Structural Evolution of the Margin and Foothills Belt of the Cordillera Oriental of Colombia (Southwest of Cusiana).

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ABSTRACT

A regional surface stratigraphic review, including field measurements, together with the subsurface lithostratigraphic and palinologic correlation of about 40 digitized well logs, along the pedemontane belt, provided a reference stratigraphic base.

Given the previous bibliographical knowledge, the integrated interpretation of geologic maps, radar imagery and hundreds of calibrated seismic lines, allowed the definition of a succesion of events in the tectono-sedimentary evolution of the area from Paleozoic to Recent.

INTRODUCTION

A regional geologic study has been conducted by TOTAL in cooperation with ECOPETROL. The aim of this project was to contribute to the knowledge of the geologic evolution through time that led to the present-day structural relationships between the margin of the Cordillera, its foot-hills and foreland area. [fig. 1].

DATA BASE AND METHODOLOGY

The data integrated in the study was built up with the cooperation of ECOPETROL. It consists of : logs related to 50 foot-hills wells; approximately 500 seismic lines; velocity information; radar and satellite imagery; field geologic cross-sections and measured columns; over 1000 surface and subsurface maps; rock-oil samples for geochemical analysis; cuttings and rock samples for paleontological analysis; bibliography.

The data base was managed with a specifically designed software. Digital location maps were prepared.

The study consisted of an integrated interpretation of all the collected data : a continuous cross check of the different types of appraisal (e.g. imagery vs. seismic interpretation) was performed. [fig.2].

TECTONO-SEDIMENTARY EVOLUTION.

PALEOZOIC

In the southern Llanos area (e.g. Negritos , Upía) a high amplitude seismic event (acoustic basement), probably referable to the pre-Cambrian metamorphic basement, appears to be strongly flexed westward, being affected toward the east by antithetic faults striking N-NE/S-SW. Thick, roughly to well-bedded series (up to ms. TWT) progressively on-lap from the west on basement (distal on-laps). These series appear to be strongly inverted and thrust-faulted along a belt that runs from "Camoa-1" to "San Pedro-1" and possibly to the east of "Cusiana". A subsequent severe erosion almost peneplanated this orogenic belt, leaving a panorama of truncated highs and remnant synclines. [fig. 3].

A second seismic stratigraphic sequence transgressively on-lap the erosional surface; it can be well-bedded and of consistent thickness

(up to 300 ms TWT) in the previous low areas, while it is probably missing or very reduced on the high, eroded trends.

Several wells penetrated Paleozoic series in the south Llanos area: these consist essentially of interbedded non-metamorphosed fossiliferous dark shales, siltstones and quartzitic sandstones, similar to those observed in the Macarena up-lift ; the age vary from lower to middle Ordovician. No evidence was found in the subsurface for sediments pertaining to both the Devonian and the Carboniferous-Permian cycles which are observed in the Eastern Cordillera (Río Batá, Quetame). Therefore an infra-Ordovician age (or older) seems to be assigned to the regional unconformity observed in the seismic lines.

Except for the doubtful reddish clays of La Jagua, Paleozoic outcrops are unknown south of the Garzón massif in the Cordillera Oriental. The Paleozoic also has not been proved in the wells in Putumayo basin, but one should consider that basically all of the wells have penetrated only a few meters under the basal Cretaceous unconformity and in addition lithologic descriptions are very poor (e.g. "metamorphic basement"). [fig. 4].On the other hand, as pointed out by O. Portilla (1991), seismic lines SE of Mocoa show thick seismic-stratigraphic sequences, essentially with parallel internal configuration, involved in large scale thrust folds and subsequentlyt peneplanated by the erosion. This sequence could be the equivalent of one of the thick sedimentary Paleozoic cycles of the contiguous Oriente basin of Ecuador.

LATE TRIASSIC-LOWER JURASSIC

Late Triassic-Lower Jurassic series (dark shales and limestones) are known in the Andean foot-hills of Ecuador. Similar sequences are reported in the Upper Magdalena area. The eastward lateral continuation of these facies is not documented.

