

Exploration Framework Atlas Series:

Volume 2: Venezuela

by

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Volume 1: Colombia

Volume 3: Ecuador-Peru-Bolivia

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CRETACEOUS STRATIGRAPHY

THE STRATIGRAPHIC DEVELOPMENT OF THE PASSIVE MARGIN

The Cretaceous stratigraphy of Venezuela shows a regional transgression, starting at the end of the Jurassic and reaching its maximum in the Early Turonian (Phanerozoic MFS). This was followed by a regional regression that continued into the Cenozoic in western Venezuela, with a latest Cretaceous (Maastrichtian-Palaeocene) transgressive pulse only in eastern Venezuela. This first-order sequence filled accommodation space created by relatively local Triassic to Barremian extension followed by regional thermal subsidence on which any eustatic sea-level changes were. The record of this can be easily divided into second-order and in some cases into third-order sequences. The use of sequence stratigraphic nomenclature here does not imply an interpretation concerning eustasy but is only descriptive, based on evidence from extensive field work, sedimentological and palaeontological analyses, all plotted on retro-deformed base-maps to produce the palaeogeographic maps in this atlas.

Cretaceous time slices presented in this report were selected in an unconventional manner. We have not selected the traditional stage-by-stage approach for the construction of the maps nor have we divided the Cretaceous into time slices of equal duration. Instead, our division of the Cretaceous system is based on facies associations which can be grouped into sequences and related depositional systems rather than forced into specific time periods. In several cases, facies or ages shown on the maps do not match the published literature for many reasons including:

- Poor dating and inadequate stratigraphic philosophies yield different names for the same unit and the same name applied to different units, both of which lead to maps full of spurious and unrelated detail, or artificial grouping of units which may be separated by one or more transgressive/regressive cycles. The maps presented here have taken care to avoid stratigraphic nomenclatural problems and if we propose to put two formations in the same map it is because we have our own direct observational evidence rather than assemblages of information from the literature.
- Different names for slightly different facies within different basins and nomenclature complications introduced by "competing" companies, surveys and universities. Why, for example, do names change from the east to the west of Venezuela or from one side to the other of the Mérida Andes? Questions such as which unit is equivalent to the La Luna or what is the age of the Capacho become common and difficult to resolve without an adequate biostratigraphic framework. The maps presented herein are viable hypotheses created with our biostratigraphic framework and with sequence stratigraphic concepts and methods.
- Many different names for completely different facies. In terms of traditional stratigraphy it is obviously correct to propose different names for facies that are different and of the same age (coeval and heteropic) but this complicates understanding regional distribution and significance of these facies changes. A clear example is the relationship between the Escandalosa Formation of the Barinas Basin, and the coeval Seboruco and La Grita members of the Capacho Formation near Mérida.

