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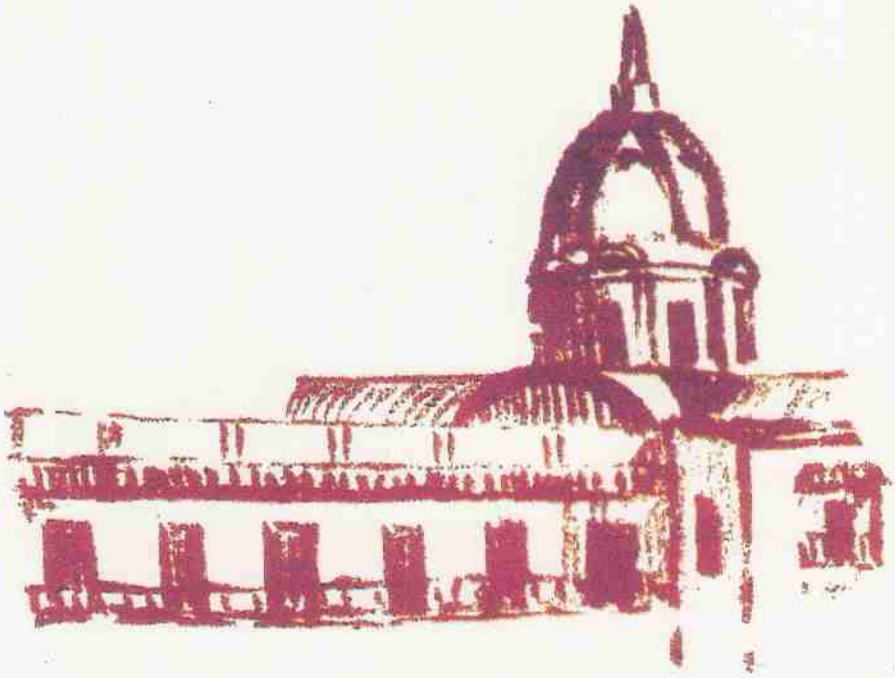

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Multidisplinary correlative evidences for polyphase geological evolution of the foot-hills of the Cordillera Oriental (Colombia).

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Abstract

In 1992, after the discovery of Cusiana, Total started a systematic geological study of the foothills of the Cordillera oriental from Venezuela to the Ecuadorian border with the main aim of better understanding the geodinamic evolution of the belt, the resulting structural deformations and the related sedimentation.

The main part of this study, covering the area SW of Cusiana to Ecuador, was conducted in 1994-1995 in co-operation with ECOPETROL (T.E.A Piedemonte Sur).

A large database was progressively built-up. Systematic base maps at 1:100 000 scale, showing seismic and wells location, main hydrography and sites, were prepared.

The correlative interpretation of this set of data, together with field controls and paleontological analysis allowed to individualise several distinct phases, superposed in time and space, in the geodynamic evolution and related sedimentation of the foothills area.

In general, structural deformations re-actived previous weakness lineaments and final tectonic styles strongly depend on previous controlling features.

The pre-Cretaceous substratum (in general, marine lower Ordovician shales/silts) is affected by strong compressive deformations (ie. thrust-folds) subsequently peneplaned, with sealing mid-Ordovician beds.

The subsequent Meso-Cenozoic evolution is characterised by numerous geodynamic phases both compressional and extensional ; the most outstanding ones being :

- uppermost Cretaceous flexuration of the foreland followed by a strong orogenic deformation (Laramide I) post-dated by Paleocene transgressive sands (Lw. Pepino/Barco Fm),
- upper Eocene compressional deformation (Laramide II) and subsequent moderate erosion postdated by MFS of the Oligocene Orteguaza marine shales,
- Oligocene-lower Miocene flexuration of the Eastern cordillera foreland followed by moderate compressional deformation ; this is sealed by Leon miocene series.
- main Andean orogeny ; it lasted through Miocene/Pliocene times and is still active ; early orogenic fore-deep molasse (Guyabo fm.) and late-orogenic piggyback series sedimentation.

The present paper tries to precise the age and style of sucessive evolution phases supporting the existence of each event with multidisciplinary evidences.

Resumen

En 1992, despues del descubrimiento de Cusiana, Total inició un estudio geológico sistemático del piedemonte de la Cordillera Oriental, desde Venezuela hasta la frontera con el Ecuador. Su objetivo era lograr un mejor entendimiento de la evolución geodinámica del cinturón orogenico, las deformaciones estructurales resultantes y los procesos sedimentarios relacionados.

La principal parte de este estudio, que cubre del suroeste de Cusiana hasta la frontera con el Ecuador fue adelantada entre 1994 y 1995 en cooperación con la Empresa Colombiana de Petroleos (TEA -Piedemonte Sur).

Una importante base de datos fue progresivamente implementada. Mapas base a escala 1 :100000 que muestran : la localización de las campañas sismicas, pozos, red hidrografica y principales poblaciones ; fueron sistematicamente elaborados.

La interpretación correlativa de estos datos, con geología de campo y análisis paleontológicos han permitido individualizar diferentes fases que se encuentran superpuestas en el espacio y el tiempo, en la evolución geodinámica y en la sedimentación relacionada al area del piedemonte.

En general, las deformaciones estructurales reactivan zonas de debilidad de lineamientos anteriores y los estilos estructurales dependen en gran parte a factores previos que los controlan.

El Precretácico, generalemente constituido por lutitas y limolitas marinas del Ordivicico Inferior, esta afectado por deformaciones compresivas fuertes (por ejemplo pliegues de cabalgamiento), selladas por capas del Ordovicico Medio, las cuales fueron posteriormente peniplanizadas.

La evolución Mezo-Cenozóica se caracteriza por numerosas fases geodinámicas compresivas y distensivas, las mas sobresalientes son :

- Flexionamiento del «foreland» durante el Cretácico Superior, seguido de una deformación orogenica (Laramida I) post-fechada por las arenas transgresivas del Paleoceno (Formaciones Pepino Inferior y Barco).
- Deformación compresional del Eoceno Superior (Laramida II) y subsecuente moderada erosión, post-fechada por la MFS de las lutitas marinas del Oligoceno - Formacion Orteguaza.
- Flexionamineto del «foreland» de la Cordillera Oriental durante el Oligoceno-Mioceno Medio, seguido de una deformación compresional moderada. Sellada por la Formación Leon.
- Durante el Mioceno-Plioceno se presenta la Orogenia Andina, aun activa. Deposito molásico orogenico de «fore-deep» temprano (Fm. Guayabo) y sedimentación orogenica tardia de «piggy-back».

Este articulo trata de precisar la edad y el estilo de las fases de evolución sucesiva soportando la existencia de cada evento con evidencias multidisciplinarias.

INTRODUCTION

The Cordillera Oriental of Colombia is a complex orogen trending in a general NE-SW extending from the Venezuelan to the Ecuadorian border (see fig. 1).

The outer eastern margin of the cordillera, together with the narrow foothills belt, owe most of their structural relief to the Plio-Pleistocene Andean tectonic phase. This present day orogenic expression is strongly controlled by successive reactivation of major mechanical discontinuities related to numerous tectonic events occurring in pre-Andean times, from the Paleozoic to the Neogene.

In general, the earlier deformational trends differ significantly from the regional Andean trend (e.g. approximately north-south for the Paleozoic events). The interaction and superposition of the more recent trends onto the earlier trends has created a number of segments along the belt with strongly different tectonic architectures. The tectonic style of the individual structures depends strictly upon the nature of the re-activated accident: as end members of the possible configurations, a syn-sedimentary sequence deposited in a normal faulted regime and later inverted on a thrust ramp can be contrasted with a re-activated thin-skin compressive thrust ramp.

The present paper has as objective the separation of consequent tectonic events through time using previous bibliographic knowledge, correlative analysis of seismic data, well logs, radar images, biostratigraphical dating etc.

The individual tectonic phases analysis are more easily distinguished in the foothills and on the foreland where tectonic deformation is less and previous events have not been obliterated by the Andean paroxysm.

Pre-Cretaceous Tectonic and Sedimentary Evolution

a) Paleozoic

In the southern-central Llanos foreland, during the Cambrian (?) and Lower Ordovician the pre-Cambrian crystalline basement was affected progressively by a regional westward north-south trending flexure. Westwards dipping, tilted mega blocks were bounded to the east by antithetic normal faults (see fig. 2); locally associated synthetic faults originated asymmetrical tilted horsts. Syntectonic fine grained sediments of terrigenous origin, were deposited to form a fore-deep sedimentary wedge in a marine environment. During the Lower Ordovician (?) there was a strong orogenic phase; during which the inner (western) part of the trough was inverted tectonically and strongly folded and thrusted. The orogeny was accompanied and followed by intensive erosion, which in past led to almost complete peneplanation. Remnant synclines and truncated thrusts (at places denuded down to the basement) were left along the orogenic belt, with only minor residual topography (see fig. 2).