MIDDLE JURASSIC

A major rift phase ocurred in the present-day Cordillera Central and Oriental areas. Discontinuous back-arc, mega half-grabens, oriented N-S, were filled by thick (up to 4000 ft. in Batá) syn-rift continental red-beds, volcanoclatics, and eventually evaporites (Motema fm. of the Putumayo foot-hills and Batá fm. on the northern Cordillera Oriental).

In the Putumayo basin many wells penetrated (usually for a few meters) red, arkosic sandstones correlatable with the Motema fm. On the contrary, in the Llanos subsurface these series are documented by wells only in the north (Arauca area). More to the south, a thin seismic-stratigraphic sequence is observed under the basal Cretaceous unconformity, which could represent the Batá fm. equivalent.

Neither the Putumayo nor the Llanos basins, provide seismic evidence of rift tectonics at these levels. On the contrary, the sequences immediately underlying the Cretaceous basal unconformity appear to have been submitted to compressional deformation and subsequent erosion being preserved only in remnant truncated synclines.

UPPER JURASSIC - EARLIEST CRETACEOUS (Neocomian-Barremian-Aptian)

Thick continental to marginal marine terrigenous series (Cáqueza Group) are found in the Medina area (Mambita section). As shown in published geologic maps and also confirmed by the radar imagery interpretation, these series extend southwestwards to the Río Ariari area where the Cordillera Oriental diminishes considerably in width. According to Cooper M. et al, 1994, the basin continued to be of the rift type.

LOWER CRETACEOUS (Upper Aptian) - CAMPANIAN

During Aptian time, post-rift thermal subsidence affected the study area. This caused the eastward shift of the sedimentation, beyond the rift margin, on the present-day foot-hills belt.Quite uniform continental to marginal marine sands series unconformably lie on ?syn-rift Jurassic or Paleozoic rocks, from the Oriente-Putumayo basin (Hollín and Caballos fms.), through the Caquetá nose to the Llanos basin (Une fm. [fig. 4].

From the late Cenomanian the Caquetá-Caguán nose is active : in the present-day foothills/foreland area, the Putumayo and Llanos

basins are clearly separated. In both basins marine-restricted circulation conditions (back-arc type) predominated but different sedimentary series (Villeta and Gachetá fms) were deposited. The Villeta fm. sequence is well developed and rather isopach in the western Putumayo : it suddenly thins east of "Tambor-1" (shale out plus on-lap) to dissapear in "Río Pescado 1-2".

CAMPANIAN- MAASTRICHTIAN

During the Maastrichtian the foreland flexuration of the Cordillera Central and Real, affected the present-day south Putumayo and western Oriente basins. In the south-western Putumayo unconformably transgressive N (Neme) sands post-date the beginning of the flexural phase. The overlying Rumiyaco fm. series (predominantly reddish-brown siltstones and shales) display strong, N-S trending, isopach variation, from about 3000 ft. in the west ("Bagre-1") to zero in the east ("La Turbia-1").

In the Llanos basin the Guadalupe- Guaduas formations represent an individual sedimentary cycle. The Guadalupe massive sandstones, phosphate bearing, of shallow marine environment can be more than 300 ft. thick; they gradually make transition to the dark mudstones of the Guaduas fm. (maximun flooding period).

UPPERMOST MAASTRICHTIAN

During this time a regional compressional phase affected the Cordillera Oriental and its foot-hills (synchronous with the Cordillera Occidental ophiolitic abduction).High angle thrust folds and pop-up like features can be observed both on seismic lines [fig. 3] (e.g. : western Putumayo, Payara-Piraña areas) and on radar imagery (? reactivation of Paleozoic features).

The compressional deformation is followed by differential erosion which can deeply truncate the structural highs (e.g. radar imagery of Río Mocoa - fig. 2 , "Payara-1/ "Piraña-1" correlation, etc.)

