.61
23	16.88	4	2.53	1.11	29.03
24	14.27	4	2.53	1.11	84.86
25	14.45	4	2.53	1.11	63.26
26	13.59	4	2.53	1.11	82.84
27	14.37	4	2.53	1.11	66.71
28	15.60	4	2.28	0.83	52.54
29	14.37	4	2.28	0.83	62.64
30	17.01	4	2.28	0.83	75.11
31	15.96	4	2.28	0.83	38.19
32	11.84	4	2.28	0.83	75.67
33	13.76	4	2.28	0.83	60.96
34	16.39	4	2.51	0.77	48.60
35	14.83	4	2.51	0.77	46.60
36	14.02	4	2.34	1.04	23.31
37	15.89	4	2.34	1.04	52.31
38	14.75	4	2.25	1.21	28.79
39	15.66	4	2.25	1.21	74.83
40	15.99	4	2.37	1.12	88.61
41	15.61	4	2.37	1.12	43.85
42	14.66	4	2.37	1.12	47.72
43	15.60	4	2.37	1.12	21.22
44	15.58	4	2.37	1.12	43.01
45	15.25	4	2.56	1.14	88.67
46	15.93	4	2.56	1.14	32.61
47	14.46	4	2.56	1.14	57.84
48	16.67	4	2.60	0.93	22.11
49	15.84	4	2.60	0.93	53.02
50	16.64	4	2.60	0.93	58.14

51	15.56	4	2.42	1.09	85.25
52	14.34	4	2.42	1.09	63.16
53	14.98	4	2.42	1.09	75.99
54	14.08	4	2.42	1.09	89.72
55	16.24	4	2.68	0.94	27.91
56	15.41	4	2.68	0.94	18.45
57	14.75	4	2.68	0.94	85.29
58	13.83	4	2.68	0.94	21.66
59	16.38	4	2.36	1.12	83.84
60	16.51	4	2.36	1.12	72.58
61	14.93	4	2.50	1.11	83.34
62	14.34	4	2.50	1.11	76.65
63	15.23	4	2.50	1.11	78.60
64	15.41	4	2.50	1.11	36.34
65	14.67	4	2.50	1.11	3.06
66	14.74	4	2.50	1.11	81.46
67	13.20	4	2.50	1.11	82.66
68	14.84	4	2.50	1.11	78.47
69	15.99	4	2.52	0.90	79.88
70	13.03	4	2.52	0.90	87.43
71	14.56	4	2.52	0.90	56.21
72	15.76	4	2.52	0.90	58.46
73	16.92	4	2.61	1.11	76.81
74	15.72	4	2.61	1.11	17.16
75	15.77	4	2.61	1.11	66.30
76	15.66	4	2.61	1.11	87.21
77	14.73	4	2.61	1.11	33.79
78	14.66	4	2.18	0.83	74.69
79	16.70	4	2.18	0.83	43.94
80	14.34	4	2.18	0.83	78.89
81	14.33	4	2.18	0.83	57.00
82	15.15	4	2.49	1.15	83.00
83	14.10	4	2.49	1.15	87.16
84	15.43	4	2.49	1.15	19.29
85	14.97	4	2.41	0.98	15.13
86	15.23	4	2.41	0.98	62.82
87	16.43	4	2.41	0.98	57.64
88	16.38	4	2.40	1.12	14.07
89	16.53	4	2.40	1.12	55.00
90	16.49	4	2.40	1.12	62.79
91	14.90	4	2.40	1.12	73.48
92	15.73	4	2.45	1.00	69.28
93	15.50	4	2.45	1.00	58.51
94	16.46	4	2.45	1.00	88.94
95	14.50	4	2.45	1.00	89.24
96	14.28	4	2.45	1.00	28.32
97	16.66	4	2.10	0.85	25.99
98	15.40	4	2.10	0.85	80.89
99	15.40	4	2.57	1.10	79.26
100	16.28	4	2.57	1.10	40.87
101	16.25	4	2.57	1.10	86.27
102	16.31	4	2.57	1.10	66.87
103	14.79	4	2.57	1.10	56.29

Mean Dpar = 2.46

Mean Dper = 1.03

Mean length (um) = 15.15+/- 0.10

Std. Dev. (um) = 1.03
 Skewness = -0.42
 Kurtosis = 0.24

BL-00-21
270-02

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	15.17	4	1.07	0.60	48.84
2	13.04	4	1.07	0.60	52.40
3	11.82	4	1.07	0.60	89.14
4	10.41	4	1.07	0.60	34.41
5	12.39	4	1.49	0.48	9.56
6	12.67	4	1.65	0.53	35.73
7	11.18	4	1.65	0.53	62.28
8	12.09	4	1.76	0.64	33.94
9	11.62	4	1.93	0.59	71.94
10	13.90	4	1.93	0.59	79.94
11	14.67	4	1.93	0.59	79.42
12	12.81	4	1.93	0.59	55.97
13	12.68	4	1.55	0.44	34.45

Mean Dpar = 1.55
 Mean Dper = 0.57
 Mean length (um) = 12.65 +/- 0.39
 Std. Dev. (um) = 1.34
 Skewness = 0.32
 Kurtosis = -0.82

BL-00-25
270-04

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	12.23	4	1.76	0.63	30.56
2	15.21	4	1.39	0.62	22.62
3	11.20	4	1.39	0.62	3.32
4	11.37	4	1.40	0.57	49.32
5	2.02	4	1.40	0.57	17.48
6	2.03	4	1.40	0.57	26.71
7	1.77	4	1.40	0.57	19.63
8	1.82	4	1.40	0.57	36.29
9	14.06	4	1.40	0.57	48.50
10	10.04	4	1.40	0.57	0.92
11	10.57	4	1.83	0.68	52.27
12	16.04	4	1.61	0.60	29.02
13	14.25	4	1.75	0.64	49.71
14	14.43	4	1.76	0.56	70.28
15	15.15	4	1.84	0.62	71.66
16	13.33	4	1.80	0.73	66.95
17	15.60	4	1.55	0.71	66.36
18	13.95	4	1.33	0.66	67.64
19	14.65	4	1.53	0.68	33.48

20	13.99	4	1.64	0.67	57.30
21	14.76	4	1.98	0.76	52.42
22	12.91	4	1.37	0.67	52.59
23	13.71	4	1.36	0.63	62.39
24	17.07	4	1.23	0.71	68.91
25	12.46	4	1.37	0.53	61.72
26	12.97	4	1.79	0.60	80.95
27	12.05	4	1.40	0.53	75.88
28	12.43	4	1.99	0.58	55.28
29	14.49	4	1.45	0.54	58.43
30	13.36	4	1.77	0.46	78.59
31	12.85	4	1.55	0.59	77.02
32	14.38	4	1.58	0.64	58.02
33	12.60	4	1.58	0.61	59.76

Mean Dpar = 1.56
 Mean Dper = 0.61
 Mean length (um) = 12.11+/- 0.73
 Std. Dev. (um) = 4.14
 Skewness = -1.65
 Kurtosis = 1.63