On some seismic lines and on the radar images (id. the Macarena high) a relatively thin sedimentary sequence seems to overlay unconformably the tectonically deformed earlier sequence. This overlying sequence is dated as Ordovician (i.e. Negritos-1), although there remains some doubt, and therefore an intra-Ordovician age should be assigned to the earlier main orogenic phase (Caledonian event).

In the northern Llanos area a similar tectonic-sedimentary setting can be seen on the seismic lines: but in this region the tilted half-grabens trend NE-SW.

No evidence was found in the subsurface of Llanos of the existence of sediments of Devonian and Carboniferous-Permian age correlable with the series observed in the Cordillera (Rio Bata, Quetame, Farallones).

Except for the dubiously datable reddish clays of La Jagua, sedimentary Paleozoic outcrops are unknown south of the Garzon massif in the Cordillera Oriental. Similarly there are no proven Paleozoic series in the wells drilled in the Putumayo basin, but normally only a few metres are penetrated, beneath the basal Cretaceous unconformity. In addition the lithological descriptions on the composite logs are generally imprecise (e.g. "metamorphic basement"). On the other hand, confirming the observations of O. Portilla, 1991, several seismic lines in the foothills belt around Mocoa show the presence of thick pre-Cretaceous seismo-stratigraphic sequences, involved in severe thrust-fold tectonics which were subsequently peneplaned by the erosion. These sequences could be the equivalent of the Paleozoic sedimentary cycles known in the contiguous Oriente basin of Ecuador.

b) Upper Triassic - Middle Jurassic

During this period there was a significant rifting phase in the present-day Cordillera Oriental area. Discontinuous, en echelon, asymmetric major half-grabens, trending mainly north-south, were filled by thick syn-rift volcanics, volcanoclastics, continental reddish conglomerates, siliceous shales and green sands (Motema, Brecha de Buenavista, Bata Formations) in a back-arc context. In the Putumayo basin many wells have penetrated (usually a few metres) red arkosic sandstones correlable with the Motema Formation. According to Ecopetrol and Beicip, 1988, these series have a thickness ranging from 1000 to 1700 feet and are preserved in an isolated graben. In our opinion, the seismic data supports the presence of relatively thin and isolated pre-Cretaceous sequences, but there is no evidence of rift tectonics.

In the whole Llanos basin, Cretaceous sediments overlay directly the marine Ordovician beds. Only in the Arauca area did the Arauquita-1 and Rio Ele-1 wells find pre-Cretaceous sediments which have been assigned to a generic Triassic-Jurassic age (equivalent. to the la Quinta Formation of Venezuela ?). Despite the fact that the expression "Arauca graben" has become a classic in literature, there is no obvious seismic evidence for rift tectonics at these levels. If an distensional phase had existed, these structures appear to have been inverted in a compressional episode in pre-Cretaceous times. It seems, therefore, to be more likely that Triassic-Jurassic sediments have been preserved in remnants of truncated synclines (see fig. 2).

Cretaceous-Neogene Evolution

a) Upper Jurassic-Lower Cretaceous

In a wide area, corresponding to the part of the Cordillera Oriental extending north of the Quetame massif and to the eastern part of the middle Magdalena valley (see fig.1), thick sequences of terrigenous derived sediments (Caliza del Guavio through Fomeque formations) were deposited in a shallow marine environment in strongly subsiding mega half-grabens (M Cooper et al., 1994).

b) Early Cenomanian

Post-rift thermal subsidence affected the previously rifted areas. This caused the eastward shift of sedimentation, beyond the margin of the rift, into the area of the present foothills and foreland. A continental/littoral series, with marine episodes, transgressed unconformably towards the east, onlapping Paleozoic eroded sediments and locally the remnants of the syn-rift Jurassic series (Putumayo, Arauca). Sedimentation was uniform in thickness and rather monotonous in character, (see fig. 3) throughout the area from the Putumayo basin (Caballos formation) across the Caqueta area, to the Llanos (Une formation).

c) Turonian-Coniacian

From the late Cenomanian, the Caqueta-Caguan area became an active structural high (Caqueta nose) and, in the present foothills area, the Putumayo and Llanos basins were differentiated. In both basins restricted marine conditions (back-arc type) predominated, but different sedimentary series (Lower Villeta and Lower Gacheta formation) were deposited. These series overlay with a slight unconformity the Caballos/Une sands. Despite their difference in facies, common shallow marine faunas are found in these sediments. The sequences progressively thin respectively towards the south west (Ariari-Apiay area) and north east (Orteguaza area) from the Llanos and Putumayo depocentres.

d) Santonian

At the end of the Coniacian, both in the Llanos and in the Putumayo basins, the environmental conditions became open-marine : this can be related possibly to a moderate, north-south trending, extensional tectonic phase that seems to re-activate the previous Paleozoic thrust-ramps. Dark grey shales with interbedded micritic limestone were deposited (Upper Villeta formation = Upper Gacheta formation, or Lower Guadalupe Group). These sediments are missing on the Caqueta nose area.

e) Campanian - Maastrichtian

In the south-western Putumayo (Mocoa-Florencia area) transgressive sands (N sands) unconformably rest on the Villeta shales. The overlying Rumiyaco Formation. series (interbedded siltstones, claystones and fine grained sandstones, dominantly reddish-brown) built up a fine sedimentary wedge displaying rapid variations of thickness (north-south organised) from more than 3000 feet in the west to zero in the east (see fig. 4 and 5b). These series extend both northwards, in the upper Magdalena valley (Guaduas formation) completing crossing the present Cordillera Oriental, and southwards in the adjacent Oriente basin of Ecuador (La Tena formation). In the Llanos basin the Guadalupe-Guaduas formations represent an individual sedimentary cycle. The Guadalupe massive sandstones, of shelf marine environment, grade upwards to the dark mudstones of the Guaduas formation (MFS) displaying a unique fining-upward log signature (see fig. 3.) The Rumiyaco series, being barren of fossils, remain undated. As already mentioned, they disappear eastwards (Florencia) so that no physical continuity can exist with the Llanos. Nevertheless, on the basis of their stratigraphical position they can generically be correlated to the Guadalupe-Guaduas formations.

The correlation Rumiyaco-Los Cuervos, usually proposed in the literature, is in our opinion to be rejected (see the considerations in the next paragraphs).

f) Uppermost Cretaceous - Lower Paleocene (Laramide Phase I)

A significant compressional tectonic phase affected the Cordillera Oriental and its foothills belt. High angle, double verging, thrust folds were generated (see fig. 6b & 7). These inverted probably the previous Santonian extensional faults and are therefore quasi north-south trending as well. The compressional deformation is particularly impressive in the Mocoa-Florencia Cordillera segment and in the upper Magdalena area (Neiva zone). It was followed there by intense differential erosion which in places truncated deeply the structural highs (see fig. 8 & 9).

g) Upper Paleocene- Lower Eocene

This time interval corresponds to an individual continuous sedimentary cycle during which a regional transgression reunified the Llanos and the Putumayo basins. Fluviatile to shore sands (Barco = Lower Pepino formation) unconformably overlay the eroded Cretaceous or even older sediments (see fig 3, 8 & 9) post dating the Laramide I tectonic phase. There is a gradual upward transition from fluviatile sands to a dominantly muddy series, with minor interbedded coal of a lower coastal plane environment (Los Cuervos=Middle Pepino formation). Sparse hard-grounds in the upper part of Los Cuervos signify a sedimentary hiatus which, based on micropalaeontological evidence lasted through the Middle Eocene.

h) Upper Eocene

During this time predominantly fluvio-lacustrine sands (M3), marine muds (M2) and coastal plain to brackish marine sands (M1) were deposited throughout the foothills area (Mirador = upper Pepino formation). At the top of Mirador sands a fine hard-ground is often present. The correlation between Mirador and Upper Pepino is supported by both lithological/log signature and palaeontological evidence. Despite the fact that no age determinations are yet available for the Middle and Lower Pepino, the log signature correlation of the Mirador/Cuervos/Barco group with the Pepino series, appears extremely reliable (see fig. 3). In addition, the Pepino and the Mirador/Cuervos/Barco sequences provide distinct and characteristic markers on the radar images (see fig. 8) that can be followed continuously along the Cordillera margin. As shown by the radar images and by wells correlation these series tend to thin considerably both on the previous truncated structural highs and in the Caqueta nose area, proving that the latter was still active during Paleocene and Eocene times.

The coeval Chicoral /Potrerillo/Doima Group of the upper Magdalena valley correlates even better with the Pepino group of the Putumayo basin. This fact indicates that the continuity of these basins persisted through Palaeogene as well as that the effects of the Laramide tectonics were still providing abundant source of clastics.