PALEOCENE - EOCENE

Throughout the foot-hills belt and the margin of the Cordillera, a massive fluvial sand bar (Barco = Lower Pepino fm) unconformably overlies the eroded Cretaceous series or even older sediments (Mocoa area) post-dating the Maastrichtian tectonic phase. This sandy bar tends to thin considerably on the previously established highs.

The fluvial sands make gradual transition to a predominant muddy series of lower coastal plain environment (Los Cuervos = middle Pepino fm.) of upper Paleocene-lower Eocene age.

The presence of some paleo-soil levels in the upper Los Cuervos section indicates that emersion periods occurred.

During upper Eocene predominantly continental sands, with minor restricted marine influx, were deposited throughout the area (Mirador = upper Pepino).

The correlation upper Pepino-Mirador is supported by both lithology-log signature and paleontologic evidences.

On the other hand we could not obtain any reliable age determination for middle and lower Pepino. Nevertheless, the log correlability with Los Cuervos and Barco in many cases (e.g.: "Putumayo-1", "Mary-1", "Medina-1", "Cusiana 2A") appears basically obligatory. In addition, the Pepino series, on one side and the Barco-Cuervos-Mirador on the other, provide a distinct and characteristic marker on the radar imagery (two predominant bars separated by a low relief belt) which can be followed continuosly all along the Cordillera margin and display the same relationship with the adjacent formations shown by the seismic lines and log correlation.

UPPERMOST EOCENE

After the deposition of the Mirador = upper Pepino series a general emersion of the area took place as evidenced by the presence of a fine hard ground; possibly a moderate erosion also occurred. The region was subsequently affected by a main compressional deformation phase.

In the foot-hills/foreland area double vergence, up-thrust-like (e.g. Apiay,Medina) or east vergent, wide, high-angle thrust folds (e.g. Payara-Piraña, Orteguaza) were built. [fig. 3].

Westward, in the present-day Cordillera Oriental, the expression of the phase is much more severe: stacks of imbricated thrust folds are observed (e.g. Pauto area). Strangely enough even the existence of this event is still controversial in the literature.

The compressional deformation was followed by differential erosion : the structural highs were in places severely truncated.

OLIGOCENE-LOWER MIOCENE

A general transgression occurred in lower Oligocene. Unconformable muds and silts of the lowermost Carbonera-C10= lower Orteguaza fms. [fig. 4] were first sedimented to infill the low (less eroded) areas. Subsequently uniform marine to paludal sands and muds were sedimented on the differentially eroded substratum (in general the greater hyatuses occur in the Caquetá nose area testifying that there the fini-Eocene phase has reactivated this high).

The sequence is extremely well correlatable throughout the foot-hills belt and the marginal Cordillera both from log signature, paleontological, seismic and radar imagery stand point, and the following nomenclature correlation is proposed :

N.Llanos		Apiay-Ariari	Putumayo
	C8	E - 3	
Carbonera	C9	T - 1	Orteguaza
	C10	E - 4	

During Oligocene- lower Miocene a regular westward flexuration of present-day foot-hills occurred. This resulted in the sedimentation of a rather monotonous sequence of alternating sandstones and mudstones of shallow marine environment (Carbonera fm. C1-C7 = Orito-Belen fm.) Overall isopach of these series display an important uniform westward increase (e.g. from 2500 ft. in the Llanos to 9000 ft.in the Medina area) building up a sedimentary prism.

Nevertheless inside these sections evidences of moderate compressional deformations (with possible associated minor erosions) are observed in the Llanos area.

MIDDLE UPPER MIOCENE

Dominantly muddy shallow marine series (León fm.) were uniformly sedimented in the Llanos basin.

The absence of paleontological or lithological arguments does not allow to establish if equivalent series were deposited in the Caquetá and Putumayo areas.