BL-00-31
270-05

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	15.34	4	1.48	0.53	55.33
2	10.99	4	1.48	0.53	40.48
3	12.85	4	1.36	0.55	86.13
4	11.51	4	1.43	0.53	86.11
5	14.22	4	1.44	0.61	82.68
6	12.16	4	1.59	0.59	48.09
7	12.64	4	1.35	0.61	36.97
8	11.58	4	1.46	0.53	10.96
9	13.25	4	1.19	0.52	75.37
10	10.27	4	1.19	0.52	72.51
11	12.79	4	1.19	0.52	15.07
12	9.70	4	1.19	0.52	49.01
13	13.03	4	1.77	0.49	35.98
14	15.23	4	2.08	0.53	78.23
15	11.26	4	2.08	0.53	45.79
16	11.86	4	2.08	0.53	65.94
17	15.35	4	2.08	0.53	18.71
18	14.28	4	1.53	0.55	52.09
19	13.12	4	1.83	0.63	49.50
20	13.71	4	1.88	0.61	53.17
21	14.33	4	1.70	0.56	33.68
22	12.77	4	1.80	0.47	62.85
23	12.45	4	1.64	0.58	70.80
24	12.00	4	1.63	0.54	50.85
25	13.66	4	1.55	0.61	60.42
26	14.19	4	2.06	0.75	62.11
27	9.94	4	1.85	0.59	88.28
28	14.60	4	1.83	0.45	25.38

29	14.30	4	1.68	0.43	85.25
30	12.87	4	1.71	0.53	36.46
31	11.69	4	1.89	0.62	82.39
32	13.24	4	1.96	0.70	75.45
33	12.64	4	1.96	0.70	29.24
34	14.96	4	1.70	0.61	57.73
35	6.82	4	1.61	0.47	42.46
36	13.24	4	1.59	0.79	85.44
37	13.32	4	1.59	0.79	5.43
38	15.79	4	2.13	0.84	26.35
39	12.25	4	1.97	0.81	66.45

Mean Dpar = 1.68
 Mean Dper = 0.58
 Mean length (um) = 12.83+/- 0.29
 Std. Dev. (um) = 1.79
 Skewness = -0.91
 Kurtosis = 1.47

BL-00-32**270-06**

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	12.81	4	2.13	1.12	33.44
2	15.73	4	2.52	1.05	11.24
3	14.88	4	2.52	1.05	58.87
4	14.53	4	1.95	0.94	19.44
5	14.74	4	2.37	0.89	42.58
6	13.41	4	1.55	0.96	23.21
7	15.93	4	2.00	0.82	76.65
8	14.18	4	2.00	0.82	18.21
9	15.77	4	2.06	0.94	45.88
10	14.49	4	2.06	0.94	53.39
11	12.56	4	1.75	1.02	44.59
12	13.64	4	2.03	0.89	10.96
13	14.08	4	2.03	0.89	34.33
14	14.70	4	1.93	1.00	17.83
15	14.71	4	1.93	1.00	58.75
16	15.14	4	1.93	1.00	54.06
17	15.60	4	1.93	1.00	42.79
18	4.66	4	1.93	1.00	14.05
19	3.59	4	1.93	1.00	56.99
20	9.04	4	1.93	1.00	11.76
21	9.24	4	1.93	1.00	25.93
22	30.26	4	1.93	1.00	60.32
23	14.36	4	2.40	0.94	73.73
24	16.09	4	2.40	0.94	86.51
25	14.56	4	2.39	0.99	69.53
26	13.74	4	2.39	0.99	38.25
27	13.93	4	2.39	0.99	50.22
28	14.67	4	1.59	0.83	59.35
29	13.28	4	1.59	0.83	73.81
30	14.73	4	1.59	0.83	62.78
31	14.28	4	1.59	0.83	70.11

32	12.76	4	1.59	0.83	40.88
33	12.90	4	1.59	0.83	72.43
34	14.07	4	1.59	0.83	61.10
35	13.13	4	1.83	0.77	78.24
36	13.92	4	1.83	0.77	58.50
37	14.00	4	1.83	0.77	79.72
38	12.29	4	1.83	0.77	85.14
39	13.73	4	1.83	0.77	23.03
40	8.32	4	1.83	0.77	47.65
41	15.05	4	1.87	0.83	87.17
42	16.31	4	1.67	0.86	4.78
43	14.50	4	1.67	0.86	51.15
44	11.60	4	1.69	0.85	88.01
45	14.59	4	2.11	0.85	20.75
46	13.80	4	2.11	0.85	62.18
47	12.26	4	2.18	0.84	43.22
48	13.64	4	2.18	0.84	58.03
49	12.28	4	2.18	0.84	69.83
50	11.99	4	2.18	0.84	65.77
51	13.99	4	2.18	0.84	67.39
52	13.95	4	2.22	0.93	72.42
53	11.06	4	2.22	0.93	46.56
54	13.70	4	2.22	0.93	58.80
55	13.24	4	1.77	0.86	71.51
56	14.25	4	1.94	0.97	54.78
57	14.35	4	1.85	0.71	27.51
58	14.93	4	1.85	0.71	42.82
59	12.68	4	2.03	0.83	44.63
60	14.33	4	1.88	0.81	74.85
61	14.30	4	1.65	0.78	76.27
62	14.60	4	2.30	0.82	57.51
63	15.83	4	2.30	0.82	44.21
64	13.87	4	2.01	0.85	80.52
65	15.95	4	2.01	0.85	62.42
66	15.19	4	2.01	0.85	63.20
67	14.43	4	2.01	0.85	87.01
68	11.14	4	2.48	0.99	32.77
69	12.45	4	2.48	0.99	70.15
70	14.56	4	2.39	0.83	78.17
71	15.71	4	2.39	0.83	76.08
72	15.40	4	2.39	0.83	21.04
73	17.37	4	2.39	0.83	58.63
74	13.44	4	2.39	0.83	67.58
75	16.21	4	2.39	0.83	14.43
76	13.13	4	2.39	0.83	63.23

Mean Dpar = 2.03
 Mean Dper = 0.88
 Mean length (um) = 13.88+/- 0.34
 Std. Dev. (um) = 2.94
 Skewness = 1.14
 Kurtosis = 13.32

BL-00-38

270-07

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	12.73	4	1.60	0.56	50.96
2	8.61	4	1.41	0.57	89.22
3	12.71	4	1.47	0.56	78.75
4	9.28	4	1.47	0.56	66.55
5	12.88	4	1.51	0.61	35.85
6	12.21	4	1.71	0.68	40.00
7	11.78	4	1.71	0.68	47.53
8	11.47	4	1.81	0.68	41.61
9	11.09	4	1.81	0.68	43.68
10	11.66	4	1.81	0.68	57.84
11	10.91	4	1.81	0.68	50.11
12	13.88	4	1.81	0.68	74.06
13	10.64	4	1.81	0.68	47.18
14	11.10	4	1.81	0.68	44.51
15	10.40	4	1.81	0.68	44.09
16	13.65	4	1.81	0.68	75.71