NOTE: The correlation between the wells logs of the Llanos foreland, Llanos foothills and the marginal Cordillera belts (id. Cusiana-2A vs. Medina-1 - fig. 3) shows that the log signature of the Upper Cretaceous-Upper Eocene interval is consistent but rapidly increasing in thickness towards the Cordillera (up to 2.5 times): this would prove that during the thermal subsidence phase, the rate of subsidence remained much higher in the previously rifted area than in the foreland one.

i) Lowermost Oligocene (Laramide Phase II)

An extremely widespread marine transgression occurred during the lower part of Oligocene.
Marine muds (lowermost Carbonera Formation. = lower part of Orteguaza formation) either disconformably overlay the Mirador/Pepino beds, in the underformed areas, or uncorformably cover the deformed and more or less eroded features (i.e the Payara and Pirana structures - fig. 7, or the Guavio palaeo-structure fig. 2 & 5a). Subsequently a thin, uniform series of marine to paludal sands and muds was deposited in the entire area testifying maximum flooding conditions. From this time onwards there was no further distinction between the Llanos and the Putumayo basins. This sequence is extremely well correlable throughout the foothills belt, from log signature (see fig. 3), as well as from palaeontological, seismic and radar image stand points.

l) Oligocene-Middle Miocene

During this long geological time, transitionally from the Orteguaza formation, a thick, rather monotonous sequence of interbedded sands and muds were deposited in a shallow marine environment in today's foothills area (Carbonera and Orito-Belen Formation p.p. - see fig. 3). In the Llanos area the Carbonera Formation forms a fine sedimentary wedge, displaying an large westwards thickening (e.g. from about 2500 feet in the foreland to over 9000 feet in the Medina area). The sedimentation was accommodated by the crustal flexure of the Llanos, probably accompanied by moderate extensional faulting (B. Colletta, oral communication). On the other hand, south of the Macarena area, the section appears to be of more regular thickness (see comparison between cross-sections a and b in fig. 5). This fact, together with the lack of the overlaying Leon argillaceous facies in the south (see next paragraphs) and of precise palaeontological dates, makes the correlation between the Carbonera and the Orito-Belen Formations quite generic.

m) Middle Miocene (early Andean Phase I)

In the Llanos foothills a moderate but evident compressional tectonic phase occurred ending the previous monotonous sedimentation. It is expressed by the formation of high-angle, double verging, faulted folds (see fig. 10); the faults probably reactivated older accidents. In the foreland area, the effects of this phase appear to be modest but as should be expected the deformations is more severe westwards, in the Cordillera area. In particular one can postulate that the Central Cordillera outer ramps (San Jacinto thrust of the upper Magdalena and the equivalent Mocoa thrust in the Putumayo) commenced being active during this phase.

n) Middle-Upper Miocene

A predominantly muddy, shallow marine series was uniformly deposited in the northern Llanos, in general paraconformity or with local unconformities (on-laps) on the Carbonera Formation (see fig. 6 & 10). This section thins or becomes progressively more sandy towards south west, and from the Macarena area is no longer recognisable.

o) Upper Miocene (early Andean Phase II)

During Upper Miocene probably the initial elevation of the Cordillera oriental commenced to the west (E. Cuervos, 1994).

Several seismic lines across the outer margin of the Cordillera and the Llanos foothill belt show indications of severe thrusting of post-Leon age, that seem to be overlain by the Guayabo beds (see fig. 5a). The seismic imagery under the major frontal Andean ramps is quite poor and other interpretations can be proposed (see next chapter).

p) Upper Miocene-Pliocene

Contemporaneously with the progressive uplift of the Cordillera in the west, a thick continental coarse grained clastic series were deposited in the Llanos area (Guayabo Formation). In the Putumayo area, the much thinner Ospina formation is considered the time equivalent of the Guayabo, but both facies and palaeontological arguments are weak, and the general tectonic-sedimentary evolution of the area appears quite different (see next chapter).

Pliocene to Recent Andean Orogeny

The Andean orogenic phase is a complex sequence of tectonic events largely responsible for the present-day structural configuration of the Cordillera Oriental and its foothills belt.

As already said, the Andean events are superimposed on a series of previous major accidents, developed through the geological time, which have often different nature and trends. The control of the pre-Andean geology on the Andean orogeny is effective both at the regional scale and at the level of the style of individual structures. As a first approximation two basic simplifying rules can be proposed from the analysis of the present general structural architecture of the Cordillera and of its foothills belt :

1. Today's overall tectonic pattern is in essence the result of the interference of two main sets of anomalies: approximately north-south trending and north-east - south-west oriented features (note that these correspond to the two main pre-Cretaceous trends). In general the structures of the first set mostly consist of eastwards verging or asymmetric double verging, thrust-folds; they generated from the early episodes of the Andean orogeny. The second set of accidents is more recent and linked in general with dextral transpressive movements; it included mainly wrench faults and inverted thrust folds.
2. The general structural relief of the chain is clearly proportional to the thickness of the Cretaceous series within the rift area, and is the faithful mirror of the Upper Cretaceous isopach map of the foreland. Thus one can speak of a "globally inverted orogenic building".

However, apart from these general common characters and because of the extremely various pre-Andean history (described in the previous chapters) the Cordillera building appears as a complex mosaic of deeply differentiated segments.

The Los Pastos segment, in the extreme south-west, is geologically part of the outer margin of the Cordillera Central of the upper Magdalena valley. This tectonic-stratigraphic unit was widely transported, during the early Andean phases, with a very low angle contact, onto the inner Putumayo foreland. Successively, in recent Andean times, the Pastos thrust sheet was re-folded together with the underlying autochthon (see cross-section c of fig. 6).

In the Mocoa area, the Cordilera Central margin was thrusted onto the south-west plunging nose of the Cordillera Oriental (see cross-section b of fig. 6).
The adjacent Mocoa-Florencia segment of the Cordillera, as already said, was flexed during the uppermost Cretaceous, and affected by intense local erosion of pre-Pepino age. The foothills belt of this segment extends to the south-west as far as the Ecuadorian border, under the Pastos thrust sheet. A narrow belt of high angle thrust and back-thrusted folds adjacent and sensibly parallel to the Cordillera interferes with divergent, approximately north-south trending, high angle thrust-folds, which constitute the extreme northward extension of the structures of the Oriente basin of Ecuador.

The narrow foothills belt can be interpreted as the most external shallow tectonic expression of deep seated transpressive dextral wrench faults, of Recent age, which caused the general uplift of the chain. On the other hand, the high angle inverted thrust-folds are essentially north-south trending structures of Laramide age, which have been reactivated in the final Andean phase. As the Laramian trends are sensibly diagonal in respect to the Andean ones, the rate of re-activation (and the consequent relief) increased progressively towards north, where the old features approach the Andean stress, up to the collision point (see for instance the Orito field structure).

North of the Mocoa-Florencia segment a large structural sector, with a cuneiform shape, includes the Garzon massif, the Uribe depression and the Macarena high. It is bounded by two straight main fault systems respectively to north-west (Altamira-Algeciras faults) and to the south-east (see fig. 1).

The Garzon-Macarena block is laterally displaced towards north-east with respect to the Mocoa-Florencia segment. The dextral pushing inside the block produced the re-activation of old basement (Paleozoic) involving north-south thrusts, namely the Payara structure and the spectacular Macarena structure.

The Altamira-Algeciras wrench faults constitute the geological boundary between the Garzon-Macarena sector and the upper Magdalena-Quetame unit. This main fault system can be interpreted as the dextral lateral escape at the south-eastern boundary of the Caribbean plate. In the upper Magdalena valley the maximum thickness of the Upper Cretaceous syn-flexural sediments (Rumiyaco eq.) are found near Garzon and Yaguara, whilst the deep erosional truncations of Laremide age are known in the Neiva area. The cumulate relative north eastward motion of the dextral Altamira fault system is in the order of 50 to 80 kms.

From a tectonic point of view, the true Cordillera Oriental rises from the upper-valley of the Rio Ariari towards the north. This overall orogenic building has a general lozenge shape, resulting, as usual, from the interference of NE-SW and quasi NS trends. Its vertex are roughly centred on the upper Rio Ariari, Girardot, Norte de Santander and Cocuy.

The present Cordillera orogen *sensu strictu* corresponds to the Lower Cretaceous rift area and represents fundamentally a mega **inversion** and shortening of the same. Inside the general rift area, a number of syn-sedimentary tilted mega half-grabens, north-east - south-west oriented, were active during Cretaceous times. These single features have been tectonically inverted during the Andean orogeny. Therefore, in general, the internal deformations of the Cordillera should be rather high-angle and the lateral shortening relatively minor.

