CRETACEOUS AND PALEOGENE SEDIMENTATION IN THE SOUTHWESTERN VENEZUELAN ANDES [1]

Sociedad Venezolana de Geólogos, Field Trip N° 4,

Víctor Campos y Tito Boesi, 14th to 17th March 1993

ACKNOWLEDGMENTS

The autors thank PDVSA and MARAVEN S.A. for permission to publish this field guide. They are equally grateful to all those who contributed valuable information and to colleagues who gave generously of their time to read and discuss the manuscript.

PART I - GENERAL GEOLOGY

ABSTRACT

Field studies of the sedimentary cover of the southwestern Venezuelan Andes were conducted, with the aim of better understanding the origin of hydrocarbon source rocks, reservoir rocks and traps.

Based on sequence stratigraphy, supported by biostratigraphic dating of outcrops and a control well, the main source rocks are interpreted as deposited under low-energy marine conditions on a Cretaceous passive margin, while the reservoir rocks and other less prolific source rocks were deposited on a Paleogene tectonically active margin.

Geochemical analysis confirms that the La Luna Formation is the main source rock. However, strong diachrornism requires unconventional methods to date the phases of structural deformation and hydrocarbon trapping, the final objective of this study.

I.1 - INTRODUCTION

The sedimentary cover of the southwestern Venezuelan Andes has been the subject of hydrocarbon exploration throughout the 20th century. Surface geology was the main focus in the first 75 years, producing useful models for exploration in the Maracaibo and Barinas basins. Subsequently the petroleum industry has expended much effort in seismic surveys along the mountain flanks, in order to define prospects.

Within the study area, Maraven acquired close to 2,000 km of reflection seismic data along the north flank between 1979 and 1991, while the south flank has seen local surveys by Maraven and Corpoven since 1980.

Integration of this seismic information with the surface geology and geochemical data allows prospects to be defined more confidently and classified in terms of their geological framework, thereby reducing exploration risk.

The future of Maraven depends in large part on this integrated exploration effort, whose main conclusions for the Southwestern Andes are reported here.

This field trip was specially prepared for the 1993 AAPG / SVG International Congress and will acquaint participants with aspects of the hydrocarbon geology of the area.

I.2 - LOCATION

The study area comprises the southwestern Venezuelan Andes, including the north and south flanks and the Táchira Depression (Figure 1). The study area extends, along the North Flank, from the Colombian border to the Río Chama; and along the South Flank from the same border to the La Vueltosa dam, embracing parts of Táchira and Barinas states.

The Táchira Depression occurs between the two flanks, at the extreme southwest of the Venezuelan Andes, adjacent to the Colombian border.

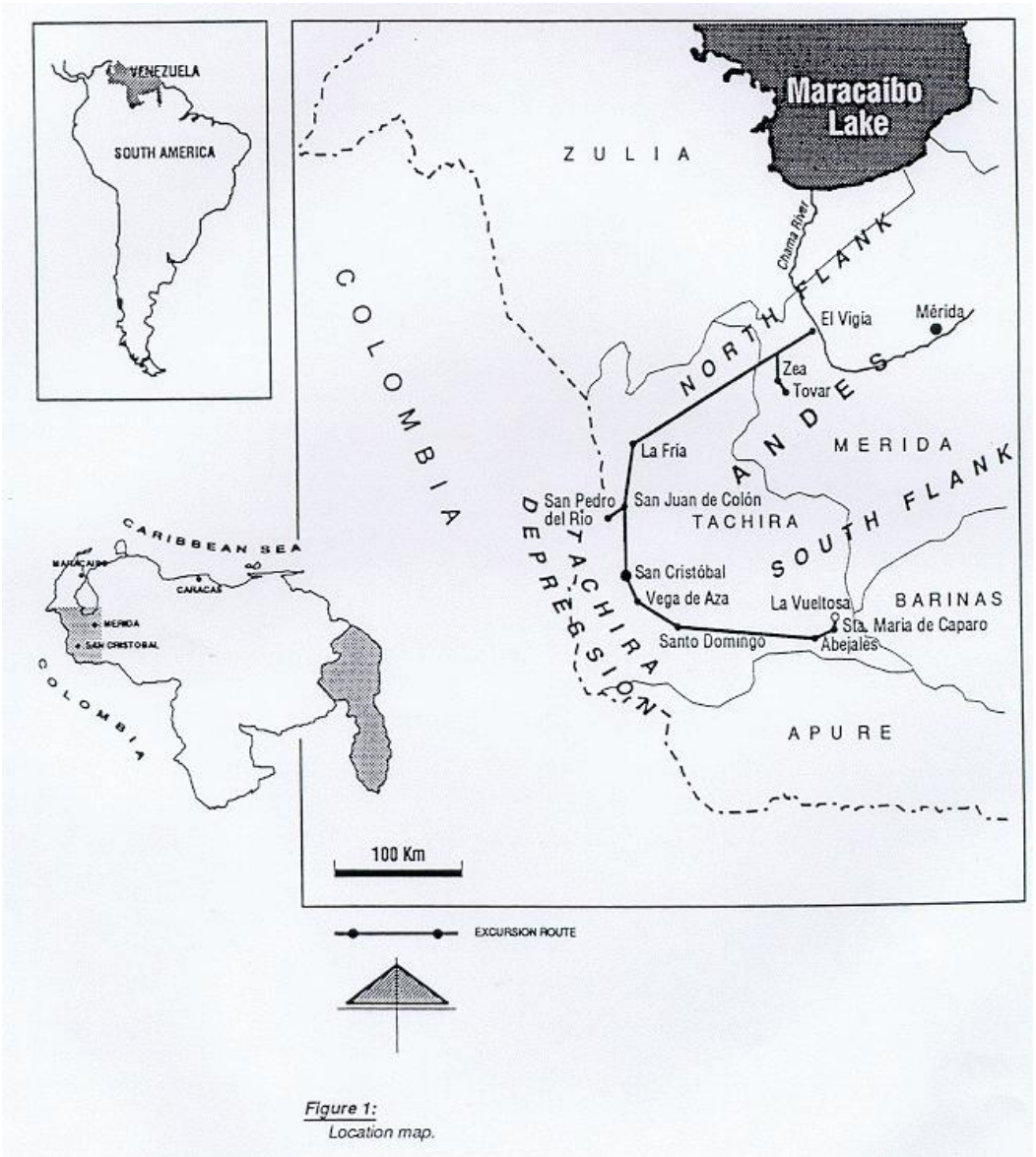


Figure 1:
Location map.

I.3 - OBJECTIVES AND SCOPE

The excursion lasts for three days, during which 11 sites will be visited, with the objective of demonstrating the main factor's which determine hydrocarbon prospectivity in the region. Among the factors to be discussed are reservoir rocks, seals, and both proven and possible source rocks, and their relation to the tectono-sedimentary history of the region.

The most interesting interval from an oil geology viewpoint is the Cretaceous and Paleogene, and the itinerary is therefore restricted to this part of the stratigraphic column.

I.4 - STRATIGRAPHY

I.4.1 - Introduction

After the pre-Cretaceous tectonic troughs of western Venezuela were filled by the Río Negro Fm and its lateral equivalents, the Cretaceous transgression began, consisting of two stages: an early, passive continental margin stage lasting from Barremian until Santonian time, and a late stage in which sedimentation occurred behind the Pacific volcanic arc, in the Campanian.

Later, in the Paleogene, the backarc basin evolved into the foredeep of the Colombian Eastern Cordillera, and deposition of the succession discussed here continued.

This link between the geology of the southwestern Venezuelan Andes and the complex tectono-sedimentary evolution of Colombia imposes the need to establish sequence stratigraphic correlations, in such a way as to allow integration of surface geology with seismic interpretations. Therefore, this paper, which essentially deals with surface geology, emphasizes those aspects which may be recognized on seismic profiles within the Maracaibo and Barinas basins in terms of seismic sequences, departing somewhat from the traditional lithostratigraphic approach.

To help the participant follow this methodology, the stratigraphic sequence is described in the order of the field trip stops.

I.4.2 - Cretaceous

I.4.2.1 - La Vueltosa/Santa María de Caparo area

The Cretaceous section of this area is basically of clastic composition, predominantly sandy, and lies unconformably on compact, red, silty sediments of the La Quinta Fm, of Jurassic age. The compactness of the latter, in contrast with the less compacted Cretaceous sediments, provides an excellent seismic reflector at the Jurassic-Cretaceous contact, or sequence boundary.

The Cretaceous succession comprises five formations, in ascending order: Río Negro, Aguardiente, Escandalosa, Navay and Burguita (Figure 2). The first two are well exposed in the abutments of the dam under construction, where they basically consist of thick conglomeratic sandstones with large-scale trough cross-stratification. The Río Negro Fm contains many red siltstone clasts, derived locally from the La Quinta Fm, with large mollusks and gastropods near the base of the formation. The Aguardiente Fm is essentially a quartzose sandstone. but some intervals are arkosic, micaceous, suggesting a different source and longer transport. The contact between the two formations is clearly noticed by the colour change from red and mottled Río Negro and the yellow and brown Aguardiente Fm sandstones.

From a sequence analysis point of view, these two formations represent an aggradational package comprising a low stand wedge (LSW) corresponding to the Río Negro Fm, passing up into platform deposits of the Aguardiente Fm An important unconformity separates the two formations (SB 107.5), each of which is considered to represent a second order cycle (Haq *et al.*, 1987).

The age of the Río Negro Fm is Barremian/Aptian (KISER, 1989) and its thickness in the region is approximately 190 m, while the Aguardienre Fm is 124 m thick and Albian in age based on ammonites (RENZ, 1982).

The contact between the Aguardiente and Escandalosa Fms, a sequence boundary which is undetectable seismically and difficult to date, is encountered on the road from the La Vueltosa dam to Santa María de Caparo. The contact is taken as the base of the first glauconitic sandstone (Figure 2), this mineral being characteristic of the Escandalosa Fm (RENZ, 1959).

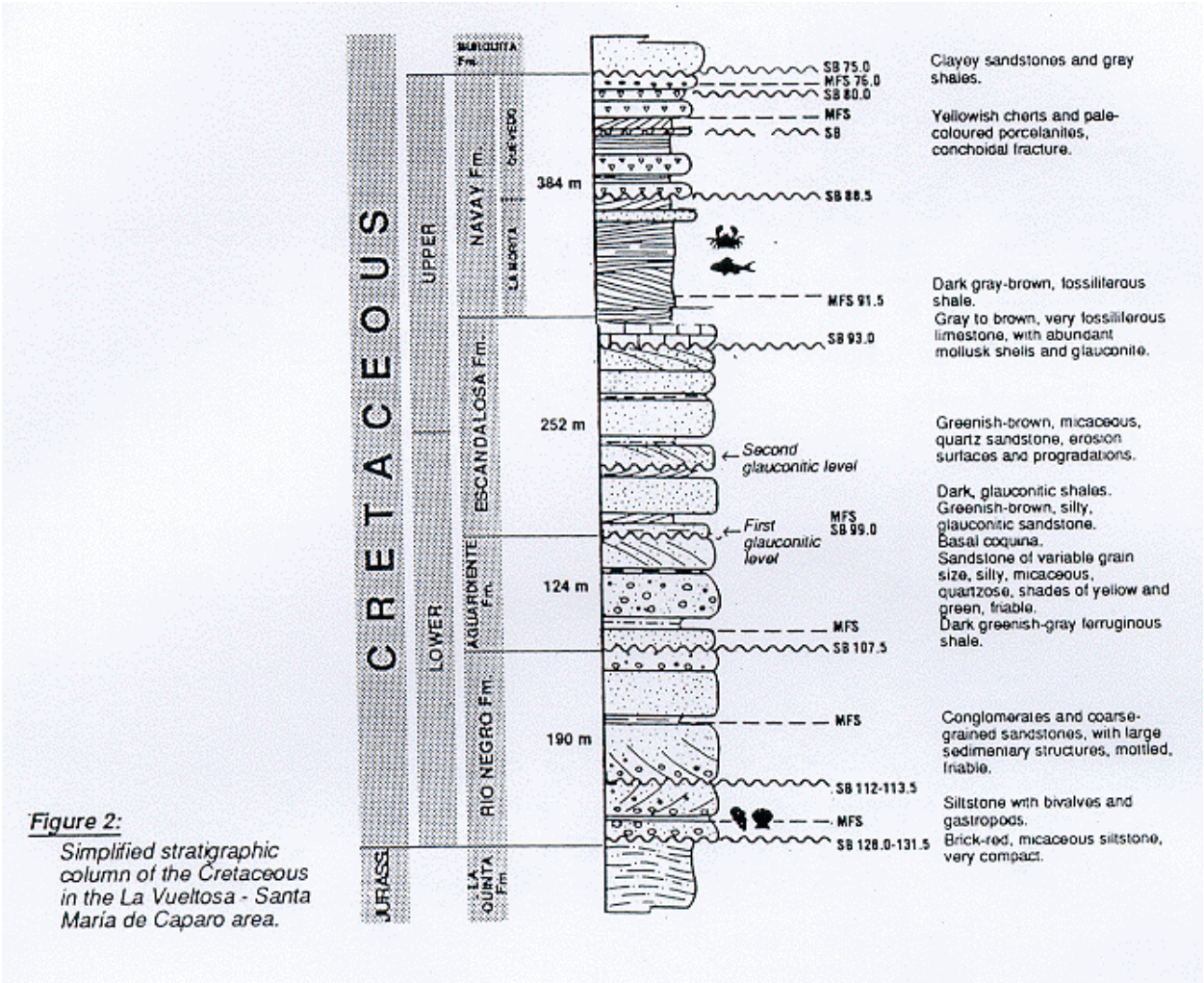


Figure 2:
Simplified stratigraphic column of the Cretaceous in the La Vueltosa - Santa María de Caparo area.

The Escandalosa Fm consists of medium to fine-grained, poorly consolidated, yellowish brown and brown sandstones, interbedded with thin, gray and dark gray to black, commonly micaceous shales. The formation is capped by 25 m-thick, yellowish grey, glauconitic, very fossiliferous

limestone, with bivalve mollusk shells and some gastropods, very similar to the Guayacán Mbr of the Capacho Fm of Notestein *et al.* (1944) (RENZ, 1959).

The depositional environment of the Escandalosa Fm is essentially coastal marine, with eustatic sea-level fluctuations over the continental shelf. Within the predominantly sandy formation are two horizons of greater glauconite concentration, one at the base and the other in the middle, related transgressive events. The latter horizon is particularly interesting, because it presents the typical features of a sequence boundary, in which, overlying a progradational unit truncated by erosion, is a ferruginous paleosoil, above which is a glauconitic sandstone representing the basal transgressive unit, and then a black shale of pelagic aspect, representing the period of maximum flooding (Photo 1). The Escandalosa Fm is 252 m thick and its age is late Albian to Turonian (KISER, 1989).

The Guayacán limestone at the top of the Escandalosa Fm represents the start of an important transgressive cycle over the Guayana Craton, culminating in the basal shales of the La Morita Mbr of the overlying Navay Fm (KISER, 1989).

The La Morita Mbr consists almost entirely of light brown and gray, silty shales with scarce fine-grained sandstones, and contains fish remains and ammonites. Oxidising depositional conditions prevented the development of hydrocarbon source rocks of commercial quality (O. GALLANGO, Pers. Comm.).

The upper part of the Navay Fm, or Quevedo Mbr (GONZALEZ DE JUANA *et al.*, 1980), consists almost entirely of yellowish white cherts and fossiliferous shales deposited in a nearshore environment (SANCHEZ AND LORENTE, 1977).

These predominantly siliceous and argillaceous sediments have been interpreted as deep marine, attributing the cherts to accumulation of radiolaria in a distal marine setting. However, the macrofossil assemblage includes large numbers of fish and crabs, suggesting instead a shallow, oxygenated, nearshore environment. Based on its stratigraphic position, the Quevedo Mbr can be interpreted in general terms as a regressive succession.

The uppermost beds of the Navay Fm are sandstones interbedded with white shales and some phosphatic beds, possibly associated with a new transgressive event of short duration, of Maastrichtian age (Kiser, 1989). The Navay Fm is 384 m thick in Santa Mana de Caparo.

Overlying the Navay Fm are micaceous, silty sandstones and light gray shales of the Burguita Fm (Renz, 1959) (Figure 2). This formation lies outside the field-trip route and is not discussed further here.

I.4.2.2 - Santo Domingo area

About 3 km north of Santo Domingo airport, on the road to San Cristóbal (Figure 1), the Lower Cretaceous crops out in typical Andean facies (Figure 3).

The section commences with Río Negro Fm conglomerates, overlain by Apón Fm limestones (RENZ, 1959), culminating in the lower part of the Aguardiente Fm. These sediments are well consolidated, unlike the La Vueltosa area.

The Río Negro Fm does not crop out along the road. The upper, entirely conglomeratic part is exposed in La Otura creek below the road, and inaccessible in this excursion.

Unconformably overlying the conglomerates are limestones of the Apón Fm. These contain a detrital component in the matrix, increasing upward and forming an interesting succession of facies, from nodular mudstones to calcareous sandstones.

At the top of the section is an interval of black claystone, with abundant internal moulds of small gastropods containing glauconite; there is also amorphous organic material associated with the maximum marine inundation in the mid-Aptian (PITELLI, 1992). The marine inundation never reached the Barinas platform and the Apón Fm is absent in the La Vueltosa area. From a sequence stratigraphy viewpoint, this facies association is difficult to interpret as a single transgressive cycle, and the more detrital part of the formation may be considered as regressive.

Overlying the Apón Fm is the progradational Aguardiente Fm, consisting of calcareous, coarse to medium-grained, brown to gray, well consolidated sandstones and thin beds of gray, micaceous, silty shale, deposited in a very shallow, nearshore marine environment.

The age of the Aguardiente Fm in the Santo Domingo area ranges from late Aptian to middle Albian (USECHE *et al.*, 1986). Where unfaulted, it is eroded and unconformably overlain by Miocene molassic sediments (MACELLARI, 1984).

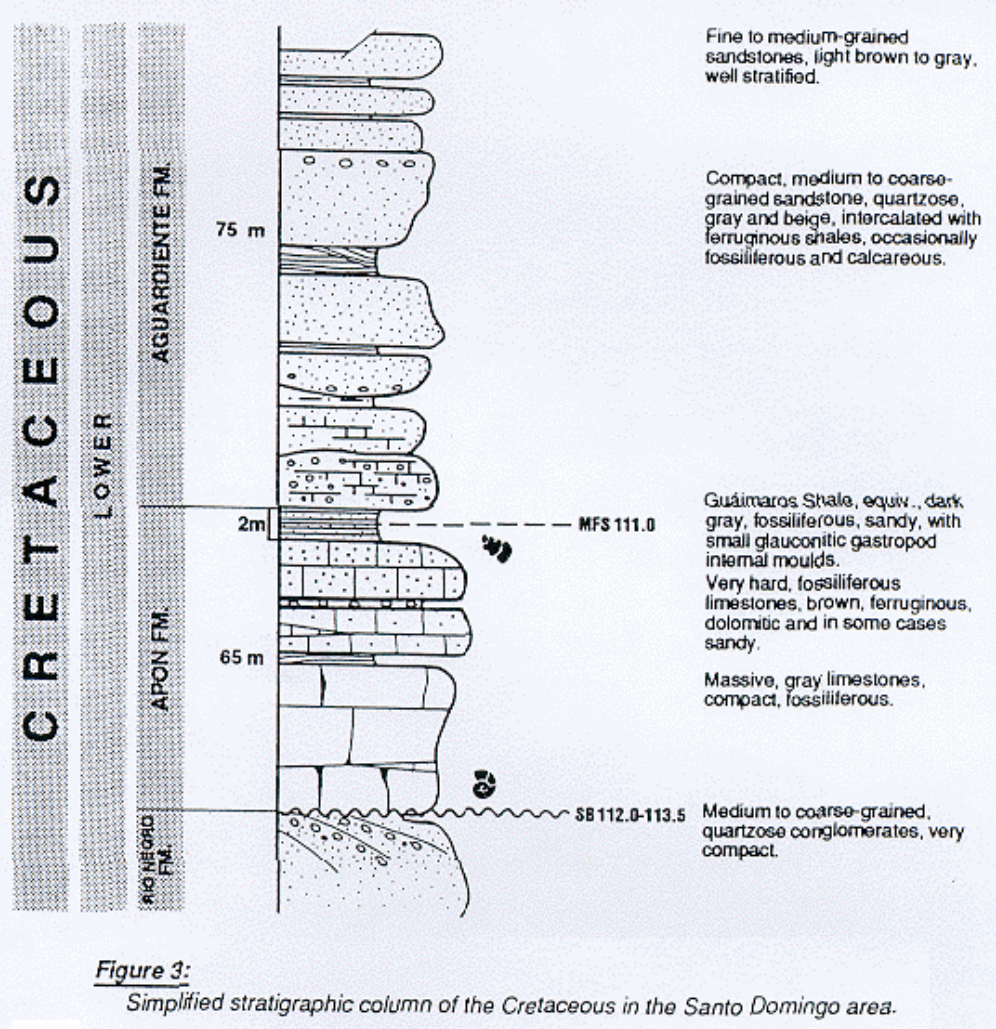


Figure 3:
Simplified stratigraphic column of the Cretaceous in the Santo Domingo area.

I.4.2.3 - Vega de Aza area

This locality lies along the same Santo Domingo to San Cristóbal highway, at a well-known outcrop of conglomerates impregnated by natural asphalt of the La Copé Fm.

The geology here is particularly illustrative of syn-tectonic sedimentation, originally studied by Macellari (1982). Emphasis is placed here on aspects of syn-tectonic sedimentation relevant to hydrocarbon habitat (I.6.2 and I.6.3).

Near Vega de Aza, in the villages of Agua Dulce and La Copé, are thin exposures of the Navay and Colón Fms, the latter of Maastrichtian age, well established by palynology (VELÁSQUEZ, 1992) (Figure 4). In another section, well bedded sandy sediments intercalated with siltstones end carbonaceous shales, belonging to the Orocué dated palynologically as Paleocene (VELÁSQUEZ, 1992), rest apparently conformably on the Colón Fm. These three formations are in erosional contact beneath conglomerates of the La Copé Fm.

The area is intensely faulted, preventing accurate measurement of thicknesses. However, the absence of faunas and the presence of distal, open-marine floras in the Colón Fm (VELÁSQUEZ, 1992), suggest the possibility that the succession here is abnormally thin, associated with a paleohigh of pre-Navay age. The geographic extent of this paleostructure is presently unknown, but its existence could explain the abrupt lateral facies change in the Campanian between the Navay and La Luna Fms, whereby only 12 km north of this area the La Luna Fm crops out in its typical North Andean Flank facies.

