TECTONICS AND PETROLEUM SYSTEMS OF THE EASTERN MARACAIBO AND FALCON BASINS: INTEGRATING OUTCROP GEOLOGY WITH ON- AND OFFSHORE SUBSURFACE SEISMIC REFLECTION AND WELL DATA

FIELD TRIP LEADERS:

Peter Bartok (Bartok, Inc., Houston, Texas)
Drs. Paul Mann and Alejandro Escalona (Jackson School of Geosciences, The University of Texas at Austin)

DATES: October 29 to November 3, 2006

FALL 2006 CBTH FIELD TRIP GUIDE:

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Cronograma generalizado de la salida de campo Maracaibo oriental-Falcón

Pre-salida (Domingo, 29 de Octubre): Llegada a la ciudad de Maracaibo (Hotel Maruma). Reunión en la noche (6:30pm) para discutir la logística de la salida con los participantes.

Día 1 (Lunes, 30 de Octubre): Maracaibo (Hotel Maruma) – Barquisimeto (Hotel Hilton)

Tema: Cuenca supergigante de Maracaibo, limite Paleógeno de la colisión entre las placas Suramericana y Caribe y paleogeografía.

Paradas: Alto de Mene Grande (Sierra Misoa), discordancia del Eoceno, Falla de Burro Negro, Falla de Valera (El Baño), Napas de Lara (Formaciones Matatere y Trujillo) y Olistolitos del Cretaceo.

Día 2 (Martes, 31 de Octubre): Barquisimeto (Hotel Hilton) – Coro (Hotel Miranda)

Tema: Estratigrafía y estructura de la cuenca de Falcón (rocas madre y yacimiento), modelos de formación de la cuenca de Falcón, evidencias de fallas transcurrentes e importancia a nivel regional.

Paradas: Formaciones Castillo/Casupal, Calizas de Churuguara, Formación Paraíso, rocas ultramaficas de edad Oligoceno tardío-Mioceno temprano, estratigrafía del Eoceno tardío y Mioceno (Formaciones Pecaya, Agua Clara, etc.).

Día 3 (Miércoles, 1 de Noviembre): Coro (Hotel Miranda) – Cumarebo – La Vela – Coro (Hotel Miranda)

Tema: Estratigrafía y estructura de las zonas costeras de la cuenca de Falcón y correlación con la cuenca de Bonaire y ensenada de La Vela: zonas estables de La Vela y Bonaire, franja de corrimientos de La Vela, fallas normales vs. corrimientos, extensión costa afuera de rocas madre y yacimiento.

Paradas: Campo de Cumarebo, capas verticales de La Vela, La Sierra de Barigua, domo de la Vela (corrimiento de Guadalupe).

Día 4 (Jueves, 2 de Noviembre): Coro (Hotel Miranda) – Península de Paraguaná – Coro (Hotel Miranda)

Tema: Estructura y estratigrafía de la Península de Paraguaná ; importancia en la geología regional y correlaciones costa afuera.

Paradas: Granito del Amparo (Permico), esquistos de Pueblo Nuevo, rocas metamórficas del Paleozoico, ofiolitas de Santa Ana y secuencias clásticas y carbonaticas del Mioceno (cuenca de Paraguaná)

Día 5 (Viernes, 3 de Noviembre): Coro (Hotel Miranda) – Maracaibo (Hotel Maruma)

Tema: Transecto E-O a través de la cuenca de Falcón y su relación con la Cuenca de Maracaibo. Interacciones entre Suramérica y el Caribe y correlaciones con el Golfo de Venezuela

Paradas: Mene de Mauroa, campos de Tiguaje y Mamon, Surco de Urumaco. Los afloramientos de en la región nor-occidental de Falcón no son de buena calidad. Por lo tanto, el enfoque se va a realizar en datos del subsuelo y mapas geológicos.

Overview of the field trip

Scope and objectives. The fall 2006 CBTH western Venezuela field trip will familiarize participants with the regional geology, stratigraphic correlations, and petroleum systems in the areas of the eastern Maracaibo Basin, the Falcon basin, and the poorly explored offshore areas of the Gulf of Venezuela, La Vela basin and Bonaire basin (**Map 1**). During the five-day trip, we will visit key outcrops ranging in age from Paleozoic to Recent that record tectonic and sedimentary events affecting the petroleum systems in this part of the South American margin. We will use available subsurface seismic reflection and well data to laterally and vertically expand our scale of observation and to better appreciate the tectonic controls on structural and stratigraphic features. Our overall objective is to better understand the continuity and linkages along an east-west transect connecting the supergiant Maracaibo basin, the marginally-productive areas of the Falcon basin, and the poorly explored offshore areas in the Gulf of Venezuela, La Vela Bay, and the Bonaire basin.

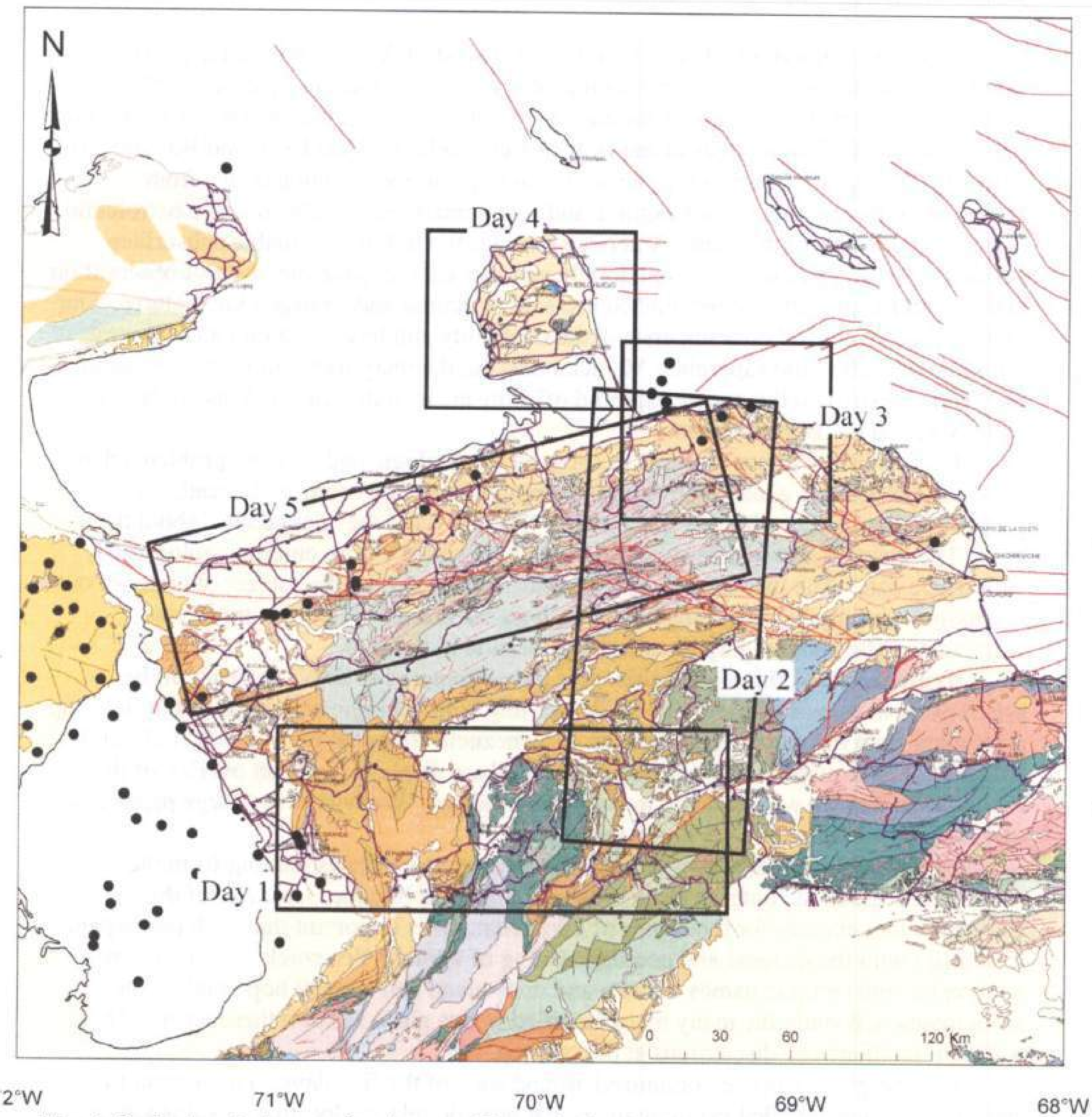
This field trip will not presume to solve all the geologic and tectonic problems that have surrounded this geologically complex region for over a century. Instead, we propose to summarize what we consider the "knowns" and the "unknowns" about the area. The known facts will be supported where possible by both outcrop geology and subsurface data. The unknown facts and controversies will be the subject of many of our discussions during the trip, along with how both the unknowns and controversies continue to affect ongoing hydrocarbon exploration in the area.

Organization of this field guide. We have attempted to distill as much of the previous work as possible into this guide, starting with geologic basemaps of the field trip area taken from the recent geologic map of Venezuela compiled by Hackley et al. (2005) (**Map 1**). These maps were compiled in GIS and are displayed with an overlay of the road system that we will be using to reach the outcrops. We will have a large paper copy of this map available for each of the stops.

Since we will be discussing geologic features at many scales ranging from the millimeter scale at the outcrop stops to tectonic features like the Great Arc of the Caribbean that extends for thousands of kilometers, its is important that each participant is familiar with the tectonic and geologic setting of western Venezuela. There are many geographic and tectonic names to learn and understand and we will hope that all the participants will study the many maps included in this guide to learn these terms. This will help facilitate our discussions at the outcrop.

The field guide has been organized around each of the five days. The section for each day contains detailed geologic maps that provide relative location of stops along with the necessary regional tectonic maps.

Next, a geologic map of the field trip area is shown with the daily areas to be cover during the five days field trip (**Map 1**). This map will serve as the main basemap during all the field trip and will be available as a large hard copy format during stops.



Map 1. Regional geologic map of northwestern Venezuela showing the regions to be visited during the five days of the field trip. Geologic map is from Hackley et al (2005). Purple line represents road network, small black dots are towns and big dots are oil fields. Map legend in next page.

Legend

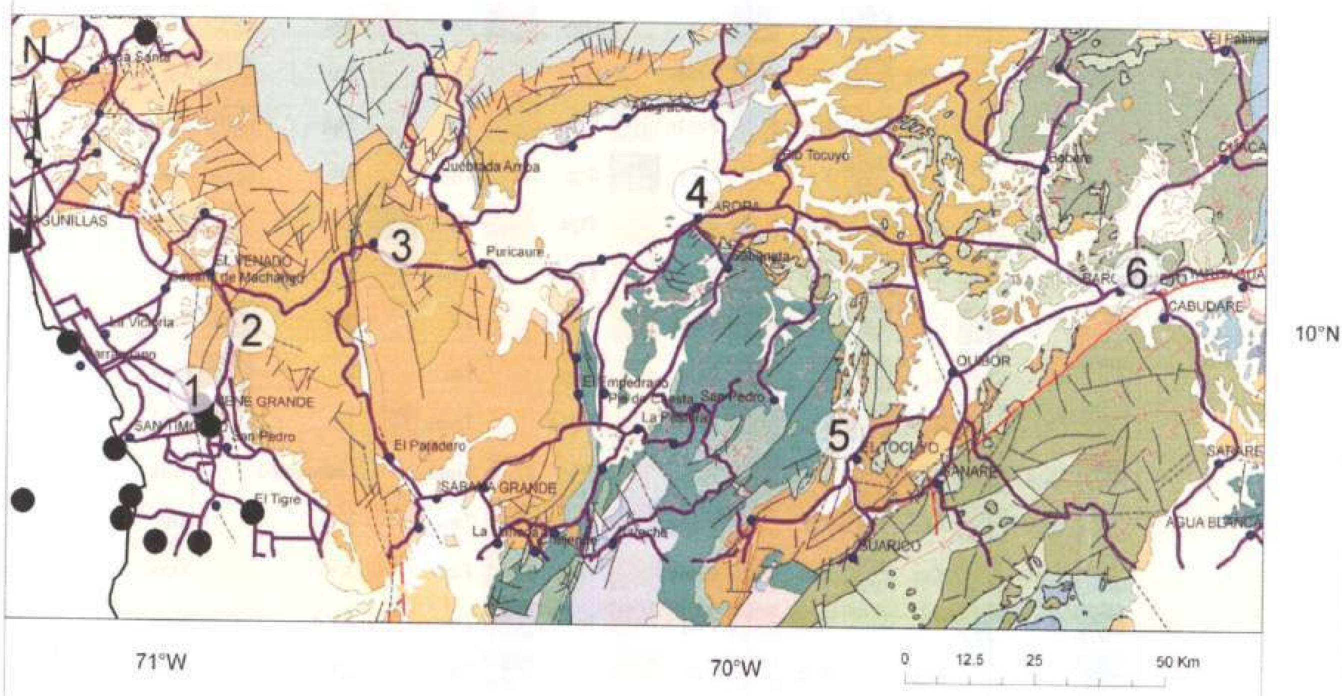
AXgr	Jpn	Klhc	Mlcr	Qlo	Tepg	Tpg	Xcci	YMd
AXi	Jt	Klhg	Mlo	Qlp	Tg	Tpl	Xcec	Ylg
AXm	KTc	Klhu	Mo	Qlr	Tgu	Tps	Xcg	Yp
CPeb	KTca	Klm	Msq	Qm	Ti	Tq	Xf1	Ypg
CPp	KTg	Klr	Pea	Qma	Tir	Tqa	Xf2	Zbv
CPrm	KTlc	Kls	PzMc	Qs	Tl	Tqi	Xg	Zi
CPrp	KTra	Km	PzMg	Seh	Tlcl	Tqq	Xg1	
CPs	KTrg	Kn	Pzag	Ssg	Tlpi	Tr	Xg2	
CaOb	KTu	Kp	Pzc	TQa	Tls	TrJu	Xgr	
Ced	KTv	Krg	Pzet	TQc	Tlsa	Try	Xgu	
Cm	Ka	Kscs	Pzett	TQem	Tlt	Tsg	Xlc	
Drc	Kc	Kt	Pzim	TQg	Tm	Tt	Xm1	
FZ	Kcm	Kta	Pzlg	TQne	Tmap	Tu	Xm2	
JKjg	Kcu	Kter	Pzllt	TQt	Tmat	Unmapped	Xma	
JKlb	Kec	Kti	Pzmg	Ta	Tmi	XYac	Xmo	
JKlm	Kes	Ku	Pzmp	Tbe	Tmo	XYci	Xmp	
JKm	Kg	Kub	Pzsj	Tc	Tmr	XYd	Xmu	
JKt	Kga	Kue	Pztp	Tca	Tms	XYr	Xpr	
JKvc	Kgu	Kulh	Pzut	Tcan	To	XYra	Xs1	
Jeb	Kl	Kulp	Pzy	Tcl	Tom	XYrc	Xs2	
Jg	Kla	Kusq	Qal	Tcm	Tor	XYrg	Xsm	
Jlg	Klaa	Ma	Qb	Tcn	Tp	XZy	Xsp	
Jlq	Klb	Mcp	Qc	Tcu	Tpa	Xa	Xu1	
Jm	Klc	Metp	Qe	Te	Tpar	Xbc	Xu2	
Jp	Klec	Mir	Qem	Tef	Tpb	Xcb	Xyf	
Jpa	Klf	Mlc	Qg	Teg	Tpc	Xcc	Xys	

DAY 1 MOnday (October 30, 2006)

Maracaibo (Hotel Maruma) – Barquisimeto (Hotel Hilton)

Theme: Maracaibo supergiant basin, Paleogene collision between the Caribbean and South American paltes and paleogeography.

Stops: Mene Grande high, Eocene unconformity, Burro Negro fault, Lara nappes (Matatere and Trujillo Fms.) and Cretaceous olistoliths.



Map 2. Geologic map from Hackley et al. (2005) showing the geologic setting for Day One stops. Purple line represents road network, small dark blue dots are towns and black big dots are oil fields. Numbers represent stops during day 1.

Regional geologic setting of the Maracaibo basin

Active tectonic setting and major faults. The Maracaibo Basin is a triangular, intermontane depression bounded to the east and west by Mérida Andes and Sierra de Perijá respectively, and by the Oca fault to the north (Mann et al., 2006) (Fig. 1). The Oca fault is interpreted as an active right-lateral strike-slip fault, with estimates of Oligocene-Recent horizontal offset ranging from 20 to 100 km (Rod, 1956; Kellogg, 1984; Audemard, 1995). The topographic axis of the Mérida Andes to the south is closely controlled by the Boconó fault, also interpreted as an active right-lateral strike-slip fault with horizontal offset ranging from 20 to 100 km (Schubert, 1982; Stephan, 1985). Towards the northeast, the Maracaibo depression is bounded by the Burro Negro and Ballenato faults that outcrop in low foothills of the Trujillo mountains (Mathieu, 1989; Escalona and Mann, 2006) (Fig. 2). The Burro Negro and Ballenato faults are parallel faults, strike northwest-southeast, and terminate near the Valera fault in the Mérida Andes (Fig. 2). Lake Maracaibo has a series of strike-slip faults trending NE-SW converging in general near Cabimas. Some of these faults are: Urdaneta Oeste, Icotea, and Pueblo Viejo (Fig. 1).

East of the Trujillo Mountains, the Lara nappes form a 75-km-long folded belt that trends northeast-southwest (Stephan, 1977, Kellogg, 1984, Mathieu, 1989) (Fig. 2). The Lara nappes are composed of Paleocene-Eocene marine sandstone and shale (significant regions have undergone prehnite-pumpellite grade metamorphism, containing large olistoliths of Cretaceous igneous and bioclastic rocks deposited during the thrusting event (Mathieu, 1989). Analysis of earthquakes, GPS data, and striated fault data by Kellogg (1984), Audemard (2001), and Colmenares and Zoback (2003) reveals that western Venezuela is undergoing present-day northwest to southeast shortening as a result of regional plate convergence between the South American and Caribbean plates (Mann et al., 2006).

Major subsurface faults. Regional seismic time slice at a depth below the surface of 3400 ms two-way travel time (TWT), covers most of the Lake Maracaibo area and part of the eastern coastal plain (Mann et al., 2006) (Fig. 2). This time slice shows prominent structural features that include N-NE-striking faults (e.g. Icotea and Pueblo Viejo faults), the Icotea pull-apart basin (Escalona and Mann, 2003) and NW-SE-striking normal faults related to foreland basin flexure (Escalona and Mann, 2006). Major regional unconformities interpreted in the stratigraphy of the Maracaibo Basin include the Pre-Cretaceous-Cretaceous unconformity, the Paleocene unconformity, the Eocene unconformity, and the middle Miocene unconformity (Lugo and Mann, 1995; Castillo and Mann, 2006; Escalona and Mann, 2003) and can be observed on the generalized stratigraphic column of the basin on Figure 3.

History of faulting and basin formation. The northeastern Maracaibo Basin was deformed by Paleogene thrusting and an associated tear fault (Burro Negro right-lateral strike-slip fault zone), related to Paleogene oblique collision between the Caribbean and South American plates (Stephan, 1977; Mathieu, 1989; Escalona and Mann, 2006). Various internal studies at PDVSA suggest that the West Tia Juana Fault, western edge of the Bolivar Coast Fields, is the westernmost limit of the parautocthonous deformation of the Lara Nappes instead of the Burro Negro fault (Bartok, personal communication).

Two different tectonic models have been previously proposed for the thick Paleogene depocenter located along the northeastern margin of the Maracaibo Basin (Fig. 4).

Foreland basin, NE-SW directed thrusting model: The first model proposes that the depocenter is a foreland basin controlled by southwestward-directed overthrusting during a late Paleocene-middle Eocene oblique collision between the Caribbean and South American plates (Mathieu, 1989; Lugo and Mann, 1995) (Fig. 4A). The second model, supported in this field guide, proposes that the asymmetric Paleogene Maracaibo sedimentary wedge was controlled by a >100-km-long motion along a right-lateral tear fault, separating SE-directed thrust sheets to the east (Lara nappes) from a more stable platform area to the west (Maracaibo Basin) (Escalona and Mann, 2006) (Fig. 4B).

Regional seismic lines recorded to 5 seconds two-way travel time reveal the structure of the asymmetric Paleogene depocenter in the northeastern part of the Maracaibo Basin (Escalona and Mann, 2006) (Fig. 5). The >100-km-long Burro Negro fault is a right-lateral strike-slip fault separating less deformed inner to outer-shelf rocks of the western Maracaibo Basin from highly deformed deep marine rocks of the eastern Maracaibo Basin. Seismic lines northeast of the Burro Negro fault zone show elongate, subsurface basins bounded by partially inverted reverse and strike slip faults filled with ~3 km of Oligocene and Miocene clastic marine sedimentary rocks. Structural highs of Eocene rocks are characterized at depth on seismic reflection lines by chaotic seismic reflections that underlie the more coherently stratified Oligocene and Miocene sub-basins. Chatellier et al. (1998) and Escalona and Mann (2006) interpret these structural highs as steeply dipping fault zones and possibly shale diapirs activated during Eocene-Oligocene oblique plate convergence (Fig. 5).

Tear fault model for the northeastern basin: The geology and overall structural configuration of the northeastern Maracaibo Basin and the Burro Negro fault zone supports its origin as a right-lateral tear fault (Escalona and Mann, 2006). In this model, the Burro Negro fault zone accommodated southeastward migration of the thrust front in the deepwater area east of the fault in the present-day Falcón region. The Paleogene clastic wedge of the Maracaibo Basin exhibits many common features of a classic foreland basin including Eocene onlap onto an arch or forebulge located near the center of present-day Lake Maracaibo (Escalona and Mann, 2006). Pestman et al. (1994) document a forebulge as early as Paleocene. This paleogeographic coincidence of the Burro Negro fault zone and the Maracaibo shelf edge suggests that the paleo-trend of the South American passive margin prior to collision was serrated in map view (Pindell and Kennan, 2001). West-to-east migration of the Caribbean-South American oblique collision formed progressively younger, parallel tear faults to the east of the Maracaibo Basin that may have formed in the same manner as the Burro Negro fault zone (Escalona and Mann, 2006).

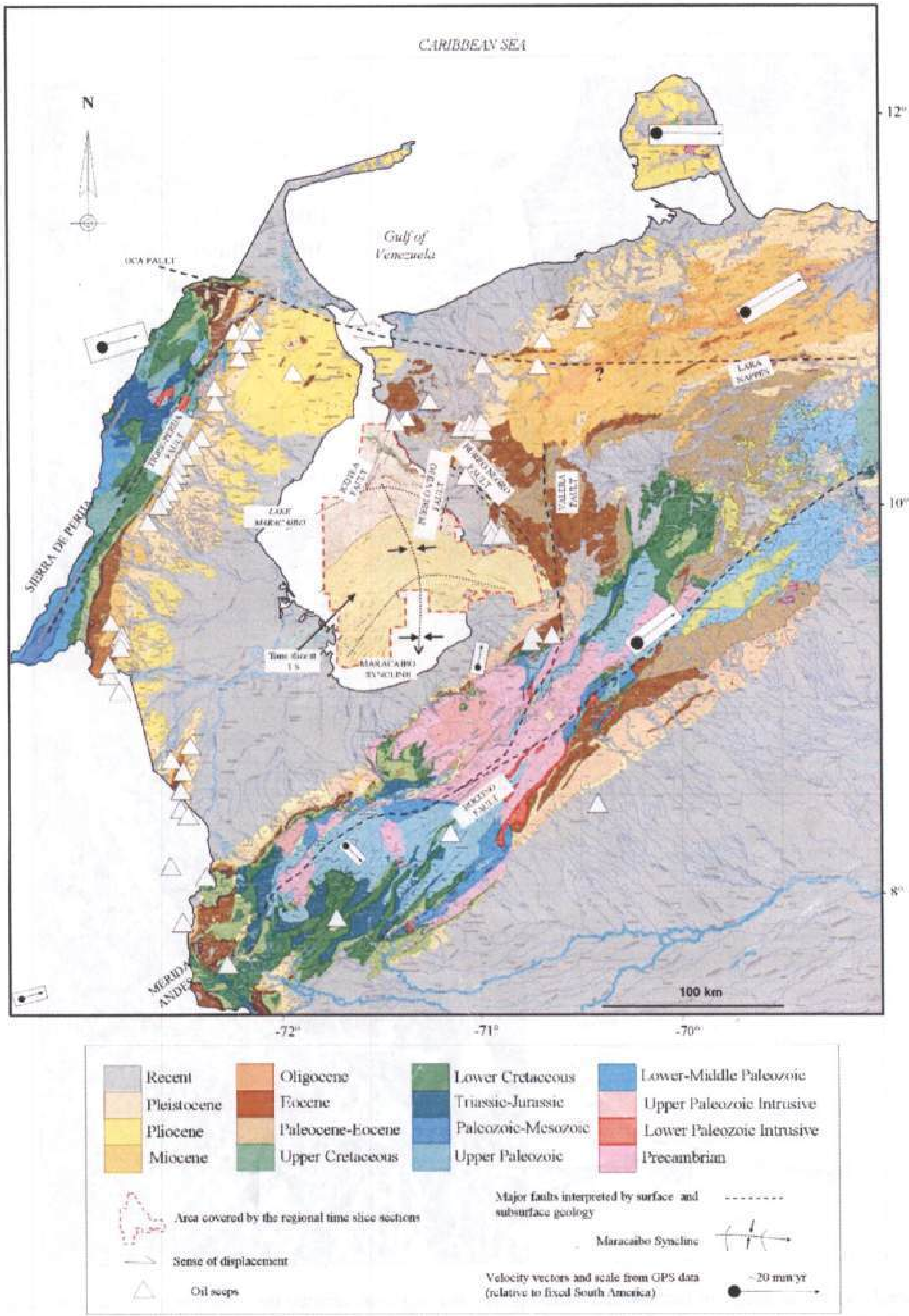


Figure 1. Surface geologic map of the Maracaibo Basin (modified from Borges, 1984) combined with seismic time slice from merge 3D dataset at 1 second beneath the floor of the Lake Maracaibo. GPS vectors from Perez et al. (2001) and Trenkamp et al. (2002) indicate direction and relative rate of displacement of the Maracaibo block to the north and northeast relative to the stable South American craton (From Escalona and Mann, 2003)

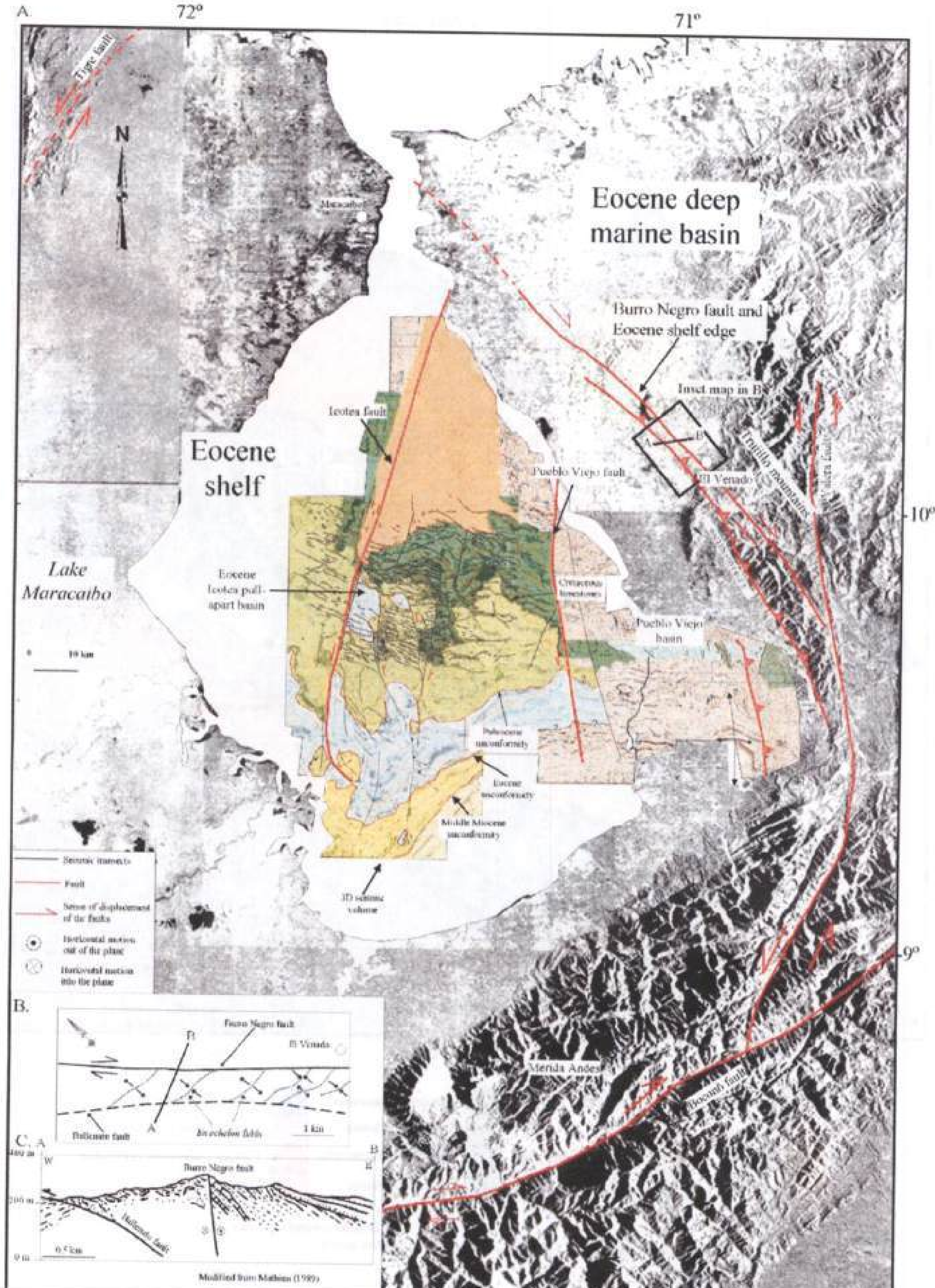


Figure 2. A) Radar image of circum-lake outcrop area and regional seismic time slice beneath the lake area at 3400 ms. Main faults include: Bocono, Valera, Burro Negro, Tigre, Icotea and Pueblo Viejo. **B)** Map view interpretation modified from Mathieu (1989) shows the Burro Negro fault as a right-lateral strike-slip fault with associated en-echelon folds. **C)** Cross-section interpretation based on outcrop mapping by Mathieu (1989) shows the subvertical dip of the Burro Negro fault and its right-lateral sense of shear. From Escalona and Mann (2006).

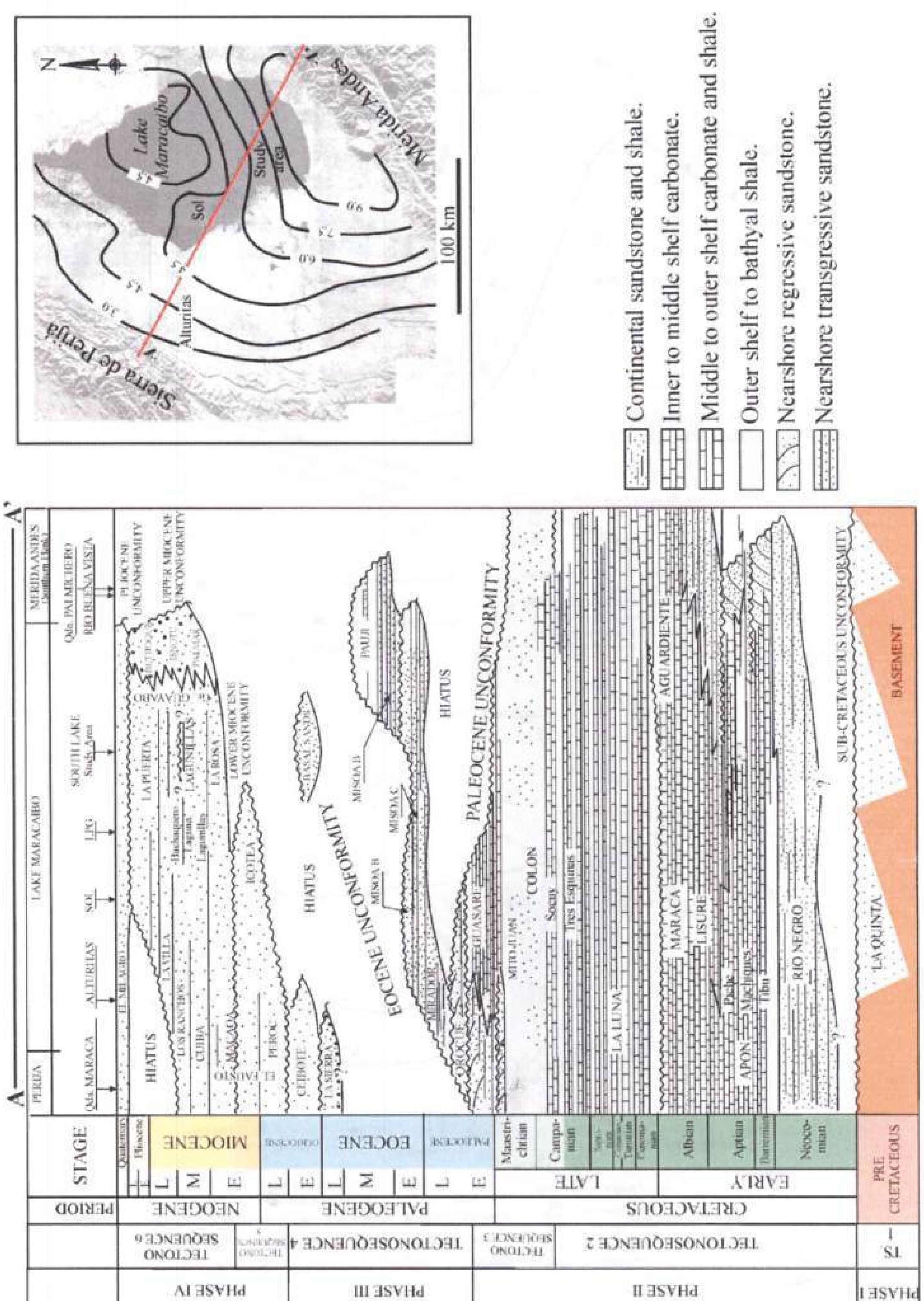


Figure 3. Chart of Mesozoic and Cenozoic formations and their sedimentary facies of the Maracaibo Basin along the line of cross section shown in the inset map (modified from Parnaud et al., 1995). Six unconformity-bound sequences in the Maracaibo Basin are recognized. The unconformities bounding the sequences represent a stratigraphic hiatus during the following four times: Pre-Cretaceous, Paleocene, Eocene, and upper Miocene. (From Mann et al., 2006).