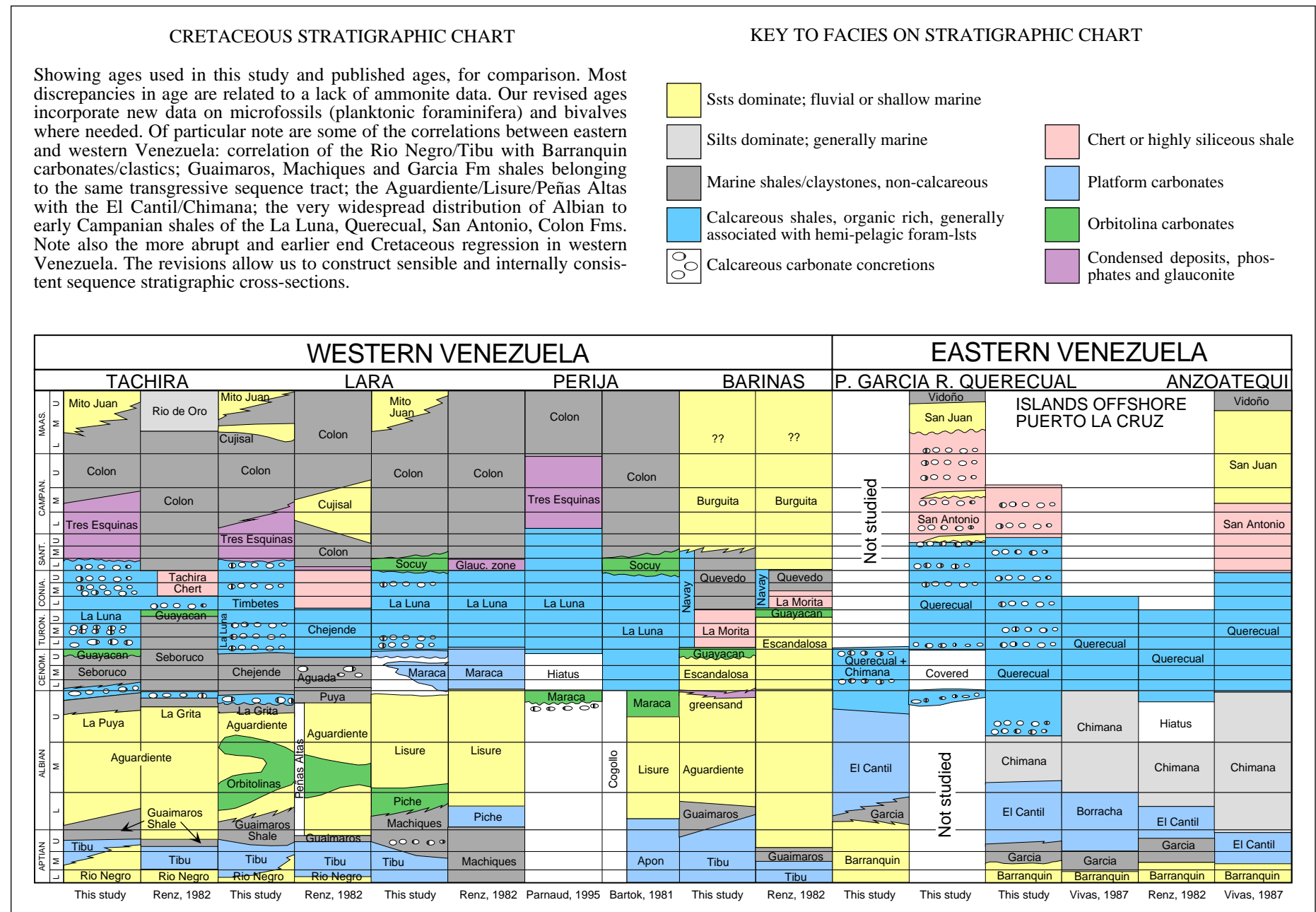
In addition to nomenclatural problems mentioned above, eastern and western Venezuela stratigraphy has been treated as completely different because those two regions are currently separated by a metamorphic belt. The two are more similar than normally usually thought but their connection gets complicated by poor biostratigraphic constraints in shallow-water facies and by differences in stratigraphic thickness. Furthermore, there are many more stratigraphic nomenclatural problems which are related to the intrinsic nature of some geologists and their need for complicating simple explanations proposing new names. The maps presented and described in this report were constructed with all these issues and constraints in mind and they follow sequence stratigraphic concepts and methods. However, all the maps comprise a time interval rather than a time line and may represent several depositional sequences which were deposited in a general trend without major breaks in deposition. For this reason the maps contain a mixture of facies of slightly different ages and should be read bearing this in mind. The maps are accompanied by detailed sequence stratigraphic cross sections for the map time interval, resolving correlatability of facies with better time precision and we also provide summary stratigraphic cross sections (Page 5b) showing our views on Cretaceous sea-level behaviour and basin filling.

Facies boundaries presented in the maps commonly improve upon facies and ages compiled from our literature search; consequently, map descriptions are only partially based on literature. Descriptions presented here contain alternative hypotheses and ideas, many of which have been tested whereas others remain untested. Another issue concerns the thickness of the Cretaceous, both the total thickness and the thickness of individual Cretaceous stages and/or formations. Thicknesses have been grossly overestimated in some regions due to non-recognition of low-angle faults, largely because many classic studies pre-date the awareness of the importance of large-magnitude horizontal displacements.