In upper Miocene probably a general up-lift of the Cordillera commenced from the west : contemporaneous flexuration of present day cordillera margin- foothills-inner Llanos area occurred. Thick syn-orogenic continental coarse clastic series were deposited (Guayabo fm.-). In the Putumayo basin the much thinner Ospina fm. is cosidered time equivalent of the Guayabo fm. but facies and paleontologic arguments are weak. It remains therefore doubtful if the basin underwent a comparable flexural phase (with the subsequent partial erosion of the series) or not.

PLIOCENE TO RECENT

A long and complex sequence of tectonic events (Andean orogeny) followed through this time up to the present-day structural configuration.

Initially a general western up-lift of the present Cordillera occurred : this created eastward mega-tilting of the future foot-hills belt with associate differential erosion (specially in the south-west Putumayo area). The pene-contemporaneous beginning of the compression, thanks to the reactivation of the outern (east) faulted margin of the Jurassic-? lowermost Cretaceous rift, induced the initial inversion of the thick western sequences (Medina area) which were possibly associated with early activation of dextral mega-wrench (Altamira/Algeciras faults). In its eastward migration the compression involved the foreland margin : due to the heterogenity of the foreland substratum itself, different structural expressions were created. N-S Paleozoic ramps were reactivated as east-vergent thrust folds (e.g. Cusiana). [fig. 3]. The outern faulted margin of the fini-Ecoene double vergence features was in general strongly reactivated, to give impressive thrust folds (up to 1 sec. displacement), while the inner flank was gently or non-reactivated. In the

last Andean phase the de.-loading induced by the intense erosion of the inner up-lifted zones determinated a strong out-of-sequence (westward) final activation of the early Andean deformations of the foreland margin.

Present-day cordillera margin, high-angle (40°-45°), frontal ramps were set in place (with vertical displacements of up to 3 kms.). These ramps dissect the previous tectonic panorama and transport older features. In places they push away decolled Tertiary series to create foot-hills pop-up structures (e.g.fig. 3 -cross-section C-C'. ').

Subsequently the previously formed wide and simple inverted folds of the Cordillera are re-deformed with further folding and outern thrusting.

In this late phase either deep-seated wrenching and dextral lateral ramps are activated.

Along frontal margin of the cordillera, dextral lateral ramp rotation can create thin-skinned thrusting involving old sediments.

