Accretion and Obduction along the Sinu-Lower Magdalena area (Northern Colombia).

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ABSTRACT

Seismic, surface and well data reveal the heterogeneous geology of Northern Colombia. The structure of the Sinu-Lower Magdalena area consists of a collage of several tectono-stratigraphic units. West from the Bucaramanga left-lateral strike-slip fault the basement is intruded by several magmatic arcs from Jurassic (in the east) to Paleogene (in the west) (Fig. 1). They suggest progressive westward migration of the magmatic arc related to subduction. West from the Plato-San Jorge Basin, the Romeral Fault separates the Sinu-San Jacinto accretionary prism from the Paleozoic and Precambrian basement of the Plato-San Jorge Basin. Seismic and well data suggest that he Sinu-San Jacinto accretionary wedge involves Cretaceous oceanic affinity rocks previously emplaced above the Paleozoic basement. Remants of this nappe are also present east from the Romeral fault. Therefore Cretaceous ophiolitic series were obducted onto the metamorphic Paleozoic basement and later on imbricated within the accretionary prism. Cretaceous ophiolitic series are though to be part of the Caribbean Plateau crust or fragments of a peri-Caribbean island arc. Along the Sinu-San Jacinto area accretion progressed from the Paleocene-Oligocene «Inner Accretionary Wedge» (exposed along the San Jacinto and Sinu areas) to the present-day Plio-Pleistocene «Outer Accretionary Wedge» of the offshore Sinu area in the Caribbean. During Oligocene time following accretion, transtensional tectonics affected the Plato-San Jorge Basin and controlled its stratigraphic evolution.

This complex structural evolution reflects a long history of oceanic accretion and obduction in Northern Colombia at least since the Cretaceous.

TECTONIC SETTING

Northern Colombia is subject to a complex geologic evolution due to the interaction of the Caribbean and the Andes, within the context of B-type subduction of the Caribbean Plate beneath the South American Plate (Case et al. 1990).

The offshore "Northern Colombia Basin" is floored by a 4 to 8 kilometers thick Caribbean Oceanic plateau crust (Bowland 1993, Van der Hilst and Mann 1994, Driscoll and Diebold 1999) that consists of complex basalt flows and sills with interbedded sedimentary rocks. The Oceanic crust of the Northern Colombian Basin is thought to be of pre-Coniacian age (Case et al. 1990). The present-day rate of convergence along northern Colombia is of about 1.3 ± 0.3 cm / year (Van der Hilst and Mann 1994) or 1.5 cm /year (Kellog and Vega 1995). There are big discrepancies on the present-day motion between the subducting Nazca and the South American Plate 6.8±0.2 cm/year according to Van der Hilst and Mann (1994) and 3.5 cm/year according to Kellog and Vega (1995).

Seismicity suggests an eastward-dipping subducting slab located between 50 and 250 kilometers depth that stops around the Bucaramanga left-lateral fault. A cluster of deep earthquakes is associated with this fault. Earthquake motion reflects the change from subduction to strike-slip (Malavé and Suarez 1995, Taboada et al. in press) (Fig. 2). Seismic tomography allows to differentiate two different segments of the Caribbean subducting slab. The southern Bucaramanga slab that dips 50° SE and the northern Maracaibo slab that dips 17 ° SSE (Van der Hilst and Mann 1994). The lack of a volcanic arc north from the Nevados area in Colombia is consistant with a shallower subducting slab that contrast with the conventional Pacific subduction south of Panama.

The Northern Panama folded belt is characterized by northward vergent imbricates, mud volcanoes, minor directional faults and the presence of gas hydrates (Reed et al. 1990). Active slumping and slope tectonics, as well as active seismicity, suggests the present-day activity of this accretionary wedge.

The geologic map of Northern Colombia (Fig. 1) shows two very distinc geological provinces, a Neogene basin covered by Miocene and Plio-Pleistocene fluvial alluvial sediments which are exposed on the surface (i. e. Plato-San Jorge), and strongly deformed and imbricated Cretaceous to Neogene strata (Sinu-San Jacinto folded belt). The basement of the Plato-San Jorge Basin consists of Precambrian and Paleozoic metamorphic rocks, locally Lower Cretaceous sediments overlie the deformed basement. These strongly deformed Cretaceous units surrounded by basement faults can be interpreted as inverted Cretaceous basins (probably back arc type). A series of Jurassic to Paleocene magmatic arcs intruded onto the metamorphic Precambrian to Paleozoic basement of the South American continent. In the Lower Magdalena area granitic batholites are younging towards the west suggesting westward migration of magmatic arcs as the South American continent was growing by lateral accretion.

South and east from Uraba, Cretaceous "ophiolitic" afinity series overlie the Paleozoic continental basement through a low angle thrust contact and are intruded by Paleocene granites. The presence of Jurassic amphibolites and amphibolitic schists east of the Bucaramanga fault suggest uplifted high pressure previously subducted rocks perhaps related to a Jurassic suture (?).

The stratigraphy of the study area varies laterally from west to east and is strongly controlled by the tectonic evolution of the active margin. We can subdivide the study region into three differentiated structural and stratigraphic domains, from east to west : the Plato / San Jorge Basin, the Sinu-San Jacinto onshore province and the offshore area (Fig. 3).