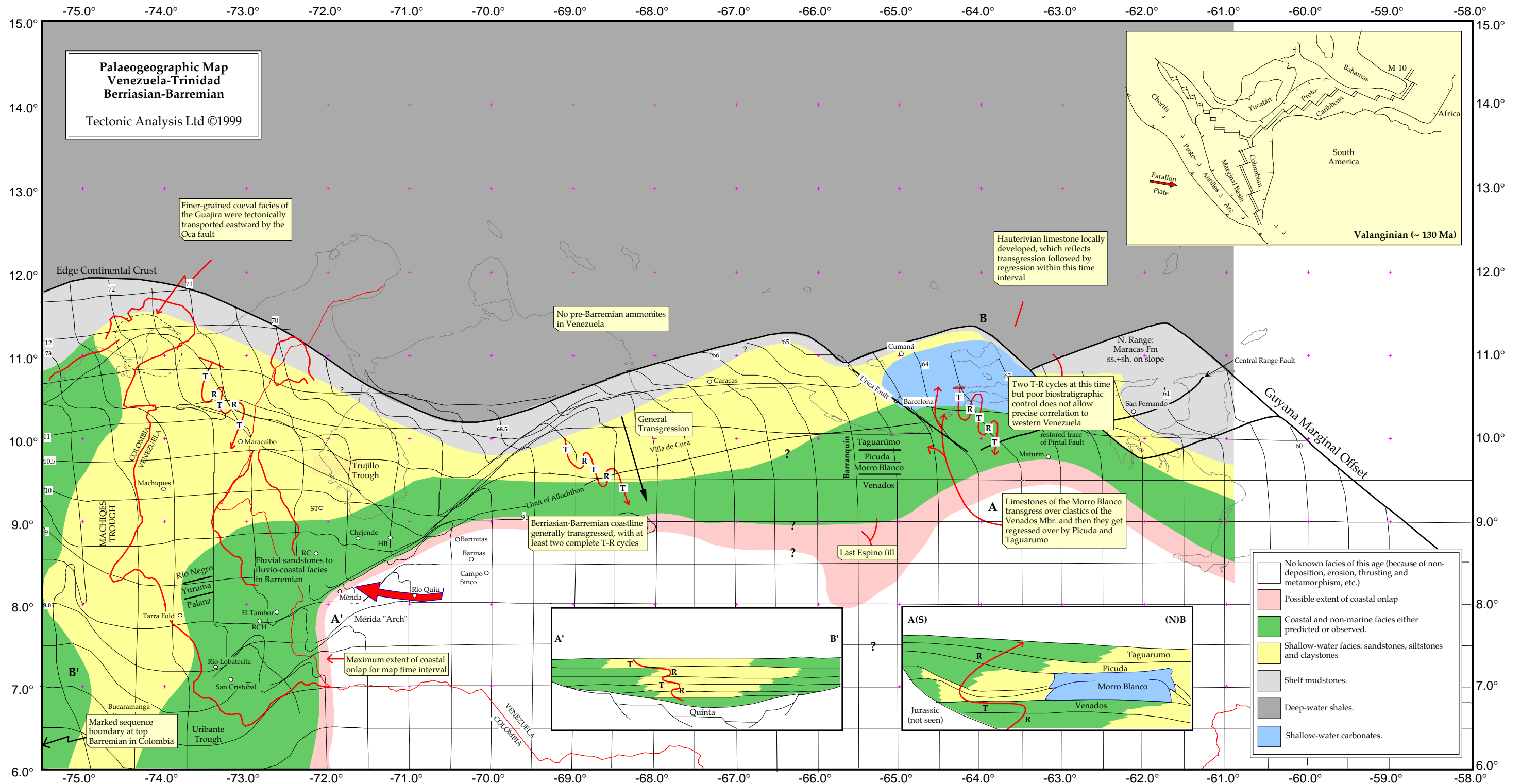
We need to re-stress the importance of the palinspastic reconstruction of the Andean orogenesis on which the Cretaceous facies and units have been plotted. Variable amounts and directions of shortening of up to 200 km and huge strike slip offsets have occurred across and within the Andes, depending on location. Acknowledgment of these displacements is essential to the proper interpretation of the original size, shape, and configuration of the Cretaceous depositional platform and data-plotting in this palaeo-reference frame allows a more accurate portrayal of facies relationships, of the platformal character of the Cretaceous, and of the parameters controlling hydrocarbon source rock quality. Also critical is the depiction

of the size and shape of the early foredeep basins along the leading edge of the early Andes - the area covered by viable source rocks was initially far larger than their present distribution and areas of early maturation and the distances over which oil migration has taken place can only be appreciated by developing the palaeogeography in the palinspastic framework. In the descriptions of the various maps which follow, we point out specific instances where the palinspastic reconstruction is particularly significant, showing how the actual basin configuration was considerably different to previous interpretations.

All the maps show a hypothetical coastal onlap region. The precise location of this (a global hypothetical line that separates regions of erosion from regions of deposition) is not possible without a complete seismic grid with accurately dated reflections. The facies boundary line between shallow-marine facies and coastal deposits represents shoreline deposits. Basinward or landward movement of this facies boundary is, by definition, transgression or regression, respectively. Transgression or regression are shown almost independently of shifts in coastal onlap, as sequence stratigraphic theory proposes. In most maps there is an arrow or a series of arrows that represent what that facies boundary lines were doing for the particular map interval.



EARLY CRETACEOUS PALAEOGEOGRAPHY



BERRIASIAN-BARREMIAN PALAEOGEOGRAPHY

Facies associations for this time interval show the effect of differential post-rift thermal subsidence, locally favouring the development of shallower-water belts well away from the Guyana Craton and resulting in development of additional shallow water facies belts away from the paleocoastline.

In the west facies of the Río Negro have relatively distal equivalents (referred as Aguardiente) and, further offshore, additional proximal equivalents are also called Río Negro. Strata in the depression between the two shallow-water belts are thicker (e.g., the Uribante, Machiques, and Barquisimeto troughs - e.g. see inset for facies relationships across one of the troughs). Facies belts in the east were similar but lower sedimentation rate favoured more carbonate productivity. Some calcareous units within the Barranquin Formation correlate laterally to the south with relatively distal facies of the Valle Grande Formation and further south with fluvial and coast-

al deposits of the Barranquin. Facies associations within the time span of this map have been regarded as potential reservoirs because of their coarse-grained nature, however, only a few places in northern South America have production from lower Cretaceous facies.