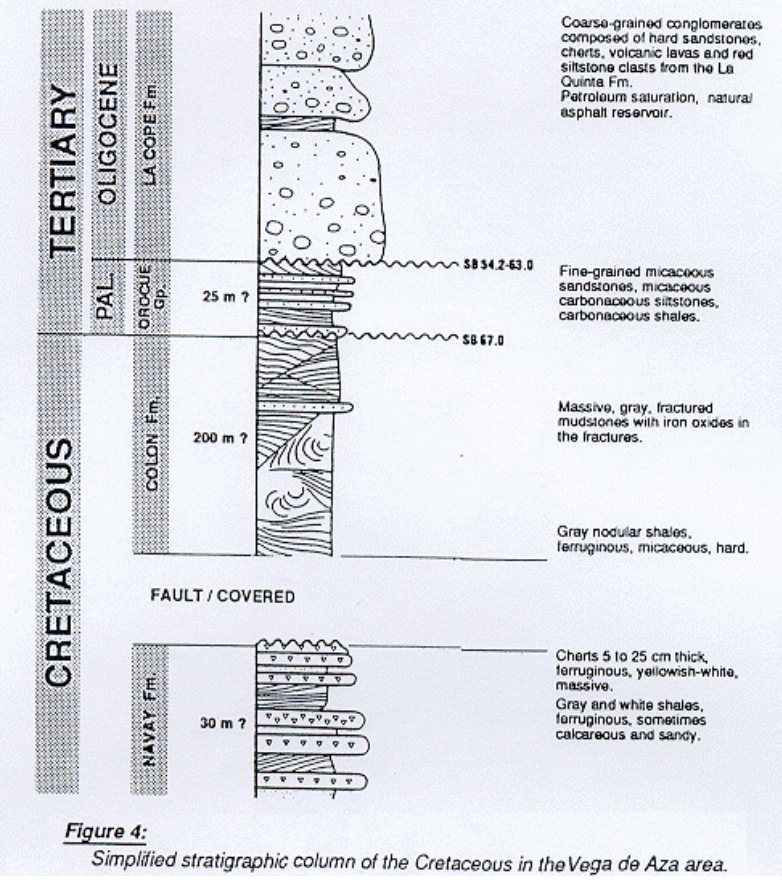


Figure 4:
Simplified stratigraphic column of the Cretaceous in the Vega de Aza area.

I.4.2.4 - San Pedro del Río area

The La Luna Fm, as described by A.H. Garner in 1926 and H.D. Hedberg in 1931, crops out extensively in northern Táchira state, in predominantly siliceous, erosion-resistant facies (Tachira Chert Mbr). However, the only complete section through the formation easily accessible by road is along Chiriría creek, about 400 m from the picturesque village of San Pedro del Río (Appendix 1).

The exposure is a fault-line scarp of the San Pedro del Río thrust (I.5.2). Exposed at the base is the upper part of the Capacho Fm and at the top is the Colón Fm.

The La Luna Fm at this locality is divided into three lithologic units (GALEA, 1990; TESTAMARAC, 1992) (Appendix 2). The lower unit consists mainly of dark gray to black, calcareous shales, rich in amorphous organic material of marine pelagic origin; the section is rich in ammonites and is characterized by spheroidal nodules of calcareous mudstone. There are also abundant thin beds of dark gray limestone which weather white. The lower unit is 33 m thick.

The upper unit mainly comprises well bedded chert layers up to 20 cm thick. The chert is black, but has been altered diagenetically to gray at the top and base of each bed. This section is 17 m thick.

The middle unit, 37 m thick, is transitional between the upper and lower lithologies and is of mixed composition. Detailed analysis reveals interesting differences with respect to the other two units; for example, some limestone beds contain horizons composed almost exclusively of foraminifers. Near the top is a bed of phosphatic limestone of regional extent, rich in P205, which is being mined nearby (ODREMAN *et al.*, 1990). Also unique to this section are volcanic andesite fragments.

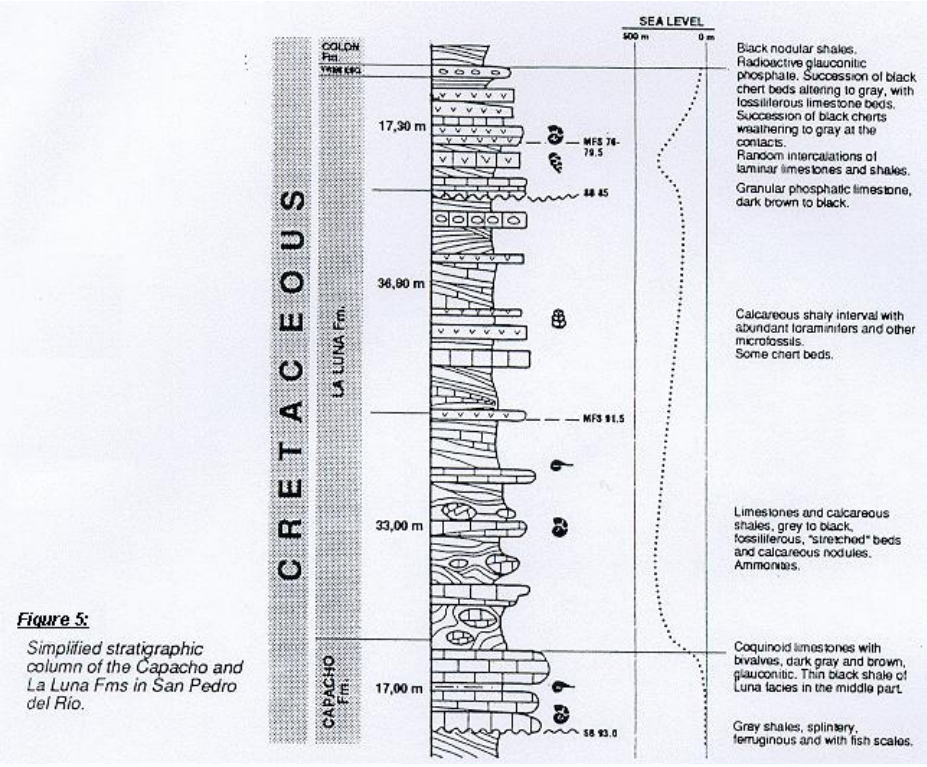


Figure 5:

Simplified stratigraphic column of the Capacho and La Luna Fms in San Pedro del Río.

In terms of sequence stratigraphy, the La Luna Fm in Chiriría creek consists of more than one cycle, as shown in the bathymetric curve of Appendices 1 and 2. The initial transgression began in the Cenomanian-Turonian (SB 93) with deposition of the limestones of the Guayacán Mbr of the Capacho Fm, with their fauna typical of high-energy, well oxygenated water. The transgression reached its maximum flooding level (MFS 91.5) in the transition zone between the lower and middle units of the La Luna Fm, as indicated by the analysis of Appendix 2.

The reliability of a sequence-stratigraphic interpretation for the middle and upper units depends heavily on how one interprets the origin of the cherts (MARCUCCI, 1976). In this report, the good preservation of the few radiolaria detected in micropaleontological studies, and the geographic position close to the Pacific volcanic arc, are the basis for assuming a combined siliciclastic/chemical origin for the cherts, representing deposition in a very distal, oxygenated environment during a general progradation, (HST), interrupted by a transgression event (TST) represented by phosphatic intervals in the upper unit.

The name La Luna Fm without doubt holds immense significance in the Venezuelan petroleum industry and occupies a privileged status in the international biostratigraphic literature. However, stratigraphic analysis suggests redefining the limits of the formation in the southwestern Venezuelan Andes, based on a more regional framework.

I.4.2.5. - Zea/Guarunes area

About 3 km from Zea, along the road linking this town with the Panamerican Highway, the Cretaceous section is exposed in its typical Andean facies, reflecting sedimentation on a passive continental margin. Its geographic position makes this outcrop important for regional correlations with the Maracaibo basin and Perijá.

The basal contact of the Cretaceous, with Paleozoic schists (Fig. 6), is interpreted as the sequence boundary SB 136, based on palynological dating of the Basal Clastics. The latter are some 30 m thick and basically consist of conglomerates and coarse-grained sandstones, with lenticular intercalations of dark gray shale. The Basal Clastics represent the basal cycle of the Cretaceous transgression.

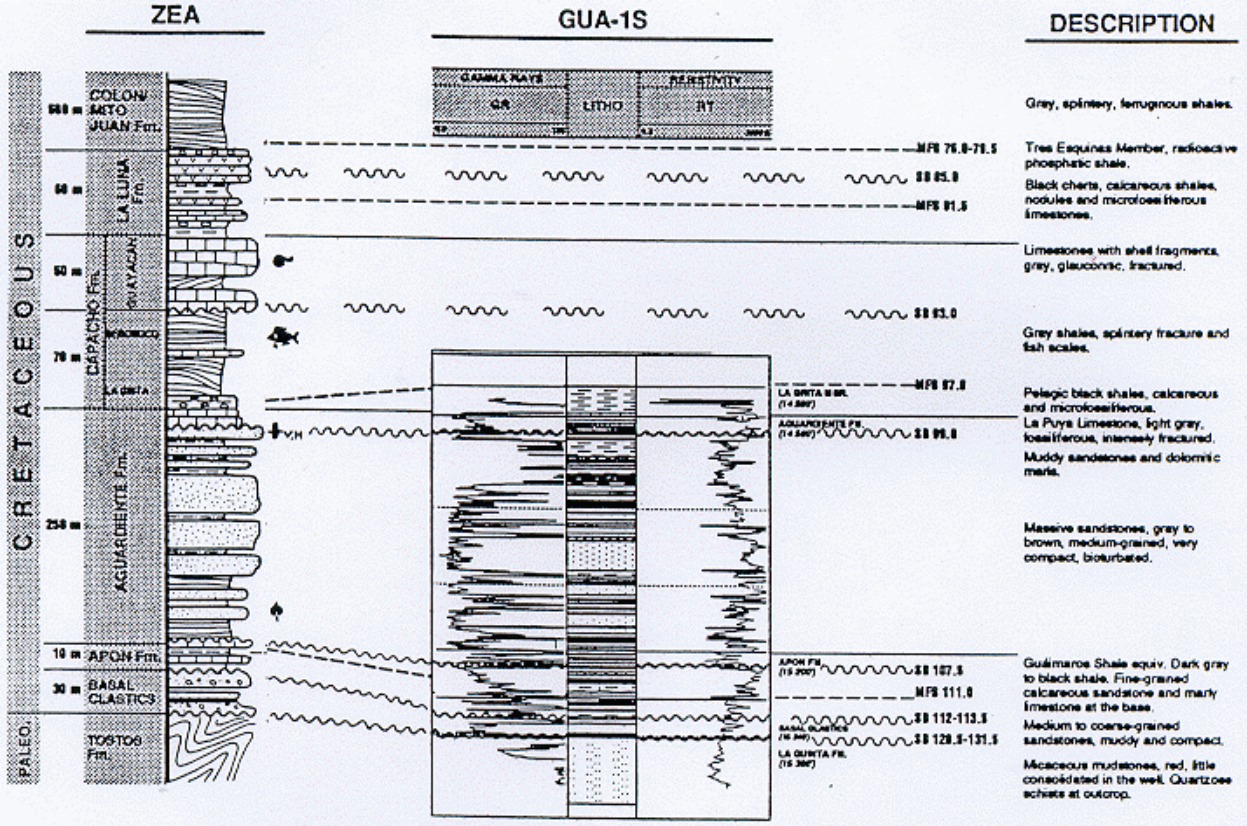


Figure 6:
Simplified stratigraphic column of the Cretaceous in the Zea area, and correlation with the well Guaruries-1S.

Overlying this cycle is the Apón Fm, consisting of mudstones and coarse conglomeratic sandstones interbedded with marls and siltstones, very similar to the Santo Domingo section in terms of lithology and depositional environment, with paleobathymetry not exceeding 20 m. The succession of facies suggests that the Apón Fm in Zea-Guaruries is mostly transgressive, as seen both in outcrop and in the Guaruries well (GUA-1S; Figure 6). This is a short cycle in which a basal sandy sequence is followed by black shale equivalent to the Guáimaros Mbr. The cycle ends with a regressive sequence of calcareous sandstones forming the upper part of the Apón Fm, and is delimited by sequence boundaries SB 107.5 and 112.

Erosionally overlying the Apón Fm is the Aguardiente Fm, consisting mainly of hard siliceous sandstones with some ferruginous intervals, interbedded with carbonaceous shales, generally reflecting high-energy coastal deposition with horizontal and vertical burrowing in the top 20 m. The Aguardiente Fm is 250 m thick and Albian in age (BOESI *et al.*, 1988).

The uppermost bed of the Aguardiente Fm is a gray fossiliferous limestone with mollusk fragments that represents an abrupt change of environment from the underlying sandstones. This bed was informally named the La Puya Limestone by Renz (1959), and is interpreted in this report as the base of a new transgressive cycle overlying an unconformity in the upper part of the Aguardiente Fm sandy facies (SB 99).

The transgressive cycle culminates with the overlying calcareous shales of the La Grita Mbr of the Capacho Fm (Figure 6). The La Grita Mbr is lithologically very similar to the basal interval of the La Luna Fm, with black pelagic shales rich in amorphous organic matter, representing maximum marine inundation at the end of the Albian (MFS 97).

In the middle of the Capacho Fm is a shale about 70 m thick. The shale is massive, dark gray to brown, with a splintery fracture and abundant fish scales. This is the Seboruco Mbr (RENZ, 1959), which contains a thin central interval of calcareous sandstones. The shales were deposited in shallow water and are interpreted as a progradational unit (MST) culminating in an unconformity (SB 93). Upon this unconformity the most extensive marine transgression over the South American passive continental margin took place, forming the La Luna sea.

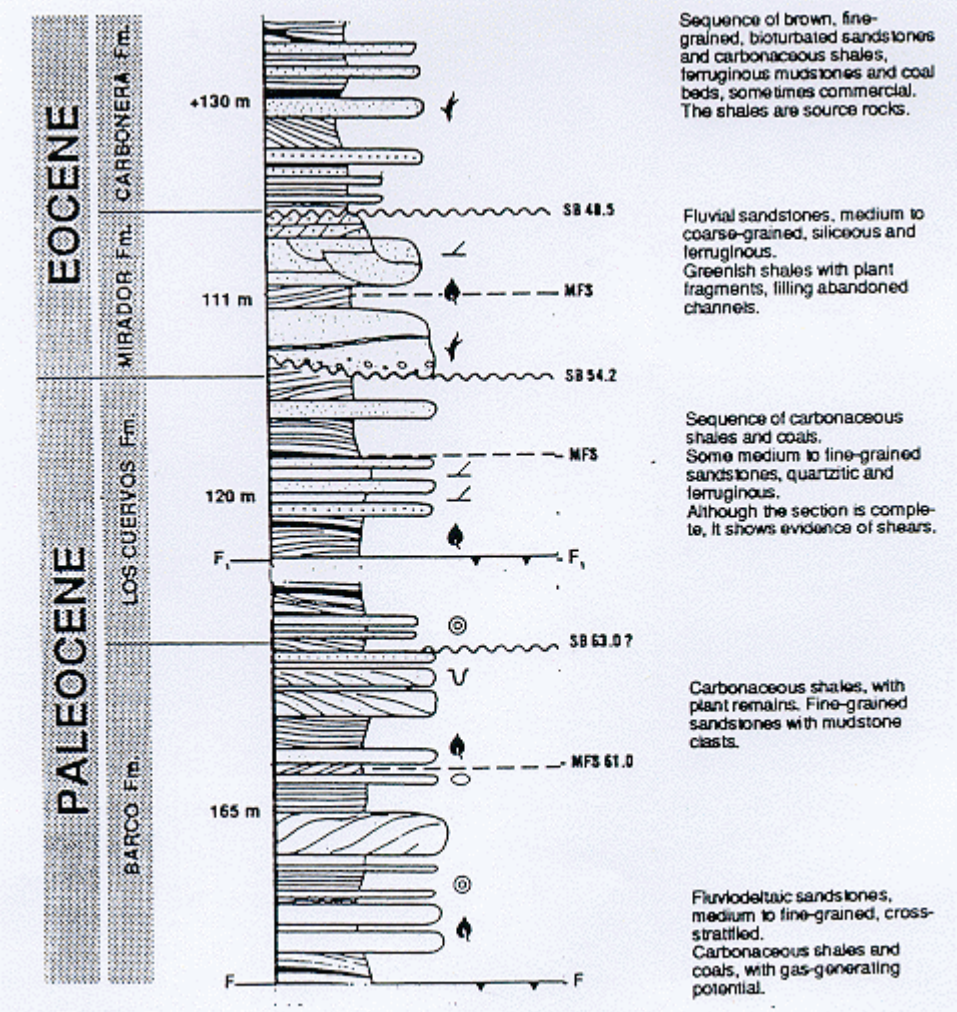


Figure 7:
Simplified stratigraphic column of the Lower Tertiary in Río Lobaterita.

The transgression of the La Luna sea began with deposition of the shallow-water Guayacán Limestone and culminated in the maximum flooding surface MFS 91.5, within the basal interval of the La Luna Fm. The 50 m-thick Guayacán Limestone formed by accumulation of bioclastic fragments, principally bivalves and some gastropods.

Outcrops of the La Luna Fm are scarce in this region, but its estimated thickness is about 60 m and, as in San Pedro del Río, it comprises three lithologic units: a lower shaly calcareous, a middle calcareous-cherty, and an upper cherty interval. The lower calcareous shales emit the typical fetid odor of hydrocarbons when hammered.

Overlying the La Luna Fm is the type section of the phosphatic Tres Esquinas Mbr, a I to 2 m-thick condensed section representing the last marine transgression of the Campanian. The maximum marine inundation is difficult to date, but is assumed to be between 76 and 79.5 My.

In the Zea area, the upper part of the Cretaceous section is represented by the Colon and Mito Juan Fms, which are faulted and locally overtured. The scarce exposures consist of hard, dark grey, silty shales with abundant microfauna in a 550 m-thick section. Sections twice as thick are known in the region, attributed among other causes to plastic flow.

The Gua-1S well is hen northeast of the Zea section, was drilled between 1989 and 1991 to evaluate the source rock and reservoir potential of the lower part of the Cretaceous.

The Cretaceous section in the borehole correlates well with the outcrop section at Zea (Fig.7) and paleontological, palynological and petrophysical studies led to an improved understanding of the subsurface Cretaceous in the Andean flank. The results of GUA-IS reveal that the sandstones of the Aguardiente Fm are poor reservoirs due to advanced diagenesis; in contrast, the Apón and La Puya limestones show good permeability and reservoir capacity, whether for hydrocarbon (La Puya) or water (Apón), on account of fracturing. The lack of fracturing in the Aguardiente Fm, as shown by sonic (SDT) and dipmeter (HLDT) logs, is unexplained.

I.4.2.6 - Correlation

The geographic distribution of the Cretaceous sections discussed in this study is shown in Appendix 1. The western region is represented by the Santo Domingo and San Pedro del Río sections, and the eastern region by La Vueltosa/Santa María de Caparo and Zea/Guaruríes.

For the benefit of readers unacquainted with the Andean lithostratigraphic nomenclature, the typical Cretaceous lithostratigraphy of Lake Maracaibo is shown in Appendix 1. The table emphasizes lithologic horizons which are helpful in sequence analysis, since the objective is to understand the relation between the outcrop and subsurface sections, as mentioned above (I.4.1).

The Cretaceous of the southwestern Andes is divided into seven cycles which, based on their duration, are second-order cycles (HAQ et al., 1987). Due to the obliquity of the correlation line with respect to the Mérida Arch (GONZALEZ DE JUANA *et al.*, 1980), the diachronism of these cycles is not obvious. However, the Vega de Aza high is evident from the late Cretaceous, breaking the depositional continuity.

Cycle 1: (SB 112-136?) Río Negro Fm/Basal Clastics

The lower limit of the cycle, estimated as SB 136, is the pre-Cretaceous basement, easily recognized in the field and somewhat harder to detect on seismic. Brackish-water shales at La Vueltosa correlate with shallow-marine shales at Zea and are attributed to maximum marine inundation (MFS 115.5).

The lower part of the cycle is interpreted as a Lowstand Wedge (LSW), whose sediments fill the Jurassic depressions and are consequently of very variable thickness; its earliest age is Neocomian.

Cycle 2: (SB 107.2-113.5) Río Negro Fm, Apón Fm

In La Vueltosa this cycle is represented by the upper part of the Río Negro Fm, while in the other areas it is dominated by the Apón Fm. The basal transgressive limestones of the Apon Fm have the same characteristics as the Río Negro Fm, are diachronous and of variable thickness.

The main level of maximum marine inundation in the Apón Fm is expressed as dark, fine-grained sediments, which are sometimes clayey and shaly as in the wells Fila - 1X and GUA - 1S, or glauconitic and mudstone-like as in Santo Domingo. This level corresponds to MFS 111 and is correlated with the Guáimaros Shale of other Andean localities and the Machiques Mbr of Perijá and Lake Maracaibo. The upper part of the cycle is regressive and easily recognized in the wells Fila - 1X and GUA - 1S and in the Santo Domingo section.

The Apón Fm is absent in La Vueltosa, which could be interpreted as a facies change, from conglomeratic facies of the upper part of the Río Negro Fm in La Vueltosa, to carbonate facies in the Santo Domingo area. Alternatively, the Apón Fm could be interpreted as a Lowstand Wedge of Aptian age which pinches out against a slope between Santo Domingo and La Vueltosa; this implies a regional slope separating the Barinas platform and the Andean basin.

Cycle 3: (SB 99-107.5) Aguardiente Fm, Lisure Fm

The cycle consists almost entirely of Aguardiente Fm and contains higher-frequency cycles, very difficult to recognize in the field. In La Vueltosa a greenish black silty shale about 2 m thick is visible in the outcrop at the dam abutment (Photo 1). This shale could correspond to MFS 101, correlating regionally with the glauconitic interval of the Lisure Fm in Lake Maracalbo.

In the Aguardiente Fm, shale intervals are thicker and more numerous toward the west, in Santo Domingo and San Pedro del Río, than in Zea and La Vueltosa, reflecting deeper water marine environments.

Cycle 4: (SB 93-99) Escandalosa, Maraca and La Luna Fms, and La Puya, La Grita and Seboruco Mbrs

During Albian and Cenomanian times a wide range of facies was deposited on the continental margin, suggesting an equally complex paleogeography.

Following a diachronous basal transgressive cycle consisting of the La Puya limestone, the Maraca Fm and the first glauconitic interval of the Escandalosa Fm, the transgression reached its maximum (MFS 97) with the La Grita Mbr in the Andes and with the base of the La Luna Fm in Lake Maracaibo. The cycle ends with the middle sandstones of the Escandalosa Fm and the shales of the Seboruco Mbr, while in the Maracaibo area condensed sedimentation of the La Luna Fm continued.

Cycle 5: (SB 85-93) Guayacán and La Morita Mbrs, La Luna Fm

The base of the cycle consists of Guayacán Mbr limestone, typically transgressive and of coastal origin, recognized throughout the southwestern Andes and extending to the Barinas-Apure

subsurface, where it has been penetrated by boreholes and is known as limestone «O» of the Cretaceous Fortuna Fm. Deeper water to the north prevented its deposition over the Maracaibo platform.

The principal maximum flooding surface (MFS 91.5) occurs in the basal shales of the La Morita Mbr and its equivalent La Luna Fm, the latter being well represented in the lower part of the San Pedro del Río section.

Cycle 6: (SB 75-85) Quevedo Mbr, La Luna Fm, chert interval, Tres Esquinas Mbr

This cycle is characterized by cherts and phosphates, whose apparent lithological simplicity disguises a very variable composition, again suggesting a complex paleogeography for this part of the continental margin.

Chert varieties can be grouped into two main types: those of the Quevedo Member of the Navay Fm (I.4.2.1) and those in the middle and upper La Luna Fm (I.4.2.4). The former occurs in the southwester flanks of the Andes and the Táchira Saddle, while the latter occur in the northern flank of the Andes and the central Táchira Saddle (I.4.2.3). The coexistence of both facies signifies not only paleogeographic complexity, but also the importance of geochemical factors in the environment of deposition.

