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FOREDEEP AND THRUST BELT INTERPRETATION OF THE MATURIN SUB-BASIN, EASTERN VENEZUELA BASIN.

by

ENRIQUE J. HUNG

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

MASTER OF ARTS

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Abstract

Foredeep And Thrust Belt Interpretation Of
The Maturin Subbasin, Eastern Venezuela Basin.

by

Enrique J. Hung

The nature of the basement underneath the Monagas foothills and the Serranía del Interior of the Eastern Venezuela Basin is unknown. It could consist of crystalline Precambrian, Paleozoic sedimentary rocks and/or Jurassic rocks deposited in half grabens. Alternative structural interpretations across the Monagas foothills range from basement-involved to non-basement-involved décollement tectonics. These hypotheses imply varying amounts of shortening along the Serranía to Foreland transect ranging from 15 to 115 km oblique component of the El Pilar fault.

The foreland-verging thrust system appears to be “in sequence”. In the Monagas foothills earlier décollements at the base of the Miocene are responsible for the formation of a complex accretionary wedge. The deeper structures of the Monagas foothills involve the Mesozoic which was thrusted following the emplacement of the Carapita accretionary wedge. Apparent “out of sequence” are due to the interference of late deeper structures with the earlier structures of the accretionary wedge.
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Chapter 1.- Introduction.

1.1.- Introduction.

The Eastern Venezuela Basin (Figure 1.1) is associated with the eastward migration of the Caribbean plate along the El Pilar strike slip fault zone and other unnamed offshore faults (e.g., Stephan et al., 1990, Pindell, 1990, Erlich and Barret, 1990). To the south, the Serranía del Interior, a Cretaceous to Paleogene passive margin sequence, was folded as a result of Neogene transpression resulting in a N70°E striking fold and thrust trend (e.g., Gutierrez, 1986; Lilliu, 1990; Chevalier, 1993). These trends continue to the south into the Monagas foothills with their large structural oil traps (Carnevali, 1989; Aymard, 1990). A 6-8 km thick Neogene foreland basin overlies a northward-dipping Cretaceous to Paleogene sedimentary rocks and a Precambrian crystalline basement of the Guyana shield to the south (Figure 1.1).

1.2.- Objectives.

Lack of subsurface data beneath the Serranía del Interior and the relatively poor seismic resolution of deep structures in the Monagas foothills are significant problems in the study area. This study offers alternative structural interpretations of the available surface and subsurface data.

The interpretation procedure involved the following steps:

- Seismic interpretation of the Monagas foothills supported by well data,
- Depth conversion of the seismic interpretation,
Figure 1.1: Location map, Eastern Venezuela Basin. Relevant structures of the Basin (After: Bellizzia et al., 1976; Robertson and Burke, 1989). Abbreviations: LBF: Los Bajos Fault; SFF: San Francisco Fault; UF: Urica Fault, and WSF: Warm Spring Fault. Dashed square represents location of map on Figure 1.2.
• Construction of a top of basement depth contour map.
• Stratigraphic correlation from surface to the subsurface.
• Construction of alternative balanced cross sections
• Restoration of the resulting interpretations

1.3.- Data Base.

A selection of subsurface data (wells and seismic) from the Monagas foothills and the Maturín sub-basin (Lagoven, S.A.) were used. The seismic data consisted of 1000 km of time-migrated 2D seismic profiles assembled into 6 regional strike and 5 regional dip profiles across the Monagas foothills.

The available well data set consisted of 50 control wells containing complete formational descriptions and seismic time-depth functions. Figure 1.2 shows all the relevant data used in this study.

The surface geology on the Serranía del Interior exposes the stratigraphy and structures involving Barremian to Tertiary rocks. The surface data include updated stratigraphic columns, cross sections and geologic maps from Rossi (1985); Vivas (1985); Chevalier (1993) and Aguasuelos Ingeniería (1994).

A 170 km long N-S transect through the Maturín sub-basin consists of 90km of seismic profiles, 12 key wells, and an 80 km long surface cross-section. Data for this study were kindly provided by Lagoven, S.A., a subsidiary of PDVSA.
Figure 1.2. - Index map showing available data: 1000 km of Seismic profiles, 50 key wells and 13 stratigraphic sections. Profile C is the Regional Cross Section. Abbreviations: AF=Anaco Fault; DF=Deformation Front EPF=El Pilar Fault; QQF=Quiriquire Fault; SFF=San Francisco Fault; UF=Urica Fault.
Chapter 2: Regional Setting.


Geologic and seismic studies (i.e., the distribution of recorded earthquakes, active volcanoes and spreading ridges) define five rigid plates in the Caribbean region: North American, South American, Caribbean, Cocos and Nazca plates as shown on Figure 2.1 (e.g., Mann et al., 1990). Eastward movement of the Caribbean plate with respect to North and South American dominates the tectonics of the area (Mann et al., 1990).

The northern Caribbean plate boundary zone extends from Guatemala in the west to the Lesser Antilles volcanic arc in the east (Mattson, 1984). The dominant motion is left-lateral strike slip with lesser extensional and compressional deformation (Burke et al., 1984). This plate boundary zone includes from west to east the Motagua-Polochic-Jocoten fault zone, the Cayman trough (i.e., the Mid-Cayman spreading center and its associated transform faults), southern Cuba, Hispaniola, Puerto Rico, the Virgin Islands, the Puerto Rico trench, and the Muertos trough (Figure 2.1).

The eastern boundary of the Caribbean plate is characterized by the west-dipping subduction of the Atlantic plate beneath the Caribbean plate associated with the active volcanic arc of the Lesser Antilles (e.g., Case and Holcombe, 1984).

The western boundary of the Caribbean plate developed during the Neogene and involves two triple junctions. To the northwest is the Caribbean-
Figure 2.1: Schematic map of the Caribbean region. Index map for crustal cross sections (Figures 2.2; 2.3; and 2.4). Abbreviations: AB=Atlantic Basin; AR=Aves Ridge; BP=Bahamas Platform; BR=Beata Ridge; CB=Colombian Basin; CCC=Cordillera Central de Colombia; CH=Chortis Arc; COC=Cordillera Occidental de Colombia; CT=Cayman Trough; EPF=El Pilar Fault; FSMO=Folded Belt Sierra Madre Oriental; GB=Grenada Basin; GAA=Greater Antilles Arc; LA=Lesser Antilles Arc; MAAS=Middle America Arc System; MAT=Middle America trench; MT=Muertos Trough; NCDB=North Caribbean Deformed Belt; NPDB=North Panama Deformed Belt; NR=Nicaragua Rise; PRT=Puerto Rico Trench; SCDB=South Caribbean Deformed Belt; RS=Romeral Suture; SC-VH=Sierra de Chiapas-Villahermosa Folded Belt; TR=Tiburon Rise; VB=Venezuelan Basin, and YP=Yucatan Platform. Solid barbs=B-subduction boundary; Open barbs=A-Subduction boundary. Modified after Di Croce, 1995.
Cocos-North American triple junction and to the southwest is the Caribbean-South American and Nazca triple junction (Mattson, 1984). The southern boundary of the Caribbean is a wide and complex zone that extends along the Venezuelan and Colombian coastal margin and includes the Boconó and the San Sebastian El Pilar strike slip fault zones. In addition this boundary zone is characterized by thrusting, right lateral strike slip and rifting (e. g., Stephan et al., 1980; Biju-Duval et al., 1983; Schubert, 1984; Mann and Burke, 1984; Mann et al., 1990). Coeval southeast vergent thrusting in the Serranía del Interior and the right lateral strike slip along the El Pilar fault suggest strain partitioning (Avé Lallemant, 1997).

Seismicity and seismic tomography of the Caribbean’s southern boundary (Figure 2.2) suggest subduction of the Caribbean plate beneath the South American plate (Van Der Hilst, 1990). Avé Lallemant (1997) describes the transpressive orogenic belt in terms of incipient subduction of the Caribbean beneath the South American plate. In his model east-west strike-slip faults are coeval with thrust faults and they share the same décollement surface (Figure 2.3). Another interpretation by Russo et al. (1993) suggests that oceanic lithosphere originally attached to South America subducts underneath the Caribbean plate toward the northwest (Figure 2.4).

Note that the location of the sections supporting these models are different, i. e., Figure 2.2 near Falcon; Figure 2.3 eastern Venezuela, Araya-Paria; Figure 2.4 eastern Venezuela near Trinidad.
Figure 2.2: Tomographic section across northwestern Venezuela. The images show the morphology of the subducting slab beneath northwestern Venezuela. (a) North-south section. (b) East-west section across northern Venezuela and Colombia (Van der Hilst, 1990).
Figure 2.3: Schematic north-south cross section through the Caribbean-South America plate boundary zone at the longitude of Margarita Island and across the Eastern Venezuela foreland. From Ave Lallemant, 1997. See Figure 2.1 for location.
Figure 2.4: Overlay of mean compensation depths (numbered bold lines) on a N-S cross-section of the plate boundary zone at 62°18' W, based on the tectonic wedging model of Russo and Speed, 1992. Tectonic units are numbered.
1) Guayana shield moho depths; 2) Foreland basin-continental crust contact; 3) Down warped continent or transitional crust Moho; 4) 18-22 km interphase; 5) Two depths to detaching or detached slab lithosphere; 6) South American slab-Caribbean crust interphase; 7) Aves Ridge Moho and 8) South, Carupano Basin sediment-Tobago terrane basement interphase? and north, Grenada basin moho. (From Russo and Speed, 1994). See figure 2.1 for location,
2.2.- Tectonic evolution of the Eastern Venezuela Basin.

The Eastern Venezuelan Basin formed as the result of the complex interaction between the South American, North American, and Caribbean lithospheric plates (e.g., Stephan et al., 1990; Pindell, 1990; Erlich and Barret, 1990). Three major tectonic stages are commonly differentiated (e.g., Di Croce, 1995):

1. a Triassic to late Jurassic rift phase (break-up of Pangea)
2. a Late Jurassic-Oligocene passive margin phase
3. an early Miocene to present active margin phase

Figures 2.5 and 2.6 show the relative movements of the plates based on the reconstruction of the Caribbean by Stephan et al. (1990). The North and South American plates separated near the end of the Jurassic (Figure 2.5a). Basaltic rocks in the Espino graben (Guárico sub-basin) dated at 162 Ma indicate that rifting occurred at least at that time (Feo Codecido et al., 1984). The rifting is followed by subsidence of the northern South America passive margin (Figure 2.5b). Cessation of sea-floor spreading between North and South America occurred around Campanian time as the proto-Greater Antilles islands arc collided with the passive margin of North America (Cuba-Hispaniola) and South America (Figure 2.5c). From late Paleocene to the present (Figure 2.5d), transpressional deformation advanced diachronously along the northern border of South America, as the Caribbean plate migrated eastward with respect to South and North America (Pindell and Barret, 1990; Lugo and Mann, 1995).
Figure 2.5. Late Jurassic to late Paleocene development of the northern and southern Caribbean area, simplified by Di Croce, 1995, after Stephan et al., 1990.

a) Breakup of western Pangea, between North and South America at the end of Jurassic;
b) Development of the passive margin of northern South America;
c) Continued development of passive margin and incipient paleo-antillean arc system;
d) Collision of greater Antilles arc from the northwest around the western corner of the passive margin of South America.

Abbreviations:
EVB = Eastern Venezuela Basin; FL = Florida; GA = Greater Antilles; MB = Maracaibo Basin; SA = South America; and YU = Yucatan.
2.5.a) OXFORDIAN-KIMMERIDGIAN (156 Ma)

2.5.b) APTIAN (118 Ma)

2.5.c) SANTONIAN-CAMPANIAN (84 Ma)

2.5.d) LATE PALEOCENE (59 Ma)
In western Venezuela transpression occurred during the early-middle Eocene (Figure 2.6a). Progressively younger transpression eventually affected eastern Venezuela and Trinidad, during late Oligocene-middle Miocene (Figure 2.6b). Thrust sheets and associated foredeep basins override the former Cretaceous passive margin sequence as a result of the eastward migration of the Caribbean plate. Volcanism in the Lesser Antilles arc and the development of the “Lara Nappes” in western Venezuela took place in the Eocene (Pindell and Barret, 1990; Stephan et al., 1990). The Oligocene is a tectonically quiet period and perhaps reflects a slowdown of the eastward Caribbean relative motion, as shown on Figures 2.6 c-d (Stephan et al., 1990).