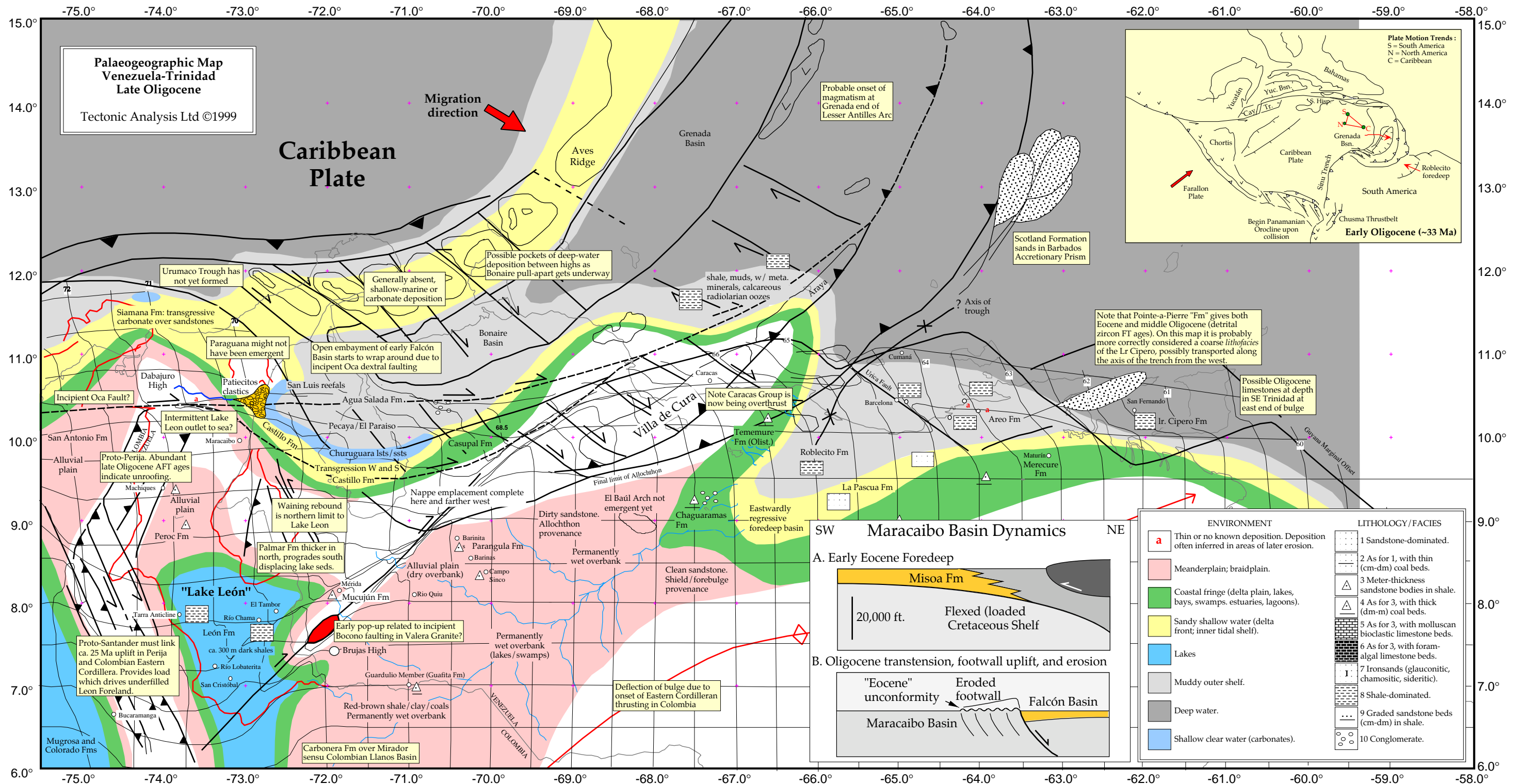
The Cretaceous system transgressed over continental facies of the Girón, La Quinta and other Jurassic red bed intervals. Generally the Cretaceous sits on a major beveling unconformity ("breakup u/c") which formed during Jurassic differential subsidence. Coastal onlap stepped south and east towards the Guyana Craton. Coastal onlap generally stepped in those directions throughout the entire Cretaceous with few exceptions (shown on the maps).

The Early Cretaceous transgression is generally composed of shallow-water siliciclastics mixed with carbonate buildups and localized reefs with little shale and few source rocks (Caqueza Gp in East. Cord. of Colombia is an exception, due to greater

water depths). In the east, the lower Cretaceous comprises siliciclastic coastal facies (Barranquin Fm) with some restricted shallow -water carbonates (e.g., Morro Blanco, Taguarumo). Coeval, very similar, facies in western Venezuela have been assigned to the Palanz, Yuruma and Río Negro fms, also composed of a mixture of coastal and shallow-marine siliciclastics with carbonate buildups.

In terms of sequence stratigraphy, the Early Cretaceous can be generally assigned to a transgressive systems tract with several regressive episodes. Transgressive-regressive episodes as well as the general transgression that occurred during this time interval are shown in the map as a wavy line with an arrow at the end. Directionality of the line implies time with the initial portion of the arrow being at the base of the time span comprised in the map and the tip of the arrow at the end of the time comprised on the map.

