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THE ROMERAL FAULT SYSTEM: A SHEAR AND DEFORMED EXTINCT SUBDUCTION ZONE BETWEEN OCEANIC AND CONTINENTAL LITHOSPHERES IN NORTHWESTERN SOUTH AMERICA

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ABSTRACT

The Romeral Fault System (RFS) extends 1600 km from Barranquilla-Colombia to Talara city-Peru and before the Pliocene. In the Middle Eocene RFS defined the northwestern border of the South America plate, being originated by a triple junction rift - rift - rift occurred from lower to middle Jurassic, when the South American sector separated from Chortis, Oaxaca and Yucatan blocks. From Late Mesozoic until Early Paleocene, the Paleo Pacific plate converged on NW South America corner being subducted when an anomalous thick oceanic crust, represented by the Caribbean plate, was accreted extinguishing gradually from the North of Peru to the North of Colombia. The collision generated a transtensive field stress in back arc region, due to the ancestral Central Cordillera rising in continental border. The RFS rocks suffered low grade metamorphism and some rocks of extinct subduction zone suffered metamorphic inversion. During Late Paleogene until Early Miocene, the convergence South America, Farallon and North America plates produced clockwise rotation in Caribbean Plate, which moved to NE producing a dextral displacement in the suture, generating big milonyte belts in the RFS rocks. With the Farallon Plate break, in the Middle Miocene, due to Galapagos triple junction activation, the Caribbean plate moved to the NNE colliding with the south of the North American plate, being trapped between South and North American plates. This caused the Costa Rica-Panama-Choco block (CRCB) collision with the NW of South America plate, deforming the north of the Northern Andes generating a change in the convergence of Nazca plate in this sector. From Late Pliocene, when convergence change finish, Carnegie Ridge collision in the south of NW South America configuring the actual lithosphere geometry and the orogenic styles of the Northern Andes. Based on Petrogenetic correlations supported by interpretation of secondary sources in geology, tectonic, petrogenesis and geophysics, a model for a regional seismotectonic characterization of this zone was done. The deformed zone represents an extinct subduction zone including fore arc basin rocks with fragments of a Lower – Late Cretaceous volcanic arc and some continental fragments of South America plate. I conclude that RFS is a weak rheologic area and a lithosphere contrast between a thick oceanic and the continental crust, presenting a high seismological activity with historically great earthquakes in Colombia and Ecuador.

Key words: Romeral Fault System, Geodynamic, Caribbean Plate, Lithosphere Delamination, Seismotectonics.

RESUMEN:

El sistema de fallas de Romeral (SFR) se extiende desde Barranquilla-Colombia hasta Talara-Perú. En el Eoceno medio definia el borde NO de la placa Suramerica, siendo originada por la triple unión de rifts ocurrida en el Jurasico temprano a medio, cuando el sector Suramericano se separó de las placas Chortis, Oaxaca y Yucatan. De el Mezozoico tardío al Paleoceno temprano, la Paleo-placa Pacifica convergió sobre el NO de Sur América para ser subducida cuando la placa Caribe fue acrecionada, extinguiendose gradualmente desde Perú a Colombia. La colisión generó un esfuerzo trans-extensivo en una región ante arco por el levantamiento de la Cordillera Central en el borde continental. De el Paleoceno tardío al Mioceno temprano, la convergencia de las placas Sur America, Farallon y Norte America produjo una rotación en la placa Caribe, que se movió al NE produciendo un gran esfuerzo y desplazamiento dextral en la sutura, como así lo evidencia la presencia de grandes cinturones de milonita en las rocas del SFR. En el Mioceno medio la placa Caribe se movió al NNE colisionando con la placa Sur America, quedando atrapada entre ésta y la placa Norte America. Esto causó la colisión entre la placa Costa Rica-Panamá-Chocó y el NO de Sur America, deformando la parte norte de los Andes, y cambiando la convergencia de la placa Nazca en esta área. Desde Plioceno tardío, cuando cesó el cambio de convergencia, la Cordillera Carnegie colisionó en el NO de Sur America configurando la actual geometría litosferica y estilos orogénicos del norte de los Andes. Con base en correlaciónes petrogénicas y una cuidadosa interpretación de fuentes secundarias en Geología, Tectónica, Petrogenésis y Geofísica, se hizo un modelo de caracterización sismotectonica de esta zona. La zona deformada representa una zona de subducción extinta que incluye rocas de postarco con fragmentos de un arco volcánico del Cretacico temprano-tardío y algunos fragmentos continentales de la placa de Sur America. Se concluye que el SFR es una área reologica debil y un contraste entre una corteza oceanica delgada y una corteza continental, que presenta una alta actividad sismologica con terremotos historicos fuertes en Colombia y Ecuador.