THE PLATO-SAN JORGE BASIN

The Plato-San Jorge Basin is a Neogene basin underlain by a metamorphic basement locally intruded by granodiorites of the so-called «Macizo Antioqueño» well-exposed in the Medellin region. The eastward extention of the Plato-San Jorge basement consist of Jurassic volcano-clastic and detritic sediments and granites. They represent the Jurassic back arc deposits that overlie the Paleozoic continental crust. Close to the Bucaramanga fault the structure of Middle Magdalena consists of a set of inverted Oligocene-Miocene basins located at the front of the Cordillera Central. The Neogene Basin that overlies this basement can be interpreted as a back-arc extensional basin controlled by large half-graben and related transfer faults. Basement-involved thrust structures are common within the Plato/San Jorge Basin. Seismic data suggest large basement involved inversion structures along the western side of the Plato/San Jorge Basin, similar in age and geometry to those located west from Bucaramanga in the Middle Magdalena area. A major fault zone, referred to as the Romeral Fault, separates the Plato-San Jorge Basin from the complex imbricated zone of the Sinu-San Jacinto area. This fault system has a long and complex structural history of extension and compression and probably strike-slip.

Basement

The basement of the Plato San Jorge Basin is different from the oceanic basement of the Sinu-San Jacinto area. The oldest rocks exposed are Precambrian granulites, migmatites, anphibolites and biotitic gneisses. Paleozoic high-grade metamorphic rocks consisting of granitic ortogneisses, hornblende and biotite bearing gneisses and migmatites overlie this section. Green schist facies metamorphic rocks consisting of amphibolites, micaceous and actinolitic schist, quatzites and marbles top the Paleozoic section (Ingeominas 1997). The basement is heterogeneous and consist of several paleozoic Terranes (Restrepo 1992). Lower Jurassic granodiorites and other granitoids intrude these metamorphic terranes. Southwest from Uraba (see Fig. 1) the metamorphic and magmatic basement is overlain by Lower Cretaceous serpentinized peridotites, gabbros, pillow-lavas and basalts. These oceanic affinity rocks are overlain by interbedded shales, sandstones, conglomerates and limestones of Cretaceous age. The shallow-water character of the sediments associated with the gabbro-basalt-pillow lavas succession suggest an atypical ophiolitic unit.

Sedimentary Section

The overlying sedimentary section consist of the basal Upper Oligocene deltaic Cienaga de Oro Formation which is exposed along the northwestern San Jorge Basin. This unit consists of basal conglomerates overlain by well-bedded varicolored quatzy sandstone, locally conglomeratic with interbedded limely siltstones, carbonaceous and silty shales and occasional limestone and coal beds, limely-sandstone and limestone. The Porquero Formation conformably overlies the Cienaga de Oro Formation. This unit is locally referred to as the "Porquero Flysch" and consists mostly of grey-greenish silty and carbonaceous shales, lutites and silstones with occasionally interbedded lenticular sandstone beds. The lower part of this unit contains Upper Oligocene-Lower Miocene deep-water fauna, which suggest a deep-water environment (Fig. 3). The upper part of the section consists of carbonaceous shales with interbedded sandstones and coal. This Upper Middle Miocene unit represents mostly delta plain deposits. The inception of the Plato / San Jorge Sub-Basins is marked by a major deep-water onlap of the Porquero Formation onto the Cienaga de Oro shallow-water unit. This Lower Miocene subsidence event is associated with the beginning of a well differenciated back arc basin area.

The Sincelejo or Tubara Formation unconformably overlies the Porquero Fm. This Upper Miocene continental unit consists of cross-bedded fine to coarse-grained sandstones, conglomeratic sandstones and conglomerates with occasionally interbeded sandy and silty grey-blue fossiliferous shales. The Pliocene Corpa Formation consists of grey shales and silstones with occasionally interbedded sandstone and conglomerate beds. These Pleistocene facies consist of alluvial deposits and fluvial terraces. The overall sedimentary succession represents a shallowing upwards filling up sequence.

THE SINU - SAN JACINTO REGION

Classically this area has been separated into the Sinu s.s. and the San Jacinto Folded Belt. Seismic, well and surface data suggest that the San Jacinto and Sinu classical areas (Duque Caro 1973) are equivalent and belong to the same Southern Caribbean Accretionary Wedge that extends from Uraba to Venezuela. Like in most of the accretionary wedges the inner parts of the prism involve older rocks than the most external parts of the prism, which are constituted by younger age rocks. The San Jacinto province of the local geologists represents the inner part of the wedge where the older Cretaceous and mostly Paleocene deformed rocks are exposed. The Sinu area represents the younger exposed part of the prism that consists mostly on Eocene and Oligocene imbricates overlain by Miocene piggy-back basins. In the Sinu-San Jacinto area sediment transport is strongly oblique to the structure. The sedimentary depocenters were shifting as the accretionary prism was being emplaced.

Basement

The core of the Sinu-San Jacinto Accretionary Complex is exposed west and south of Uraba and along the Isthmus of Panama (see Fig. 3). According to well data basement consists of Cretaceous gabros, basalts and pillow-lavas, intruded by Paleocene monzodiorites, monzonites, sienites and gabros. These oceanic crust deposits are unconformably overlain by the volcanoclastic Barroso Formation. This unit consists of basalts and diabases with sandstones and conglomerates that represent reworked volcanic rocks and volcano-sedimentary deposits (Island arc ??).