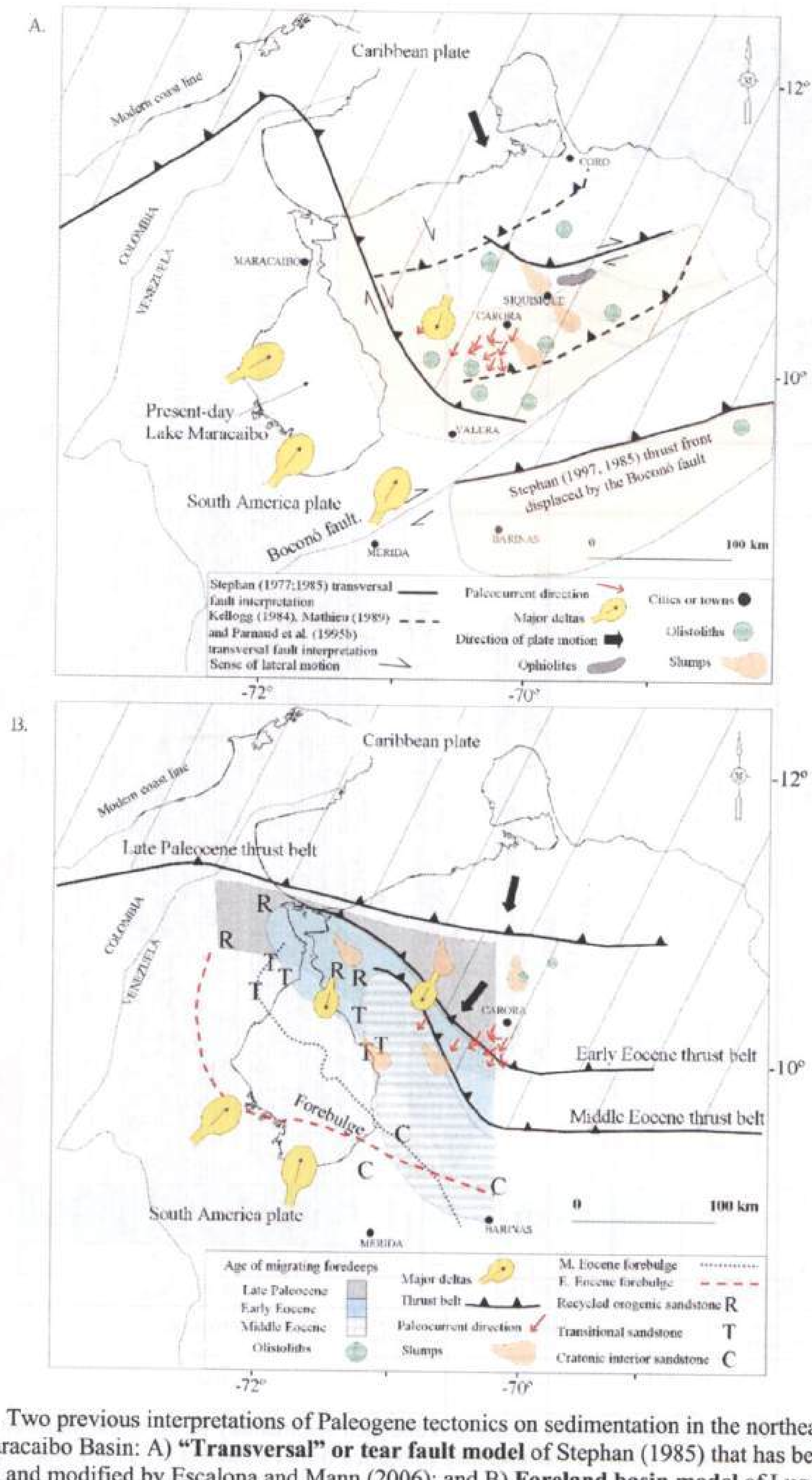


Figure 4. Two previous interpretations of Paleogene tectonics on sedimentation in the northeastern region of the Maracaibo Basin: A) **"Transversal" or tear fault model** of Stephan (1985) that has been recently discussed and modified by Escalona and Mann (2006); and B) **Foreland basin model** of Lugo and Mann (1995) showing southwest-directed thrust faulting and no strike-slip faulting along the trend of the Burro Negro fault zone. From Escalona and Mann (2006).

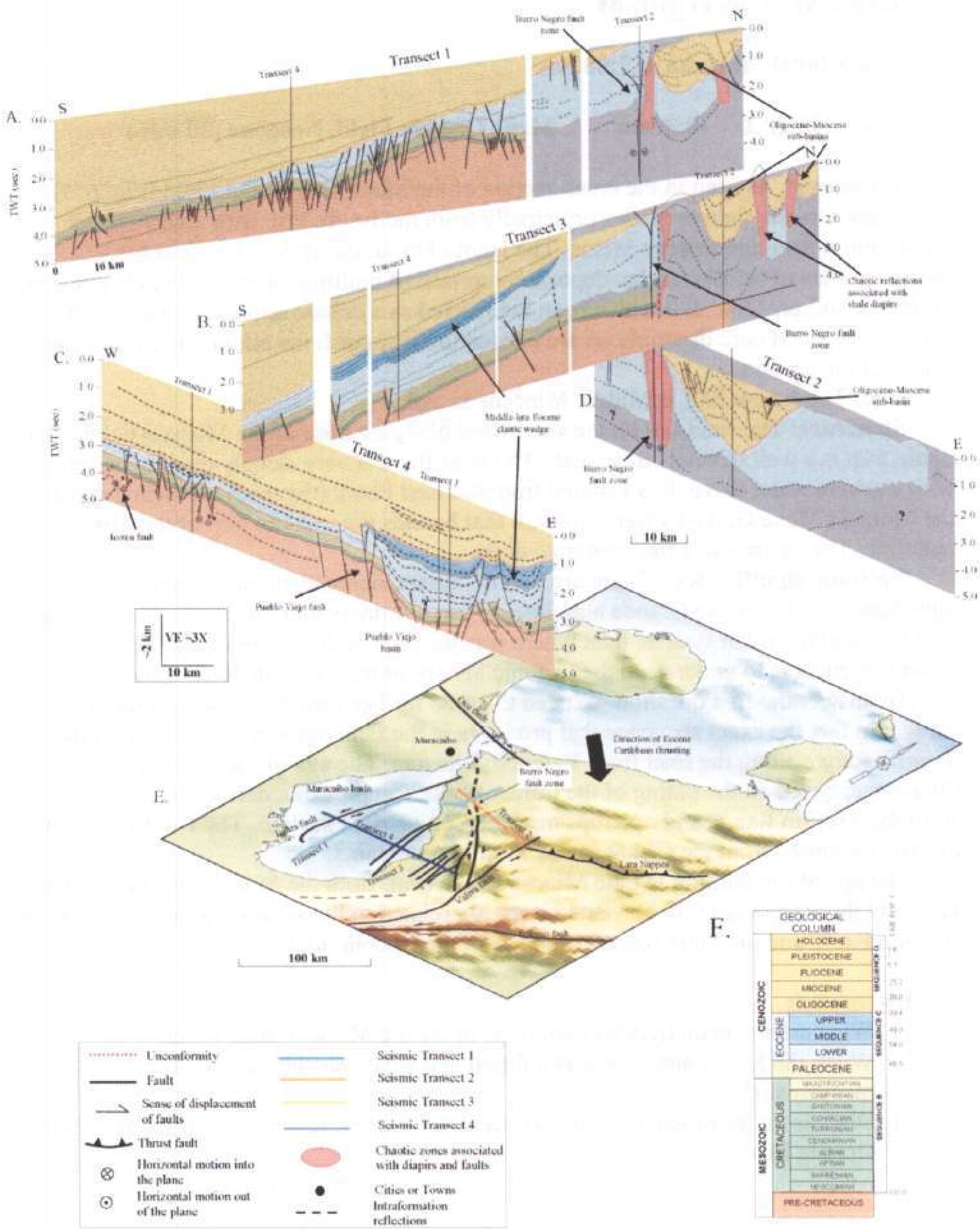


Figure 5. Fence diagram showing the structural and stratigraphic subsurface architecture of the central and eastern part of the Maracaibo Basin and location of main faults (from Escalona and Mann, 2006). Note the following relationships: 1) Pre-Oligocene rocks are highly folded east of the Burro Negro tear fault but are relatively undeformed west of the Burro Negro tear fault; 2) an asymmetric wedge of Eocene clastic rocks pinches out in the central part of present-day Lake Maracaibo; and 3) Eocene clastic rocks thicken abruptly thicken east of the Burro Negro fault zone..

Day 1 stop descriptions

Leave hotel Maruma at 7:00 am

- **STOP 1 ~8:30am Mene Grande Field, Neogene (30 min)**

Lithology: As seen in the cross-section of the Mene Grande Oil Field (Fig. 6, 7). The Mene Grande field produces principally from the Isnotu Fm. with a very minor contribution from the Eocene Misoa. The Isnotu Fm. in the area of the field has characteristics of an alluvial fan deposit comprised of multiple interfingered channels and extensive soil profiles. It has also been interpreted as a deltaic sequence (Alcala, 1993) (Fig. 8). Detailed core descriptions are needed to distinguish the alluvial fan vs. deltaic origin of the section.

Age: The Isnotu FM. is Middle Miocene in age

Structure: The field lies on the southward plunging nose of the Misoa Aticline. The updip trap is a well developed tar seal. The west flank is very steeply dipping surface with a severe water drive. It is isolated from the East Flank (the main producing area) by the Motatan/Mene Grande strike-slip fault that bounds the western part of the Misoa anticline. The eastern side has moderate dips.

Tectonic significance: There are two important elements in the tectonic significance of the Mene Grande anticline: 1) First, if the Isnotu Fm. in the Mene Grande Field is an alluvial fan system, then where was the mountain that sourced it?; 2) The second element is to understand the tectonic history of the Motatan/Mene Grande Fault.

To answer the first question we need to go no further than the adjacent Trujillo Range. In fact the exact sequence that produces in the field outcrops at the base of the Trujillo Range along the road from Valera to Motatan. The age of the Trujillo Range is Oligocene, based on the dating of the Caracol delta complex that derives its sediments from the Trujillo Range and outcrops near the Chama river section. The Isnotu Fm. was probably sourced from the Oligocene of Trujillo mountains.

The age of the faulting is Late Miocene to Recent. Both the Motatan-Mene Grande fault and the Valera fault, to be visited later, are related to the strike-slip movement of the Bocono Fault, and probably represent splays of the Bocono fault.

Discussion:

1) What are the main hydrocarbon traps in the the Mene Grande Field?
2) When the Misoa anticline was uplifted and what was the main deformation mechanism?
3) Discuss the significance of the Miocene Isnotu Fm. reservoir facies in the Mene Grande field

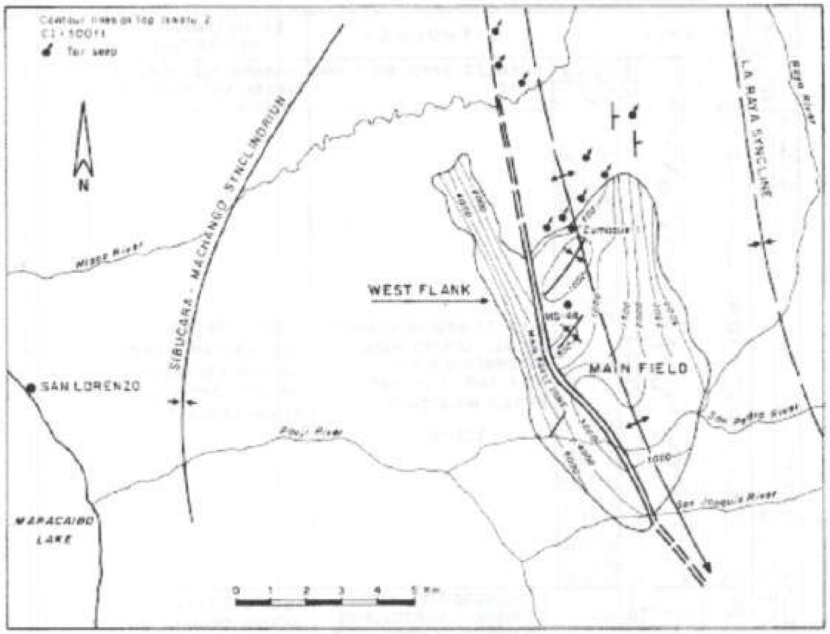


Figure. 6. Map View showing the anticline structure of the Mene Grande field (Form Alcala, 1993).

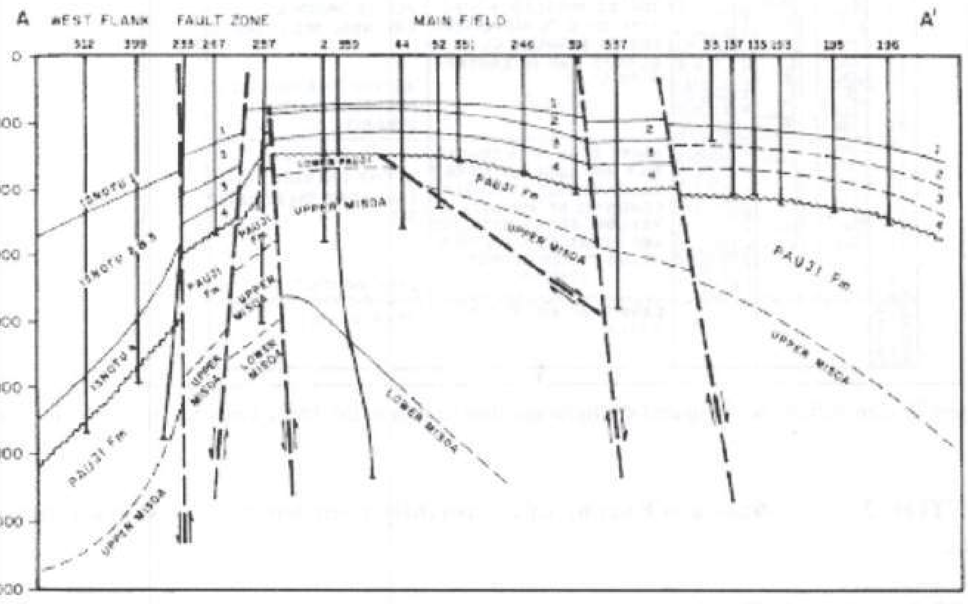


Figure 7. Cross-section across the Mene Grande Field. The reservoirs are located in the Miocene Isnotu Fm. (Alcala, 1993)

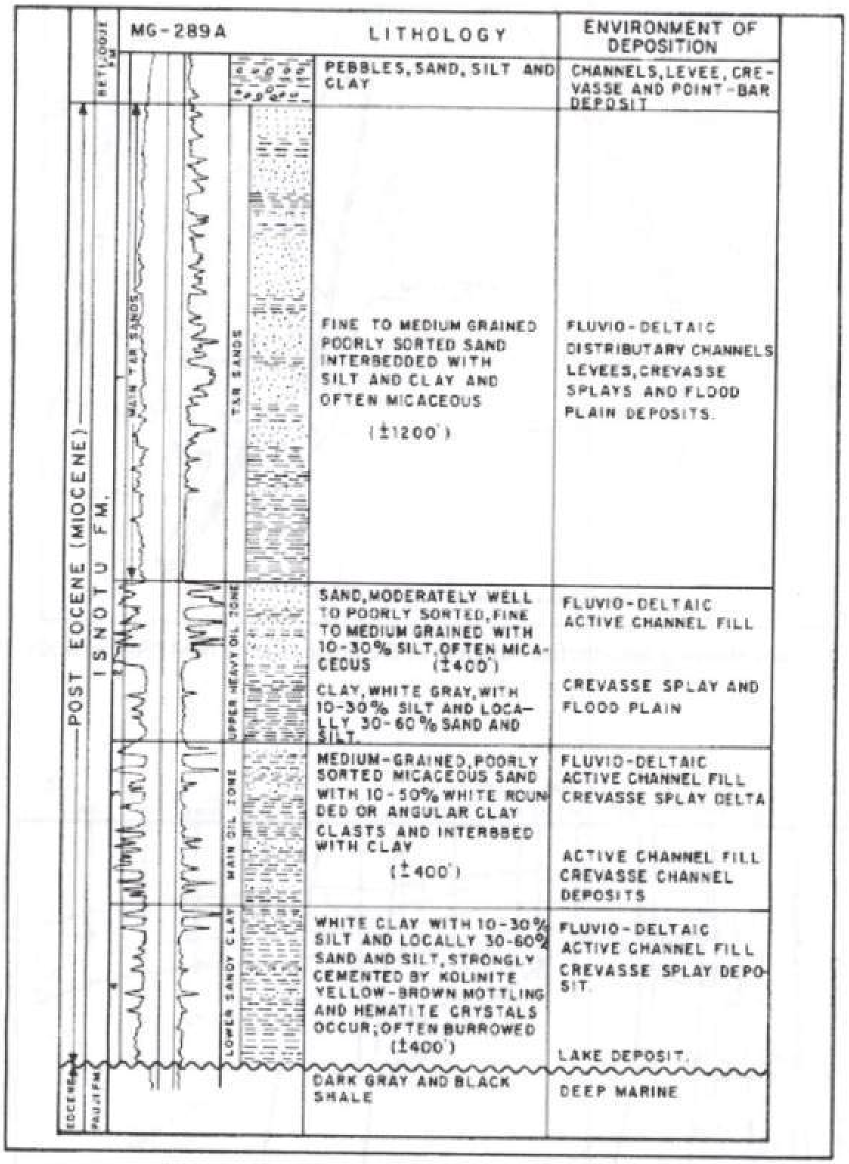


Figure 8. Generalized well log and stratigraphic description in the Mene Grande Field (Alcala, 1993)

• **STOP 2** **~9:30 am Eocene unconformity near the Burro Negro fault zone.**

STOP 2A (20 min): The first stop will focus on the shore facies of the Misoa B series that outcrops along the road. This outcrop has been assigned to the informal B6-B9 interval of the **Misoa Fm**. and correspond to the shelf edge delta complex of the Misoa Fm. There is significant bioturbation and coarsening upward sequences.

Discussion:

What environment of deposition does the facies observed suggest?

STOP 2B (30 min): this segment of the Burro Negro Fault lies along the northern limit of the Misoa Range (Map 2, Fig. 1). Note the intensive convergent deformation including the kink bend folds and overturning (Fig. 9). The stratigraphic section corresponds to the upper Misoa B. Sole marks in the area suggest the possibility for slope deposits.

Discussion:

Considering that the Misoa Fm. is the best Eocene reservoir in the Maracaibo basin, what would be the best plan for a production well in a overturned section similar to the outcrop shown in Figure 9?

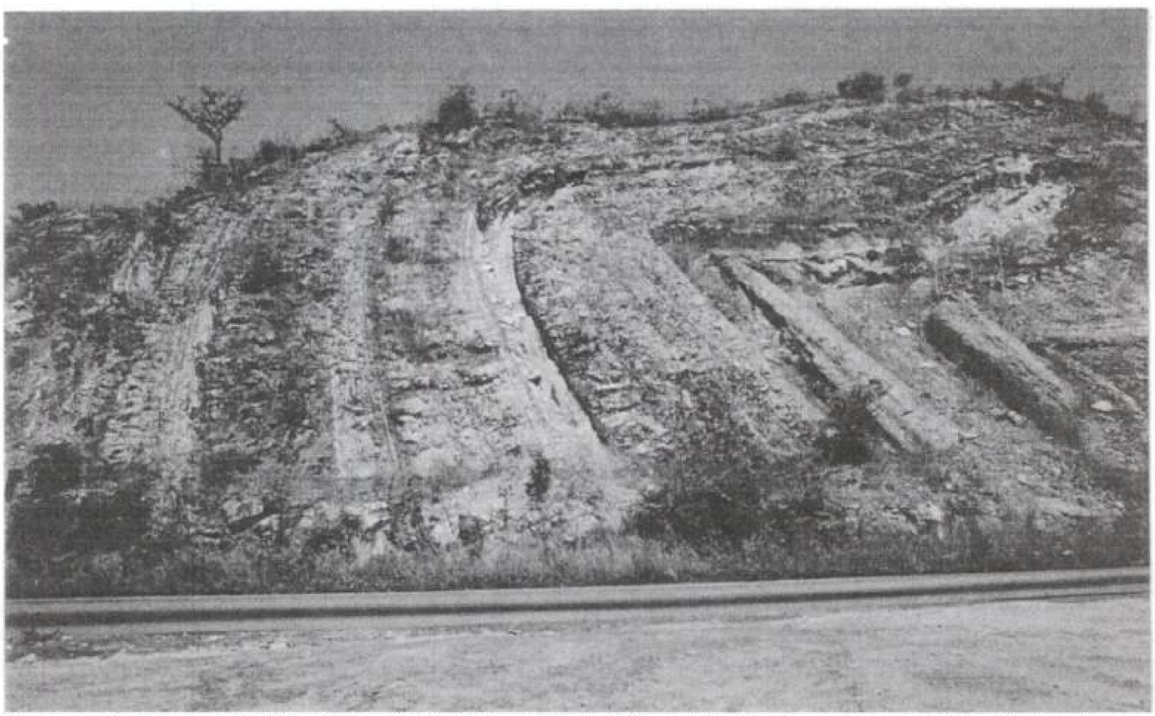


Figure 9. The area north of the Misoa Anticline is severely deformed by the Burro Negro Faults. Note that the beds are overturned.

PHOTO STOP: (1 km from the last stop) the angular unconformity of the Misoa Fm overlain by the Isnotu Fm.

• STOP 3 ~12:00 pm. Trujillo Formation northeast of Lake Maracaibo. El Baño (~45 min)

We have driven through Paleocene Trujillo deep water shales since the last stop. As we approach the Valera fault the topography becomes more rugged and we observe the outcrop of El Baño (Fig. 10). The granite is Ordovician in age and similar to many granites of the Andes. Granites of this age formed during Caledonian orogenic episode in the Proto-Andes. Overlying the granite are normal sequences of the Cogollo Group and La Luna Formation. It is important to note that these sedimentary rocks are not metamorphosed and represent the Cretaceous passive margin

Discussion:

What is the tectonic mechanism responsible for the observed structures seen in this outcrop?

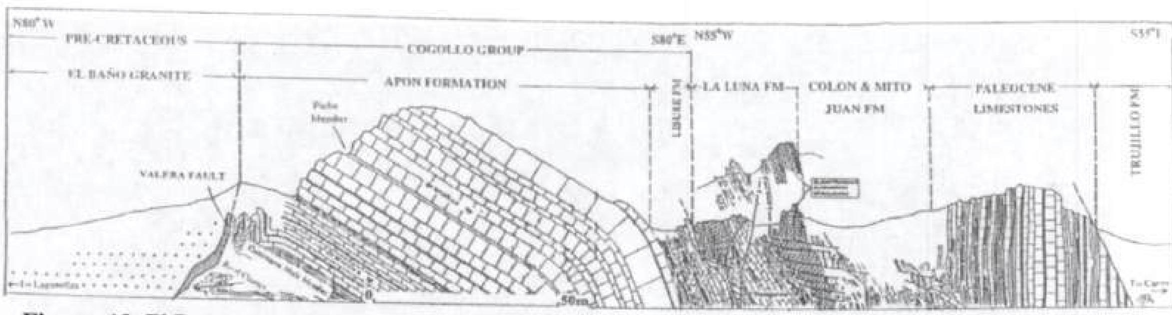


Figure. 10. El Baño outcrop (first described by Habicht, 1960), central Trujillo. Note the preservation of the Cretaceous sequence overlying the Ordovician granite.

12:45 Lunch

3:00 Pass through Carora and stop at Service Station for a view point of Cretaceous olistoliths; discussion and rest stop (30 minutes)

Please cross the highway very carefully. On the hills on the north side of the highway we will see olistoliths of the Cogollo Group embedded in the Matatere Fm. This is a very important outcrop because it shows clear evidence for the unconformable contact between the two formations and that the Barbacoas Platform was elevated during the Paleocene.

In the satellite imagery of Figure 11 we can observe that the structural grain on the Barbacoas Platform is very different than the structural grain of the Matatere Fm. as first observed by Stephan in 1977.

Discussion:

What is the origin of the two different structural styles observed in the satellite image on Figure 11?

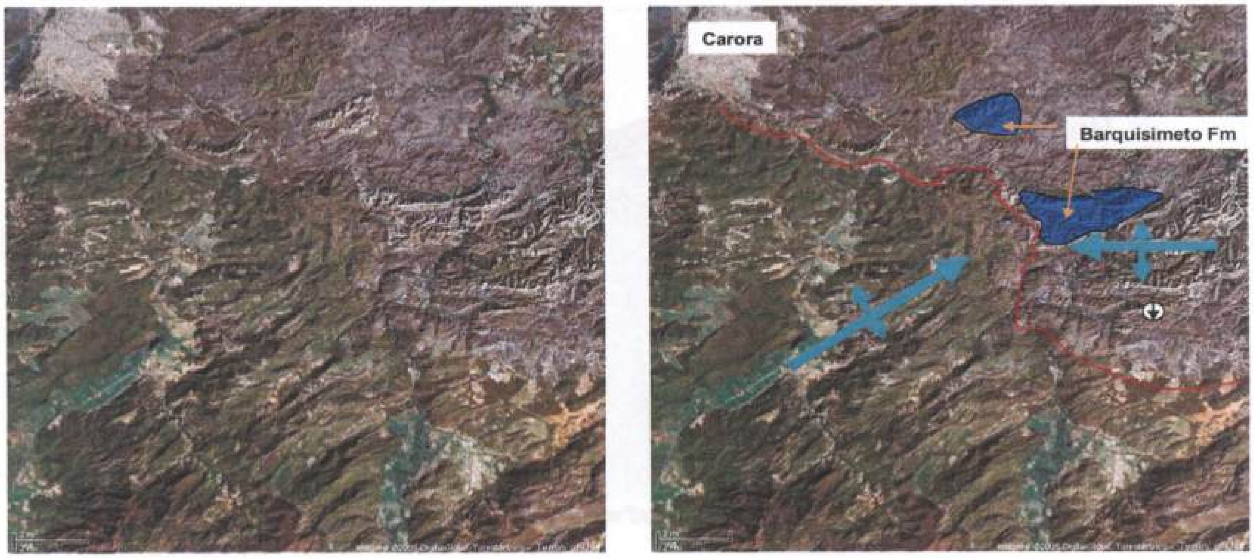


Figure. 11. Satellite image (http://www.google.com, October 2006) of the Barbacoas Platform. Note the structural grain of the Matatere is reddish and trends EW; The grain of the Barbacoas platform (Andes) is green and trend NE-SW.

In order to understand the Barbacoas platform (Andes), we need to understand the stratigraphy surrounding the platform:

1) On the western flank of the Barbacoas high lies the Paleocene Rancheria Fm. turbidites that imply bathyal conditions along its western flank.
2) Along the northern margin lies the Paleocene Valle Hondo shallow-water carbonates. Along the southeastern corner, at Humocaro Bajo, lies Paleocene Moran delta complex (next stop)
3) Unmetamorphosed Cogollo and La Luna Fms. outcrop on the Barbacoas platform and formed olistoliths shed into the Matatere Fm. north of the Barbacoas platform

Discussion:

Was the Barbacoas Platform buried or uplifted by the Nappes?

One possible model would be similar to the tectonic evolution of the eastern Bonaire basin (Fig. 12). The Barbacoas high may have been an elevated horst block (foot wall) created by extension prior to the nappe shortenning or by north-directed back-thrusting during the thrusting of the nappes. Instability in front of the elevated block produced slumping that formed Cretaceous olistoliths now found in the deep basinal depocenter of the Matatere Fm.

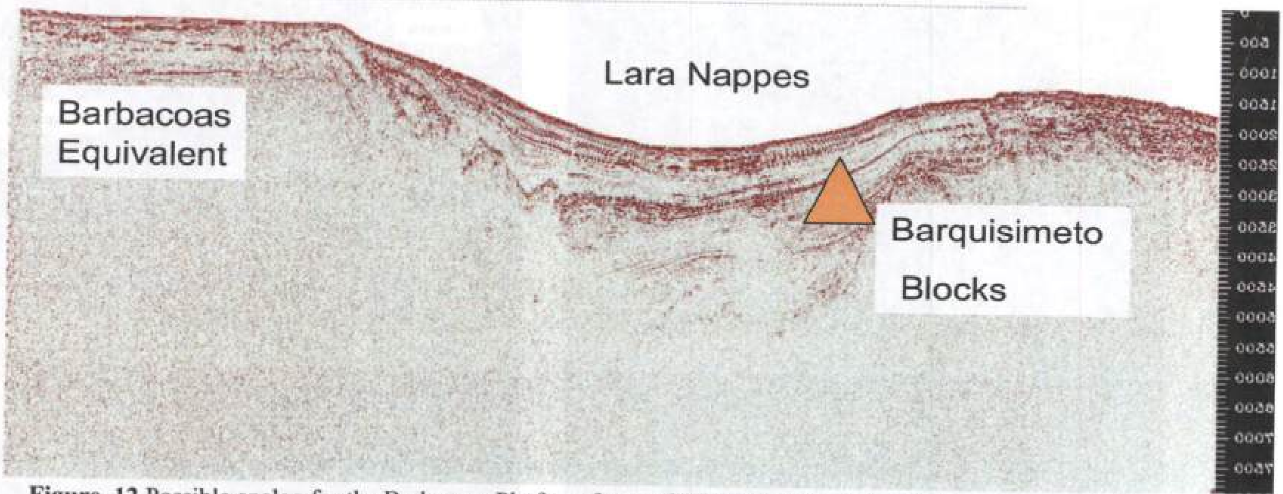


Figure. 12 Possible analog for the Barbacoas Platform from a GULFREX seismic line in the eastern part of the Bonaire basin, offshore Venezuela

- **STOP 4 ~4:30 (Photo-stop) Lara Nappes between Maracaibo and Falcon basins (20 min)**

There will be a brief photo stop to show the Lara Nappes from north to south. The location of the photo is marked on Figure 11 with a small balck arrow on the right side. In the foreground, the nappes and in the background is the Barbacoas High. This high the termination of the visible Merida Andes.

Discussion:

Considering the tectonic models proposed so far; Do you think the Cretaceous passive margin continues under the Nappes?

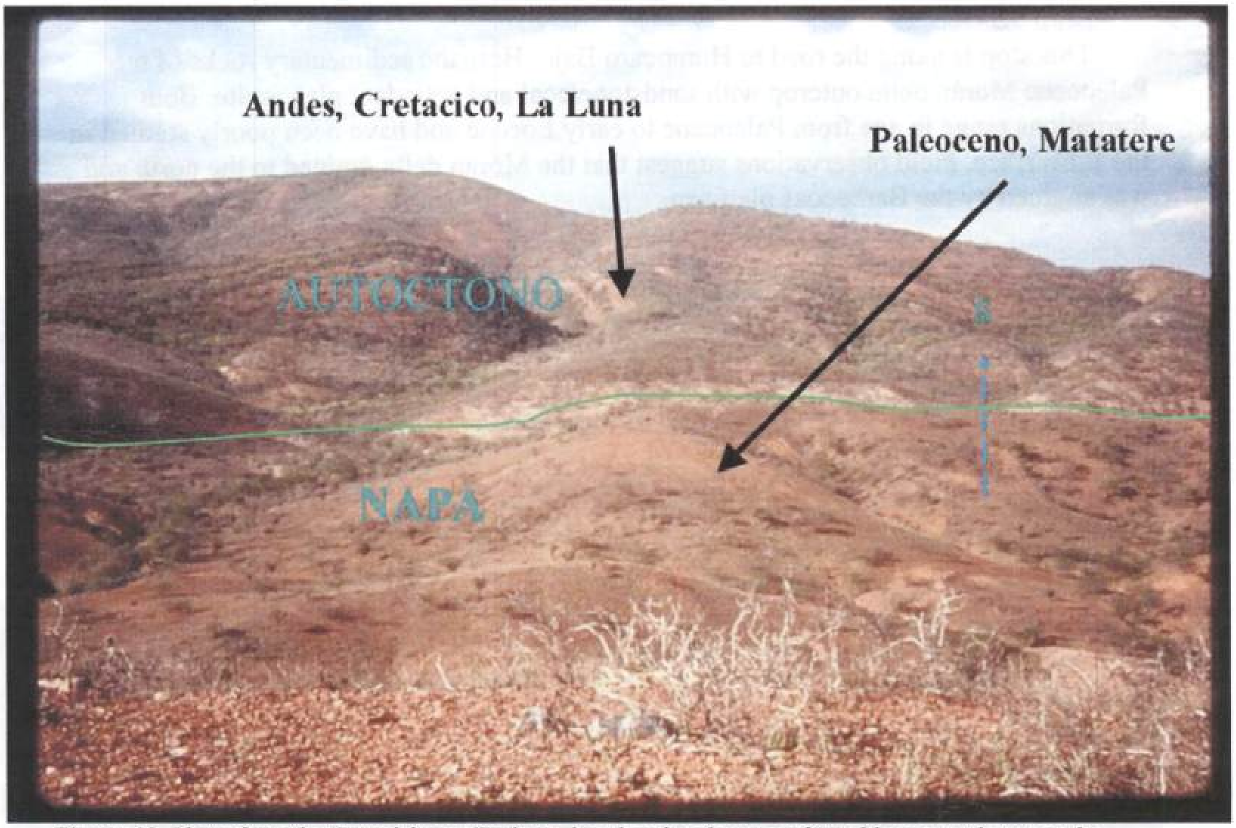


Figure 13. Photo from the Barquisimeto Basin region showing the unconformable contact between the allochthonous Lara nappes (late Paleocene Matatere Formation) and the autocthonous Cretaceous passive margin. Note that the Andean section has not been displaced. The Barbacoas Platform is in the background and has perfectly preserved Cretaceous sequences. The small circle in Fig. 11 shows the location of the picture.

- **STOP 5A ~5:30 :south of El Tocuyo. Barquisimeto Fm (Lower to Middle Cretaceous) overlying the Paleocene Matatere Fm.**

1) The valley marksthe trace of the Bocono Fault zone
2) The eastern flank of the valley is comprised of rocks associated with the Caracas Group. The principal outcrops are metamorphic Lower Cretaceous rocks of the Nirgua Fm. It is important to note that within the pelitic facies Tintinids and Calpionella (Bellizzia and Rodriguez, 1968) have been observed and are suggested to have been derived from the Yucatan platform.
3) The mountains to the far west are part of the Barbacoas Platform and have been uplifted both by the Paleocene Barbacoas uplift and the Miocene Andean uplift.
4) The white hills in the foreground are the Cretaceous Barquisimeto Fm olistoliths contained with the metamorphosed Paleocene Matatere fm.

In this stop we can observe the characteristics of the Barquisimeto/Matatere contact showing clear evidence of direction of transport to the south (Figs. 1 and 15). How can the deformation of the Matatere shales be used to determine the direction of sediment transport?

Stop 5B

This stop is along the road to Humocaro Bajo. Here the sedimentary rocks of the Paleocene Morán delta outcrop with sandstone/coal and abundant glauconite. Both formations range in age from Paleocene to early Eocene and have been poorly studied in the subsurface. Field observations suggest that the Moran delta drained to the north and was sourced by the Barbacoas platform.