As far as the foothills/near foreland belts are concerned, there are several significant remarks can be made.

1. As already said, the present tectonic style strictly depends upon the nature of the previous re-activated accident. From this standpoint four sets of different structural features can be distinguished:

   A. High angle, asymmetrical large thrust-folds, involving extremely thick sedimentary series, with sub-vertical or reverse outer flanks, associated with ramp synclines and with minor lateral displacement. These features were originated from the inversion of Lower Cretaceous syn-sedimentary normal ramps.

   B. Short cuts and high angle structural inversions of the inner foreland near the rift margin. These deformations occur under the outer Cordillera thrust-ramps; they are tectonically complex and poorly imaged on the seismic lines. They probably re-activate peripheral Lower Cretaceous normal ramps (see for instance the Cumaral structure on fig. 5a).

   C. Relatively thin-skin thrusts resulting from the re-activation of old Paleozoic thrust ramps, at the convergence point between the quasi north-south Paleozoic trends with the north-east - south-west trending Andean front (see typically the Cusiana structure - fig. 2).

2. The uplift of the Cordillera was rapid and recent, as substantiated by the fact that inside the Guayabo formation there are no apparent unconformities.

3. Globally the present day frontal margin of the northern Cordillera Oriental can be interpreted as issued from a dextral transpressive mega-inversion of the outer Lower Cretaceous rift margin. Its foothills belt is very reduced and narrow and represents the shallow accommodation of major deep seated dextral wrench faults; these are the subsurface evidence in the Llanos foothills of the Altamira-Algeciras mega wrench system.

4. The frontal Cordillera ramps pushing induces thrust surfaces inside the Tertiary sedimentary cover. Preferential decoupling levels are represented by the maximum flooding surfaces as, for instance, the base of Orteguaza formation. This major unconformity can also be re-activated as a passive back-thrust roof. Nevertheless on one hand, seismic evidence for blind thrusts with significant passive roofs remain questionable, on the other hand these are not really necessary to account for the present tectonic setting.

5. Due to the important erosional rate of the uprising Cordillera there is a general tendency to a westward out of sequence late activation of the frontal Cordillera ramps. So the Yopal fault ramp crosscuts the Cusiana ramp and the Guaicaramo ramp is younger that the Yopal one, in as much as it cuts recent sediments (Necessidad conglomerates) that on-lap the western flank of the Guavio anticline. That the dextral wrenching is still active as shown by the shifting of the river courses.

CONCLUSIONS

In the area corresponding today to the Cordillera Oriental of Colombia and its foothills/foreland, a series of tectonic phases from the Palaeozoic times to Miocene (pre-Andean phases), with often different trends and characters, are superimposed. The main recognisable orogenic events are :

- flexuring of the pre-Cambrian basement,
- intra Ordovician thrust folding (Caledonian orogeny) mostly N-S trending,
- Upper Jurassic/Lower Cretaceous rifting, roughly NE-SW oriented,
- Upper Cretaceous flexuring followed by uppermost Cretaceous compressional events (Laramide phase I),
- Upper Eocene compressional events (Laramide Phase II)
- early Andean flexuring followed by moderate compressional events.

The subsequent main Andean orogenic cycle (Pliocene to Recent), which is responsible for most of present day relief of the Cordillera, overprints the different expressions of the above phases.
Trends and style of the final deformations depend essentially on the nature of the re-activated older structures.

The various combination of Andean and pre-Andean accidents has led to the individualisation of significantly differentiated segments within the general orogenic building.

The main recognisable segments are characterised as follows :

- the Los Pastos segment geologically forms part of the outer margin of the Cordillera Central : it is thrust at a low angle, on the inner Putumayo foreland,
- the Mocoa-Florencia segment is flexed and subsequently orogenised and eroded in Upper Cretaceous times (Laramide I),
- the cuneiform Garzon-Macarena segment, bounded by two systems of deep-seated wrench faults, is affected by a strong right-lateral displacement (to the N-E) relatively to the Putumayo : internal shortening is expressed by east verging thrusts,
- the whole of the Cordillera Oriental sensu strictu is strongly displaced toward the NE (over at least 80 kms) due to the Altamira-Algeciras dextral wrench faults,
- the bulk of the Cordillera sensu strictu can be interpreted as a mega-inversion of the Lower Cretaceous rifting area, with associated late-Andean transpressive deformation along the outer margin (subsurface continuation of the Altamira-Algeciras faults) largely responsible for the foothills structure.

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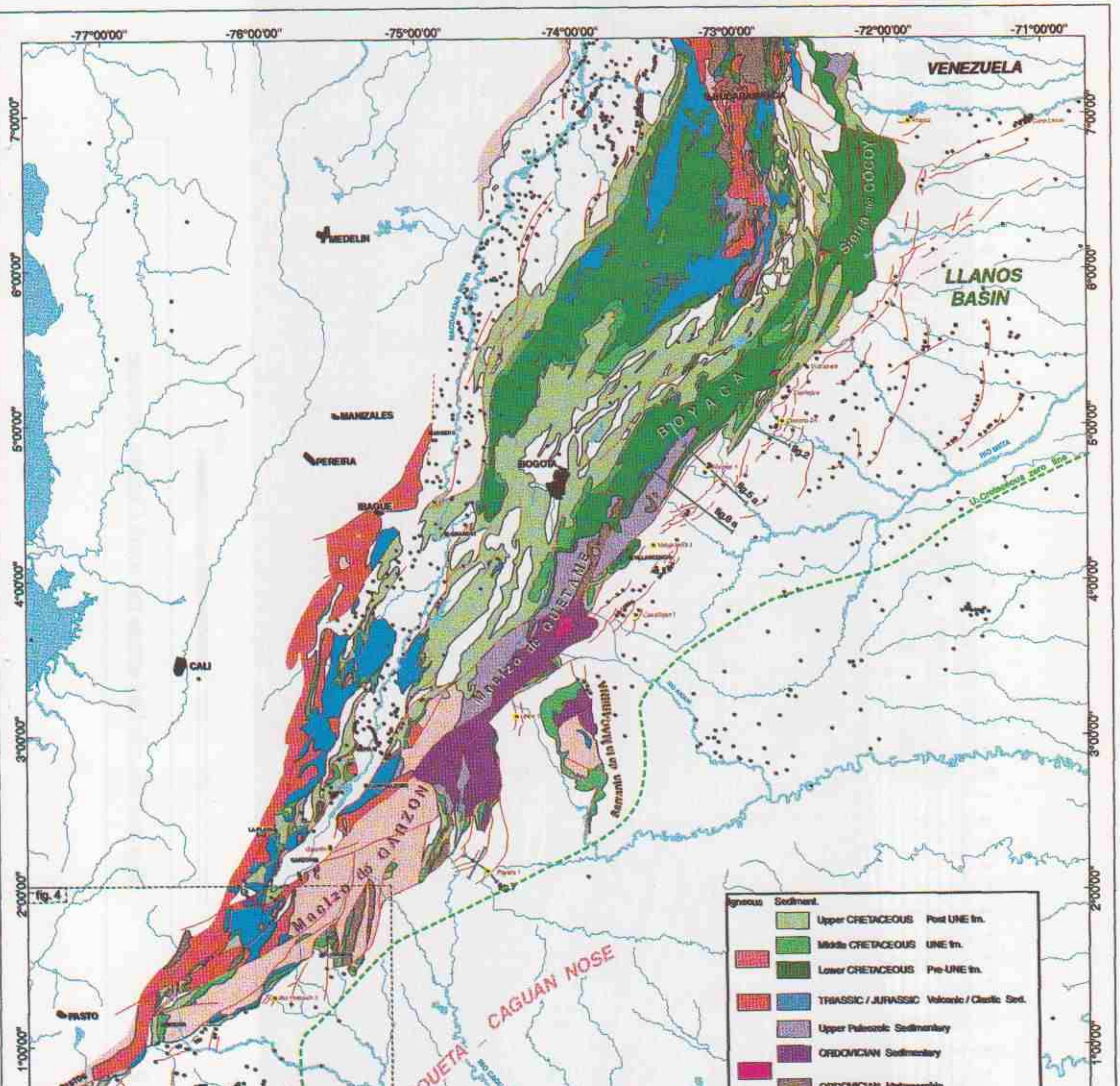