Mean Dpar = 1.70
 Mean Dper = 0.65
 Mean length (um) = 11.56 +/- 0.37
 Std. Dev. (um) = 1.45
 Skewness = -0.27
 Kurtosis = -0.74

BL-00-44**270-08**

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	13.48	4	1.77	0.74	21.97
2	14.20	4	1.77	0.74	29.84
3	14.86	4	1.77	0.74	69.05
4	10.25	4	1.77	0.74	6.91
5	14.22	4	1.77	0.74	62.23
6	9.98	4	1.77	0.74	65.42
7	16.00	4	1.83	0.71	29.71
8	13.94	4	1.83	0.71	89.88
9	13.91	4	2.06	0.76	60.30
10	15.26	4	1.93	0.84	52.78
11	15.67	4	1.74	0.76	72.72
12	14.86	4	1.70	0.76	69.08
13	16.15	4	1.96	0.69	89.09
14	15.61	4	1.96	0.69	89.62
15	13.14	4	1.96	0.69	53.02
16	13.05	4	1.96	0.69	32.31
17	12.77	4	1.96	0.69	56.25
18	14.50	4	2.63	0.86	50.12
19	13.54	4	1.73	0.82	72.52
20	13.99	4	2.46	0.64	49.04
21	11.29	4	1.84	0.61	68.07
22	15.18	4	1.84	0.61	55.83
23	16.27	4	1.73	0.80	86.28

24 14.90 4 2.13 0.98 39.66

Mean Dpar = 1.91
 Mean Dper = 0.74
 Mean length (um) = 14.04+/- 0.35
 Std. Dev. (um) = 1.69
 Skewness = -0.90
 Kurtosis = 0.14

BL-00-48

270-09

no confined tracks observed

BL-00-72

270-15

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	14.69	4	2.02	0.77	43.35
2	12.67	4	1.68	0.74	79.53
3	15.49	4	1.88	0.76	26.45
4	15.04	4	1.28	0.85	29.44
5	14.39	4	1.80	0.75	6.28
6	14.50	4	1.83	0.73	68.92
7	15.40	4	1.83	0.73	86.10
8	12.85	4	1.83	0.73	49.63
9	13.29	4	1.98	0.80	69.09
10	15.27	4	1.98	0.80	51.85
11	14.66	4	1.95	0.82	76.36
12	12.23	4	1.97	0.72	89.37
13	14.54	4	2.28	0.80	87.14
14	15.01	4	2.28	0.80	47.03
15	14.55	4	2.28	0.80	77.76
16	13.55	4	1.88	0.92	87.21
17	17.01	4	1.92	0.59	28.92
18	12.90	4	1.93	0.74	19.94
19	13.14	4	1.71	0.82	77.81
20	11.41	4	2.10	0.66	60.40

Mean Dpar = 1.92
 Mean Dper = 0.77
 Mean length (um) = 14.13+/- 0.31
 Std. Dev. (um) = 1.34
 Skewness = -0.08
 Kurtosis = -0.57

BL-00-92

270-23

Track Number	Length (microns)	Etch Figures	Dpar (microns)	Dpar (microns)	Angle to c-axis (degrees)
1	12.17	4	2.41	0.89	83.79
2	12.79	4	2.41	0.89	84.42

3	14.44	4	2.41	0.89	68.09
4	15.15	4	2.41	0.89	31.53
5	13.87	4	1.84	0.78	49.39
6	15.21	4	1.95	0.86	68.21
7	15.41	4	1.95	0.86	29.05
8	16.28	4	2.01	0.84	81.18
9	13.46	4	1.18	0.65	43.44
10	14.52	4	1.84	0.97	74.48
11	13.53	4	1.84	0.97	30.21
12	12.83	4	1.84	0.97	77.96
13	15.87	4	1.84	0.97	86.94
14	13.69	4	1.84	0.97	1.50
15	14.61	4	1.91	0.75	39.49
16	14.90	4	2.03	0.77	79.78
17	12.90	4	2.03	0.77	16.54
18	13.12	4	2.03	0.77	54.37
19	17.06	4	1.79	0.77	44.61
20	14.03	4	1.79	0.77	82.53
21	13.71	4	1.79	0.77	17.47
22	11.51	4	1.95	0.82	46.05
23	10.98	4	1.95	0.82	73.93
24	15.42	4	2.28	1.08	41.03
25	13.81	4	2.19	0.95	68.61
26	14.28	4	2.19	0.95	74.63
27	14.52	4	2.19	0.95	69.21
28	14.75	4	1.78	0.75	86.98
29	15.23	4	2.08	0.67	77.63
30	14.63	4	2.38	0.96	17.87
31	15.45	4	2.38	0.96	74.44
32	15.01	4	2.23	0.85	19.20
33	16.35	4	2.20	0.79	25.45
34	11.29	4	2.20	0.79	79.27
35	12.67	4	2.20	0.79	39.85
36	15.12	4	2.19	0.79	67.54
37	15.47	4	1.53	0.70	89.66
38	14.43	4	1.53	0.70	36.62
39	15.46	4	2.04	0.82	66.28
40	14.11	4	2.04	0.82	26.36
41	15.54	4	2.04	0.82	73.26
42	12.67	4	2.04	0.95	57.60
43	15.06	4	2.04	0.95	62.12
44	14.09	4	2.04	0.95	29.25
45	14.69	4	2.04	0.95	46.81

Mean Dpar = 2.02
 Mean Dper = 0.85
 Mean length (um) = 14.27+/- 0.20
 Std. Dev. (um) = 1.34
 Skewness = -0.50
 Kurtosis = -0.15

Apatite Fission-Track Age Data

DR-01 (a) (first)

Grain Number	Natural Tracks	Induced Tracks	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)	Etch Figures	Dpar (microns)	Dper (microns)
1	21	119	200	37.21	9.33	12	4	1.74	0.71
2	3	31	60	20.43	12.47	10	4	1.94	0.65
3	18	80	136	47.40	12.97	12	4	1.99	0.65
4	6	76	100	16.67	7.20	15	4	1.78	0.64
5	2	16	30	26.38	19.90	10	4	2.18	0.99
6	6	50	100	25.33	11.14	10	4	2.00	0.78
7	9	19	60	99.39	41.05	6	4	2.08	0.60
8	3	25	36	25.33	15.61	14	4	1.54	0.51
9	15	67	100	47.17	14.03	13	4	1.99	0.70
10	8	89	100	19.20	7.26	17	4	1.93	0.58
11	8	41	100	41.13	16.26	8	4	1.72	0.70

Mean Dpar = 1.90
 Mean Dper = 0.68
 Chi-squared = 18.115
 Chi-squared prob= 0.053
 Pooled Age (Ma) = 34.1 +/- 4.6
 Mean Age (Ma) = 36.9 +/- 8.1
 W.Mean Age (Ma) = 27.5 +/- 4.0
 Median Age (Ma) = 26.4- 1.6+ 8.3