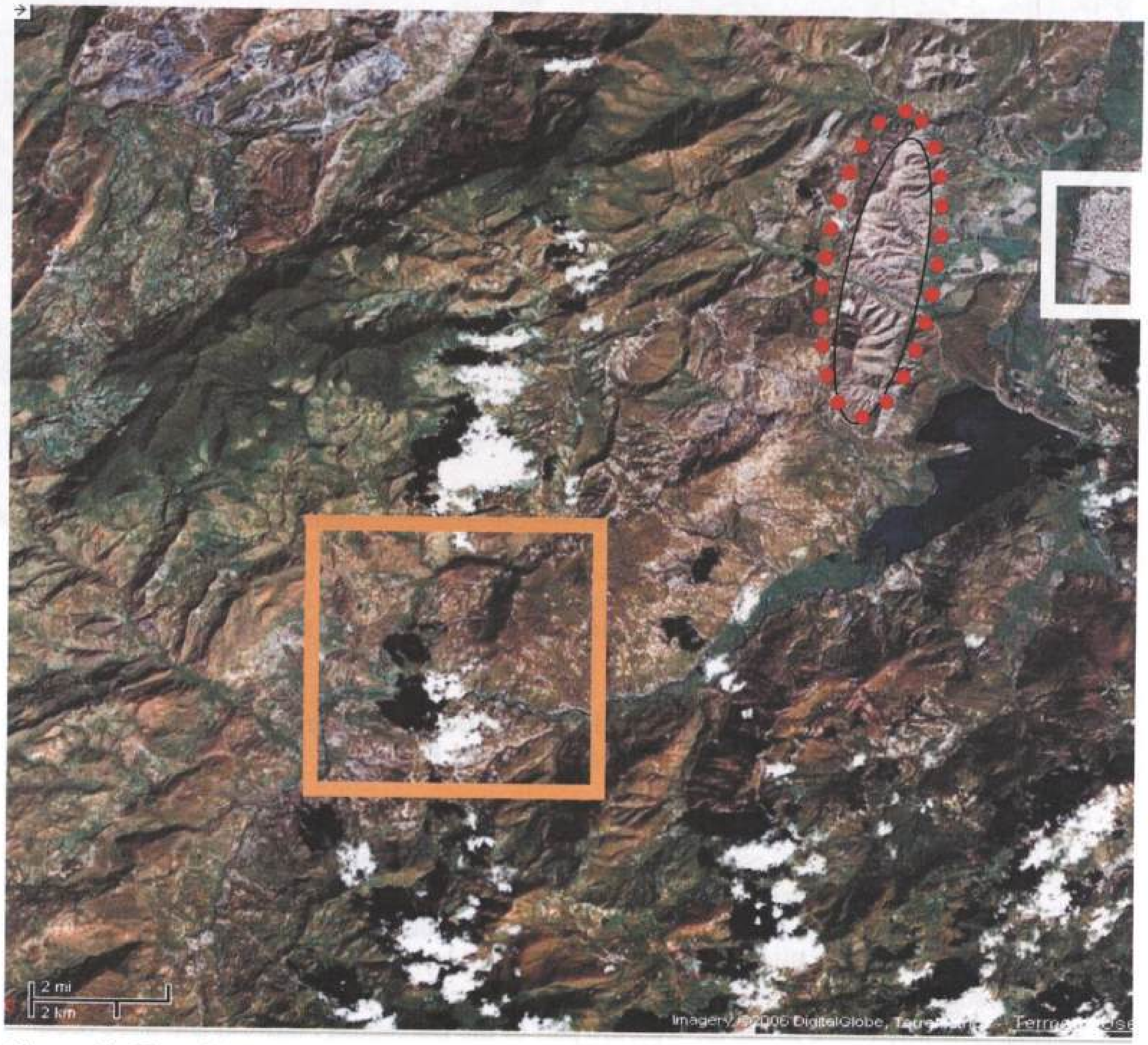


Figure. 14. The red dotted circle is the Barquisimeto outcrop. The white square the right rihgt is the city of El Tocuyo. In the center of the satellite image, orange square, is the outcrop of the Moran delta. (http://www.google.com, October 2006)

Discussion:

Was the Paleocene Moran delta the precursor of the Eocene Misoa delta (proto-Maracaibo)?

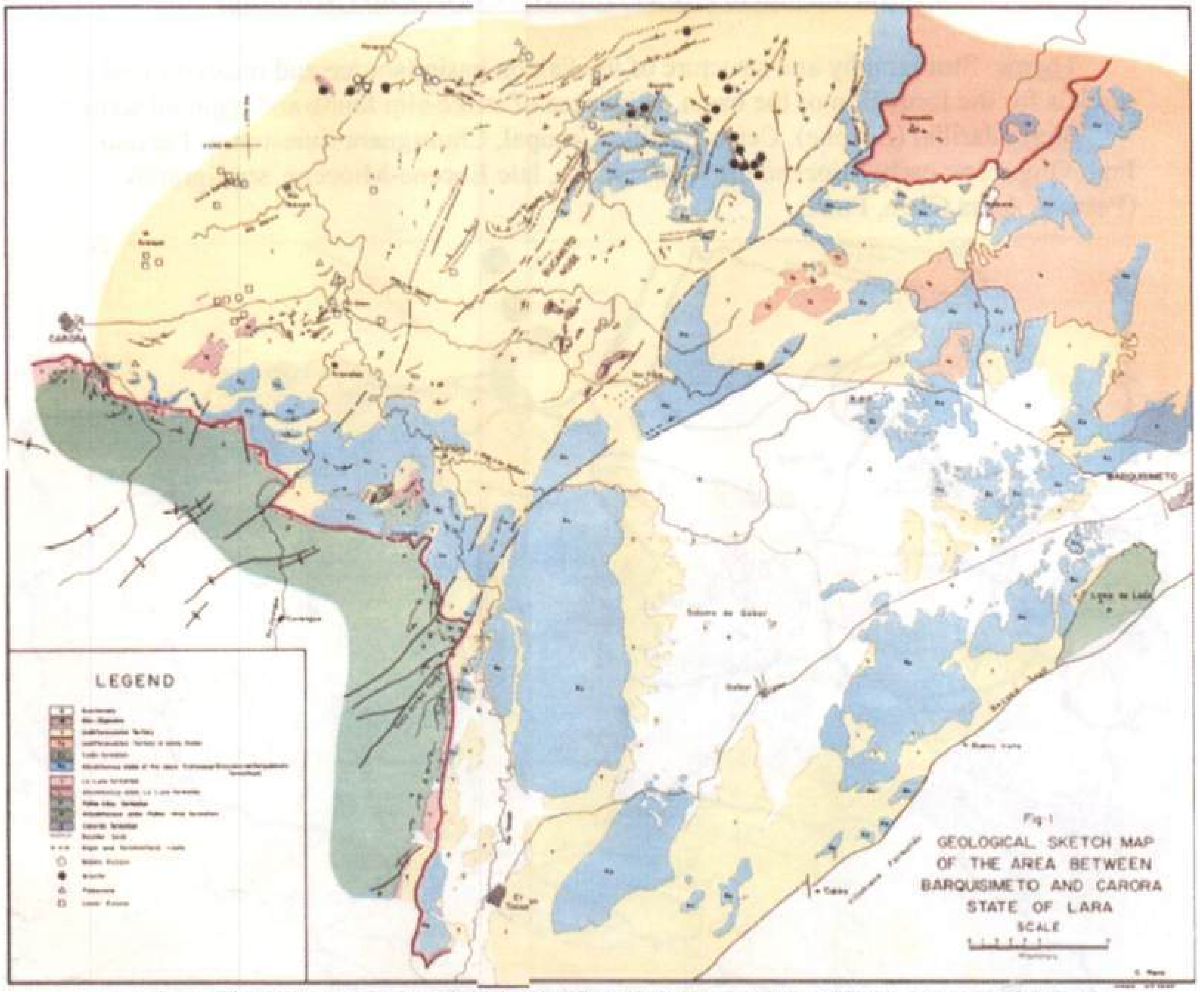


Figure 14. Geologic map of the Barquisimeto-Carora region showing Cretaceous limestone blocks (olisotlotihs, blue) within Paleogene rocks (yellow). (Renz, 1956, internal. Shell Exploration). The southern blue outcrop is stop 5B

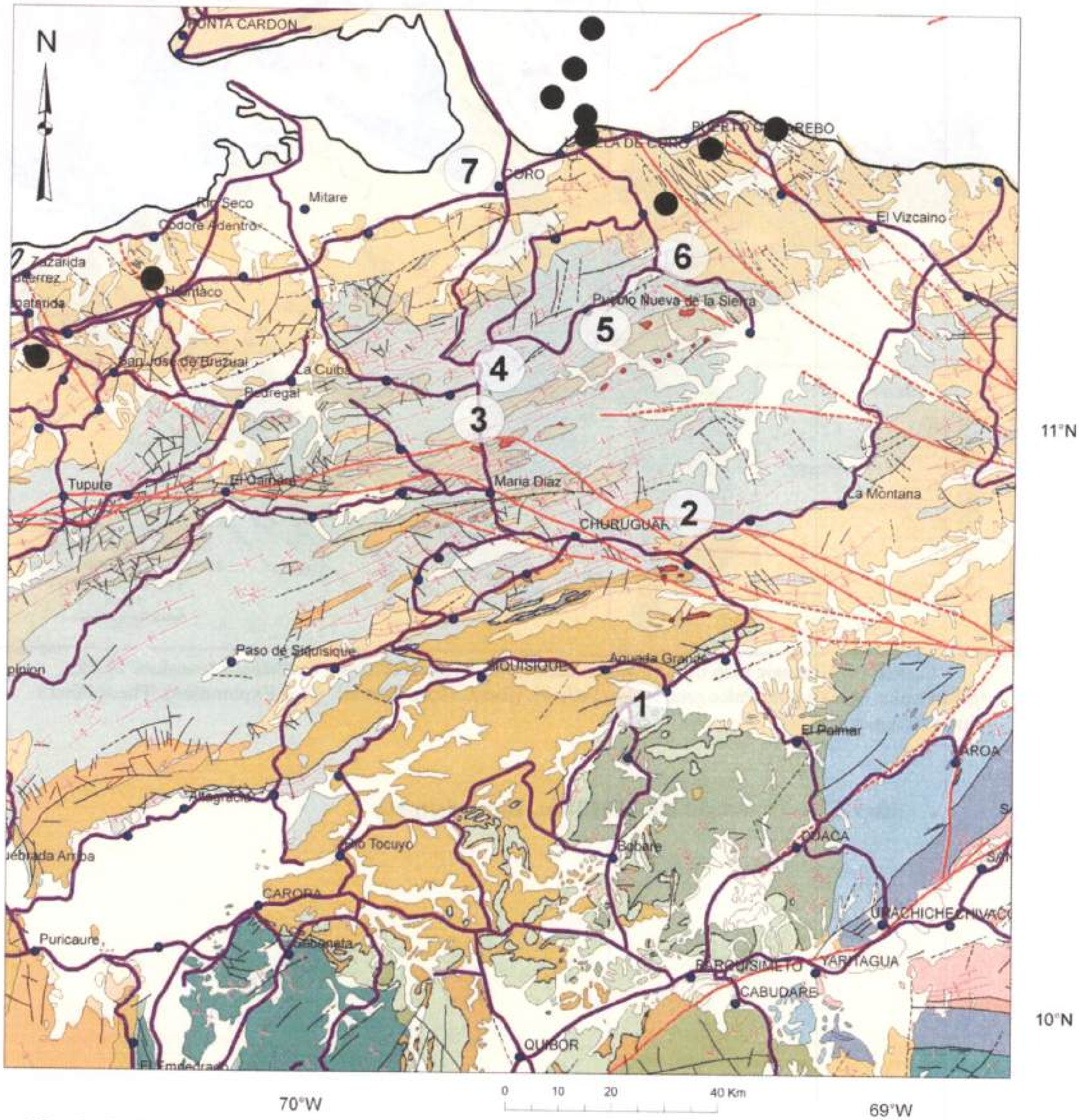
- **Stop 6 ~7:00 Hotel Hilton, Barquisimeto**

DAY 2 Tuesday (October 31, 2006)

Barquisimeto (Hotel Hilton) – Coro (Hotel Miranda)

Theme: Stratigraphy and structure of the Falcon basin (source and reservoir rock), models for the formation of the basin, evidences of strike-slip faults and regional setting.

Stops: Jarillal (Eocene), Cerro Castillo/Casupal, Churuguara limestones, Paraíso Fm., Oligocene-early Miocene ultramafic rocks, late Eocene-Miocene stratigraphy (Pecaya, Agua Clara, Fms.).



Map 3. Geologic map showing the geologic setting of stops for Day 2. Purple line represents road network, small black dots are towns and big dots are oil fields. Geologic base map is from Hackley et al. (2005).

Regional setting of the Falcon basin

Active tectonic setting. The present-day tectonic setting in the southeastern Caribbean is controlled by the eastward motion of the Caribbean plate relative to South America at a rate of about 20 mm/yr as shown by GPS-based geodetic results (Trenkamp et al., 2002; Pérez et al., 2001) (Fig. 15). The Oca-Ancon de Iturre fault zone is a right-lateral strike-slip fault system that cuts across the northwestern margin of South America and forms the westernmost strand of a sub-parallel zone of right-lateral strike-slip faults that includes the San Sebastian and El Pilar fault zones (Audemard, 2001) (Fig. 15). North of the Leeward Antilles, the Caribbean plate underthrusts the South America plate (Kellogg, 1984; van der Hilst and Mann, 1994; Taboada et al., 2000; Colmenares and Zoback, 2003). To the east, the Atlantic plate (North and South America) underthrusts the Caribbean plate at the Barbados accretionary prism (Westbrook et al., 1988) (Fig. 15).

Regional structural geology and outcrop pattern. The Falcon basin is an inverted Oligocene-Recent U-shape basin opening in the northeastward direction to the Bonaire basin. The basin is deformed into a ENE- oriented "anticlinorium", or nested group of anticlines (Wheeler, 1963; Muessig, 1984; Audemard, 1995) (Fig. 16). The centerline of the basin is cored by the oldest sedimentary rocks in the basin (Eocene and Oligocene) and these older rocks are intruded by alkaline basaltic intrusions of Oligocene-early Miocene age (23-15 Ma) (Muessig, 1984; McMahon, 2000). Marine sedimentation started in the Oligocene as a large marine transgression from the NE that continued though the early Miocene (Macellari, 1995). During the middle-late Miocene, northwest-southeast shortening and inversion of previous structures resulted in uplift of the Falcon basin. From the middle Miocene to Recent time, most of the Falcon basin has been subaerially exposed. The stratigraphy at the northeastern end of the basin extends offshore into the La Vela area and Bonaire basin where it has been mapped using seismic reflection and well data (Audemard, 1995; Macellari, 1995; Gorney et al., in press).

Figures 17 and 18 show a generalized north-south generalized stratigraphic chart across the Falcon basin (Audemard, 1995) and schematic paleogeographic maps (Wheeler, 1963; Macellari, 1995), respectively. During Oligocene and early Miocene time, the U-shape Falcon basin was rimmed on the northern and southern flanks by reefal limestones of the San Luis and Churuaguara formations and the central axis was filled by deepwater facies of the Paraiso, Pecaya and Agua Clara formations (Fig. 18A-B). Following an early-middle Miocene uplift and unconformity, deposition continued only in the northern regions of the basin where shallow marine to continental sedimentation show progressive pulses of uplift (Audemard, 1995; Macellari, 1995) (Figs. 17 and 18).

Previous tectonic models for the Falcon basin. Tectonic models for the Falcon basin put forward by both oil industry and academic geologists can be classified into two groups: 1) **opening of a Cenozoic pull-apart basin** along east-west-striking, plate-margin parallel right-lateral strike-slip faults (Muessig, 1978; Muessig, 1984; Boesi and Goddard, 1991; Macellari, 1995) (Fig. 19A); and 2) **opening of an east-west trending back-arc basin** in a subduction setting (Audemard, 1993; Audemard, 1998; Mann, 1999; Porras, 2000) (Fig. 19B) or in a subduction system that originated in a north-south orientation and was subsequently rotated clockwise by 90° into its present east-west orientation along the South American margin (Skerlec and Hargraves, 1980) (Fig. 19B).

The pull-apart model first proposed by Muessig (1978) suggests the presence of a large (~ 200 km) right-lateral fault stepover in late Eocene-Oligocene time between the Oca fault in the south and the South Caribbean deformed belt in the north (Fig. 19A).

This proposed pull-apart basin encompasses both the present-day onshore Falcón and offshore Bonaire basins (Fig. 19A). Muessig (1984) proposes a diffuse pull-apart zone consisting of areas of stable basement highs (e.g. Guajira, Paraguana, Los Monjes, Leeward Antilles islands) and intervening, subsiding basins (e.g. Urumaco trough, Falcón basin, La Vela Bay, and Bonaire basin) (Fig. 19A). Major structural highs are linked to roughly northwest-striking strike-slip faults (Fig. 19A). Pull-apart-related subsidence is inferred to be of late Eocene-Oligocene age based on the ages of the oldest Falcón basin marine sedimentary deposits and alkali basalt magmas that were intruded into the Falcon sedimentary sequence during the late Oligocene-early-Miocene (Muessig, 1984; McMahon, 2000).

A second tectonic model proposes that the Falcón, Bonaire, and Grenada basins once formed a continuous Late Cretaceous-Eocene back-arc basin associated with the Great Arc of the Caribbean (Audemard, 1993; Audemard, 1998; Mann, 1999; Porras, 2000) (Fig. 19B). This preexisting basin would have included the Grenada basin of the Lesser Antilles, the Bonaire basin and the Falcon basin. Its age is not well known due to the lack of well data but assumed by most workers to be Paleogene (Mann, 1999). The large-scale continuity of the arc-related belts of the southeastern Caribbean and the Paleocene-Eocene age for the undeformed Grenada basin in the Lesser Antilles lends support to the back-arc model (Mann, 1999) (Figs. 15 and 19B).

A third model by Gorney et al. (in press) based on a larger integration of on- and offshore data (Fig. 20) proposes that northwestern Venezuela and the Leeward Antilles contain elements of both the pull-apart model (Muessig, 1984; Macellari, 1995) (Fig. 19A) and the intra-arc model (Audemard, 1993; Audemard, 1998; Porras, 2000; Fig 19B). East-west striking, Eocene-Oligocene normal faults onland in the Falcon basin and offshore in the Bonaire basin support the intra-arc opening of the Falcón and Bonaire basins, while younger, Oligocene to Recent northwest-striking normal faults on- and offshore support the pull-apart model.

History of faulting. As we will observe on Day 3 of the field trip and on offshore lines we will display from the Bonaire basin, east-west striking normal faults pre-date the northwest-striking normal faults, as shown by older (Paleogene) basin fill in the Falcón and Bonaire basins and younger (Oligocene-Miocene) basin fill in the Aruba and West Curacao basins (Fig. 20). East-west striking normal faults are no longer active (with the exception of the normal faults bounding the Paraguana basin) (Gorney et al., in press) (Fig. 20).

Falcon basin in a larger tectonic framework. According to Gorney et al. (in press), the Falcon pull-apart zone developed as the Caribbean plate continued to move eastward relative to South America. Eastward plate motion and transtension forms the northwest-trending Aruba, West Curacao, and East Curacao basins (Figs. 20B-C). A possible plate mechanism for the formation of broad and diffuse pull-apart zone is indicated by previous GPS surveys by Perez et al. (2001) that are summarized in Figure 1A. Rates of plate movement in western Venezuela are slower by 2-5 mm (~ 10-20%) than rates of motion in eastern Venezuela and the Lesser Antilles arc (Fig. 15) (Pérez et al., 2001). This differential of rate in the east-west direction could be accommodated by the formation of basins. We assume that the differential has existed since at least late Oligocene-early Miocene time since this is the time when these basins began to open (Gorney et al., in press).

A period of rapid north-south convergence between the North and South American plates began around the Oligocene-Miocene boundary (Müller, et al., 1999). This large scale convergence between the Americas may have combined with northeastward and northward movement of the Maracaibo block to inhibit the eastern motion of the Caribbean plate in this region (Fig. 15). The differential in plate motion resulted in early Miocene rifting within the Leeward Antilles ridge along northwest-striking normal faults as previously discussed by Pérez et al. (2001), Escalona et al. (2003), and Gorney et al. (in press).

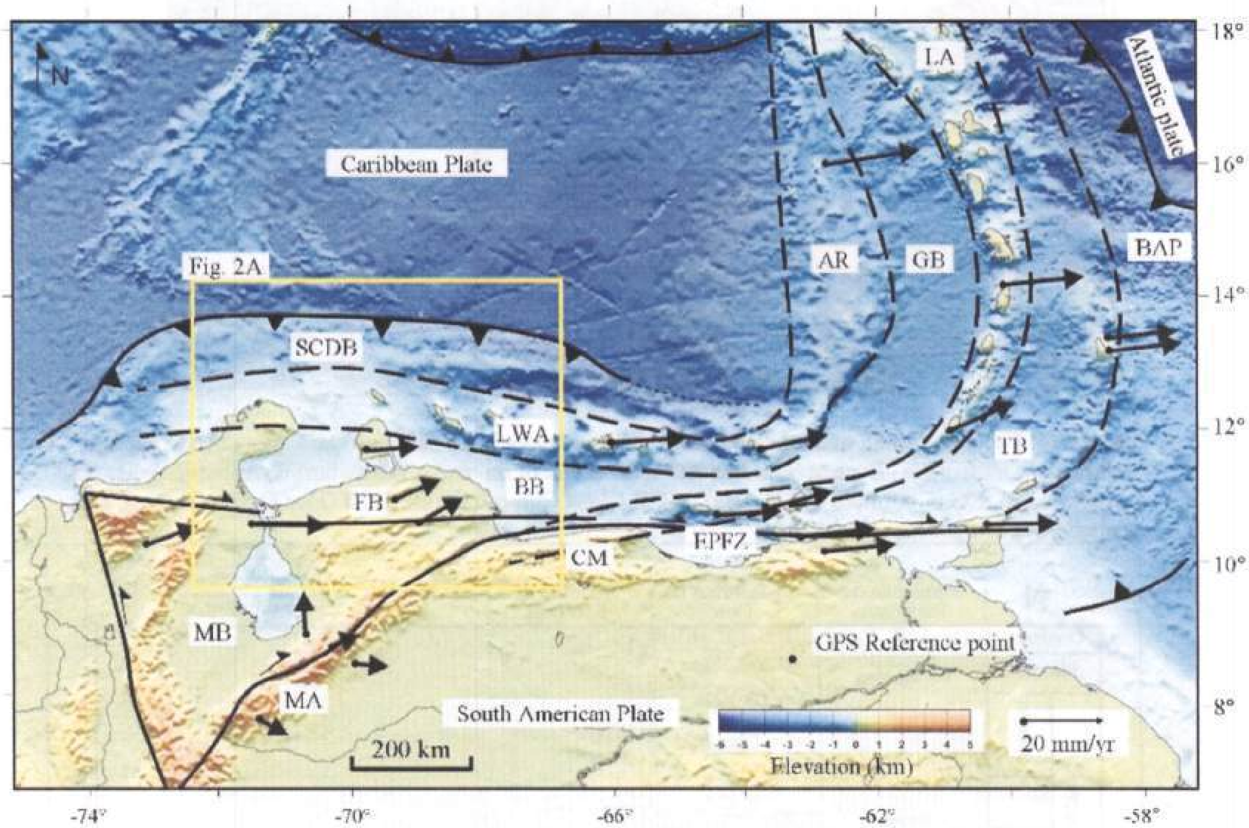


Figure 15. Major tectonic features of the southeastern Caribbean. Tectonic provinces include: **BAP** (Barbados accretionary prism), **LA** (Lesser Antilles arc), **TB** (Tobago basin), **GB** (Grenada basin), **AR** (Aves ridge), **LWA** (Leeward Antilles ridge), **SCDB** (South Caribbean deformed belt), **BB** (Bonaire basin), **MA** (Mérida Andes), **CM** (Caribbean mountains), **MB** (Maracaibo block), and **EPFZ** (El Pilar fault zone). Black arrows represent GPS vectors compiled from Trenkamp et al. (2002) and Perez et al. (2001). Yellow box indicates area map shown in Figure 8. Fixed reference point for GPS vectors is shown in eastern Venezuela.

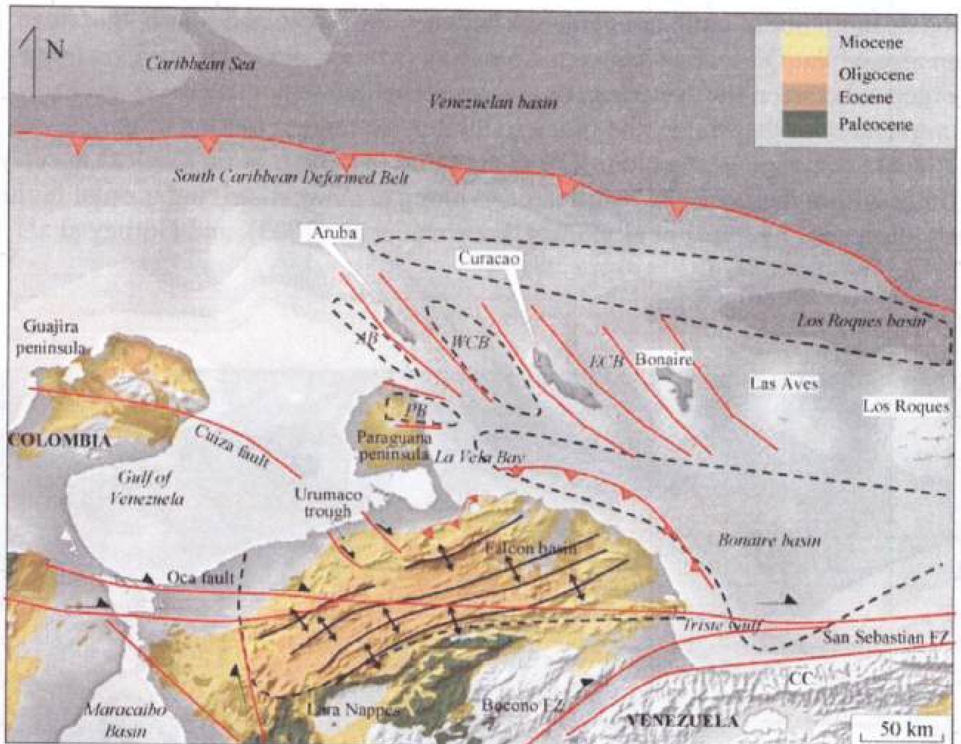


Figure 16. Tectonic setting of the Falcon basin showing major folds and faults and ages of outcropping sedimentary units from . Dashed lines indicate areal extent of on- and offshore basins. Abbreviations: **AB** (Aruba basin), **CC** (Cordillera de la Costa), **WCB** (West Curacao basin), **ECB** (East Curacao basin), **PB** (Paraguana basin).

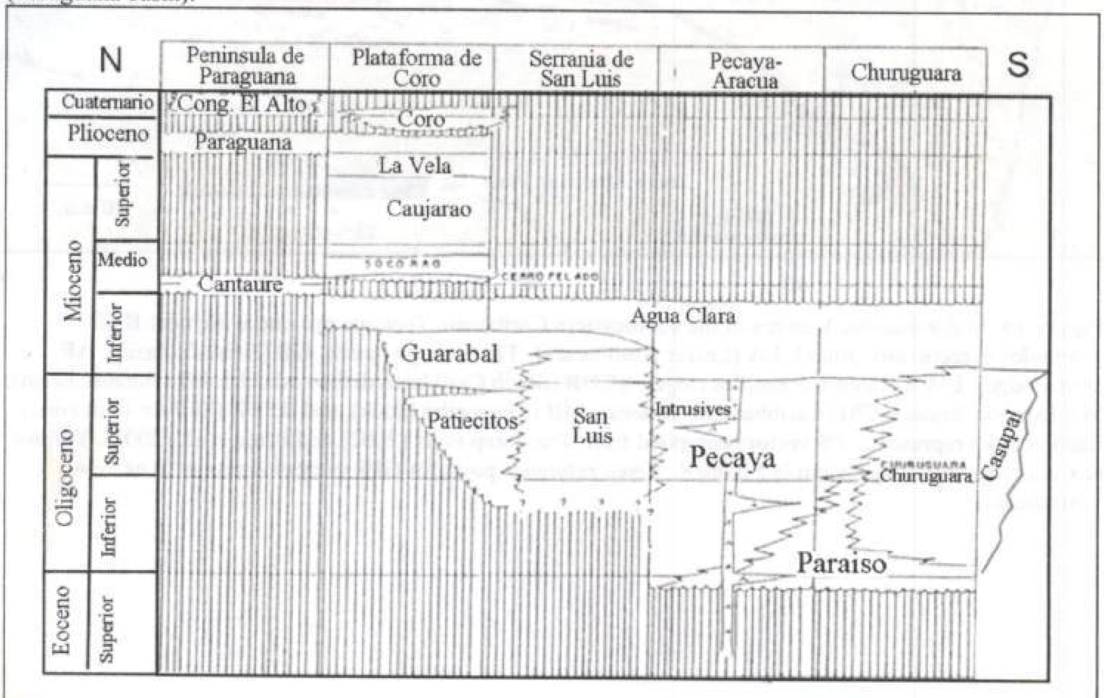
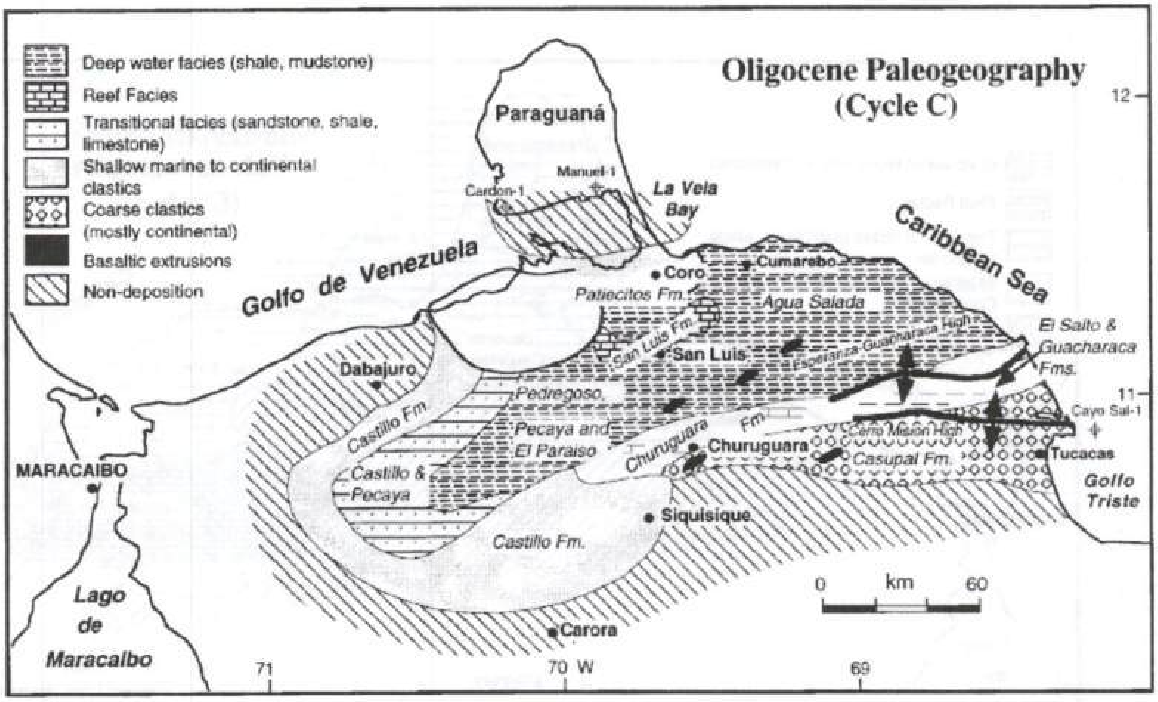
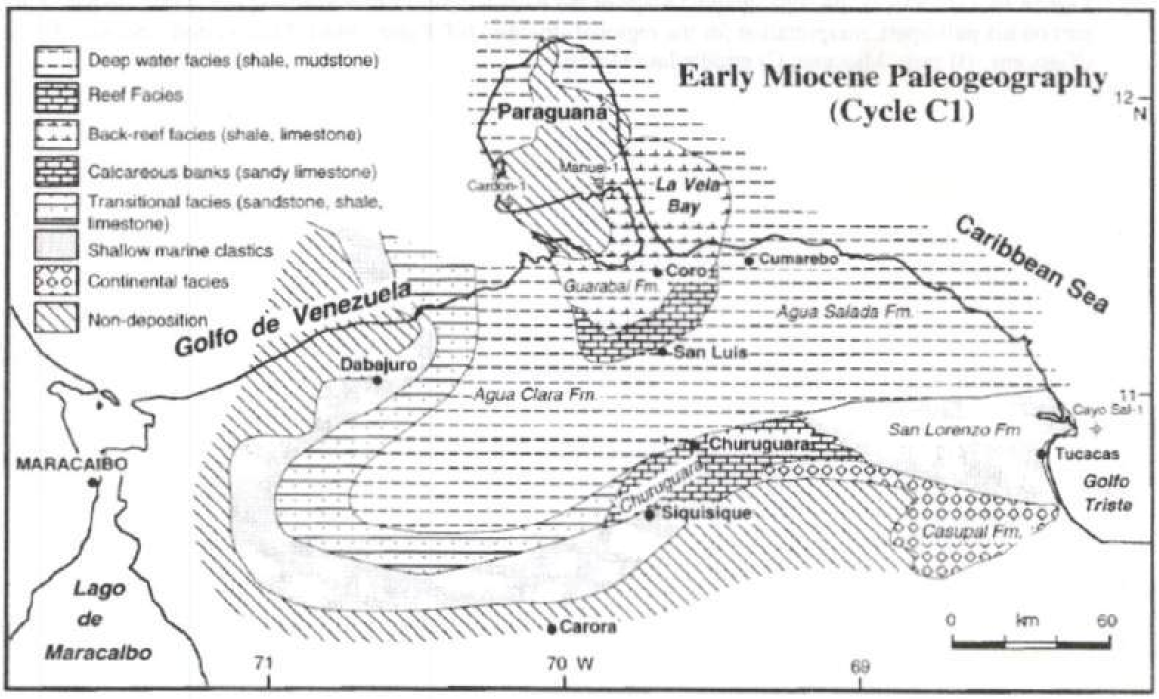


Figure 17. Generalized stratigraphic chart of the Falcon basin from Audemard (1993). The line of sections starts in the north (Paraguana Peninsula) and extends to the south (Churuguara).