fig. 1 Pre-Tertary geologic map of the Cordillera Oriental

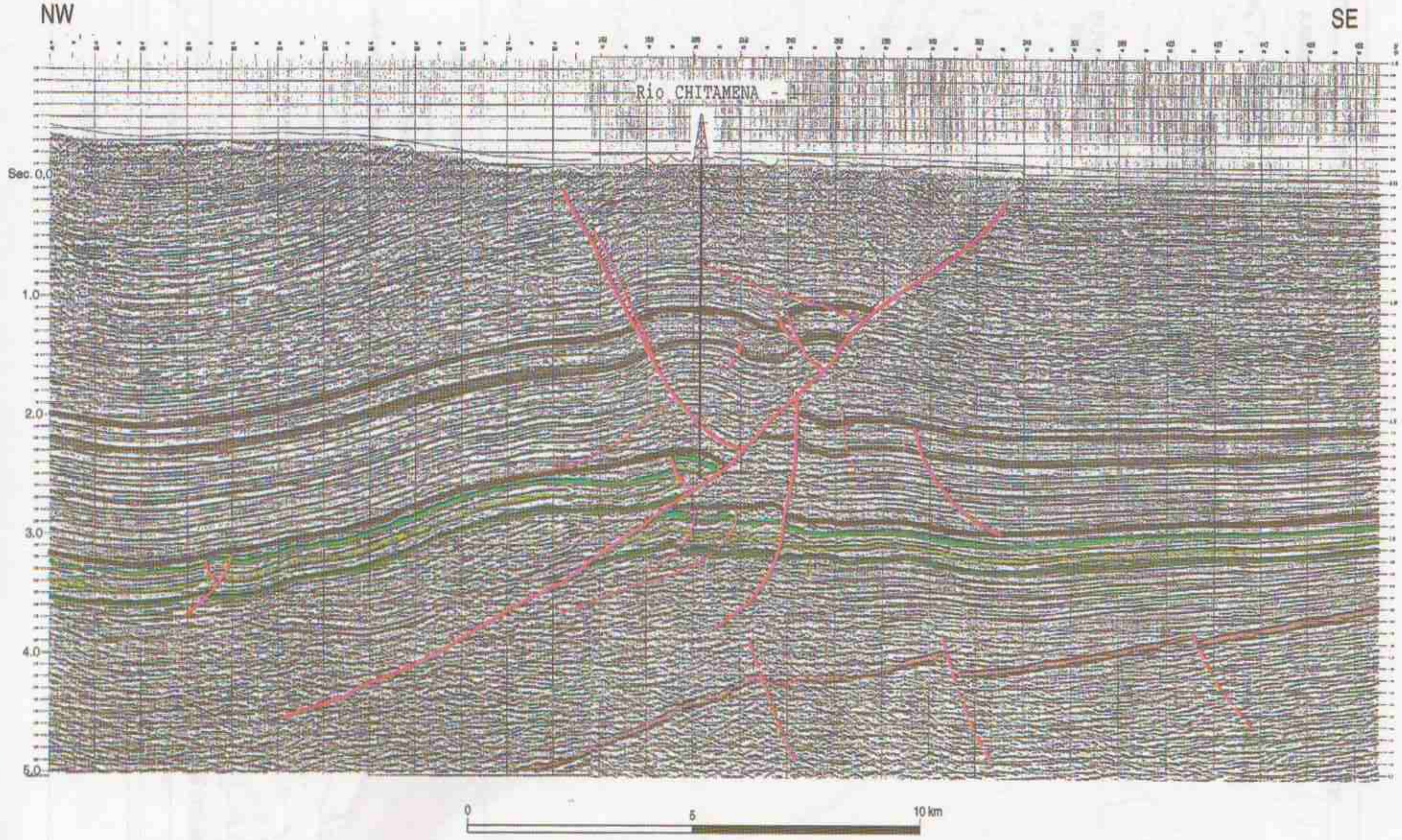

fig. 2 Migrated seismic line across the south Cusiana structure

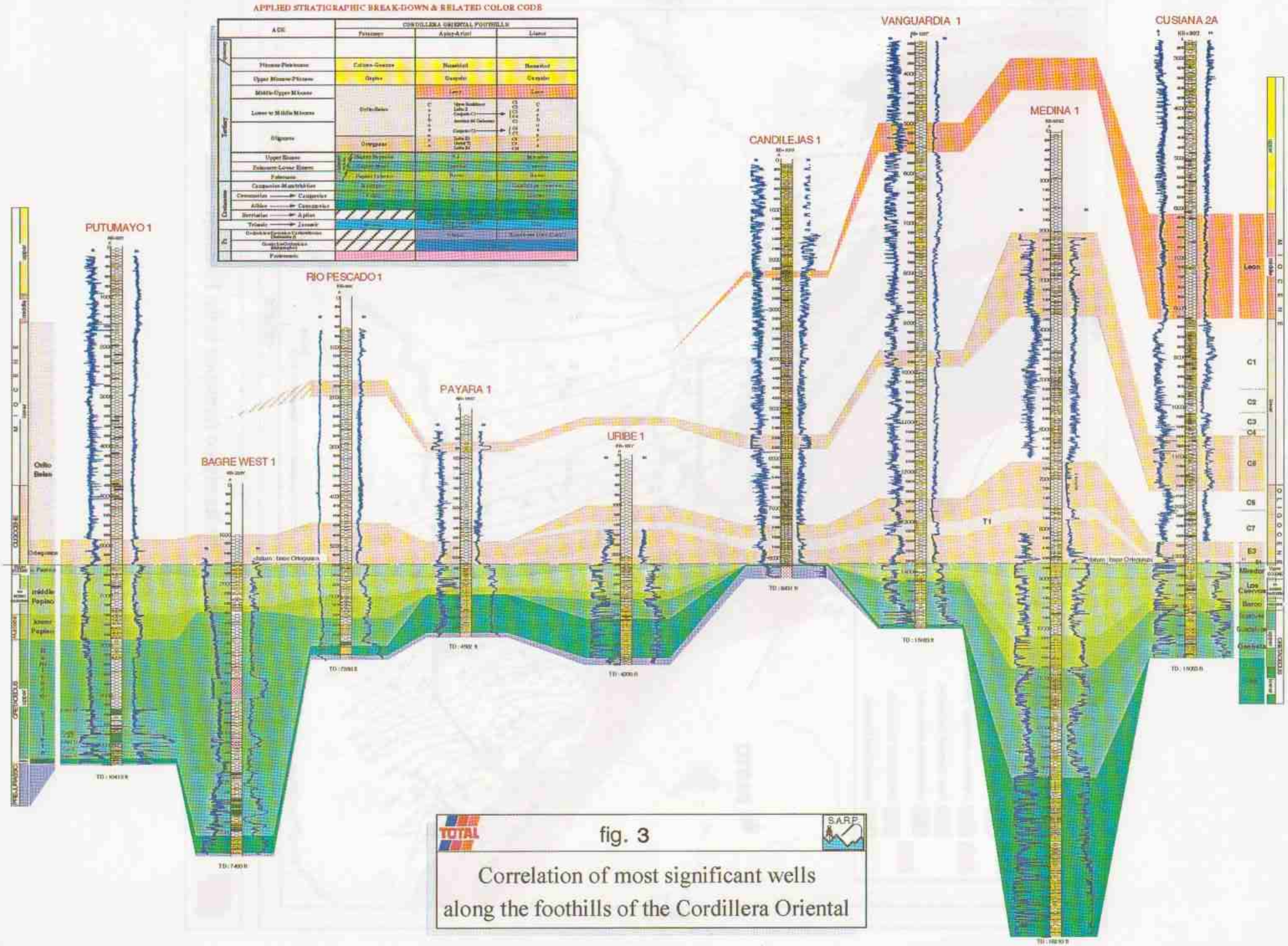

fig. 3

Correlation of most significant wells along the foothills of the Cordillera Oriental