DR-01 (b) (second)

Grain Number	Natural Tracks	Induced Tracks	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)	Etch Figures	Dpar (microns)	Dper (microns)
1	4	29	60	29.15	15.73	9	4	1.86	0.63
2	5	42	54	25.17	12.09	15	4	2.14	0.72
3	6	39	80	32.50	14.50	10	4	2.16	0.77
4	11	60	100	38.72	13.10	12	4	1.90	0.83
5	4	26	50	32.50	17.66	10	4	1.74	0.54
6	4	49	80	17.27	9.09	12	4	2.16	0.53
7	4	51	100	16.59	8.72	10	4	1.82	0.63
8	6	59	100	21.50	9.38	12	4	1.34	1.12
9	10	47	100	44.91	15.07	9	4	1.80	0.67
10	15	102	200	31.07	8.97	10	4	1.90	0.70
11	12	121	200	20.97	6.58	12	4	1.86	0.73

Mean Dpar = 1.88
 Mean Dper = 0.72
 Chi-squared = 6.576
 Chi-squared prob= 0.765
 Pooled Age (Ma) = 27.4 +/- 3.9
 Mean Age (Ma) = 28.2 +/- 3.7
 W.Mean Age (Ma) = 24.8 +/- 3.7
 Median Age (Ma) = 29.1- 3.7+ 1.6

BL-99-19a

SER-01

Grain Number	Natural Tracks	Induced Tracks	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)	Etch Figures	Dpar (microns)	Dper (microns)
1	17	136	32	26.47	7.15	83	4	1.98	0.68
2	1	33	45	6.43	6.54	14	4	1.39	0.53
3	2	67	40	6.33	4.57	33	4	2.28	0.74
4	5	48	36	22.06	10.53	26	4	1.91	0.57
5	2	14	30	30.24	22.99	9	4	1.59	0.61
6	4	67	45	12.65	6.60	29	4	2.27	0.97
7	2	19	36	22.29	16.68	10	4	1.61	0.77
8	5	82	36	12.92	6.05	44	4	1.67	0.63
9	7	63	64	23.53	9.57	19	4	2.39	0.67
10	1	53	64	4.00	4.05	16	4	1.78	0.70
11	5	88	25	12.04	5.63	69	4	1.88	0.66
12	8	85	20	19.94	7.55	83	4	1.66	0.59

13	6	61	36	20.83	9.08	33	4	1.78	0.68
14	7	104	36	14.26	5.69	56	4	1.76	0.71
15	4	29	16	29.20	15.76	35	4	1.49	0.58
16	0	23	24	0.00	9.45	19	0	0.00	0.70
17	5	122	48	8.69	4.03	50	2	1.65	0.54
18	16	216	64	15.70	4.27	66	4	1.56	0.58
19	1	28	50	7.57	7.73	11	3	1.90	0.50
20	0	23	27	0.00	9.45	17	1	1.73	0.62
21	2	54	24	7.85	5.69	44	3	1.94	0.51
22	5	49	80	21.61	10.30	12	4	1.66	0.67
23	4	58	40	14.62	7.65	28	4	1.76	0.68
24	0	14	40	0.00	15.72	7	0	0.00	0.00
25	5	66	36	16.05	7.56	36	4	1.64	0.54
26	1	19	78	11.16	11.48	5	2	2.06	0.71
27	2	70	64	6.06	4.37	21	3	1.20	0.60
28	2	47	36	9.02	6.56	25	2	1.74	0.68
29	3	126	36	5.05	2.98	68	4	2.12	0.69
30	2	72	36	5.89	4.25	39	1	1.72	0.71
31	0	13	18	0.00	16.97	14	2	1.80	0.87
32	0	77	36	0.00	2.78	42	0	0.00	0.00

Mean Dpar = 1.79
 Mean Dper = 0.65
 Chi-squared = 40.093
 Chi-squared prob= 0.127
 Pooled Age (Ma) = 13.3+/- 1.6
 Mean Age (Ma) = 12.3+/- 1.9
 W.Mean Age (Ma) = 8.6+/- 1.2
 Median Age (Ma) = 11.6- 1.5- 2.3

BL-99-2

SER-02

Grain Number	Natural Tracks	Induced Tracks	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)	Etch Figures	Dpar (microns)	Dper (microns)
1	1	13	16	16.33	17.00	16	1	2.54	0.85
2	5	172	100	6.17	2.85	33	4	2.06	0.76
3	5	42	40	25.25	12.13	20	4	1.97	0.75
4	1	8	80	26.51	28.20	2	1	1.76	0.56
5	1	16	80	13.27	13.72	4	1	1.61	0.91
6	2	21	30	20.21	15.05	14	4	1.54	0.60
7	0	41	16	0.00	5.26	50	3	1.94	0.84
8	2	38	25	11.18	9.16	30	4	1.33	0.68
9	6	30	30	42.36	19.27	19	4	1.89	0.69
10	6	15	16	84.45	41.39	18	4	1.78	0.56
11	0	40	80	0.00	5.39	10	0	0.00	0.00
12	4	51	16	16.65	8.75	62	4	1.66	0.63
13	2	5	32	84.45	71.00	3	4	1.68	0.57
14	4	24	48	35.32	19.30	10	2	1.84	0.56
15	11	74	40	31.51	10.51	36	4	1.87	0.63
16	1	172	32	1.24	1.24	105	1	1.35	0.67
17	7	103	100	14.43	5.76	20	4	1.74	0.55
18	4	25	25	33.91	18.48	19	4	1.93	0.62
19	7	62	64	23.95	9.75	19	4	2.21	0.84
20	10	157	64	13.52	4.55	48	4	1.72	0.53
21	4	21	30	40.35	22.26	14	4	1.86	0.64
22	0	19	24	0.00	11.50	15	3	1.99	0.52
23	6	51	56	24.95	10.97	18	4	1.58	0.77
24	3	22	24	28.91	17.95	18	2	1.66	0.57
25	13	121	70	22.79	6.91	34	4	2.11	0.69
26	1	21	64	10.11	10.38	6	2	1.55	0.65
27	12	103	36	24.71	7.81	56	4	1.82	0.61
28	6	73	32	17.44	7.55	44	4	1.84	0.66
29	0	8	21	0.00	28.20	7	0	0.00	0.00
30	33	239	60	29.28	5.95	77	4	1.91	0.51
31	4	28	30	30.29	16.38	18	4	1.95	0.56
32	1	44	36	4.83	4.90	24	3	1.82	0.66
33	9	162	90	11.80	4.16	35	4	1.15	0.57
34	8	51	40	33.25	12.94	25	4	1.85	0.69
35	9	64	36	29.82	10.90	35	4	2.11	0.70
36	13	90	20	30.62	9.43	88	4	1.98	0.78
37	3	29	40	21.95	13.43	14	3	1.83	0.64
38	7	35	70	42.36	17.89	10	4	2.02	0.60