LATE OLIGOCENE PALAEOGEOGRAPHY



LATE OLIGOCENE PALAEOGEOGRAPHY

From Late Oligocene time, continuing oblique collision was accompanied by the onset of the Andean Orogeny and the onset of E-W trending transcurrent faulting along northern South America, which eventually involved the Falcón Basin. Continued eastward migration of the Caribbean Plate required E-W trending dextral faults to propagate through the allochthons (once part of the Caribbean Plate) once they "docked" against northern South America. The eastward propagation of overthrusting, then docking, implies that strike-slip and associated basins also younged east - with present day propagation occurring in easternmost Venezuela and Trinidad. In the Falcón area, dextral slip may have been incipient at this time (on **Page 13b** we outline why we think this is not the *primary* cause of basin initiation) but strike-slip and pull-apart formation is more prominent in the Miocene. Propagation of crustal-scale dextral faults would have continued the unloading effect noted on **Page 13b**, enhancing Falcón subsidence and northern Maracaibo rebound (see inset above). Most of the rebound had occurred by the latest Oligocene or earliest

Miocene, prior to deposition of the Icoetea Fm. The eroded area was then transgressed by the La Rosa Formation sea in the Early Miocene, driven by load-induced subsidence related to Andean thrusting. By now, the leading edge of subducted Caribbean lithosphere had reached to beneath eastern Lake Maracaibo, requiring underthrusting along the north side of the Leeward Antilles, at this time located just north of Falcón. This "trench" must also have propagated eastwards with the leading tip of a scissors type fault zone (see inset on **Page 13a**) with the Leeward islands forming a large wedge, with likely very complex internal deformation, overlying oppositely-dipping underthrust zones. At about this time, arc volcanism began in the southern Lesser Antilles and extension in Grenada Basin slowed.

A dramatic increase in rate of westward advance of South America over the mantle at ca. 25 Ma seems to have kick-started Andean orogeny in the west, with the tectonic load of the rising Perija Andes and Santander Massif driving the depression filled by "Lake Leon" in the Maracaibo area, which was filled by overlapping coarse sediments prograding from west (Peroc Fm) and ?NE (Palmar Fm). Explicit evi-

dence for Merida Andes uplift is less clear. Chert pebbles in the basal Guayabo Fm might have come from the Santander Massif. 21-24 Ma AFT ages are known only from the Valera Granite (?local Bocono Fault related pop-up?) - all other ages are late Miocene. No Mérida-derived alluvial-fan conglomerates are known. In the Barinas Basin, the fine-grained alluvial basal Parangula Fm passed south into the coal-bearing Gardulio Mb of the Guafita Fm and the Carbonera Fm (Colombian Llanos usage) which may have been part of a broadly NE-directed low gradient (?intermittent marine incursions?) river system which allowed Lake Leon to drain into the Roblecito foredeep. The Villa de Cura nappe was shedding sediment of "orogenic" sediment southwards into the Guárico sub-basin of central Venezuela (regressive, east-younging Chaguaramas Fm). Just west of the Gulf of Barcelona, the olistostromes of the Tememure Fm reflect rapid trench then accreted to the allochthons in the earliest Miocene. Distally along the trench, turbidite sands reached into the proto-Caribbean ocean (Scotland Fm of the Barbados accretionary prism). In the early Miocene, emergence of the prism provided detritus for the Naricular Fm of the western Serranía.

SUMMARY BASIN CHART: BARINAS

Time	Setting/Stage	Stratigraphy	Source	Reservoir	Seal	Timing		
						Traps	Matur'n	Migration history
Quaternary	Accelerating uplift of Mérida Andes, part of load directed toward Barinas Basin, with up to 5 km foredeep fill (thermal blanket).	Guanapa				Thrust related, especially during R. Yuca Fm. (Lt. Miocene-?Pliocene)	Matur'n beginning in sub-thrusts of Mérida.	E-ward and S-ward migration from sub-thrusts in Andes. Foredeep fill is generally not deep enough for intra-basinal maturation.
Pliocene		Rio Yuca						
Miocene L M E		Rio Yuca Parangula (Quebradon)						
Oligocene L E	Rebound of Lara foredeep causes regression, erosion	Unconformity and hiatus						
Eocene L M E	Distal foreland basin (of Lara nappes, northern Maracaibo) Passage of peripheral bulge. Block faulting, erosion down to Turonian on horsts.	Paguey Masparrito Gobernador Unconformity and hiatus		Gobernador sandst., 1°	Paguey Shale	Normal faulting		Possible arrival of oil from northern Maracaibo (Lara) foredeep (Pauji/Paguey time). Oils would have been biodegraded immediately, due to lack of burial in the Barinas Basin.
Paleocene L E								
Upper Cret L E	Passive margin	Burguita Navay Escandalosa Aguardiente	Navay/La Luna, II <4% TOC	Burguita 2° Escandalosa 2°	Navay?, but brittle fracture			
Lower Cret L E	Rift-flank flexural uplift?	Peneplained unconformity and hiatus						
Jurassic	Rifting of Yucatán from Venezuela margin	local La Quinta						

Basin: BARINAS

I, II, III, type org matter. F, fault. S, strat. C, combo.

mostly non-marine
 mostly marine

Known
Inferred

SEDIMENTOLOGY AND STRATIGRAPHY OF WESTERN VENEZUELA

2) Orocué Gp (Los Cuervos Fm) and Mirador Fm, Tarra Anticline.