Farther north, in the Maracaibo area, the condensed section the Tres Esquinas Mbr represents almost the entire Campanian, contemporaneous with the upper unit of the La Luna Fm in San Pedro del Río (TESTAMARCK, 1992).

Based on the presence of volcanic detritus in the middle and upper part and the facies complexity, Cycle 6 was tectonically situated at the northeastern limit of the basin, behind the Pacific volcanic arc.

Cycle 7: (SB 67-75) Burguita and Colón/Mito Juan Fms and Transitional Unit

These formations are characterized by their generally shaly nature, except for the Burguita Fm, whose sandstone/shale ratio approaches unity.

The geometry of these formations is more easily studied in the subsurface by seismic reflection than in the scarce outcrops. On account of their thick shaly sections and their stratigraphic position, the formations of this and the previous cycle play an important geodynamic role, commonly acting as horizons of structural detachment.

Sedimentation during this final Cretaceous cycle was controlled by the compressive belt of the Colombian Cordilleras and by the margin of the Guayana Shield, marking the start of a long period of foreland development which was to affect Paleogene sedimentation along the whole west flank of the Mérida Arch (AUDEMARD, 1991).

I.4.3 Tertiary

I.4.3.1 - Río Uribante Depression

Tertiary outcrops are scarce in the Río Uribante area. However, toward the east near the town of Abejales, seismic profiles show a section of about 300 m interpreted as Río Uribante Paleocene-Eocene (Audemard, 1991), thinning gradually toward the south (Figure 14). The Depression

Oligocene section behaves similarly, but reaches a thickness of 1000 m against the mountain front where it reaches its maximum development.

Southeast of the Río Uribante Depression, sedimentation was controlled by the Brujas High, as shown by thinning toward this structure. On the crest of the High a molassic section interpreted as Miocene-Pliocene rests unconformably on the Lower Cretaceous. The latter is a key horizon for seismic interpretations in the area (Figure 14). The molassic section could be an equivalent of the Guayabo Gp (GONZALEZ DE JUANA *et al.*, 1980), but outcrops in the Andean foothills are scarce and this correlation remains unproven. In the foothills adjacent to the Río Uribante Depression are molasse exposures resting on a thin Paleogene section and also on rocks of the two oldest Cretaceous cycles. This unconformable relationship between the Miocene-Pliocene molasse and the older sediments of the Andean flank is unique to the Río Uribante Depression and suggests the presence of pre-Miocene structures analogous to the Brujas High (I.4.2.3).

I.4.3.2. - Vega de Aza area

In this area is an interesting section of conglomerate known as the La Copé Conglomerate or La Copé Fm (MACELLARI, 1982). The coarse fraction is mostly subrounded clasts of chert from the Navay Fm, with subordinate clasts of compact pre-Navay sedimentary rocks. The presence of exclusively Cretaceous and pre-Cretaceous clasts in the formation suggests two possible ages:

A. Miocene/Pliocene conglomerate in which only resistant Cretaceous and pre-Cretaceous clasts have been preserved.

B. Paleogene (Oligocene?) syn-tectonic conglomerate derived by erosion of extensive outcrops of Navay and La Luna Fm chert.

In case A, the La Copé conglomerate would be molasse associated with the Andean uplift, equivalent to the Miocene-Pliocene Betijoque Fm conglomerates (MACELLARI, 1982).

Case B would indicate pre-Miocene tectonic activity of the structure that gave rise to the conglomerate, with interesting implications for hydrocarbon generation and migration in the area, as discussed below (I.6).

However, in either case, the presence of a Cretaceous structure beneath the conglomerate appears possible (I.4.2.3), more so considering the relation between the molasse and the Cretaceous in the adjacent Río Uribante area.

I.4.3.3 - Río Lobaterita area

The lower part of the Paleogene crops out here, resting on a thick transitional Cretaceous to Paleocene section whose limits are hard to define, being lithologically similar to shales of the Paleocene Orocue Gp but late Cretaceous in age. This section is informally known as the Transitional Unit, a locally used term (BOESI *et al.*, 1988).

In the west bank of the Río Lobaterita, about 5 km south of the town of San Pedro del Río (Appendix 1), is a good exposure of the Orocue Gp (NOTESTEIN *et al.*, 1944) in fault contact with Colón Fm shales; Quatemary fluvial terraces are also visible (Figure 7). In the Venezuelan Andes, the Orocue Gp is divisible into two formations, not three as in Santander del Norte in Colombia, namely the Barco and overlying Los Cuervos Fms (MARQUEZ and CHIRINOS, 1987).

A characteristic of the Paleocene section is that its shales, constituting about 60% of the interval, are carbonaceous and have source-rock properties, as discussed later (I.6.1.2).

In the Barco Fm, three facies' associations are recognised: prodelta, lower delta plain and middle delta plain. Each facies association contains sand bodies capable of storing hydrocarbons, but the best reservoir characteristics are in the lower delta plain, in distributary channel sandstones (MARQUEZ and CHIRINOS, 1987).

The Barco Fm shows erosion surfaces which are obviously related to sequence boundaries, but these are difficult to identify in seismic lines. Figure 9 compares this interesting section at Río Lobaterita with well logs from Fila-1X, located about 25 km to the south, in the Ureña - San Felix structural block, north of the Capacho thrust. This comparison allows the main systems tracts to be identified, a useful tool when this information is projected onto the seismic line.

The mostly shaly Los Cuervos Formation contains carbonaceous shales. siltstones, coal beds and some channel sands, in an association interpreted as upper delta plain (MARQUEZ and CHIRINOS, 1987). The upper part is exposed along the road under construction to Lobatera, and shows intense tectonic folding of the shales and erosional truncation by the overlying basal sandstones of the Mirador Fm This section, like the Barco, correlates quite well with the Fila - 1X borehole.

Farther south along the road is a complete section of the Mirador Fm (Figure 7). This is a sandy sequence divisible into three units. The basal unit about 66 m thick consists of sandstones deposited in meandering channels. The middle unit, 5 m of greenish-gray shales, reflects inundation of the delta plain; it correlates well with Fila - 1X (Figure 9), indicating regional distribution. The upper unit comprises 39 m of planar-cross-stratified sandstone, of braided stream origin, capped by a friable, white siliceous sandstone.

The succession of sedimentary environments at Río Lobaterita suggests a generally regressive cycle, in which the Mirador Fm fluvial sandstones mark the end of the cycle.

The main sequence boundaries coincide with the formation limits. Marine flooding surfaces in the Paleogene section, unlike the Cretaceous, are difficult to recognize in the field, although not in well logs.

The succeeding Carbonera Fm is at least 130 m thick (Figure 7), and consists mainly of fine-grained sandstones at the base, with abundant wave ripples and, as the formation name implies, abundant carbonaceous shales and coal beds, which are being mined nearby at Lobatera.

The Carbonera Fm rests unconformably on the Mirador Fm. At the unconformity, pollen zones corresponding to almost the entire Middle Eocene are missing, representing about 4 Ma (BOESI *et al.*, 1988). This horizon is a sequence boundary of regional extent and a wide age range (SB 36.0 - 49.5).

I.4.3.4 - Río Chama area

The best-exposed Tertiary section in the North Andean Flank occurs in the banks of the Río Chama, about 15 km south of the town of El Vigía. The new El Vigía - Estánquez highway is under construction on the west bank of the river and unfortunately many of the rockwall exposures are being sprayed with a cement retaining screen. However, at the start of construction the section

was studied by geologists from the Ministerio de Energía y Minas, the universities, Maraven and Total, providing stratigraphic control for the GUA - 1S well about 15 km to the northwest.

The Tertiary section begins about 200 m north of the SantaTeresa tunnel, with a short section of lower Paleocene rocks (VELASQUEZ, 1991) resting on the Colón Fm (Figure 8). This interval belongs to the Orocué Gp and is mainly shales with some fine-grained sandstones. The top of the Orocué is incised by fluvial channel sandstones belonging to the overlying Carbonera Fm, of middle to late Eocene age (VELASUQEZ, 1991). This contact is an important unconformity which omits the Mirador Fm (I.4.3.3) and possibly part of the Orocué Gp, a long hiatus of about 20 My.

Throughout the Andean flank the Carbonera Fm is characterized by carbonaceous shales and coal beds, the latter well exposed in the bed of the Río Chama. There are also abundant cross-stratified sandstones with oil staining, as in the Gua-1S well. Northward the section continues with a long exposure of the León Fm, of Oligocene age (PITTELLI, 1990).

The lower part of the León Fm is basically shaly with some sandstone interbeds which contain plant detritus and wave-rippled upper surfaces, interpreted as lacustrine (HIGGS and MEDEROS, 1992). The upper pan, informally named the Caracol Mbr (ARMINIO and ALLEN, 1990), contains a higher proportion of sandstone, arranged in cycles of upward-thickening beds. The sandstones contain wave ripples and plant remains and reflect deposition on a lacustrine delta plain influenced by marine incursions. The Caracol Mbr is Oligocene in Río Chama (VELASQUEZ 1991; RULL, 1992), and occurs in other sectors of the North Andean Flank, where it is known as the Palmar Fm, normally assigned an early Miocene age (GONZALEZ DE JUANA *et al.*, 1980).

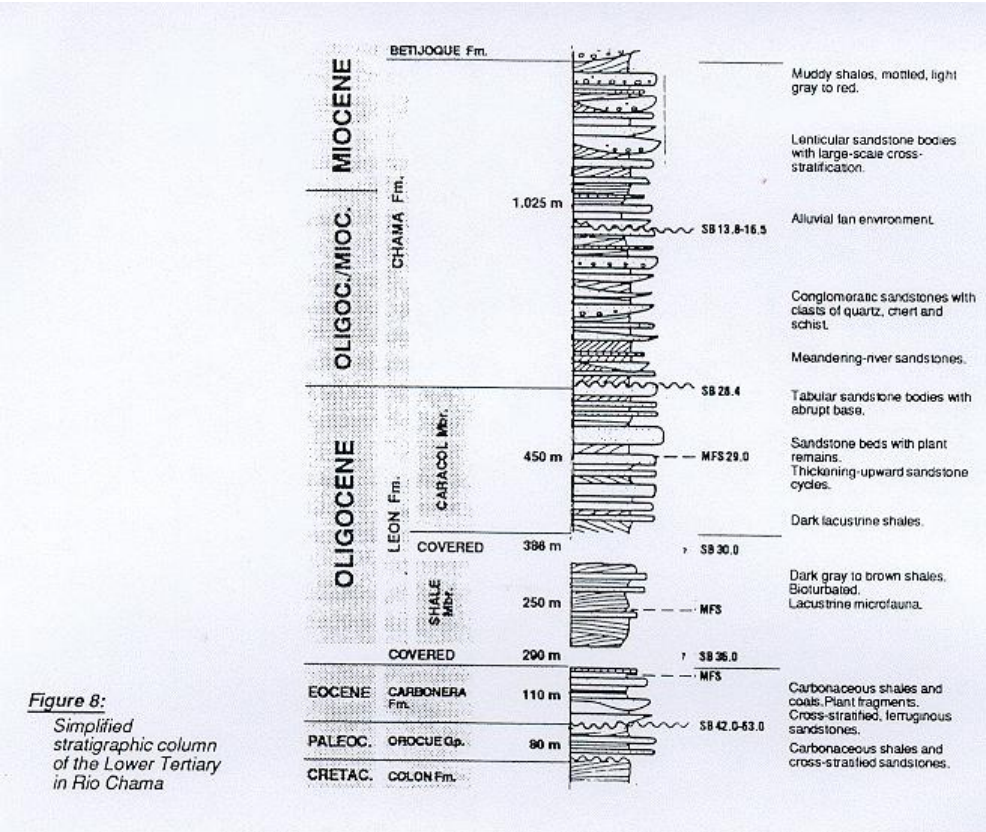


Figure 8:
Simplified stratigraphic column of the Lower Tertiary in Rio Chama

Unconformably overlying the León Fm are thick sediments of the informally named Chama Formation (ARMINIO and ALLEN, 1990). This begins with a short sequence of sandstones with the same fluviodeltaic characteristics as the Caracol Mbr, and continues with medium-grained conglomeratic sandstones characterized by pebbles of quartzite and white to light gray chert. The pale chert is probably diagenetically bleached chert derived from the La Luna Fm (I.4.2.4; HIGGS and MEDEROS, 1992). The coarse grain size reflects syntectonic deposition.

The section continues transitionally into the Miocene (Figure 8), consisting of abundant conglomeratic sandstones of fluvial channel origin, interbedded with mottled claystones and shales.

In the upper part of the Chama Fm the lenticular geometry of the sands is more pronounced, reflecting an abrupt change in the Miocene fluvial systems. A sequence boundary (SB 15.5) interpreted at this level correlates with the Gua-1S well.

The Chama Fm is partially equivalent to the Isnotú Fm (ARMINIO and ALLEN, 1990), whose outcrops are scarce in the northern sector of the North Andean Flank, but relatively abundant in the south.

The Río Chama section ends with the lower part of the Betijoque Fm, comprising sandstones, conglomerates and shales and representing true Andean molasse.

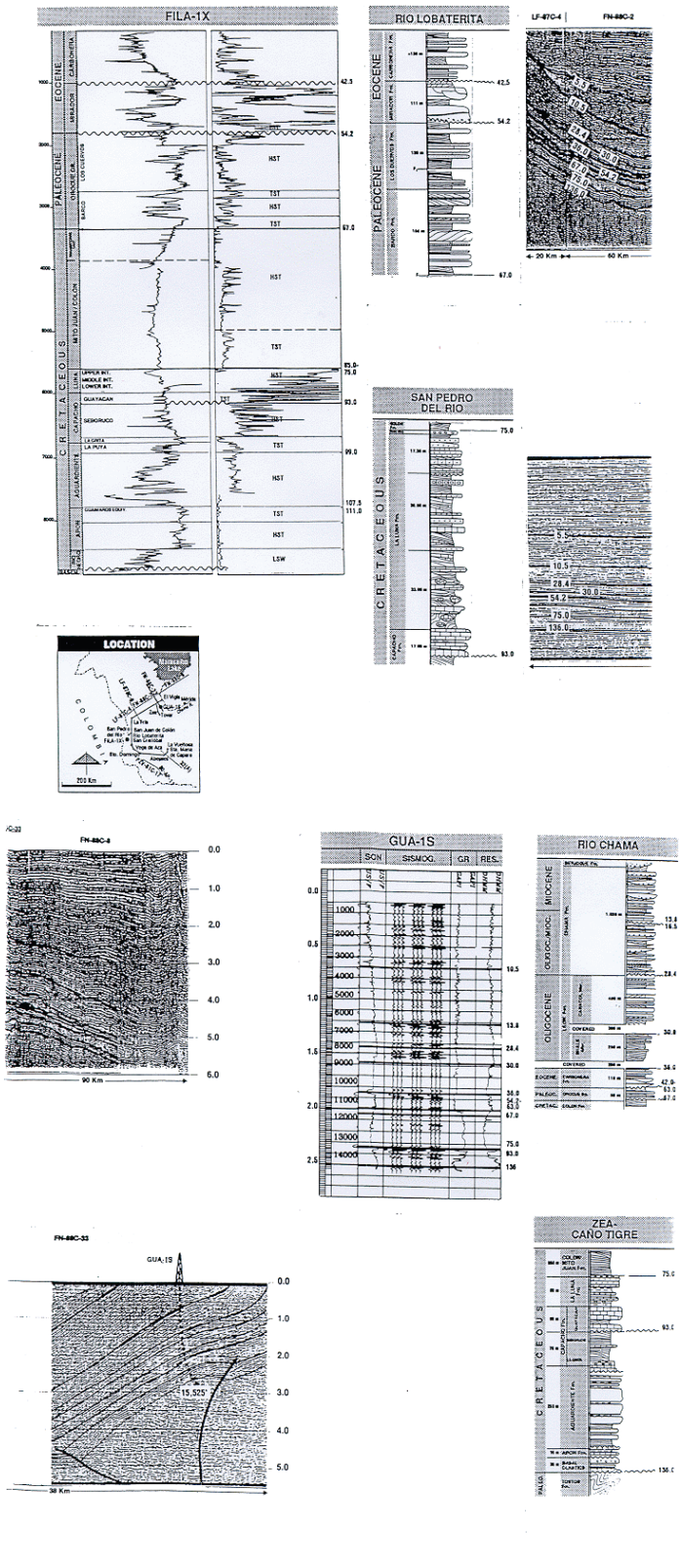


Figure 9:
Sequence stratigraphic interpretation of the North Andean Flank.

I.4.3.5 - Correlation

Deposition of the Paleogene section took place in an evolving foreland, with notable syn-depositional tectonic activity of the La Vega de Aza High and the west flank of the Avispa High. The tectonism is reflected in the stratigraphic table of Appendix 1, which brings out the different lateral continuities of the Cretaceous and Tertiary successions.

The difficulties of chronostratigraphic correlation between the Tertiary between the south flank of the Andes and the Táchira Depression are shown in the aforementioned table, which illustrates a distinct asymmetry in the pre-Paleogene foundations, and pronounced variations in the Paleogene lithostratigraphy in time and space. The table also shows the correlation problems between the molasse, namely the Betijoque and La Copé Fms; two possible ages are shown for the latter (I.4.3.2).

In the Táchira Depression, the only erosional remnants of the Paleogene section occur in the Ureña-San Feliz, San Antonio-Lobatera, and Rubio-San Cristóbal structural blocks (I.5.2.1) (Figure 13). The Paleogene section in these blocks can be reconstructed with the help of existing wells, suggesting a southward thinning which reflects the geometry of the foreland depositional platform (AUDEMARD, 1991). However, paleostructures such as the Brujas and Vega de Aza Highs distort this thinning and highlight the influence of tectonism during Paleogene sedimentation.

Special emphasis was given to stratigraphic studies in the North Andean Flank. A sequence analysis was performed integrating the studied outcrop sections, the wells Fila-1X and Gua-1S, the LF-87C-4/FN-88C-2-8 seismic line and the FN-88C-33 line. Biostratigraphic dating is essential in determining the main sequence boundaries. The synthesis is shown in Figure 9, which includes the key information provided by each control point and the multidisciplinary methodology for interpreting the main sequence boundaries.

The exercise attempts to date reflectors on the composite line using indirect control points such as the outcrops at Río Lobaterita, San Pedro del Río, Zea-Guraruríes and Río Chama and the Fila-1X well, and direct control in the form of the Gua-1S well and the FN-88C-33 line, where the well is located.

The synthetic seismogram from Gua-1S shows three reflectors, corresponding to sequence boundaries and regularly used in structural interpretations of the area. The lowest reflector corresponds to the top of the La Luna Fm, whose estimated age in the Zea are is 75 My The second reflector is related to a long hiatus between the base of the Carbonera Fm, of late middle Eocene age, and the erosionally truncated Paleocene, a relationship confirmed by the Gua-1S well. The hiatus decreases toward the sothwest extremity of the line due to intercalation of the lower Eocene Mirador Fm; consequently, this reflector is not useful for structural deformation studies. The third reflector is Oligocene, corresponding to the sharp lithologic break at the top of the León Fm shales.

An important aspect of the Oligocene is that the Caracol Mbr (León Fm), a third-order cycle (HAQ *et al.*, 1987), has a lenticular form, in conflict with the characteristic foreland geometry. In the south flank of the Andes the Oligocene thickens toward the mountains (Fig. 14), again suggesting syn-depositional tectonism in the general Andean area.

An important conclusion of this exercise is the relevance to hydrocarbon prospectivity of the eastward thinning of the Paleogene, reflecting the foreland geometry. This raises the possibility of a gigantic stratigraphy trap in which a sandstone wedge comprising the Barco, Mirador and Carbonera Fms. is confined by Colón Fm shales below and León shales above. Closure of the trap in other directions is yet to be proved.

I.5 - STRUCTURAL GEOLOGY

I.5.1. - Introduction

The Venezuelan Andes are an internal mountain chain whose history differs in many respects from the rest of the South American Andes. The Venezuelan Andes extend for approximately 460 km northeastward, separating the two large Neogene sedimentary basins of western Venezuela: The Lake Maracaibo basin to the north and the Apure-Llanos in the south. The so-called Táchira Depression is a saddle which separates the southwestern Venezuelan Andes from the Eastern Cordillera of Colombia.

The tectonic evolution of the Andes is a controversial subject which has been greatly elucidated by exploration campaigns in both Hanks in the past few years. Deep mountain-front structures have been interpreted and mapped geophysically, whereas the structure of the mountain core, where traditional seismic cannot be acquired, has yet to be resolved.

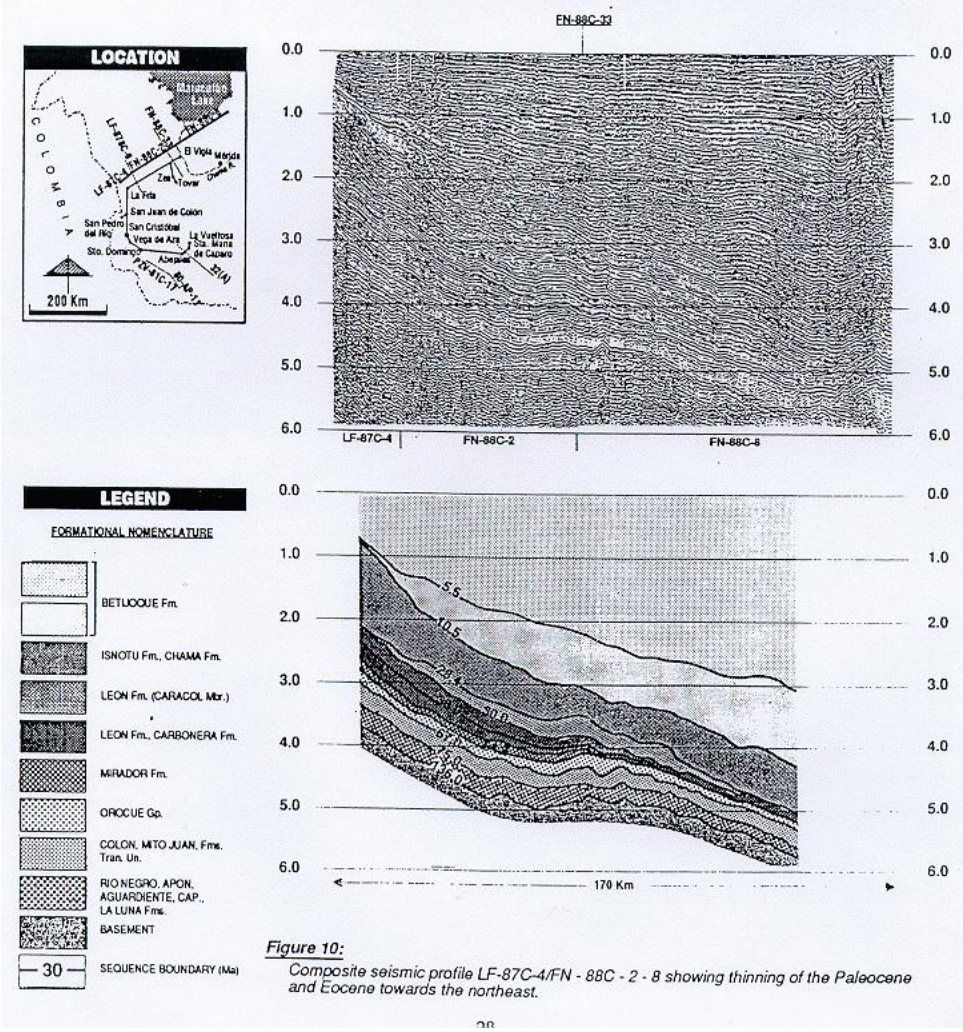


Figure 10:
Composite seismic profile LF-87C-4/FN - 88C - 2 - 8 showing thinning of the Paleocene and Eocene towards the northeast.