A)


Deep water facies (shale, mudstone)
Reef Facies
Transitional facies (sandstone, shale, limestone)
Shallow marine to continental clastics
Coarse clastics (mostly continental)
Basaltic extrusions
Non-deposition
Oligocene Paleogeography
(Cycle C)
Paraguaná
Cardon-1
Manuel-1
La Vela Bay
Caribbean Sea
Golfo de Venezuela
Coro
Cumarebo
Patiecitos Fm.
Agua Salada
San Luis Fm.
San Luis
Esperanza-Guacharaca High
El Salto & Guacharaca Fms.
Dabajuro
Castillo Fm
Pedregoso,
Pecaya and El Paraiso
Castillo & Pecaya
Churuguara Fm
Churuguara
Cerro Mision High
Casupal Fm.
Cayo Sal-1
Tucacas
Golfo Triste
MARACAIBO
Siquisique
Castillo Fm.
Lago de Maracaibo
Carora
0 km 60
71
70 W
69
12
11

B)


Deep water facies (shale, mudstone)
Reef Facies
Back-reef facies (shale, limestone)
Calcareous banks (sandy limestone)
Transitional facies (sandstone, shale, limestone)
Shallow marine clastics
Continental facies
Non-deposition
Early Miocene Paleogeography
(Cycle C1)
Paraguaná
Cardon-1
Manuel-1
La Vela Bay
Caribbean Sea
Golfo de Venezuela
Coro
Cumarebo
Guarabal Fm.
Agua Salada Fm.
San Luis
Dabajuro
Agua Clara Fm.
San Lorenzo Fm
Cayo Sal-1
Tucacas
Churuguara
Churuguara
Siquisique
Casupal Fm.
Golfo Triste
MARACAIBO
Lago de Maracaibo
Carora
0 km 60
71
70 W
69
12 N
11

C)

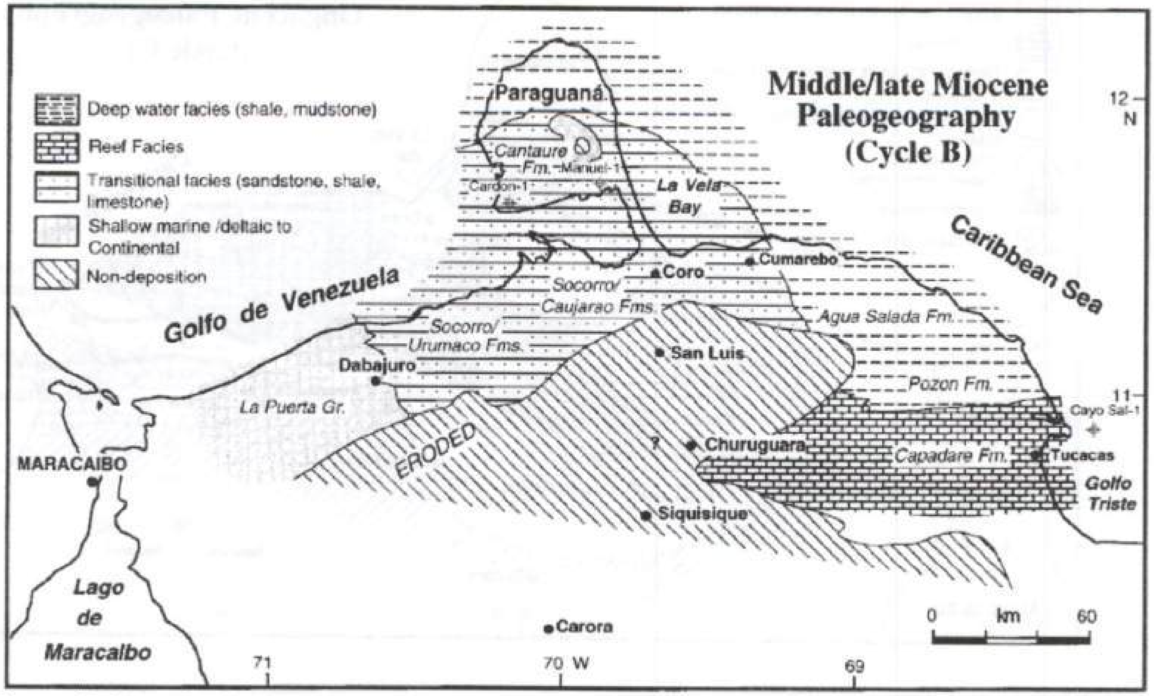


Figure 18. Generalized paleogeographic maps of the Falcon basin from Macellari (1995) that are based in part on his pull-apart interpretation for the regional structure (cf. Figure 14A). Time periods include: A) Oligocene; B) early Miocene; C) middle/late Miocene.

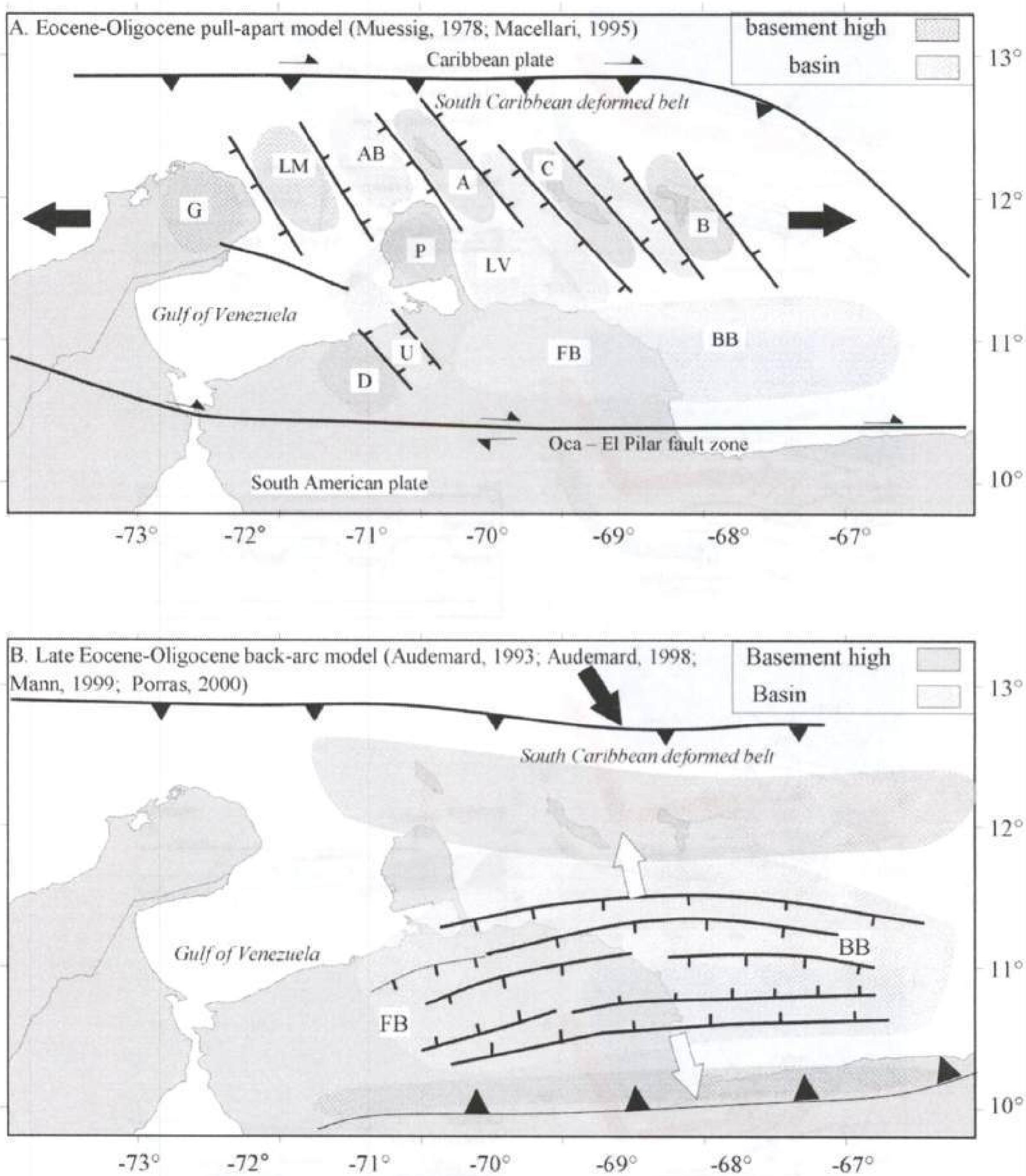


Figure 19. Comparison of A) Eocene-Oligocene pull-apart and B) Late Eocene-Oligocene back-arc models for the Falcón basin. A) **Pull-apart model for Falcón and Bonaire region** of northwestern Venezuela, illustrating the distribution of northwest-trending Eocene-Oligocene highs and sub-basins modified from Muessig (1984). Northwest-striking normal faults control regional subsidence of basins separated by highs. Abbreviations: G (Guajira peninsula), LM (Los Monjes islands), D (Dabajuro high), U (Urumaco trough), AB (Aruba basin), P (Paraguana peninsula), A (Aruba island), LV (La Vela bay), C (Curacao island), FB (Falcón basin), BB (Bonaire basin), B (Bonaire island). B) **Contrasting model for Eocene-Oligocene backarc basin opening model**. East-west striking normal faults time control the initial north-south basin opening during early Eocene-Oligocene. Note that in both models the Leeward Antilles ridge (shaded area) remains a stable high on the northern flank of the basin.

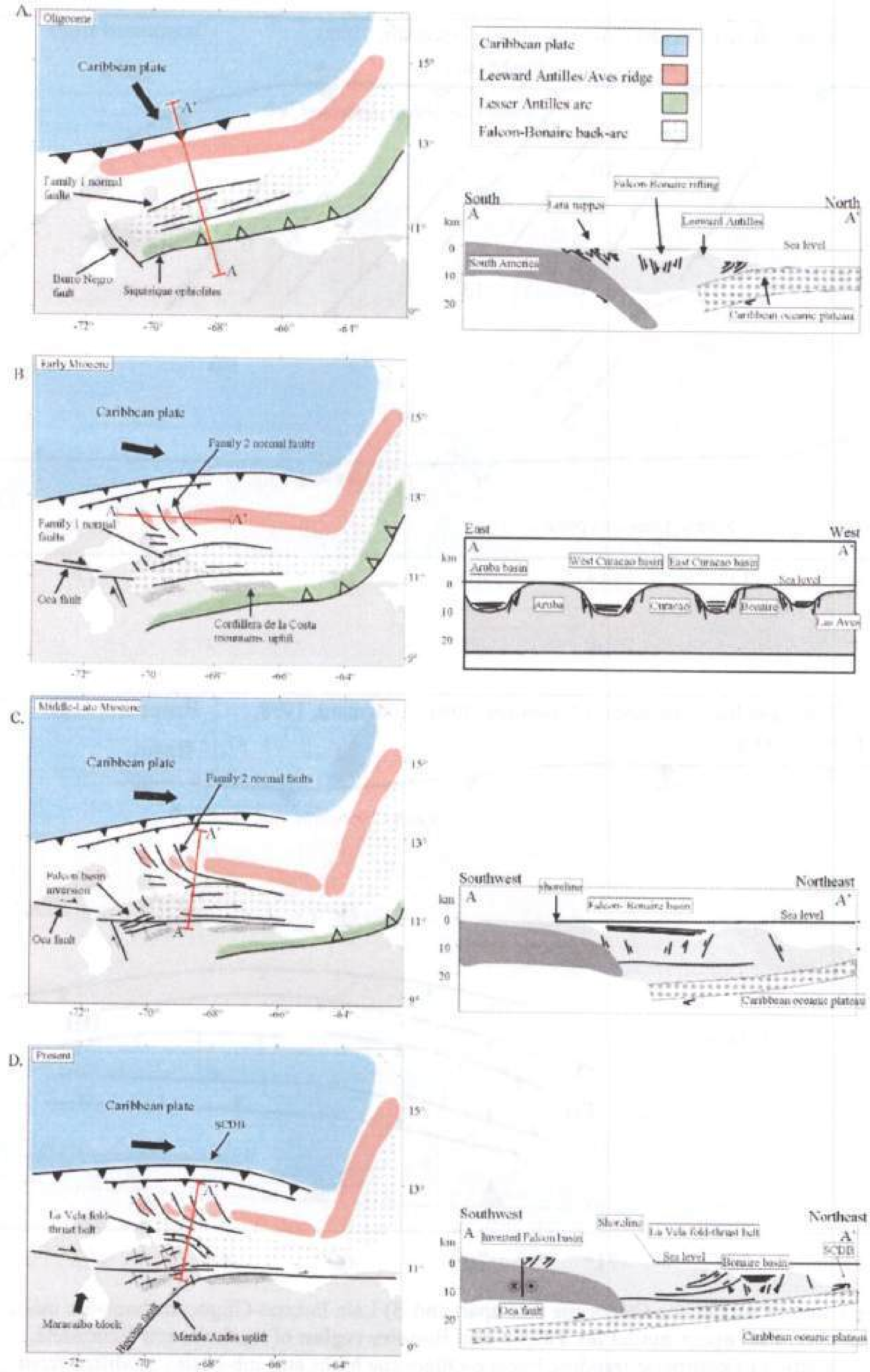


Figure 20. Schematic paleotectonic reconstructions of southern Caribbean and northern Venezuela illustrating the three Cenozoic tectonic phases affecting the region (from Gorney et al., in press). The Lesser Antilles arc is in green, the Aves-Leeward Antilles ridge in red, and zones of subsidence are in a stippled pattern. Lines of cross-sections are shown as red lines on the maps to the left. In this model, opening of the Falcon-Bonaire basin is Eocene-Oligocene in age and therefore accompanies collision between the Great Arc and the continental margin.

Day 2 Stop description

- **Departure 7:00 am Leave the Barquisimeto Hilton Hotel**

~8:00 Road to Churuguara, Cretaceous Barquisimeto Fm.(View from bus only)

Lower to Upper Cretaceous Barquisimeto Fm. (detailed description in Gonzalez de Juana and others, 1980). This unit was deposited on the passive margin of northern South America prior to the Eocene collision of the Great Arc of the Caribbean (Fig. 14).

Lithology. The predominant lithology to examine is a variegated meta-argillite alternating with low-grade metamorphic arenite and siltite. The arenite is generally fine-grained and contains grains of black chert. In the meta-argillite, a phyllitic sheen is sometimes observed due to the presence of finely crystalline, sericitic mica. Fresh argillite is dark gray in color but on weathering will be multi-colored.

Age. The age of the Barquisimeto Fm. was determined on the basis of stretched ammonites located in outcrops north of Barquisimeto (the work had been done by the Ministerio de Energia y Minas, 1978). (Gonzalez de Juana et al., 1980)

Structure. The Barquisimeto outcrops as a large fold, the formation is a multi-colored shale, showing foliation. The Barquisimeto Fm is exposed all along the northbound Route 1 up to the outcrop of the Matatere Fm. near the Tocuyo river valley. About 50 km from the start of Route 1, our stop for the Barquisimeto Fm. will show multi-colored and folded metasedimentary sandstone and shale beds.

Tectonic significance. One of the most interesting aspects of the Barquisimeto Fm. is that it overlies the Paleocene/Eocene Matatere Fm. The entire Barquisimeto complex is a series of olistoliths tectonically transported with the Lara nappes from the area of the Caribbean arc to the north. The Barquisimeto Fm. was emplaced in the Barquisimeto Trough during the late Cretaceous to early Paleogene time as part of a large clastic wedge.

Discussion:

What is the origin of the Lara nappes and how can their tectonic transport direction be determined? What is the relationship on time between the emplacement of the Lara nappes relative to the Maracaibo foreland basin and the opening of the Falcon basin?

8:30 View from the bus and photo stop: Paleocene Matatere Fm.

Paleocene Matatere Formation (detailed description in Gonzalez de Juana et al., 1980). The Matatere Fm. was deposited within the Trujillo foredeep and has undergone low-grade metamorphism (Fig. 4).

Lithology. The conglomeratic channel facies and finer levee-overbank facies were both deposited as turbiditic submarine channels and overbank deposits in a bathyal slope environment. At this stop the Matatere sequence consists of stacked channel sequences filled with conglomerate and sandstone and levee-overbank facies (thin-bedded argillaceous facies). The conglomeratic channel facies consists of stacked, fining-upward sequences containing basal, polymictic pebbles. The finer facies includes shale and a heterolithic facies of thinly-interbedded shale and sandstone. The sandstones are poorly to moderately sorted, fine-to-medium grained, dark to gray, and contain numerous rock fragments. Sole marks have been observed at the base of several sandy beds. The Matatere facies do not show any visible effects of metamorphism, as is commonly observed in the older Barquisimeto Fm.

A few kilometers north of Santa Ines the Matatere Formation crops out as light brown, buff-colored rocks without any visible metamorphism.

Age. Its latest Paleocene age has been determined by correlation with the Moran Formation, its unmetamorphosed lateral equivalent.

Tectonic significance. The Matatere Fm. is considered to be para-autochthonous whereas the Barquisimeto Fm is considered to be totally allochthonous in origin. The polymictic composition of the pebbles including mafic volcanic rocks suggest that the Matatere Formation was mainly sourced from the advancing Lara Nappes to the north.

Structure. The Matatere Fm. is exposed as vertical to steep dipping beds in close vicinity of extensive outcrops of the low-grade metamorphic in the Barquisimeto Fm.

Discussion

Is the Matatere Formation pre-, syn-, or post-tectonic? Do the sandy units have any reservoir potential?

- **STOP 1 ~9:30 am Eocene-Oligocene Casupal Fm. (45 min)**

Eocene Casupal Formation (detailed description in Gonzalez de Juana et al, 1980). The Casupal Fm. i underlies reef carbonate rocks of the Churuguara Formation (Fig. 17).

Lithology. The Castillo (Fig.21) and Casupal Fm. (Fig.22) facies assemblage appears to be fluvial-dominated in the area of Stop 3. The paleoenvironment of deposition is similar to those of the Guarabal and Patiecitos formations farther to the north (Fig. 18A). The formation is composed of a series of conglomerate, sandstone, shale, and local coal deposits whose combined thickness may exceed 1300 m. Elsewhere, east of Churuguara, shallow-marine facies including bioturbated sandstone and thin fossiliferous limestone has been commonly observed. To the west, this carbonate facies transitions into clastic sandstone and conglomerate of the Castillo Fm. The Castillo Fm. unconformably overlies the Paleocene Matatere Fm.

Stop 3 is 20 km south of the town of Churuguara (Map 3). The roadcuts expose multi-colored lithologies illustrating the main facies and characteristics of the Casupal formation. The main lithological facies present at this stop include mottling, variably weathered and oxidized, clayey to silty shale, fine to coarse-grained sandstone with abundant chert fragments, and relatively thin but common conglomeratic intervals. The lithofacies are arranged in both coarsening-upward and fining-upward cycles with the fining upward ones being more common.

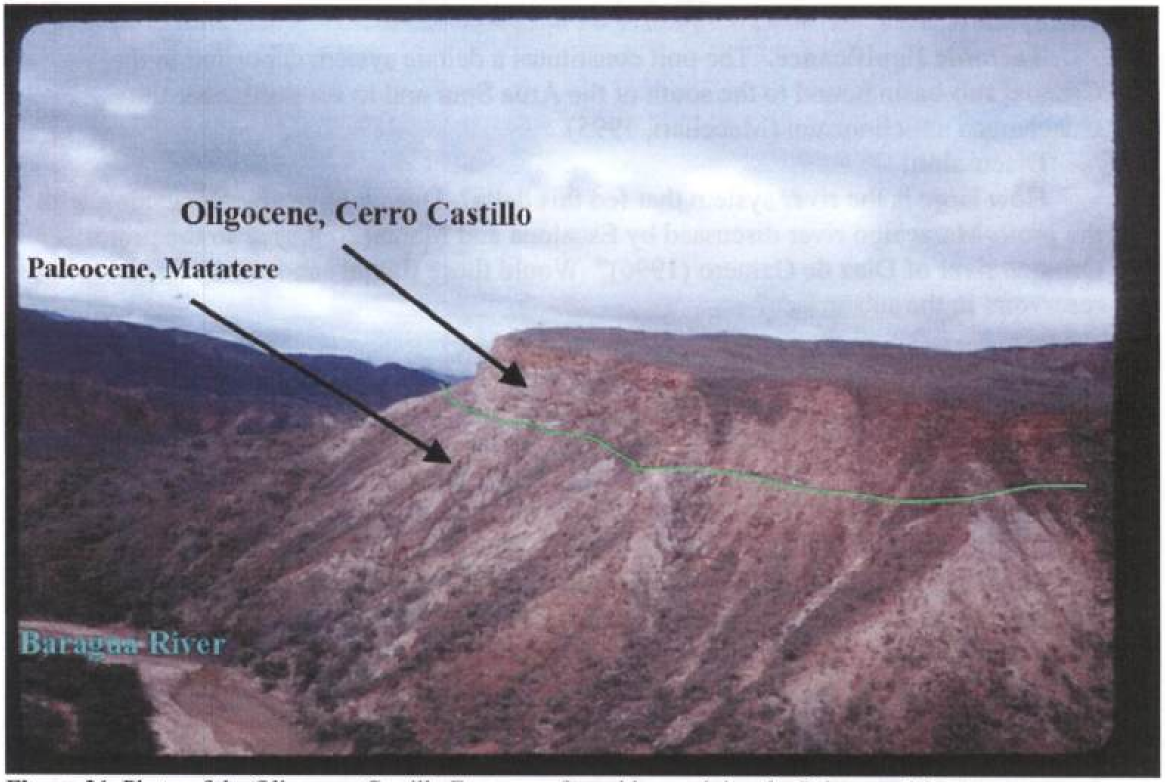


Figure 21. Photo of the Oligocene Castillo Fm. unconformably overlying the Paleocene Matatere formation along the valley wall of the Baragua River.

Figure.22 Outcrop of the Casupal delta complex, south of Churuguara. This is the first clastic unit to infill the Falcon Basin and is equivalent to the Paraiso Fm.The delta is likely to have formed the platform for the Churuguara reef.

Tectonic significance. The unit constitutes a deltaic system deposited in the Casupal sub-basin bound to the south of the Aroa Spur and to the north near the Guacharaca anticlinorium (Macellari, 1995).

Discussion:

How large is the river system that fed this delta? Does it have any connection with the proto-Maracaibo river discussed by Escalona and Mann (2006b) or to the proto-Orinoco river of Diaz de Gamero (1996)? Would these fluvial sands make good reservoirs in the subsurface?

- **11:00 am Lunch in Churuguara (early lunch)**

- **STOP 2 1:00 pm Oligocene-early Miocene Churuguara Fm. exposed in quarry (30 min)**

The Churuguara Fm. (Fig. 23) crops out in the south-central Falcon basin as a series of mixed silicilastic and carbonate intervals (Wheeler, 1963) (Map 3; Fig. 17). Local reef buildups also occur within this formation. The Churuguara Fm. overlies the Paraiso Fm. in the Central Falcon basin and the Castillo Fm. in the western basin (Fig. 17). Sands of the formation are dominantly quartz-bearing and contain some glauconite. The base of the unit lies in the *Globorotalia opima opima* zone. The formation is overlain by the Agua Clara Fm. The limestone is sandy and commonly appears as bedding units that are 3-5 m thick that can swell locally in thickness up to 30-m-thick biostromes and bioherms. These limestone units contain a rich fauna of corals, pelecypods and gastropods. The beds are deformed by common calcite veins and stylolytes. Near its contact with the underlying El Paraiso beds, the Churuguara strata dip 45 to 50 ° northward, whereas at this outcrop they dip about 30° northward. A possible thrust-faulted contact has been postulated by Bartok as transpression associated with the Churuguara Fault between the Churuguara and El Paraiso beds. From fossil evidence the Churuguara limestones were deposited as discrete reefal or carbonate shoals on a marine shelf (Wheeler, 1963). The carbonate banks were separated from one another both in space and time by extensive neritic shale deposits (Fig.18B).

In this stop the Churuguara limestone beds occur interbedded with thick buff to brownish shale. The limestones vary from cross-stratified bioclastic packstone to grainstone, the former being more common. There is a possibility that the dark shale present may be the basal Churuguara or underlying Paraiso Fm.

The quarry excavates one of the biohermal/biostromal buildups of the Churuguara Formation (Fig. 24). The fauna in the limestone shows a broad faunal diversity indicative of open marine condtions. Locally, the limestone records reefal development by the presence of boundstone made up of colonies of corals and scattered bivalves and gastropods. Note that these limestones are only partly equivalent to the Cauderalito Fm (Fig. 18). The latter is equivalent to the upper Churuguara Fm.

Discussion question: Estimate the thickness of the unit in the quarry and determine which direction is likely to thicken the most.

Could this unit serve as a reservoir in the subsurface? What problems might it face as a reservoir?

Figure 23. Outcrop of the Oligocene-early Miocene Churuguara reef facies of the Falcon basin near the town of Churuguara. This reef facies was deposited along the southern shelf margin of the deep-marine Falcon basin during the Oligocene and early Miocene.

- **STOP 3 2:30 pm Aracua- Late Eocene-early Oligocene Paraiso Fm. and Miocene intrusive rocks of the Falcon basin (45 min)**

In the central Falcon basin, the Oligocene section that crops out is known as the El Paraiso Fm (Map 3). Wheeler (1963) described the strongly folded and faulted unit as a sandy shale with quartz sand and slightly carbonaceous shale. The section commonly shows infrequent massive sand with more common thinner sands showing cross-bedding and ripple-marked surfaces.

The sand has a high chert content. Black chert is observed in sandstone outcrops at Siquisique and may correlate to in situ outcrops of Paleozoic rocks on the Paraguana Peninsula (Map 5, Day 4). The Paraiso Formation is dominantly shaly and may be as much as 1000 m thick (Gonzalez de Juana et al., 1980). There is a gradual deepening of water depth towards the top of the formation. Occasionally El Paraiso Fm. is seen to concordantly overlie the Eocene Jarrillal Fm. Near the town of Churuguara the unit directly underlies the Churuguara Fm. The Paraiso Fm. is inferred to be the first transgressive system tract deposited in the newly created Falcon Basin. From the available field evidence, the El Paraiso facies was probably deposited in a near shore coastal to shallow marine shelf. The presence of coal beds, extensive interference ripples, mature quartzitic sandstone composition, and the general upward coarsening tendency imply sedimentation in a near shore, high-energy environment such as littoral to sublittoral bars and barrier bars. The thick dark shales were deposited in a lagoonal to prodeltaic shelf environment.

In this stop near Aracua, the strongly deformed Oligocene Paraiso Fm. with interbedded sandstones shows the effects of its proximity to Oca right-lateral strike-slip fault zone (Map 3). As a group these faults are informally named in this study as the Central Falcon faults. The Paraiso Fm. contains thin interbeds of sandstone and is dominantly shales. The latter are carbonaceous. No source potential is attributed to these shales.

The second objective for stopping at Aracua is to observe the igneous intrusives into the Paraiso Fm. (Fig. 24). Muessig (1984) described the rocks as dominantly olivine basalt intruding gneisses that form xenoliths in the basalt. The igneous intrusives (Figs.24, 25) have been dated as 15 to 23 Ma (Muessig, 1984; McMahon, 2000). It should be noted that in other localities the basalts also intrude the Pecaya Fm (Map 3). As will be discussed later in the trip, similar intrusives have been observed on the northern Paraguana Peninsula (drilled by well PG-1X) (PDVSA, internal report) (Map 5).

Figure 24. Oligocene intrusives at Aracua within the Oligocene sedimentary rocks of the Paraiso Fm.

Discussion:

Why are igneous rocks of this age only found in the Falcon basin and are not present either the Maracaibo basin or the Eastern Venezuelan basin? Are the igneous rocks related to strike-slip faulting, back-arc extension or some other tectonic process?

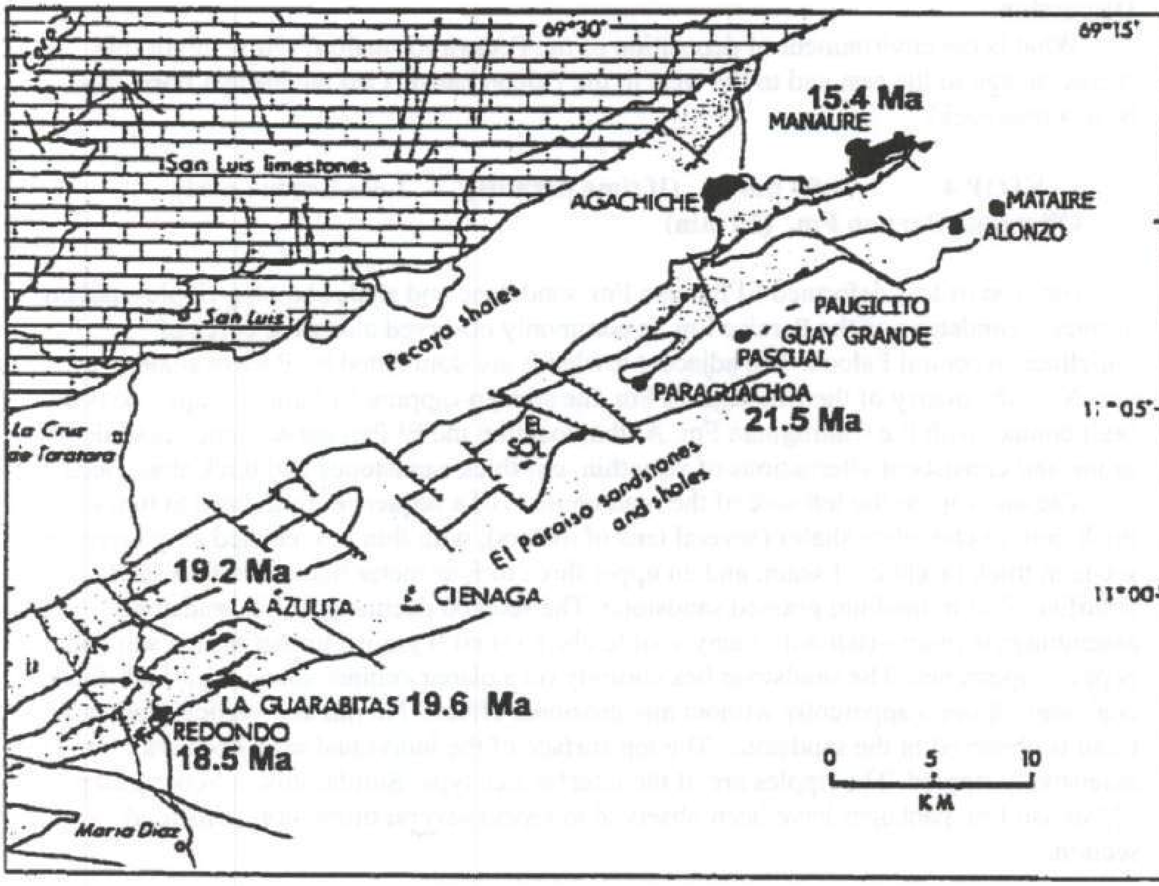


Figure 25. Location of intrusive rocks within deep-marine sedimentary rocks of the Paraiso and Pecaya Formations. Age of intrusions range from 15 to 23 Ma (from McMahon, 2000)

ADDITIONAL STOP IF TIME PERMITS (Oligocene Pecaya Fm.)

The Pecaya Fm. is a progressively deepening clastic section deposited in the main depocenter of the Falcon basin (Map 3). It is dominantly dark shale but has no reported source rock potential (internal Maraven report). The Pecaya Formation, characterized by a deep chocolate color, occurs extensively along the new Churuguara-Coro road (Map 3). The lower contact of the Pecaya Fm. with the underlying El Paraiso Fm. is not observed in outcrop along this road. Except for its shallow water fauna and the associated thick sandstone beds, the El Paraiso shale appears very similar to those of the Pecaya Fm.

At this stop, observe the thick, dark gray to dark chocolate color of the Pecaya Formation. A more typical outcrop of the Pecaya Formation is found about 5 km from Aracua. The sequence consists of monotonous shales with occasional thin stringers or bed of silty sandstone or limestone. The color varies from dark gray in the unaltered rock to deep chocolate brown in weathered surfaces. Many cross-cutting veins of calcite and occasional gray to reddish ferruginous yellow nodules are common. No macrofossils have been observed although the Pecaya Fm. is highly fossiliferous with microforaminifers (Wheeler, 1963).

Discussion:

What is the environment of deposition of the Pecaya formation? How might this facies change to the east and to the west in the Falcon basin? Can the Pecaya Formation be a source rock?

- **STOP 4 ~4:00 pm (If time permits) Late Eocene-early Oligocene Paraiso Fm. (20 min)**

Outcrop of less deformed El Paraiso Fm. sandstone and shale showing ripple-marked surfaces. Sandstone of the Paraiso Fm. is commonly observed along the cores of anticlines in central Falcon. The adjacent lowlands are dominated by Pecaya shales.

Near the quarry of the Churuguara Fm. the steelyp-dipping El Paraiso sequence is in fault contact with the Churuguara Fm. At that location the El Paraiso sequence is shale-prone and consists of alternations of very thin, cm-thick sandstones and thick shale beds.

The outcrop on the left side of the road consists of a sequence, from base to top, of thick dark to chocolate shales (several tens of meters), with thin intercalated silty layers, a six-inch thick bright coal seam, and an upper three to four meter thick silicified, cross-stratified, fine to medium grained sandstone. The stacked decimeter thick sandstone assemblage is quartz-rich with many visible black (chert?) grains, imparting it a salt and pepper appearance. The sandstone lies abruptly on a planar contact above a six-inch-thick coal seam, though apparently without any erosional effects. No marked vertical grain size trend is observed in the sandstone. The top surface of the individual sand beds are extensively rippled. The ripples are of the interference type. Similar upward-coarsening El Paraiso Fm. packages have been observed to repeat several times along this road section.

Discussion:

What is the environment of deposition of the Paraiso formation at this locality? How would this unit be expressed on a well log? What is its reservoir potential?

- **STOP 5 ~5:00 pm Oligocene-early Miocene San Luis Fm. exposed at Hueque water falls (30 Min)**

The San Luis Fm. contains the thickest and most pure carbonate rocks along the eastern flank of the basin. Occasionally the limestone intervals may be as much as 100 m thick. The limestone contains up to 10 % quartz grains as well as dark, igneous rock fragments. The limestone often contains the reef-building corals, *Porites* sp. and *Montastrea* sp. (Fig. 26) The Lower San Luis Fm. may have developed during the *Globorotalia opima opima* zone (Oligocene) and extended up to the *Catapsidrax dissimilis* zone with the principal carbonate buildup occurring during the *Globorotalia ciperoensis ciperoensis* zone (Wheeler, 1963). The upper San Luis Fm is equivalent to the Agua Clara Fm (Fig. 17).

In this stop, we will observe the San Luis Fm. exposed at the Hueque waterfall along the southern flank of the San Luis ridge. From a sequence stratigraphic framework it is clear that this interval contains thick limestone beds comprised dominantly of carbonate debris swept from a nearby carbonate shelf. Bryozoa, various species of corals and other biogenic particles are observed. The carbonates are well bedded and are therefore not likely to be debris from the carbonate San Luis shelf into basinal black shales. Wheeler (1963) considered the unit to be part of the San Luis Fm (Fig. 17).

Figure. 26 Coral debris storm deposit of the San Luis Fm. (Miocene). Outcrop is located west of the town of Curimagua.

Discussion questions: How can this limestone can attain its level of purity within a surrounding clastic basin? Was this unit ever subaerially exposed and how might exposure affect its reservoir potential?

- **STOP 6 ~5:45 pm Early Miocene Agua Clara and (Eastern) Pedegroso Fms., Dos Bocas (30 min)**

During the last phase of the San Luis and Churuguara Limestone development in the early Miocene a maximum flooding surface is observed in the Agua Clara Formation at the *Catapsidrax dissimilis* zone (Wheeler, 1963). The resulting shale of the Agua Clara Formation provides the major hydrocarbon source rock of the Falcon Basin (Payne, 1951). The upper San Luis shales grade laterally into the Agua Clara as do the debris flow deposits of the Pedregoso Fm. (Fig. 17). The formation is dominantly shales with local thin beds of sandstone and carbonate. It is usually black when fresh and may weather to a reddish color.

At this stop, just beyond the village of Dos Bocas, extensive gray shales with intermittent thin limestone beds of the Agua Clara Fm. crop out on the side to the road. The outcrop nearest to the village is a light gray to dark gray fissile shale with a thin 30-

40-cm-thick dark bioclastic packstone dipping westward. Another thin limestone bed here measures 10-20 cm thick. One can speculate if these may be poorly developed equivalents of the basal Cauderalito Member observed in the offshore La Vela area and elsewhere (Figs. 18 and 31). In the limestone, abundance broken fossil debris is common along with intraformational clay clasts. Algal rims coat bioclastic grains and large fossil shells are also present.