Palabras clave: Sistema de fallas Romeral, Geodinamica, Placa Caribe, Delaminación de Lithosphere , Sismotectonica.

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INTRODUCTION

RFS is known as a first order shear zone between 0,5 and the 8° N in the western flank of the Cordillera Central in Colombia. This shear zone has three parallel or unparallel faults intersecting each to other showing in general an echelon configuration (Barrero et al., 1969). The RFS extends from the gulf of Guayaquil in Ecuador (Risnes, 1995; Aspden et al., 1992; Litherland and Aspden, 1992), until 11,5° N near to Barranquilla in the Colombian Caribbean platform (Duque, 1980).

The first relation of these faults with basic and ultrabasics rocks was given by Barrero et al. (1969), later Maya and González (1995), organized the geologic units surrounding to the Cauca - Almaguer or Romeral Fault. These authors define four litodemic mega units conforms the RFS. One unit is a continental basement represented by the Cajamarca Complex to the east of the San Jerónimo fault. Other ones are sedimentary and volcanic rocks owning a low grade metamorphism in some sectors, defined as Quebradagrande Complex (Nivia et al., 1996) which limits the Cajamarca Complex at the east as San Jeronimo fault, and with Arquía Complex at the west as Silvia – Pijao fault. The other is Arquía Complex composed of igneous and sedimentary rocks with low to medium grade of metamorphism, besides basic and ultrabasics with HP-LT rocks.

Finally at the west of the Arquía Complex limited by Cauca - Almaguer or Romeral Fault, volcanic rocks has present together Mesozoic basic and ultrabasics complex in tectonic contact with Meso-Cenozoic marine sediment intercalations that represent the denominated Provincia Litosferica Oceánica de la Cordillera Occidental (PLOCO) and Dagua Structural Complex (Nivia, 1996). Here the author shows that the RFS begins from the north of La Guajira Peninsula to the northwest Peruvian Paita Bay (Fig. 1), and shows a recent seismotectonic analysis of the RFS according to this model in Colombia.