Mean Dpar = 1.81
 Mean Dper = 0.66
 Chi-squared = 80.252
 Chi-squared prob= 0.000
 Pooled Age (Ma) = 19.6+/- 2.1

Mean Age (Ma) = 23.8+/- 3.7
 W.Mean Age (Ma) = 7.3+/- 1.1
 Median Age (Ma) = 23.4- 2.8+ 1.8

BL-99-5**SER-03**

Grain Number	Natural Tracks	Induced Tracks	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)	Etch Figures	Dpar (microns)	Dper (microns)
1	3	16	24	39.79	25.25	13	2	1.33	0.60
2	5	19	36	55.77	28.41	10	4	1.36	0.93
3	1	62	36	3.43	3.47	33	2	2.15	0.73
4	6	35	60	36.39	16.36	11	4	1.75	0.54
5	1	72	36	2.96	2.99	39	1	2.79	0.75
6	7	101	80	14.74	5.89	25	4	1.71	0.66
7	2	125	30	3.40	2.44	81	3	1.81	0.68
8	1	31	36	6.86	7.00	17	0	0.00	0.00
9	2	44	40	9.67	7.04	21	2	1.94	0.61
10	0	16	36	0.00	13.74	9	0	0.00	0.00
11	4	27	16	31.46	17.05	33	4	2.10	0.66
12	8	98	36	17.35	6.54	53	4	2.06	0.62
13	5	61	36	17.42	8.23	33	4	1.61	0.71
14	4	53	16	16.05	8.42	54	4	1.89	0.72
15	3	33	36	19.32	11.76	18	3	2.08	0.63
16	2	10	16	42.43	33.05	12	3	2.16	0.71
17	2	46	16	9.25	6.72	56	3	2.03	0.64
18	1	12	16	17.71	18.50	15	1	1.21	0.67
19	3	53	36	12.04	7.21	29	4	1.64	0.59
20	5	67	36	15.87	7.47	36	4	2.00	0.65
21	12	118	24	21.61	6.79	95	4	1.77	0.61
22	6	93	80	13.72	5.89	23	4	1.82	0.67
23	0	14	40	0.00	15.77	7	0	0.00	0.00
24	3	34	60	18.75	11.40	11	2	1.61	0.53
25	5	135	40	7.88	3.65	66	3	1.30	0.53
26	0	8	16	0.00	28.25	10	0	0.00	0.00
27	3	68	56	9.38	5.59	24	4	1.94	0.71
28	24	215	64	23.72	5.47	65	4	1.85	0.59
29	0	71	48	0.00	3.03	29	0	0.00	0.00
30	7	41	9	36.24	15.12	88	4	1.95	0.73
31	1	17	16	12.51	12.91	21	2	1.78	0.44
32	0	5	16	0.00	46.61	6	2	2.76	0.78
33	4	51	36	16.67	8.77	28	4	1.71	0.62
34	5	35	36	30.34	14.72	19	4	1.75	0.70
35	0	8	16	0.00	28.25	10	0	0.00	0.00

Mean Dpar = 1.86
 Mean Dper = 0.66
 Chi-squared = 56.309
 Chi-squared prob= 0.009
 Pooled Age (Ma) = 15.2+/- 1.8
 Mean Age (Ma) = 16.1+/- 2.7
 W.Mean Age (Ma) = 8.3+/- 1.2
 Median Age (Ma) = 14.7- 2.4+ 1.5

BL-99-16**SER-04**

Grain Number	Natural Tracks	Induced Tracks	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)	Etch Figures	Dpar (microns)	Dper (microns)
1	2	43	50	9.91	7.21	17	2	1.76	0.53
2	5	163	130	6.54	3.02	24	4	2.00	0.60
3	6	127	100	10.07	4.29	25	4	1.95	0.69
4	5	31	36	34.30	16.77	17	4	2.11	0.63
5	0	4	10	0.00	59.51	8	1	1.90	0.64
6	2	14	20	30.39	23.11	14	2	1.03	0.67
7	1	18	36	11.83	12.20	10	1	0.92	0.90
8	2	4	30	105.73	91.98	3	2	2.20	0.73
9	10	90	36	23.65	8.12	48	4	1.76	0.71
10	29	154	24	40.03	9.75	124	4	2.93	0.78
11	5	41	70	25.95	12.48	11	4	1.98	0.64
12	1	93	30	2.29	2.31	20	1	1.49	0.61
13	8	27	36	62.87	25.93	15	4	2.04	0.62
14	3	58	56	11.02	6.59	20	4	1.56	0.57
15	5	34	50	31.28	15.20	13	4	1.66	0.67
16	4	11	24	77.07	45.45	9	3	1.61	0.66
17	11	81	80	28.89	9.59	20	4	1.82	0.70

Mean Dper = 0.69
 Chi-squared = n.a.
 Chi-squared prob = n.a.
 Pooled Age (Ma) = 95.6 +/- 15.4
 Mean Age (Ma) = n.a.
 W.Mean Age (Ma) = n.a.
 Median Age (Ma) = n.a.

BL-99-6**SER-16**

Grain Number	Natural Tracks	Induced Tracks	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)	Etch Figures	Dpar (microns)	Dper (microns)
1	7	55	16	27.43	11.24	66	4	2.68	0.85
2	0	22	36	0.00	10.06	12	0	0.00	0.00
3	4	44	50	19.61	10.37	17	4	2.13	0.32
4	3	104	64	6.23	3.68	31	3	2.17	0.65
5	46	272	45	36.43	6.54	116	4	2.20	0.66
6	39	313	60	26.86	5.07	100	4	2.24	0.78
7	11	55	32	43.06	14.66	33	4	1.95	0.64
8	11	52	25	45.53	15.57	40	4	1.65	0.73
9	2	32	18	13.49	9.89	34	3	1.61	0.47
10	5	19	18	56.60	28.83	20	4	1.69	0.60
11	1	55	90	3.93	3.98	12	1	1.92	0.63
12	7	26	50	57.90	25.11	10	4	1.68	0.55
13	0	5	25	0.00	47.30	4	0	0.00	0.00
14	4	3	15	281.77	216.46	4	4	1.57	0.51
15	1	24	25	9.99	9.21	18	4	1.49	0.56
16	4	13	16	66.13	38.20	16	4	1.71	0.78
17	0	12	30	0.00	18.77	8	1	2.32	0.75
18	3	50	70	12.95	7.77	14	3	2.40	0.82
19	0	36	40	0.00	6.10	17	0	0.00	0.00
20	34	230	30	31.95	6.42	147	4	2.35	0.77
21	15	42	30	76.69	23.92	27	4	1.93	0.77
22	6	35	30	36.93	16.60	22	4	1.52	0.70
23	1	17	50	12.69	13.10	7	1	1.46	0.59

Mean Dpar = 1.89
 Mean Dper = 0.69
 Chi-squared = 67.918
 Chi-squared prob = 0.000
 Pooled Age (Ma) = 29.0 +/- 3.2
 Mean Age (Ma) = 37.9 +/- 13.0
 W.Mean Age (Ma) = 16.0 +/- 2.1
 Median Age (Ma) = 26.9- 6.1- 5.5