The microfacies diversity within the Agua Clara Fm. observed at this stop records the depositional complexity within the Agua Clara Fm. The different facies noted in this traverse include:

1. Dark gray to gray, thick and uniform shales
2. Thin limestone with basal grading and abundant heterogeneous clasts and grains of diverse origin.
3. Thinly interbedded sandstone, siltstone and shale with bioturbation, macrofossils and orange colored clayey nodules.
4. Coarsening-upward shale - siltstone - fine sandstone with abundant fossil debris.

The Agua Clara black shales is rich in organic matter and is considered the principal source rock in Falcon basin (Payne, 1951). The limestones may also contain source rock potential and should be investigated.

Discussion questions: What kerogen type is likely present in the Agua Clara shale? Would this kerogen type be oil or gas prone? What is the distribution of the Agua Clara Fm?

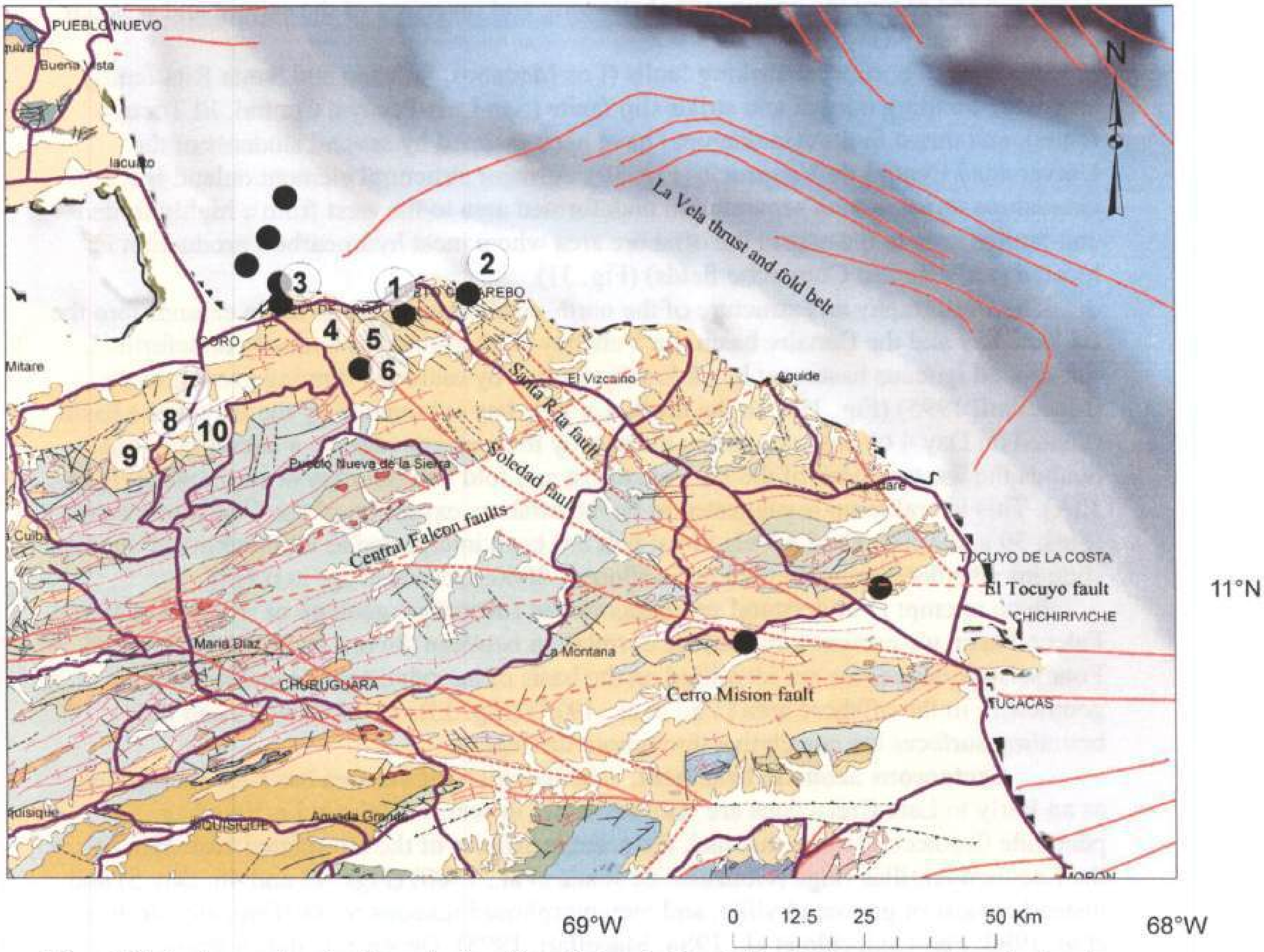
STOP 7 ~7:00 pm Drive straight to the Miranda Hotel in Coro.

Day 3 Wednesday (November 1, 2006)

Coro (Hotel Miranda) – Cumarebo region – La Vela – Coro (Hotel Miranda)

Theme: Stratigraphy and structure of the coastal areas of the Falcon basin and correlation with the La Vela Bay and Bonaire basin: normal vs. thrust belt in the La Vela Bay and Bonaire basin; extension of source and reservoir rocks offshore.

Stops: Cumarebo field, vertical bedding of La Vela, La Sierra de Barigua, La Vela anticline realted to the Guadalupe thrust.



Map 4. Geologic map showing the geologic setting of stops for Day 3. Purple line represents road network and big black dots are oil fields. Geologic base map is from Hackley et al. (2005).

Regional setting of the northeastern Falcon basin and stratigraphic correlations to offshore basins in La Vela Bay and the Bonaire basin

On- and offshore stratigraphy

Onshore-offshore seismic sequences and age constraints. The north-northeastern onshore Falcon basin contains the youngest stratigraphic units in the basin (Map 4; Fig. 17 and 29). On top of the middle Miocene unconformity, coastal-shallow marine (Socorro, Caujarao and La Vela Fms.) to continental (Coro Fm.) sedimentary rocks were deposited and record the continuous shallowing and inversion of the central and western parts of the basin (Fig. 18).

A series of northwest-striking faults (Los Medanos, Soledad and Santa Rita faults), east-west-trending normal and strike-slip faults (San Luis-Pecaya, Central, El Tocuyo faults), and thrust faults (Gualdalupe) have been mapped by several students of the Universidad Central de Venezuela (Fig. 30). A major structural element onland is the Guadalupe thrust, which separates an undeformed area to the west from a highly folded and faulted area to the east in the offshore area where most hydrocarbon production is located (La Vela and Cumarebo fields) (Fig. 31).

The stratigraphy and structure of the north-northeastern Falcon basin extends into the La Vela bay and the Bonaire basin. La Vela bay is interpreted as a mostly undeformed, flat-topped igneous basement block locally faulted by eastward-dipping growth faults (Macellari, 1995) (Fig. 31). To the north, La Vela bay is bounded by the Paraguana basin (visited on Day 4 of this trip) and to the east by the western edge by a lateral ramp that bounds the western limit of the La Vela thrust and fold belt (Gorney et al., in press) (Fig. 32A). This lateral ramp is suggested to be the offshore extension of the Guadalupe thrust (Figs. 30 and 32B). The La Vela thrust belt has been interpreted as a thin-skinned, gravity slide into the deepwater Bonaire basin (Porras, 2000; Gorney et al., in press).

In an attempt to understand and integrate the subsurface geology of this part of the Falcon basin, we present a subsurface correlation between the on- and offshore regions. Four seismic sequences are identified on the basis of lap relationships and reflection geometries in the offshore area (Vail et al., 1977) (Fig. 33). The sequences and the bounding surfaces are correlative throughout the region.

Cretaceous acoustic basement. The basement of the area has been interpreted as an Early to Late Cretaceous arc (Gorney et al., in press). Wells in La Vela bay penetrate Cretaceous rocks that lack the oceanic affinity of the arc-related basement of the Leeward Antilles ridge (Gonzalez de Juana et al., 1980) (Figs. 45 and 46, Day 5) and instead consist of gneiss, phyllite, and metamorphosed igneous rocks (González de Juana et al.,1980; Feo-Codecido et al., 1984; Macellari, 1995). On seismic data a strong regional basement reflector is visible (Figs. 33 to 34). This reflector separates the overlying sedimentary units, represented as coherent and continuous seismic strata, from underlying basement. Acoustic basement is generally chaotic in nature, with scattered continuous events possibly indicative of igneous sills or dikes, similar to those known from outcrop studies on Aruba (Jackson and Robinson, 1994) (Figs. 34 and 35).

Late Eocene-Oligocene Sequence 1 (S1): El Paraiso-Pecaya Fms. equivalents. This sequence unconformably overlies the acoustic basement (Figs. 34 and 35). Low frequency, variable amplitude reflectors onlap the acoustic basement reflector in each of the seismic sections (Figs. 34 and 35). This sequence is thickest (3000-4000 m) in the eastern part of the study area in the Bonaire basin (Figs. 34 and 35). In the Aruba, West Curacao (Fig. 36), and Paraguana basins, this unit is notably thinner (500-1000 m) than the overlying sequences. Chaotic and shingled reflectors of the Bonaire basin (Fig. 36B-C) suggest erosion of sediments from the Leeward Antilles ridge and re-deposition in the central Bonaire basin (Gorney et al., in press). A different seismic character is found in the Aruba, Paraguana, and West Curacao basins, where parallel reflectors onlap basement (Gorney et al., in press) (Fig. 36).

Sequence 1 spans the interval from late Eocene to late Oligocene based on published well data and onland-offshore correlations (Fig. 33). In the Falcón basin, these deposits are composed of deep-marine shale up to 4 km thick deposited during initial opening of the Falcón-Bonaire basin, as inferred from onshore well data. Well data from Curet (1992) in the Aruba basin show that this sequence is predominantly claystone and shale deposited on a deep marine depositional setting (Curet, 1992).

Late Oligocene-early Miocene sequence 2 (S2): Agua Clara-Cerro Pelado equivalents. Sequence 2 comprises the thickest seismic unit in the offshore basins and rests unconformably on Sequence 1 (Figs. 34 to 35). This sequence is dated to be late Oligocene-early Miocene based on its correlation with well data in Figure (Gorney et al., in press). In general, this interval was a period of major shale deposition throughout the Falcón and Aruba basins (Macellari, 1995). The thick sedimentary packages are controlled by northwest-striking normal faults of Oligocene-Recent age (Figs. 30). In the Bonaire basin, wedge-shaped features are interspersed with parallel, low-amplitude reflectors (Fig. 36C). A pronounced angular unconformity caps Sequence 2 in the Paraguana and West Curacao basins (Figs. 36). This unconformity correlates with the Middle-Miocene unconformity of Biju-Duval et al. (1982) in La Vela bay and the Bonaire basin. In the Aruba basin, Curet (1992) identifies a depositional hiatus at the middle-late Miocene corresponding to an unconformity in the seismic data. This unconformity also correlates with the angular unconformity capping Sequence 2 (Middle Miocene unconformity) (Fig. 36), suggesting that this unconformity is time-transgressive between the Bonaire basin and the Aruba basin (Gorney, et al., in press). Audemard (1993; 1998; 2001) also widely reports an early-middle Miocene unconformity onshore.

Middle-late Miocene Sequence 3 (S3): Socorro and Caujarao Fms. equivalents. Middle to late Miocene Sequence 3 reflectors lapout along the middle Miocene unconformity north of the Bonaire basin (Figs. 34 to 36). Audemard (1993; 1998; 2001) interprets this unconformity to mark the age of initial inversion of the onshore Falcon basin. This inversion event may be equivalent in the offshore basins to the angular unconformity capping sequence 2. In the Paraguana, Aruba, and West Curacao basins, strong, high frequency reflectors display northward-prograding, clinoformal geometries (Fig. 36). These depositional patterns in addition to well data information (Fig. 33) suggest that the Middle Miocene unconformity capping Sequence 2 represents a major transition from deep water to a shallower-water depositional setting above the Middle Miocene unconformity as observed in the onnland geology (Gorney et al., in press).

Sequence 3 strata in the Bonaire basin do not show evidence for progradation as seen in the Paraguana and West Curacao basins (Figs. 31B, 34, 35 and 36). Instead, sequence 3 shows mainly parallel reflectors (Fig. 34). The variation in seismic character among basins suggests that the Middle Miocene unconformity is not uniformly represented in each basin and that this event did not affect the entire region simultaneously. Instead, inversion occurred in a diachronous, eastward-younging manner as discussed by Audemard (2001). The time-transgressive character of the Middle Miocene unconformity offshore suggests that it is also closely related to the west-to-east, post-middle Miocene inversion of the Falcon basin (Biju-Duval et al., 1982; Boesi and Goddard, 1991; Macellari, 1995; Audemard, 1993; Audemard, 2001).

Late Miocene-Pliocene sequence 4 (S4): La Vela-Coro Fms. equivalents. Reflector geometries in offshore Sequence 4 resemble those in Sequence 3 (Fig. 34). In La Vela bay and the West Curacao basin, Sequence 4 is conformable with underlying late Miocene Sequence 3 (Figs. 31B and 36). Northward-prograding clinoforms in La Vela bay extend from the coastline to beyond the Paraguana basin (Fig. 31B). The regressive character of this sequence is correlated with Pliocene-Pleistocene Coro and La Vela formations that are known from wells along the eastern coast of Falcón (Wheeler, 1963; Boesi and Goddard, 1991) (Fig. 33). A series of deep-sea channel systems and basin floor fans mark Sequence 4 in the West Curacao basin (Fig. 36). The northwest-southeast oriented profile of Figure 27 displays several channel-like features and mound-shaped basin floor fans, probably deposited roughly north-south. This orientation implies a sediment source derived from the south for the West Curacao basin, consistent with the northward direction of sediment transport observed from clinoforms in La Vela Bay (Fig. 31B). In the central and southern Bonaire basin, Sequence 4 onlaps the highly folded top of Sequence 3.

On- and offshore fault systems

Fault family 1: Eocene-Oligocene east-west trending normal faults. This fault set consists of sub-parallel normal faults striking roughly east-west within the offshore Bonaire basin (Figs. 34 and 35). Reflection data shows that these faults penetrate into acoustic basement and deform the oldest sedimentary layers of Paleogene age (Figs. 34 to 35). These faults are suggested to extend onland (Fig. 30). To the west, Family 1 faults extend into La Vela bay, but we see no evidence for these faults extending onshore (Audemard, 2001). Offshore growth of sedimentary layers on the downthrown side of these normal faults indicates active faulting during deposition of the oldest Paleogene sedimentary units in the Bonaire basin (Figs. 34 and 35). With the exception of the Paraguana basin-bounding normal faults (Fig. 30), these normal faults are all truncated by the Middle Miocene unconformity (Figs. 34 and 35). Near the coast, these faults are overthrust by Neogene thrust faults of the La Vela thrust-fold belt (Figs. 30 and 32). Some of the underlying normal faults demonstrate Neogene reactivation and inversion closer to the shoreline (Figs. 34 and 35). This reactivation is probably related to transpressional movements along the Bocono-El Pilar-San Sebastian fault system (Fig. 30).

Family 2: Oligocene-Recent northwest trending normal faults. A second group of Oligocene-early Miocene normal faults (Family 2) strike northwest and bound the basement highs of the Leeward Antilles islands (Fig. 30). These faults extend from the basement through most of the sedimentary section visible on the reflection data. In a few locations on Figure 37 (East Curacao basin), seafloor offset is indicative of recent fault movements. These faults dip more steeply (50° to 60°) than the Eocene-Oligocene Family 1 normal faults (< 45°). Large grabens (up to 30 km wide), including the Aruba basin and the West Curacao basin, are controlled by these normal faults (Fig. 37). These fault bounded basins contain thick Oligocene to early Miocene sequences as observed in the seismic data (Fig. 37)

Family 3: Late Miocene-Recent west-northwest trending reverse faults – La Vela fold and thrust belt. A ~20-km wide and ~150-km long fold-thrust belt is interpreted offshore of eastern Falcón (Figs. 24). These faults strike sub-parallel to the Eocene-Oligocene Family 1 normal faults (Fig. 34 and 35) and form a zone of imbricate thrust faulting that contrasts with the more isolated and steeply dipping normal faults (Figs. 34). Family 3 reverse faults detach above or near the top of basement (Fig. 34). A detachment surface is mapped on seismic reflection lines within Paleogene strata at a depth of 4.5 seconds two way travel time (TWT), or roughly 6 km, near the coast of Falcón. The fold-thrust belt trends parallel to the coast of Falcón for 150 km and dies out to the west in La Vela bay (Figs. 30 and 31). Vertical offset is apparent within 0.5 seconds TWT of the seafloor through late Miocene sediments (Figs. 34 and 35).

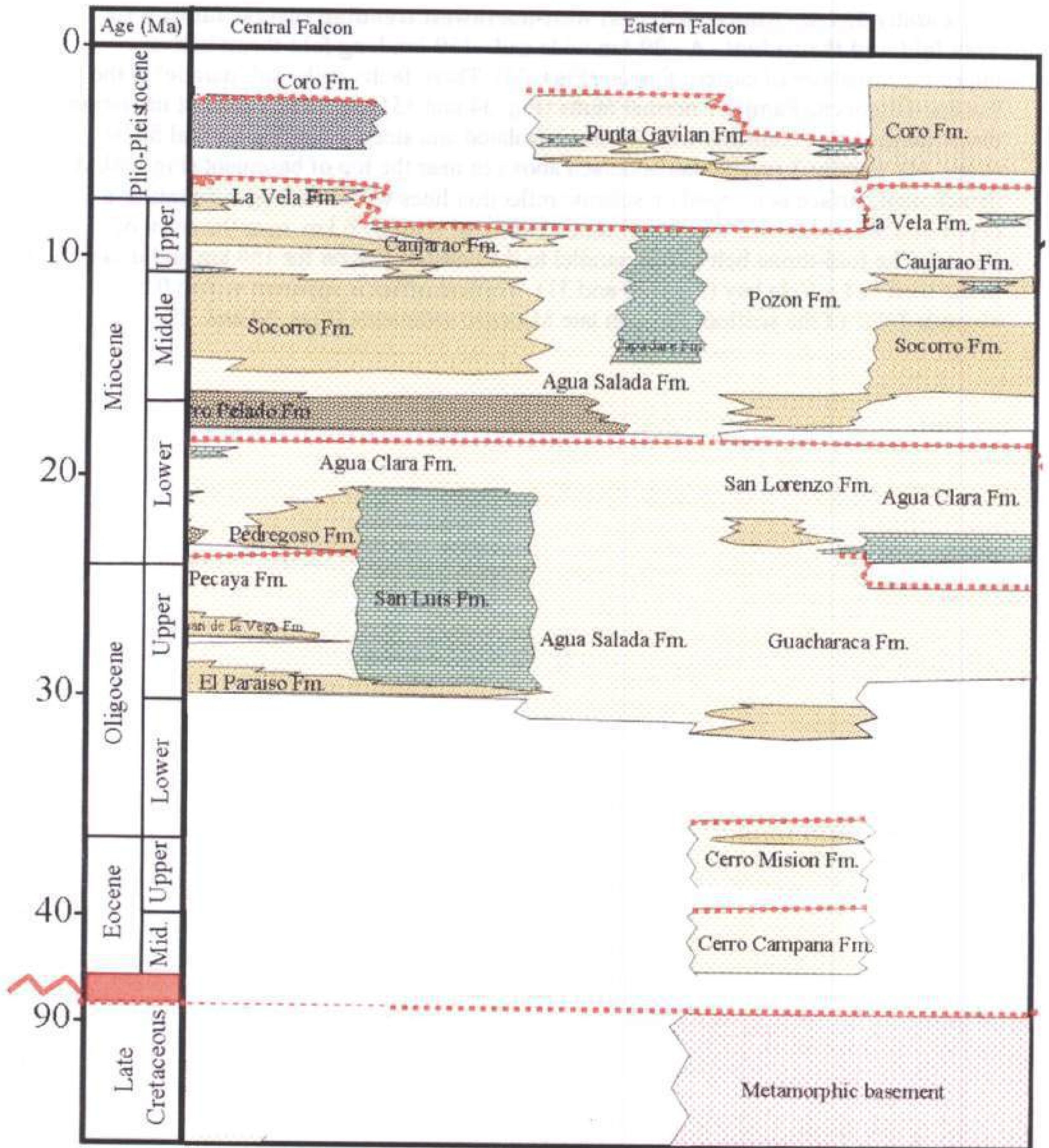


Figure 29. Generalized stratigraphic chart of the central and eastern Falcon areas (modified from Macellari, 1995)

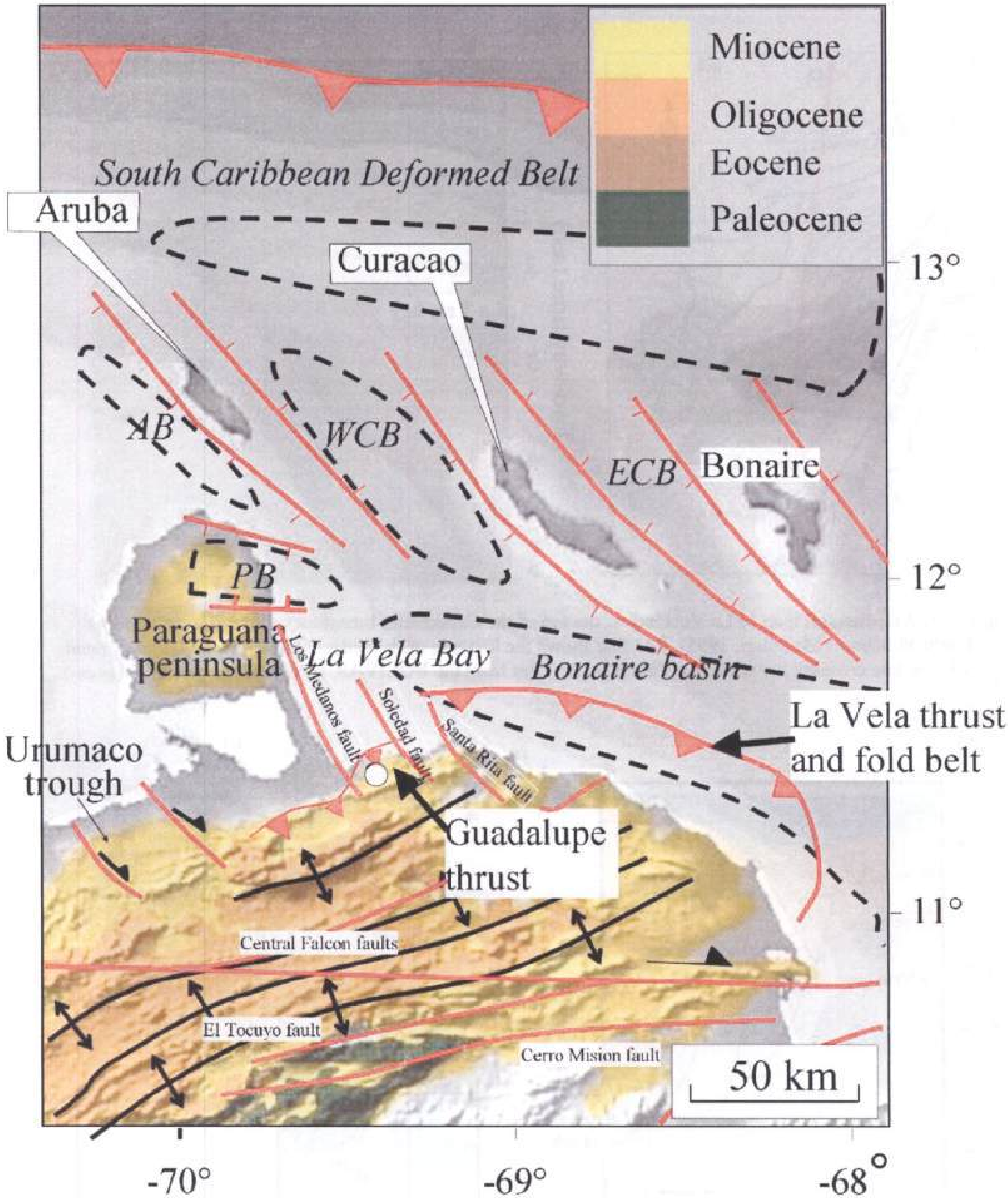


Figure 30. Geologic map of the central and eastern Falcon basin showing the location of the La Vela bay, Bonaire basin, Gualdalupe thrust and La Vela fold-thrust belt. Dashed lines indicate areal extent of on- and offshore basins. Abbreviations: **AB** (Aruba basin), **WCB** (West Curacao basin), **ECB** (East Curacao basin), **PB** (Paraguana basin). White dot shows relative location of the La Vela-6 well.

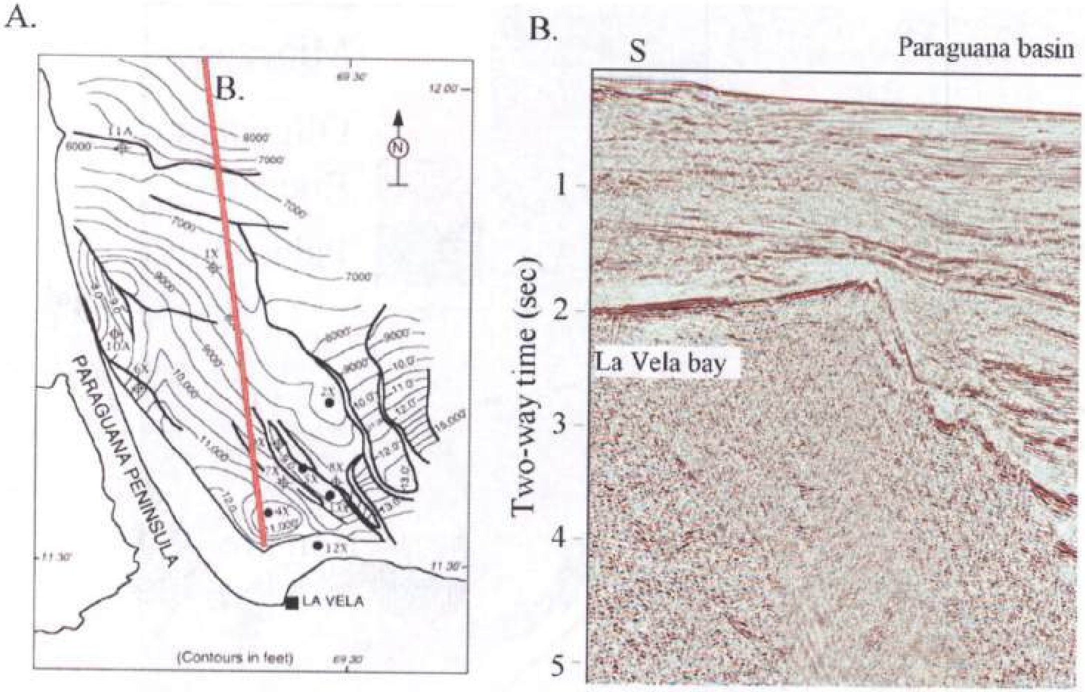


Figure 31. A) Structural map of La Vela bay of the top of the Cauderalito limestones of the Agua Clara Fm. (early Miocene) (Macellari, 1995). Red line shows the location of the seismic line on B. B) Uninterpreted seismic line crossing the stable La Vela platform area from the BOLIVAR survey (Gorney et al., in press).

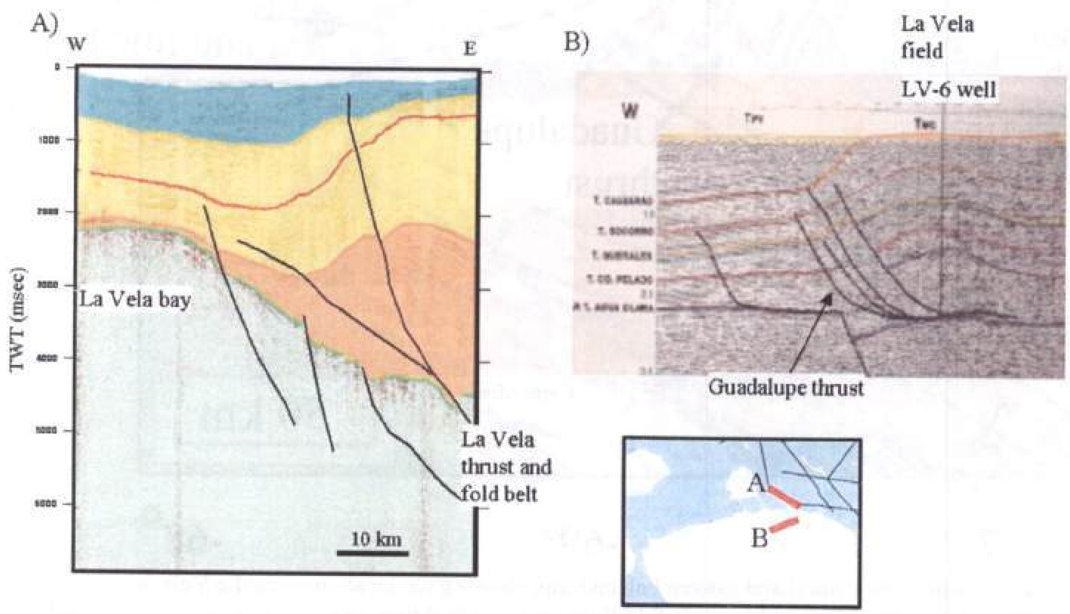


Figure 32. A) Interpreted east-west seismic line offshore Falcon basin showing the transition between the La Vela bay and the La Vela fold-thrust belt. B) Interpreted east-west seismic line onshore crossing the La Vela field (well LV-6 for reference) and showing the Guadalupe thrust. The Guadalupe thrust is suggested to be a tear fault that bounds the western edge of the La Vela thrust and fold belt and continues offshore (cf. Gorney et al., in press).

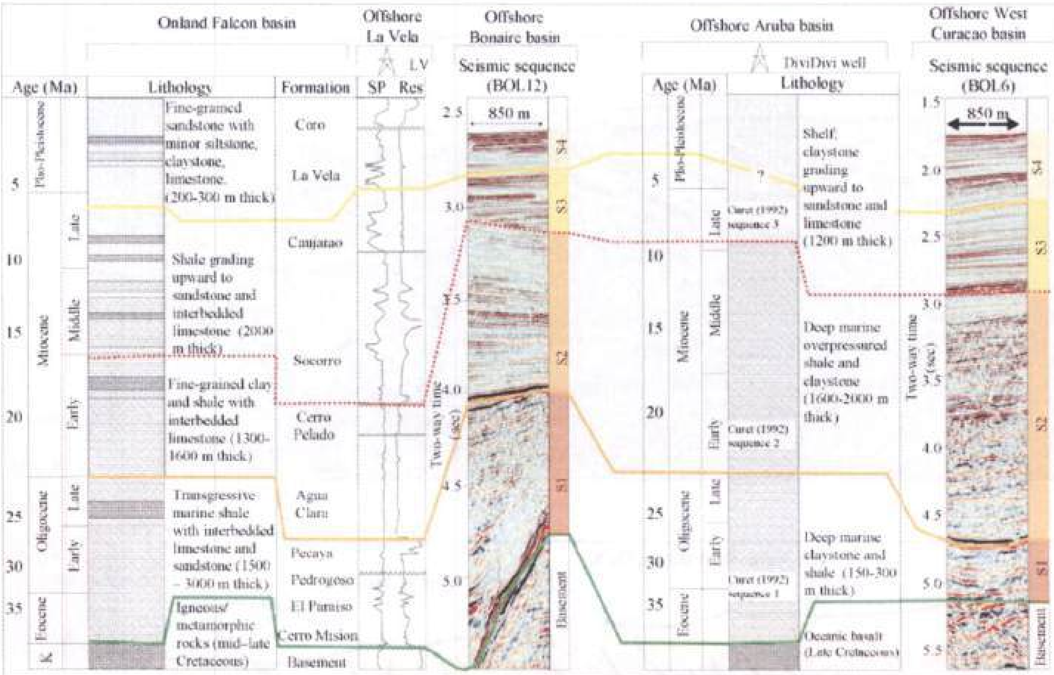


Figure 33. Lithologic formations of the Falcón basin correlated with offshore well and seismic data and correlation of Aruba basin well data with seismic sequences. Falcón stratigraphic data and type log is modified from Gonzalez de Juana (1980). Aruba basin well data compiled from Curet (1992). Figure is from Gorney et al. (in press).

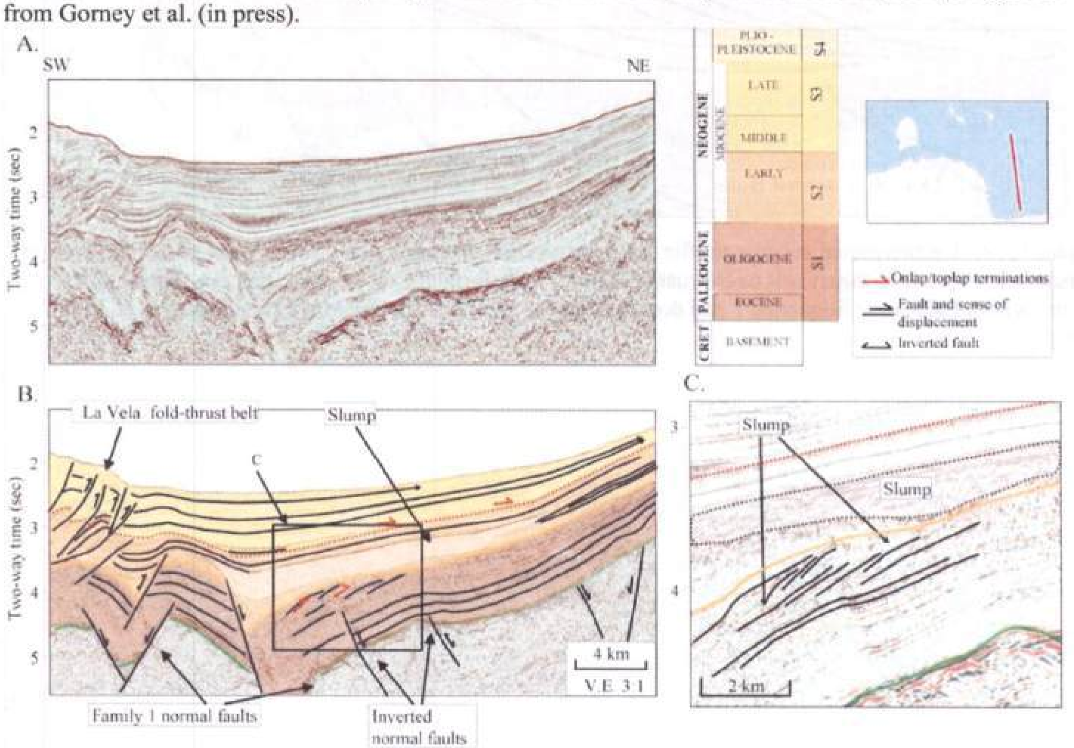


Figure 34. A) Uninterpreted seismic section from Bonaire basin. B) Interpreted section showing Eocene-Oligocene Family 1 normal faults bounding horst and graben structures that controlled deposition of seismic sequences 1 and 2. C) Detail suggests that chaotic zone corresponds to debris flows (from Gorney et al., in press).