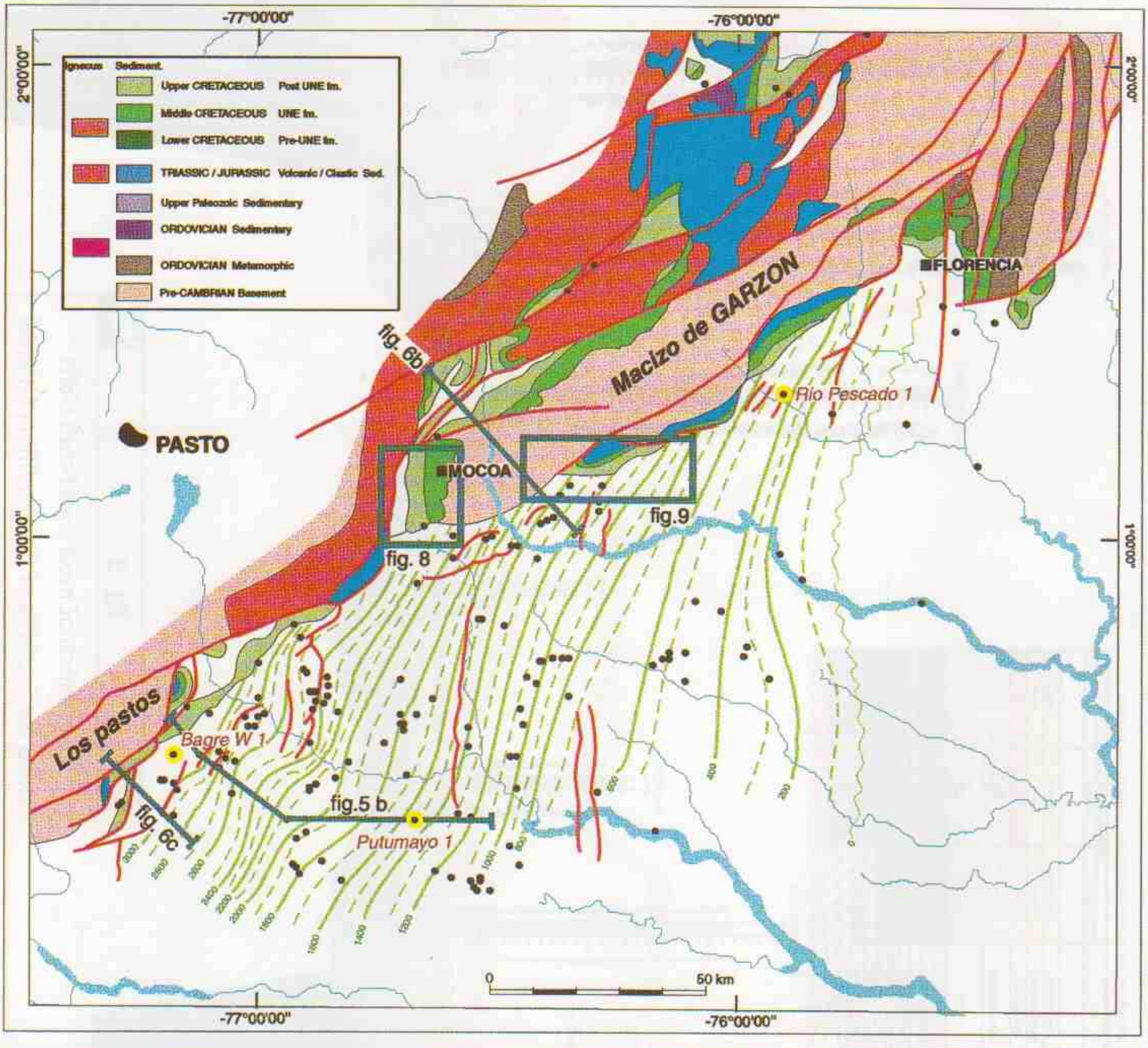

fig. 4 Simplified isopach map of the Rumiyaco formation in the Putumayo basin. c.i. = 100'

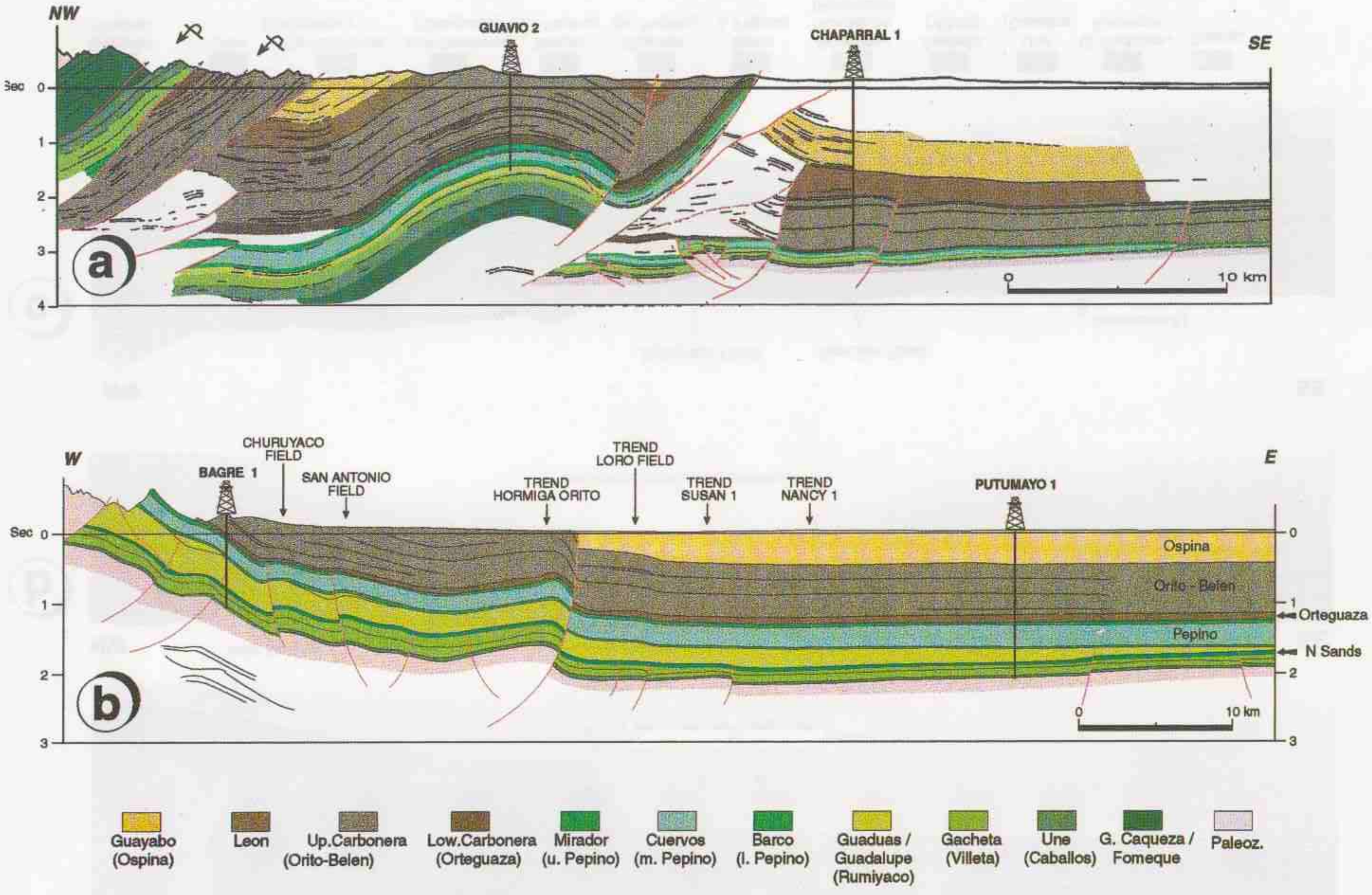

fig. 5 Interpreted line drawing of migrated composite seismic lines across the Llanos and Putumayo foothills/foreland.