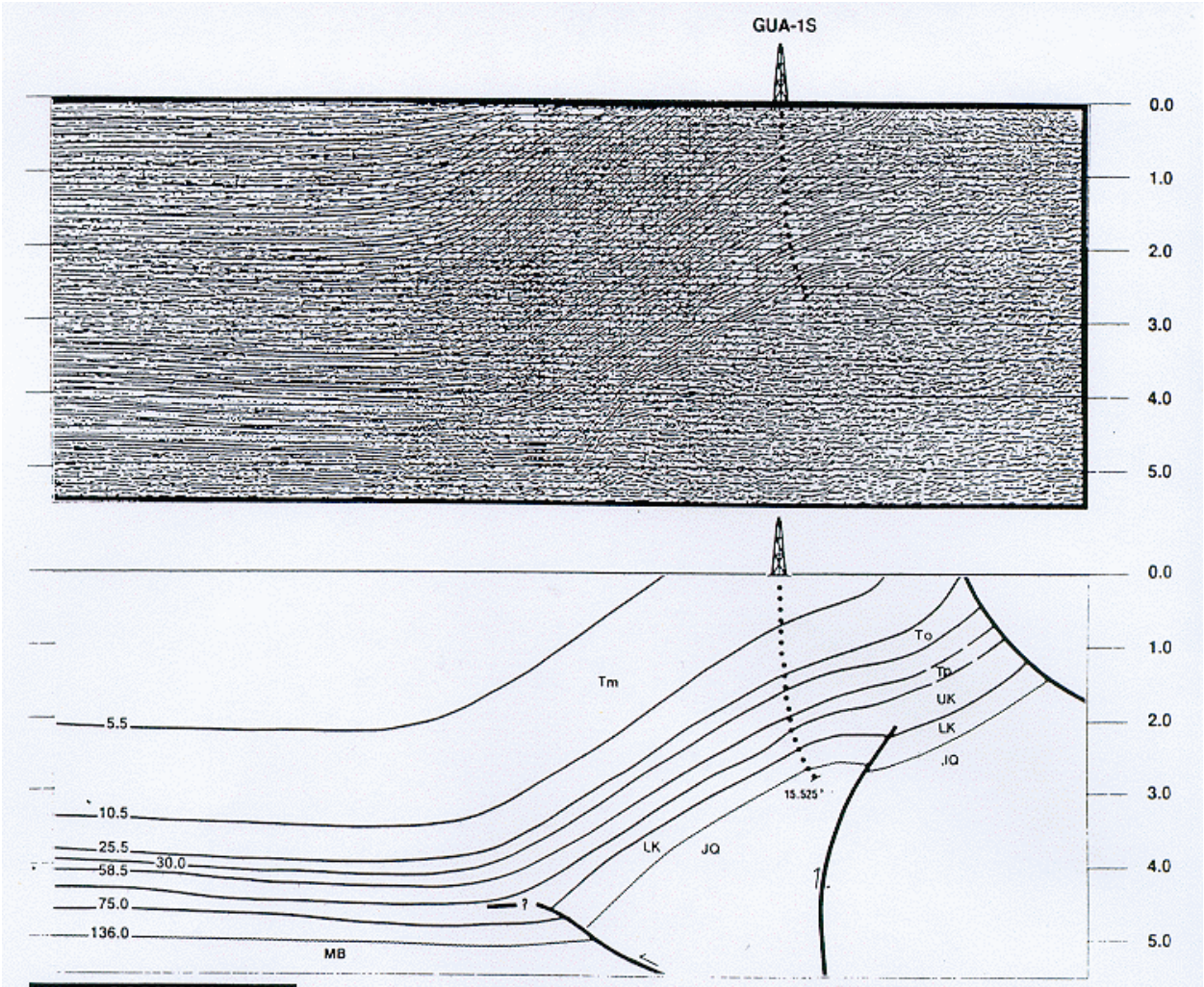


Figure 11:
Interpreted seismic profile FN - 88C - 33.

Other geophysical techniques besides seismic have been used in the Andes, such as land gravity, aerogravity and aeromagnetics. Gravity anomalies have been detected which in many cases do not correspond to surface rock densities. Recent gravity models of the foothills (CARSON HELICOPTERS INC., 1988) confirm the existence of thrusts, dipping between 30 and 50 degrees, whose presence had been suggested by seismic profiles. Combining both methods, displacements in the order of 5 to 6 km were detected in the Cretaceous and Tertiary sedimentary column (Figures 11 and 12), as well as the thinness of basement slices involved in the thrusts.

Among the structural interpretation techniques yet to be applied in the Andes is the integration of radar and aerial photography with seismic. This has been attempted on a regional scale (Figure 13) in order to achieve a coherent deformation model, which is necessary in order to understand the genetic relation between the Venezuelan and Colombian Andes.

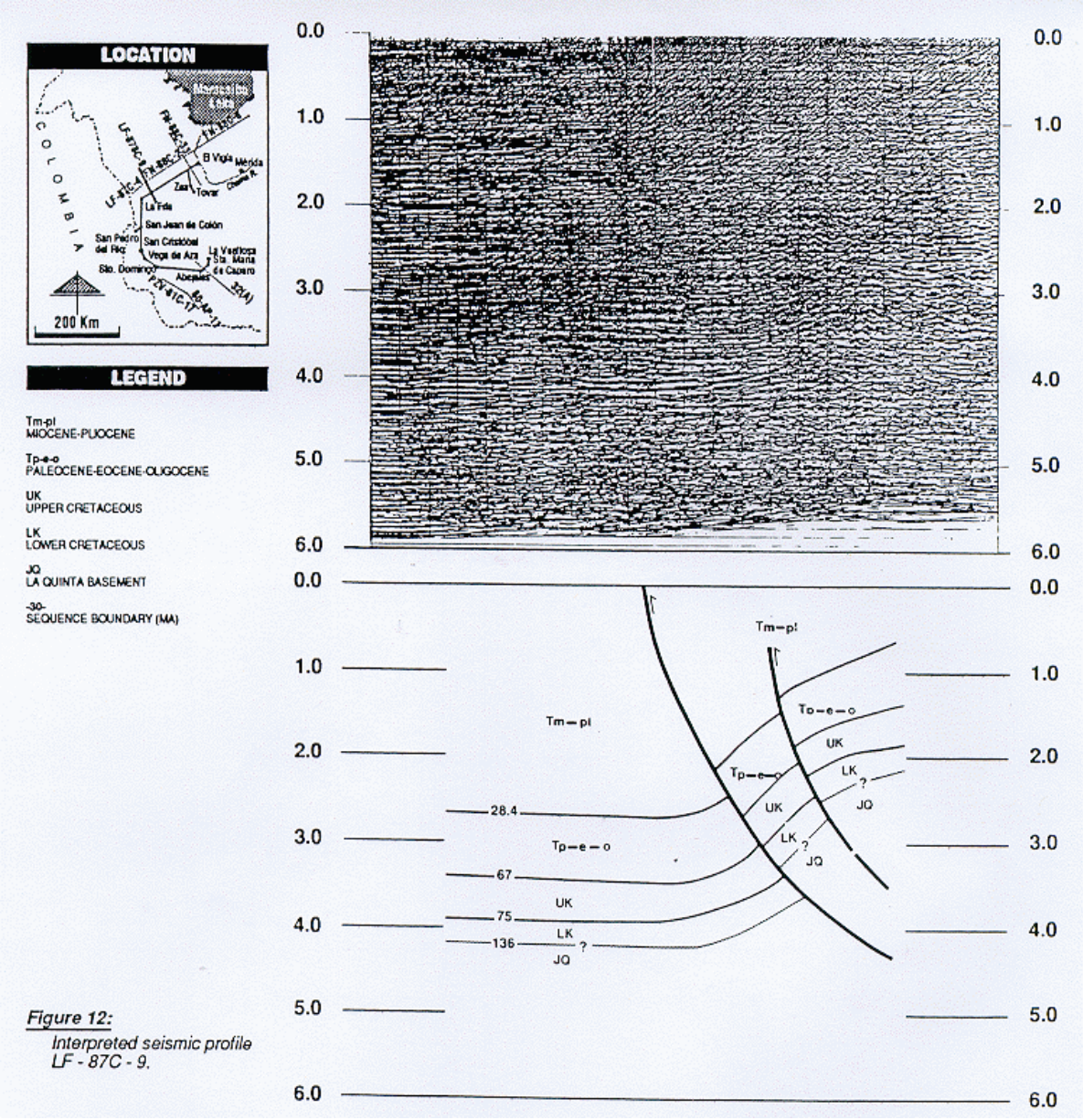


Figure 12:
Interpreted seismic profile LF - 87C - 9.

I.5.2 - Structural analysis of the area

I.5.2.1 - South Flank

Structurally the south flank is dominated by the Santo Domingo Depression. An apparently inactive fault with a strong surface expression, known as the Uribante Fault, can be identified on radar images. The fault trace appears to be displaced by a series of low-angle faults trending from southwest-northeast to east-west (Figure 13).

The southernmost part of the zone, between El Piñal and Río Caparo, is dominated by south-verging thrusts (Figs. 14 and 15). Two seismic lines from the Páez project (PZV-81C-19 and 80-AP-11), carried out in the 80's, were selected as representative of this type of deformation.

Interpretation of these lines reveals an anticline at depth, beneath the late Tertiary unconformity (Figure 14). Examination of logs from wells Burgua -1X, -2X, -3X and -4X reveals progressive erosion of the Cretaceous and early Tertiary succession north-northwestward, toward the so-called Brujas High, where Jurassic basement rocks are overlain with angular unconformity by Tertiary molasse possibly younger than 10.5 My (Figure 14).

Farther northeast, in the La Vueltosa area, are thrusts of regular geometry which indicate tectonic transport toward the northwest, generally cutting the Cretaceous and the Jurassic and pre-Jurassic basement at outcrop (Figure 15). Numerous folds-oriented northeast-southwest, parallel to the mountains, occur throughout the region.

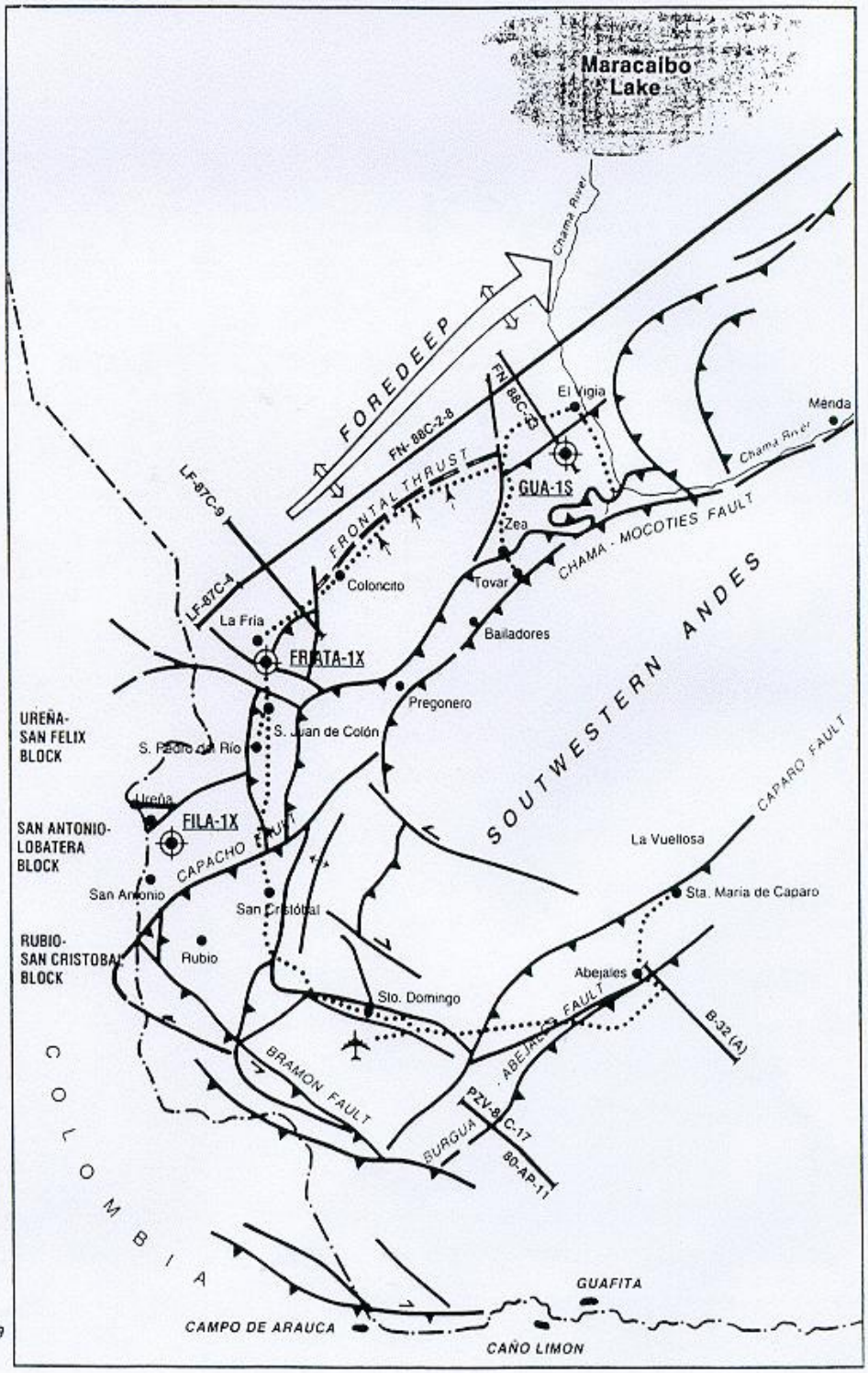


Figure 13:
Interpreted structure of the southwestern Andes.

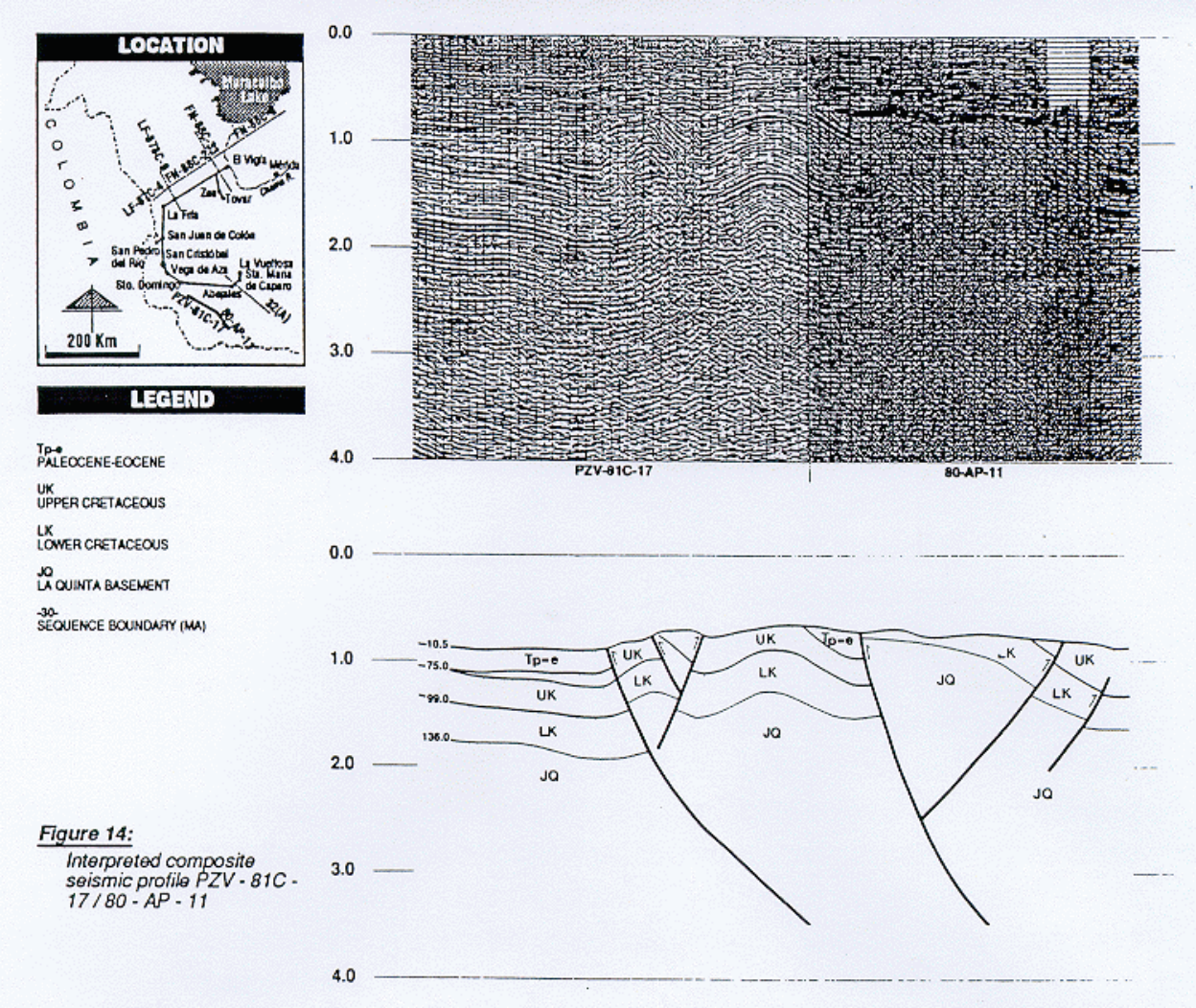


Figure 14:
Interpreted composite seismic profile PZV - 81C - 17 / 80 - AP - 11

I.5.2.2 - Táchira Depression

In the Táchira Depression, no exploration seismic has been conducted to date, except for the La Fila survey in the Ureña sector, close to Colombia. This region is extremely complex structurally, due to the interaction of two different compressive regimes: the northwest-southeast stress regime of the Venezuelan Andes and the east-west regime of the Cordillera Oriental of Colombia. The result is extensive fracturing of the entire sedimentary coyer end the development of a series of structural blocks influenced by both regimes. Seven main structural blocks and numerous sub-blocks were recognized by Meier (1983) and Laubscher (1987), based on large-scale mapping (1:100,000 or less). Recent studies by Maraven at a smaller scale (1:250,000) recognize three large blocks, informally named the Ureña-San Félix, San Antonio-Lobatera, and Rubio-San Cristóbal blocks (Fig. 13).

The Ureña-San Felix block is bounded in the north by the frontal thrust of the Andes, in the south by the San Pedro del Río Fault, and laterally by strike-slip faults-oriented northwest-southeast.

The San Antonio-Lobatera block is separated from the Rubio block by the Capacho Fault, which shows apparent dextral strike-slip offset and an undetermined vertical component of throw. The

San Antonio block is subdivided into three sub-blocks by the Michelena and Quebrada Seca-Llano Grande Faults, which are oriented northwest-southeast and show sinistral strike-slip offset.

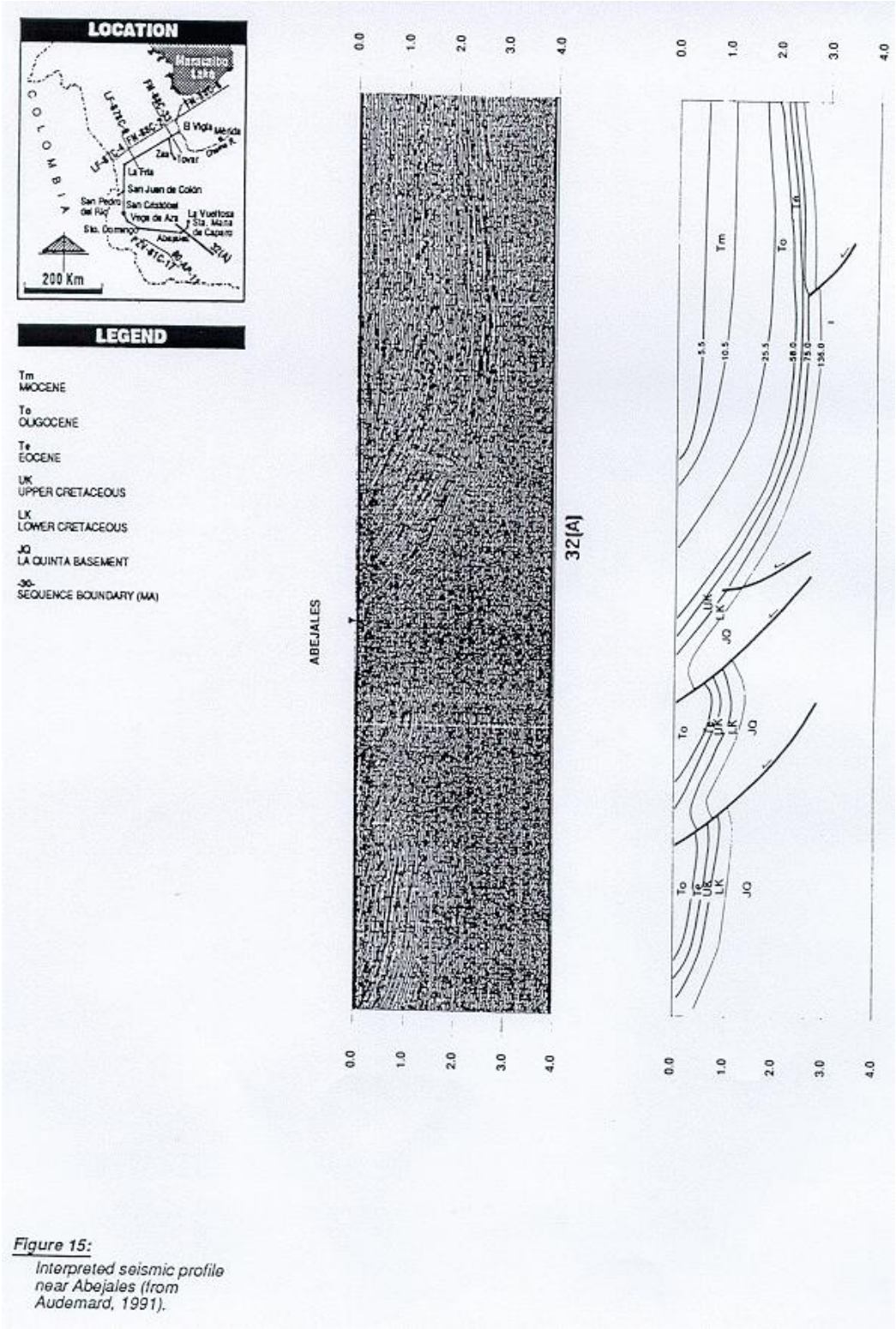


Figure 15:
Interpreted seismic profile near Abejales (from Audemard, 1991).