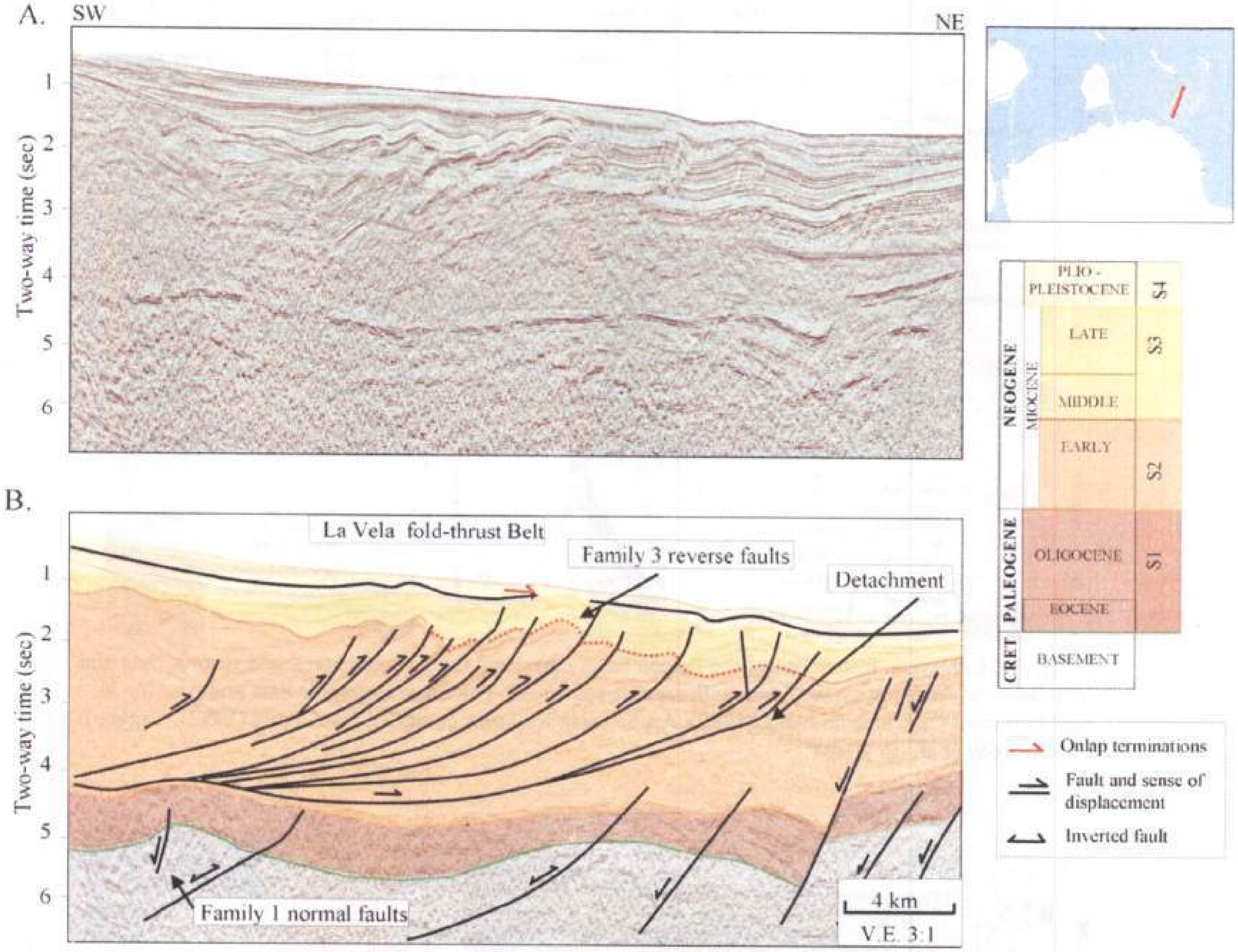


Figure 35. A) Uninterpreted seismic profile from the western Bonaire basin. B) Interpreted seismic section. Offshore La Vela fold-thrust belt overthrusts relatively undeformed Cretaceous basement. Basal thrust occurs within Paleogene Sequence 1 and does not appear to root in the basement (from Gorney et al., in press).

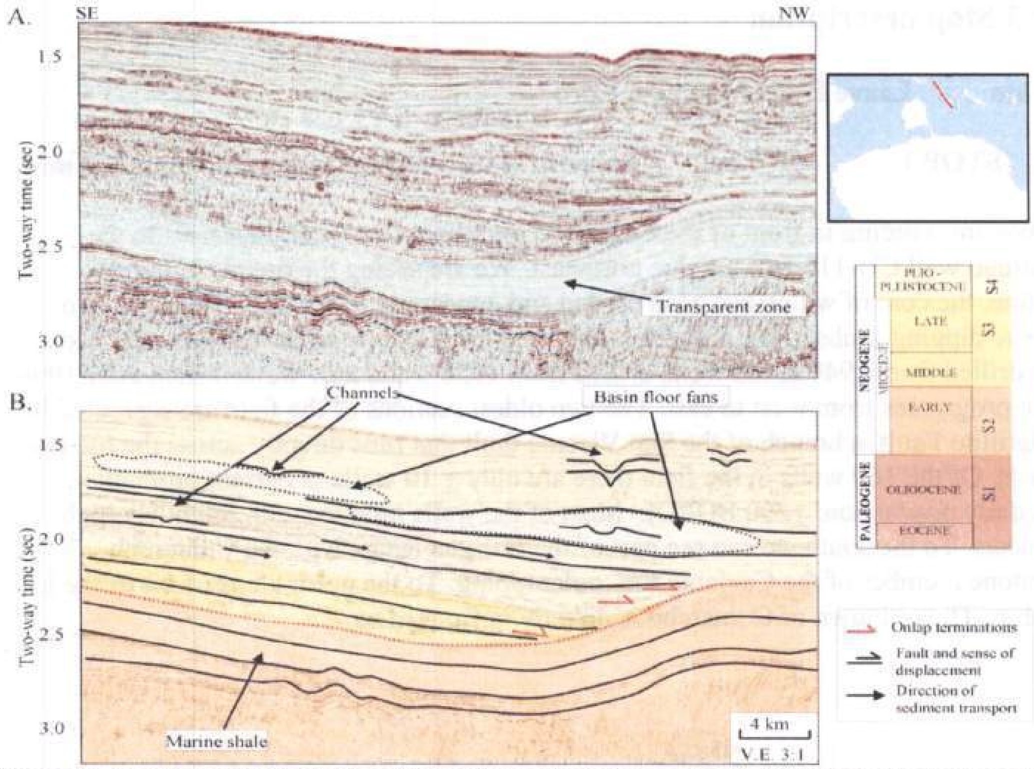


Figure 36. A) Uninterpreted seismic section from the West Curacao basin. B) Interpreted seismic section. Black arrows indicate direction of northward prograding clinoforms of middle to late Miocene age. Middle Miocene unconformity (red-dashed line) is onlapped by reflections of sequences 3 and 4. Channel systems and apparent basin floor fans in Sequence 4 are described by Gorney et al. (in press).

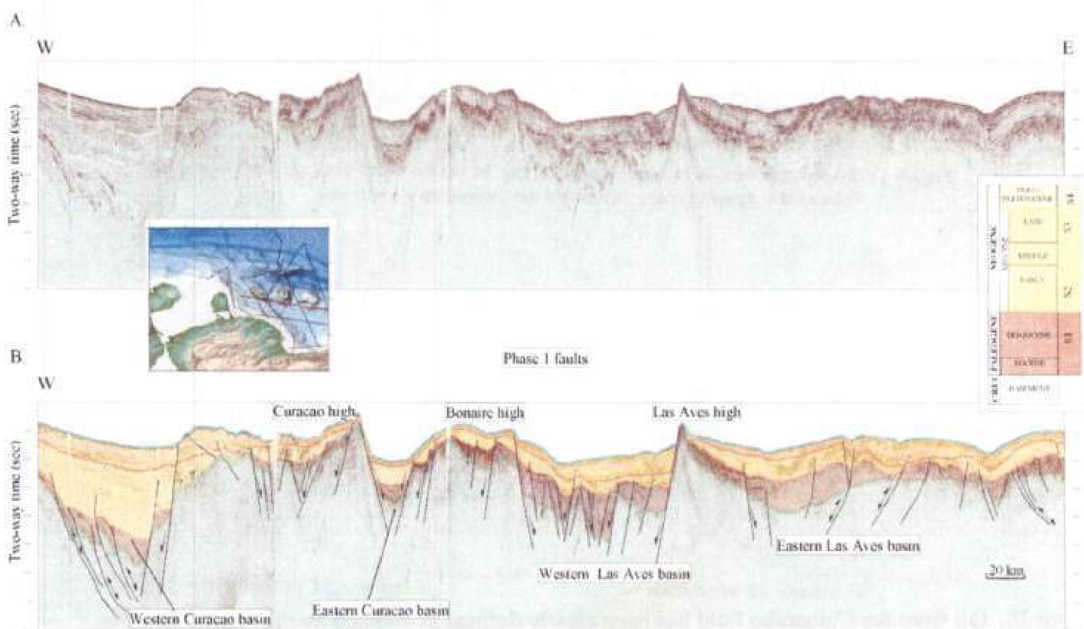


Figure 37. A) Uninterpreted seismic line south of the Leeward Antilles island arc. B) Interpreted seismic line showing Family 2 normal faults controlling the rifted basins separating the Leeward Antilles island arc (from Gorney et al., in press).

Day 3 Stop description

8:00 am Leave Hotel Miranda, Coro

- **STOP 1 ~9:15 am Structural view of the Cumarebo dome (30 min)**

We are standing in front of the Cumarebo anticline. Our location is next to the Cumarebo well CU-115 looking due northeast. We are seeing the broad Cumarebo anticline, the core of which has been eroded and appears as a saddle between the two opposite dipping limbs of the anticline. The field itself can be separated into very old wells drilled from 1940's, old wells drilled from 1950's and new wells drilled after 1996 as one progresses from west to east. The two oldest sections of the field are separated by the Hatillito Fault, a branch of the San Vicente fault that runs directly across the old town (Map 4). Of the 160 wells in the field there are only ± 10 wells in current production (total daily production: ±200 BOPD). Most of the wells produce with relatively high water cuts. To the south we can see part of the Barigua Ridge with the Cumarebo Limestone member of the Caujarao Fm. outcropping. To the north we see hills of the La Vela Fm. The old town of Cumarebo is directly in front of us.

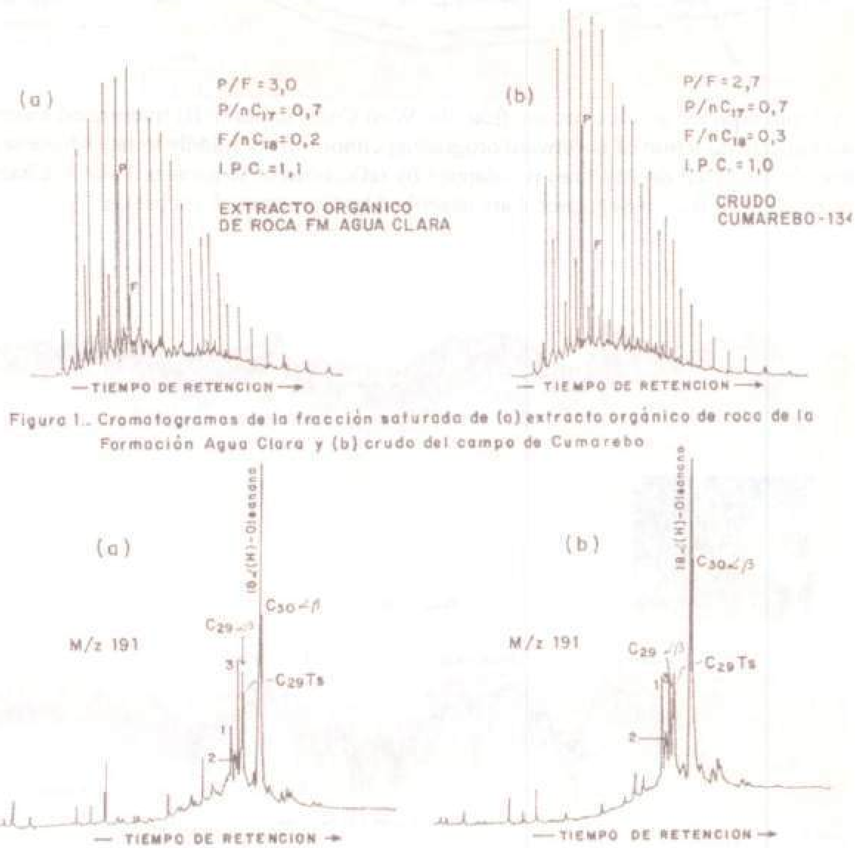


Figure 38. Oil from the Cumarebo field has been clearly defined as sourced by the Agua Clara Fm. However, there are two kitchens in the region. The first is northwest of Cumarebo and charges the field. The second is located between the La Vela offshore field and Paraguana. The Agua Clara here has a strong continental affinity and as a consequence the crudes are very paraffinic and more gas-prone (Del Ollo et al., 1994).

- **STOP 2 ~10:00 am Panoramic view (20 min)**

Detour off main road to well locations CU-149 and CU-151. From this location we can view the western portion of the Cumarebo anticline and review and discuss the structural implications of the features observed in outcrop and their significance for understanding the offshore region. The eastern limit of the main Cumarebo Field is the Santa Rita Fault. The influence of the Santa Rita Fault will be reviewed in conjunction with the results of the Tocopero well. It should be noted that both the San Vicente and Santa Rita Faults extend into the offshore La Vela basin (Fig. 30 and Map 4).

Discussion:

What is the relationship between the NW normal faults interpreted onland and in the La Vela bay with the La Vela thrust and fold belt offshore?

- **STOP 3 ~11:15 am Drive past the ferry terminal in direction of Caujarao and La Vela (30 min)**

The Caujarao Fm. has three members: the Muaco, Mataruca and Taratara. The formation was deposited at the time that the main episode of thrusting was occuring beneath the Barigua Ridge/anticline. The ridge strikes northeast southwest from Cumarebo to the town of Caujarao. The middle member, Mataruca, is dominated by carbonates known as the Cumarebo limestone, Trincheras, and Damsite (outcrop is located at the dam on the Coro River). It is laterally equivalent to the Capadare limestone of East Falcon. The limestone interval is only found along paleo-highs as discussed at the previous locality. Sandstone from the Muaco member of the Caujarao Fm. provides the principal reservoirs of the Cumarebo field.

The environment of deposition of the formation was dominantly coastal. The unit lies within the *Globorotalia menardi* zone. There is a transitional contact with underlying Socorro Fm. The Cumarebo limestone has been interpreted as carbonate bank and shoal which developed during a low stand of sea level. Paleobathymetrically the rest of the Caujarao Fm., which is mainly shaly with thin limestones and sandstones, was deposited in an environment varying from outer neritic (80 to 150m) to upper bathyal (150 to 500 m) (Wheeler, 1963). Both the sandstone and limestone are potential reservoir rocks. In the Cumarebo field the Caujarao limestones, capping the shoaling upward shale-sandstone sequence, act as reservoir seals due to diagenetic cementation, where the reservoirs are the sandstones. The capping limestones stand out as resistent vertical ridges forming the scarp face of the massive Barigua Ridge.

The La Vela Fm. is an interval of carbonate-rich sandstone and shale. It has three members: the Curazaito, Chiguaje and El Veral. The Curazaito is domintly shaly. The base of the unit is in the *Globorotalia margaritae* zone. The Chiguaje member is more marine and contains benthonic fauna of the *Textularia falconensis* zonula (Gonzalez de Juana et al., 1980). The El Veral is a glauconitic, highly fossiliferous member that outcrops at the Cumarebo oil field. Diaz de Gamero (1996) concludes that the Veral member was deposited in a marine environment of deposition on a continental shelf to slope facies.

In this stop, the outcrops along the shore are upper Caujarao and Lower La Vela sandstone and shale. Their steep dips are produced by a series of thrusts that are called the Taima-Taima or Guadalupe thrust faults. These are the northernmost extension of the thrust system in Falcon (Fig. 30 and Map 4). This fault system seems to correlate offshore with the tear fault that bounds western edge of the La Vela thrust and fold belt (Fig. 30).

Discussion:
How could one distinguish a tear fault from a reverse fault in the field and on subsurface data?
What might have controlled the original location of this fault? Would the area north or south of this fault be more promising for exploration?

- **STOP 4 ~12:00 am La Vela 6 well (30 min)**

The La Vela 6 well is one of the deepest wells (11,030 feet) drilled in the Falcon coastal area (Map 4, south of stop 1). A brief presentation on the stratigraphic results from this key test well will presented at the wellsite.

The sequence in the well log includes:

0-5650 ft	La Vela to the top of Agua Clara
5650 – 6400 ft	Agua Clara Fm. with a base in the *Catapsydrax dissimilis* zone.
6400 – 9600 ft	Pedregoso Fm. ? The interval has no source rock potential
9600 ft	Thrust fault repeats section
9600 - 9700 ft	Agua Clara Fm. *G. insueta* to *C. Stainfrthi*
9700 – 11030 ft	Pecaya Fm? (*C. dissimilis* to *G. ciperoensis*)

Miocene thrusting occurred in the northern Falcon basin. The age of the faulting is clearly defined by the development of the (upper Miocene) Cumarebo limestone along the crest of the anticline. The Cumarebo limestone (also known as the Mataruca Member of the Caujarao Fm.) is late Middle Miocene in age.

It is important to note that the Miocene to Pliocene in the Southern Caribbean was a prolific period of reef building. All highs at or near wave base were focal points for carbonate buildups. The Barigua ridge/anticline you can see looking to the south was no exception. In eastern Falcon the Capadare Limestone also formed at the crest of a fold. The key to its identification on seismic is to seek out on lapping sequences onto a paleo high. In all cases these features correspond to fold-hosted carbonate buildups.

The outcrops around the well site include the upper La Vela Fm. (El Veral Member, upper Miocene) (Fig. 29). The upper La Vela is dominantly shale-rich with abundant varigated shales and gypsum. The environment of deposition was paralic with a significant exposure index. As the highstand system tract associated with the Upper La Vela began to reach its maxima, more open marine conditions prevailed and led to abundant bioturbation including large *Thalassinoides* borrows, and biostromes rich in *Pecten*, *Ostrea* and other biogenic components. One particular species, *Ostrea messor* sp., serves as an index fossil for age dating the lower Pliocene.

Many pecten shells are still articulated and record the low energy environment of deposition for the La Vela Fm. Along the north side of the well site an advanced state of tropical weathering accentuates the interconnecting *Thalassinoides* network.

In front of us we observe the vegetated and almost flat-topped Barigua ridge to the south behind the valley. The Las Polonias well is located across the valley at the foothills of the Barigua ridge. The section of Mio-Pliocene outcropping here is very similar to those in the Paraguana Peninsula (Hunter and Bartok, 1974).

Discussion:
What is causing the folding upon which the reefs grow?
Was the folding longlived or shortlived?
Which would make a better reservoir: the reef itself or the reef debris deposited in deeper water?

LUNCH ~12:30 pm

- **STOP 5 ~1:15 pm Middle-late Miocene Cumarebo Limestone (30 min)**

Drive to Guaibacoa and study the outcrops of the Cumarebo limestone. The limestone is highly weathered and forms caliche. Fossil fragments are still recognizable. The Cumarebo limestone develops along the entire length of the Barigua Ridge but is not present in complete sections north of the ridge.
The entire section is slightly dipping to the north. As one drives to the south the section becomes progressively older. Immediately south of the reef the outcrops begin with the Lower Caujarao and Socorro Fms.

Discussion:
Could the Cumarebo limestone act as a good reservoir?
If so, what is its the subsurface extension?

- **STOP 6 ~2:00 pm Middle Miocene Querales Shale (15 min)**

The Querales Shale represents the depositional event associated with one of the major Miocene MFS (16.2 Ma) and its shales are noted for their rich fauna. It lies near the boundary between the *Globigerinatela insuta* and the *Praeorbulina glomerosa* zones and mostly within the latter. As the drive continues, the underlying Cerro Pelado (Ricoa) section can be observed. These rocks weather to a bright red color.

Discussion:
Can the Querales Shale represent a good regional reservoir seal both on- and offshore?

- **STOP 7A 2:30 pm Middle Pliocene Socorro to Coro Conglomerate; cross road to San Luis (60 min)**

The Middle Pliocene Coro conglomerate has a very local distribution. It is found exclusively south of the city of Coro. The best outcrop is located along the Coro Caujarao road and along the Coro River (Fig. 39).

In this outcrop, overturned vertical to subvertical beds of Coro conglomerate is exposed on both sides of the road going south from the city of Coro to Churuguara. Here the average dip is about 60-80° to the north. The Coro Conglomerate extends from La Vela de Coro to an area about 2 km west of Coro (Map 4 and Fig. 29).

The sequence consists of alternating beds of lenticular conglomerate, sandstone and thicker silty micaceous shale. The typical motif is a small-scale, fining-upward sequence consisting from base to top: conglomerate - sandstone - silty shale. The fining upward channel-form and lenticular discrete conglomerate and sandstone are laterally extensive and pinchout at the scale of the outcrop.

The conglomerate is poorly sorted and highly polymictic in composition. Compositionally the pebbles and boulders are angular to subangular to subrounded depending on the composition of the clasts. Clasts include limestone, red sandstone, chert and vein quartz. The limestone, most probably from the Caujarao Fm., may be up to 30 cm in diameter. Maximum size observed is 1.5m in diameter. The composition of the clasts indicates that inversion of the Falcon Basin during the Mio-Pliocene triggered debris flows from such pre-existing formations as Caujarao, Socorro and Cerro Pelado. This coarse grained formation may also be an indication of the initiation of the La Vela fold and thrust belt offshore.

The Coro conglomerate was deposited in an alluvial fan to braid plain environment in an area proximal to a coast. The marked lenticularity and thinness of the coarser facies (conglomerate and sandstone in channels) in contrast to the much thicker lightly mottled silty shales imply episodic sedimentation, probably related to repeated uplifts of the source area. Pulsed uplifts resulted in rapid sedimentation of the bedload channel deposits in an otherwise quieter lower alluvial fan to alluvial plain depositional setting.

Figure 40. Photo showing the Coro conglomerate outcrop. The conglomerates were sourced locally by the Caujarao Fm.

Discussion:

What is the tectonic significance of the Coro conglomerate?

STOP 7B

Pliocene La Vela Formation

The Pliocene La Vela Fm. is exposed on the same road cut in continuation of the Coro Conglomerate of the last outcrop. The contact between the two formations is apparently transitional. Both the proportion of conglomeratic sandy beds and the maximum size of the clasts and pebbles in them progressively dwindle from the Coro Conglomerate (Fig. 40) to the La Vela Fm.

The beds are vertical to subvertical and dip south. Near the transition zone there is a bed of sandstone showing intense bioturbation including the horizontal traces of the type *Thalassinoides*. The main lithologies in the La Vela Fm. are gray silty shales, thin trough cross-bedded sandstones, and thin lenticular conglomerate.

The shale beds vary from gray to mottled and are oxidized in color. They are much thicker than those in the overlying Coro Conglomerate. The maximum thickness of a shale bed is 80 to 100 m. The sandstone and conglomerate beds are thin and lenticular in nature, totally encased within the shales, and pinch out within a short distance. The basal scours of the conglomerates are clearly observed. The pebble size of the La Vela conglomerates seldom exceeds 1 to 2 cms and consists of abundant calcareous shells, quartz, sandstones, and black chert. Fining-upward sequences are common in the lenticular channel-form units. In this outcrop the fossil shells are both intact and fragmented. In other La Vela outcrops there are frequent coquina beds of bivalves and gastropods (*Turritela*).

The La Vela facies were deposited in a transitional marginal marine coastal environment. The oxidized shales are similar to subaerially-exposed delta plain and coastal, finer alluvial fan deposits. The abundance of fossil shells of shallow marine origin corroborates their coastal depositional milieu. The conglomeratic intervals are the precursor of increase tectonic activity related to the Coro Conglomerate sedimentation. Overall the La Vela sediments show a marked regressive character from the underlying fully marine Caujarao Fm.

STOP 7C

Upper Miocene to Lower Pliocene Caujarao Formation.

Further southward along the road beyond the stretch of La Vela outcrops, there is a long gap in the road section due to a valley cut across thick La Vela/Caujarao transitional shales. Beyond this valley the first shale and limestone of the the Caujarao shale is exposed. The Caujarao sequence consists of alternations of shale, calcareous bioturbated sandstone and limestone with irregular thickness.

The Caujarao sequence dips south whereas the La Vela and Coro conglomerate sequence dips northward. A fault affects this sequence, as shown also by the extremely chaotic and deformed nature of the underlying Socorro beds.

The Caujarao Fm. as shown above essentially consists of three main facies: limestone, sandstone and shale. It varies in age from Middle Miocene to Lower Pliocene (Wheeler, 1963; Gonzalez de Juana et al., 1980). According to the same authors it is 868 m thick in the northeastern part of Falcon. The basal third, represented by the Cumarebo limestone in the Cumarebo field is about 250 m thick and was deposited in an open marine middle neritic environment (30 to 80 m). Giffuni et al. (1992) interprets the Cumarebo limestone as carbonate banks and shoals which developed during a lowstand of sea level. Paleobathymetrically the rest of the Caujarao Fm., which is mainly shaly with thin limestones and sandstones, was deposited in an environment varying from outer neritic (80 to 150 m) to upper bathyal (150 to 500 m).

Both the sandstone and limestone are potential reservoir rocks. In the Cumarebo field the Caujarao limestones capping shoaling upward shale-sandstone sequence acts as reservoir seals because of diagenetic cementation of the sandstones.

STOP 7D

Middle Miocene Socorro Formation

Although not confirmed from paleontology, it has been postulated that the calcareous sandstone that overlies the Cantaure Fm. may correspond to the Socorro Fm (Fig. 29). The unit is comprised of a series of meter-thick sandstone intermixed with shale. The sandstone shows spheroidal weathering that results from the bonding effect of lithohamnium algal limestone observed in the sediment.

The Socorro Fm. sandstone (Fig. 39), shale and some impure limestones are transitional with the overlying Caujarao Fm. In between the two formations exists a gap of shale which may belong to either of the formations. The basal Socorro sandstone is about a meter thick and very fine-grained, cross-stratified with markedly lenticular sandstone dipping steeply toward the north. Thin gypsum laminae are observed along the bedding planes. Immediately below the sandstone is a thin, meter-thick dirty calcareous sandstone with abundant scattered shells of bivalves including *Pecten*. The sandstone is bioturbated with recognizables traces of *Thalassinoides* and other trace fossils including subvertical burrows.

We proceed southward to a spectacular section of the Socorro Fm. near the junction of old (N-S) and new (E-W) Churuguara roads. The whole sequence is approximately 50 m thick. From this point, the Socorro outcrops pass into the shale of the underlying Querales shales.

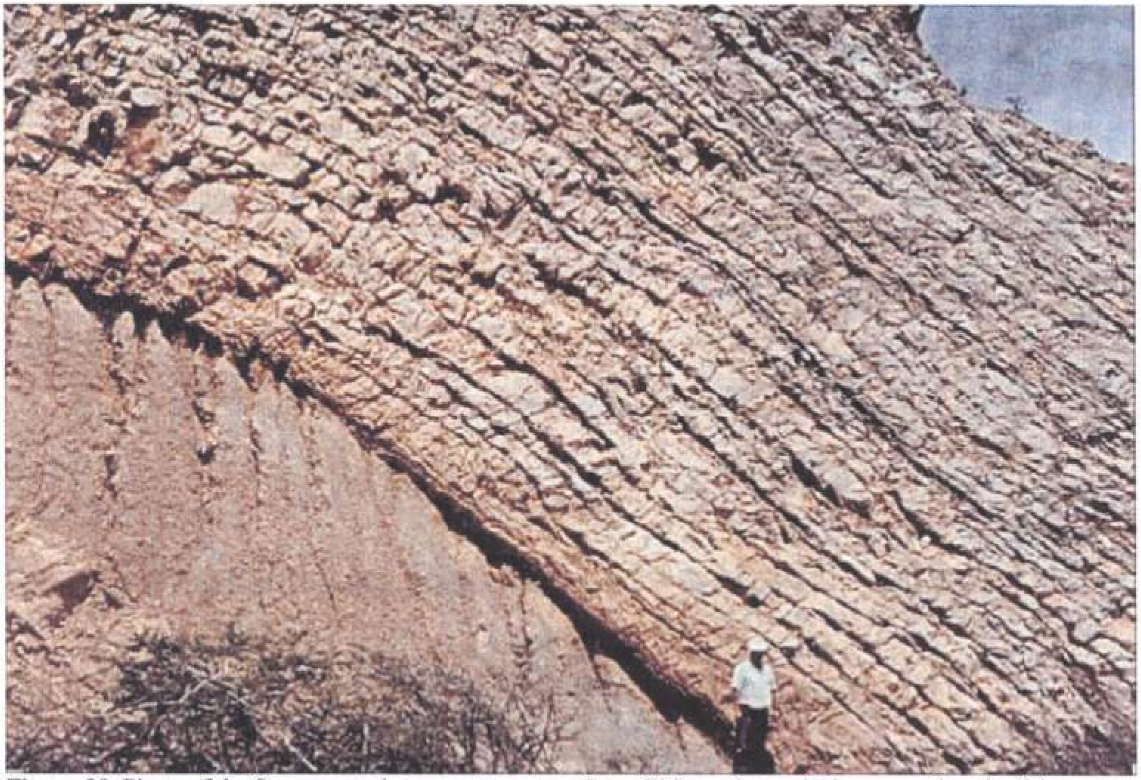


Figure 39. Photo of the Socorro sandstone outcrop near Coro. This sandstone is the reservoir unit of the Cumarebo field in the northern Falcon basin.

- **STOP 8 ~4:00 pm Early Miocene Guarabal Fm. (15 min)**

The Guarabal Fm. is age equivalent to the upper San Luis Fm. and constitutes the backfill of the fringing reef. It is noticeably coarse grained with granule and pebble size fractions. The composition is dominantly quartz but note the significant amount of chert. The provenance is probably from the Paraguana Peninsula.

Most of the interval exposed on this stretch of the road shows stacked sequences with a fining-upward tendency, implying an alluvial channel and overbank origin for the Guarabal Fm. The rock has a distinct banded appearance where the individual bands consist of microconglomerate, coarser conglomerates, pebbly sandstones and sandstones. Also the Guarabal facies is festoon crossbedded in some areas. The meter to three meter thick sandstone beds are interstratified with common conglomerate lenses and thin lenticular shale units. Small faults and common slickensided strata are common in this area.

- **STOP 9 ~4:30 pm Late Oligocene-early Miocene Patiecitos Fm. (30 min). Time permitting. If not, this stop will be done on DAY 5**

The Patiecitos sandstone underlies the San Luis Reef (Fig. 29) and is equivalent to the Casupal and Paraiso Fms. It represents the early transgressive phase of the Falcon Basin. About 4 km from the last stop of the Guarabal Fm. we come to an outcrop of gray shale and thin sandstone beds. Here the reddish color and the conglomeratic component of the Guarabal Fm. is missing. This zone is transitional between the Guarabal and the

Patiecitos Fm. The Patiecitos strata continue on this road for many kilometers. We will not traverse the whole Patiecitos section. The Patiecitos Fm. in this road section consists of mainly poorly sorted sandstones, abundant shales, some thin limestone beds and occasional carbonaceous shales, thin lenticular coal beds and laminae. One such thin 0.5 m limestone bed, with abundant corals, bivalves and gastropods, is exposed on the road at a distance of about 28 km from Coro. It is common to find very thin stringers of pebbly sandstones in the Patiecitos Fm. However, at the present outcrop neither the limestones nor the pebbly facies are present. The Patiecitos sequence commonly shows fining and thinning upward tendency.

Discussion:

Can the Patiecitos shale act as a detachment surface for overlying limestone and clastic rocks?

- **STOP 10A ~5:00 View of the Falcon Basin. Time permitting. If not, this stop will be done on DAY 5**

From San Luis looking south you will see a view of the Aracua high and if the day is clear, in the far distance you can Churuguara. Moving the other flank of San Luis we can see Coro and the Middle Miocene platform of the Cerro Pelado and younger sediments

STOP 10B 5:30 Stop San Luis Fm.

San Luis Lower Miocene coralline facies. This is mostly a storm deposit with broken corral stems. Look at the orientation of the corrals and determine the direction of the shore.

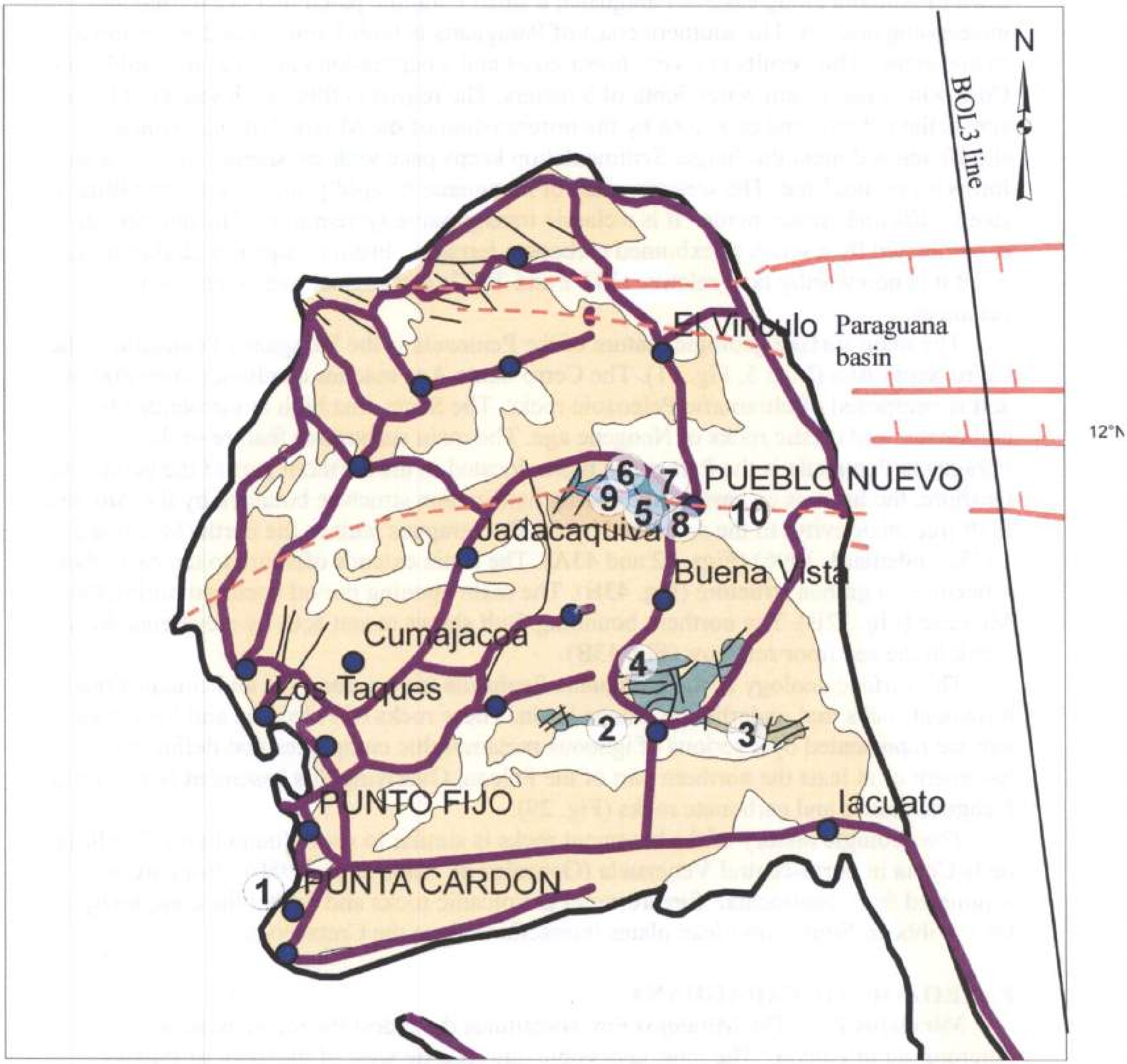
6:00 pm Return to Coro. Hotel Miranda and discussion

Day 4 Thursday (November 2, 2006)

Coro (Hotel Miranda) – Península de Paraguana – Coro (Hotel Miranda)

Theme: Structure and stratigraphy of the Paraguana Peninsula.; Regional imporatnce and offshore correlations.