Upper Cretaceous-Paleogene

The Cretaceous sedimentary section unconformably overlies the basalts, green schists, gabros and pillow-lavas of the oceanic crust. Seismic data shows a major angular unconformity between the oceanic crust and the overlying Cretaceous strata in the Cerro Purgatorio area (San Jacinto Folded Belt). The lowermost Cretaceous sedimentary unit is Coniacian in age and is locally referred to as the Cansona Formation and is time equivalent and has similar facies than the La Luna Formation. The Cansona Formation consists of lidites, cherts and limestones interbedded with pelagic shales and siltstones that can reach 150 meters of thickness (Duque-Caro 1973) (Fig. 3). The Finca Vieja Member of the Cansona Fm. constitutes the major source rock within the area. The Upper Cretaceous section constitutes a deepening-upwards section that is overlain by Paleocene-Middle Eocene San Cayetano / Carreto hemipelagic shales with interbedded turbiditic sandstones and conglomerates. The Paleocene section consists in the Tolu area, of normal-graded sequences of fine-grained sandstone, siliceous silts and grey shales of the San Cayetano Formation (Duque-Caro and Guzman 1995). The Paleocene detritic siliciclastic section is terminated by the Eocene La Risa reefal limestone. The Eocene Lorica-1 well drilled 9000 feet of Middle Eocene Chengue Formation, which consists of interbedded grey to brownish silty-mudstone, marl and fine to coarse grained sub-angular to sub-rounded grey sandstone. Strong lateral facies changes of the Eocene section along the Tolu area seem to be related to the emplacement of an oceanic basement high.

Neogene sediments are widespread along the Sinu-San Jacinto area. Most of the Neogene units are exposed on the surface and were encountered by several exploratory wells. The Oligocene section is mostly composed by shale with occasional interbedded sandstone in the onshore area (Ingeominas 1997). The Oligocene-Lower Miocene Floresanto Formation (or Flysch) consists of deep-water turbiditic sandstone, limestone, sandy-claystone and pelagic shale with occasional thin-bedded conglomerate beds. The Upper Miocene Pajuil Fm. consists of sandstones and conglomerates interbedded with shales and occasional siltstones that represent shallow water beach deposits. The Pliocene Corpa Formation consists of grey shale and siltstone with occasionally interbedded sandstone and conglomerate beds. They represent fluvio-deltaic facies in the west and fluvial-alluvial facies in the east.

THE URABA REGION

Seismic data suggest that the region of Uraba is occupied by an Oligocene to Pliocene flexural basin that unconformably overlies the oceanic or Island arc rocks of the northern Panama Accretionary Wedge. A thick volcanoclastic unit penetrated by several wells (i. e. Apartado-1, Uraba-1 and Chigorodo-1) unconformably overlies the acoustic basement formed by oceanic crust rocks. Seismic data suggest the presence of imbricates within the oceanic basement, also affected by normal faulting. Volcano-clastic deposits of probably Eocene age apparently fill the initial trench stage of the basin that evolved into a classical foredeep basin. The Foredeep section changes from deep to shallow water siliciclastic Oligocene to Pleistocene sediments. Nearly N-S trending dominantly west-vergent anticlines with local back-thrusts involving the Neogene section of the Uraba Basin represents the leading edge of the Sinu Accretionary Wedge. This contact, classically referred to as the Uranita fault, is a complex double-vergent thrust, locally resolved in a Triangle Zone. Oil seeps are common along this fault zone. Contrary to most published sketch tectonic maps the Sinu Accretionary wedge and the Uraba flexural basin overlies and overprints the underlying structures of the Panama Accretionary wedge. Towards the north the Uraba flexural Basin becomes the trench of the offshore Sinu Accretionary Wedge.

STRUCTURAL EVOLUTION

Northern Colombia underwent a very complex tectonic evolution, strongly different on each side of the Romeral fault system. Figure 4 shows a NE-Sw trending depth section and a reconstruction of the deformation with a Top Oligocene datum. We subdivided the evolution of this region in four periods from older to younger.

Upper Cretaceous–Paleocene

During Coniacian time deep-water organic rich sediments composed of shaly limestones and chert overlie basalt and gabro of the already obducted (eastward vergent thrusting) oceanic crust. Deep-water sediments mostly shales with occasional turbiditic sandstones were deposited during Paleocene time. This deep-water section was only deposited west of the paleo-Romeral system, no deposition took place east of that line. By that time Paleozoic gabros, mafic rocks, basalts and metamorphosed marine facies were already obducted onto the South American continent. This Paleozoic basement was intruded by Jurassic and Cretaceous granitic batholits and incorporated to the continent. The Romeral fault offsets the obduction contact between the Paleozoic continental crust with the Lower Cretaceous obducted slab and its overlying "trench type" sedimentary section. South of Uraba the thick Upper Cretaceous-Paleocene section pinches out against the emergent oceanic basement of the Central Cordillera. The Upper Cretaceous to Paleocene section could have been deposited within a trench-type setting related to the subduction of the Caribbean Plate underneath the South American one.