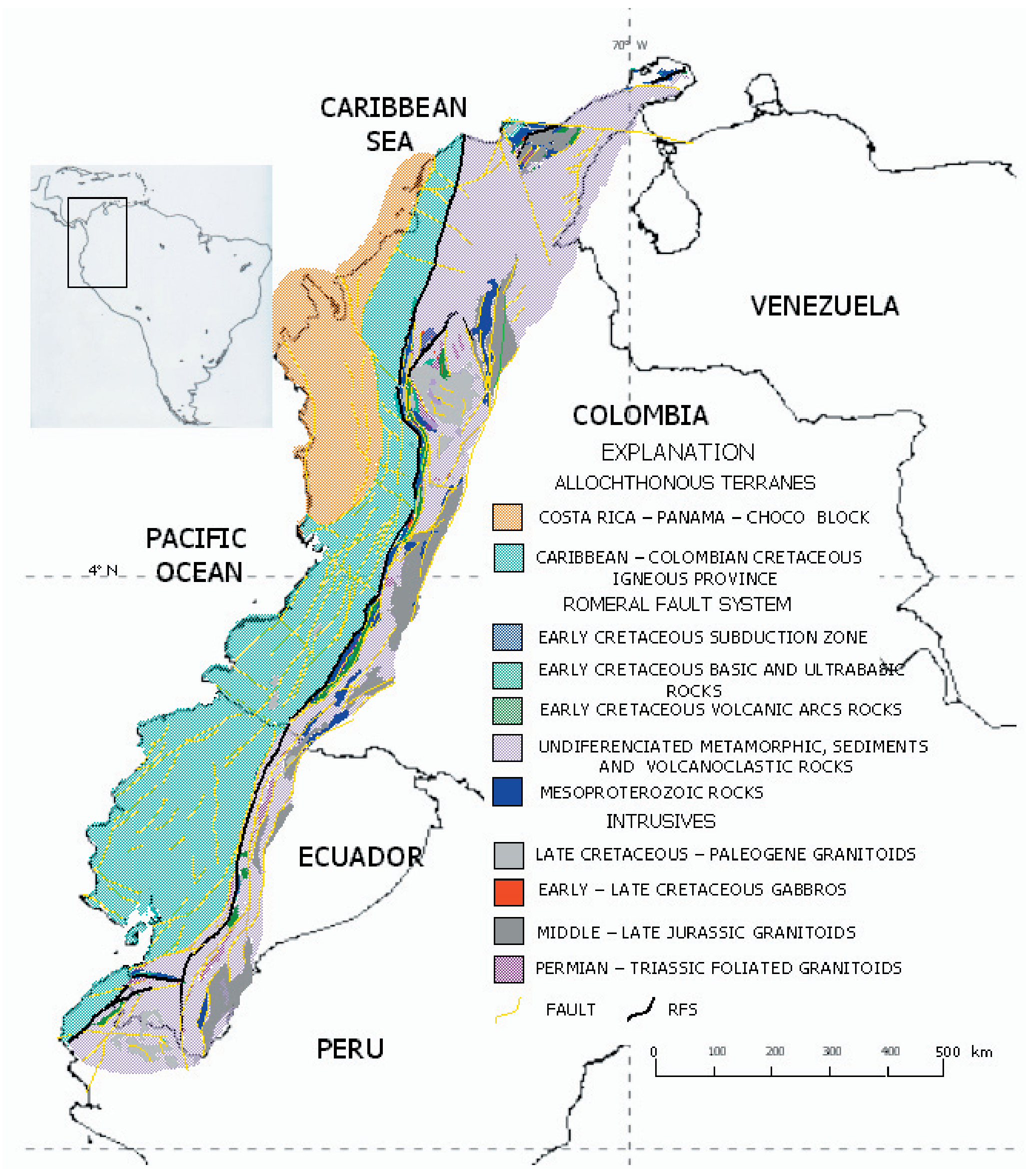

Fig 1. Simplified tectonic – stratigraphic sketch of Romeral Fault System with its localization in the South American continent (left inset). The RFS is black thick traces and others first order fault thin yellow traces. This map show principal geologic unites and allochthonous terranes influenced in their geodynamic evolution from Triassic.

PETROLOGICS AND TECTONIC ASPECTS

From isotopic data of RFS five thermal events of second order in this South America were shown sector in Colombia (Maya, 2001, 1992; Aspden et al., 1987) and in Ecuador (Noble et al., 1997; Spikings et al., 2002, 2001, 2000; Aspden et al., 1992 a and b).

FIRST THERMAL EVENT

During Permian-Triassic lapse the Pangean superplume activity (Maruyama, 1994) origined the first thermal event on northwestern South American lithosphere (figs. 2 A and B). In Colombia the isotopic event verification was given by Vinasco et al. (2003), Ordóñez and Pimentel (2001 a) and Maya (2001, 1992). The presence of Triassic (foliated or not) granitoids at La Guajira Peninsula (Maya, 2001), and at Sierra Nevada de Santa Marta (Tschanz et al., 1974), coincide in age as some presented in the Cordillera Central and characterized by foliation and dynamic metamorphism as described by Vinasco et al. (2003), Maya (2001), Orrego and Paris, (1999) and Etayo et al. (1986), and also in Ecuador by Noble et al. (1997) for the Amotape terrane and for Aspden et al. (1992 a) for Cordillera Real.

This thermal event indicates a NE - SW extensive phase in Cordillera Central axis, at La Guajira Peninsula and in the Sierra Nevada de Santa Marta. In the lithosphere of Cordillera Central and others orogenic provinces mentioned above, suffered the same event (Fig. 2 C). In Ecuador, both the Cordillera Real and El Oro Complex in the Amotape terrane (Noble et al., 1997; Aspden et al., 1992 a) register the same event. The high values in the relation Sr87/Sr86 with an order of 0,70877 - 0,71065 in the Metatonalita of Puquí (Ordóñez and Pimentel, 2001a), estimate a source primary old continental crust which coincide equally with the Neís of Puquí, confirming a common cortical homogeneous source. These values coincide with those showed by Aspden et al. (1992 a), with the type S granitoids of the Cordillera Real. The values showed for εNd (248Ma) point for the Metatonalita of Puqui (Ordóñez and Pimentel, 2001a) and the granitoids in the Amotape terrane of Ecuador at El Oro Complex (Noble et al., 1997) coincides.