BL-99-31**SER-19**

Grain Number	Natural Tracks	Induced Tracks	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)	Etch Figures	Dpar (microns)	Dper (microns)
1	14	18	30	166.24	60.81	11	4	1.28	0.87
2	16	50	60	68.92	20.60	16	4	1.71	0.67
3	3	33	25	19.65	11.96	25	4	1.93	0.71
4	12	46	36	56.24	18.81	24	4	1.65	0.63
5	14	105	64	28.80	9.53	31	4	1.79	0.65
6	24	214	48	24.24	5.59	95	4	1.79	0.79
7	11	69	40	34.43	11.53	33	4	1.94	0.69
8	0	46	9	0.00	4.77	98	1	1.99	0.64
9	2	42	16	10.30	7.50	50	3	1.92	0.74
10	3	26	9	24.93	15.34	55	2	1.51	0.70

Mean Dpar = 1.75
 Mean Dper = 0.71
 Chi-squared = 48.892
 Chi-squared prob = 0.000
 Pooled Age (Ma) = 32.9 +/- 4.5
 Mean Age (Ma) = 43.5 +/- 16.4
 W.Mean Age (Ma) = 17.4 +/- 3.0
 Median Age (Ma) = 26.9- 3.6- 14.5

BL-99-18**SER-20**

Grain	Natural	Induced	Quads	FT Age	1 sigma	Uranium	Etch	Dpar	Dper
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Number	Tracks	Tracks	(dmnls)	(Ma)	(Ma)	(ppm)	Figures	(microns)	(microns)
1	51	115	30	95.64	17.93	73	4	1.35	0.68
2	1	76	160	2.86	2.89	9	3	2.78	0.91
3	157	321	64	105.40	13.46	95	4	2.08	0.86
4	1	29	64	7.49	7.64	9	2	1.84	0.61
5	16	192	150	18.08	4.94	24	4	1.82	0.85

Mean Dpar = 2.09
 Mean Dper = 0.78
 Chi-squared = 84.680
 Chi-squared prob= 0.000
 Pooled Age (Ma) = 66.6+/- 7.5
 Mean Age (Ma) = 46.0+/- 25.6
 W.Mean Age (Ma) = 13.5+/- 2.5
 Median Age (Ma) = 18.1- 7.9+ 57.5

FC-01

no grain ages

FC-01

no grain ages

BL-00-21**270-02**

Grain Number	Natural Tracks	Induced Tracks	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)	Etch Figures	Dpar (microns)	Dper (microns)
Number	Tracks	Tracks	(dmnls)	(Ma)	(Ma)	(ppm)			
1	31	158	18	37.52	9.00	199	4	1.83	0.60
2	11	61	30	34.49	11.65	44	4	1.87	0.59
3	7	118	18	11.37	4.52	141	4	1.62	0.49
4	4	235	36	3.26	1.67	141	4	1.55	0.55
5	4	38	28	20.16	10.73	29	4	1.74	0.59
6	2	3	4	126.61	116.05	16	4	1.84	0.73
7	1	24	6	7.99	9.18	96	2	2.01	0.61

Mean Dpar = 1.74
 Mean Dper = 0.59
 Chi-squared = 41.693
 Chi-squared prob= 0.000
 Pooled Age (Ma) = 19.0+/- 2.9
 Mean Age (Ma) = 34.6+/- 17.8
 W.Mean Age (Ma) = 6.5+/- 1.6
 Median Age (Ma) = 20.2- 6.3+ 9.6

BL-00-23**270-03**

Grain Number	Natural Tracks	Induced Tracks	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)	Etch Figures	Dpar (microns)	Dper (microns)
Number	Tracks	Tracks	(dmnls)	(Ma)	(Ma)	(ppm)			
1	25	30	36	158.94	45.00	18	4	1.81	0.59
2	18	22	30	156.09	51.26	16	4	1.96	0.78
3	4	15	12	51.29	29.17	27	3	1.77	3.68
4	11	13	24	161.36	67.44	12	4	1.95	0.75
5	18	30	40	114.93	35.53	16	4	1.81	0.61
6	48	118	50	78.08	14.84	51	4	1.60	0.58
7	49	95	64	110.37	21.80	28	4	1.80	0.57

Mean Dpar = 1.81
 Mean Dper = 0.65
 Chi-squared = 10.087
 Chi-squared prob= 0.121
 Pooled Age (Ma) = 105.9+/- 13.3
 Mean Age (Ma) = 118.8+/- 20.3
 W.Mean Age (Ma) = 93.5+/- 12.2
 Median Age (Ma) = 114.8- 12.5+ 25.8

BL-00-25
270-04

Grain Number Number	Natural Tracks Tracks	Induced Tracks Tracks	Quads (dmnls) (dmnls)	FT Age (Ma) (Ma)	1 sigma (Ma) (Ma)	Uranium (ppm) (ppm)	Etch Figures	Dpar (microns)	Dper (microns)
1	5	27	12	35.83	17.70	48	4	1.94	0.66
2	2	13	9	29.78	22.76	31	2	1.87	0.57
3	1	11	25	17.62	18.46	9	1	2.06	0.71
4	8	61	28	25.40	9.78	46	4	1.87	0.53
5	4	40	9	19.37	10.29	95	4	2.47	0.58
6	1	7	9	27.66	29.66	17	1	1.64	0.62
7	7	12	20	112.21	54.17	13	4	1.74	0.50
8	6	60	16	19.37	8.45	80	4	1.99	0.69
9	0	8	25	0.00	25.76	7	0	0.00	0.00
10	1	9	18	21.52	22.76	11	2	2.01	0.70
11	1	27	9	7.18	7.34	64	2	2.25	0.64
12	2	25	28	15.50	11.47	19	4	1.93	0.78
13	3	15	16	38.69	24.68	20	3	1.62	0.60
14	6	98	25	11.87	5.09	84	4	1.73	0.56
15	4	31	36	24.99	13.44	18	4	1.51	0.61
16	3	6	9	96.30	69.56	16	4	1.41	0.68
17	1	15	28	12.92	13.39	11	2	2.13	0.66
18	1	17	18	11.40	11.77	20	2	1.71	0.71
19	2	32	56	12.12	8.89	12	4	1.81	0.65
20	8	58	50	26.71	10.31	25	4	2.03	0.76
21	7	38	16	35.65	14.95	51	4	2.01	0.70
22	8	11	6	139.60	65.88	39	4	1.55	0.60
23	0	10	16	0.00	20.38	13	0	0.00	0.00
24	5	19	64	50.86	25.91	6	4	2.14	0.68
25	6	39	32	29.78	13.29	26	4	1.52	0.61
26	3	31	16	19.75	11.44	41	2	1.81	0.65
27	46	281	36	31.69	5.68	166	4	2.06	0.69
28	3	65	50	8.95	5.34	29	4	1.61	0.62
29	4	16	21	48.33	27.31	16	4	1.80	0.71
30	21	262	70	15.53	3.75	80	4	1.79	0.53
31	1	31	30	6.26	6.38	22	2	1.83	0.66
32	10	50	50	38.69	13.78	21	4	2.33	0.66
33	0	8	20	0.00	25.76	9	0	0.00	0.00
34	6	27	40	42.98	19.72	14	4	1.91	0.71
35	6	51	27	22.79	10.01	40	4	1.51	0.64
36	6	48	36	24.21	10.67	28	4	1.77	0.68
37	3	77	20	7.56	4.49	92	4	1.60	0.73
38	9	68	30	25.63	9.34	48	4	1.64	0.75
39	2	22	32	17.62	13.09	15	2	1.78	0.52
40	24	282	50	16.49	3.76	120	4	1.94	0.64
41	11	75	15	29.40	9.46	107	4	1.97	0.65
42	5	26	28	37.21	18.43	20	4	1.72	0.70
43	6	54	64	21.52	9.43	18	4	1.93	0.81
44	11	66	16	32.26	10.84	98	4	1.77	0.56