Upper Eocene-Oligocene

A thick volcanoclastic unit was deposited above the Cretaceous oceanic crust along the Uraba area. This thick unit may be related to the Panama retro-Accretionary Wedge or to an Island Arc located between the Panama and Northern Colombia prisms. Similar volcanoclastic rocks were deposited along a half-graben structures located above the basement of the Plato-San Jorge (Puerta Negra area).

According mostly to surface data the base of the piggy-back basins can be as old as Upper Eocene. The Accretionary wedge is overlain by Upper Eocene to Miocene piggy-back basins. These basins were mostly filled by turbidites up to the Middle Miocene when sedimentation become transitional (shallow-water) to continental (fluvial-alluvial). A huge Oligocene Flysch depocenter occurred along the Arboletes-South Cordoba area. Hypothetic reconstruction suggest a wedge type geometry in this area during Oligocene time. In the offshore area the sedimentation was characterized by deep-water shale that eventually became overpressured.

While accretion was taking place in the west (Sinu-San Jacinto area) E-W trending normal faulting and strike-slip deformation (?) was taking place along the Plato-San Jorge area in an overall transtensional scenario.

Miocene

The upper part of the piggy-back basin fill sedimentation changed from marine to transitional and finally to continental. Shallow-water to continental deposition in the east was coeval with deep water deposition in the west, present-day Caribbean Sea. The uplift of the accretionary wedge resulted in a major regression or seaward facies shift. This uplift may be related to the underplating and subduction of the the underlying Caribbean oceanic crust or may be the result of post-orogenic uplift like in the whole Colombian Cordillera. East of the Romeral fault system a N-S trending basement-involved thrusting developed along with major inversion of pre-existing half-graben structures. NW-SE trending Oligocene normal faults were inverted during Miocene time, so low areas during the Oligocene become high areas during Miocene time. Basement-involved doublely-vergent thrusting in the east was coeval with thin-skinnned thrusting in the west.

Pliocene-Present

Since Pliocene time, sedimentation depocenters shifted towards the offshore area. A major regresion was responsible of a rapid facies change from coastal to marine sediments that become marginal marine and eventually continental. The shallowing upwards effect of this regresion can be clearly seen along piggy-back basins of the Floresanto area (Fig.). Widespread fluvial-alluvial deposition represented by the continental Corpa Formation took place along both sides of the Romeral fault.

The evolution of the Sinu-San Jacinto accretionary wedge can be traced by the shifting of sediment depocenters. This aparent migration towards the offshore is disrupted by lateral ramps and the emplacement of oceanic basement ridges oblique to the thrust transport direction, like the Tolu Ridge.

DISCUSSION

Seismic and surface data suggests that Piggy-Back Basins developed from Upper Eocene to Upper Miocene time. Most of these basins were initially filled by deep-water sediments up to the Middle Miocene and then by transitional to continental («Molassic») deposits. The presence of parallel and very widespread Oligocene turbiditic sandstones in the Floresanto area may suggest the presence of an Oligocene foreland basin that was deformed later on. This hypothesis is consistent with our reconstruction (Fig. 4) and it would imply a younger age for the piggyback basins located above the Accretionary Wedge. The shifting of sedimentary depocenters reflects the westward migration of the accretionary wedge.

One of the most intriging aspects of the structure of the region is the contact between the metamorphosed basement that underlies the Plato–San Jorge Basin to the east and the strongly deformed Upper Cretaceous to Neogene sedimentary section of Sinu-San Jacinto to the west. This major geologic contact poorly exposed on the surface and with a complex seismic expression is the Romeral Fault. The mapping pattern inferred from seismic data suggest a steeply eastward-dipping fault with at least three clear kinematic stages: Reverse offset during Late Cretaceous to Paleocene time, Normal offset during Eocene-Oligocene time and compressional reverse offset during Pliocene / Pleistocene time. Inversion structures are present in the contact area along the Romeral fault system.. The Romeral Fault System represents a sharp rheological contact that separates two very different structural styles. Thin-skinned detachment thrusting west of Romeral (Sinu-San Jacinto Accretionary Wedge) consisting of deformed Upper Cretaceous-Paleocene Trench deposits was coeval with Basement–involved deformation east from the Romeral fault system (Plato-San Jorge Basin). Regardless of the major role play by the Romeral fault, seismic and surface data suggest that the Romeral fault is not the suture between the obducted Cretaceous ophiolitic series with the Paleozoic basement. Seismic data shows a major westward dipping thrust within the acoustic basement overlie by volcanoclastic sediments which was reactivatred during the Neogene (Fig. 5). This contact is cross-cut by the steeply eastward dipping Romeral Fault. This observations along with the presence of widespread ophiolitic rocks east from the Romeral fault (see Fig. 1) suggest that the Romeral fault was not the Obduction suture.

The «ohiolites» thrusted onto the basement of the South American Plate may represent obducted fragments of a large peri-Caribbean set of Cretaceous island arcs, the so-called Great Arc of the Caribbean of Burke (1988) or parts of the over-thickened Caribbean Plateau crust.