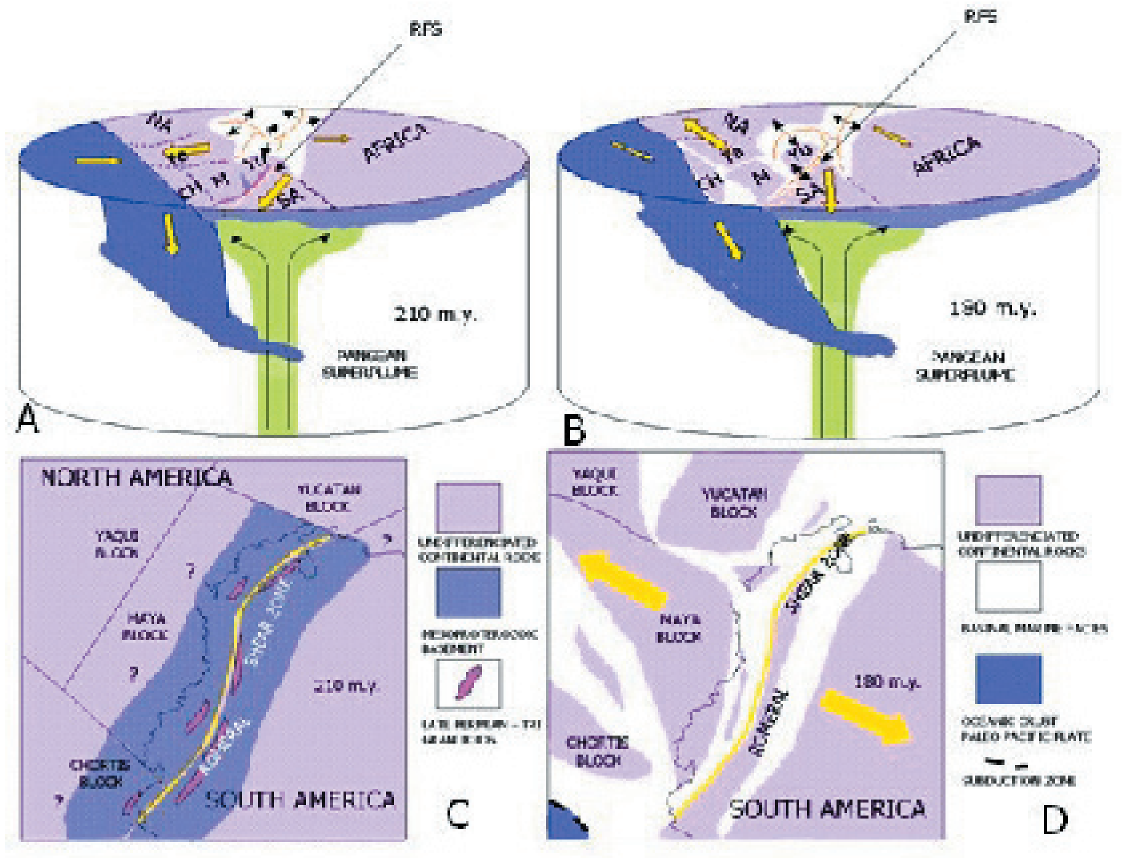

Fig. 2. Global Geodynamic panorama from west hemisphere for Upper Triassic (A) and Lower Jurassic (B). In C y D, local geodynamic view for the northwestern South American corner in same time.

The presence of foliated granitoids or not, with intermediate magmas and corresponding to this lapse is also verified equally in the Chortis Block (Donnelly et al., 1990) and the Acatlán Complex in the Oaxaca terrane and Chiapas Massif of the Maya Block (Centeno – García y Keppie, 1999; Molina – Garza et al., 1992; Yáñez et al., 1991; Moran – Centeno, 1985). In Acatlán Complex the observed granitoid is contemporary to those of South America, and presents a strong cortical contamination with positive values for ε_{Nd} (Yánez et al., 1991), indicating a high lithosphere thinning in the Maya block, compared with the Northern Andes lithosphere, during this lapse.

The previous affirmations indicate that the high values in the relation Sr87/Sr86 and the negative values of contemporary εNd, point out a magmatism that extends for this whole lapse, besides that geochemical and isotopic data determine a petrogenetic environment corresponding to a pre-continental rifting phase (Wilson, 1989), originated by the influence of the Pangean superplume. The continental crust relation to Chortis and Maya blocks and South America, present similar geochemical (Noble et al., 1997) and paleomagnetic tendencies (Molina - Garza et al., 1992), with a common Mesoproterozoic basement associated to Grenvillian belt (Kroonenberg, 2000; Yáñez et al., 1991) (Fig. 2 C).

Las Aradas–Baños–Romeral shear zone postulated by Aspden et al. (1992 a), obey a stress mechanism generating cratonic extension of first order in this sector of South America. According to these authors, I indicate that the result of the triple junction rift-rift-rift caused by the Pangean superplume activity in this time separated Laurentia from Gondwana (Figs. 2 A and B). This phenomenon produced a magmatism corresponding to this thermal event, which originated the continental border that defined the northwestern margin of South America plate during the Early Jurassic. This border defines the shears zone composing the RFS (Figs. 2 C and D). The Guaicaramo paleo–suture zone, in this region and time is an exception.