The Rubio-San Cristóbal block is limited to the west by the Bramón Fault (BELLIZZIA *et al.*, 1976) and to the east by the Sabaneta Fault (Figure 13). The first fault is oriented northwest-southeast and the second north-south, culminating south of Santa Ana de Rubio in a small thrust associated with the La Alquitrana structure. This block is apparently related to the Vega de Aza paleostructure. The Bramón Fault is of regional extent, traceable for more than 50 km, and shows sinistral strike-slip movement and northeastward overthrusting of the Colombian Cordillera Oriental over the Rubio-San Cristobal block.

I.5.2.3 - North Flank

Interpretation of seismic lines acquired in the region from El Vigía to La Fría during the 1987-1990 campaign reveals a frontal thrust of regional extent (Figure 13) whose surface trace generally coincides with the topographic break of the foothills. In this region, where close to 2,000 km of seismic lines have been recorded to date, two lines have been selected as illustrative of the deformation style (FN-88C-33 and LF-87C-9).

The first line is about 7 hens southwest of El Vigía, crossing the location of the Gua-1S well (Figure 11). The line immediately shows a monocline dipping at 35 degrees towards the foredeep, as measured in the well.

In the flexure zone, younger thrusts cutting as high as the late Cretaceous are visible. The end of the line shows a thrust fault whose surface trave is very evident, not only on radar images but also in the field (SERVIGEOMIN, 1991). Finally, at sequence boundary SB 5.5, strong divergence of the seismic reflectors is seen, related to progressive flexural movement of the monocline (Figure 11).

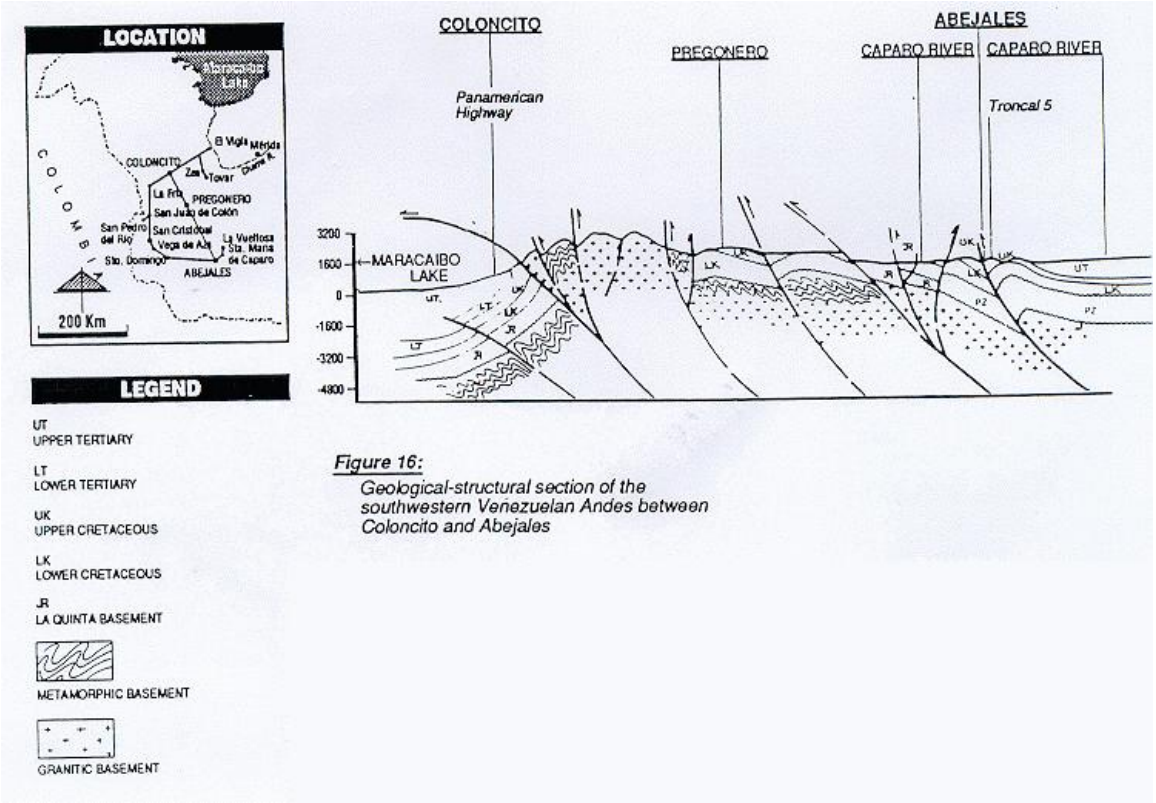


Figure 16:
Geological-structural section of the southwestern Venezuelan Andes between Coloncito and Abejales

Line LF-87C-9 is near the town of Coloncito (Figure 12) and shows that the frontal thrust cuts as high as the youngest Tertiary, suggesting progressive shortening of the whole sedimentary cover toward that region.

Regional seismic interpretation, like the aerogravity and aeromagnetic maps, reveals the Andean foredeep and shows that it is asymmetrical, not only in a transverse sense but also longitudinally (Figure 10), with the foredeep axis plunging toward the northeast. This geometry is of obvious importance in the generation and rnigration of hydrocarbons.

I.5.3 - Deformation model

The structural geometry described in the previous paragraph leads to a proposed deformation model with the axis of maximum compression (sigma 1) horizontal and oriented northwest-southeast, responsible for shortening on the frontal thrust faults of the North Andean Flank, as well as on the San Pedro del Río backthrust, the Capacho thrust, and the Sabaneta-Santa Ana thrust. In this model, the strike-slip faults-oriented northwest-southeast, such as the Quebrada San Sebastián, Quebrada Seca and Bramon Faults, would be lateral ramps of the frontal thrusts (Figure 13).

Small dextral strike-slip components on some of the thrust faults, such as the Capacho, can be explained by contemporaneous tectonism in the Colombian foreland, pushing due east.

Finally, the Cretaceous and Paleogene stratigraphic relationships suggest the existence of pre-Andean structures in the La Copé-Vega de Aza area and possibly toward the Santo Domingo area, masked by the younger, more violent tectonism. However, neither these structures nor those caused by the push from the west negate the proposed model (Figure 16), in which a horizontal principal stress produced a structural framework of north verging thrusts, in some cases affected by post-emplacement adjustments or collapse.

I.6 - GEOCHEMISTRY

I.6.1 - Source Rocks

A source rock is considered here to be any rock shown by laboratory analysis to be capable of generating hydrocarbons, regardless of its present state of thermal maturation. The search for source rocks in the Maracaibo and Barinas-Apure basins began in the flanks of the Andes and the Perijá range, where time-equivalent strata crop out. A. H. Garner (1926) is credited as being the first to describe the hydrocarbon generative properties of the La Luna Fm. Since then, oil companies have focussed on the La Luna Fm, carrying out systematic geochemical studies of ever-increasing sophistication in order to quantify its generating potential and to determine the varying levels of maturation across the basin.

However, later discoveries of oil seeps associated with type-III (terrestrial) organic matter prompted a search for additional source-rock intervals, resulting in the discovery of source rocks in the Orocué Gp and the Carbonera Fm. At present, as part of the exploratory effort in the North Andean Flank, rocks of the entire Cretaceous and Tertiary column are being systematically evaluated for their potential as source rocks.

I.6.1.1 - Marine source rocks

Consideration of maximum flooding surfaces in the Cretaceous passive margin heads Marine source to the conclusion that not only the La Luna Fm has source-rock properties, but also the rocks Machiques Mbr of the Apón Fm (MENDEZ, 1991) and its equivalent Guáimaros Shale (Appendix 1), and also the La Grita Mbr of the Capacho Fm and its equivalents.

However, the La Luna Fm retains its status as principal source rock, owing to its thick organic-rich interval. This interval thins from the Maracaibo area (400 feet) to the southwester Andes (minimum 100 feet at San Pedro del Río; Figure 5). Farther south, near Vega de Aza, the La Luna Fm changes facies and loses its source potential.

Despite these important variations in its generation potential, the La Luna Fm remains the best source rock, even in areas like the Táchira Depression, where it exhibits its poorest potential. The La Luna is therefore considered the source of all type II crudes in the study area, unless their derivation from one of the other Cretaceous intervals associated with an MFS is specifically proven.

From the San Pedro del Río section, gas chromatograms (C_{10}+ saturated fraction) typical of a type II source rock are yielded by a sample from the lower La Luna interval (Figure 17) and a sample representative of the middle interval (Figure 18). Despite the high grade of thermal maturation, there seems to be higher oxygenation in the sample from the middle interval, where cherts begin to appear more frequently in the section, suggesting a decrease in anoxic properties towards the middle and upper La Luna. This increase in oxygen in the formation is interpreted here as caused by silica transport from the continent, as discussed in I.4.2.4 and I.4.2.6.

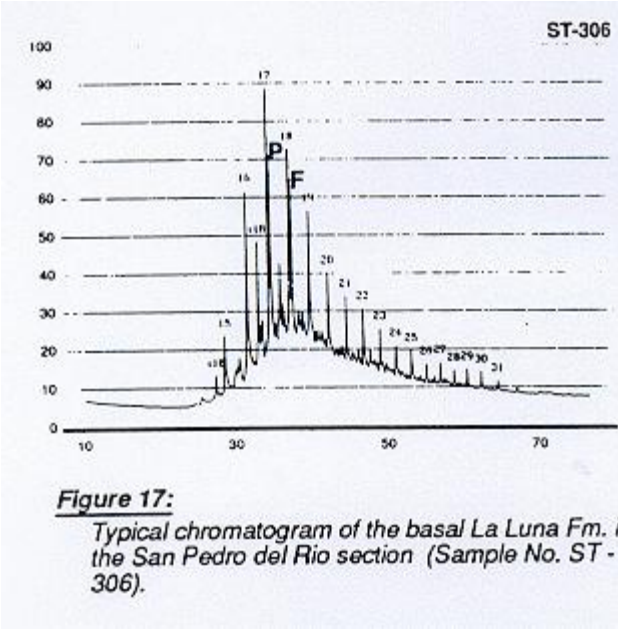


Figure 17:
Typical chromatogram of the basal La Luna Fm. in the San Pedro del Rio section (Sample No. ST-306).

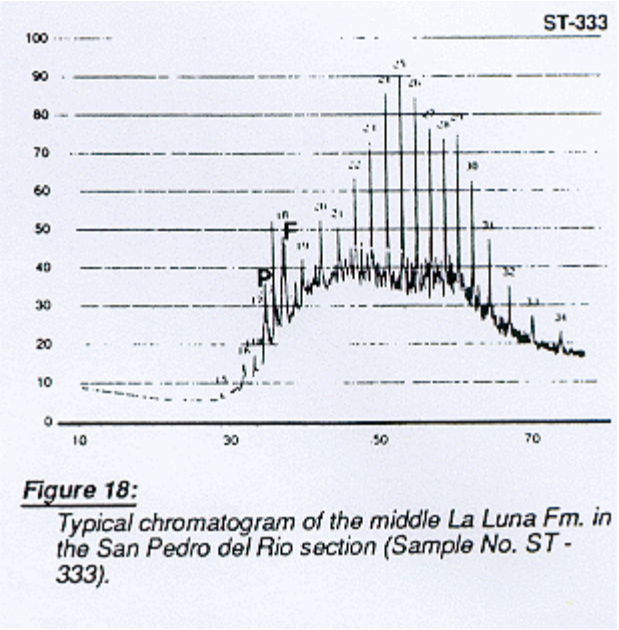


Figure 18:
Typical chromatogram of the middle La Luna Fm. in the San Pedro del Rio section (Sample No. ST-333).

The results presented above are valid for the Lake Maracaibo - San Pedro del Río correlation line and are not taken to be general.

I.6.1.2 - Terrestrial source rocks

Systematic analysis of samples from the Paleogene section of the North Andean Flank have identified terrestrial source rocks. In particular, the coals and carbonaceous shales of the Carbonera Fm and Orocué Gp have kerogen of type III with potential to generate gas and crude (CASSANI *et al.*, 1989). In Figure 19, a gas chromatogram (saturated C_{15}+ fraction) is given for a sample from each of these formations, showing:

A - The relative abundance of C_{24}+

B - The pristine/phytane ratio >4.

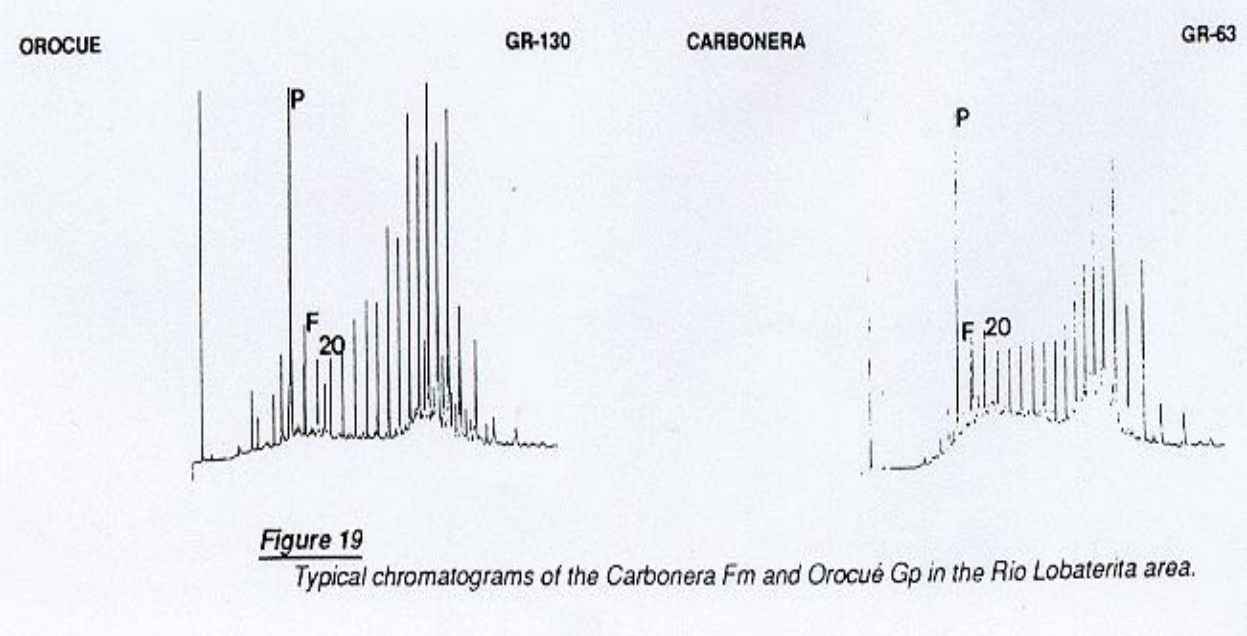


Figure 19
Typical chromatograms of the Carbonera Fm and Orocué Gp in the Río Lobaterita area.

The outcrop section exhibits low thermal maturity, which favors exploration in areas which have undergone burial recently, such as the La Fría sector of the North Andean Flank foredeep.

I.6.2 - Oil types

Analysis of seep samples from the North Andean Flank, La Alquitrana and La Copé allows the crudes to be classified into three categories:

- A - Crudes derived from type II marine source rocks.
- B - Crudes derived from type III terrestrial source rocks.
- C - Crudes of mixed origin.

The first category includes: crude from impregnated Arguardiente Fm sandstone in the Caña Brava sector, on the bank of the Río Charna; condensate produced on test in the Gua-1S well; and crude from the La Alquitrana structure in the Táchira Depression. The absence of seeps of this type in the rest of the area covered by this excursion and in the south flank is noteworthy.

Category B seeps are abundant in the area, as represented by the Las Hemández seep, whose chromatogram is shown in Figure 20 for correlation with Tertiary source rocks, taking into account the natural biodegradation which it has suffered. The Carbonera Fm sandstones in well Gua-1S contain residual crude of this category.

Category C seeps are confined to impregnations in the La Copé conglomerates. The corresponding chromatogram (Figure 21) is difficult to interpret due to natural biodegradation but suggests a mixed origin. Crudes from the Tarra and Los Manueles fields belong to this category (TALUKDAR *et al.*, 1985).

As an alternative possibility, the similarity between the chromatograms of the La Copé sample and the middle La Luna Fm (Figure 18) leads to an interesting alternative hypothesis for the origin of the La Copé and La Alquitrana crudes (I.6.3).

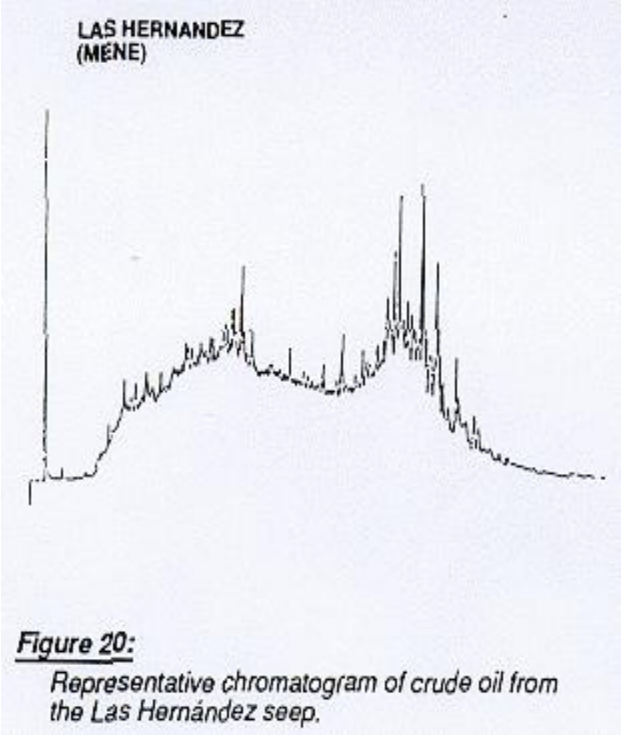


Figure 20:
Representative chromatogram of crude oil from the Las Hernández seep.

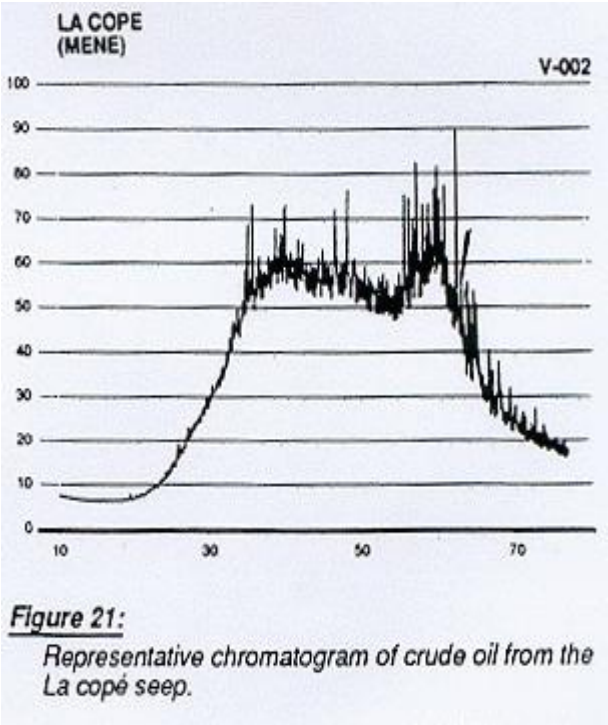


Figure 21:
Representative chromatogram of crude oil from the La copé seep.

I.6.3 - Generation and migration

For discussion of this topic the region is divided into two sectors: firstly, the Táchira Depression, including the Santo Domingo area; and secondly the North Andean Flank between La Fría and the Río Chama.

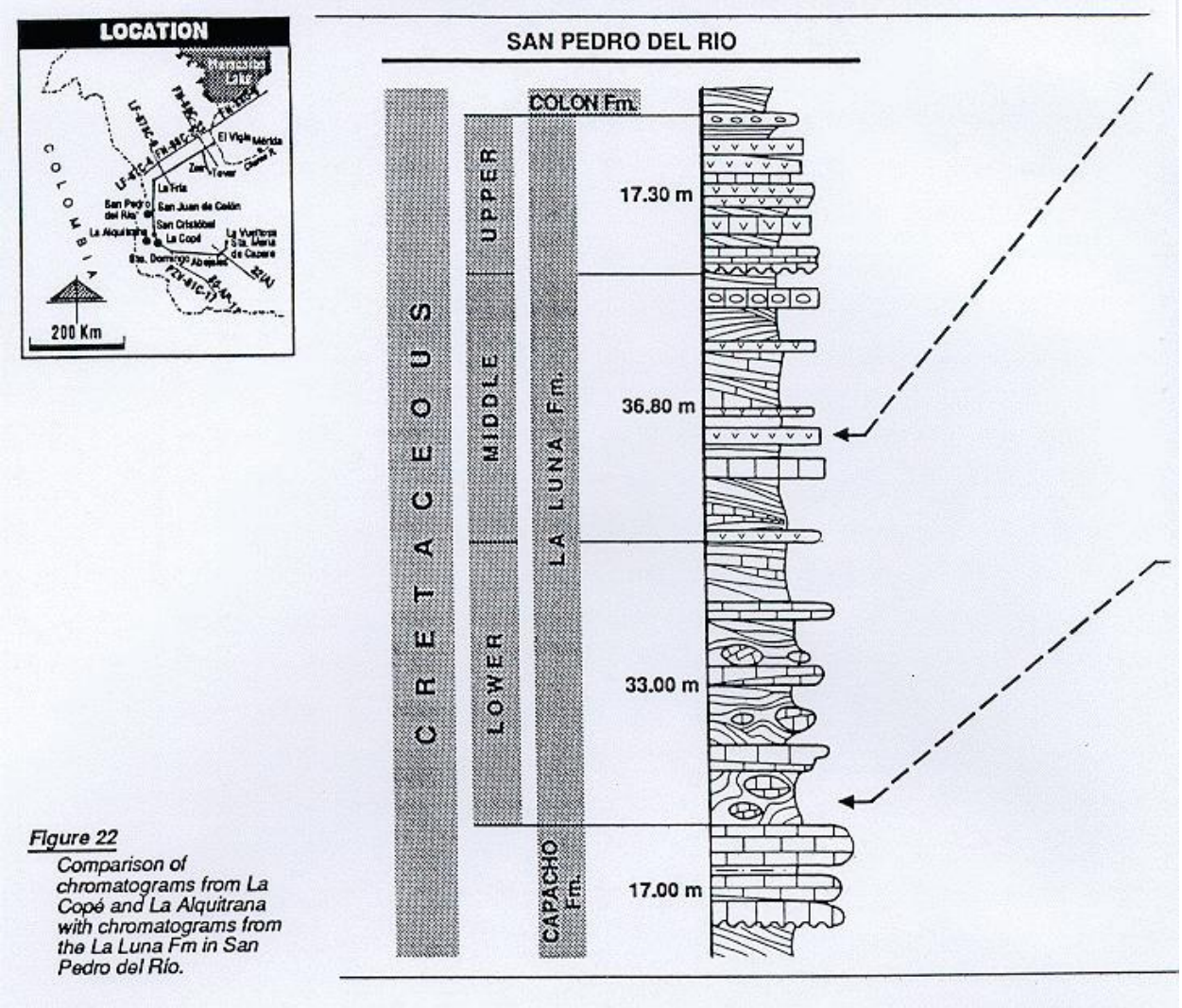


Figure 22
Comparison of chromatograms from La Copé and La Alquitrana with chromatograms from the La Luna Fm in San Pedro del Río.