CONCLUSIONS

- The Sinu and San Jacinto classical provinces are part of the same Paleocene to Oligocene Accretionary Wedge. Referred to here as the « Inner Accretionary Wedge » in contrast to the « Outer Accretionary Wedge » that constitutes the Neogene offshore prism.
- Cretaceous oceanic plateau ophiolitic series were obducted (east-vergent thrusting) onto the Paleozoic basement and later on involved (west-vergent thrusting) within the Sinu-San Jacinto wedge.
- The Uraba Basin represents a Miocene-Pliocene flexural basin related to the loading of the Sinu-San Jacinto accretionary prism. It changes laterally into the present-day trench of the Offshore Sinu Accretionary Wedge.
- The Romeral fault offsets the suture between Cretaceous obducted oceanic crust (proto-Caribbean plate) and the basement of South America and therephore does not represent a suture. This fault has follow a poliphasic transpressional and transtensional evolution. The Romeral system controlled the Late Cretaceous-Paleocene trench that later on will become the Inner Accretionary Wedge (i . e. Sinu-San Jacinto folded belt).

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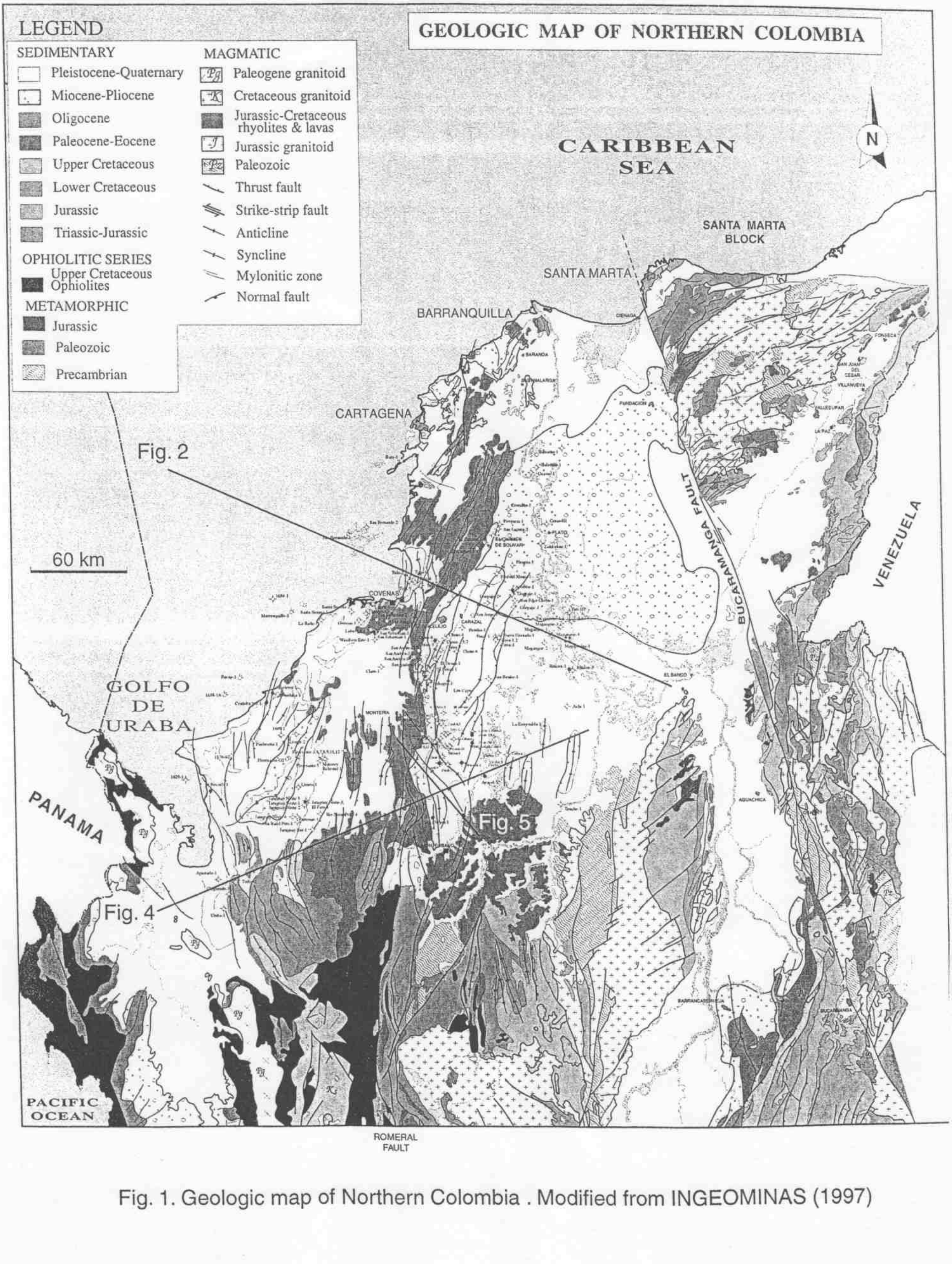

Fig. 1. Geologic map of Northern Colombia . Modified from INGEOMINAS (1997)