Using the nomenclature of Bally and Snelson (1980) the northward A subduction of South America merges with the westward B subduction of the Central Atlantic. The southward B-subduction of the Caribbean plate underneath South America is connected to the A-subduction of northern Venezuela. Therefore the transpressional Neogene folded belts of eastern Venezuela and southern Trinidad and the dominantly transtensional southeast Caribbean are formed at a triple junction of three subduction zones.

2.3.- **Geologic Provinces.**

The Eastern Venezuela Basin may be divided into three geological provinces:

1) The Serranía del Interior, 2) The Monagas foothills and 3) the Maturín Foreland.
Figure 2.6. Four stages of the development of the southern Caribbean boundary, from Eocene to Present associated with the eastward migration of the Caribbean Plate (after Stephan et al., 1990 and Di Croce, 1995).

(a) Compressional deformation due to Caribbean-South America affecting much of northwestern Venezuela;

(b) and (c) Continuation of the oblique convergence of the Caribbean and South American plates. The result is the emplacement of a transpressional folded belt and the associated eastward migration of the foredeep depocenter; d) From late Pliocene to present kinematic change in the Eastern Venezuela Basin is associated with a decrease in contraction and an increase in the strike-slip deformation. Abbreviations:

AC = Andes Cordillera; AR = Aves Ridge; BR = Barbados Ridge; BR = Beata Ridge; CB = Colombian Basin; CCC = Central Colombian Cordillera and COC = Cordillera Occidental de Colombia CP = Cocos Plate; CT = Cayman trough;
CU = Cuba; EVB = Eastern Venezuela Basin; GB = Grenada Basin; GYB = Guyana Basin; LA = Lesser Antilles; MB = Maracaibo Basin; NP = Nazca Plate; PR = Puerto Rico; SA = South American plate; VB = Venezuelan Basin; YU = Yucatan;
Major geologic faults within this division are: The El Pilar, Urica, San Francisco, Pirital, and Los Bajos faults, and the Deformation front itself (Figure 2.7).

2.3.1.- Serranía del Interior.

The Serranía del Interior includes a southeast verging folded belt with its folds and thrusts orientated roughly N70°E (e.g., Rossi, 1985; Gutierrez, 1986). Surface maps show the lengths of the folds being around 70 km with wave length of 5 km.

The faults bordering the Serranía are:

1) The E-W striking El Pilar strike-slip fault to the north,
2) The N70°E striking Pirital thrust fault complex to the south,
3) The NW-SE striking Urica fault zone and
4) The Los Bajos fault zone to the east

The San Francisco right lateral tear fault dissects the Serranía into two blocks: the Bergantín block to the west and the Caripe block to the east and merges with the Quiriquire fault to the south (González de Juana, et al., 1980). The dissection of the folds and thrust by the Urica, San Francisco and Los Bajos tear faults implies west to east diachronous deformation in the same way as the north to south thrust progradation showing significant strain partitioning (Avé Lallemant, 1997).

2.3.2.- Monagas Foothills.

To the south of the Pirital and Quiriquire thrusts, the folded belt continues in the subsurface and stops at the deformation front (Lilliu, 1990).
On the surface shale anticlines parallel the thrust fault orientation (Subieta et al., 1987). These shale anticlines are evidence of the Neogene compressional events. This alignment on the surface and its diapiric expression on seismic profiles in the subsurface define the deformation front throughout the Eastern Venezuelan Basin. North of the deformation front the Monagas foothills include giant medium and light oil fields (e.g., El Tejero, El Carito, El Furrial, Corozo and Boquerón, see Figure 2.8; Aymard et al., 1990).

2.3.3.- The Maturín foreland.

The foreland is bounded by the deformation front to the north-northwest, by the Guyana shield to the south and by the Atlantic Ocean to the northeast. The southern margin of the foreland is characterized by basement involved normal faults that define the prolific oil bearing structures of traditional oil fields (see Figure 2.8). Overlying these normal faulted blocks, listric growth faults occur affecting Neogene sedimentary rocks. In the Mapirito area of the foreland, listric faults dip toward the east-northeast (Figure 2.9).
Figure 2.8: Oil fields of the foothills (El Furrial trend). The figure shows the complexity of the explored structures on a simplified top Oligocene structural map in depth. See Figure 2.7 for location.
Figure 2.9: Seismic time map of Neogene listric faults of the foreland (Mapirito area), Maturin Sub-basin. Labeled contours interval is 200 ms, Middle Miocene shelf break is also indicated. From Daza and Prieto, (1990). See Figure 2.7 for location.
Chapter 3:  Stratigraphy.

3.1.-  Introduction.

The stratigraphy of the eastern Venezuelan foreland basin is best described in five units from bottom to top:

- Crystalline Precambrian Basement.
- Paleozoic.
- Jurassic.
- Passive Margin Sequence (Cretaceous to Oligocene)
- Neogene Foredieep.

Appendix A is a glossary of the formation names. Illustrations for this chapter are referred in the summarized index column (Figure 3.1).

3.2.-  Crystalline Precambrian basement.

The crystalline Precambrian basement crops out to the south in the Guayana shield where it is dated between 3600 and 800 Ma by Martin-Bellizzia (1974), Mendoza (1977), and González de Juana et al. (1980). It consists mainly of meta-sedimentary and meta-igneous rocks. Metamorphic facies varies from amphibolite to granulite facies. The metamorphic rocks are intruded by granites (Feo-Codecido et al., 1984).

In the subsurface, the top of the Guayana shield forms the deepest continuous reflectors on the seismic profiles of the Maturín sub-basin. The basement dips gently toward the north from the Orinoco River to underneath the
### SUMMARIZED STRATIGRAPHY

<table>
<thead>
<tr>
<th>AGE</th>
<th>FORMATION</th>
<th>THICKNESS (m)</th>
<th>LITHOLOGY</th>
<th>TECTONIC ACTIVITY</th>
<th>OIL &amp; GAS</th>
<th>FIGURE</th>
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<td>FLUVIAL Deltas Silts, Shales and Fine Grained Sandstone</td>
<td>FOREDEEP</td>
<td>OIL &amp; GAS</td>
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<td>DENSE FUCHS AND GLAUCONITE Shales</td>
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<td></td>
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<td>SARCIA</td>
<td></td>
<td>190</td>
<td>SANDSTONE + LIMESTONE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BARREMIAN</td>
<td>BARANDUIN</td>
<td>1300-1700</td>
<td>SANDSTONE + LIMESTONE + INTERRACED SHALS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JURASSIC</td>
<td>LA QUINTA</td>
<td>?</td>
<td>Non transgressive beds with minor tuff interbedded</td>
<td>RIFTING</td>
<td>BASEMENT</td>
<td>3.2</td>
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<tr>
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<td>CARRAL HATO VIEJO</td>
<td>1900</td>
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<td>Fine Grained Sandstone and Siltstone.</td>
<td>BASEMENT</td>
<td>3.2</td>
</tr>
<tr>
<td>PRECAMBRIAN</td>
<td></td>
<td>?</td>
<td>Metagneous and Metasedimentary rocks.</td>
<td></td>
<td>BASEMENT</td>
<td>3.2</td>
</tr>
</tbody>
</table>

![Figure 3.1: Index figure. Summarized stratigraphy of the Eastern Venezuela Basin.](image-url)
frontal folds of the Serranía del Interior (e.g., Lilliu, 1990; Chevalier, 1990; Di Croce, 1995). A seismic time structural map shows the smooth contours of the basement from the Guayana shield towards the northern foothills and northeastern offshore area (Figure 3.2).

3.3.- Paleozoic.

Paleozoic sedimentary rocks in the Guárico sub-basin to the west of the basin have been reported by Feo-Codecido (1984). The Carrizal well west of the Maturín sub-basin penetrated 1,827 m (5990 ft) of Cambrian Hato Viejo and overlying Cambrian Carrizal formations (Appendix A). These rocks may correspond to prominent reflectors seen on the seismic profiles in the Maturín sub-basin. A Pre-Mesozoic subcrop map (redrawn from Feo-Codecido, 1984) shows the stratigraphic distribution and regional structure of Paleozoic rocks in the Eastern Venezuela Basin (Figure 3.3).

3.4.- Jurassic.

The Jurassic Espino graben has been described from the Machete-Zuata field (González de Juana et al., 1980), west of the Maturín Sub-basin; it trends southwest-northeast. The graben is filled with red-beds and intercalated basalt flows (162 Ma) (Feo-Codecido et al., 1984). An east-west seismic profile from the Orinoco offshore shows typical Jurassic half-graben geometry following this trend (Figure 3.4). The width of these structures is in the order of 5-10 km.

3.5.- Passive Margin Sequence (Cretaceous to Oligocene).

The Eastern Venezuela Basin merges to the southeast into the Atlantic
Figure 3.2: Top of the basement map in TWT. Abbreviations: AF=Anaco fault; BAP=Barbados Accretionary Prism; EPF=El Pilar fault; LBF=Los Bajos fault; UF=Urica fault; SFF=San Francisco fault; (from Feo Codecido, 1984 and Di Croce, 1995).
Figure 3.3: Generalized subcrop map for Pre-Mesozoic time. Stratigraphic column from the Anaco trend show Paleozoic and Jurassic sediments (lower left). Legend of the structural symbols (lower center) and location map for Jurassic-lower Cretaceous Graben System from northeastern Brazil (Tacutu Graben). Abbreviations: AF=Anaco fault; BAP=Barbados Accretionary Prism; LBF=Los Bajos fault; PF=El Pilar fault; SFF=San Francisco fault; UF=Urica fault. (From Feo Codecido, 1984 and Di Croce, 1995).
Figure 3.4: a) Uninterpreted and b) interpreted segment of seismic profile offshore northeastern Venezuela showing evidence of Jurassic half graben systems. SB-1 is the top of the Basement and, SB-2 top of Jurassic. (See Di Croce, 1995).
passive margin of South America. The passive margin sequence consists of Cretaceous to Oligocene marine clastic rocks although some carbonates may be present in the Cretaceous section. Reconstructions for the Oligocene show the passive margin as a thick wedge thinning toward the south with onlap terminations against the Precambrian rocks of the Guayana shield (e. g., Hedberg, 1950; Rosales, 1973; González de Juana et al., 1980, Erlich and Barret, 1992).

Juan Di Croce (1995) recently described correlations establishing stratigraphic control from the offshore Orinoco platform to the Serranía del Interior and to the Maturín sub-basin (Figures 3.5, 3.6, and 3.7).

Di Croce’s correlations are here accepted because a critical evaluation of his work is beyond the scope of this study. In the same vein I have accepted the stratigraphic work done previously in the Serranía (e. g., Rossi, 1985; Vivas, 1985, Chevalier, 1990, and Aguasuelos 1994). A simplified correlation of several surface sections is shown in Figure. 3.8. A seismic example from the Orinoco offshore illustrates the onlap of Cretaceous sediments underlain by the continuous reflectors of the top of the Precambrian crystalline basement (Figure 3.9).

3.5.1.-Lower Cretaceous (Barremian-Albian).

Paleogeography of the Eastern Venezuela Basin shows a southern sediment source for the Cretaceous clastic rocks (González de Juana et al., 1980; Rohr, 1991; Erlich and Barret, 1992). Lower Cretaceous stratigraphic columns show how Barremian sedimentary rocks grade upward from continental
Figure 3.5: Passive margin correlation from a well offshore and a stratigraphic column from Chevalier (1990) onshore (Serrania del Interior) from Di Croce, 1995. See Appendix A for formation names.
Figure 3.6: Regional correlation of Cretaceous to Paleogene passive margin sequence from east to west: offshore Guyana (G) - Orinoco delta (A) - onshore folded belt (J-I) - Maturin sub-basin foreland (H). From Di Croce, 1995. A comparison of well A with J shows that the Orinoco platform section is much sandier than the more carbonate rich section in the Serranía.
Figure 3.7: Foreland well correlation of the passive margin sequence shows Cretaceous sediments thickening to the north. SB-1 is the top of the crystalline basement. From Di Croce, 1995. See Appendix A for formation and group names.
Figure 3.8: Correlation of selected sections of the Serranía del Interior simplified after Rossi, 1985; Aguasuelos, 1994. Datum top of Cenomanian. Upper right shows location of the stratigraphic columns. Abbreviations: IF = Inner Foothills; OF = Outer Foothills. See Appendix A for formation names.
Figure 3.9: a) Uninterpreted, b) Interpreted offshore Orinoco delta seismic profile showing the regional configuration of Cretaceous onlap overlying the north-dipping basement monocline. SB-2.1 is the top of Upper Cretaceous. From Di Croce, 1995.
facies at the base into shelf to shallow marine for Lower Aptian sediments at the Serranía del Interior (Figure 3.10). This facies change for the lower Cretaceous has been generalized by Rossi (1989) into three cycles as follows:

1) A transgression at the base of the García Member (upper Aptian),
2) A carbonate platform of the El Cantil Formation (lower Albian),
3) A remarkably strong transgression of the Chimana Formation (upper Albian).