LIST OF FIGURES

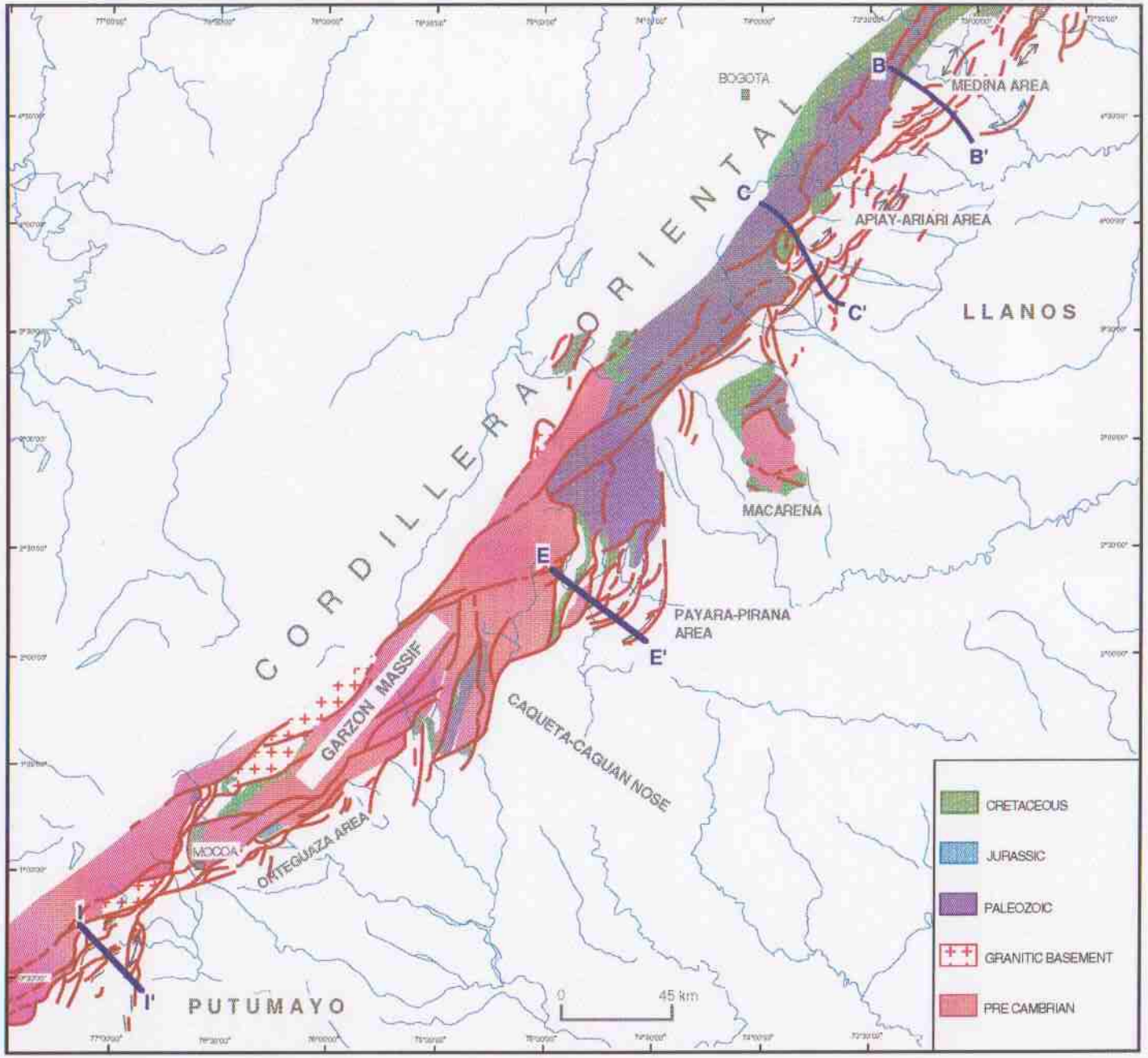
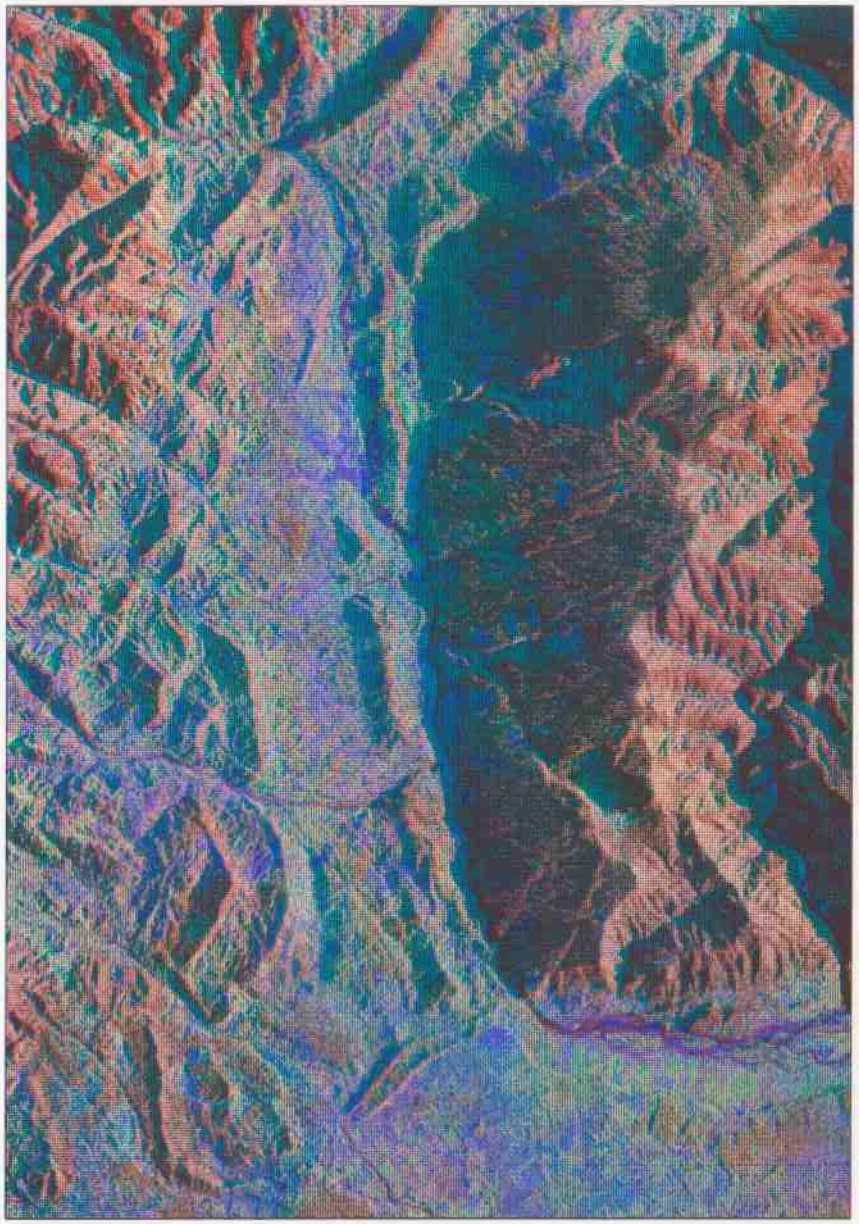