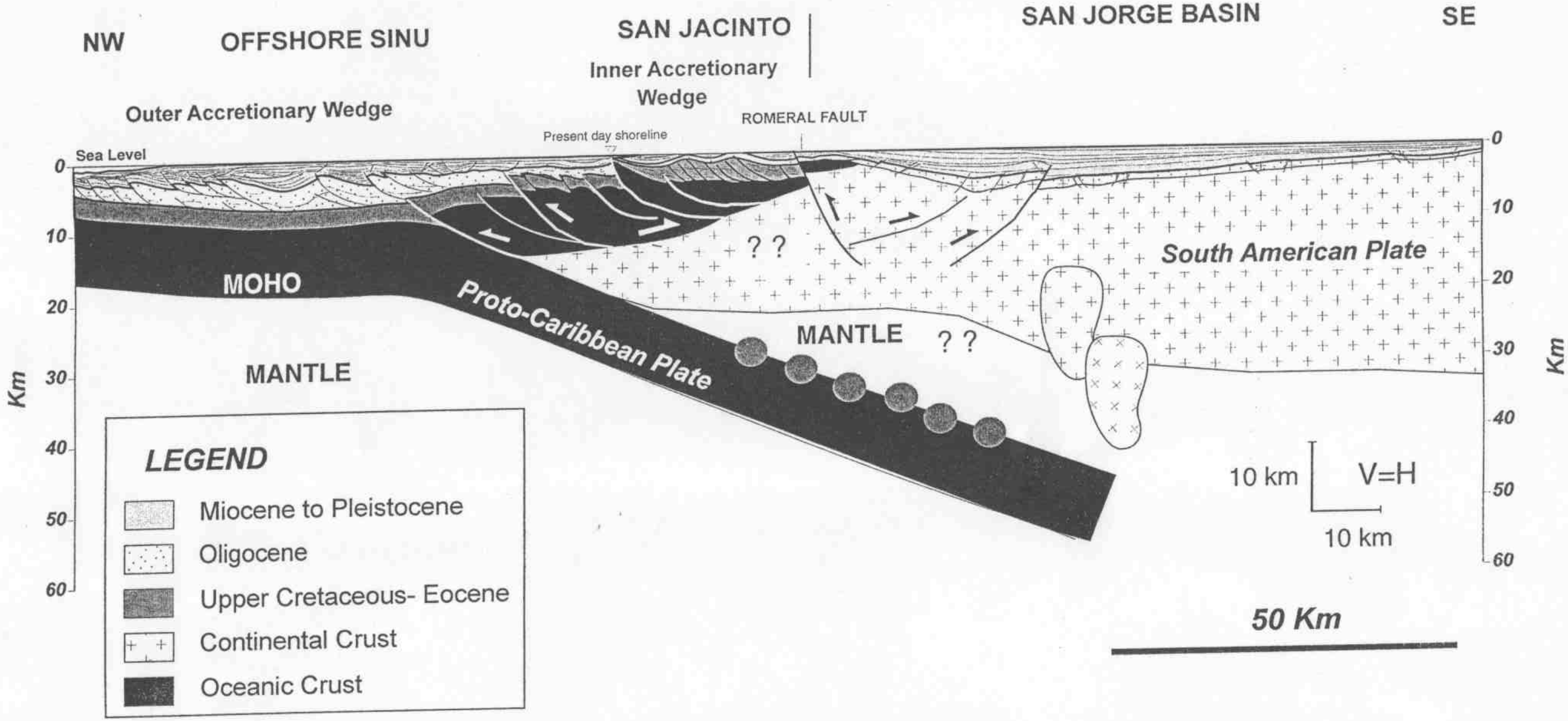

Fig. 2. Onshore to offshore sketch section along the Sinu-Lower Magdalena area based on seismic, surface and well-log data. The location of the Caribbean subducting slab is based on focal mechanisms from Malave and Suarez (1995). See Figure 1 for approximate location. The section has no vertical exageration.