The late Albian transgression is by some authors related to the opening of the south Atlantic Ocean (Mitchum and Vail, 1977). The associated upper Albian black shales are common worldwide and Schlanger and Jenkins (1976) consider these black shale as indicative of local reducing conditions associated with tropical weather conditions and strong biological activity.

3.5.2.- Upper Cretaceous.

The Cenomanian to Coniacian sequence of sedimentary rocks overlies the big Albian transgression. Reducing conditions terminate with the globally correlatable regression of Coniacian age (Schlanger and Jenkins, 1976). Within this interval the Querecual Formation was deposited which is the most important source rock of the Eastern Venezuelan Basin (Hedberg, 1937; González de Juana, 1980; Aymard, 1990). A stratigraphic column from the Serranía shows the character of the Querecual Formation and the overlying sequence of Santonian to Maastrichtian age (Figure 3.11).

The southerly sediment supply persists into the late Cretaceous. In addition, evidence of exposure of the underlying continental sediments suggests
Figure 3.10.- a) and b) Lower Cretaceous outcrops in the Serrania del Interior Localities 3 and 4 respectively, showing Barremian to Albian age rocks and formation tops, (see Appendix A); c) Paleowater depths and d) location of surface stratigraphy from Rossi, 1985; Aguasuelos, 1994.
Figure 3.11.- a) Upper Cretaceous outcrops in the Serrania del Interior. Locality 8 showing Cenomanian to Paleocene age rocks and formation tops. (see Appendix A): b) Paleowater depths and c) location of the section. Stratigraphy from Rossi, 1985; Aguasuelos, 1994.
erosion and consequently the advance of the coast line toward the north (e. g., Rossi, 1985; Di Croce, 1995).

3.5.3.- Paleocene.

The absence of upper Maastrichtian preceding the Paleocene suggests a hiatus corresponding to the lower Paleocene and part of the Maastrichtian in the localities of the Serranía (Hedberg and Pyre, 1944; González de Juana, 1980).

The lithology of the Paleocene section of the Maturín sub-basin suggests a shallow water facies. Coeval deep water sedimentary rocks in Trinidad contain allochthonous Cretaceous blocks probably as a result of gravitational slumps (Rohr, 1991, Di Croce, 1995).

3.5.4- Eocene.

Fossils relating to a transgression in the neritic domain are present in the uppermost portion of the Vidoño Formation (see Appendix A). Paleogeographic reconstruction of the eastern Venezuela and Trinidad passive margins from relative plate motions between the Caribbean and South American (Rohr, 1991) show a broad shelf-edge that merges into a slope towards the east in Trinidad during Eocene time as shown on the middle Eocene paleogeographic map (Figure 3.12).

3.5.5.- Oligocene.

In the Monagas foothills the Oligocene is the most productive reservoir of the basin. Best reservoirs occur in the Naricual and Los Jabillos Formations (e. g., González de Juana et al., 1980; Arnstein, et al., 1985; Carnevali, 1989).
Figure 3.12: Middle Eocene Paleogeographic map showing the position of the reconstructed passive margin (solid line) with respect to the present day coast line (dashed line) (From Rohr, 1991).
Environments associated with these sedimentary rocks range from shelf to shallow water, showing evidence of high sedimentation rates (Hedberg, 1950). Seismic data offshore the Orinoco delta suggest a progradation probably associated with Oligocene lowstand deltas (Figure 3.13).

To the south and west coeval sedimentary rocks in the foredeep are included in the Merecure Formation (see Appendix A). The absence of Oligocene faunas in this formation and the orientation of the passive margin suggest that the zero edge for Oligocene sedimentary rocks is due to erosional truncation (Figure 3.14).

3.6.- Neogene foredeep.

The eastern Venezuelan Neogene represents the fills the Maturín foredeep basin. Compilation of the biostratigraphy of a well in the Monagas foothills provides a generalized paleo-water-depth curve (Figure 3.15).

Wells in the basin have reported up to 6100m - (20000ft), entirely of Neogene sedimentary rocks. A north-south correlation of key wells along the Maturín sub-basin illustrates the position of the Maturín sub-basin axis marked by the deepest point of the section. In addition this axis roughly coincides with the deformation front (Figure 3.16).

Three sedimentary transport directions characterize the foredeep basin fill, i. e.: an important longitudinal west to east transport, a southerly sediment source from the adjacent Guayana shield, and a limited northwesterly sediment supply from the emergent folded belt of the Serranía del Interior, which is deposited in small satellite basins (DiCroce, 1995).
Figure 3.13: a) Uninterpreted, b) Interpreted offshore Orinoco delta seismic profile showing upper Oligocene seismic terminations suggesting north prograding sequences. SB-2.2, SB-2.23, and SB-2.3 lower, middle and top of Oligocene respectively. From Di Croce, 1995.
Figure 3.14: Facies map of the upper Oligocene shows the zero edge of the Oligocene sediments given by the erosional boundary on the Merécure formation to the south. To the north Narical and Areo formations are shown. Abbreviations refer to: AF = Anaco fault; UF = Urica fault; SFF = San Francisco fault; LBF = Los Bajos fault; EPF = El Pilar fault. From Di Croce, 1995. See Appendix A for formation names.
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<th>FORMATION</th>
<th>AGE</th>
<th>SEQUENCE XX (from blow)</th>
<th>ZONATION XX (1969)</th>
<th>PALEOENVIRONMENT</th>
<th>OBSERVATIONS</th>
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<td>Upper Oligocene</td>
<td>SB-3</td>
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<td></td>
<td>Globigerina ciperoensis</td>
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Figure 3.15: Stratigraphic column and inferred paleo-water depths from a well on the Monagas foothills. SB-3 is the basal foredeep unconformity. Note the sudden deepening of the water depth across this unconformity. Modified from Lagoven internal report, in Di Croce, 1995.
Figure 3.16.- Well Correlation from Quiriquire Field to the Orinoco Tar-Oil Belt. Key well along axis of the Maturin Sub-basin. See lower right map for location.
wells from the Foredeep show maximum thickness of the Neogene Foredeep coinciding
3.6.1.- Lower to middle Miocene.

In the Monagas foothills, lower to middle Miocene sedimentary rocks are found to form an accretionary wedge overlying the folds and thrusts involving Cretaceous to Oligocene strata. Faunas from lower to middle Miocene rocks have been described as the "normal Carapita fauna" by Stainforth (1971).

Within the foredeep the lower to middle Miocene can be divided into depositional sequences with backstepping cycles at the bottom and forestepping to aggradational cycles toward the top. These packages were deposited in a littoral to shallow marine setting with coastal bars that prograded mainly from west to east (DiCroce, 1995). These cycles contribute to the foredeep fill of a 'V-shaped' basin that in map view narrows westward and widens eastward toward the Atlantic Ocean (Figure 3.17).

3.6.2.- Upper Miocene.

The upper Miocene is characterized by a coarsening upward patterns widely observed on well logs which represents an overall regressive system, that may be divided from bottom to top in two different lithofacies: 1) a shallow water to outer shelf/upper bathyal setting 2) a continental to coastal plain environment dominated by highstand sequences.

3.6.3.- Pliocene to Pleistocene unit.

The Plio-Pleistocene unit is a widely correlatable sequence recognizable on seismic and well data (Figure 3.18). To the west and northwest the sequence onlaps against the emerging folded belt. Lithology and fossils from wells indicate
Figure 3.17: Facies map of the middle Miocene shows the V-shaped foredeep basin, where distribution of sediments and their respective environments are indicated. Abbreviations: AF=Anaco fault; BAP=Barbados Accretionary Prism; EPF=El Pilar fault; LBF=Los Bajos fault; SFF=San Francisco fault, and UF=Urica fault. From Di Croce, 1995. See Appendix A for formation names.
Figure 3.18: Seismic isopach map of the Pliocene shows the migration of the depocenter from the contours 3.5 s and 5.0 s for south of Maturin and Trinidad respectively. Abbreviations: AF=Anaco fault; BAP=Barbados Accretionary Prism; DF=Deformation Front; EPF=El Pilar fault; GFP=Growth Fault Province; LBF=Los Bajos fault; SFF=San Francisco fault, and UF=Urica fault. From Di Croce, 1995.
facies ranging from littoral and marginal marine to mostly continental (Figure 3.15). This unit corresponds to an overall regressive cycle that includes a fining upward facies at the base followed by a coarsening upward deposition toward the top.
Chapter 4: Methodology.

4.1.- Introduction.

The main purpose of this study is to construct alternative and internally consistent cross sections that best define the geologic problems of the folded belt. The following steps were involved:

1) Line drawings of seismic profiles and correlation with wells,

2) Depth conversion of line drawings,

3) Balanced cross sections across the Monagas foothills,

4) Regional transect.

4.2.- Line drawings.

Line drawings of seismic profiles trace the most relevant reflectors. They are based on preliminary interpretations that emphasize robust data and neglect artifacts. Representative seismic profiles were selected to cover the area and short profiles were combined to form grid of regional profiles. Next, key wells were selected and, the line drawings were done with consistent standards.

Eleven profiles form the regional grid, which involves about 1000 Km of seismic data and consists of five NS and six EW profiles.

Line drawings combined with the well control permit to correlate the major stratigraphic units. From bottom to top, these units are: Lower Cretaceous, Upper Cretaceous; Paleogene; Lower and middle Miocene; upper Miocene, Pliocene and Pleistocene (e.g. Figures 4.1). Structural styles and the details of the interpretation of these profiles will be discussed in Chapter 5.
Figure 4.1: a) Uninterpreted seismic profile showing typical seismic packages. b) Line drawing of the seismic profile showing the correlation. Vertical line represent wells.
4.3.- Depth conversion.

Depth conversion of the line drawings was done using interval velocities obtained from wells. These interval velocities are averaged and tested by the wells to derive a representative interval velocity for each unit.

The interval velocity is the average velocity of a layer in the subsurface between two horizons (Sheriff, 1991). To determine this velocity, the average velocity and the two way time (TWT) for the top and base of each layer is required (equation 4.1; i.e., Dix, 1955). Input to this equation are the velocities and TWT for the correlated tops. This information is gathered from the time-depth curves and logs (e.g., VSP, Check shots) of the available wells.

Equation 4.1:

\[ V_{\text{int}} = \sqrt{\frac{V_n^2 \cdot T_n - V_{(n-1)}^2 \cdot T_{(n-1)}}{T_n - T_{(n-1)}}} \]

Where:

- \( V_{\text{int}} \) ➔ The interval velocity
- \( V_n \) ➔ The average velocity from the surface to the base reflector
- \( V_{(n-1)} \) ➔ The average velocity from the surface to the top reflector
- \( T_n \) ➔ The two way time from the surface to the base reflector
- \( T_{(n-1)} \) ➔ The two way time from the surface to the top reflector

The results of the rounded up typical interval velocities are listed in Table 4.1.

For completeness rounded density values were also included.
Table 4.1

<table>
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<th>VELOCITY (m/s)</th>
<th>DENSITY RANGE (gr/cm³)</th>
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<td>2100</td>
<td>2.17-2.24</td>
</tr>
<tr>
<td>PLIOCENE</td>
<td>2400</td>
<td>2.17-2.30</td>
</tr>
<tr>
<td>UPPER MIOC.</td>
<td>2700</td>
<td>2.23-2.28</td>
</tr>
<tr>
<td>MIDDLE &amp; LWR MIOC</td>
<td>2800</td>
<td>2.31-2.40</td>
</tr>
<tr>
<td>PALEogene</td>
<td>3600</td>
<td>2.48-2.50</td>
</tr>
<tr>
<td>UPPER K</td>
<td>3900</td>
<td>2.50-2.58</td>
</tr>
<tr>
<td>LOWER K</td>
<td>4400</td>
<td>2.56-2.75</td>
</tr>
</tbody>
</table>

For density range values see: Bonini (1978); Lilliu (1983); Vierbuchen (1984); Instituto de Ingenieria-Universidad Simón Bolívar (1988); Espinoza and Martin (1990); Carnevali et al. (1994); Passalacqua et al. (1995); and Martinez (1995).