SECOND THERMAL EVENT

This event is indicated by Middle to Late Jurassic big batholiths of Colombia and Ecuador (Maya, 2001, 1992; Noble et al., 1997; Aspden et al., 1992 b, 1987 b; Etayo et al., 1986; Álvarez, 1983; Tschanz et al., 1974). This magmatic arc observed from Sierra Nevada de Santa Marta to the north until Zamora batholith in the Cordillera Condor in the southeastern Ecuador (Fig. 1). The origin of this arc has not been clarity defined. In Colombia Aspden et al. (1987 b) indicate that it is product of Jurassic subduction zone and Álvarez (1983) classifies several of these granitoids as type I. For Ecuador, Aspden et al. (1992 a & b), give a similar classification for greater Jurassic batholiths of Cordillera Real. However taking in account geodynamic considerations for this lapse that belongs for Jurassic period (Fig. 3 A), there is not clear about the origin and the presence from this great magmatic belt of intermediate character in northwestern Gondwanaland. It is clear that the panorama for Jurassic period in this sector is an extensive field stress related to rifting (Mojica and Kammer, 1995), it is common too the presence of marine and platform sedimentation accompanied by strong subaerial volcanism such in Colombia as in Ecuador (Kammer and Mojica, 1995; Aspden and Litherland, 1992; Etayo et al., 1986). The same features arise at Maya block, although in this block the volcanism is not as apparent as in Northwestern South America, on the contrary, there is showing two sectors with different evolutions in this lapse. To the west a subduction zone is manifested and to the east extensive phases with strong marine transgressions where these last ones affect a large part of the Chortis block and the entirety Yucatan block during this time (Donnelly et al., 1990; Servais et al., 1986; Tardy et al., 1986; Moran – Centeno, 1985). The petrogenetic origin of the granitoids type I is not clear according to the geodynamic panorama presented during this period for the South American northwestern corner, it could be obeys more to a rifting phase than a subduction zone, due to the long lapse so of this magmatism has been registered by radiometric data.

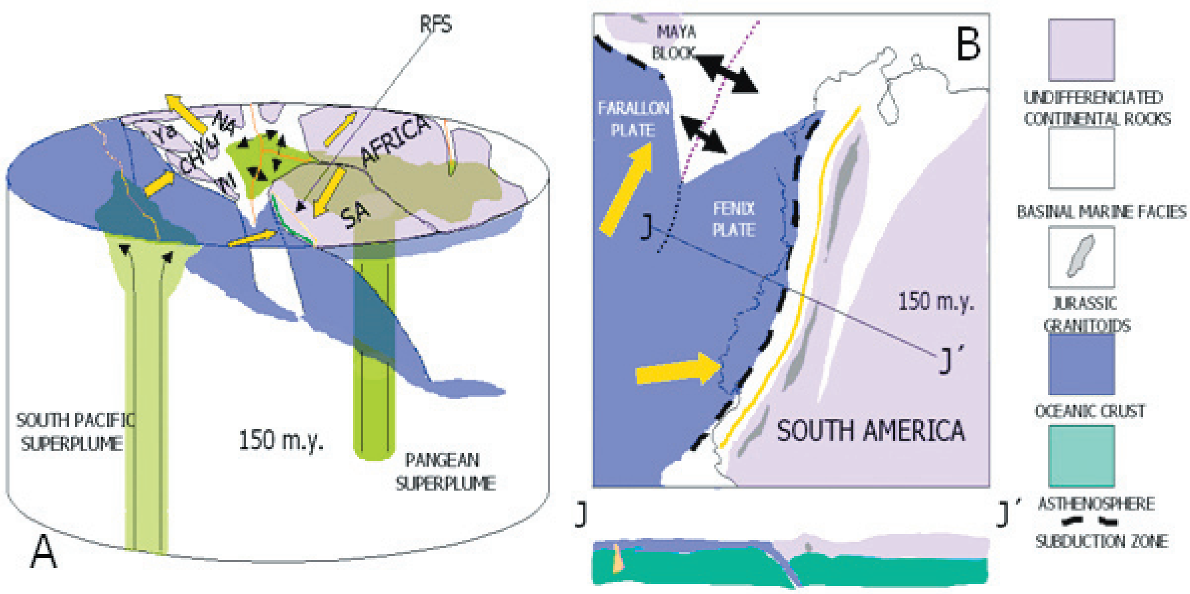

Fig. 3. Global Geodynamic panorama from west hemisphere for Upper Jurassic (A). In B local geodynamic view for the northwestern south American corner in same epoch with cross section J – J´. See text for more details