Táchira Depression

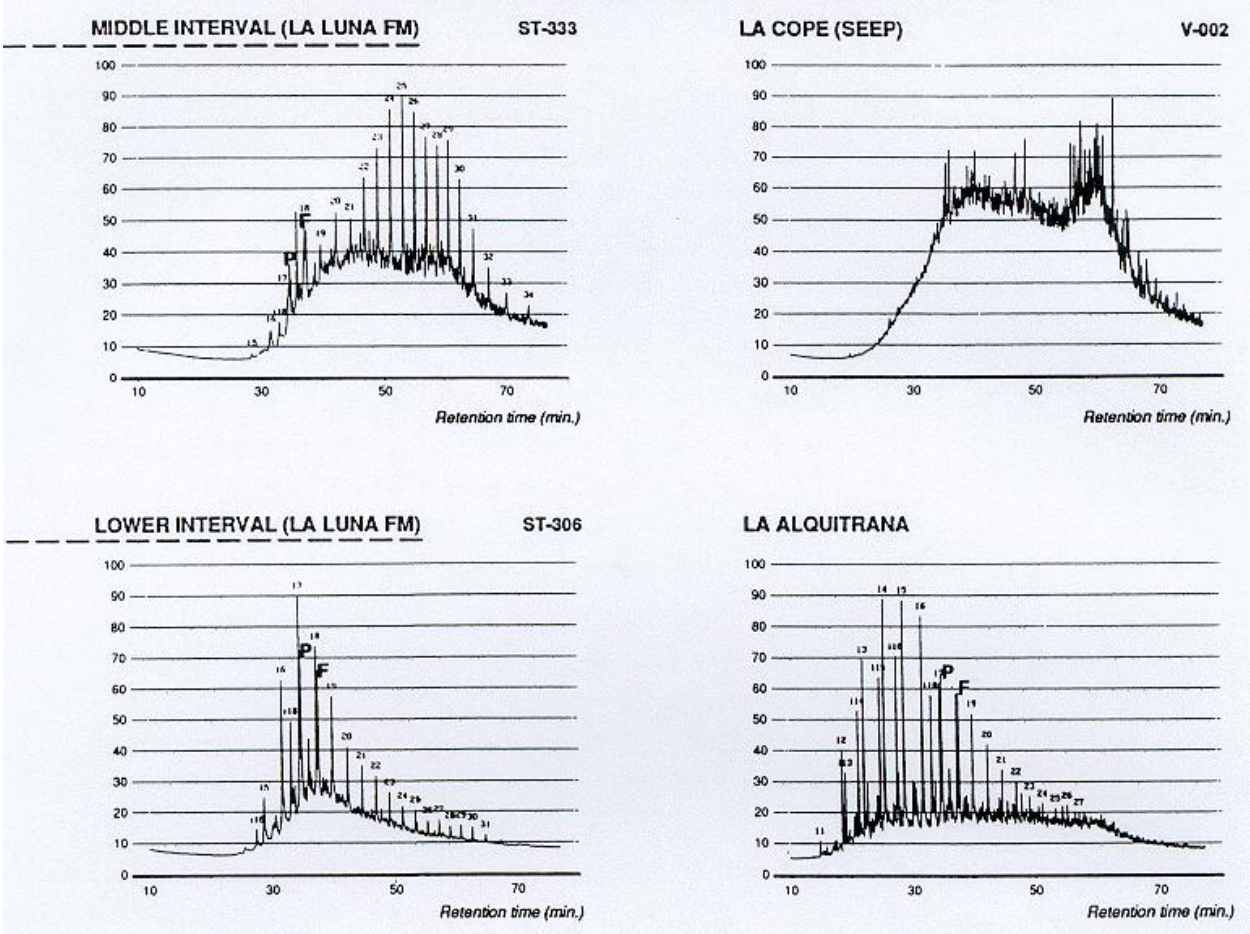
As mentioned above, the crudes of La Copé and La Alquitrana may be associated with the La Luna Fm, given the similarity of the respective chromatograms (Figure 22). In contrast, when crudes from these seeps are compared with the terrestrial source rocks of the Carbonera Fm and Orocué Gp (Figure 19), notable discrepancies are seen in the abundance of C_{24}+ and in the pristane/phytane ratio. Consequently, association of the La Copé and La Alquitrana crudes with the La Luna Fm appears more feasible than with the Carbonera or Orocué. This correlation leads to the proposal that maturation of the La Luna Fm gave rise to different phases of crude expulsion.

Disintegration of the Táchira Depression into structural blocks (I.5.2.2), of possible Miocene age, favors only small hydrocarbon accumulations restricted to areas of high structural relief, as in La Alquitrana.

North Andean Flank

The Andean foredeep has played an important role in the generation and migration of hydrocarbons. Its asymmetrical geometry, with the southeastern flank being steeper and the

longitudinal axis plunging northeastward, favors migration of hydrocarbons mountainward and southwestward, toward La Fría. For entrapment of crudes in the North Andean Flank (southwestem sector), traps must be pre-Andean (pre-Miocene?) and must have retained their integrity throughout the ensuing Andean tectonism.



Other important geochemical aspects of the area are:

A - The existence of source rocks in addition to the La Luna Fm, such as the Orocué Gp and Carbonera Fm

B - Early maturation of the La Luna Fm, in the Late Oligocene, as shown by the burial history diagram of the Friata-1X well (Figure 23).

The first factor is clearly positive and is related to the numerous seeps of terrestrial origin in the foothills, indicating that the Tertiary source rocks, in addition to their gas potential, have generated oil. However, no commercial accumulations of this type of crude have been discovered yet.

The second factor is less positive, and suggests total loss of hydrocarbons generated by the La Luna Fm is likely unless two conditions are met:

- Andean orogeny commencing earlier, in the Oligocene, or the presence of older
- Present traps are completely sealed.

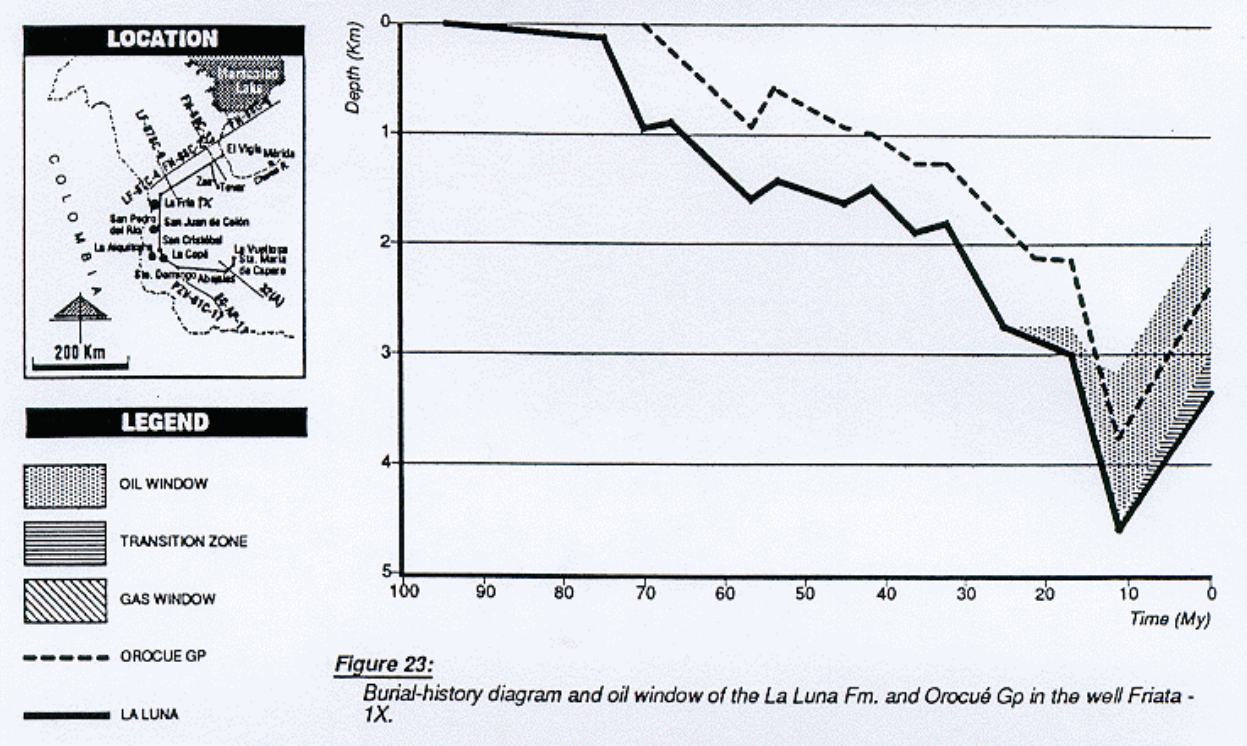


Figure 23:
Burial-history diagram and oil window of the La Luna Fm. and Orocué Gp in the well Friata - 1X.

Regarding the first condition, pre-Andean structures can be confused. For example, interpretation of seismic line LF-87C4/FN-88C-2-8 (Figure 10) shows a broad fold with thinning of the Mirador Fm against the west flank, suggesting that the structure pre-dates SB 48.5.

With respect to the second condition, above the basal Cretaceous section there are three continuous shaly intervals, namely the Seboruco Mbr of the Capacho Fm, the Colón Fm (I.4.2.6) and the Oligocene León Fm (Appendix 1); such an abundance of seals is unique to this area.

I.7 - EXPLORATION ACTIVITY

I.7.1 - South flank (Santo Domingo Area)

The following is a summary of the exploration history of the southwestern Venezuelan Andes.

Exploration commenced in this area in 1938 when Shell Company of Venezuela recorded experimental digital lines under difficult conditions due to frequent flooding.

From 1951 to 1958 the same company ran an extensive program in Apure state, including three lines over the Brujas High, detected in the previous survey, to locate the first exploratory wells.

Seismic:

In 1979 Maraven started recording reconnaissance digital seismic, using Vibroseis, over a wide area in Apure state, with the same difficulties experienced by Shell in the past. After defining the regional structure, Maraven recorded 376 km with Vibroseis during the dry season of 1980, and a further 296 Km in 1981. Two important regional reflectors were identified, «K» at the top of the Colón Fm and «L» on the Guayacán limestone, allowing refuned structural interpretation and an improved model of the Brujas High.

Wells:

The only existing wells in the Andean foothills in the Santo Domingo Depression are Burgua-1X to 4X, drilled by Shell in 1953 and 1954 during a brief but intense exploratory campaign which included the Táchira Depression and areas of the Venezuelan plains. This campaign was prompted by favourable regional studies, including the presence of seeps in the foothills of the Nula Massif, and the Brujas High was ranked as highly prospective.

The long section generated by Burgua-1X, together with Burgua-2X and -3X (TD 8,804 and 3,978 feet, respectively), provided valuable stratigraphic information and confirmed structural interpretations.

I.7.2 - Táchira Depression

Seismic:

Neither seismic nor potential-field surveys are known to have been conducted in this area. All exploratory geophysical exploration has been for minerals, mainly phosphates and coal, by the Ministry of Energy and Mines and private companies.

Wells:

In 1887 the La Alquitrana well was successfully completed on the structure of the same name, near the town of Rubio. This attracted the attention of exploration companies who subsequently carried out extensive field work.

In 1939 Shell drilled a series of wells to evaluate the La Alquitrana structure, notably Alquitrana-1X with a total depth of 3,701 feet. The same company then conducted a more regional exploratory survey of the Rubio-San Cristóbal block, drilling four additional wells, including Fila-1X which reached basement at 9,030 feet.

I.7.3 - North Flank

Potential-field methods:

Following gravity studies by Bonini *et al.* (1981), integrating local surveys done by oil companies, Maraven/Carson Helicopters completed an aeromagnetic/aerogravity survey in 1988 covering an area of 7,000 km², including the entire North Andean Flank and the Catatumbo area. The survey had three objectives:

A - Locate the structures of highest relief.

B - Assist planning of seismic surveys.

C - Integrate the results with seismic.

The first two objectives have been met, while the third is Still in progress, with active participation of Simón Bolívar University in the form of Ph.D. thesis.

Seismic:

Between 1987 and 1991 Maraven acquired about 4,000 km of seismic lines in the North Andean Flank, nearly half of which lie within the area of this report. Most lines were acquired using dynamite, with some Vibroseis lines along roads.

Wells:

The first wells were Onia-1 to -7 drilled by Sun between 1923 and 1929, reaching depths of 843 to 1,271 feet without encountering commercial hydrocarbons. In 1952 Shell drilled Friata-1X on a surface anticline, bottoming in Paleocene sediments at 12,651 feet. Fluorescence was reported near the top of the Mirador Fm in the interval 11,858 to 11,901 feet, but mechanical problems prevented full evaluation of the well.

Until then, wells in the North Andean Flank had drilled only the Tertiary section unsystematically without discovering commercial hydrocarbons.

As part of its current exploratory effort, Maraven drilled Gua-1S on a faulted monocline in the Onia area, with evaluation of the Cretaceous as primary objective and the Tertiary as secondary. The well reached a total depth of 15,525 feet in sediments of the La Quinta Fm and discovered gas and condensate in fractured limestones in the upper part of the Aguardiente Fm (La Puya Limestone). Production tests yielded 8 MMcf/d and 250 BPD of condensate at hydrostatic pressure. The Aguardiente massive sands were petroliferous but incapable of producing due to their low permeability. Sandstones of the Carbonera Fm were found to be saturated with residual oil.

These results from Gua-1S demonstrate the hydrocarbon trapping capacity of the North Andean Flank, and reduce the risk factor for future exploration wells.

1.8 - CONCLUSION

Cretaceous sedimentation took place during seven second-order cycles, of which - the first five correspond to a passive continental margin, the sixth to a backarc basin, and the last to the initial western foreland.

- The definition of second-order cycles requires the use of forrnational members.
- Cretaceous cycles 5 and 6 contain eustatic unconformities enhanced by tectonism.
- In the southwestern Andes the Cretaceous formations are slightly diachronous and the Paleogene more so.

The main Tertiary sequence boundaries are identifiable in the field and their absolute ages cover wide ranges.

The Paleogene depocenter lay to the west of the study area. Despite local complications, the Paleogene thins to the east, reflecting the foreland geometry.

Structural deformation commenced in the Cretaceous in an extensional setting and continued in the Paleogene, when it gradually became compressional.

Post-Paleogene tectonism is dominantly compressive, causing north-verging thrusts with lateral ramps.

Cretaceous source rocks, preferentially developed in the north flank of the mountains, are associated with marine maximum flooding surfaces (MFS).

The La Luna Fm in the extreme south of the area and its equivalent Navey Fm have low organic matter concentrations.

In the North Andean Flank there are terrestrial source rocks which, in addition to their gas potential, have generated oil.

Crude oil of the La Copé seep and La Alquitrana structure are possibly derived from the La Luna Fm.

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ABSTRACT

The excursion itinerary (Appendix 1) consists of 11 stops intended to demonstrate the most relevant geological events in the exploration evaluation of the southwestern Venezuelan Andes.

The excursion commences in Santo Domingo airport in Táchira state, with a panoramic view of much of the south flank of the Andes (atmospheric conditions permitting).

The first outcrops to be visited are Lower Cretaceous in "Barina's facies", at the La Vueltosa damsite, and constitute a starting point for understanding the rest of the Cretaceous in the southwestern Andes. Later, in the Santo Domingo area, the Cretaceous is seen in "Andean facies", and the participant will note interesting contrasts with the La Vueltosa section. These differences allow visualization of the passive continental margin paleogeography. Further on, ascending the tectonic Táchira saddle, large faults such as the Bramón will be seen, representing the lateral ramps of the frontal thrusts of the southwestern Andes.

At the Vega de Aza stop, tectonic problems and their possible influence on Cretaceous and Tertiary sedimentation will be discussed. Vega de Aza is the site of the La Copé asphalt seep and is a key area for investigating syn-deposinonal tectonics. The implications of this locality for hydrocarbon habitat will be discussed, concluding the first day of the excursion.

The second day is dedicated to the Táchira Depression. The route to San Pedro del Río, where typical La Luna Fm outcrops occur, crosses the three structural blocks (Rubio-San Cristóbal; San Antonio-Lobatera; Ureña-San Félix), whose physiography reflects the main thrust faults, the most prominent of which is the Capacho Fault. For the first time, participants will see outcrops of the thick Paleogene sequence, forming mountains supported in some cases by the Mirador sandstone and in others by Carbonera Fm sandstones.

In San Pedro del Río, a complete section of the La Luna Fm will be visited along Chiriria creek. As well as showing the three typical facies of the La Luna, the section illustrates the Turonian-Santonian transgression, including the Guayacán limestone.

The second half of the day is dedicated to the Río Lobaterita section comprising the Orocué Gp and Mirador Fm and, depending on accessibility, the lower part of the Carbonera Fm Field pyrolysis of type m source rocks in the Orocué Gp will be demonstrated. This interesting stop will conclude with an attempt to interpret the systems tracts, with the help of logs from the Fila-1X well, located in Ureña.

The third day is dedicated to the north flank of the mountains. A lower Cretaceous section along the road to Zea will be examined, depending on traffic conditions. The Stop is convenient for discussing the correlation between this section and the Gua-1S well nearby, using the well logs to complete the sequential interpretation of poorly exposed parts of the outcrop, such as the Apón Fm.

The last part of the excursion is in the Río Chama valley, between El Vigía and Santa Teresa tunnel, along the road under construction to Estánquez. This is the most complete Tertiary section exposed in the north flank of the Andes. The main sequence boundaries will be seen, from the Paleocene-Eocene to the Oligocene-Miocene. Problems in the practical use of these boundaries will be discussed. Finally, evidence for the age of the main Andear deformation will be reviewed.

PART II - EXCURSION GUIDE

II.1 INTRODUCTION

As part of the international congress and exhibition of the AAPG-SVG in Caracas, from the 14th to 17th March 1993, five field trips will be run in Venezuela to demonstrate the advances achieved by the national oil industry in understanding the geology of Venezuela and its application to petroleum exploration.

CRETACEOUS AND PALEOGENE SEDIMENTATION IN THE SOUTHWESTERN VENEZUELAN ANDES is the title of this excursion, number 4 in the series, organized and led by Maraven with the participation of the Ministry of Energy and Mines of Venezuela. This excursion, together with number 2, constitutes part of Maraven's contribution to the congress.

The objective of the excursion is to show participants the results of a multidisciplinary exploration program in one of the most difficult areas of the foothills to evaluate. This new approach to the geology of the area helps in understanding the tectonosedimentary history using the techniques of sequence stratigraphy.

Appendix 1 is the key instrument of the excursion. The message contained in this table is the very specific use which sequence analysis makes of the lithostratigraphic nomenclature, applying formation names (frequently at member level) which are indispensable for reconstructing the sedimentary history of the region.

The participant will come to appreciate the problem of seismic acquisition and processing in this mountainous zone, and the impact of this problem in the interpretation and costs of the project.

The project has not yet finished and the exploratory effort continues. Consequently, participants are invited to discuss the weaknesses and strengths of the interpretations presented in this work. Such interaction, for which the authors would be most grateful, is sure to improve the final product.

II.2 - ROUTE AND ITINERARY

(Appendix 1)

DAY	TIME	ACTIVITY
1	6:00 am	Drive to Maiquetía airport by bus.
	8:00 am	Flight VE 031 Maiquetía-Santo Domingo.
	9:00 am	Arrive Santo Domingo and depart immediately for La Vueltosa by bus.
	10:30 am	La Vueltosa/Santa María de Caparo.
		Stops 1 to 4: Cretaceous Río Negro, Aguardiente, Escandalosa and Navay Fms. ("Barinas Facies").
	12:30 pm	Lunch (Comedor de Cadafe).
	2:00 pm	Depart for Santo Domingo.
	3:30 pm	Santo Domingo.
		Stop 5: Río Negro, Apón and Aguardiente Fms. ("Andean Facies").
	4:45 pm	Vega de Aza.
		Stop 6: Cretaceous Navay and Colón Fms, Paleocene Orocué Gp and Oligocene(?) La Copé Fm Hydrocarbon aspects.
	5:30 pm	Drive to San Cristóbal.
	6:30 pm	Hotel Tamá (Special Program).
2	8:00 am	Depart for San Pedro del Río.
	9:00 am	San Pedro del Río.
		Stop 7: Mid- to upper Cretaceous Capacho and La Luna Fms. Geochemical aspects.

	11:00 am	Visit to the village.
	12:00 m	Lunch in the Centro de Amigos de San Pedro del Río.
	1:30 pm	Depart for Río Lobaterita.
	2:00 pm	Río Lobaterita.
		Stop 8: Paleocene Barco and Los Cuervos Fms, Eocene Mirador and Carbonera Fms Geochemical aspects.
	4:00 pm	Depart for San Juan de Colón.
	4:30 pm	Hotel Las Palmeras.

3	8:00 am	Depart for Zea/Guaruríes.
	10:00 am	Arrive at Zea and return to section.
		Stop 9: Cretaceous Basal Clastics, Apón, Aguardiente, Capacho, and La Luna Fms, in typical "Andean facies".
	11:00 am	Depart for Río Chama.
	12:00 m	Río Chama.
		Stop 10: Paleocene Orocué Gp and upper Eocene Carbonera Fm. And León Fm.
	1:00 pm	Quick lunch on the banks of the Río Chama.
	1:30 pm	**Stop 10 (cont'd):** Caracol Mbr of the León Fm.
	2:00 pm	**Stop 11:** Oligocene-Miocene Chama Fm, syn-sedimentary tectonism.
	2:30 pm	Depart for Mérida airport.
	4:30 pm	Arrive at airport.
	5:45 pm	Flight VE 100, Mérida-Caracas.
	6:30 pm	Arrive at Maiquetía.
	7:30 pm	Arrive at Caracas Hilton by bus.

II.3 - DAY 1

II.3.1 - La Vueltosa/Santa María de Caparo area

* Cumulative distance (Km).

Flight VE 031, Maiquetía-Santo Domingo at 8:00 am.

Arrival 9:00 am.

*

000.0 Leave the airport for Santa María de Caparo, following highway Barinas Troncal N° 5 (see itinerary map, Appendix 1).

068.0 Turn left towards Santa María de Caparo.

069.0 Town of Abejales.

076.0 Town of Los Bancos, exotic church architecture on left-hand side.

077.0 Ignore turning to Borde Seco dam; continue towards the right in the direction of La Vueltosa.

080.0 Observe exposures of the Burgüita Fm, equivalent to the Colón Fm in the Barinas subsurface.

085.0 Santa María de Caparo, office of CADAFE, prime contractor for the Uribante-Caparo hydroelectric system.

092.1 Arrive at the dam under construction. Outcrops of lower Cretaceous Río Negro and Aguardiente Fms in the abutments.

093.1 Arrive at Stop 1.

STOPS 1, 2, 3 AND 4 – OBJETIVES:

The Río Negro, Aguardiente and Escandalosa Fms constitute a thick conglomeratic sandy packet, representing the “Barina’s facies”, deposited close to the Guayana Shield. The interval covers an age range of more than 20 My:

72- Find the second-ordeer sequence boundaries and the marine flooding surfaces, which permit correlation of the section with order localities in the area (Appendix 1).

B- Consider the immaturity of the sediments and discuss the tectonostratigraphic significance of this immaturity.

STOP 1 – 000.0

View of the diversion channel and the extraction tower. Walk 200 m to the foot of the tower, where the unconformable contact between the Río Negro Fm and the La Quinta Fm (basement) is exposed (Figure 2).