The resulting velocities are applied to each profile to estimate the depth of every horizon. Depth calculations are made every 5 km along all the profiles, defining some 250 distributed control points. Depth calculations on each point consist of the sum of the values from top to bottom of the resulting interval thickness, by using equations 4.2 and 4.3.

Equation 4.2:

\[ D_i = \frac{V_i \cdot T_i}{2} \]

Where:

- \( D_i \) ➔ the singular values of thickness for each layer
- \( V_i \) ➔ the average velocity for each layer (\( V_{\text{m}} \))
- \( T_i \) ➔ the seismic time of the layer

The depth to each control point is determined by:
Equation 4.3:

\[ Z_i = \sum_{i=1}^{n} D_i \]

Where: \( Z \) \( \rightarrow \) The depth for each horizon.

4.4.- Balanced cross sections and regional transect.

Balanced cross sections use simple geometries to permit a restoration to the pre-deformed stage (e.g., Dahlstrom, 1969; Boyer and Elliot, 1982; Suppe, 1983).

NNW-SSE oriented profiles were selected to construct balanced cross sections, because these profiles are roughly parallel to the assumed path of transport direction.

Some interpretations assume no basement involvement, are based on seismic reflectors showing a gentle northerly dip of the basement that may be extrapolated far toward the north. This is compatible with previous interpretations (e.g., Feo Codecido, 1984, Cabrera, 1985). The very limited available information was utilized to construct a basement map to provide internal consistency for the profiles (Figure 4.2). My interpretations show that the basement is overlain by a wedge of northward thickening Cretaceous-Paleogene sequences (see also, Rosales, 1972, Chevalier, 1990, Roure et al., 1994, Passalacqua et al., 1995). The estimated total thickness for the Cretaceous is
Figure 4.2.- Foreland and Monagas foothills Basement map. Contour Interval 250m. Geologic Provinces are indicated on the right edge. The thrust fault north of the foothills is correlated with the San Francisco-Quiriquire fault from surface map (Chevalier, 1990). Northern boundary to the Inner foothills the gray-white contact south from the San Francisco-Quiriquire fault.
compatible with the thickness derived from surface geology (Rossi, 1985, Aguasuelos, 1994).

In some of my interpretations the top of the basement coincides with the interpreted basal décollement surface for the thrust faults of the area. Alternative interpretations that involve the basement will be discussed later.

Finally, a surface profile across the Serranía del Interior (i.e., Chevalier, 1990) was simplified and reduced to the same scale as the subsurface data (Figure 4.3) to provide restorable geometries for both the foreland and the Serranía in a regional transect which will serve as the main basis for alternative interpretations.

4.5.- Restoration.

The reconstruction of the balanced cross sections assumes a combination of line length and area conservation (e.g., Dahlstrom, 1969; Suppe, 1983). This validation technique provides cross sections that are internally consistent and show a more plausible geometric representation of the geology (Butler, 1994). Balanced cross sections are rarely unique structural solutions; instead they help to narrow down and to define important structural problems.

The base of lowermost Miocene probably coincides with the basal foredeep unconformity that formed in response to the inception of the folded belt. In this context the datum utilized for the restorations is the top of the Oligocene and base of lower Miocene boundary.
Figure 4.3: a) Surface section across the Serranía del Interior (from Chevalier, 1990) b) Interpreted thickness and basal decollement surface on the Serranía del Interior cross section (Bally et al., 1995). Suggested thickness is provided from updated stratigraphic columns (Aguasuevos, 1994).
4.6.- Summary.

The methodology used provided the following elements for the interpretation of the folded belt (Plates 1 and 2):

- A well supported grid of interpreted line drawings
- A set of (1:1) depth-converted profiles with a consistent basement top for the foreland and the Monagas foothills.
- Internally consistent north-south oriented balanced cross sections
- The restoration of the balanced cross sections
- The relation of the observed surface and subsurface styles
Chapter 5: Interpretation.

5.1.- Introduction.

The subsurface interpretations in this study are mostly based on the line drawings of seismic profiles across the Monagas foothills. On the other hand, published surface maps and cross sections support the interpretation of the Serranía del Interior. Profile C and its alternative interpretations is a regional transect that ties the Foreland to the Serranía del Interior.

The subsurface interpretation of the Monagas foothills will be discussed; first, by describing the NNW-SSE dip profiles, and then turning to the WSW-ENE strike profiles. Finally the analysis of six different interpretations of the Foreland-Serranía will be presented.

5.2.- North-South Balanced profiles.

From south to north the following provinces are differentiated (Figure 5.1):

a) The Foreland

b) The Outer Foothills and

c) The Inner Foothills.

The Foreland includes the portion south of the deformation front; to its north the Outer foothills are bounded by the Pirital thrust fault. The inner foothills correspond to the area north of the Pirital thrust fault and south of the Neogene onlap against the Serranía outcrops (Figures 5.1). The Pirital high located in the inner foothills is typically a near surface anticlinal complex bordered to the south
Figure 5.1.- Index map showing location of seismic profiles, regional transect Profile C, depth slice and maps of this chapter. Abbreviations: QQF=Quiriquire Fault; SFF= San Francisco Fault; UF= Urica Fault. Black dots represent key wells.
by the Pirital base thrust. North to the Pirital high the Morichito satellite Basin occupies the northern flank and syncline of these anticlinal complex.

5.2.1.- The Foreland.

Seismic profiles show the foreland basement dipping gently to the North. High angle normal faults offset the basement and the overlying Cretaceous to Paleogene sequence. The fault planes are interpreted mostly as dipping to the north and occasionally to the south (Figures 5.2.a and b).

The sedimentary cover overlying the basement thickens toward the north. To the south these sediments gradually wedge out, permitting the Precambrian rocks to outcrop on the Guayana shield (González de Juana, 1980; Di Croce, 1995).

5.2.2.- The “Outer Foothills”.

In the southern edge of the outer foothills reflectors representing upper Miocene and younger sedimentary rocks show steep dips that define frontal anticlines often associated with mud “diapirs” of the deformation front. These reflectors diverge downward from the center of the diapiric compressional fold, showing steep synclines that flank the diapir zone (Figure 5.3). Upward convergence of the uppermost Neogene reflectors against the surface suggests young growth for these shale anticlines.

Listric thrust faults and associated imbricates form the main structures of the outer foothills. The thrust faults are generally interpreted to flatten with depth.
Figure 5.2.a: Foreland seismic data showing offset between strong reflectivity packages in the south (2-3 s) overlain by poor resolution that improves to the top on Tertiary to Recent sedimentary rocks. See figure 5.1 for location.
Figure 5.2.b: Line drawing of profile on figure 5.2.a. Showing south dipping normal faults (2-3 s) overlain by northward thickening Neogene sedimentary rocks. See figure 5.1 for location.
Figure 5.3. a) Uninterpreted seismic profile across the shale anticline.  
b) Interpretation in a line drawing showing how reflectors diverge from the apex of the shale anticline. The near surface reflectors are truncated. The Axis of the southern syncline corresponds to the southern edge of the outer foothills.
and to merge on top of the basement (Figures 5.4.a and b). Imbricates and characteristic fault propagation folds may be described from south to north.

(1) Anticlines with crests at typical depths between 6-7 km. Wavelength of the structures varies between 4-5 km and the total width of the ramps approximately 7-10 km. The anticlines are fault propagation folds (Suppe, 1983).

(2) The level of décollement reaches depths in the order of 10-12 km (see Plate 1)

(3) Profile A (Plate 1) is across the giant El Furrial field. The Paleogene top of the structures is about 5 km deep and the structures are 8 km wide.

(4) Well developed anticlines with Paleogene crests less than 5 km deep with ramps underlying the Pirital thrust fault. These hydrocarbon bearing structures are part of the El Furrial trend described earlier (see Figure 2.9).

Note that structures involving Middle to lower Miocene often appear to be disharmonic with the underlying structures (e.g., upper Miocene synclines coincide with anticlines involving Oligocene/lower Miocene). The data are not sufficient to resolve the structural details within this interval; however, well tops often indicate repeated Miocene sections (intra-Carapita deformation). In addition these Miocene sediments show high pore pressure, an ideal condition for internal decoupling within the Carapita (Roure et al., 1994).
Figure 5.4.a: Seismic data showing strong reflectors (3-4s) describing lower fold geometries overlain by offset fold axis of the upper reflectors (>2s). For location see figure 5.1.
Figure 5.4.b: Line drawing of seismic profile on figure 5.4.a. The figure shows the outer foothills thrust and folds. Note the Neogene disharmonic folds overlying the Cretaceous to Oligocene folds. See Figure 5.1 for location.
It is here suggested that deformation occurred in sequence with an early phase of deformation involving only the higher Carapita shales followed by later deformation involving Cretaceous to Oligocene sedimentary rocks (Figure 5.5). Commonly the definition of "in sequence" is not given. In the context of this study "in sequence" refers to succession of the deformation proceeding from the inside to the outside of the folded belt and from top to bottom. Here as in many other folded belts multiple décollement levels are involved.

5.2.3.- The Inner Foothills.

The inner foothills consist of imbricates that repeat the Cretaceous to Paleogene section, placing the thrusts and related folds close to the surface. These duplex structures override the outer foothills folds. The Carapita section which originally formed the cover of the lower units is now accumulated in the form of the complex described earlier from the outer foothills. Minor decoupling surfaces are also interpreted at the base of the upper Cretaceous (Figure 5.6). The higher units evidently involve a thicker section than the underlying units because the Cretaceous-Paleogene passive margin sequence originally thickened to the north (Figure 5.6).

Intra-Miocene unconformities converge onto the Pirital high; to the north perched and sometimes tilted satellite basins are often developed (e. g., Morichito Basin). Figure 5.6 is a portion of seismic profile across the Morichito satellite basin. The base of this basin is interpreted to be middle Miocene and the top of these isolated basins is upper Miocene (see also Lilliu, 1990; Chevalier; 1990; Linares, 1992; Carnevali et al. 1994; Passalacqua et al. 1995).
Figure 5.5: Two stage deformation with thrusts using Fault bend folds. This sketch mimics the interpretation for the early deformation of the higher Carapita accretionary wedge and later and deeper deformation involving Mesozoic folds of the Monagas foothills. Numbers follow the sequence of deformation. I₅ and I₇ represent "out of sequence".
Figure 5.6: a) Uninterpreted seismic data from the inner foothills. Strong reflectors in the center (2s) describe the fold geometry. Note the offset of upper reflectors (>2s), and the high-dip reflectors converging to the south. b) Interpreted line drawing showing the inner foothills thrust and folds. Crest of some folds underneath appear eroded, showing lower Miocene in contact with upper Cretaceous. See figure 5.1 for location.
To the north this unconformity truncates the crest of the anticlines suggesting continued growth for the near surface blocks of the inner foothills.

5.3.- East-West Strike Profiles.

The description of the strike profiles involves also the lateral correlation of the structures previously examined on the north-south balanced cross sections. The same structural subdivisions are also used.

5.3.1.- The Foreland (Profile K and west half of Profile J).

The foreland area is characterized by basement involved normal faults and flat Neogene reflectors. Seismic profiles show the foreland basement plunging to the east. High angle normal faults offset the basement and the overlying Cretaceous to Paleogene sequence. Orientation of these normal faults is not well known. They are here interpreted mostly as dipping to the west and occasionally to the east (Figures 5.7.a and b).

The Neogene sedimentary cover thickens toward the east. The eastward thickening of the Neogene is associated with the regional eastward progradation of these units (see Di Croce, 1995).

5.3.2.- The Outer Foothills (Profiles J, west half of I, H, and G east half).

The transition between the Foreland and the outer foothills is shown on the eastern portion of Profile J on Plate 2.

Frontal ramps, lateral ramps and imbricates form the main structures of this portion. The arcuate faults flatten with depth to coincide with the top of the
Figure 5.7.a: Foreland seismic data showing offset between strong reflectivity packages on the south (4 s) overlain by poor resolution that improves to the top on tertiary to recent sediments. Note the divergence from east (1.5 s) to west (2.5 s) toward the top within Tertiary to Recent sediments. For location see figure 5.1.
Figure 5.7.b: Line drawing of profile on figure 5.7.a. Showing west dipping normal faults (4-5 s) overlain by east thickening Neogene sediments. Note the Mapirito normal faults involving Middle to Lower Miocene. See Figure 5.1 for location.
basement. These thrusts may be described as follows:

(1) Gentle deep structures with crests at typical depths between 6-7 km. Length along strike of the structures varies between 20-25 km and the

(2) total length of the lateral ramps approximate 30 km (Profiles J east half and I)

(3) The level of décollement reaches depths in the order of 10 - 12 km.