Stops: Amparo Grnaite (Permian), Pueblo Nuevo schists, Paleozoic metamorphics, Santa Ana ophiolites and Miocene clastic and carbonates rocks (Paraguana basin)



Map 5. Geologic map showing the geologic setting of stops for Day Four. Purple line represents road networks. Geologic base map is from Hackley et al. (2005).

Regional tectonic setting of the Paraguana Peninsula and surrounding areas

Central Falcon can be divided into several distinct geomorphologic regions. One salient feature of Falcon is the Paraguana Peninsula (Maps 1 and 5). It is nearly 2500 km^2 and is connected to the Falcon mainland by an isthmus 30 km long, five km wide during low tide, and less than six meters in elevation.

The coastal sectors of the Paraguana Peninsula are unique in that all four shores offer different geomorphologies. The eastern coast shows the effects of a gradual relative sea level drop. Coastal cheniers provide the raw material for dune sands to develop. At the town of Adicora along eastern Paraguana, a small coralline patch reef is exposed and undergoing erosion. The southern coast of Paraguana is fault-bounded and downthrown to the south. This results in a very linear coast and a depression known as the Golfete de Coro with a maximum water depth of 5 meters. The region is filled with sediment blown across the isthmus and produced by the progradation of the Mitare delta carrying a significant sediment discharge. Sedimentation keeps pace with subsidence and the area forms a vast tidal flat. The western coast of Paraguana is rapidly submerging resulting in steep cliffs and embayments. It is a classic transgressive system tract. The northern coast is dominated by a series of exhumed carbonate terraces. From a sequence stratigraphic point it is noteworthy how relative HST's and TST's can coexist over such short distances.

The main surface geologic feature of the Peninsula is the Paraguana Peninsula is the Cerro Santa Ana (Map 5, Fig. 41). The Cerro Santa Ana reaches an altitude over 800 m and is composed of ultramafic Paleozoic rocks. The Santa Ana high is surrounded by carbonates and clastic rocks of Neogene age. The main subsurface feature of the Paraguana Peninsula is the Paraguana basin, located in the northern part of the peninsula. Onshore, the basin is an east-west trending half-graben structure bounded by the Adicora fault (recent activity) to the south and by the Cumaraguas fault to the north (Macellari, 1995, Audemard, 1996) (Figs. 42 and 43A). The basin extends offshore to the east where it becomes a graben structure (Fig. 43B). The main opening period occurred during the Miocene (Fig. 32B). The northern bounding fault shows recent activity a evidence by a break in the sea floor reflector (Fig. 43B).

The surface geology of the Paraguana Peninsula is very complex and contains the basement rocks that underlie the Falcon basin. These rocks of Paleozoic and Mesozoic age are represented by a serious of igneous-metamorphic complexes that define the basement of at least the northern part of the Falcon. Overlying this basement is a series of Neogene clastic and carbonate rocks (Fig. 29).

The geologic history of the basement rocks is similar to rocks found in the Cordillera de la Costa in north-central Venezuela (Gonzalez de Juana et al., 1980). Both areas originated from continental, forearc rocks to volcanic rocks and reflect the complexity of the Caribbean-South American plates interactions since the Cretaceous.

PALEOZOIC OF PARAGUANA

Miralejos Fm. The Miralejos Fm. constitutes the oldest Paleozoic basement outcropping in Falcon. The most accessible outcrops lie west of the town of Pueblo Nuevo and north of the town of San Jose, central Paraguana Peninsula. The unit is comprised of schist, marble, black chert and gneiss. All are rich in quartz, feldspar, muscovite and locally garnet and apatite. The unit was first described by Feo-Codecido (1963) and subsequently redefined by Feo-Codecido et al. (1974). It constitutes the basement through which Permian granites have intruded and hence provide at least a Carboniferous age. It should be noted that this unit has yet to be accepted into the Stratigraphic Lexicon and should still be used as an informal name.

Similar units have been observed on the Yucatan Peninsula in the northern Caribbean. There they are known as the Macal Series of the Maya Block (Bartok, 1993). In the Santa Marta Block a similar unit is known as the Chundua Group (Tschanz et al., 1974). In both cases these latter units have been considered to be of Carboniferous age. Therefore, together with Miralejos they may be lateral equivalents of the Mucuchachi, Tostos and Sabaneta Formation of the Merida Andes in western Venezuela and were originally deposited in the foredeep associated with the southern margin of the Pangea suture. The Miralejos unit is fractured with a dominant fracture direction to the north-northeast.

Amparo granite. The Amparo granite forms the bulk of the Mesa de Cocodite, central Paraguana Peninsula. It is fault-bounded to the north by the Adicora Fault and is likely fault-bounded along its other margins. The granite is medium-grained, massive and occasionally foliated. It was first described by O. Renz in the late 1950's (internal Shell report) and named the Paraguana granite. Subsequently, MacDonald (1968) formally named the unit the El Amparo granite. The unit may be described as a diorite intruded by a series of dykes (both felsic and mafic). Quartz, pegmatitic and andesitic intrusives are also observed. Epidote is common and is likely associated with hydrothermal solutions. The age of the unit was determined by U/Pb determinations on titanite. The results ranged from 262 to 265 Ma (Permian). The granite is similar in description and age to those found at the El Baul high, Toas Island, Palmar High (Perija), Guajira Peninsula, and the Maya Block (southern Yucatan) (Feo-Codecido, 1954; Blaser and Dusembury, 1960; Martin-Bellizzia, 1961; 1968; Bartok, 1993). In all cases they correspond to the Hercynian-Alleghanian orogenic event associated with the Pangea suture.

Pueblo Nuevo Fm. Unconfomably overlying the Paleozoic basement of Paraguana are a series of metasedimentary rocks ranging from phyllite and schist to orthoquartzite. The best estimate for their thickness is 1400 m. The unit outcrops at several localities on the Mesa de Cocodite with the best outcrops at Monte Cano (abandoned radar station) and the Quebrada El Pizarral. The unit is predominantly a pelitic, slightly carbonaceous phyllite with local metaconglomerate and sandstone. The sandstone can be observed near the Quebrada. El Pizarral. Thin layers of chert are also observed. The thick pelitic Pueblo Nuevo Fm. appear to have been deposited in the Jurassic foreland basin that developed following the Early Jurassic rift of the southern Caribbean. Orthoquartzite associated with the phyllites crop out south of the Quebrada El Pizarral near the old Canture house.

Santa Ana Complex. The Santa Ana Complex (Figs. 41 and 44) is only observed along the southern third of the Paraguana Peninsula. It is present along the Cerro Arajo, in the towns of Santa Ana, Siraba, Capuana, Tausabana and El Rodeo. The elevations vary as a function of their mineral assemblage and attain elevations of up to 830 m on the Cerro Santa Ana. Miocene terraces are observed to lap onto the complex. Mendez and Martin-Bellizzia (1960) first described the petrography of the ultramafics and the anorthosites of the complex. A study by Martin-Bellizzia and Iturralde de Arozena (1972) carried out a detailed mapping of the unit and separated the complex into the zoned ultramafics of the Tausabana-El Rodeo, the anorthosite of Siraba-Capuana and the subvolcanic complex of Santa Ana. K/Ar age determination yielded an age of 120 to 130 Ma for the subvolcanic rocks of Santa Ana and the Siraba olivine gabbro (Santamaria and

Schubert, 1974). Aeromagnetic surveys over East Falcon suggest that the region is underlain by oceanic crust (Bosch and Rodriguez, 1992) which is likely comagmatic with the complex observed at Santa Ana.

Zoned ultramafics of Tausabana-El Rodeo. The ultramafic complex at Tausabana is exposed over 8 km in length and 2.5 km in width. From the core outward the unit begins with a dunite and associated boudinages of chromite; serpentinized harzburgite of a dark green color; olivine-pyroxene and an intrusion of gabbro and hornblende pyroxene. Anorthosite, trocolite, and norite dykes are also observed. The unit is described as a complex of graded flows.

Zoned olivine-anorthosite gabbro of Siraba-Capuana. The westernmost portion of the El Rodeo complex is in fault contact with the zoned olivine-anorthosite gabbro of the Siraba-Capuana area that intrudes the former and comprises 2.5 times its size in outcrop and over four times its volume. Both the lineations and foliations of the complex are consistent with the other mafic units. Its geochemical affinitiy and mineralogy (forsterite, augite, olivine, diopsidic clinopyroxene and labradorite-bytowite plagioclase with inverse zonation) imply a temperature and pressure of emplacement of 1250 deg. C and 5-9 kb pressure.

Subvolcanic, stratified tholeiites of Santa Ana. The zoned gabbro separates the zoned ultramafics of the stratified subvolcanic tholeiites of Santa Ana in fault contact. The subvolcanics show gradation and stratification with abrupt contacts between fine and coarse-grained assemblages as well as graded coarse to fine. It is comprised of diopsidic clinopyroxenes with a calcic plagioclase in a feldspar matrix. Geochemically it is classed as an olivine tholeiitic basalt with a moderate aluminum content. It formed under hydrated conditions at pressures of 9-13 kb. Once again the structural parameters coincide with those of the other mafic complexes.

The Cerro Arajo Complex. Cerro Arajo is located west of the main Santa Ana complex and is primarily a plagioclase diabase with diopsidic augite and magnetite as an accessory mineral. The eastern portion of the area is comprised of the Siraba anorthosite and is the region actively quarried. The western portion is composed of the aphanitic basalt, gabbro and gabbro basalts of the Santa Ana Complex.

Paragentic relationships among the various ultramafic complexes of Paraguana. The geochemical relationships of the complex show comagmatism but the various units did not form simultaneously even though they are in close proximity (Mistage et al., 1993). The ultramafics and gabbros are intrusive. They are associated with xenoliths of serpentinized peridotite. The contacts between the various zones show mylonites, chlorite and the formation of albite. They do not show intrusive contacts or gradational contacts. It is therefore suggested that they were not contemporaneously emplaced. Diorites are absent.

It is postulated that the Santa Ana Complex formed as oceanic crust in close proximity to an island arc system. The complex was uplifted during extension of the oceanic crust and subsequently obducted as the plates undergoing suturing. The absence of metamorphism, the Pacific character of the rock assemblage imply that the complex forms part of Lara Nappes and were likely associated with the Baudo terrain in the Western Cordillera of Colombia. The Baudo terrain is characterized by peridotite gabbros with tholeiitic basalts, low in K and containing chromite (Case, 1974).

TERTIARY TRANSGRESSION ON PARAGUANA

Early Miocene Cantaure Fm. This unit is 75 m thick with a basal transgressive carbonate developing directly over the Amparo granite. The lower portion of the formation is a sandy marl with a wide faunal diversity of macrofossils (Jung, 1965). The upper unit is similar and includes the *Ostrea aguaclarensis paraguanensis* Hodson associated with the lower Miocene. The age of the unit ranges from *Globigerinatelsa insueta* to the *Praerbolina glomerosa* zone. Therefore the unit is equivalent to the uppermost Agua Clara, all Cerro Pelado and Querales Fms.

Middle Miocene Socorro Fm. Although not confirmed from paleo reports, it has been postulated that the calcareous sandstone that overlies the Cantaure Fm. may correspond to the Socorro Fm. The unit is comprised of a series of meter-thick sandstone inermixed with shale. The sandstone shows spheroidal weathering that resulted from the bonding effect of lithohamnium limestone observed in the sediment.

Late Miocene Caujarao Fm. Along the eastern flank of the Mesa Cocodite lie a series sandstones and limestones that are very similar to the Caujarao Fm. of northern Falcon.

Late Miocene-Pliocene Paraguana Fm. The Paraguana Formation has three distinct members. The El Hato Member is a varigated shale with significant gypsum and abundant ferruginous material. The Amuay Member is a carbonate section that rims the entire peninsula. The El Alto conglomerate is limited to the eastern portion of the Peninsula. The best exposures of the El Hato are located on Cerro Pelon, north of Pueblo Viejo and at Guaquira Arriba, near El Hato. The exposure of the Amuay member at Punta Cardon and Judibana contain rich faunal assemblages. The age of the unit has been determined as basal Pliocene, *Globorotalia margaritae* zone.

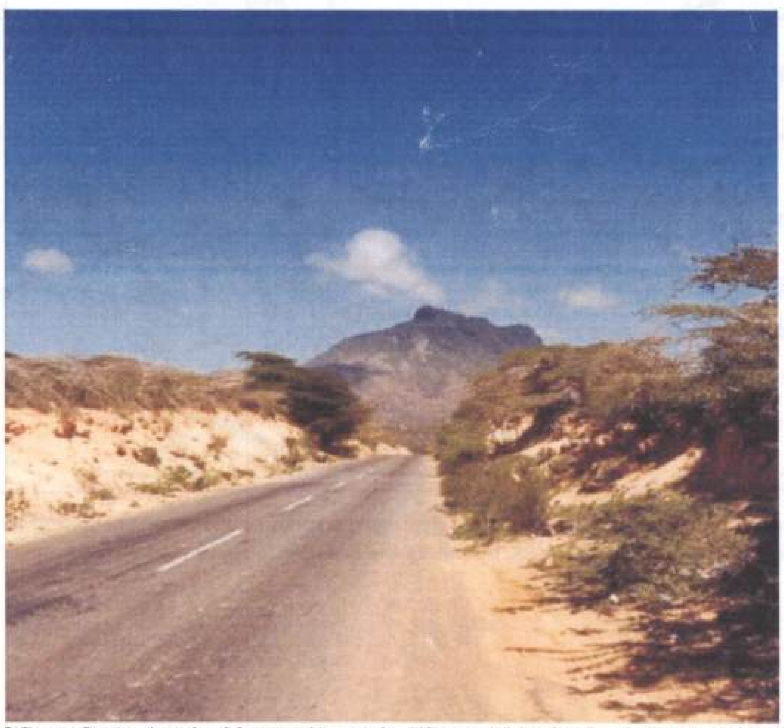


Figure 41.View of Cerro Santa Ana looking to the north. The rocks in the foreground are the Paraguana Fm. or the lateral equivalent to the Pliocene La Vela Fm.

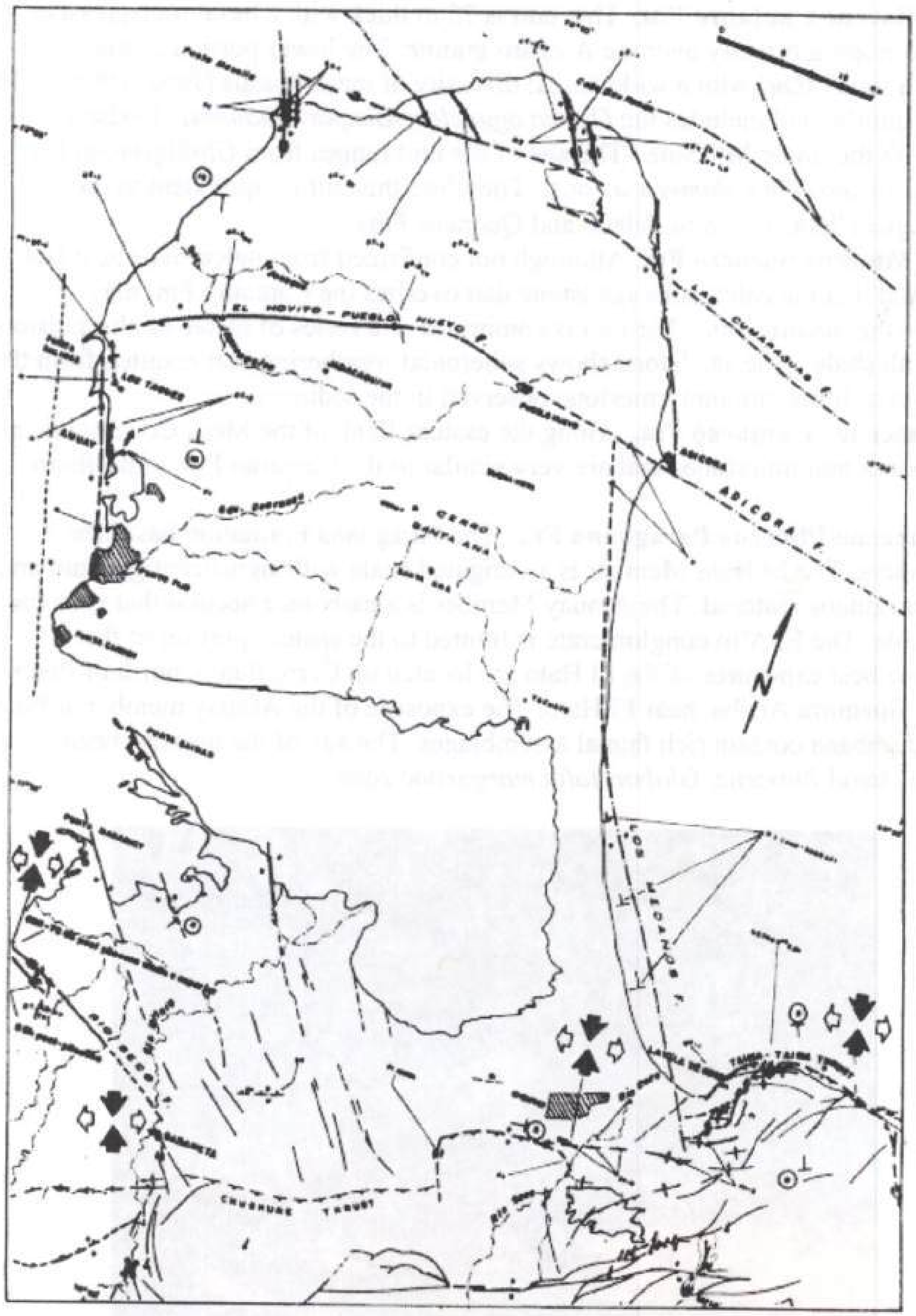


Figure 42. Neotectonic map of the Paraguana Peninsula (Audemard, 1996). The main faults are the E-W-striking Adicora and Cumaraguas faults, bounding the Paraguana basin, and the N-S-striking Medanos fault.

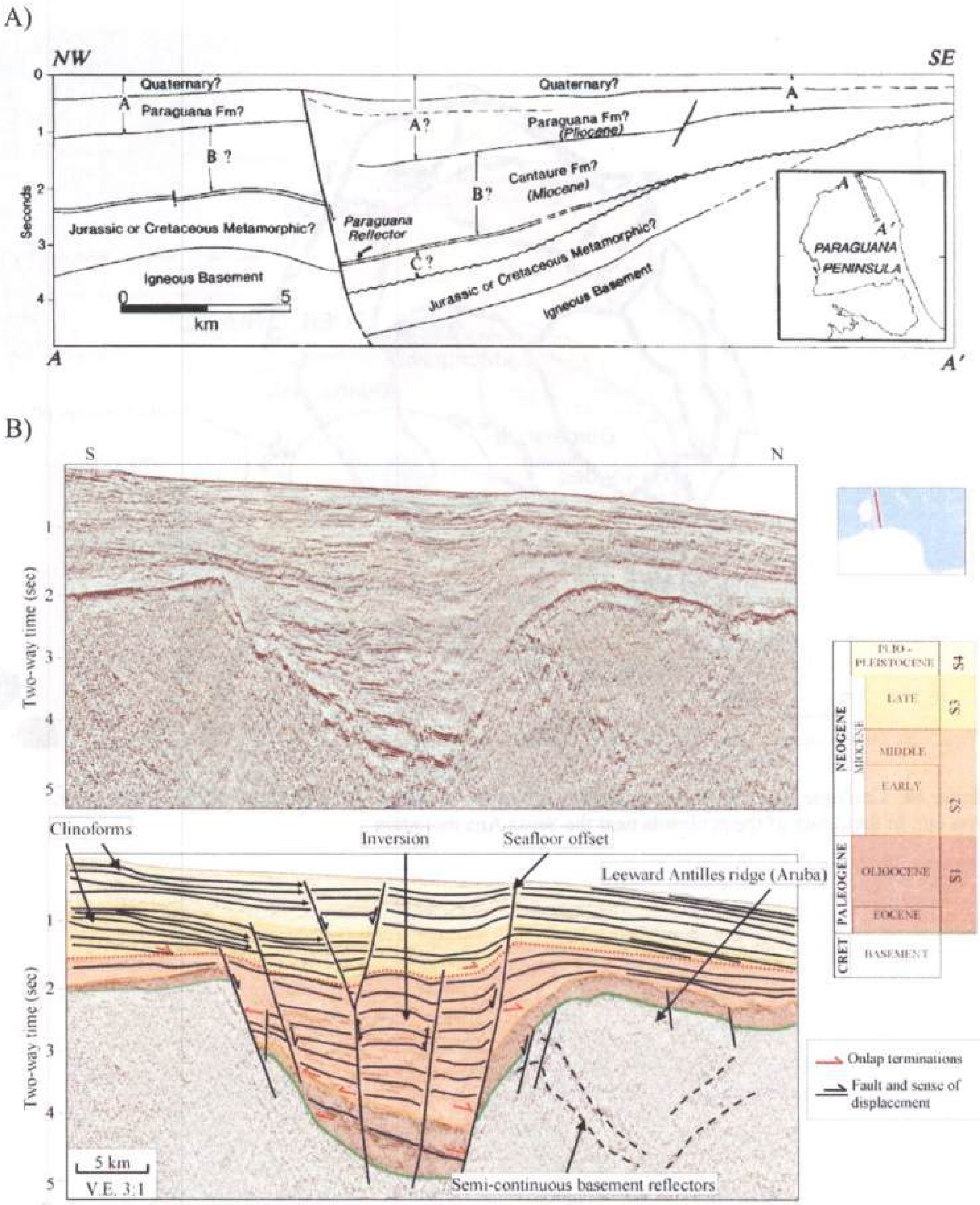


Figure 43. A) Interpreted seismic section in the northeastern aprt of the Paraguana Peninsula showing the Paraguana half-graben filled with Miocene sedimentary rocks. The main bounding fault to the south is the Adicora fault (modified from Macellari, 1995). B) Seismic line parallel to the eastern offshore Paraguana Peninsula. The Paraguana basin is a graben structure formed during the early-middle Miocene. The northern bounding faults are probably the Cumaraguas fault, which shows recent activity as indicated by its scarp breaking the seafloor.

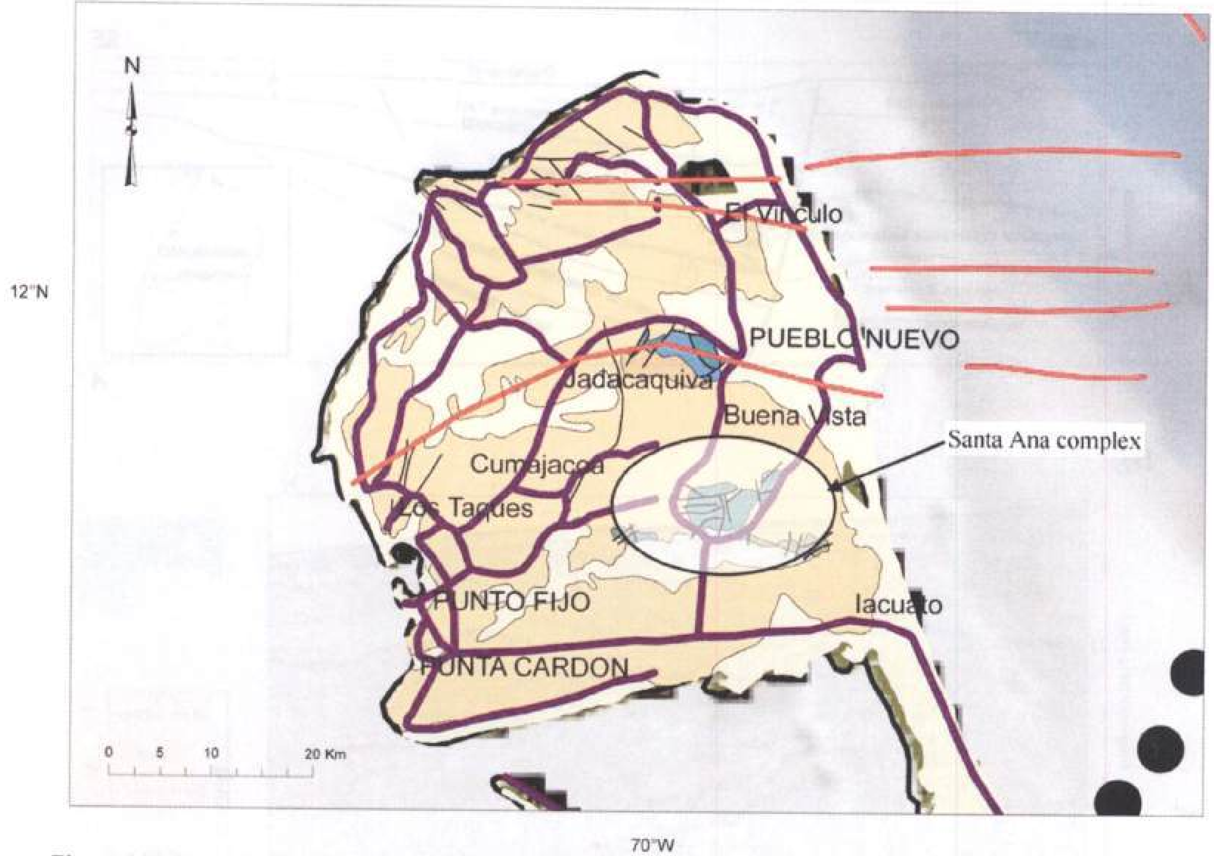


Figure 44. Geologic map showing the surface geology in the island. The Paleozoic and Mesozoic rocks crop out in the center of the peninsula near the Santa Ana mountain .

Day 4 Stop description

8:00 am Leave hotel

- **STOP 1 ~9:30 am Cardon refinery camp (30 min).**

A fundamental observation to be made is the difference in coast lines between eastern and western Paraguana. As noted, the eastern coast is a classic coastline associated with a TST. As the coast drowns large embayments develop and the river systems become estuaries. It is interesting to note that the westward tilt of the Paraguana provides for contemporaneous TST system tract along the western shores and an HST along its eastern shores.

The outcrop itself is the best exposed section of the Amuay member of the Paraguana Fm. Except for the local El Alto Conglomerate the Amuay Member is the upper part of the Paraguana Fm. and overlies the El Hato Member observed at Cerro Pelon. The outcrop of the Amuay Member was first described by Rodriguez (1968). The scarp is approximately 30 m and is comprised of a series of intercalated sandy carbonate banks and marly shales. This member rims the entire peninsula. However, its internal structure is destroyed by the development of caliche.

At the outcrop note a few salient features. The upper surface contains very large *Thalassinoides* burrows, very similar to the ones observed at the La Vela 6 well location. At the same time the macrofaunal assemblage confirm the correlation with the La Vela Fm. A small *Bryozoan* reef can be observed approximately 15 m from the base of the scarp. The foraminiferal assemblage suggests very shallow waters. Among the macrofossils the most important are the *Ostrea haitensis* Sowerby, *O. messor* Maury and *Pecten amusium*.

Discussion:

Observe the type of shoreline and consider its implications for recent tectonics. Are Pliocene sediments deposited in open marine conditions?

- **STOP 2 ~10:30 am Entrance to the rock quarry at Cerro Arajo. Drive 1 km to the quarry (30 min)**

The quarry is located along the eastern section of the Cerro Arajo Complex. As observed on the map of the igneous complex, the unit corresponds to the anorthosite-gabbro of Siraba. Please read the description provided above. Previous investigators have described the strataform gabbro and dyke swarms as suggestive of an ophiolite complex. The importance of this system of outcrops is that it corresponds to the interior zone of the Caribbean Nappes. The magnetic anomalies under East Falcon indicate that the nappe-related mafic and ultramafic complexes underlie its Tertiary sedimentary cover. Note the importance of these rock suites as parent material for Tertiary sediments in the region.

Discussion:

Observe the banding in the igneous rocks that is typical of ophiolite sequences.

What is the tectonic significance of this ophiolite? Are there similar ophiolites in Venezuela?

- **Optional stop STOP 3 ~11:30 am Gabbros of the Santa Ana Fm. (20 min)**

Arrive at El Rodeo. The outcropping gabbro has a high content of labradorite. The section to the east of this outcrop contains pegmatitic gabbro and gneissoid gabbro.

Discussion:
How is it possible to have such a large variety of igneous complexes in such close juxtaposition?

- **Optional STOP 4 ~11:45 am Santa Ana hill view (20 min)**

Turn right at the entrance to the park. Observe the blocks scattered about the park. The predominant rock is an aphanitic basalt with local porphyry basalts. This rock type makes up most the main Santa Ana hill. The core of Santa Ana is composed of gabbro basalts.

LUNCH ~12:00

- **STOP 5 ~1:00 pm Outcrop of the Miralejos (30 min)**

The strongly foliated gneiss and schist at Miralejos form the basement framework into which the Amparo granite has intruded. Well developed fracture patterns can be observed. Note the high content of black chert. If you recall from the previous trip chert pebbles and granules were observed in the Guarabal outcrops near the San Luis Reef. The Miralejos complex is the most likely source.

Note that this area lies along the western extension of the Adicora Fault. To the north lies the Central Paraguana graben that was described by Macellari (1995).

Discussion:
In the following stop we will visit the Amparo granite that has been dated as Permian. What age should the host rock be? Are there similar rocks in the Caribbean? What are the tectonic implications?

- **STOP 6 ~2:00 pm Amparo Granite, Permian (10 min)**

Arrive at the entrance to Cerro La Luz (the old radar station). At the entrance to the park center the outcrops are highly weathered El Amparo granite. The granite has been dated as Permian (262-265 Ma) and intrudes the Miralejos complex. The fracture patterns in the granites trend north-south.

Discussion:

What is the significance of this granite outcrop for exploration? How could these type of rocks serve as a reservoir?

- **STOP 7 ~3:00 am Pueblo Nuevo Formation, Jurassic (30 min)**

From the house of Cantaure walk north to the Quebrada El Pizarral. The Pueblo Nuevo outcrop in the creek has undergone a lower grade of metamorphism. Within these slates MacDonald (1968) and O. Renz and P. Bartok have located fragments of Jurassic ammonites. Minor foliation can be observed but much less than at the old radar station.

On the return to the bus notice that the area in front of the old Cantaure house is comprised of an orthoquarztite. This is the sandy facies of the Pueblo Nuevo metamorphics. Near the town of San Jose the metaconglomerates of the same formation can be observed.

- **STOP 8 ~4:00 pm Amparo granite and Cantaure Fm. (30 min)**

Walk south 500 m to the Quebrada El Barbasco. The formation you will observe along the walk is the Cantaure Fm. (late Lower Miocene). Please continue walking to a fresh outcrop of the Amparo granite.

El Amparo granite is a dark gray-green granite with strong hydrothermal epidote deposition. The fresh outcrop provides a clearer view of its deformation and fracture patterns. If the group wishes some members may wish to study the granite more closely while the remainder of the group will study the Cantaure Fm.

Return to the Quebrada El Barbasco. The Lower section of the Cantaure Fm. outcrops 500 m to the east with large *Balanus* growing on the granite basement. At the Quebrada Barbasco a diverse macrofaunal assembage has been studied by Jung (1969). Currently the holotype collection resides at Natural History Museum, Basel, Switzerland. The foraminiferal assemblage were studied by Hunter and Bartok (1974) and determined to be in the *Globigerinatela insueta* zone. Along the hills to the south, near the small shelf on the hill is where the *Praeorbulina glomerosa* zone was determined. It is therefore clear that the Cantaure Fm. is laterally equivalent to the Cerro Pelado Fm. and its Querales member. It represents the maximum flooding event MFS 16.5. It is also evident that during this time the paleo-island of Cocodite was reduced to its minimum expression. Along the hills north of the Quebrada the Cantaure Fm. contains the large specimens of the *Ostrea haetensis sowerby*, an index fossil for dating the Lower Miocene.

- **STOP 9 ~4:45 pm Socorro Fm. (15 minutes)**

The sandstone outcrops overlying the Cantaure Fm. were deposited in a coastal environment. The sandstone shows a unique spheroidal weathering pattern. This is caused by the presence of Lithothamnium algae associated with the sandstone. No age determination has been made of the sandstone. However, by superposition and concordance with the underlying Cantaure Fm. the unit correlates with the Socorro Fm.

Discussion:

The Socorro Fm is one of the producing intervals in the La Vela offshore field. The sands are derived from the Amparo granite. In what other direction could the sands have shed?

Optional STOP 10 ~5:30 pm Paraguana Fm. (30 minutes)

Walk up Cerro Pelon. The outcrop is the reference section of the Paraguana Fm. (Hunter and Bartok, 1974). The shale at the base of the hill shows the same varicolored pattern observed in the La Vela Fm. Correlation between the two is more striking in its macrofauna content. Varieties of *Pecten* and *Ostrea* , particularly *Ostrea messor* , reinforce this correlation. The macrofossil beds crown the hilltop.

~6:00 pm Return to Coro. Hotel Miranda

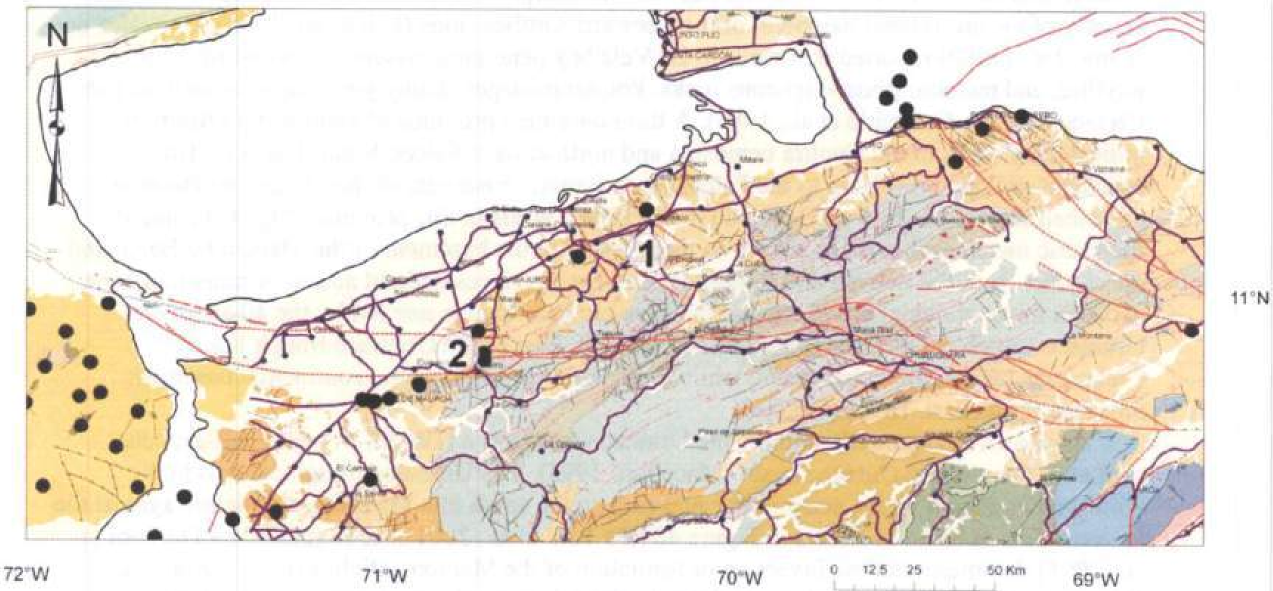
Day 5 Friday (November 3, 2006)

Coro (Hotel Miranda) – Maracaibo (Hotel Maruma)

Theme: E-W transect along the central and western Falcon basin and its relation with the Maracaibo Basin. South America-Caribbean interactions and correlations with the Gulf of Venezuela.