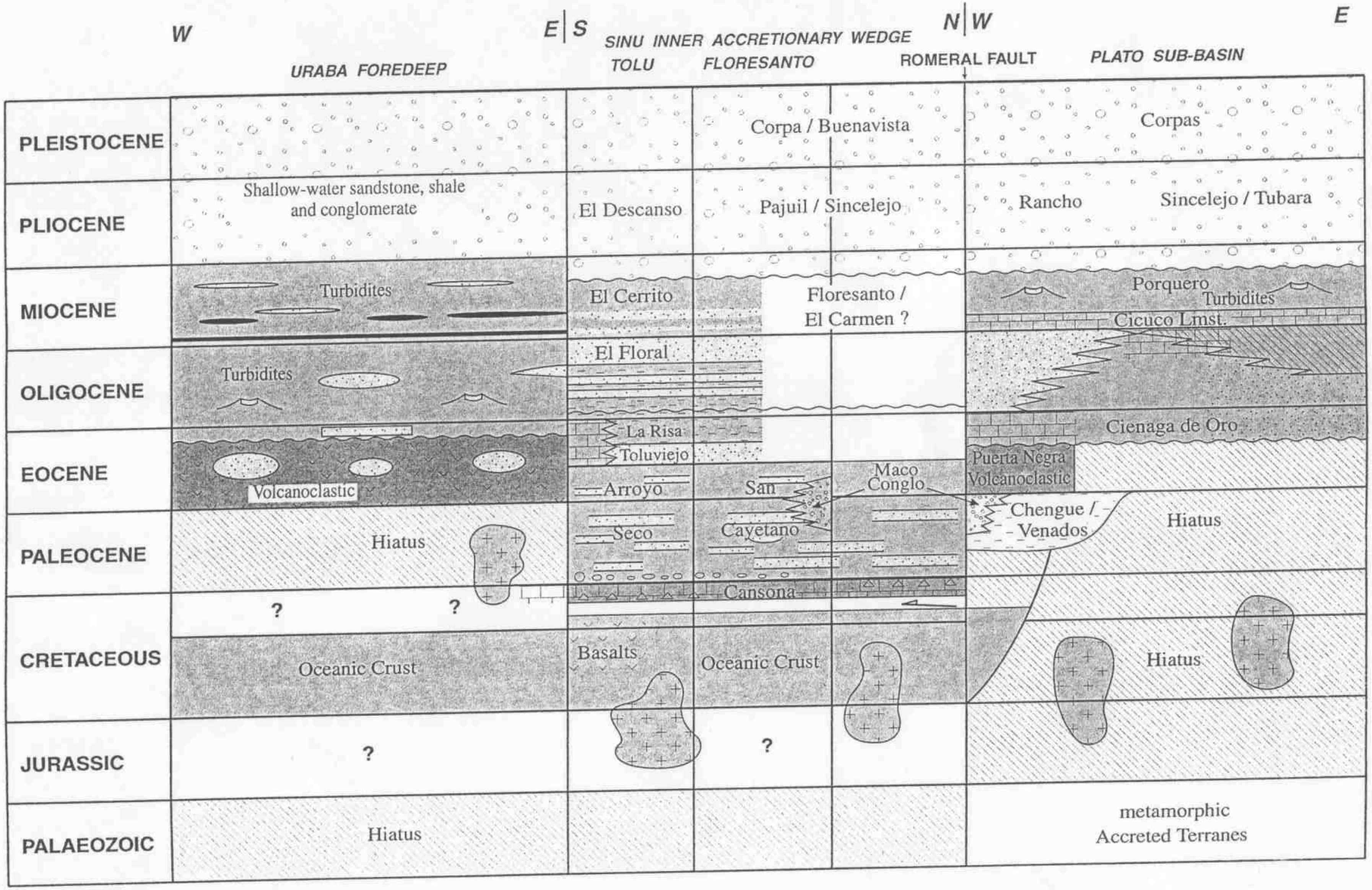

Fig. 3. East to West Lithostratigraphic Correlation along the Sinu-Lower Magdalena area.