(4) Profile H is across the El Furrial and Boquerón oil fields. The top of the structures is about 5 km deep with an length along strike of 15-20 km.

In the outer foothills, structures typically plunge to the east. Minor blocks along the lateral ramps show the possible repetition of the Cretaceous to Paleogene sequence. Pliocene to Recent thickens toward the east indicating probably eastward sediment transport (see Figures 5.8.a and b).

5.3.3.- The Inner Foothills (Profiles F and G West half).

As mentioned previously, the inner foothills consist of imbricates that place Mesozoic sedimentary rocks on top of Oligocene to Mesozoic sedimentary rocks. The basal décollement at the top of the basement, is consistently shown plunging to the east and all major thrust ramps are connected to the basal décollement as shown on the cross section (see plate 2). Some detachments bring lower Cretaceous on top of lower Miocene (Figure 5.9). Intra-Miocene unconformities converge onto the Pirital high. Perched and sometimes tilted satellite basins are often developed (e.g., Morichito Basin). The
Figure 5.8.a: Seismic data from an outer foothills strike view showing some strong reflectors (3.5-4s). See Figure 5.1 for location.
Figure 5.8.b: Line drawing from seismic data on figure 5.8.a. The figure shows the outer foothills thrust and folds. Deep structures not evident on the seismic are supported from N-S intersections and wells. See figure 5.1 for location.
Figure 5.9: a) Uninterpreted seismic data from the inner foothills. Strong reflectors in the center (2s) describe the fold geometry. Note the offsets of the upper reflectors (>2s), and the high tilted reflectors converging to the ENE. b) Interpreted line drawing shows the inner foothills thrust and folds. See Figure 5.1 for location.
base of these satellite basins is interpreted to be the top of middle Miocene and the top of these isolated basins is upper Miocene. Miocene sedimentary rocks forming satellite basins on the sides of the Pirital high show lower Miocene onlapping Paleogene strata to the west and a conformable contact to the east (Figure 5.10).

5.4.- Depth slice maps.

Depth converted profiles were used to construct “depth slices”. These slices represent the map view of horizontal planes cutting across the depth converted data set. Two depth slices (5 km and 7 km) were selected to summarize the interpretation of the subsurface. Note that this presentation approximately corresponds to the time slices of 3-D seismic surveys. In this context it should be noted that 3-D seismic time slices will eventually provide greatly improved seismic interpretations.

A depth slice at 5 km illustrates the complex thrust faults and the relation between the inner and outer foothills. The widespread distribution of the lower to middle Miocene represents the accretionary wedge of the foothills and great part of the foreland. In the foreland the depth slice shows the distribution of the Cretaceous to Paleogene sedimentary rocks (Figure 5.11)

A deeper slice at 7 km again shows the connection of the thrust faults and correspondence of structures underlying the Pirital imbricates and the complete outer foothills. Lower Miocene are distributed around deep structures and forming narrow wedges along some thrusts (Figure 5.12). In the foreland lower
Figure 5.10: Depth conversion for strike ENE-WSW inner foothills strike profiles. The figure shows the interpreted basal décollement surface plunging to the east (12 km deep) on top of the basement and minor decollements on lower Miocene (6 km deep) and lower Cretaceous (4 km deep). Thickness of the overthrusted higher units is greater than the lower units of the outer foothills. See Figure 5.1 for location.
Figure 5.11.- The depth slice 5 km deep illustrates the connection of thrust faults and the correspondence of structures from the foothills. Abbreviations: DF = Deformation front; PF = Pirital Fault. The deformation front, the Pirital fault, and the Tertiary-Cretaceous contact are the boundaries for the Foreland, Outer Foothills, and Inner Foothills respectively.
Figure 5.12.-The depth slice 7 km deep illustrates the connection of thrust faults and the correspondence of structures from the foothills. Abbreviations: DF= Deformation front; PF= Pirital Fault. The deformation front, the Pirital fault, and the Tertiary-Cretaceous contact are the boundaries for the Foreland, Outer Foothills, and Inner Foothills respectively.
Cretaceous and the basement are shown in the with interpreted orientation of the normal faults and distribution of Cretaceous and Paleogene sedimentary rocks.

5.5.- Serranía del Interior.

The style of the folds of the Serranía del Interior contrasts with foothills and its complex duplex structures and fault propagation folds that involve the Mesozoic (e.g., Jusepín and Quiriquire). The Serranía is characterized by a typical set of décollement folds and faults of the type described from the Jura mountains or Melville Island (e.g., Bally et al., 1985; Harrison and Bally, 1988; Harrison, 1991) (see Figure 5.13).

The San Francisco tear fault has a pronounced lateral offset (Rod, 1956; Rosales, 1973 and Rossi, 1985). The fault is nearly vertical along its NW trend, with a right lateral strike slip offset of the fold axis. To the south the San Francisco tear fault emerges and joins the Quiriquire thrust fault. The Quiriquire thrust probably continues in the subsurface as the décollement of the major thrust faults of the area.

The Neogene is eroded over the Serranía del Interior. The map shows an erosional pattern involving Barremian rocks to the north and gradually younger late Cretaceous and Paleogene outcrops to the south and west of the map. Near the El Pilar strike slip fault, erosion exposes the oldest rocks of the Serranía Barranquin Formation. Farther south, the outcropping folds and thrusts strike N70°E with gradually younger strata exposed up to the San Francisco tear fault,
Figure 5.13: Geologic map of the Serrania del Interior, simplified from Creole, 1965; Rossi, 1985; Chevalier, 1993. Location of surface cross section C, and surface columns are illustrated (Aguasuelos, 1994).
where Oligocene sedimentary rocks are on the surface. To the south of the San Francisco fault, early Cretaceous rocks are exposed again. A similar pattern is shown on the 5 km deep depth slice (Figure 5.14).

5.6.- Foreland-Serranía del Interior transect.

Different versions of regional cross section C show varying interpretations of deep structures beneath the Serranía and their relation to the subsurface structure of the foothills. The most significant problem is the space available between a hypothetical extrapolated foreland Basement top and the outcrops (Figure 5.15). The most important unknown is the nature and thickness of the rocks underlying the lower Cretaceous of the Serranía (i.e., the section below the oldest outcropping stratigraphy shown on Figure 3.8).

5.6.1.- Previously published regional cross sections.

Several authors have drawn cross sections from the Serranía del Interior to the foreland. They all tried to deal with the above mentioned problem proposing single solutions (Figure 5.16) illustrating contradicting interpretations. Rosales, 1973, using mostly surface geology made a schematic cross section which shows from south to north:

(a) Shelf and shallow marine sediments affected by tectonic subsidence in the Foreland.

(b) Foothills structures that display an accretionary wedge that does not involve the basement.

(c) Deformed sedimentary rocks are shown across the Serranía to the El
Figure 5.14: Surface and depth slice (5Km) combined. The figure shows the structural style of both provinces. North of the gap outcrops of the Serrania showing tighter folds. South of the gap depth slice 5 km deep. Abbreviations: DF= Deformation Front; PF= Pirital Fault.
Figure 5.15: Space problem between an extrapolated monoclinal basement and the unknown base of the folded Mesozoic folded unit of the Serrania del Interior.
Figure 5.16: Selected published transects across the Serranía and Monagas foothills:

1) Rosales, 1973. Shallow marine sediments are affected by tectonic subsidence in the Foreland. The foothill structures display an accretionary wedge that does not involve the basement.

2) Rossi, 1985, shows a Deformed Neocomian to Lowermost Miocene platform. The crystalline basement and Paleozoic sediments are involved in the Serranía.

3) Roure, et al., 1994, shows décollement coinciding with the base of the Barrancas formation. "Out of sequence" Pirital thrust remobilize structures of El Furrial and Orocuai oil fields. Passalacqua et al., 1999, shows a high-density intracrustal wedge to fit the gravimetric high of northern Serranía, a deep crustal root beneath the belt and northward dipping South American Moho are suggested.

4) Chevalier, 1995, displays a common décollement at the base of the Cretaceous Basement is involved for the Pirital and San Francisco faults.

5) Martinez, 1995 suggests a common basal décollement lower Cretaceous Kink based geometry describes fault-bend-fold and "anticlinal stack of overlapping anticlines". Decapitated structures are shown underlying the Pirital thrust imbricates.
Pilar fault and in the internal Serranía a high basement block is postulated.

(d) Suggests the possible correlation of this passive margin with the Gulf of Paria and Trinidad.

(e) Orientation of folds axis trending N70°E, and an overall plunge to the west.

(f) Strong erosion increasing to the north.

Rossi, 1985, also using mostly surface data establishes details on the stratigraphy and the structures of the Serranía del Interior. He also provided an interpretation of the subsurface structures that in general involves the following:

a) The assumption of a continental margin platform from Neocomian to lowermost Miocene.

b) An episode of vertical compressional movements affecting the Serranía. Dated from uppermost Oligocene base of Miocene.

c) Assumes Paleozoic sediments and basement involved in the folded belt.

d) Estimates 28% of shortening across the Serranía structures.

Roure et al., 1994, utilizes the internal geometry of the foredeep and chronostratigraphy of syntectonic deposits to constrain the sequence of deformation. These additional tools contributed to the following conclusions:

a) Lower Miocene in-sequence foreland vergent thrust belt.
b) Suggests that décollements are coinciding with coals in the Barranquín Formation or evaporites on late Jurassic or early Cretaceous. Other possible décollements are locally Quercual and lower Miocene.

c) Mud diapirs associated with the dewatering of the Carapita facies.

d) The "out of sequence" Pirital thrust active during the deposition of Pleistocene remobilizes previously emplaced structures (El Furrial and Orocual structures).

Passalacqua et al., 1995, constructed a crustal section interpreting magnetic and gravimetric data. Their conclusions suggest the following:

a) A major gravimetric low along the basin axis shows the progressive northward deepening of the Moho.

b) Positive magnetic anomalies on the southern flank of the basin probably result from shallow basaltic intrusions along the thinned part of the paleomargin or from crustal heterogeneities.

c) A high-density intracrustal wedge is needed to fit the gravimetric high north of the Serranía; the solution requires a deep crustal root beneath the belt and a northward dipping South American Moho.

d) Shortening 45 km in the basement and 90 km in the sedimentary cover discrepancy suggest rifting.

Chevalier (1995), using seismic calibrated by well data, proposed the following:

a) Common décollement base of the Cretaceous.
b) First compression dated as basal-middle Miocene affecting the complete folded belt.

c) Second compression reactivation post middle Miocene time involving basement on the Pirital and San Francisco faults. Chevalier also suggests possible inversion of earlier graben systems.

d) Compression is extended to the foreland. The total shortening is about 2%.

Martinez, 1995, utilizes a kink based geometry e. g., Suppe (1983) to interpret a data set located south to the San Francisco fault combining surface and subsurface data. He postulates the following:

   a) A common basal décollement at the base lower Cretaceous through the entire folded belt.

   b) Additionally décollements within the middle Miocene are considered for the inner foothills.

   c) Kink geometry suggest fault-bend folds for the foothills and an “anticlinal stack of overlapping anticlines” (e. g., Mitra 1986) is suggested for the inner foothills.

   d) Shows decapitated structures underlying the Pirital thrust imbricates.

   e) Gravity modeling based on 20 km deep profiles suggest the Maturín sub-basin overlying a pre-Cretaceous Graben.

5.7.- Hypothesis on Foreland-Serranía Transect.

Profile C ties the modified surface section of the Serranía to the foothills and foreland. Six different hypotheses will be examined (Plate 3 ) as follows:
1. Basement-involved structures across the whole area

2. Basement-involved structures only underneath the Serranía

3. Paleozoic Sediment wedge underlying the foothills but involved in the Serranía.

4. Inversion of Jurassic half-grabens underneath the Serranía

5. Multiple décollement surfaces

6. Extensive duplex structures beneath the Serranía

Table 5.2 compiles the main characteristics for these hypotheses, listed in the order of increasing shortening.

5.7.1. - Basement-Involved structures.