FIGURE 1 SKETCH MAP OF THE CORDILLERA ORIENTAL FOOTHILLS AREA

FIGURE 2 : MERGE LANDSAT TM - RADAR IMAGE AND GEOLOGICAL MAP . MOCOA AREA



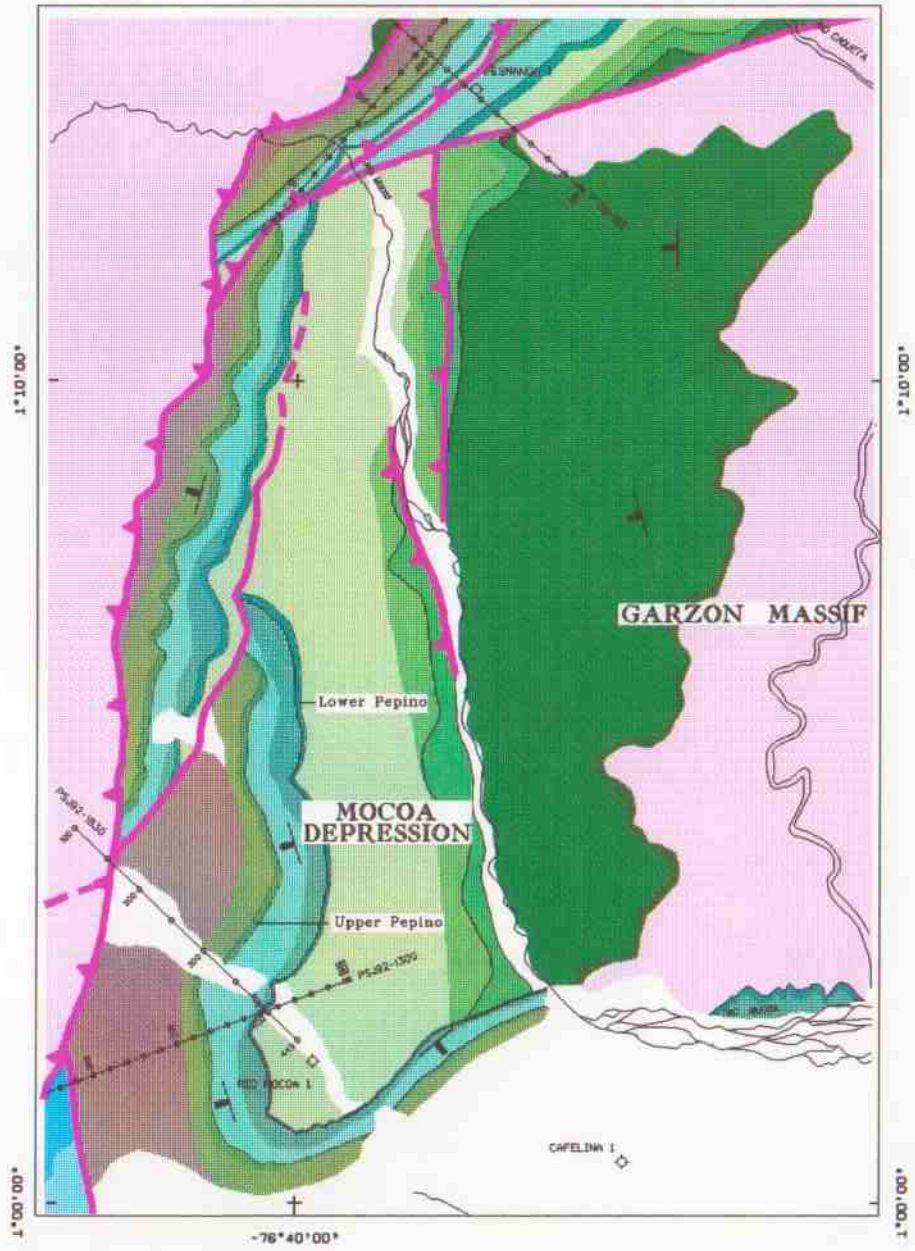
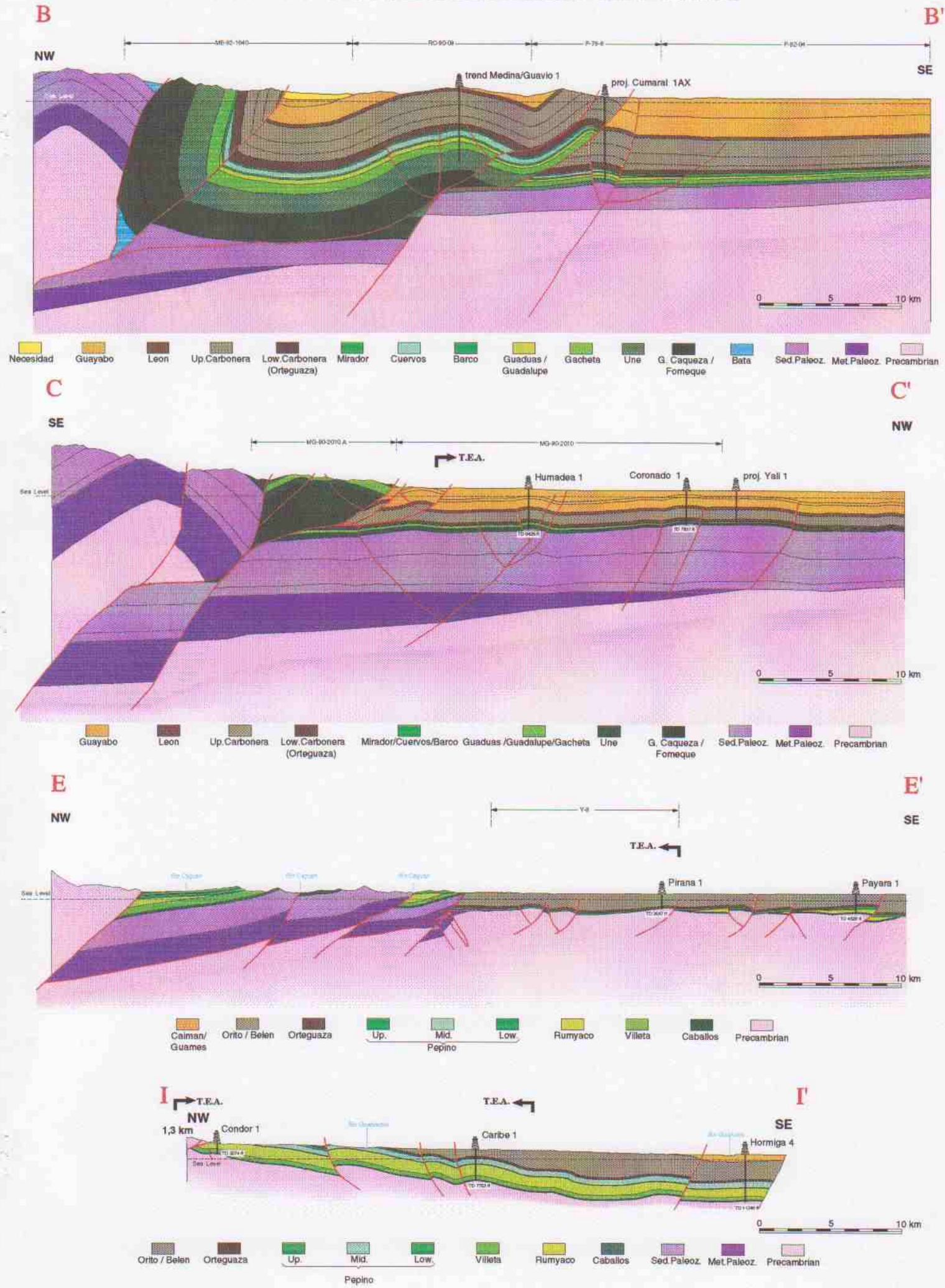