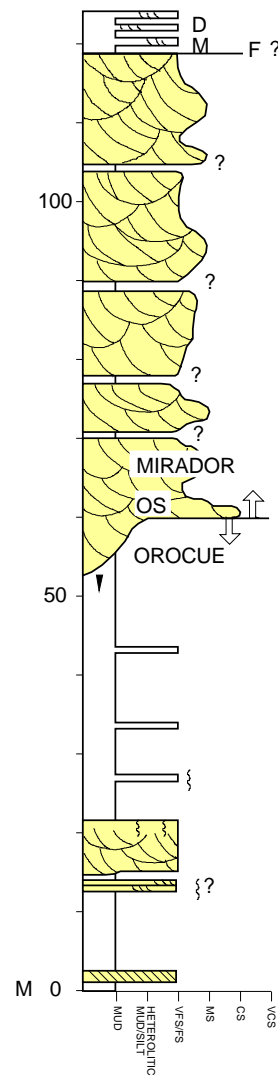
Type area of the Mirador Fm ssts, underlain by mudstones of the Los Cuervos Formation (Orocué Gp). Lower units of the Orocué, i.e. Catatumbo, Barco Fms are not exposed here. Nearby, a large oilseep occurs in Orocué Gp sandstones.

Age: Los Cuervos Fm is Paleocene and the Mirador is lower and middle Eocene, but palynological dating is not particularly good in this area.

Facies description: Lower 50 m consists of Los Cuervos gray and mottled gray-pink, massive mudstones with some rootlet levels, with a 6 m cross-stratified sandstone, with bioturbated upper surface. Nearby there are coal beds lower down.

Mirador is mostly fine-medium sst. Sst up to 15 m thick are separated by 1 m pale gray, structureless mudstones. Lowest sst has an incised base, with ca. 7 m relief over 40 m laterally with basal 1 to 2 m coarse grained and oil stained.

Facies interpretation: Los Cuervos mudstones interpreted as aggradational paleosoils formed in a fluvial- or delta-plain overbank setting. The associated sandstone interpreted as a fluvial (more likely given distance from sea) or distributary channel. Mirador sandstones interpreted as fluvial deposits, in association with overbank-paleosol mudstones. With evidence for lateral accretion elsewhere this implies a meandering, rather than braided, stream setting. The incised base of the Mirador, combined with regional thickness variations suggests it fills incised valleys, implying an unconformable contact with the Los Cuervos. Palynology shows no detectable time gap, suggesting that the relative sea-level fall was of short duration, possibly corresponding to one of the three Type-1 sequence boundaries clustered near the Paleocene-Eocene boundary on the Haq et al. (1988) chart.



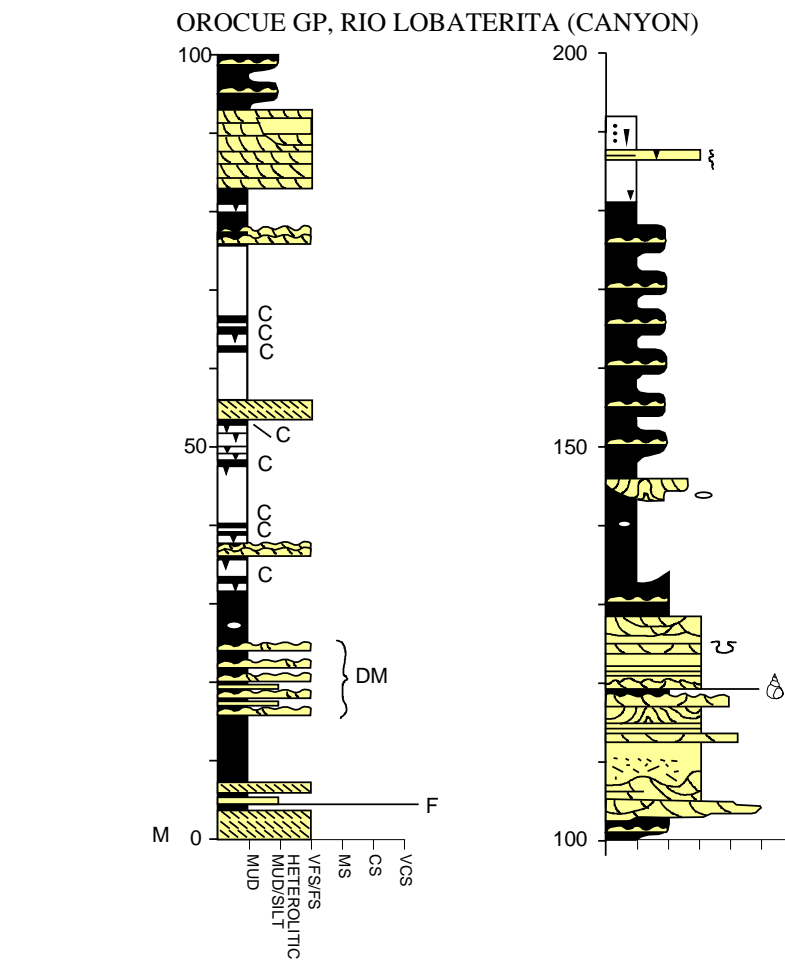
3) Orocué Gp (Catatumbo, Barco, Los Cuervos fms), Río Lobaterita canyon. (Logs above right)

Entirely within the Orocué Gp comprises mudstone-rich intervals at the base and top, separated by a 50 m sandstone-dominated unit, consistent (both lithology and thickness), with the tripartite Orocué Gp regional stratigraphy.