The “Basement-Involved” hypothesis assumes high angle reverse faults throughout the folded belt. The basement forms a regional synform, with its deepest portion coinciding with the basin axis. The southern portion of the synform is characterized by normal faults, whereas the north portion involves north dipping reverse faults, and the top of the basement ranges between 4 km and 6 km deep. Intrabasement-décollement is assumed to be on a crustal scale. Minimum shortening of about 35 km (20%) it is distributed between all reverse faults (Plate 4).

The main problem with this interpretation is the presence of a shallow, presumably magnetic basement. Magnetic data published so far do not show corresponding uplift with an abrupt relief of some 8 km at the south margin of the Serranía (see Potié, 1989).
Table 5.1: Six different hypotheses for regional Profile C.

<table>
<thead>
<tr>
<th>Hypotheses</th>
<th>Minimum Shortening Approximated (%) · (Km)</th>
<th>Décollements</th>
<th>Age Of Deformation</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basement-Involved deformation.</td>
<td>9% 16 Km</td>
<td>Intrabasement</td>
<td>Middle Miocene to Present</td>
<td>High angle reverse faults throughout the folded belt. Basement controls a Regional Synform</td>
</tr>
<tr>
<td>Basement-Involved deformation beneath the Serrania. In the foothills, only sediments are involved.</td>
<td>20% 35 Km</td>
<td>Intra-basement</td>
<td>Middle Miocene to Present</td>
<td>Thick wedge of Precambrian Rocks is juxtaposed to sediment-involved structures in the foothills. Regional basement ramp surface deepens to the north to join the El Pilar at 35km depth.</td>
</tr>
<tr>
<td>Paleozoic Sediment Wedge</td>
<td>21% 37 Km</td>
<td>Infra-Paleozoic</td>
<td>Middle Miocene to Present</td>
<td>A wedge of Paleozoic sediments underlie the folded belt. Regional low angle ramp detaches Paleozoic sediments from the underlying Basement thus decoupling the whole Serrania.</td>
</tr>
<tr>
<td>4 Graben Inversion</td>
<td>21% 37 Km</td>
<td>Intra-basement</td>
<td>Middle Miocene to Present</td>
<td>Serrania high inverted half grabens.</td>
</tr>
<tr>
<td>5 Imbricates with Multiple Long Décollements</td>
<td>63% 110 Km</td>
<td>Base Pre-Barranquín.</td>
<td>Middle Miocene to Present</td>
<td>Ramps emerging on high angle thrusts. Greater thickness for Pre-Barranquín sediments assumed.</td>
</tr>
<tr>
<td>6 Duplex beneath the Serrania</td>
<td>66% 115 Km</td>
<td>Base Pre-Barranquín.</td>
<td>Middle Miocene to Present</td>
<td>Duplication of the passive margin sequence. Multiple anticline structures beneath the Serrania.</td>
</tr>
</tbody>
</table>
5.7.2.- Basement-Involved only under the Serranía.

Beneath the Serranía a thick wedge of Precambrian rocks is juxtaposed to the décollement structures of the foothills. Intra-basement regional décollement surfaces suggest the underlying autochtonous at least 30 km north of the present day section, see reconstruction (Plate 5). In addition the base of the Pre-Barranquín section and Miocene (Carapita base) are shown as minor décollements. The Quiriquire thrust fault, juxtaposes Precambrian crystalline basement to sediments of the foothills. The Quiriquire thrust is shown to be the frontal ramp of a large structure associated with the San Francisco tear fault as previously suggested from the surface map. Here again the published magnetic data do not show an obvious magnetic basement uplift.

5.7.3.- Paleozoic Sediment Wedge.

This hypothesis assumes a regional low angle ramp detaching Paleozoic sediments from the Basement. The ramp decouples the whole Serranía from the undeformed basement. The slope of the top of the basement increases beneath the foothills and can be estimated to reach depths of about 35 km (see Plate 6). Relatively undeformed Paleozoic sedimentary rocks in the basin have been reported from wells to the west in the Guárico sub-basin. This interpretation suggests a distribution to the northeast of the Paleozoic sediments beneath the Eastern Venezuela folded belt (see Feo Codecido, 1984). Positive evidence supporting this interpretation will only come with better pre-Cretaceous seismic resolution and drilling.
5.7.4.- Inverted half graben structures.

In this interpretation the assumed inversion of Jurassic half grabens is combined with late Jurassic - early Cretaceous evaporites that may coincide with local décollements (e.g., Roure et al., 1994)(Plate 7). Syn-rift sequences may correspond to a Triassic to late Jurassic rift phase (e.g., Burke, 1988; Stephan et al., 1990; Pindell, 1990; Di Croce, 1995). The presence of Triassic to upper Jurassic rift fill supported by wells from the Espino Graben to the west, where late Jurassic La Quinta Formation overlies thick Paleozoic rocks of the Hato Viejo and Carrizal Formations, see Appendix A (Hedberg, 1950; Beck, 1978; Fiorillo, 1982; Feo Codecido, 1984; Bartok, 1993)(See Figure 3.3). This interpretation agrees in principle with Roure et al., 1994 and Chevalier et al., 1995; however, here the assumed thickness of the synrift deposits is much larger (see Plate 7).

The interpretation is weak because seismic in the foreland shows only very limited Triassic-Jurassic extension. However conclusive mapping of the Jurassic of the Espino Graben to the east could strengthen this interpretation. To the northeast in the Gulf of Paria and Trinidad folded belt three wells have penetrated into evaporites of late Jurassic-early Cretaceous age suggesting the possible detachment of the overlying rocks (Arstein et al., 1985; Chiock, 1985).

5.7.5.- Imbricates with multiple décollements.

This interpretation shows imbricates associated with high angle thrusts. The greater thickness of Pre-Barranquín sediments corresponds to a northward
passive margin thickening (Plate 8). Similar but smaller imbricate structures characterize the foothills.

Reconstruction of this interpretation implies substantial shortening estimated in the order of 110 km. In the Gulf of Paria and Trinidad well data have shown late Jurassic to early Cretaceous evaporites as a possible décollement level (Roure, 1994). On the other hand, shale-rich formations such as the Querecual (see Appendix A) may serve as additional décollement surface (Chevalier et al., 1995). In the same way it is conceivable that shale-rich formations like García and Chimana (See Appendix A) are potential detachment surfaces involved in the highly imbricated structures cited in this interpretation (Plate 8).

This interpretation like the preceding versions needs to be tested by gravity and magnetic models. However ultimately much better seismic across the foothills and deep seismic reflection data across the Serranía calibrated with wells will convincingly constrain this interpretation.

5.7.6.- Duplex structures beneath the Serranía.

This interpretation suggests extensive shortening and repetition of Cretaceous-Oligocene passive margin sequence beneath the Serranía and part of the foothills. Complex duplex structures are assumed to occur beneath the Serranía. Notice that a decoupling surface occurs on top of the lower Miocene (Carapita formation) part of which is now represented by an accretionary wedge in the foothills (Plate 9). Sediments in this accretionary wedge show high pore pressure (Ysaccis et al., 1993; Octavio et al., 1996), an ideal condition for
decoupling within the Carapita (see Gretener, 1981). The overriding imbricated blocks are evidently thicker than the underlying units because the Cretaceous-Paleogene passive margin sequence is assumed to thicken toward the north.

The autochthonous Precambrian basement remains undeformed and possibly continues to the north coinciding with the regional décollement. The El Pilar strike-slip fault also merges into this major detachment which as a whole can be viewed as the basis of a transpressional orogenic float; see Oldow, et al. (1990) and Bally et al. (1995).
Chapter 6: CONCLUSIONS.

6.1.- CONCLUSIONS.

1. The nature of the basement is poorly defined. Whether the basement consists entirely of crystalline Precambrian or else of Paleozoic sediments and/or Jurassic half grabens cannot be decided on the base of the available data.

2. Assuming little or no basement involvement in the structures of the Monagas foothills, the top of the basement may be extrapolated at least to the southern edge of the Serranía del Interior. However the top of the basement could also dip farther north and extend all the way to the El Pilar strike-slip fault. Extrapolation of a gently northward dipping foreland basement top creates a significant space problem.

3. Basement-involved interpretations suggest shortening in the order of 15-30 km for a point near the El Pilar fault. However interpretations that do not involve the basement show the largest amount of shortening, implying a northward displacement of the El Pilar fault in excess of 100 Km. Thus alternative hypotheses imply that shortening across the Serranía to foreland transect may range from 9% to 66%.

4. The foreland-verging thrust system appears to be “in sequence”, i.e. the deformation proceeds from top to bottom and from north to south.

5. In the Monagas foothills décollements at the base of the Miocene are responsible for the formation of the complex Carapita accretionary wedge. The
deeper structures of the Monagas foothills involves the Mesozoic and were formed after the Carapita accretionary wedge. Apparent “out of sequence” relations at the surface and in the shallow subsurface are due to the interference of late lower structures with the earlier structures, of the Carapita accretionary wedge.

6. The choice between the various interpretations given in this paper is important because basement involvement under the Serranía leaves no prospects for hydrocarbon, whereas the duplex interpretation leaves room for sizable gas exploration targets.

6.2.- What Next?

1. To check the various hypotheses we need more extensive gravity transverses across the Serranía and new gravity models. Magnetic models are also necessary to compare and constrain the position of a hypothetical magnetic basement beneath the Serranía del Interior and underneath the Monagas foothills structures.

2. It is expected that even after gravity and magnetic modeling, a number of alternative models will survive because of the uncertainty in the density assumptions for different layers.

3. Only deeper and better quality conventional seismic across the Monagas foothills and successful crustal profiles from offshore Caribbean through the Serranía will further constrain the models before testing them by drilling.
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Appendix A

Stratigraphic Glossary

1.-  **Paleozoic**

**Formation Name:** Hato Viejo

Defined by: Hedberg, 1942

**Age:** Cambrian

**Lower Boundary:** Unconformable, underlain by the Precambrian crystalline basement.

**Upper Boundary:** Conformable, overlain by the Carrizal Formation.

**Lithology:** Medium- to coarse -grained arkosic-quartzitic sandstone.

**Thickness:** Max. 100 m.

**Key fossils:** Not known.

**Environment:** Continental

**Type section and distribution:** Well Hato Viejo 1 and in subsurface of Anzoátegui state.

**Formation Name:** Carrizal

Defined by: Hedberg, 1942

**Age:** Cambrian.

**Lower Boundary:** Conformable, underlain by the Hato Viejo Formation.

**Upper Boundary:** Unconformable, overlain by the Temblador Group or Oficina Formation.
Lithology: Massive dense greenish argillites, remarkably homogeneous, variably silty intercalated with beds of sandstone or pebble conglomerate.

Thickness: Max. 650 m.

Key fossils: Poorly preserved fish remains.

Environment: Continental

Type section and distribution: Well Carrizal 1 in Anzoátegui state and has been penetrated by wells in Guárico state and Southwestern Anzoátegui.


2.- Cretaceous

Formation Name: Barranquín (Sucre Group)

Defined by: Liddle, 1928.

Members from bottom to top: Taguarumo, Picuda, Morro Blanco and Venados.

Age: Neocomian-Barremian-Aptian

Lower Boundary: Unknown

Upper Boundary: Conformable, overlain by the El Cantil Formation.

Lithology: To the south of the Serranía mainly sandstone coal and shale. To the north limestone and bioclastic and calcareous pelites.

Thickness: 1300 m to 1700 m.

Key fossils: Nannoplankton (Nannoconus colomii), benthic foraminifera (Choffatella decipiens) and Rudists (Caprina sp and Amphitricoceous sp)

Environment: Continental/fluvial/deltaic/littoral.
Type section and distribution: Barranquín village and Cumana-Cumanacoa road. Widely distributed in the Serranía del Interior, Mochima Bay, Las Caracas Island, Pico García and Cerro El Algarrobo.


Formation Name: El Cantil (Sucre Group)

Defined by: Liddle, 1928.

Member: García.

Age: Late Aptian to middle Albian.

Lower Boundary: Conformable, underlain by the Barranquín Formation.

Upper Boundary: Conformable, overlain by the Chimana Formation.

Lithology: Three units: lower unit glauconitic shale and alternation of limestones pelites shales and quartz clays; middle unit, sandy sequence; and upper unit, made up of thick limestone beds with variable thickness up to 400 m.

Thickness: Max. 850 m.

Key fossils: Planktonic foraminiferal (Chakoina cabri), ammonites (Zone A. Nisus) and Orbitolina texana.

Environment: Shallow water and marginal marine.

Type section and distribution: Rio Punceres and widely distributed in the Serranía del Interior.