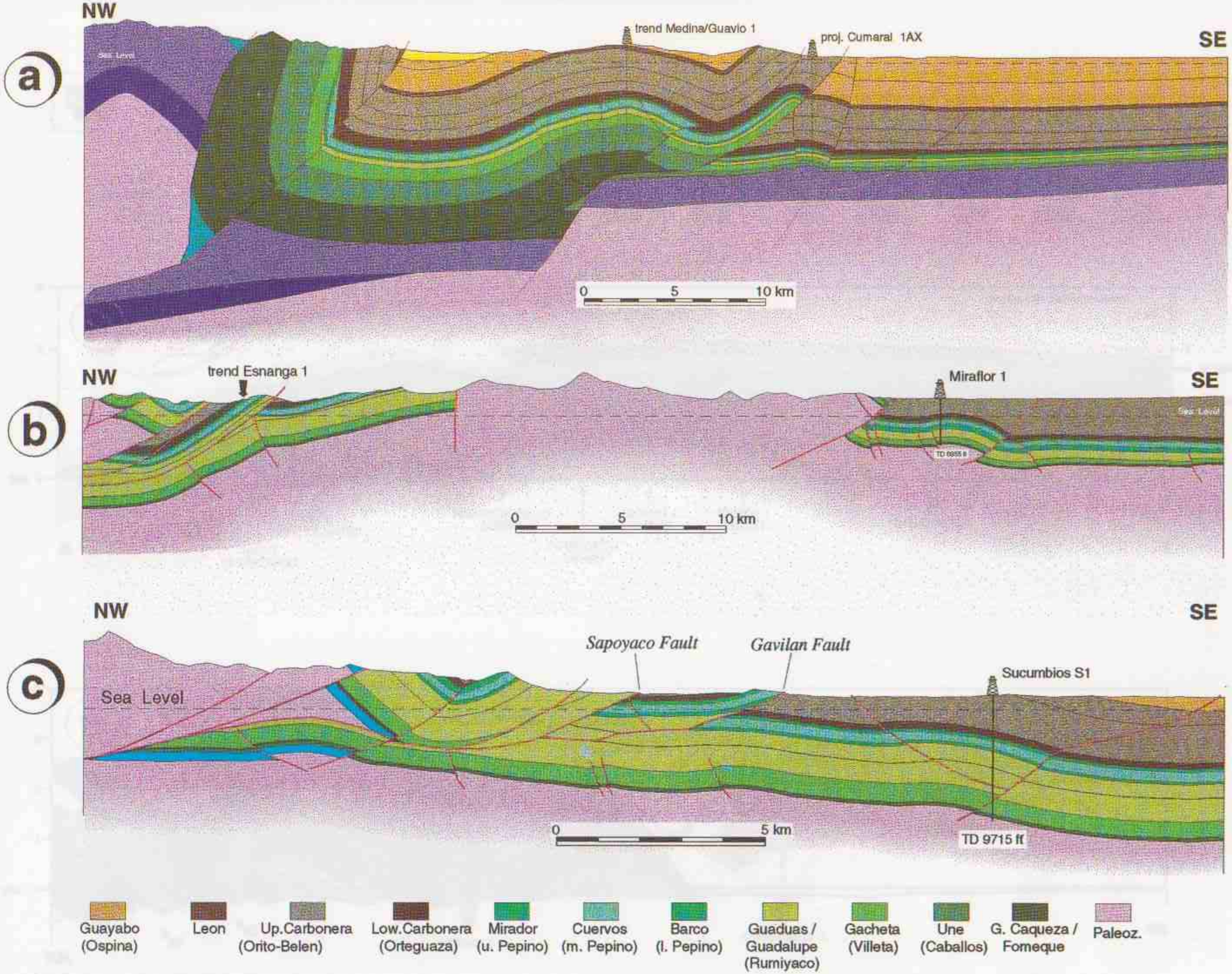

fig. 6 Regional geologic cross sections across the Llanos and Putumayo basins

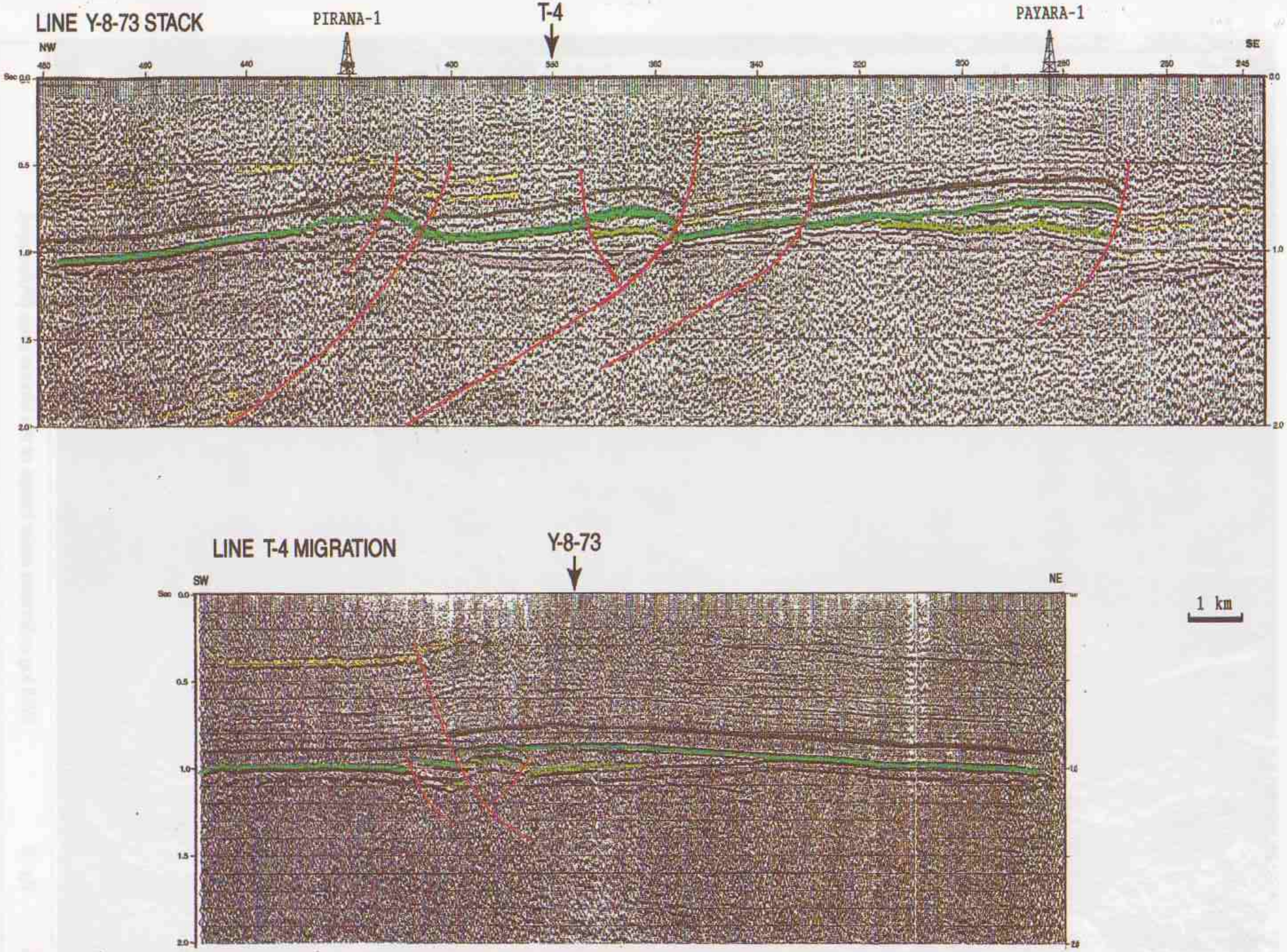

fig. 7 Perpendicular seismic lines in the Payara-Pirana area

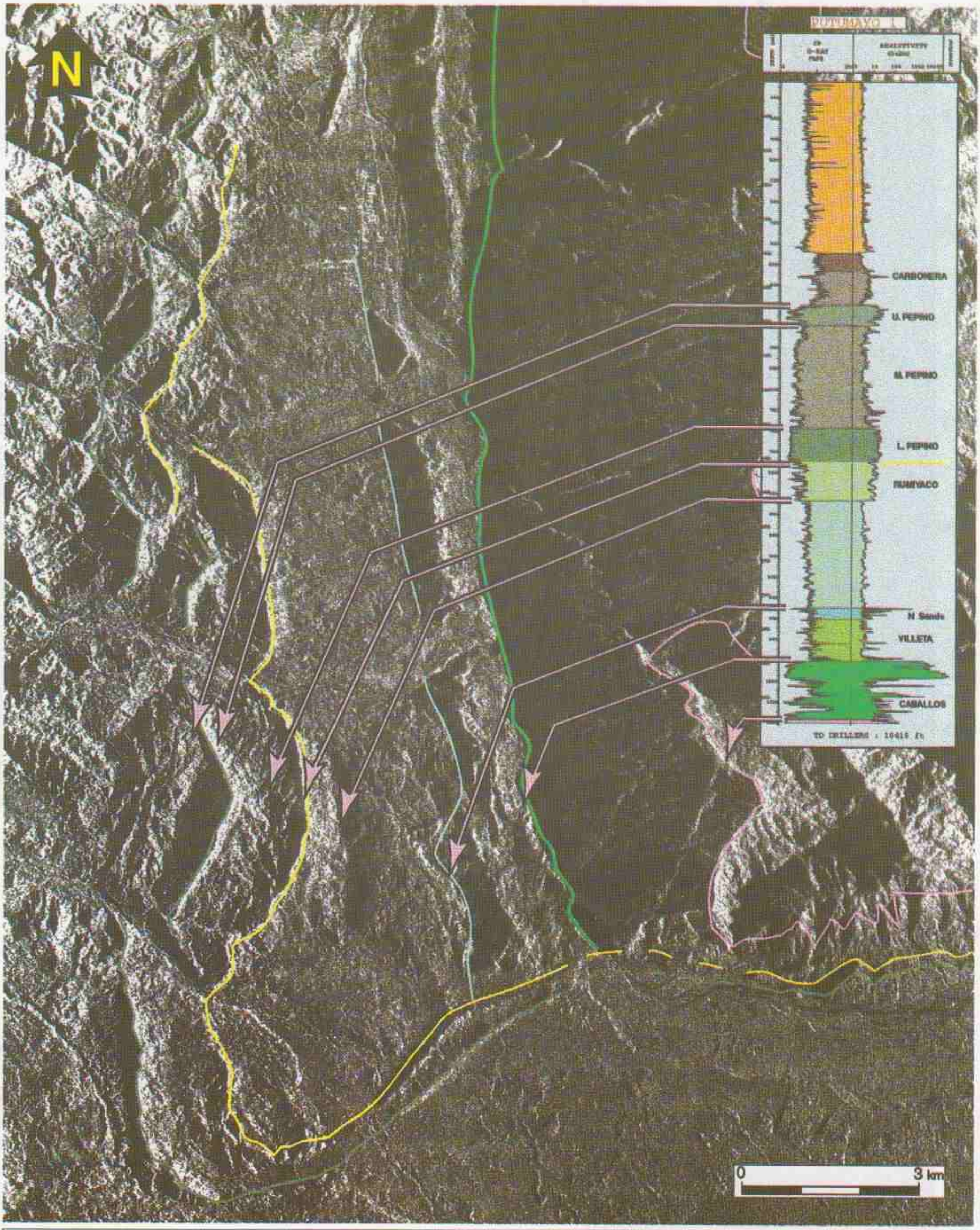

fig. 8 Well log calibrated radar image of the Mocoa area (Putumayo).