Age: Fossils are rare in the Orocué Group. Most palynological data suggests it is Palaeocene. On our paleogeographic maps, we assume the Catatumbo Formation to be Lower Paleocene and the Los Cuervos Formation to be Upper Paleocene (Pages 10b, 11a).

Facies description: Lower 30 m are dark gray mudstones, succeeded by 50 m of pale gray and mottled gray-pink, massive mudstones with rootlets and coal beds. The subsequent Barco Fm includes meter-scale sandstones, cross-bedded, locally structureless and containing mud chips. Gastropods at 119 m. Above is a 50 m heterolithic interval (Los Cuervos Fm), with streaks of silts and asymmetrical ripple strings varying rhythmically on a dm scale. There is an undulating discordance (2 m relief in 10 m) at 133 m filled by mudstone. At 145 m, a channel has ca. 12 m of relief over 50 m laterally, infilled and overlapped by heterolithics. Pale mottled mudstones with roots and micro-nodules cap the section.

Facies interpretation: The lower dark mudstones are interpreted as offshore or lacustrine, possibly part of a "wet" alluvial, or delta plain. The overlying pale mudstones may be paleosoils, showing long-term aggradation of mud, probably in an alluvial or delta plain. The sandstone bodies of the Barco Fm are interpreted as fluvial or distributary channels. The combined facies of the Catatumbo-Barco sug-



gest deposition in delta or wet alluvial plain lakes cut by channels. In the Los Cuervos Fm, the rhythmic heterolithics are interpreted as offshore-lacustrine deposits. Asymmetrical-ripple strings may represent dilute, river-fed turbidity currents, common in lakes. The mud-draped discordance at 133 m is interpreted as a slide- or slump scar. In contrast, the channeloid discordance at 145 m is interpreted as a non-depositing channel, filled passively after abandonment by onlapping strata, including a basal slump bed. The succeeding upward-convex packages are interpreted as underflow-fed, point-sourced depositional lobes, again found in lakes. The combination all suggests a lacustrine delta-front environment. The mudstones capping the section may be paleosoils, interpreted as floodplain deposits, consistent with the overall fluvial and/or deltaic Orocué interpretation here.

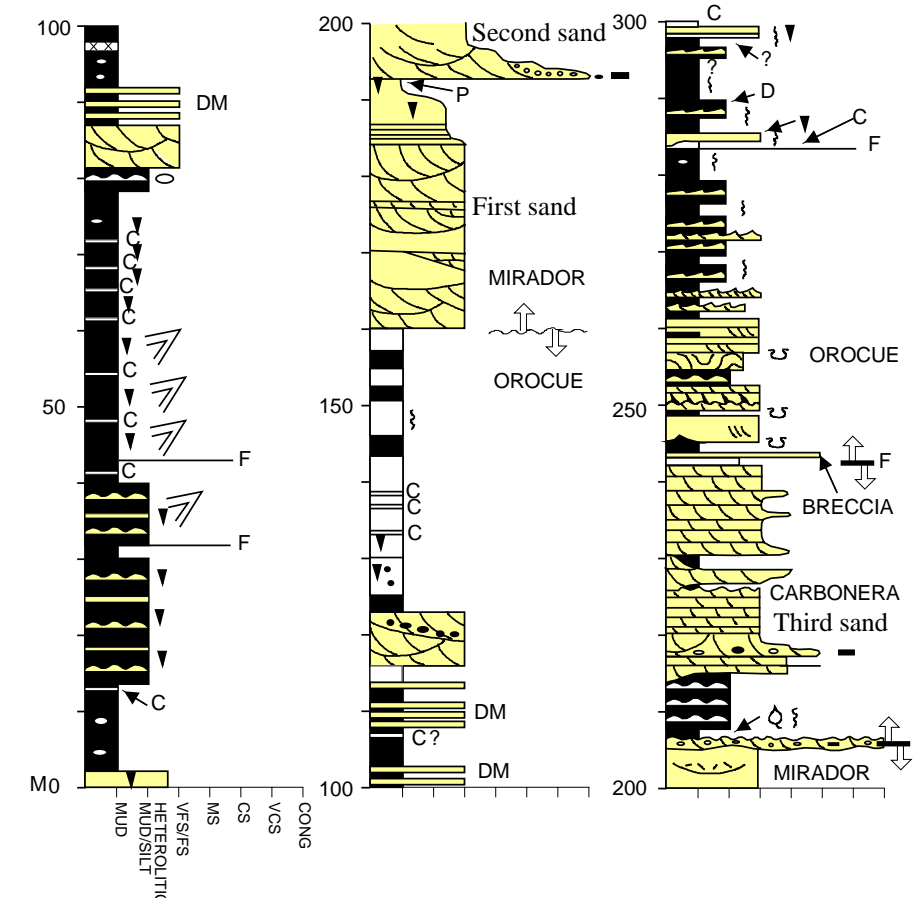
4) Orocué Group (Los Cuervos Fm), Mirador Fm and Carbonera Fm, Río Lobaterita valley. (Logs shown above right)

The section shows two mudstone units, separated by three thick (10-30 m) sandstones (160-242 m). The mudstones can be assigned to the Los Cuervos Fm. We assign only the lower two of the three sands to the Mirador Fm. The "third sand", plus the underlying heterolithic interval (206-215 m) probably belong to the Carbonera Fm with a basal transgressive lag and a different depositional environment. This unconformity (at 205 m) at the base of the Carbonera Fm is noted regionally.