Member Name: Garcia.
Defined by: Rod and Maync, 1954.
Age: Aptian.
Lower Boundary: Conformable, underlain by the Barranquín Formation.
Upper Boundary: Conformable, overlain by the El Cantil Formation.
Lithology: Limestones and fossiliferous brown shales.
Thickness: Max. 100 m.
Key fossils: Choffatella decipiens
Environment: Shallow water.
Type section and distribution: Pico García, near Aragua de Maturín, Monagas State.

Formation Name: Chimana (Sucre Group)
Defined by: Hedberg and Pyre, 1944.
Age: Middle to upper Albian.
Lower Boundary: Conformable, underlain by the El Cantil Formation.
Upper Boundary: Conformable, overlain by the Querecual Formation.
Lithology: Gray shale, gray limestone and fine to coarse glauconitic sandstone.
Thickness: Max. 270 m.
Key fossils: Abundance of pelagic fauna of ammonites, belemnites, foraminifera and nannoplankton.
Environment: Open marine shelf.

Type section and distribution: Chimana Grande island.


**Formation Name:** Temblador (Temblador Group)

Defined by: Hedberg, 1942.

Age: Middle Aptian to Albian.

Lower Boundary: Erosional unconformity underlain by the crystalline basement.

Upper Boundary: Conformable, overlain by the Tigre Formation.

Lithology: Sandstone and shale.

Thickness: Max. 690 m.

Key fossils: Unidentified plant remains.

Environment: Continental (fluvial) to coastal marine.

Type section and distribution: Well Tigre-1. Distributed in the subsurface southern Anzoátegui and Monagas.


**Formation Name:** Tigre (Temblador Group)

Defined by: Hedberg, 1950.

Members: Subdivided into three Members in the Guárico subbasin: La Cruz at the base, Infante and Guavina at the top.

Age: Cenomanian-Campanian..
Lower Boundary: Conformable, underlain by the Canoa Formation.

Upper Boundary: Unconformable, overlain by the Oficina or Merecure Formation.

Lithology: Glauconitic sandstone, carbonaceous shale and dolomitic limestone.

Thickness: Max. 510 m.

Key fossils: Ammonites, brachiopods, bivalves, fish and foraminifera.

Environment: Deltaic-nearshore-marine.

Type section and distribution: Well Tigre-1. Distributed in the subsurface southern Anzoátegui and Monagas.


Formation Name: Querecual (Guayuta Group)

Defined by: Hedberg, 1937.

Age: Cenomanian-Santonian.

Lower Boundary: Conformable, underlain by the Chimana Formation.

Upper Boundary: Conformable, overlain by the San Antonio Formation.

Lithology: Limestone and pyritic-black shale with abundant concretions.

Thickness: 250 m to 650 m.

Key fossils: Pelagic foraminifera (Globigerina, Globotruncana and Gumbelina), ammonites and inoceramus.

Environment: Open-marine shelf and deep water.
Type section and distribution: Rio Querecual southeast Bergantín town and widely exposed in the Serranía del Interior.

Comments: The Querecual Formation represents the main hydrocarbon source rocks of Eastern Venezuelan Basin.


Formation Name: San Antonio (Guayuta Group)

Defined by: Hedberg, 1937.

Age: Santonian-Campanian.

Lower Boundary: Conformable, underlain by the Querecual Formation.

Upper Boundary: Conformable, overlain by the San Juan Formation.

Lithology: Dark shale, glauconitic limestone finely laminated and calcareous sandstone.

Thickness: 350 m to 950 m.

Key fossils: Foraminifera (Siphogenerinoides).

Environment: Outer shelf.

Type section and distribution: Rio Querecual and extending along the Serranía del Interior.


Formation Name: San Juan (Santa Anita Group)

Defined by: Hedberg, 1937.

Age: Maastrichtian.
Lower Boundary: Conformable, underlain by the San Antonio Formation.

Upper Boundary: Conformable, overlain by the Vidoño Formation.

Lithology: Mostly fine- to coarse-grained well stratified sandstone, shale and siltstone.

Thickness: Max. 520 m.

Key fossils: Benthic foraminifera (Cyclamina).

Environment: Turbidites deposited in an outer shelf to deep water.

Type section and distribution: Rio San Juan a sidebranch of Rio Querecual. Well exposed along the Serranía del Interior.


3.- Tertiary

Formation Name: Vidoño (Santa Anita Group)

Defined by: Hedberg and Pyre, 1944.

Age: Late Maastrichtian-Paleocene.

Lower Boundary: Conformable, underlain by the San Juan Formation.

Upper Boundary: Conformable, overlain by the Caratas Formation.

Lithology: Mainly black, calcareous, glauconitic and massive shale interbedded with minor thin beds of glauconitic sandstone and calcareous siltstone.

Thickness: 200 m to 305 m.
Key fossils: Benthic foraminifera (Rhabdammina, Spiroplectammina, Gaudryina, Trochammina, Bulimina and Eponides) and planktonic foraminifera (Globotruncana Gansseri and Globorotaria rex).

Environment: Open marine shelf to deep water.

Type section and distribution: Rio Quercual near Vidoño locality, 6 km east of Barcelona. Exposed mostly in the Serranía del Interior.


Formation Name: Caratas (Santa Anita Group)

Defined by: Hedberg, 1937.

Member: Tinajitas.

Age: Eocene.

Lower Boundary: Conformable, underlain by the Vidoño Formation.

Upper Boundary: Unconformable, overlain by the Los Jabillos Formation.

Lithology: Calcareous and dolomitic siltstone, fine- to medium-grained sandstone and brownish gray shales and limestones.

Thickness: 330 m to 600 m.

Key fossils: Orbulinoides beckmanni, Truncorotaloides rohri, Globigerina linaperta, Globorotalia Wilcoxensis, Globorotalia cerroazulensis, Globigerina ampliapertura and macroforaminifers such as Asterocyclina sp., Plioplepida tobleri and Tubulositum sp.

Environment: Shallow to deep water.
Type section and distribution: Rio Querecual. Exposed along the Serranía del Interior.


Formation Name: Los Jabillos (Merecure Group)

Defined by: Hedberg, 1937.

Age: Lower Oligocene-basal middle Oligocene.

Lower Boundary: Erosional unconformable, underlain by the Caratas Formation (Tinajitas Member).

Upper Boundary: Conformable, overlain by the Areo Formation.

Lithology: Thick-bedded fine- to coarse-grained quartzitic sandstone locally glauconitic.

Thickness: 150 m to 340 m.

Key fossils: Benthic foraminifera, ostracods, bivalves and gastropods.

Environment: Shallow water upon a near-shore platform (littoral to sub-littoral).

Type section and distribution: Rio Querecual. Exposed as prominent topographic marker across most of northeastern Anzoátegui.


Formation Name: Areo (Merecure Group)

Defined by: Hedberg, 1950.

Age: Upper Oligocene.

Lower Boundary: Conformable, underlain by the Los Jabillos Formation.
Upper Boundary: Conformable, overlain by the Naricual Formation.

Lithology: Mostly dark gray glauconitic shales and occasional gray quartzitic sandstones.

Thickness: 250 m to 1200 m.

Key fossils: Globorotalia opima opima and Globorotalia ciperoensis ciperoensis.

Environment: Deep water.

Type section and distribution: Rio Areo. Exposed mostly in streams in northwesternmost Monagas and northeasternmost Anzoátegui.


Formation Name: Naricual (Merecure Group)

Defined by: Hedberg and Pyre, 1944.

Age: Uppermost Oligocene to early Miocene.

Lower Boundary: Conformable, underlain by the Los Jabillos Formation.

Upper Boundary: Conformable, overlain by the Carapita Formation.

Lithology: Carbonaceous shales, sandy shales and sandstones followed by coal-bearing package interbedded with massive quartzitic medium- to coarse-grained sandstone and gray shales.

Thickness: 1800 m.

Key fossils: Globorotalia kugleri and abundant preserved plants.

Environment: Unstable shelf with high rate of sedimentation and evidence of turbidite facies.
Type section and distribution: Vicinity of the coal mining town of Naricual.

Well exposed in the valley of the Rio Naricual, in the mines and in the roads of this area.


**Formation Name:** Merecure.

**Defined by:** Hedberg, 1937.

**Age:** Late Oligocene-early Miocene

**Lower Boundary:** Unconformable, underlain by the Temblador Group.

**Upper Boundary:** Conformable, overlain by Oficina Formation.

**Lithology:** Mostly fine- to coarse-grained sandstones and carbonaceous shales.

**Thickness:** Max. 580 m.

**Key fossils:** Not known.

**Environment:** Fluvial and lacustrine to shallow marine.

Type section and distribution: Wells in Santa Ana field, Anaco trend.


**Formation Name:** Carapita.

**Defined by:** Hedberg, 1937.

**Member:** Chapapotal.

**Age:** Lower Miocene-middle Miocene.
Lower Boundary: In outcrop conformable, underlain by the Aro Formation.

Upper Boundary: In subsurface unconformable, overlain by La Pica Formation.

Lithology: Mostly dark gray to black calcareous and microfossiliferous shales and occasionally intercalations of thin beds of fine-grained sandstone.

Thickness: 800 m to 2000 m.

Key fossils: Globorotalia ampliapertura, Globorotalia opima opima, Globigerina ciperoensis ciperoensis, Globorotalia kugleri, Catapsydrax dissimilis, Globigerinatella insueta, Globorotalia fohsi, Globorotalia mayeri and Globorotalia menardii and abundant benthic foraminifera.

Environment: Outer edge of the continental platform to deep water (upper part of the lower continental slope).

Type section and distribution: Quebrada Carapita, tributary to Rio Querecual.

Extended in the subsurface of the Eastern Venezuela Basin and northeastern Anzoátegui.


Formation Name: Oficina.

Defined by: Hedberg et al., 1942.

Age: Lower Miocene to middle Miocene.

Lower Boundary: Conformable, underlain by the Merecure Formation.

Upper Boundary: Conformable, overlain by the Freites Formation.
Lithology: Gray to brownish-gray shales, light gray, fine- to coarse-grained sandstones and siltstones, with lignites, lignitic shales, sideritic and glauconitic sandstones and thin limestones.

Thickness: 200 m to 2000 m.

Key fossils: Bolivina, Operculinoides, Robulus, Elphidium, Rotalia, Buliminella and Globorotaria fohsi.

Environment: Terrestrial (fluvial, lacustrine) to marginal or shallow marine.


Formation Name: Freites.

Defined by: Hedberg et al., 1942.

Age: Middle Miocene.

Lower Boundary: Conformable, underlain by the Oficina Formation.

Upper Boundary: Conformable, overlain by the La Pica Formation.

Lithology: Shaly, fine-grained, gray and slightly glauconitic sandstones, greenish-gray fissile shales and yellow-green, medium to coarse-grained, glauconitic, calcareous or sideritic fossiliferous sandstones.

Thickness: 270 m to 1000 m.

Key fossils: Mollusks (Chione, Chlamys, Tellina, Corbula and Anomia) and foraminiferas.
Environment: Open marine space, moderate water depth.

Type section and distribution: Wells not specified in the Oficina field, Anzoátegui state.


Formation Name: La Pica.

Defined by: Hedberg et al., 1950.

Age: Upper Miocene.

Lower Boundary: Conformable, underlain by the Carapita and Freites Formations.

Upper Boundary: Locally unconformable, overlain by the Las Piedras Formation.

Lithology: Mostly gray shales and silty shales, occasional fine-grained sandstones.

Thickness: Max. 2000 m.

Key fossils: Rich in foraminifera (Zone of Globorotalia menardii, Zone of Discamminoides tobleri, Zone of Sigoilina and Zone of Textularia).

Environment: Shallow marine.

Type section and distribution: Well La Pica-1, Monagas state. Distributed in the subsurface of the Eastern Venezuelan Basin.


Formation Name: Morichito.
Defined by: Lamb and De Sisto, 1963.

Age: Upper Miocene ?.

Lower Boundary: Unconformable, underlain by the Carapita and Freites Formations.

Upper Boundary: Unconformable, overlain by the Las Piedras Formation.

Lithology: Conglomerates, sandstones and siltstones.

Thickness: Max. 1600 m.

Key fossils: Not known.

Environment: Continental (alluvial fans).

Type section and distribution: Well Morichito-1, Monagas state. Distributed in the subsurface of the Pirital-Jusepín field.

Additional References: González de Juana et al., 1980.

**Formation Name:** Las Piedras.

Defined by: González de Juana, 1946.

Age: Late Miocene-Pliocene.