It's possible that magmatism in this initial phase was a product of residual effect of rifting phase that was developed progressively from the Triassic thinning continental lithosphere and then in the Middle Jurassic it obeyed with more security a derived magmatic arc of a subduction zone (Fig. 3B). The regional tectonic development in this lapse shows the possible creation of big shears and cortical shearing in normal or oblique tendency as a result of a transtensive regimen originated during this rifting phase (Fig. 2).

On the other hand the tectono – stratigraphic panorama that is shown in the RFS that is referring for Maya and González (1995) indicate with their litodemics unites let see the geodynamic development of a subduction zone during the lapse Late Jurassic – Lower Cretaceous (Fig. 4). This age is considered for this subduction zone, due to the contemporary with a possible component strike slip continuing some from these shears when it was developed an region of oblique subduction during Late Jurassic. As an examples of these mega shears how the Palestina Fault, the fault systems Pericos - Mulato - Otú, Chusma – La Plata and Salinas, Sibundoi and Suárez to the east of the RFS in Colombia and faults systems as Chingual, Cosanga and Méndez in the oriental flank of Cordillera Real in Ecuador.

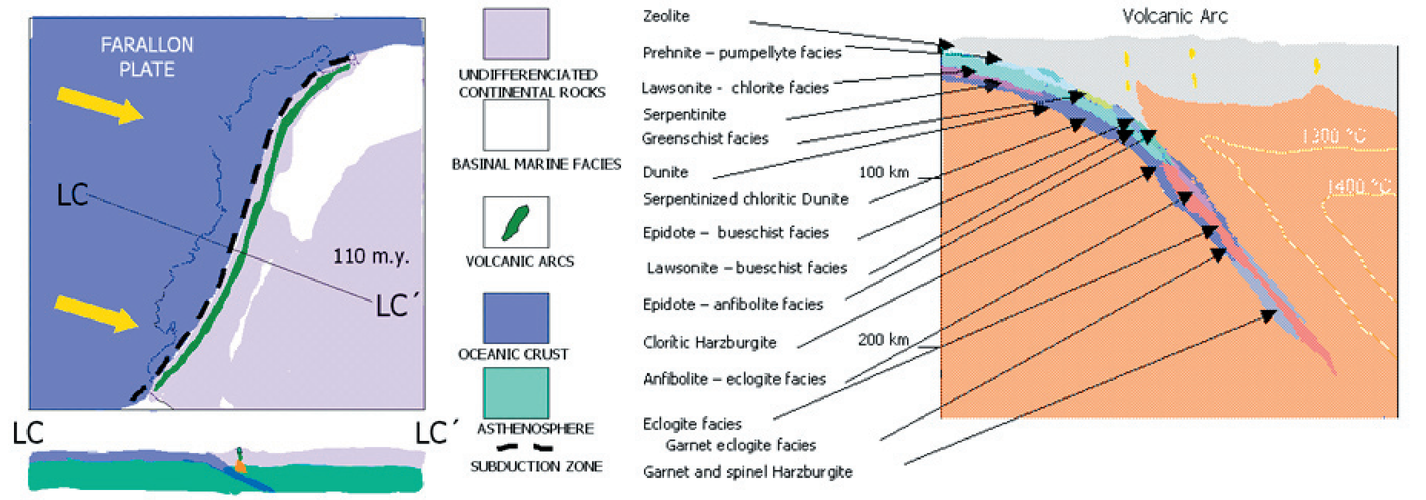

Fig. 4. Left: Local geodynamic view for the northwestern South American corner in Aptian times and cross section LC – LC´. See text for more details. Right: Steep slab subduction zone petrogenetic simple model showing the metamorphism and transformation phases itself sensu Peacock (1993) and Hacker et al. (2003 a y b).This hypothetic model suggest petrologic analogy with Arquía Complex together with basic and ultrabasic rocks, HP - LT rocks and arc volcanic Quebradagrande Complex.

THIRD THERMAL EVENT

This event extend from end of Late Jurassic until of the Lower Cenomanian in Late Cretaceous along of the RFS. It's represent by extinct subduction zone (Arquía and Quebradagrande Complexes, besides to basic and ultrabasics rocks (Álvarez, 1987 a and b) that accompany this tectono - stratigraphic framework).