Mean Dpar = 1.84
Mean Dper = 0.65
Chi-squared = 80.211
Chi-squared prob = 0.000
Pooled Age (Ma) = 23.4 +/- 2.5
Mean Age (Ma) = 28.9 +/- 4.8
W.Mean Age (Ma) = 17.6 +/- 2.0
Median Age (Ma) = 23.5- 2.1- 2.4

BL-00-31
270-05

Grain Number Number	Natural Tracks Tracks	Induced Tracks Tracks	Quads (dmnls) (dmnls)	FT Age (Ma) (Ma)	1 sigma (Ma) (Ma)	Uranium (ppm) (ppm)	Etch Figures	Dpar (microns)	Dper (microns)
1	13	214	108	11.84	3.52	42	4	2.11	0.66

Mean Dpar = 2.11
Mean Dper = 0.66
Chi-squared = n.a.
Chi-squared prob = n.a.
Pooled Age (Ma) = 11.8 +/- 3.5
Mean Age (Ma) = n.a.
W.Mean Age (Ma) = n.a.
Median Age (Ma) = n.a.

BL-00-32
270-06

Grain Number	Natural Tracks	Induced Tracks	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)	Etch Figures	Dpar (microns)	Dper (microns)
Number	Tracks	Tracks	(dmnls)	(Ma)	(Ma)	(ppm)			
1	10	79	21	24.80	8.57	79	4	1.83	0.68
2	2	14	9	27.98	21.28	33	2	1.54	0.78
3	8	61	20	25.69	9.89	64	4	2.02	0.86
4	4	32	16	24.49	13.15	42	3	1.70	0.72
5	0	17	16	0.00	11.91	22	1	2.07	0.70
6	2	23	32	17.05	12.65	15	2	1.90	0.60
7	5	129	28	7.60	3.52	97	4	1.80	0.63
8	1	12	12	16.34	17.06	21	2	2.01	0.70
9	8	72	50	21.78	8.31	30	4	1.78	0.64
10	1	18	60	10.90	11.23	6	1	2.00	0.58
11	18	127	9	27.76	7.36	297	4	2.34	0.85
12	5	52	30	18.85	9.96	37	4	1.86	0.60
13	6	53	70	22.19	9.73	16	4	1.95	0.86
14	1	2	8	97.42	119.58	5	1	1.02	0.71
15	10	68	6	28.80	10.04	239	4	1.98	0.87
16	0	3	24	0.00	75.37	3	0	0.00	0.00
17	6	28	12	41.93	19.18	49	4	2.18	0.74
18	2	14	12	27.98	21.28	25	4	2.19	0.87
19	24	136	32	34.55	8.17	90	4	2.46	0.90
20	6	29	16	40.49	18.46	38	4	1.66	0.78
21	4	19	24	41.20	22.92	17	3	1.76	0.82
22	4	20	25	39.14	21.68	17	4	1.81	0.86

Mean Dpar = 1.90
 Mean Dper = 0.75
 Chi-squared = 20.221
 Chi-squared prob= 0.507
 Pooled Age (Ma) = 24.7 +/- 3.1
 Mean Age (Ma) = 27.2 +/- 4.9
 W.Mean Age (Ma) = 19.6 +/- 2.6
 Median Age (Ma) = 25.2- 2.7- 3.0

BL-00-38
270-07

Grain Number	Natural Tracks	Induced Tracks	Quads (dmnls)	FT Age (Ma)	1 sigma (Ma)	Uranium (ppm)	Etch Figures	Dpar (microns)	Dper (microns)
Number	Tracks	Tracks	(dmnls)	(Ma)	(Ma)	(ppm)			
1	22	34	40	126.40	36.13	19	4	1.98	0.66
2	15	18	40	162.34	58.32	9	4	1.90	0.95
3	27	34	125	154.79	41.90	6	4	1.94	0.81
4	17	9	30	362.27	152.31	6	4	1.85	0.84
5	13	29	30	87.93	30.20	20	4	1.93	0.72
6	8	33	100	47.65	19.19	7	4	1.94	0.78
7	39	31	36	243.53	61.96	18	4	1.79	0.78
8	18	13	30	267.53	99.85	9	4	2.01	0.87
9	13	15	69	168.75	65.45	5	4	1.85	0.69
10	89	132	60	131.66	21.09	46	4	2.01	0.97
11	11	8	40	265.71	125.40	4	4	1.89	0.75
12	32	33	36	188.52	49.30	19	4	1.92	0.84
13	20	23	30	169.30	53.62	16	4	1.64	0.83
14	23	16	28	277.53	93.22	12	4	1.84	0.86
15	27	43	30	122.70	31.79	30	4	1.74	0.72
16	17	28	80	118.68	37.79	7	4	2.17	0.75
17	236	258	125	177.98	21.76	43	4	2.05	0.76
18	10	65	100	30.28	10.59	14	4	2.16	0.85
19	4	58	40	13.59	7.12	30	3	1.64	0.86
20	6	14	36	84.00	41.57	8	4	1.77	0.66
21	17	20	80	165.54	56.30	5	4	2.00	0.78
22	18	20	100	175.15	58.72	4	4	1.88	0.70
23	19	37	40	100.52	29.56	19	4	1.71	0.68
24	27	34	16	154.79	41.90	45	4	1.86	0.65

Mean Dpar = 1.89
 Mean Dper = 0.79
 Chi-squared = 102.813
 Chi-squared prob= 0.000
 Pooled Age (Ma) = 141.3 +/- 13.6
 Mean Age (Ma) = 158.7 +/- 21.8
 W.Mean Age (Ma) = 63.1 +/- 6.9
 Median Age (Ma) = 159.6- 15.1- 7.6