Lower Boundary: Unconformable, underlain by the Freites and the La Pica Formations.

Upper Boundary: Unconformable, overlain by the Mesa Formation.

Lithology: Sandstones, carbonaceous siltstones, shales and lignites.

Thickness: Max. 1370 m.

Key fossils: Quinqueloculina fusca and mollusks (Corbicula monagasensis, Corbicula desolai and Hyria trinitaria).

Environment: Fluvial deltaic to shallow marine.
Type section and distribution: Well Las Piedras-1, Monagas state. Distributed in the subsurface of the Eastern Venezuela Basin.


Formation Name: Mesa.

Defined by: Hedberg and Pyre, 1944.

Age: Pleistocene.

Lower Boundary: Unconformable, underlain by the Las Piedras Formation.

Lithology: Red, coarse-grained sandstones, pebbles, siltstones and shales.

Thickness: Max. 270 m.

Key fossils: Not known.

Environment: Coalescing alluvial fans, deltaic and paludal.

Type section and distribution: Widespread topographical features consisting of flat-topped hills with abrupt sloping sides, along Anzoátegui and Monagas States.

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UMI
NORTH-SOUTH OF THE MATURIN

PROFILE A

FOOTHILLS | INNER FOOTHILLS

PROFILE B

FOOTHILLS | INNER FOOTHILLS
CONVERSION

OUTER FOOTHILLS    INNER FOOTHILLS

J   I   H   G   F

DEPTH (Km)
0   2   4   6   8   10   12
LEGEND

- TOP OF PLIOCENE
- TOP OF UPPER MIOCENE
- TOP OF MIDDLE MIOCENE
- TOP OF OLIGOCENE
- TOP OF CRETACEOUS
- TOP OF LOWER CRETACEOUS

PROFIL
PLATE 1

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UMI
LINE DRAWINGS

PROFILE J

FORELAND
EAST-WEST PROFILES OF THE MATURIN SUB-BASIN
DEPTH CONVERSION
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UMI
1) Basement-Involved Structures

2) Basement-Involved Structures
Only Beneath Serranía
3) Paleozoic Sediment Wedge

4) Inversion Of Jurassic Half-Graben
6) Extensive Duplex Structures Beneath The Serranía
Elements

SURFACE SECTION
SERRANÍA DEL INTERIOR

NW

DEPTH (KM)
<table>
<thead>
<tr>
<th>HYPOTHESES</th>
<th>MINIMUM SHORTENING</th>
<th>DÉCOLLEMENTS</th>
</tr>
</thead>
</table>
| **1) Basement-Involved deformation.** | 9%  
16 Km | Intrabasement  
High Base |
| **2) Basement-Involved deformation beneath the Serrania. In the foothills, only sediments are involved.** | 20%  
35 Km | Intra-basement  
Base Pre-Barracquín and Miocene (Carapita base)  
Thick sedimentary basin  
Regime north |
| **3) Paleozoic Sediment Wedge** | 21%  
37 Km | Infra-Paleozoic  
Base Pre-Barracquín  
Lower Miocene  
A well belt  
Regime sediments  
Depositional deposits |
| **4) Graben Inversion** | 21%  
37 Km | Intra-basement  
Locally:  
Top of Jurassic  
Lower Miocene  
Serrania |
| **5) Imbricates with Multiple Long Décollements** | 63%  
110 Km | Base Pre-Barracquín  
Lower Miocene  
Top of Barremian (in Serrania)  
Ramp  
Great assuran |
| **6) Duplex beneath the Serrania** | 66%  
115 Km | Base Pre-Barracquín  
Lower Miocene  
Duplication  
Multiple |

**LEGEND**

- **P** S PLEISTOCENE
- **P** P PLEISTOCENE
- **P** M PLAGIOCENE
- **M** U UPPER MIOCENE
- **M** L LOWER AND MIDDLE MIOCENE
- **T** L PALEOGENE
- **K** U UPPER CRETACEOUS

**LOC**
<table>
<thead>
<tr>
<th>MINIMUM SHORTENING</th>
<th>DÉCOLLEMENTS</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>APPROX (%) - (KM)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9% 16 Km</td>
<td>Intrabasement</td>
<td>High angle reverse faults throughout the folded belt. Basement controls a Regional Synform</td>
</tr>
<tr>
<td>20% 35 Km</td>
<td>Intra-basement Base Pre-Barranquin and Miocene (Carapita base)</td>
<td>Thick wedge of Precambrian Rocks is juxtaposed to sediment-involved structures in the foothills. Regional basement ramp surface deepens to the north to join the El Pilar at 35km depth.</td>
</tr>
<tr>
<td>21% 37 Km</td>
<td>Infra-Paleozoic Base Pre-Barranquin, Lower Miocene</td>
<td>A wedge of Paleozoic sediments underlie the folded belt. Regional low angle ramp detaches Paleozoic sediments from the underlying Basement thus decoupling the whole Serranía.</td>
</tr>
<tr>
<td>21% 37 Km</td>
<td>Intra-basement Locally: Top of Jurassic Lower Miocene</td>
<td>Serranía high inverted half grabens.</td>
</tr>
<tr>
<td>63% 110 Km</td>
<td>Base Pre-Barranquin, Lower Miocene Top of Barremian (in Serranía)</td>
<td>Ramps emerging on high angle thrusts. Greater thickness for Pre-Barranquin sediments assumed.</td>
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<tr>
<td>66% 115 Km</td>
<td>Base Pre-Barranquin, Lower Miocene</td>
<td>Duplication of the passive margin sequence. Multiple anticline structures beneath the Serranía.</td>
</tr>
</tbody>
</table>

LOCATION MAP

[Map showing geographical locations]
2) Basement-Involved Structures Only Beneath Serranía
4) Inversion Of Jurassic Half-Graben
SURFACE SECTION
TERRANÍA DEL INTERIOR
6) Extensive Duplex Structures Beneath The Serranía
5) Imbricates with
Multiple Long
Décollements
6) Duplex beneath the
Serrania

<p>| | | |</p>
<table>
<thead>
<tr>
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<tr>
<td>63%</td>
<td>110 Km</td>
<td>Base Pre-Barranquín. Lower Miocene Top of Barremian (in Serrania)</td>
</tr>
</tbody>
</table>
| 66% | 115 Km | Base Pre-Barranquín. Lower Miocene

Ramps emerge
Greater thickness assumed.
Duplication of
Multiple anticlines.

LEGEND

PS
PI
MIU
MII
TL
KU
KL
BR
PB BR
JJ
PZ
PC

PLEISTOCENE
PLIOCENE
UPPER MIOCENE
LOWER AND MIDDLE MIOCENE
PALEogene
UPPER CRETACEOUS
LOWER CRETACEOUS
BARREMian
PRE-BARRANQUIN
JURASSIC
PALEOZOIC
PRECAMBRIAN BASEMENT

LOCATIONS

CARIBBEAN

GUARICO SUBBASIN

FOREDEEP AND THRUST BELT INT OF THE MATURIN SUBBASIN, EASTERN DEPARTMENT OF GEOLOGY AND RICE UNIVERSITY
ENRIQUE J. HUNG (199
<table>
<thead>
<tr>
<th>Percentage</th>
<th>Location</th>
<th>Description</th>
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<tr>
<td>63%</td>
<td>Lower Miocene</td>
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<td>66%</td>
<td>Base Pre-Barranquín, Lower Miocene</td>
<td>Duplication of the passive margin sequence. Multiple anticline structures beneath the Serranía.</td>
</tr>
<tr>
<td>110 Km</td>
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<tr>
<td>115 Km</td>
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**LOCATION MAP**

![Location Map of the Caribbean Sea, showing major geological features like Margarita Island, Guayana Shield, and the Maturin Subbasin.]

**PLATE 3**

FOREDEEP AND THRUST BELT INTERPRETATION OF THE MATURIN SUBBASIN, EASTERN VENEZUELA BASIN.

DEPARTMENT OF GEOLOGY AND GEOPHYSICS

RICE UNIVERSITY

ENRIQUE J. HUNG (1997)
Hypothesis 1:

LEGEND

- PS  PLEISTOCENE
- PI  PLIOCENE
- MIU  UPPER MIocene
- MLC  LOWER AND MIDDLE MIocene

EL PILAR FAULT

SCO FAULT
Maturín Foreland-Serranía del Interior

Hypothesis 1: Basement Involved

LEGEND

- PLEISTOCENE
- PlioCENE
- UPPER MIOCENE
- LOWER AND MIDDLE MIOCENE
- BARREMIA
- PRECAMBRIAN

EL PILAR FAULT

PLATE 4

Enrique Hung, 1997.
Hypothesis 2: Basement involved beneath the ancient foreland basin
Maturín Foreland-Serranía del Interior

Hypothesis 2: Basement Involved Beneath The Serranía

LEGEND

PS PLEISTOCENE

TL PALEOGENE

PI PLIOCENE

KU UPPER CRETACEOUS

MIL UPPER MIocene

EL LOWER CREtACEOUS

MIL LOWER AND MIDDLE MIocene

BR BARREMIAN  PRE-BARRANQUIN

PC PRECAMBRIAN

BASEMENT

DEPTH (KM)

32

36

EL PILAR FAULT

PLATE 5

Enrique Hung, 1997.
Maturín Foreland
Serranía del Interior

Hypothesis 3: Paleogene Sedimentation

LEGEND

PS  PLEISTOCENE
PI  PLEISTOCENE
MU  UPPER MIOCENE
MI  MIDDLE MIOCENE
PL  LOWER AND MIDDLE MIOCENE
TL  PALEogene
PC  PRECAMBRIAN

FRANCISCO FAULT

A T
Maturín Foreland-
Serranía del Interior

Hypothesis 3: Paleozoic Sediments

LEGEND

PLEISTOCENE

PLIOCENE

UPPER MIocene

LOWER AND MIDDLE MIocene

PALEOGNE

UPPER CRETACEOUS

LOWER CRETACEOUS

BARREMIAN

PALEOZOIC

PRE-CAMBRIAN

BASEMENT

EL PILAR FAULT

PLATE 6

Enrique Hung, 1997.
Maturín Foreland-Serranía del Interior

Hypothesis 4: Inverted Grabens

LEGEND

<table>
<thead>
<tr>
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<th>Abbreviation</th>
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<tr>
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<tr>
<td>Pliocene</td>
<td>PI</td>
</tr>
<tr>
<td>Upper Miocene</td>
<td>MIU</td>
</tr>
<tr>
<td>Lower and Middle Miocene</td>
<td>MIL</td>
</tr>
<tr>
<td>Paleogene</td>
<td>TL</td>
</tr>
<tr>
<td>Upper Cretaceous</td>
<td>KU</td>
</tr>
<tr>
<td>Lower Cretaceous</td>
<td>KL</td>
</tr>
<tr>
<td>Barremian</td>
<td>BR</td>
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<tr>
<td>Pre-Barranquín</td>
<td>PBR^7</td>
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<tr>
<td>Jurassic</td>
<td>JJ</td>
</tr>
<tr>
<td>Paleozoic</td>
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</tr>
<tr>
<td>Precambrian</td>
<td>PGB</td>
</tr>
</tbody>
</table>

EL PILAR FAULT

PLATE 7

Enrique Hung, 1997.
Maturín Foreland-Serranía del Interior

Hypothesis 5: Multiple Decollements

LEGEND

PLEISTOCENE

PLIOCENE

UPPER MIocene

LOWER AND MIDDLE MIocene

PALEOGENE

UPPER CRETACEOUS

LOWER CRETACEOUS

BARREMian

PRE-BARRANQUIN

PRECAMBRIAN BASEMENT

EL PILAR FAULT

PLATE 8

Enrique Hung, 1997.
Mature Serran Hypothesis

LEGEND

PLEISTOCENE
PLEIOECE
UPPER MIOCENE
LOWER ANNI MIDDLE MIOCENE

UL T

SAN FRANCISCO FAULT
Maturín Foreland-Serranía del Interior

Hypothesis 6: Duplex Structures

**LEGEND**

- **PLEISTOCENE**
- **PLIOCENE**
- **UPPER MIOCENE**
- **LOWER AND MIDDLE MIOCENE**
- **PALEOGENE**
- **UPPER CRETACEOUS**
- **LOWER CRETACEOUS**
- **BARREMIAN**
- **PRE-BARRANQUIN**
- **PRECAMBRIAN BASEMENT**

**EL PILAR FAULT**

PLATE 9

Enrique Hung, 1997.