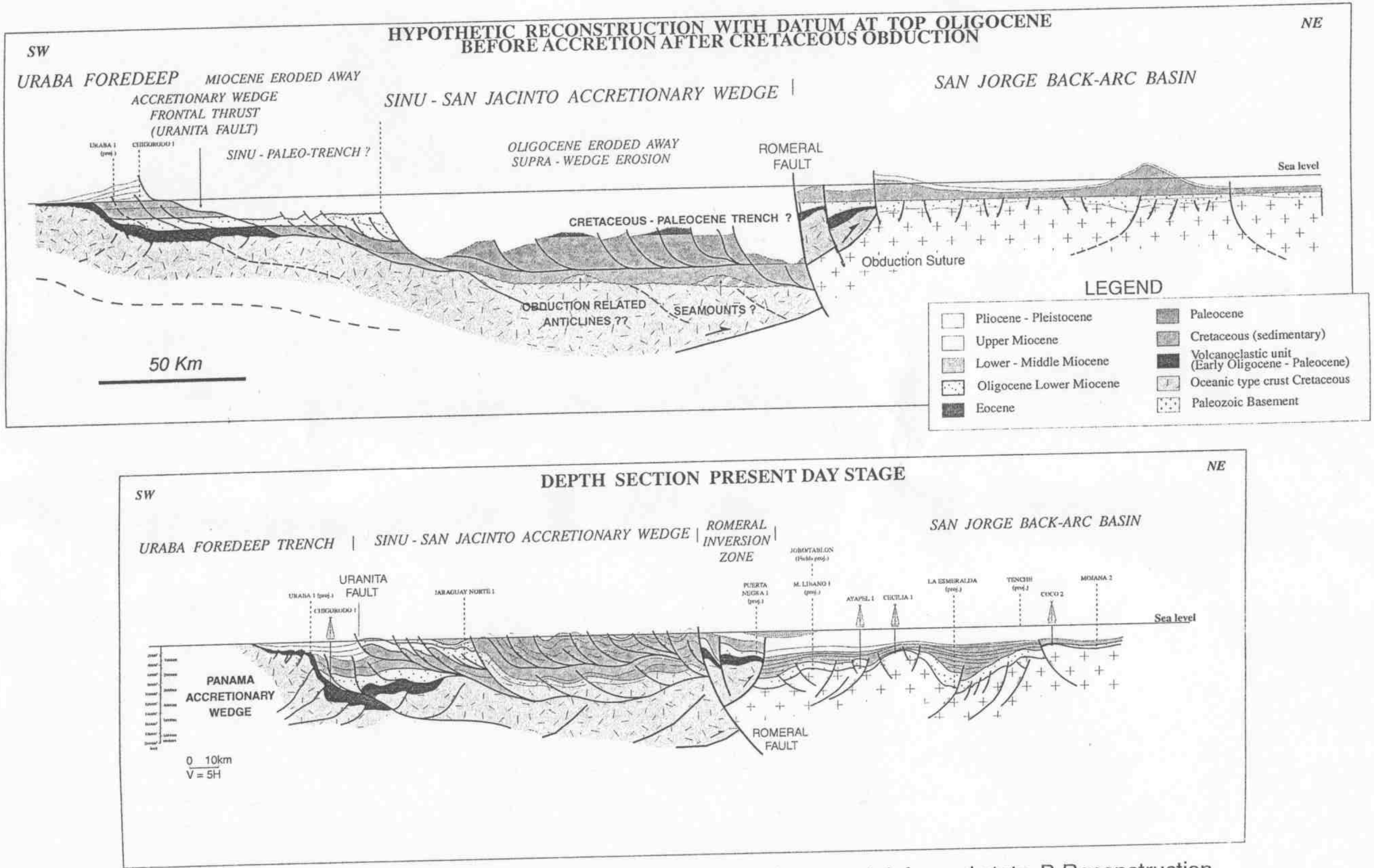

Figure 4. Depth section based on seismic and well-log data. A. present deformed state. B Reconstruction See Figure 1 for location. The section is five times vertically exagerated.

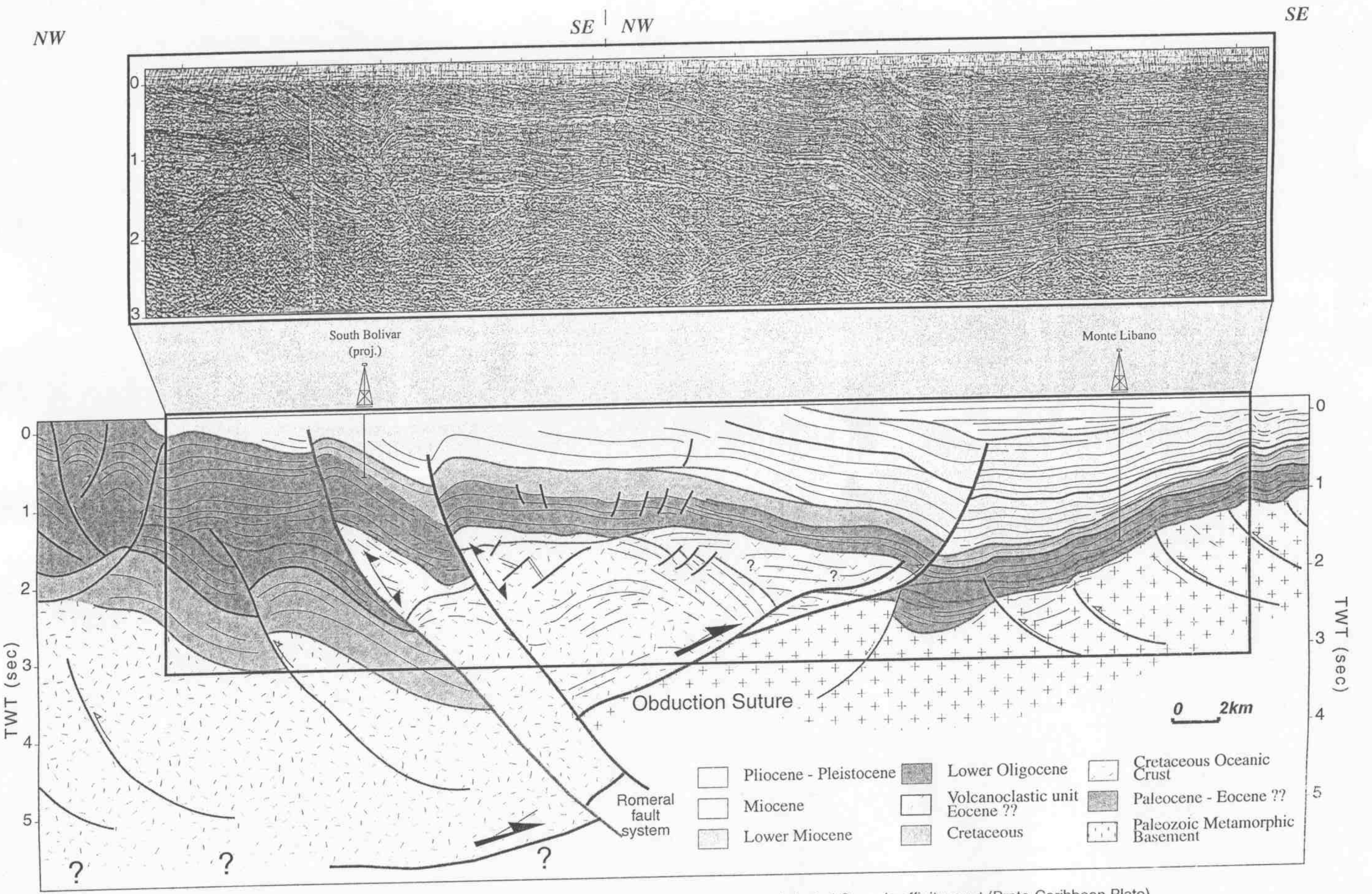

Fig. 5. Seismic line and line-drawing of the contact between the Cretaceous obducted Oceanic affinity crust (Proto-Caribbean Plate) and the Paleozoic Basement of the Plato-San Jorge Basin (South American Plate).