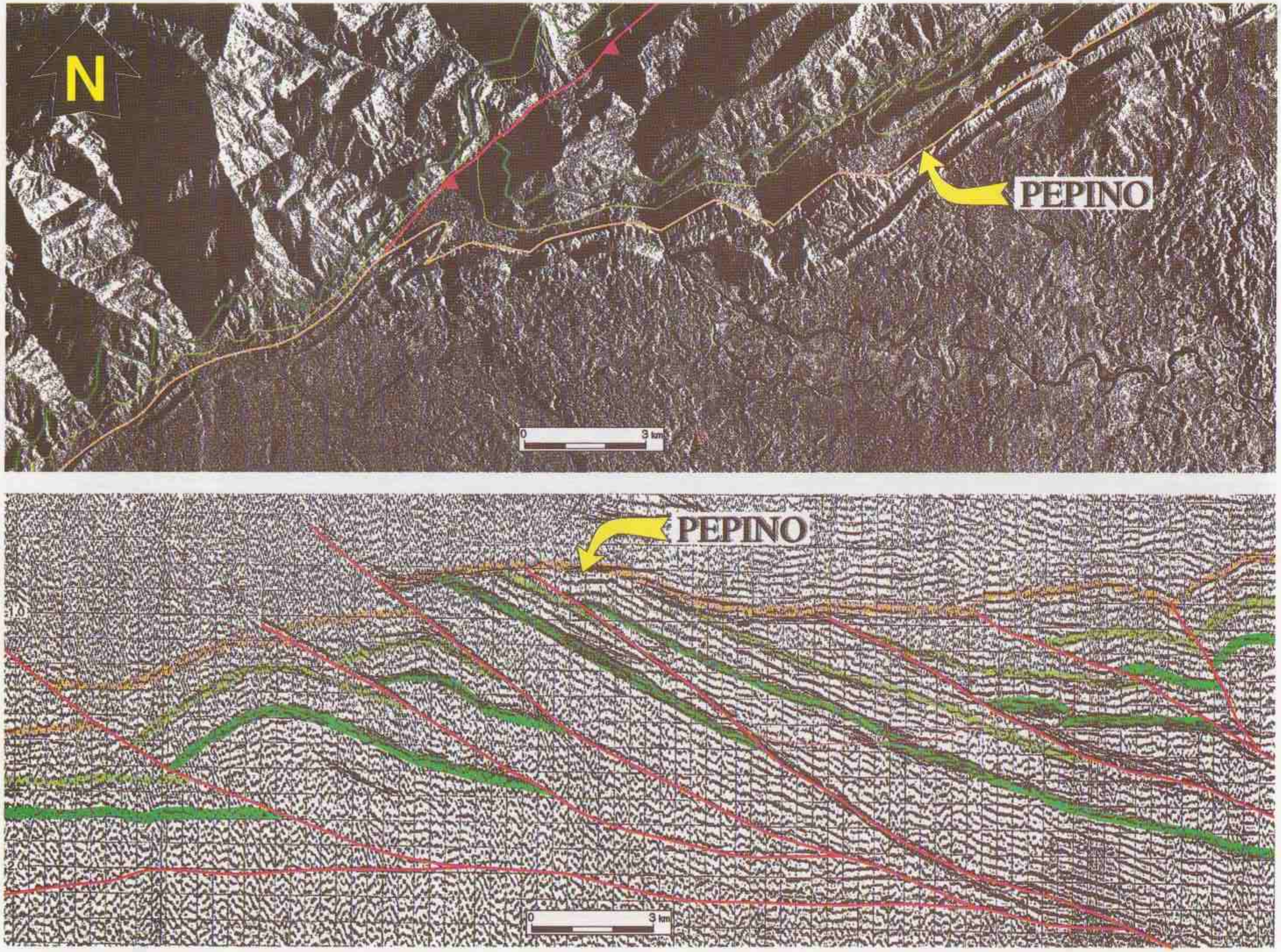

fig. 9 Compared radar image of the Cordillera margin and seismic line of the adjacent foothills East of Mocoa (Putumayo).

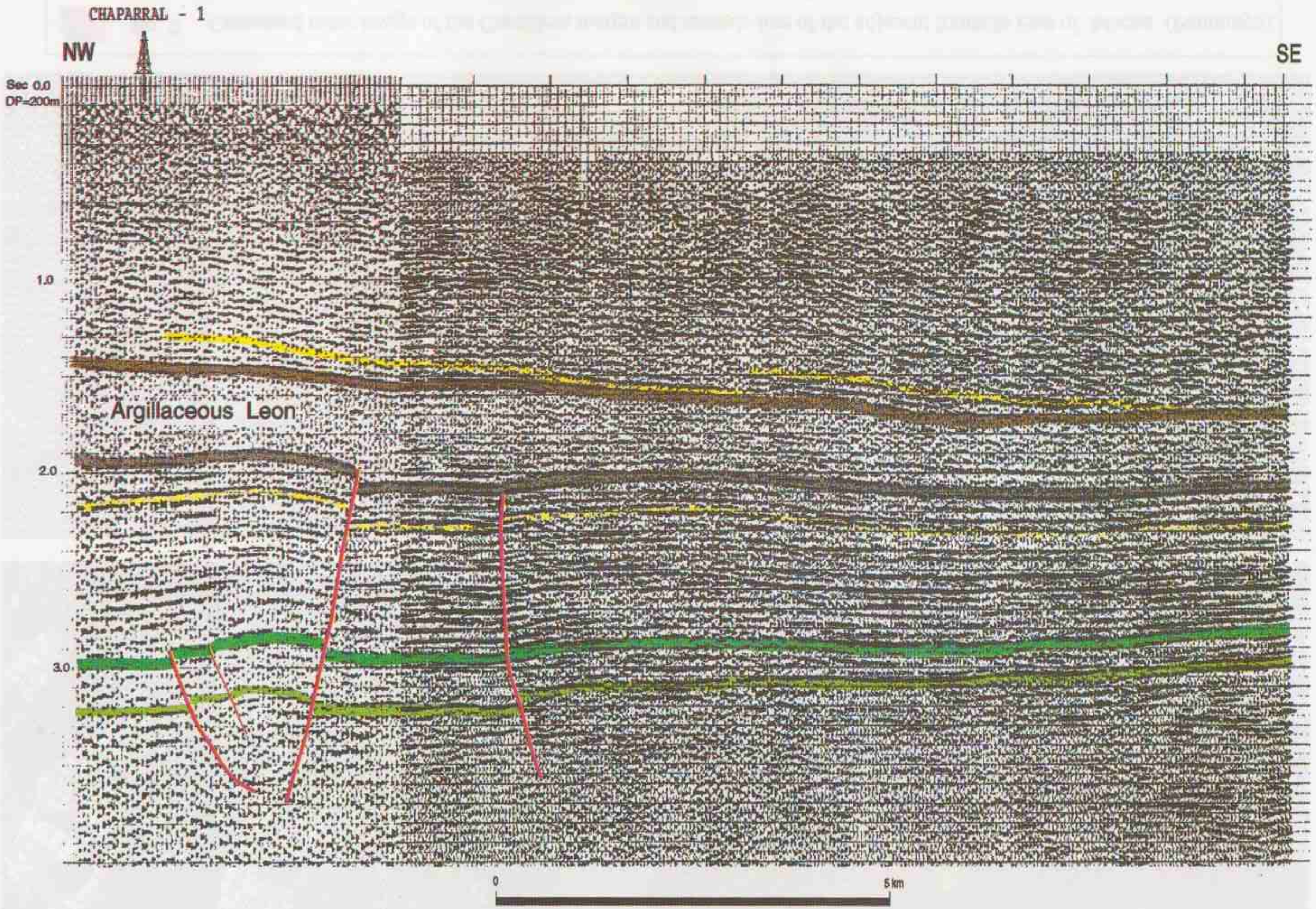

fig. 10 Detail seismic line (unmigrated) across central Llanos foothills. South East part of fig. 5a