Correlatively with the Quebradagrande Complex (Nivia et al., 1996; Maya and González, 1995), in their age and stratigraphic characteristic like the association of volcanic and sedimentary rocks with or without metamorphism, these are the Paraukrien Formation in La Guajira Peninsula, the magmatism that produce the Riolita Golero and granitoids of contemporary age in the Sierra Nevada de Santa Marta and the Metabasaltos y Piroclásticas Asociadas next to the San Pablo Formation in the Campamento terrane in Colombia (Maya, 2001; Etayo et al., 1986; Tschanz et al., 1974; Hall et al., 1972).

For Ecuador this correlation is made with the Alao - Paute unit with Alao terrane in the western flank of Cordillera Real (Aspden and Litherland, 1992), and the Celica Formation to the south of Loja terrane and in the Amotape terrane (Jaillard et al., 2002, 1999). The Quebradagrande Complex has been considered that represents a magmatic arc located above a subduction zone (Nivia et al., 1996). In the case of La Guajira Peninsula and Sierra Nevada de Santa Marta rocks, this type of confirmations has not been made, while Alao - Paute unit is very deformed (Aspden and Litherland, 1992). The Celica Formation allows let see the development of a fore arc basin which was controlled by a convergence regime (Jaillard et al., 2002, 1999). The spiderdiagrams shown for diverse points that Quebradagrande Complex by Nivia et al. (1996) and for the volcanic rocks of the Celica Formation in Ecuador for Jaillard et al. (2002), indicates that derived magmas of a subduction zone (Wilson, 1989).

The Arquía Complex just as it age and petrologic characteristic described in the literature (Maya, 2001, 1992; Maya and González, 1995), let see that it is igneous and sedimentary rocks associated to oceanic crust that have suffered diverse grades of metamorphism, related by their space and time features with a typical subduction zone due its physical conditions (Hacker et al., 2003; Peacock, 1993, 1990).

Next to these rocks there associate belts or fragments of blue schist, gabbros and ultrabasics rocks (Fig. 4). The same way is observed with Arquía and Quebradagrande Complexes in several sectors like in Pacora, Pijao, Barragán and Jambaló (Maya, 2001; Álvarez, 1995). The same situation happened with the Ruma terrane rocks in La Guajira Peninsula and the Seville microterrane in Sierra Nevada de Santa Marta (Maya, 2001; Etayo et al., 1986; Tschanz et al., 1974), their petrologic associations let perceive a subduction zone. In Ecuador similar fragments presented as Peltetec Ofiolitic Complex in the western flank of the Cordillera Real and Raspas Metamorphic Complex in the Amotape - Tahuin terrane (Bosch et al., 2002; Arculus et al., 1999; Aspden and Litherland, 1992; Litherland and Aspden, 1992; Aspden et al., 1987 a).

Assuming the stratigraphic and tectonic context of RFS with Arquía Complex and basic and ultrabasic rocks shows in Fig. 1, Ernst (1988), indicates that retrograde metamorphism that some of these units present is typical for subduction zones as part of its tectonic history in HP - LT rocks like blueschists and eclogites, produced an ascent of subducted material toward to surface after detachment takes place of descending slab, adding in this process mantle material like ultrabasics rocks. These processes of exhumation obey to changes in the convergence among the plates or to a complete ceasing of the subduction. England and Molnar (1993), indicate that the heat dissipation rate for volume unit in the shearing regions where rocks are exhibited with high grade of metamorphism juxtaposed with rocks of low grade of metamorphism, are the product of the shears stress and strain rate. For that reason the areas of high heating not necessarily coincide with those of more deformation. This situation makes difficult to determine how were distributed the dissipation sources of shear heating in this area when it was active. About this, Aoya et al. (2002), estimate for these mechanisms a clockwise sense trajectory to the pressure versus temperature during a change in the convergence during a subduction development zone which is mainly related to a subduction jump, interpreting for this that a rock fragment with previous metamorphism and an equivalent thickness at the perpendicular distance between the old and the new subduction zone, must have an effect on the post collision heating, but this won't require a special source of heat or tectonic event. This phenomenon causes the deviation of the conditions in the temperature from the metamorphism to a low relation of temperature and pressure in the contemporary geotherms along the upper limit of the subduction zone. About on this context, Cloos (1993) estimates that when a collision is present in a subduction zone, ceases its development and is presented a new subduction zone with its own jump, causing a dramatically change over the convergence model and a movement of the plates that made origin to the first subduction zone.