Stops: campos de Tiguaje and Mamon and Surco de Urumaco

Note: Outcrops in this region of northwest Falcon are of poor quality. For that reason, subsurface data will be emphasized along with geologic maps.



Map 6. Geologic map showing the geologic setting of stops for Day Five. Purple line represents road network, small blue dots are towns and big black dots are oil fields. Geologic base map is from Hackley et al. (2005).

Basement provinces of western Venezuela and the Leeward Antilles

Three basement provinces of western Venezuela and the Leeward Antilles are identified based on well data compiled from González de Juana (1980), Curet (1992), and Macellari (1995), along with previous basement mapping efforts of Feo-Codecido et al. (1972) (Fig. 45). Three wells drilled southwest of Aruba (Curet, 1992) reveal that basement in this area is composed of metamorphosed igneous rocks of the Cretaceous Caribbean arc (Fig. 45). Tholeiitic basalts of oceanic affinity are present on several of these wells and are similar to Cretaceous igneous outcrops of the Leeward Antilles islands (Jackson and Robinson, 1994).

Well data from onshore Falcón and La Vela bay, reveal a different basement province associated with a Late Cretaceous intra-arc setting in this area (Fig. 45). These wells, primarily in western and central Falcón reveal Cretaceous metamorphosed igneous rocks that lack the oceanic affinity of the arc-related basement of the Leeward Antilles ridge (Macellari, 1995). González de Juana et al. (1980) reported that wells in La Vela bay penetrated basement consisting of gneiss, phyllite, and metamorphosed igneous rocks. Potassium/argon dating yields ages of early to Late Cretaceous (Feo-Codecido et al., 1984). A third basement province of continental affinity is indicated by wells in the Guajira peninsula and northwestern Falcón basin (Fig. 45). This basement province is related to the Paleozoic to Jurassic basement of the Maracaibo Basin as described from wells by Feo-Codecido et al. (1984). Wells in this province (Fig. 45) contain Paleozoic metamorphic rocks similar to those found in the basement of the Maracaibo Basin and are distinct from the two arc and intra-arc basement provinces defined above. A transition zone between the continental basement and the intra-arc basement is marked by the 40-km-wide Urumaco trough (Macellari, 1995) (Fis. 45 and 46). East of the Urumaco trough lies the Cretaceous metamorphic basement, while to the west is the Paleozoic continental basement province (Macellari, 1995) (Fig. 46).

As shown in Figures 46 and 47, the Urumaco trough is a NW-SE-trending half-graben, similar to the western Curacao basin (Macellari, 1995). The Urumaco trough extends to the northwest as shown on the seismic line and ends to the south into the Mamon anticline against the inverted Falcon basin as shown in Figure 48 (De Toni et al., 2001). As suggested by De Toni et al. (2001) the interpretation, inversion or formation of the Mamon anticline occur during the Pliocene to Recent. The trough opened during the Miocene where a large clastic system developed known as the Urumaco formation. Diaz de Gamero (1996) suggested that this large fluvio-deltaic system was the location of the Miocene proto-Orinoco River before it got shifted to the east as a result of the Caribbean-South American convergence and Andean uplift (Fig. 49A). More recent work by Guzman and Fisher (2006) and Escalona and Mann (2006b) suggest that the Urumaco delta was related to the proto-Maracaibo river which connected through the Falcon Channel in the northeastern part of the Maracaibo basin, and that this system was independent of the proto-Orinoco River. The proto-Orinoco River drained to the east in the Eastern Venezuela basin and was separated from the Falcon basin since late Eocene times by the Lara nappes (Fig. 49B and C).

As mentioned before, the Urumaco trough separates two basement provinces, Paleozoic-continental basement to the west from a Cretaceous-intra-arc basement to the east. So, the key questions related to this region are:

1) **What is the basement beneath the Urumaco trough**? De Toni et al. (2001) on Fig. 48 interpret a continental basement with overlying sedimentary rocks similar to those found in the Maracaibo basin. However, depending on the piercing point used (western of eastern edge of the Urumaco trough) to restore the right-lateral strike-slip motion along the Oca fault, this may not be the correct interpretation. Figure 50 is a proposed restoration along the Oca fault using as a piercing point the western edge of the Urumaco trough. This restoration can explain why sedimentary rocks similar to those found in the Maracaibo Basin overlap the northern part of the western Falcon basin, north of the Oca fault. The Oca right-lateral strike-slip fault zone is part of the complex strike-slip boundary between the Caribbean and South American plates (Audemard, 1995). Its horizontal motion during the late Tertiary is relatively small (<100 km; Rod, 1956;

Kellogg, 1984). The Burro Negro fault intersects the Oca fault near the northern margin of the Lake Maracaibo. By restoring ~80 km of strike-slip motion, the westen edge of the Urumaco trough (Lagarto fault) correlates as the continuation of Paleogene proto-shelf edge represented by the Burro Negro fault. We also suggest that this boundary extends and connects to the Cuisa fault through the Gulf of Venezuela defining the post Caribbean-South American convergence continental boundary.

2) **Where is the extension of the Maracaibo Eocene age fluvial-deltaic sandstones into the Gulf of Venezuela?**

3) **Near the continental boundary along the Urumaco trough, what is the age and type of source rocks found in the Mamon anticline and in the northwestern extension of the Urumaco trough?**

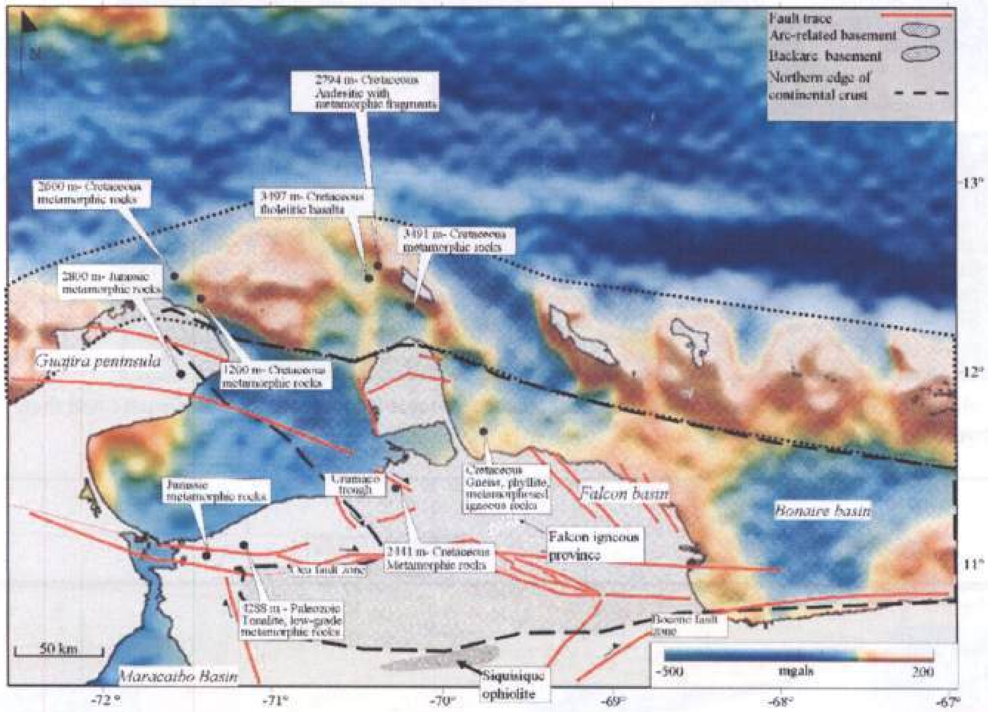


Figure 45. Map showing the known ages of basement rocks in the northern Falcon and Maracaibo basins, and offshore regions. Offshore map of GEOSAT gravity shows major basement trends.

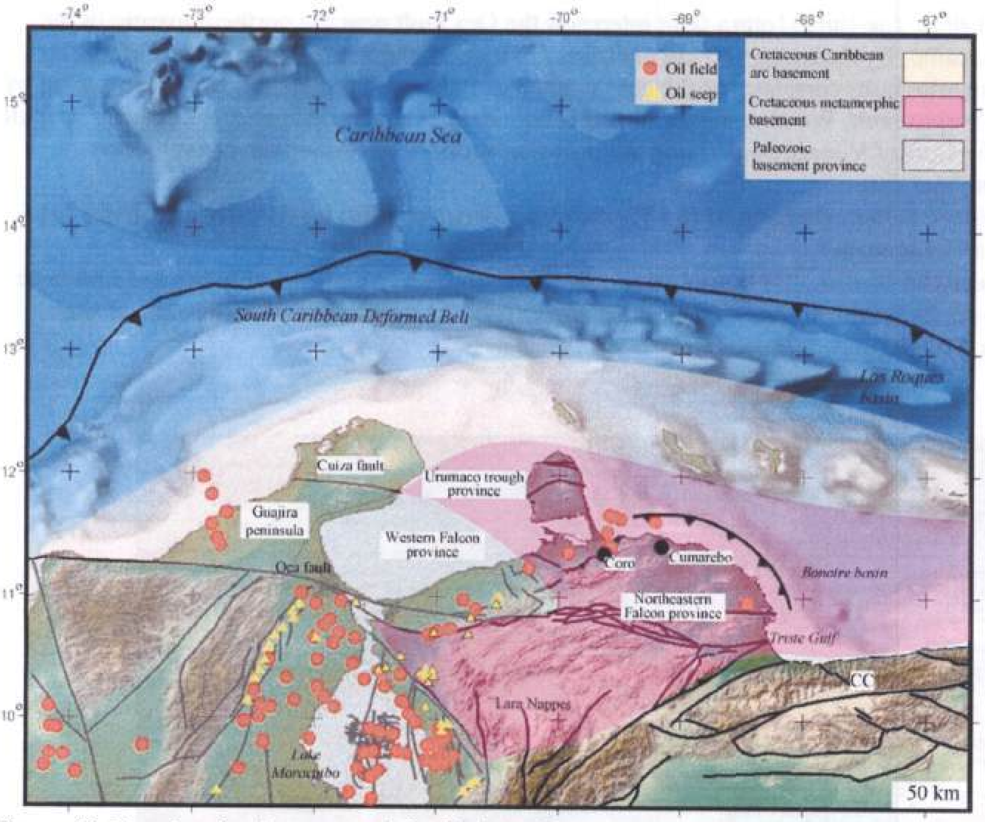


Figure 46. Map showing the suggested distribution of basement types in northwestern Venezuela and their relation to hydrocarbon types.

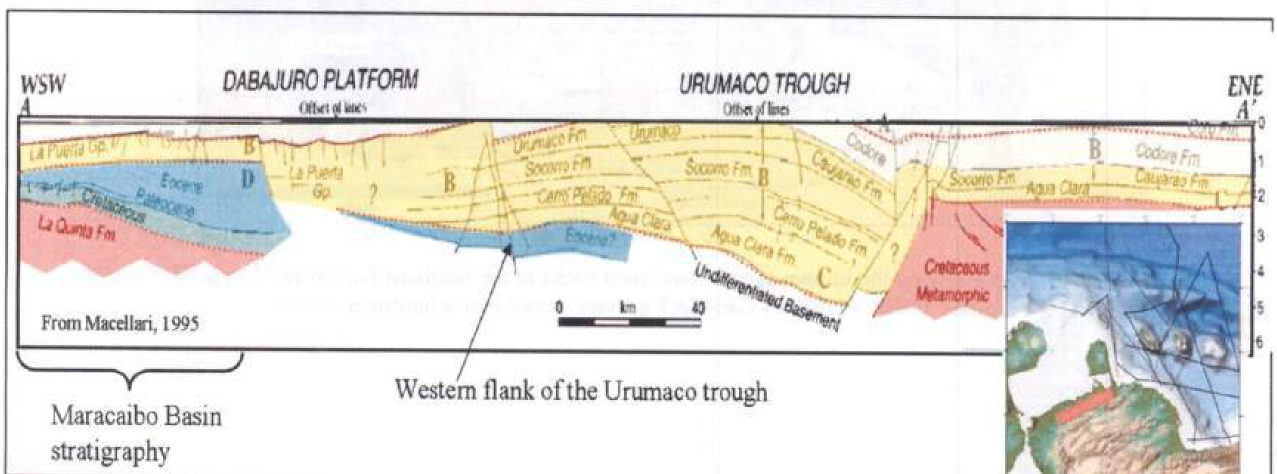


Figure 47. Interpreted seismic line along the northern coast of central and western Falcon showing the half-graben structure of the Urumaco trough (modified from Macellari, 1995)

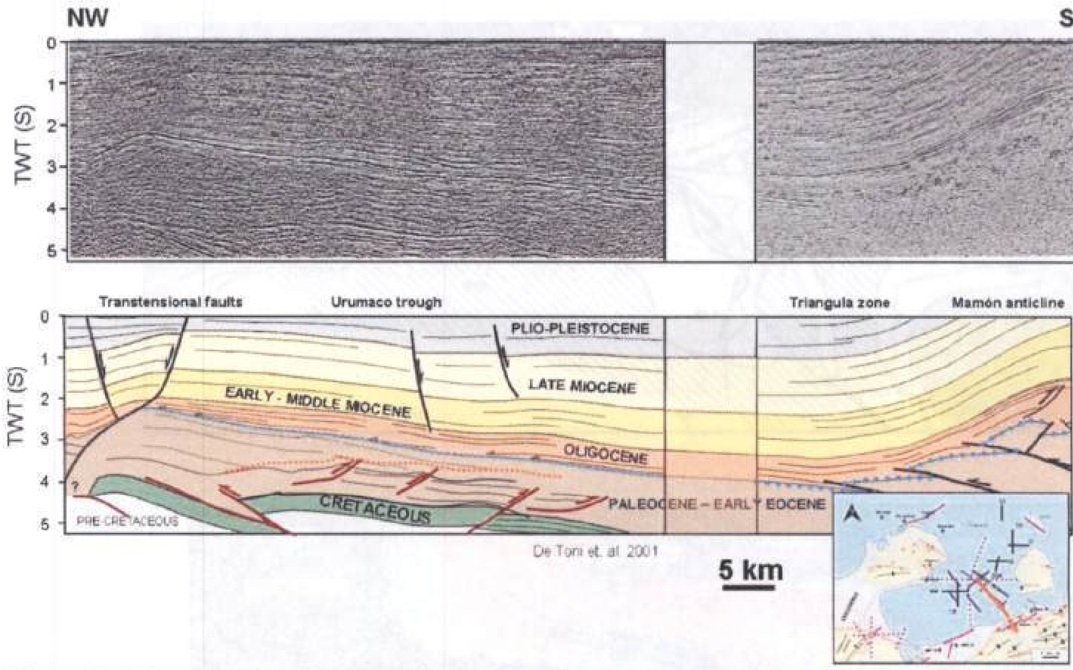
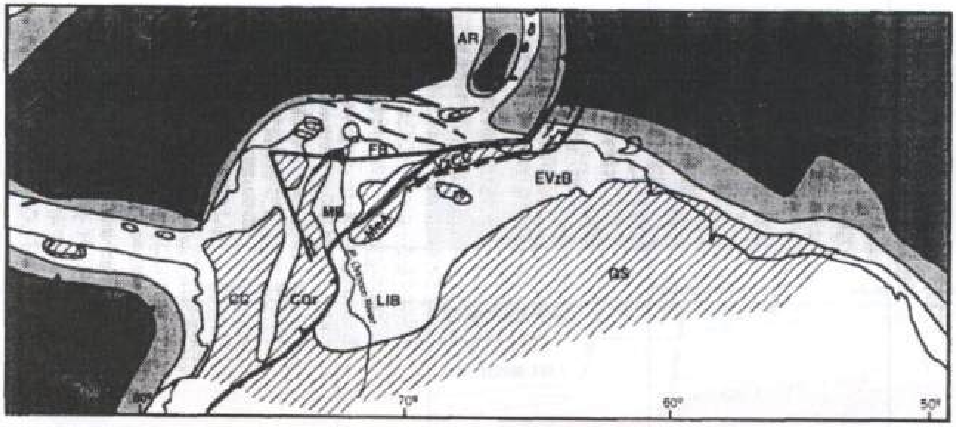


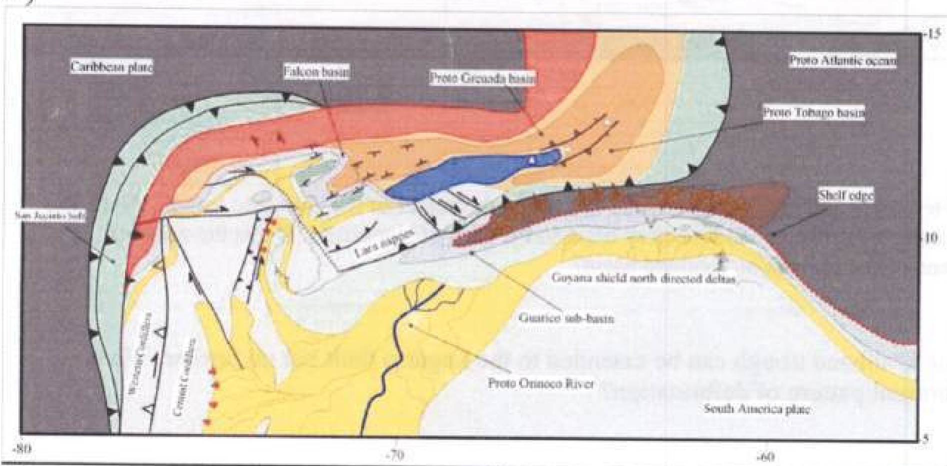
Figure 48. Uninterpreted and interpreted seismic line along the center of the Urumaco trough. Note that this feature is the deepest sedimentary basin in the Gulf of Venezuela. Is this the northern extension of the Marcaaibo foreland basin?

Discussion:
Thrusting in the Urumaco trough can be extended to the Lagarto fault but no further. What controls this unusual pattern of deformation?

A)



B)



C)

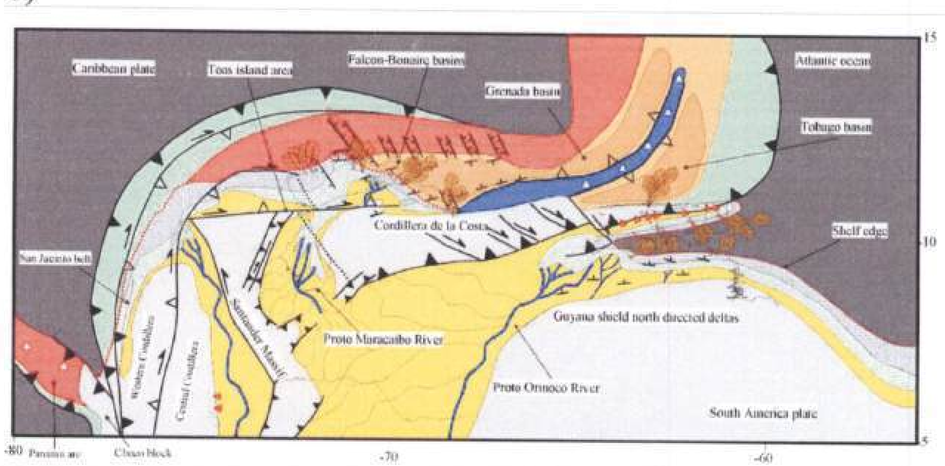


Figure 49. A) Paleogeographic map of the early Miocene showing the proto-Orinoco River draining through the Maracaibo basin and its inferred delta located in the Urumaco trough region (Diaz de Gamero, 1996). B) Paleogeographic map of the middle Oligocene showing the distribution of main drainages in northern South America. C) Paleogeographic map of the middle Miocene showing the reactivation fo the proto-Maracaibo river draining through the Maracaibo basin into the Urumaco trough (Escalona and Mann, 2006b)

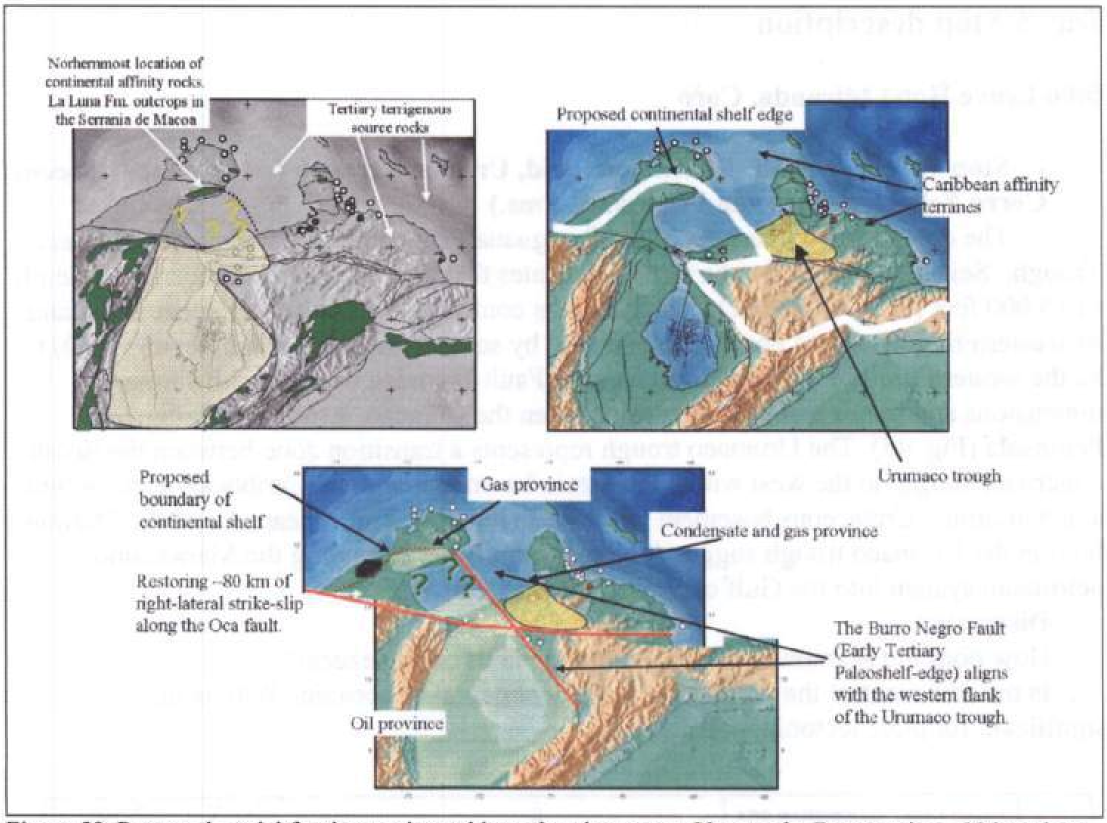


Figure 50. Proposed model for the continental boundary in western Venezuela. By restoring ~80 km along the Oca fault, the western edge of the Urumaco trough aligns with the Paleogene proto-shelf edge (Burro Negro fault) of the Maracaibo basin

Day 5 Stop description

8:00 Leave Hotel Miranda, Coro

- **Stop 1 ~9:30 El Mamon Field, Urumaco trough (middle-late Miocene Cerro Pelado, Socorro and Urumaco Fms.)**

The depression to the west of the Paraguana Peninsula is known as the Urumaco Trough. Seismic lines across the trough indicates that the top of the Oligocene at a depth of 10,000 feet (Figs. 47 and 51). The trough is controlled by Miocene-Recent faults and its western limit (Lagarto Fault) is considered by several authors (Pumpin et al., 1980) to be the western limit of the Caribbean nappes. Fault-bounded troughs with similar dimensions and trends can be observed between the Curacao, Aruba and Paraguana Peninsula (Fig. 45). The Urumaco trough represents a transition zone between the South American margin to the west with a Paleozoic basement, and the Caribbean terranes with a metamorphic Cretaceous basement to the east (Fig. 51). The appearance of the Mamon field in the Urumaco trough suggests the opportunity for extending the Maraacaibo petroleum system into the Gulf of Venezuela (Fig. 50).

Discussion:

How does the Mamon field extend into the Gulf of Venezuela?

Is the basement of the Urumaco trough continental or oceanic? Why is this significant for plate tectonic models?

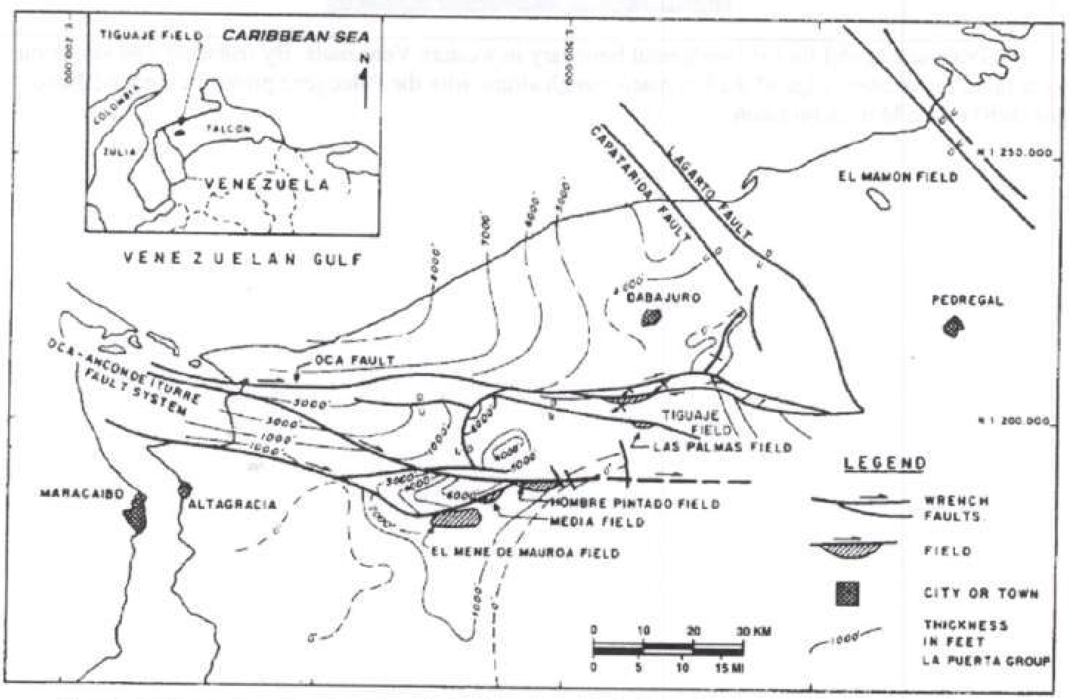


Figure 50. Map view showing the relative location of oil fields in western and central Falcon (from Molina, 1993).

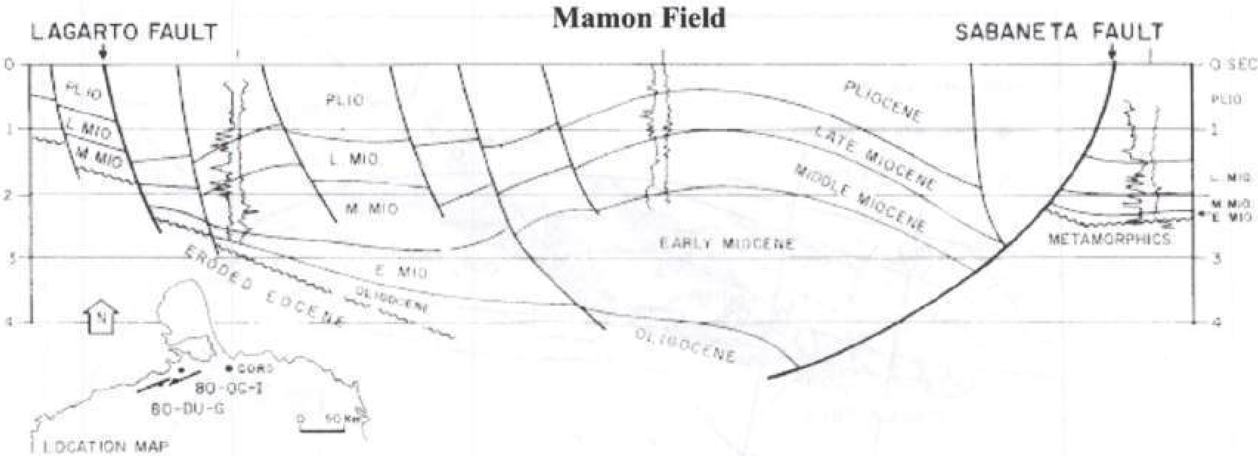


Figure 51. Cross-section showing the Urumaco trough and the anticline of the el mamon field int he center of the trough (Boesi and Goddard, 1991)

LUNCH ~12:00 Dabajuro area

- **Stop 2 ~1:30 Tiguaje field (main reservoir: Miocene La Puerta Fm.)**

The Tiguaje Field has been the largest field discovered in Falcon onshore since the beginning of exploration in Venezuela in the 1920's. It was discovered by its surface expression and adjacent oil seeps. The structure is a three-way dip closure and fault closure against the Oca Fault (Figs. 51 and 52). The main producing formation is the Miocene La Puerta sandstones unconformably overlying Eocene shales. The source rock for the region has been identified as the Agua Clara Fm (Fig. 29). The importance of the field is the presence of commercial hydrocarbons in the region. The problem is the volume of oil. There are at least four possible causes that come to mind: 1) The Agua Clara Formation in close proximity to the field is too lean to generate significant accumulations; 2) the seal is inadequate; 3) the distance from kitchen to reservoir is too great and there is a lack of adequate carrier beds; 4) the deformation postdates the generation. Further studies are required.

There are additional opportunities in the region that should be considered. One is the extent and presence of Eocene turbidites in the region. One study that may be suggested is to determine the variability of source rock character within the Agua Clara and other candidate source rocks within the basin.

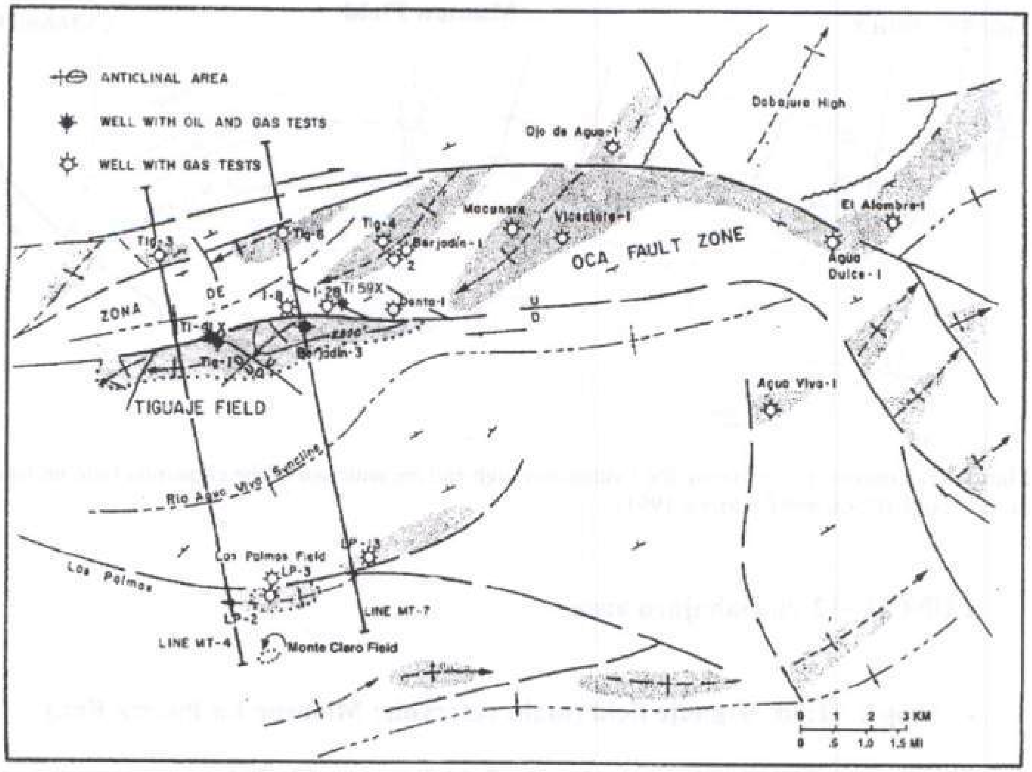


Figure 51. Map showing the main structural elements of the Tiguaje Field (Molina, 1993).

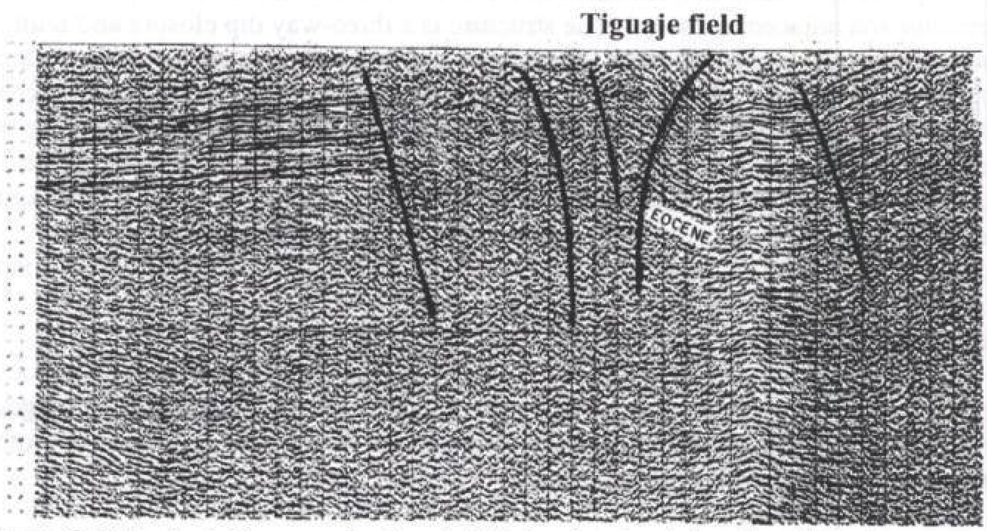


Figure 52. N-S seismic line across the Tiguaje field showing the relationship with the flower structure produced by right-lateral strike-slip motion of the Oca fault (Molina, 1993).

Discussion:

Is the Tiguaje field the northward continuation of the Maracaibo Basin Petroleum system?

What is the effect of the Oca fault on the regional structure of the region?

5:00 Arrive to Hotel Maruma, Maracaibo

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