Observe the contrasting consolidation of the sediments of both formations. The Río Negro Fm contains a conglomerate with 2 to 5 cm clasts overlaying the unconformity. The grain size decreases upward and large-scale trough cross-stratification is visible. A thin layer of mollusk shells about 40 m above the base of the formation reflects the first marine invasion, possibly of Barremian age. The shells are fragmented and difficult to extract from the rock, but previous workers have identified forms such as *Unio* sp., *Corbula* sp., *Megacucullaca* sp. And *Crassatella* sp., implying an age range of Barremian-Aptian.

Looking west, in the opposite abutment of the dam, the contact between the red, mottled sediments of the Río Negro Fm and the yellows and browns of the Aguardiente Fm is visible (Photo 1).

Return by the same route, toward Stop 2.

STOP 2 – 001.6

Road sign 35 kph, contact between the Aguardiente and Escandalosa Fms. In the succession of conglomerates and sandstones of the Río Negro, Aguardiente and Escandalosa Fms, the grain size gradually decreases upward, such that the Escandalosa Fm lacks conglomerate. However, the problem in the field is to identify the formation contacts using firmer criteria than the granulometry.

The base of Escandalosa Fm is recognized by its glauconite content. The contact is placed at the base of a greenish brown, silty, glauconitic sandstones (Figure 2).

STOP 3 – 002.7

Roadcut in the Escandalosa Fm An intraformational unconformity is visible, interpreted as a sequence boundary (Photo 2). This stop comprises two exposures about 200 m apart, allowing the unconformity to be seen in three dimensions. The unconformity is difficult to interpret as of tectonic origin. The unconformity truncates the underlying stratification (Photo 2).

The overlying sequence begins with a greenish brown glauconitic sandstone which rests on a ferruginous paleosoil and continues with a dark gray fossiliferous shale interpreted as marine.

The glauconitic bed is the second glauconitic horizon in the Escandalosa Fm (Figure 2).

STOP 4

OBJECTIVES:

A -Interpret the environment of deposition of the Guayacán limestone, based on its mineralogy and fossils.

B -Identify the marine flooding surface (MFS 91.5) in the overlying section (La Morita Mbr).

C -Visit the cherty section of the Quevedo Mbr and observe the immaturity of the sediments.

004.0

I, fossiliferous limestone with abundant marine bivalve shells and some gastropods. These fossils are difficult to extract unbroken from the rock but include examples

of *Astarte* sp., *Acanthocardia* sp., *Limatula* sp. And *Eriphyla* sp., of Cenomanian-Turonian age (Appendix 1).

This limestone of possible Turonian age marks the top of the Escandalosa Fm (Figure 2) and occurs in the subsurface in the oilfields of Barinas, where it is known as Limestone “O” of the Fortuna Fm.

On account of the similarity between this limestone and the Guayacán Mbr of the Capacho Fm in Táchira and Mérida states, it is considered genetically related to the latter and interpreted as the basal coastal sediment of the Cretaceous transgression, which was to reach its maximum during deposition of the La Luna Fm and La Morita Mbr of the Navey Fm In summary, the Escandalosa Fm represents the coastal equivalent of the Capacho Fm and contains two transgressive intervals, represented by the two glauconitic horizons (Figure 2), the lower being of regional importance.

005.9

The section continues with a sequence of dark gray to brown silty shales belonging to the lower part of the Navay Fm and known as the La Morita Mbr (Figure 2). This member is poorly exposed in the La Vueltosa area due to virtually complete vegetation cover. However, work on the dam produced new exposures, allowing verification that the organic-carbon content is too low to be a good source rock.

Farther on the upper part of the Navay Fm crops out, the dominant Ethology being light gray to l chert. This is known as the Quevedo Mbr, whose age extends into the early Maastrichtian.

The depositional environment of the Navay Formation is quite well defined by macrofossils as nearshore marine, in very shallow water. During the short stop it will be possible to find examples of hexapod crabs and fish remains of the family Clupeidae, like *Gasteroclupea* sp.

007.0

Entrance to the town of Santa Maria de Caparo. On the left of the road, the upper beds of the Quevedo Mbr are exposed, including a siliceous, phosphatic bed with a pelletoidal texture. In this area, mineral exploration has encountered various phosphate beds with the help of scintillometers. Some geologists consider these phosphate beds to reflect the end of the Cretaceous passive margin and to represent the southernmost expression of the so-called Tres Esquinas Mbr.

007.2

Arrival at the CADAFE camp (lunch), then continue to Santo Domingo.

010.0

To the left is a ridge with outcrops of the Burguita Fm (Figure 2), covered by vegetation, this silty end sandy formations interpreted as the shoreward equivalent (toward the craton) of the Colón Fm (Appendix 1).

016.4

Town of Los Bancos.

022.4

Enter Abejales and continue toward Santo Domingo.

068.9

Entrance to Santo Domingo airport.

070.0

On the right, exposures of upper Miocene molasse.

071.6

In the right bank of the road is a sequence of Miocene sediments in unconformable contact (covered) with the upper part of the Aguardiente Fm.

Discussion:

In this part of the southeast flank of the Tachira saddle, it is common to find sediments of Miocene age in unconformable contact with much older formations, ranging in age from early Cretaceous, as in this case, to middle Eocene (Appendix 1).

This relationship between the molasse and the Paleogene and Cretaceous sediments is an important contrast, not only with the Tachira Saddle, where there are no significant quantities of molasse, but also with the north flank of the Andes (I.4.3.2 and I.4.3.5), where the molasse lies almost transitionally upon the Lower-Middle Miocene.

Analysis of the configuration illustrated in Appendix 1 suggests the presence of structures older than the Miocene Andean orogeny, more clearly demonstrated by the Brujas High to the southeast (Figure 14).

From this point the bus begins its ascent of the southeast flank of the Táchira Saddle and during the next ½ hour the only visible exposures are thick sandstones of the Río Negro and Aguardiente Fms and limestones of the Apón Fm, in sections repeated by northwest-verging thrusts (Figure 14).

In this part of the route, depending on cloud conditions, the participant can observe toward the west the physiographic expression of the faults which form the lateral ramps of the frontal thrusts (Figure 13). Notable among these is the Bramon Fault, which has a complex geometry and separates two provinces of different tectonic style.

II.3.2 – Santo Domingo area

STOP 5 – OBJECTIVES:

A -After viewing the section, evaluate the differences between this partial sequence ot the Apón/Aguardiente Fms, and the La Vueltosa section, belonging to the same cycle.

B -Identify the maximum flooding surface (MFS 111) in the Apón Fm, and study the overlying Aguardiente Fm regressive system.

072.3

Lower Cretaceous section typical of the Andean region (Figure 3). Walk 150 m along the left side of the road to the locality of interest. Use extreme caution due to the traffic of heavy vehicles. Return by the same route.

The section begins with a basal sequence of conglomerates and sandstones of the Río Negro Fm, exposed in the banks of the river below the highway, inaccessible to participants. Exposed along the road are fossiliferous limestones of the Apón Fm, brown and dark gray in color, commonly clayey, sandy and very hard. Towards the top of the formation are shales with ellipsoidal and spheroidal mudstone nodules, followed by a dark gray bed 2 m thick with abundant internal moulds of small gastropods containing glauconite, in a structureless black clay matrix. This bed, together with the underlying nodular shales, is of marine pelagic character (MFS 111) and is correlated with the Guáimaros Mbr of the Apón Fm, which is of widespread occurrence in the rest of the Andes (Appendix 1). The Guáimaros shale is also correlated with the Machiques Mbr of the Maracaibo area, which has revealed source-rock properties in recent studies.

Immediately above the shale is a sequence of Aguardiente Fm sandstone, hard, siliceous and sometimes calcareous, representing the regressive portion of the cycle. Although this section of the Aguardiente is truncated by a fault, it is quite representative of the formation in the southwestern Andes and is important in showing the sequence context of the Aguardiente.

Discussion:

Walking back to the bus the participant can ponder the following points for discussion during the journey to the next stop:

1 -The absence of the Apón Fm in La Vueltosa. Is the interpretation in Appendix I valid? Or is the Apón Fm represented at La Vueltosa as a conglomeratic facies? In the latter case, in which part of the section would it occur?

2 -How can the great difference in degree of sediment consolidation between La Vueltosa and Santo Domingo be explained?

II.3.3 - Vega de Aza area

STOP 6 - OBJETIVES:

A -Local stratigraphic relations (Figure 4) permit interpretation of a paleo high, active from the Santonian until the Eocene (Appendix 1).

B -Conglomerate of the La Copé Formation rests unconformably on Paleocene and Cretaceous rocks of the paleo high.

C -Examine the composition of the conglomerate and interpret its possible origins, as well as the origin of the petroleum which impregnates it (Figures 21 and 22).

92.9

Vega de Aza. We have climbed the south flank of the Andes and are now in the Táchira Saddle. This Stop is an outcrop of only about 1 Km² but encapsulates a large part of the multidisciplinary philosophy of this excursion.

Most prominent are the conglomerates of the La Copé Fm, saturated with viscous, biodegraded petroleum (I.6.2 and I.6.3). Apart from the geochemical value of these impregnations, these conglomerates were considered in previous studies to be laterally equivalent to the Miocene-Pliocene Betijoque Fm, well exposed in the north flank of the Andes, representing molasse deposited during uplift of the Andes (Appendix 1). In Vega de Aza, the La Copé Fm rests unconformably on eroded shales of the Colon - Burguita Fm of Maastrichtian age (I.4.2.3.) and on sediments of the Paleocene Orocué Gp. (Photo 3). The contact is clearly visible in the roadbank, about 20 m from the stop.

Discussion:

A -Two important factors lead to alternative interpretations of the origin of the conglomerates:

1 -The virtual absence of molasse in the entire area of the Táchira Depression; and

2 -The conglomerate clasts are derived mostly from Cretaceous formations, with notable predominance of cherts from the Navay Fm (I.4.2.3).

B -What is the origin of the petroleum which saturates these conglomerates? Is there any relation between these impregnations and the La Alquitrana seep/reservoir?

100.6

El Corozo. Tuming on left-hand side for Santa Ana-La Alquitrana-Rubio. Continue toward San Cristóbal.

The participant now begins to see, toward the west, the typical topography of hills composed of Paleogene sandstone, belonging to the Rubio-San Cristóbal structural block (Figure 13). The lows and valleys correspond to outcrops of the Cretaceous Colón Fm and terraces of the Río Torbes.

111.5

Enter San Cristóbal. Ovemight at the Hotel Tamá.

II.4 - DAY 2

000.0

Las Lomas district, at the Avenida Libertador entrance. Leave San Cristóbal heading for San Pedro del Río. We are still within the Rubio-San Cristóbal structural block. Shales of the Colón Fm crop out on both sides of the road. Flowage of the shales causes road stability problems. To the north, the northern block of the Capacho Fault is visible (Figure 13), and to the east is the El Oso structural high, one of the highest points in the Táchira Depression.

009.5

End of the autopista.

010.0

On the left, toward the west, the town of Capacho is visible, located very close to the trace of the Capacho Fault (Photo 4). The Capacho Fault separates the Rubio-San Cristóbal and San Antonio-Lobatera structural blocks, and intersects the Panamerican Highway.

011.0

Capacho Fault breccia in the right bank of the road.

012.2

Palmira National Guard checkpoint.

017.2

"Cementos Táchira" plant, whose raw material is limestone of the Guayacán Mbr of the Capacho Fm (see Stop 4).

018.2

La Luna Fm, of Cenomanian-Campanian age, containing a high proportion of chert and partially equivalent to the Navay Fm (Figure 2).

022.5

Outcrop of the La Luna Fm.

027.7

Lobatera Mine, exploiting La Luna Fm phosphates.

033.3

Town of Michelena. To the right is a view of El Zumbador peak. A turning to the right leads to Queniquea-El Cobre, the site of old copper mines in the Jurassic La Quinta Fm.

037.2

In the west is the Mirador Fm sandstone, forming the most prominent geomorphological feature of the San Antonio-Lobatera structural block (Photo 5).

043.9

Turn left on the alternate route to Ureña, leading to San Pedro del Río.

048.4

Entrance to San Pedro del Río, a beautiful village of colonial architecture, restored by its own inhabitants at the beginning of the 80's. Looking southwest from the village, Mirador Fm sandstone can be seen capping the mountain (Photo 6).

II.4.1 - San Pedro del Río area

STOP 7 - OBJETIVES:

A -Study the section representative of the La Luna Formation for the southwestern Andes (Figure 5), examine the criteria for subdividing it into three intervals, and compare its area lithology with the La Luna Fm of other areas.

B -Recognize the main facies and examine the relationship between these facies and the geochemical properties of the rocks (Figures 17 and 18).

049.2

Ranch at outskirts of the village. The use of tick repellent is advisable. Walk about 400 m along the banks of Chiriría creek, which runs along the trace of the San Pedro del Río thrust. A hill to the north of the La Luna Fm outcrop, located southwest of the village (Appendix 1), provides a panoramic view of the entire section (Photo 7).

From the hill (Figure 5):

The interval of interest begins on the left with shales belonging to the Seboruco Mbr of the Capacho Fm, and continues towards the right with limestones of the Guayacán Mbr of the same formation. These limestones are rich in mollusk fragments and glauconite grains. Above the limestones is a complete sequence of the La Luna Fm, which can be divided into 3 intervals. The lower interval consists of shales and limestones, containing the typical nodules which characterize the formation through out the basin. The middle interval is basically shaly and calcareous, with a laminar texture and some chert beds. The upper interval has a 1.7 phosphatic limestone at the base which is commercially exploited in some areas (see km 027.7). The rest of the upper interval consists almost entirely of chert. Overlying this interval is the Tres Esquinas Mbr a 1.0 m phosphatic limestone with abundant glauconite and high radioactivity.

At the foot of the exposure (Appendix 2):

The participant can walk the length of the cliff section, about 200 m, examining details according to his or her interests. For stratigraphic information see I.4.2.4.

The geochemical properties of the shales and limestones in the lower interval of the La Luna are those of a type II source rock (I.6.1.1). However, the geochemical characteristics of the middle interval aue somewhat different (I.6.2 and I.6.3). In the thin shales of the middle interval, Renz (1982) discovered a famous example of the ammonite *Lenticeras andii* (GABB), beautifully decorated with complicated suture lines, which he used to assign an early Coniacian age. It is worth noting that Renz excluded from the La Luna Fm the upper, cherty interval, whose age is considered to be Campanian based on microfauna (PITELLI, 1992).

Return to San Pedro del Río. The villagers a hospitable and proud of the touristic attributes of their village, but are unaware of the scientific importance of the area.

Lunch, then leave for Río Lobaterita, where the Paleocene and Eocene section is exposed.

000.0

Leave San Pedro del Río, heading for Río Lobaterita.

000.9

Bridge over the Río Lobaterita.

001.2

Turn right on a dirt track that leads to the roadbed of the unfinished La Fría-San Cristóbal autopista. Drive along the left lane of the (unpaved) autopista. Observe the ridge to the right where the following upper Cretaceous and lower Tertiary sequence crops out: Colón Fm, Transitional Unit, Orocué Gp and Mirador Fm.

004.8

In the left bank of the road, part of the Transitional Unit is exposed.

II.4.2 - Río Lobaterita area

STOP 8 - OBJETIVES

A -Examine the sequence of depositional environments, from the lower part of the Orocué Gp to the Mirador Fm (Figure 7), and propose a systems-tract correlation with the Fila-1X well (Figure 9).

B -Demonstrate the source-rock properties of the carbonaceous shales of the Orocué Gp.

005.5

Arrive at the roadcut section of the Paleocene Orocué Gp and the Eocene Mirador and Carbonera Fms (Figure 7).

The area has complex structures such as folds and fold-faults (Photo 8). Nevertheless, in this part of the valley there is a virtually complete section of the Los Cuervos and Mirador Fms. This provides participants with the first opportunity to see the Paleogene formations, and to examine their geochemical, sedimentological and stratigraphic properties.

The participant is invited to descend the bank of the adjacent Río Lobaterita to walk the Barco Fm section exposed along the river, and to examine the three types of sandy facies and their reservoir properties (I.4.3.3). Farther upriver the mainly shaly Los Cuervos Fm is exposed, containing sandstones interpreted as upper delta plain and lacking the good reservoir properties of the Barco Fm.

While at this stop, field-pyrolysis tests will be attempted, to demonstrate the type m source rock properties of the carbonaceous shales (I.6.1.2).

The upper part of the Los Cuervos Fm contains coal beds which ignite spontaneously in the summer. This phenomenon can be seen in the small valley to the west of the river; if there is no wind, the trace of the outcrop can be followed by the columns of smoke ascending vertically.

In the autopista section, the Los Cuervos Fm terminates in a zone of intense folding related to a south-verging thrust fault whose strike is perpendicular to the road.

Overlying the Los Cuervos Fm shales, in erosional contact, are fluvial channel sandstones of the Mirador Fm (Figure 7). Three sedimentary units are easily distinguished in the Mirador: lower sandstone; middle shale; and upper sandstone. Participants will observe the excellent reservoir properties of the Mirador.

At the end of the section is a friable, white quartz sandstone. Overlying this, again unconformably, is the Carbonera Fm (I.4.3.3).

Discussion:

The sections illustrated in Figure 9, which includes a log from the Fila-1X well at approximately the same scale as the section in figure 7. Sequence analysis of the well log enhances the environmental interpretation of both sections, and simultaneously introduces the theme of the North Andean Flank, which will be studied during the third day of the excursion.

End of studied section. Leave Stop 8, heading for San Juan de Colón (Hotel Las Palmeras).

008.5

National Guard checkpoint of San Juan de Colón. Entrance to the home town of famous musician Pedro Antonio Ríos Reina.

011.6

Hotel Las Palmeras.

II.5 - DAY 3

000.0

Leave for Zea (Stop 9), where the lower and middle Cretaceous section will be visited. The route goes northward, toward the town of La Fría, following in large part the surface trace of the lateral ramp of the North Andean frontal Thrust. The fault lifts the eastern block, forming mountainous topography, while to the left is the valley of the Río Lobaterita, which flows toward the plains of the Río Zulia, northward, descending the northwest flank of the Táchira Saddle, from a height of 750 m at Stop 8 to 100 m near La Fría.

005.0

In the Río Lobaterita valley, thick sequences of the early Eocene Mirador Fm crop out (Photo 9), belonging to the Ureña-San Felix structural block (Figure 13).

006.0

In the right bank of the road are occasional exposures of the basal Cretaceous sequence.

010.0

Looking north from this point, if the sky is sufficiently clear, one can see the southern Catatumbo plain, where the drainage systems of Colombia and Venezuela unite and discharge into Lake Maracaibo.

026.0

Town of La Fría, near which is the Friata-1X well (I.6.3), located on the anticline of the same name. A little north of the town, the composite seismic line of Figure 9 begins. The line and the Panamerican Highway run parallel toward the northeast, following the foothills.

038.0

The road intersects the seismic line LF-87C-9 (Figure 12). Recent activity of the frontal thrusts has uplifted the fluvial terraces, hence the undulations of the highway.

060.0

Las Hernández terrace, on the left, near which was collected a seep sample which, when analysed, revealed characteristics of terrestrial crude, like others in the foothills zone (I.6.2) (Figure 20).

067.5

Bridge over the Río Escalante.

078.5

Turn right towards Zeal. The road narrows and heads southeast, directly into the mountain flank.

098.5

Arrive at the town of Zeal. The town is hidden among high peaks and is dominated by a graceful church. The bus will turn around and return to km 095.5, site of Stop 9.

II.5.1 - Zea/Guaruríes area

STOP 9 - OBJETIVOS

A -Examine the section representative of the Lower Cretaceous (Figure 6) in the highest point of the Mérida Arch reached on this excursion.

B -Demonstrate the thinning of the RÍo Negro/Basal Clastics and Apón Fms.

C -Identify the transgressive and regressive sequences, and examine their relationship with reservoir and source rocks.

101.5

Lower Cretaceous section. The Cretaceous sequence begins with an interval of basal clastic resting discordant on Paleozoic schists (Figure 6). This is not a typical section of the Río Negro Fm, but is present everywhere in the Andes and the Maracaibo Platform, representing the initial transgression over a very irregular topography on the southern margin of Tethys (I.4.2). One of the most notable topographic irregularities was the Mérida Arch, on whose southwestern flank we are presently situated. This explains the thinness of the basal clastics and the Apón Fm, the latter being of very variable thickness and locally almost disappearing, as in the Las Hemández area. These thickness variations are demonstrated in Figure 6, which correlates the surface section with the Gua-1S well, located about 15 Km to the northeast. The thickness irregularities of the

Apón Fm are not well understood, but are possibly related to an intraformational unconformity detected in the upper part of the Apón in the Gua-1S well.

The upper part of the section includes the Aguardiente Fm sandstones, whose upper limit is important for regional correlations. Overlying the unconformity is the La Puya limestone, followed by the La Grita Mbr, these forming a transgressive system of regional extent (Appendix 1).

The section continues on the left side of the road, where shales of the Sebonuco Mbr of the Capacho Fm are well exposed. These shales are recognized by their brown colour and splintery fracture; fish remains and scales may be found by excavating with a hammer, taking care not to damage the roadbank.

In the upper part of the Seboruco Mbr is another notable sequence boundary (I.4.2.6) (Figure 6). Overlying this is the Guayacán limestone, which constitutes the start of the second transgression of the so-called La Luna sea (Appendix 1).

Discussion:

In the stratigraphic literature, the La Puya limestone has always been considered as the Andean continuation of the Maraca Fm of Perijá, with which the La Grita Fm forms part of the transgressive cycle of the La Luna Fm (Figure 9) (Appendix 1). However, the regional extent of the Guayacán Mbr, whose age is uncertain, raises the possibility that the Guayacán, not the La Puya, is the equivalent of the Maraca Fm. This implies two regional transgressive events: the La Grita Mbr, with its basal sediments represented by La Puya, and the La Luna Fm, with its basal sediment formed by the Maraca/Guayacán.

The importance of this analysis is highlighted by the presence of a thick sequence of Seboruco Mbr shales associated with a condensed section of La Luna/La Grita facies. The paleogeographic implications of this fact contrast with the traditional concept, in the literature, of the "La Luna Sea". The drilling of exploratory wells in the foothills and plains south of Lake Maracaibo will clarify these doubtful correlations in the Cretaceous, and also in the Tertiary.

The well exposed part of the section at Stop 9 ends with the Capacho Fm and the participant is invited to return to the bus, but not without first testing with the hammer and the nose the source-rock qualities of the La Luna Fm, which is poorly exposed in the banks of the road. Depart for the Río Chama to visit the Tertiary section (Stops 10 and 11).

114.0

Descend from the mountains and return to the Panamerican Highway.

122.5

To the right of the road is the Sumandes plant, a Maraven project which will supply fuel by pipeline to the Andean region.

144.0

Town of El Vigía, an agricultural-ranching nerve centre for the southern Lake and the Andes.

146.0

At the last traffic light on the Panamerican Highway in El Vigía, turn right on the road to Mérida.

147.5

Turn left on the autopista under construction toward Estánquez. The highway follows the west bank of the Río Chama, heading upstream.

159.5

Arrive at SantaTeresa, at the southern mouth of the tunnel. View of the Caña Brava structural nose, whose northern flank is deeply incised by the Río Chama.