BL-00-44
270-08

Grain Number Number	Natural Tracks Tracks	Induced Tracks Tracks	Quads (dmnls) (dmnls)	FT Age (Ma) (Ma)	1 sigma (Ma) (Ma)	Uranium (ppm) (ppm)	Etch Figures	Dpar (microns)	Dper (microns)
1	3	50	12	11.86	7.12	87	4	2.08	0.78
2	2	6	6	65.64	53.87	21	3	1.85	0.86
3	4	37	28	21.36	11.38	28	4	1.83	0.82
4	2	14	12	28.21	21.45	24	3	2.14	0.71
5	5	65	21	15.21	7.17	65	4	2.15	0.92
6	22	178	12	24.42	5.88	310	4	1.94	0.74
7	8	88	24	17.97	6.80	77	4	1.79	0.79
8	1	9	24	21.95	23.21	9	1	2.53	0.96
9	4	70	35	11.30	5.88	42	4	2.21	0.75
10	6	143	21	8.30	3.53	142	3	2.00	0.84
11	6	111	30	10.69	4.57	77	4	2.17	0.78
12	3	80	28	7.42	4.41	60	1	1.48	0.57
13	2	14	50	28.21	21.45	6	4	1.67	0.80
14	8	88	16	17.97	6.80	115	4	2.43	0.79
15	6	54	50	21.95	9.62	23	4	1.92	0.84
16	25	39	40	125.64	33.83	20	4	1.92	0.74
17	5	22	36	44.83	22.52	13	4	1.82	0.71

Mean Dpar = 2.00
Mean Dper = 0.79
Chi-squared = 85.041
Chi-squared prob= 0.000
Pooled Age (Ma) = 20.7 +/- 2.7
Mean Age (Ma) = 28.5 +/- 7.7
W.Mean Age (Ma) = 13.6 +/- 2.0
Median Age (Ma) = 21.4- 3.5- 2.5

BL-00-48
270-09

Grain Number Number	Natural Tracks Tracks	Induced Tracks Tracks	Quads (dmnls) (dmnls)	FT Age (Ma) (Ma)	1 sigma (Ma) (Ma)	Uranium (ppm) (ppm)	Etch Figures	Dpar (microns)	Dper (microns)
1	5	22	64	45.06	22.63	7	4	1.61	0.89

Mean Dpar = 1.61
Mean Dper = 0.89
Chi-squared = n.a.
Chi-squared prob= n.a.
Pooled Age (Ma) = 45.1 +/- 22.6
Mean Age (Ma) = n.a.
W.Mean Age (Ma) = n.a.
Median Age (Ma) = n.a.

BL-00-72
270-15

Grain Number Number	Natural Tracks Tracks	Induced Tracks Tracks	Quads (dmnls) (dmnls)	FT Age (Ma) (Ma)	1 sigma (Ma) (Ma)	Uranium (ppm) (ppm)	Etch Figures	Dpar (microns)	Dper (microns)
1	31	29	25	210.53	57.11	24	4	1.52	0.70
2	2	25	8	16.00	11.83	65	4	1.66	0.67
3	1	13	6	15.38	16.01	45	1	1.44	1.02
4	12	84	36	28.54	9.12	48	4	1.99	0.79
5	22	303	30	14.52	3.42	209	4	2.02	0.80
6	12	36	20	66.39	22.80	37	4	2.07	0.89
7	39	112	70	24.98	4.72	92	4	2.05	0.74
8	2	48	12	8.34	6.06	83	2	1.79	0.94
9	2	31	9	12.90	9.47	71	4	2.10	0.58
10	12	96	16	24.98	7.92	124	4	1.94	0.81
11	2	11	12	36.30	28.06	19	2	1.80	1.05
12	1	8	12	24.98	26.57	14	1	1.91	0.82
13	3	13	28	46.04	29.73	10	2	1.54	0.60
14	0	13	9	0.00	16.01	30	0	0.00	0.00
15	3	60	40	10.00	5.98	31	2	2.01	0.77
16	7	10	12	138.64	69.28	17	4	2.28	0.83
17	8	206	60	7.77	2.87	71	4	1.74	0.74
18	11	195	40	11.28	3.62	101	4	1.95	0.72

Mean Dpar = 1.87

Mean Dper = 0.79
 Chi-squared = 170.069
 Chi-squared prob= 0.000
 Pooled Age (Ma) = 22.8+/- 2.6
 Mean Age (Ma) = 39.0+/- 13.5
 W.Mean Age (Ma) = 14.0+/- 1.8
 Median Age (Ma) = 20.5- 3.3+ 5.7

BL-00-81
270-18

Grain Number Number	Natural Tracks Tracks	Induced Tracks Tracks	Quads (dmnls) (dmnls)	FT Age (Ma) (Ma)	1 sigma (Ma) (Ma)	Uranium (ppm) (ppm)	Etch Figures	Dpar (microns)	Dper (microns)
1	8	46	20	34.95	13.70	47	4	2.26	0.94
2	5	10	15	99.98	55.38	14	4	2.00	0.75
3	1	33	9	6.10	6.22	75	2	1.21	0.93
4	1	22	12	9.15	9.39	38	1	2.16	0.91
5	3	49	14	12.33	7.40	72	3	2.01	0.91
6	40	283	18	28.42	5.35	323	4	2.04	0.80
7	1	14	16	14.38	14.93	18	4	1.86	0.69
8	4	38	21	21.18	11.27	37	4	2.13	0.79
9	3	33	12	18.29	11.13	56	4	1.87	0.88
10	1	2	16	99.98	122.73	3	1	1.71	0.90
11	10	209	30	9.63	3.22	143	4	2.31	0.82
12	4	27	16	29.79	16.15	35	4	1.92	0.91
13	2	42	32	9.59	6.99	27	1	1.95	1.05
14	9	94	50	21.56	7.77	34	4	2.18	0.72
15	8	125	24	12.88	4.82	107	4	2.01	0.89
16	19	206	65	18.56	4.71	65	4	2.12	0.68

Mean Dpar = 1.98
 Mean Dper = 0.82
 Chi-squared = 31.561
 Chi-squared prob= 0.007
 Pooled Age (Ma) = 19.6+/- 2.5
 Mean Age (Ma) = 28.0+/- 8.0
 W.Mean Age (Ma) = 15.1+/- 2.1
 Median Age (Ma) = 18.4- 2.9+ 4.1

BL-00-92
270-23

Grain Number Number	Natural Tracks Tracks	Induced Tracks Tracks	Quads (dmnls) (dmnls)	FT Age (Ma) (Ma)	1 sigma (Ma) (Ma)	Uranium (ppm) (ppm)	Etch Figures	Dpar (microns)	Dper (microns)
1	4	4	24	199.66	142.14	3	4	2.12	0.85

Mean Dpar = 2.12
 Mean Dper = 0.85
 Chi-squared = n.a.
 Chi-squared prob=n.a.
 Pooled Age (Ma) = 199.7+/-142.1
 Mean Age (Ma) = n.a.
 W.Mean Age (Ma) = n.a.
 Median Age (Ma) = n.a.

APPENDIX F. ADDITIONAL REFERENCES

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