FIGURE 3 GEOLOGICAL CROSS-SECTIONS - LOCATION MAP



APPLIED STRATIGRAPHIC BREAK-DOWN & RELATED COLOR CODE

AGE		CORDILLERA ORIENTAL FOOTHILLS		
		Putumayo	Apiay-Ariari	Llanos
Quaternary				
Tertiary	Pliocene-Pleistocene	Caiman-Guames	Necesidad	Necesidad
	Upper Miocene-Pliocene	Ospina	Guayabo	Guayabo
	Middle-Upper Miocene	Orito-Belen	Leon	Leon
	Lower to Middle Miocene	Orito-Belen	Carbonera: Upper Sandstones; Lutita E; Conjunto C1; Arenisca del Carbonera	Carbonera: C1, C2, C3, C4, C5
	Oligocene	Orito-Belen / Orteguaza	Conjunto C2; Lutita E3; Unidad T1; Lutita E4	Carbonera: C6, C7, C8, C9, C10
	Upper Eocene	condensed section: Pepino Superior	T 2	Mirador
	Paleocene-Lower Eocene	condensed section: Pepino Medio	Cuervos	Cuervos
	Paleocene	condensed section: Pepino Inferior	Barco	Barco
Cretaceous	Campanian-Maestrichtian	Rumiyaco	K 1	Guadalupe-Guaduas
	Cenomanian → Campanian	Villeta	K 1	Gacheta
	Albian → Cenomanian	Caballos	K 2	Une
	Berriasian → Aptian		Lutitas de Macanal-Fomeque	C. Guavio - L. Macanal - A. Juntas - Fomeque
	Triassic → Jurassic	Motema	Brechas de Buenavista (Portlandiano)	Bata
Pz	Ordovician-Devonian-Carboniferous (Sedimentary)		Güejar	Farallones (Dev-Carb.)
	Cambrian-Ordovician (Metamorphic)		Quetame	
	Proterozoic			

FIGURE 4 APPLIED STRATIGRAPHIC BREAKDOWN

MEMORIAS-I

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