II.5.2 - Río Chama area

STOP 10 AND 11 - OBJETIVES:

A -One of the most important yet obscure unconformities in the Tertiary of the Andean area region will be examined at Stop 10 (Figure 8). Sandstones of the Carbonera Fm rest unconformably on a section of the lower Orocué Gp.

B -The thickest sandstones of the Carbonera Fm are impregnated by hydrocarbons of terrestrial origin.

C -Examine the Oligocene section, of notable thickness, and the characteristics which allow correlation of its youngest sediments with the conglomerates of the La Copé Fm.

159.5

Paleocene section overlying shales of the Colón Fm (Figure 8). The contact is not well exposed due to a cover of recent sediments. Due to intense deformation of the Colón Fm in the valley, thickness estimates of both the Colón and the Paleocene are uncertain.

The Paleocene section is assigned to the lower part of the Orocué Gp, and its thickness is estimated as over 80 m.

Erosionally overlying the Paleocene is a series of fluviodeltaic sandstones of the Carbonera Fm, of late Eocene-Oligocene age, containing residual petroleum of type III (Photo 10); the erosion surface truncating the Orocué beds represents a considerable hiatus (I.4.3.5). The regional importance of this hiatus is illustrated in Figure 9, in which an implicit question is:

What is the relationship between this hiatus and the age of Misoa Fm of the Maracaibo area?

Walking up to the section, we reach the shales of the León Fm of Oligocene age, and then arrive at the foot of an impressive cliff exposing the Caracol Mbr of the León Fm (Photo 11) (Figure 8).

Lunch: A "bucare" tree on the banks of the Río Chama offers shade for a quick lunch. The theme for discussion is syn-depositional tectonism ... It is impossible to visit the Río Chama section without discussing syn-depositional tectonism!

Palynological and micropaleontological zonation's made in this section to provide stratigraphic control for the drilling of Gua-lS allow the sequence boundaries to be identified relatively easily (Figure 9). Once again, correlation of these unconformities with Gua-1S confirms the existence of tectonic events of Oligocene age (I.4.3.5), which may or may not be associated with the Andean orogeny. However, the importance of this exercise is that it proves the existence of structures and

stratigraphic traps which pre-date the (middle to late Miocene) maturation of the Cretaceous type II and Paleogene type III source rocks.

As a result of the Andean orogeny, these traps were modified and, in some cases, destroyed, as can be seen in Figure 8 (I.6.3). Finish lunch and travel by bus to Stop 11.

STOP 11

Oligocene conglomerates. These conglomerates are rich in fragments of Navay-type chert and resemble the La Copé Fm conglomerates in Vega de Aza (I.4.3.2). What happened in the Andean region in the Oligocene?

This stop includes a walk toward El Vigía to visit the Miocene section (outside the scope of this excursion), in which a complete change takes place, at about the 15.5 My level in the Chama Fm, in the geometry of the sandstone bodies, indicating the development of fluvial systems on unstable slopes (Photo 12). Correlation of these middle Miocene events with a tectonism different from that of the Oligocene appears advisable.

End of the excursion. Return by bus toward El Vigía and drive to Mérida airport (journey time 1.5 hours).

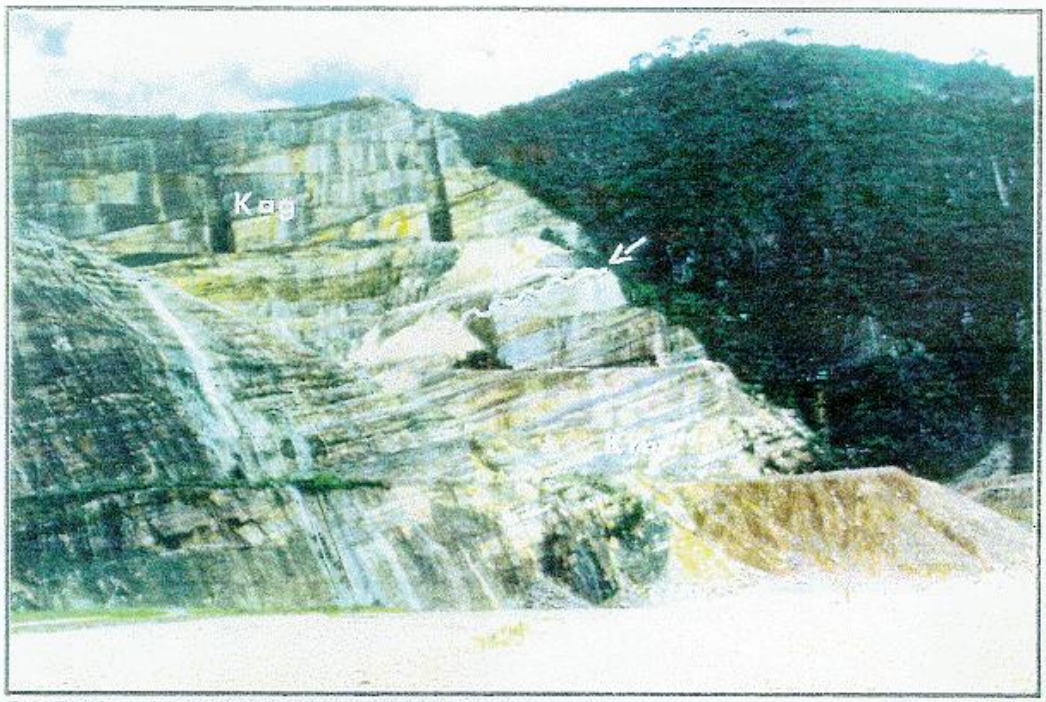

PHOTO No. 1 :View of the dam abutment, La Vueltosa.

View of the La Vueltosa dam abutment, from the diversion channel, where the contact can be seen between the Río Negro Fm, with its pink colors, and the Aguardiente Fm, colored yellow and gray.

PHOTO No. 2: Intraformational unconformity in the Escandalosa Fm.

The unconformity in the lower part of the bank separates a lower regressive interval from an upper transgressive interval. The transgressive section contains greenish glauconitic sandstones and dark shales. The unconformity surface is marked by a thin ferruginous crust at the base of the glauconitic sandstone.

63

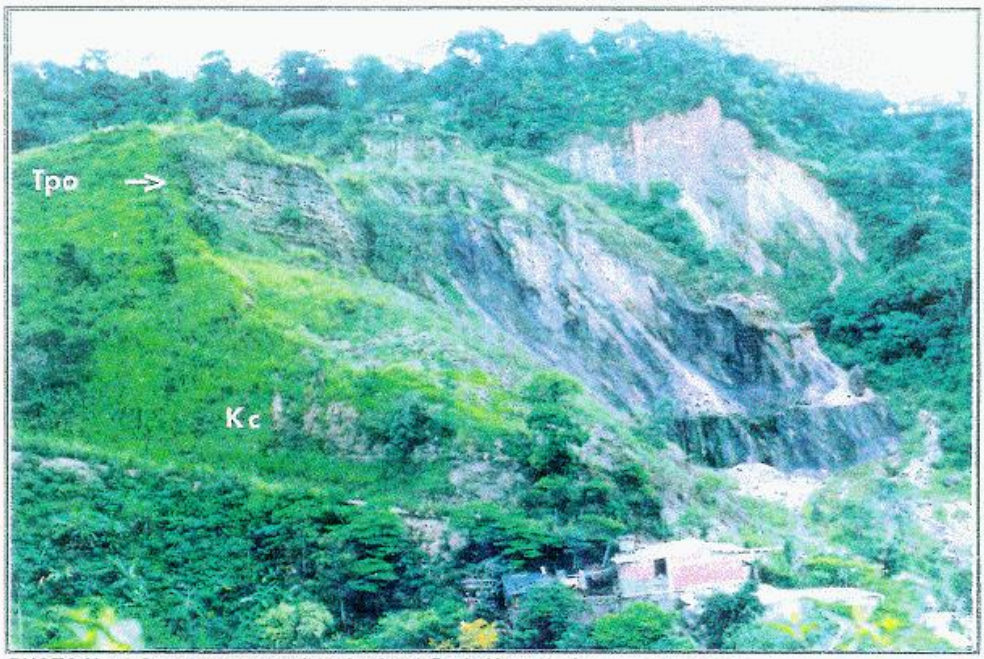

PHOTO No. 3 Conglomerates of the La Copé Fm in Vega de Aza.

The conglomerates are saturated with viscous hydrocarbon and occur in unconformable contact on the Colón Fm and the Orocué Gp.A complex structural scenario is seen within a relatively small area, suggesting tectonic activity before, during and after deposition of the conglomerate.

PHOTO No. 4: Trace of the Capacho Fault.

The town of Capacho, renamed Independencia, lies to the left, very close to the fault, whose surface trace is indicated by the almost rectilinear course of the river. In the south, to the left of the fault, is the Rubio-San Cristóbal structural block. In the north, to the right, is the San Antonio-Lobatera structural block.

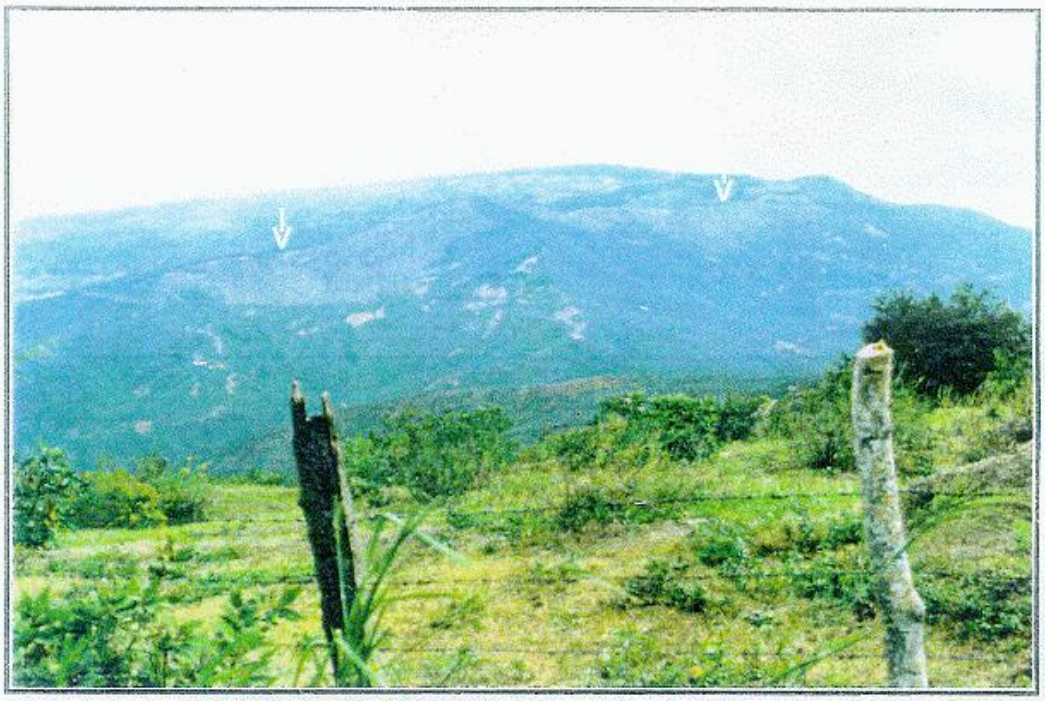

PHOTO No. 5:View of the Mirador Fm from the Panamerican Highway.

The Mirador Fm is a thick sandstone, forming topographic highs throughout the Táchira Depression, and constituting a good marker in field mapping and photogeologic interpretation.

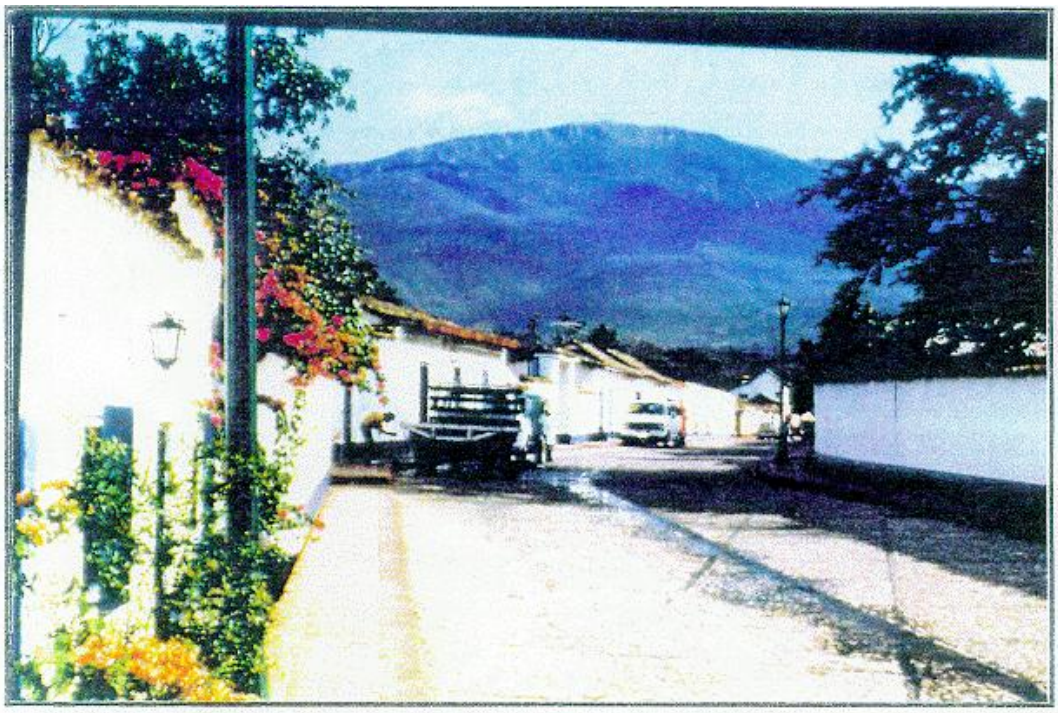

PHOTO No. 6:View of the Mirador Fm from San Pedro del Rio.

San Pedro is overlooked by the Mirador sandstone, which has produced close to 20 MM bbls in Los Manueles and Concordia fields.

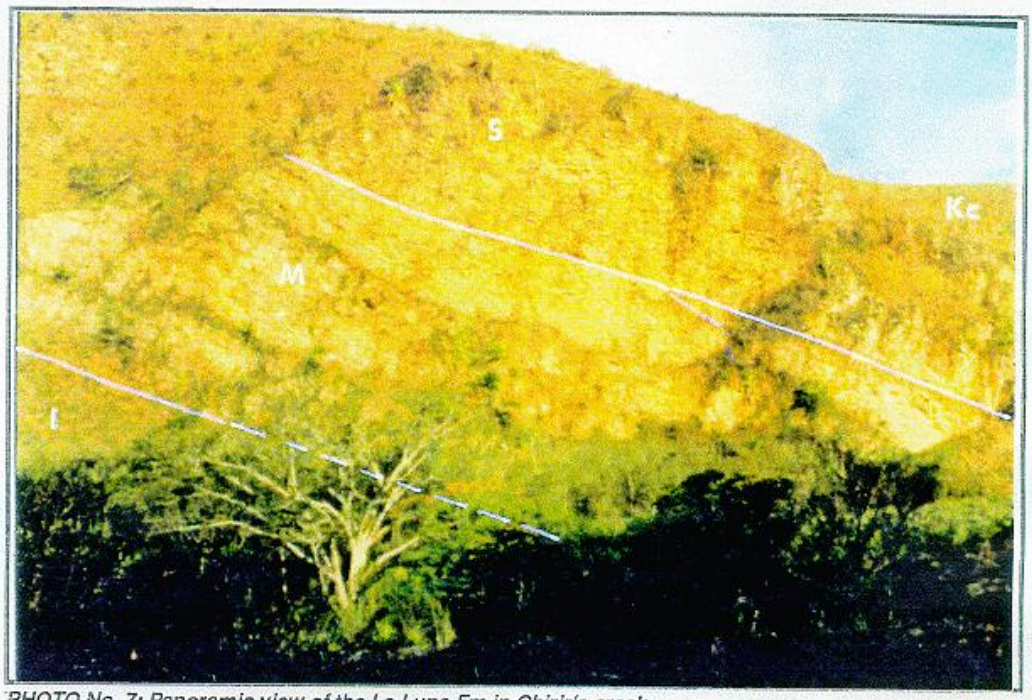

PHOTO No. 7: Panoramic view of the La Luna Fm in Chiriría creek.

From the hill to the north of the exposure, the three lithologic units of the La Luna Fm can be partially distinguished: upper cherty; middle calcareous-cherty (with bands of vegetation); and on the left, almost completely covered, the lower unit with its typical calcareous shales and spheroidal concretions.

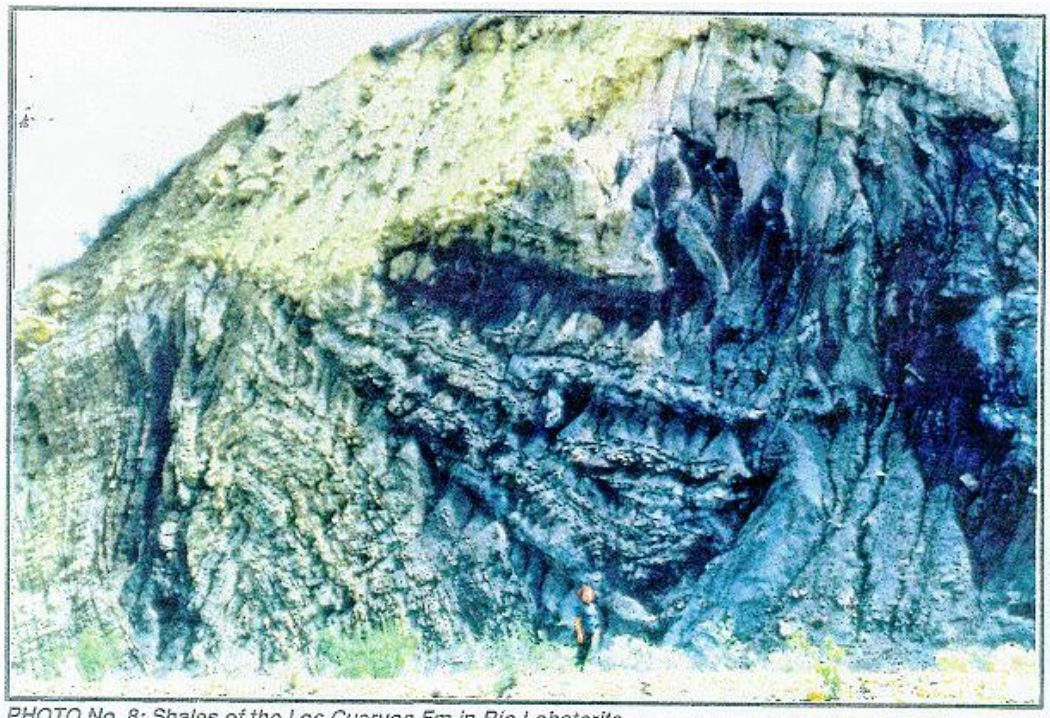

PHOTO No. 8: Shales of the Los Cuervos Fm in Río Lobaterita.

Intensely folded sediments of the Los Cuervos Fm (Orocué Gp) reflect the complex compressive tectonics of the area. These deltaic carbonaceous shales are capable off generating hydrocarbons.

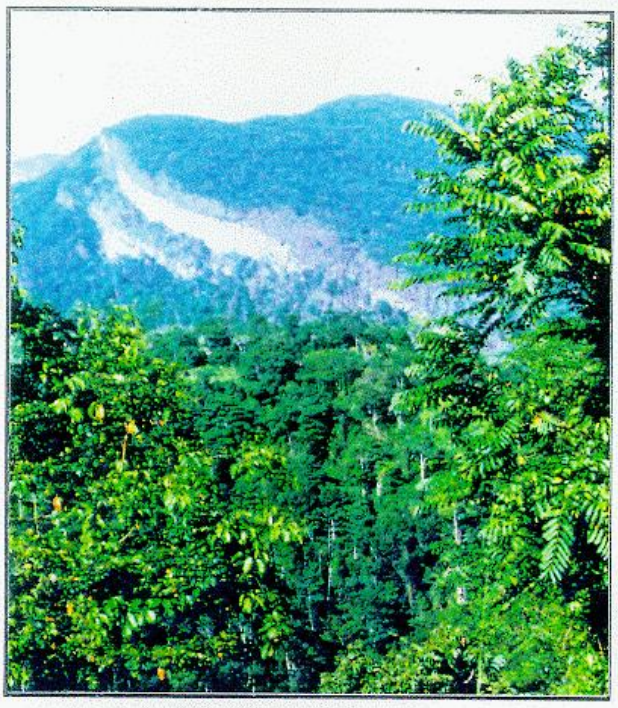

PHOTO No. 9: The Mirador Fm in the Ureña-San Félix structural block

Cliff-forming sandstones of the Mirador Fm crop out in the northern prolongation of the Río Lobaterita. The section is intensely deformed owing to its position in the zone of interaction between the frontal Andean thrust and the Ureña-San Félix structural block.

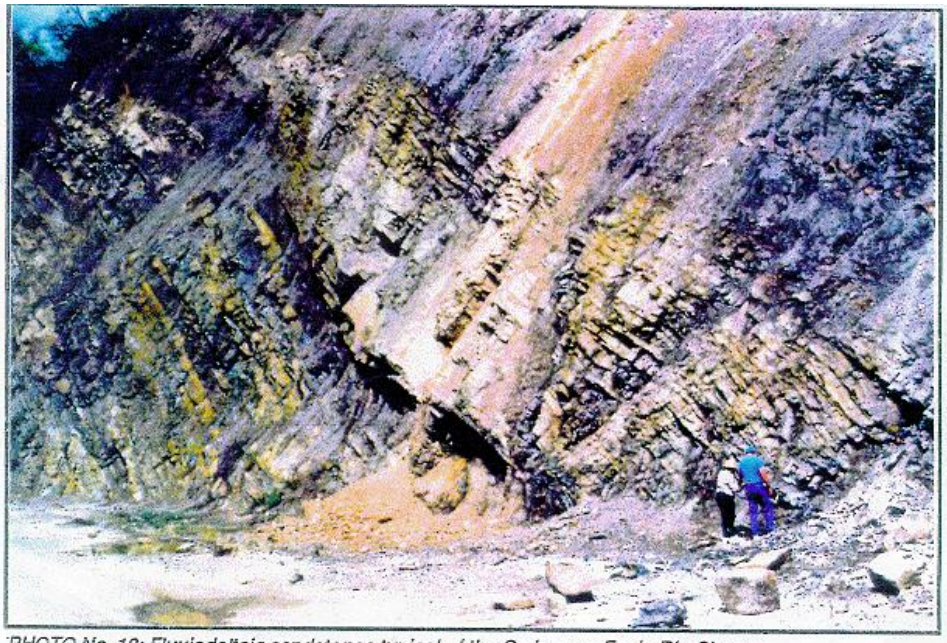

PHOTO No. 10: Fluviodeltaic sandstones typical of the Carbonera Fm in Río Chama.

Sand-Filled channel cuttings interdistributary bay sediments in the Carbonera Fm. The delta-plain environement of the Carbonera Fm favoured the deposition of coal beds with potential to generate gas and oil.

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[1] Sociedad Venezolana de Geólogos, Field Trip N° 4, Víctor Campos y Tito Boesi, 14th to 17th March 1993