Age: The Carbonera Fm "third sand" is late Middle or Late Eocene age, coeval with the main reservoir at Guafita and Canõ Limon, all probably similar tide-influenced delta deposits. Thus this section could be a useful outcrop analog for reservoir-modeling studies. The upper mudstone-dominated interval (260-300 m) gave palyno-ages of Early Eocene and Late Paleocene-Early Eocene, suggesting a repetition of the Orocué Gp by a fault, with associated breccia.

Facies description: The Los Cuervos Fm (0-160 m) is dominated by variably colored mudstones with rootlets, coal interbeds and crocodile remains. The "first sand" and "second sand" (Mirador Fm) are sharp-based, trough cross-stratified, fine-sand

OROUCUE Gp. + MIRADOR FM., RIO LOBATERITA (ROAD + CANYON)

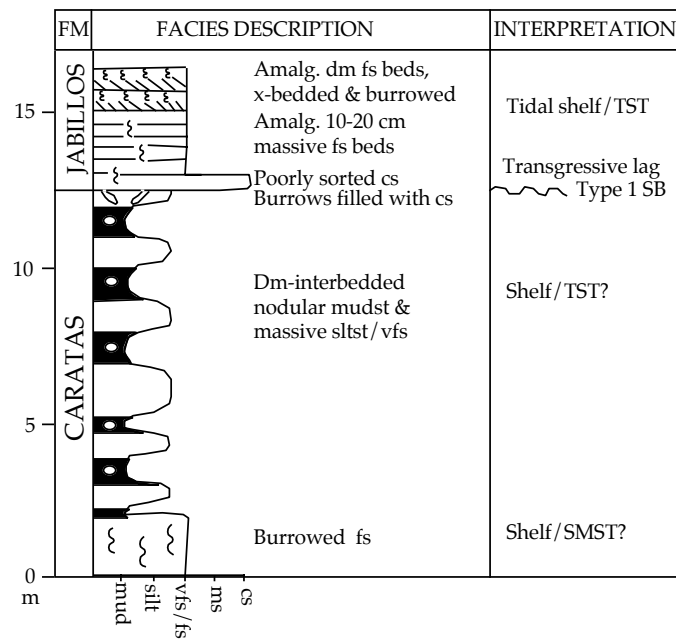


with coarse sand/pebbles common in the lower 2 m of the "second sand" (quartzite and chert), with no burrows. Capping the "second sand" is a thin (1-1.5 m), trough-cross-stratified bed whose foresets alternate between fine sandstone and conglomerate (base of Carbonera), with some tabular mudclasts up to 40 cm long. The base of the bed undulates irregularly; the top has symmetrical ripples. Overlying is a coarsening-upward succession, starting with burrow-mottled mudstone, followed by 7 m of heterolithics and topped by the tabular cross-bedded channel-filling "third sand" (part of Carbonera Fm). Above 243 m, probably faulted Los Cuervos, is dominated by: (1) burrow-mottled mudstones; and (2) heterolithics, slightly burrowed facies. Rootlets are present in a 10 cm mudstone bed at 285 m. Thin coal beds are noted at 284 m and at 300 m.

Facies interpretation: The Los Cuervos (0-160 m) was deposited in a mud-dominated alluvial or delta floodplain environment prone to emergence (rootlets, palaeosols), with local peat marshes (i.e. coals) consistent with the regional context and crocodile remains. The base of the Mirador "first sand", representing the contact between the Los Cuervos and Mirador formations, appears to be planar and concordant, possibly an unconformity of short duration. The "first" and "second" sands are fluvial-channel deposits fining into laterally accreted upper point-bar sediments, in a meandering rather than braided channel. Sediments above (Carbonera) represent a transgressing shoreface, leaving a thin lag overlying a ravinement surface (the thin pebbly bed at 206 m), with mudclasts derived by wave-erosion of a retreating cliff. The overlying heterolithics are subaquatic, deposited above a marine-shelf "flooding surface", show tidal influence, probably deposited on the fringe of a prograding shelf- or delta-front sand bar (third sand) with a scoured base. Progradation eventually established a delta-plain over the entire region (consistent with the coal beds). In the upper, repeated interval of Los Cuervos Formation, the burrowed mudstones and heterolithics are interpreted as subaquatic, while the scarce coal beds and rooted intervals indicate occasional emergence and marsh development, again suggesting an alluvial plain with permanent lakes fringed by marshes.

SEDIMENTOLOGY AND STRATIGRAPHY OF EASTERN VENEZUELA

CARATAS- LOS JABILLOS UNCONFORMITY, RIO QUERECUAL



Reference Section for Los Jabillos Fm, Río Querecual.