With the above-mentioned, the tectonic – stratigraphic disposition along of RFS showing retrograde metamorphism phenomena being observed in Arquía Complex and rocks associated in the places like Pijao and Barragán in Colombia and equally in the Raspas Metamorphic Complex in Ecuador (Maya, 2001; Mojica et al., 2001; González, 1997; Bosch et al., 2002, Gabrielle, 2002; Arculus et al., 1999). The cause of this tectonic history in this subduction zone is the increase and collision during the lapse Late Cretaceous – Early Paleogene of continental and Caribbean – Colombian Cretaceous Igneous Province or Caribbean plate fragments in the western margin of South America (Aspden and McCourt, 2002; Spikings et al., 2002, 2001; Kerr et al., 1998; Nivia, 1996; Litherland and Aspden, 1992; Aspden et al., 1987 a). Equally synchronous at this event also manifested a basic magmatism in back arc region toward the east of RFS at Cordillera Oriental in Colombia and Oriente Basin in Ecuador (Moreno et al., 2001; Barragán and Baby, 1999; Barragán et al., 1997). This obeys in Ecuador probably to a slab roll back derived of a ceasing of the subduction with a possible slab break off mechanism in Early - Late Cretaceous lapse (Barragán and Baby, 2004)

In tectonic evolution during this thermal event, the fundamental shear of RFS represented by Silvia – Pijao fault that puts in the limit the Arquía and Quebradagrande Complexes in Cordillera Central. Simarua fault in La Guajira Peninsula and Seville Lineament in Sierra Nevada of Santa Marta, Colombia, those which present some likeness in age and petrologic with the Arquía Complex and the volcanic or equivalent arcs (Maya, 2001; Maya and González, 1995; Tschanz et al., 1974). In Ecuador this shear is represented by not differentiated traces of Peltetec fault that separate to the Unit Alao – Paute of the Ofiolitic Peltetec Complex in the Cordillera Real, and Tahuin Dam fault located between Amotape terrane and Raspas Metamorphic Complex, in Amotape Range at southwestern Ecuador, and Celica fault between Amotape terrane and the Celica Formation at east flank of Amotape Range in northwestern Peru (Bosch et al., 2002; Jaillard et al., 1999; Aspden and Litherland, 1992; Aspden et al., 1987 a). San Jerónimo fault (Maya and González, 1995) separates the Quebradagrande Complex of the western continental lithosphere in Colombia. Cannot be identifying with some equivalent trace that completes the paper of this fault in La Guajira Peninsula and Sierra Nevada de Santa Marta. This appreciation can be confirmed in Ecuador at Baños – Las Aradas faults (Aspden and Litherland, 1992), but not at Amotape terrane.

The fundamental shear here proposed, was originated during the development of this subduction zone during this thermal event, but their present current tectonic - stratigraphic disposition obeys to changes during the evolutionary course of this continental margin in Cenozoic times.

FOURTH THERMAL EVENT

The fourth thermal event extends from Late Cretaceous until Late Eocene (Ordóñez et al., 2001; Aspden et al., 1992 b, 1987 b). This thermal event presented in this lapse for western Colombia are related to the thermal activity of two different lithospheres, one properly oceanic to the west and other related to the continental margin, showing both two unlike geodynamics panoramas.

For the oceanic lithosphere located to the west of the RFS during Aptian - Albian was manifested in abundant extrusion of the Pacific superplume in the Ocean Pacific basin, causing an exaggerated increase of the oceanic crust in this sector of the planet (Larson, 1991). This crust conforms part of the paleo - Pacific plate or paleo - Caribbean (Mauffret and Leroy, 1997), which begins to accreted with the western margin of South America during Campanian in Ecuador (Aspden and McCourt, 2002; Kerr et al., 2002).

After the Aptian - Albian event in the central Pacific, during the lapse Cenomanian – Turonian lapse has an apparently reappearance of the phenomenon, indicating like a special characteristic the presence of komatiítes and picrite tuffs with a high MgO contents. These lavas are presented in several places of the Caribbean plate and in the sites 803, 1185 and 1187 at the oriental flank of the oceanic Ontong Java plateau in the Kroenke submarine canyon which dispose among the atolls of Ontong Java and Nukumaru in the Nauru basin (Kerr, 2003; Mahoney et al., 2001; Arculus et al., 1999; Mamberti et al., 1999; Alvarado et al., 1997; Orrego and Espinosa, 1989; Alvarez, 1987 b).

The coincidence of the ages for both igneous provinces, the strong likeness among the Cretaceous faunas of the Caribbean with the Line – Nauru basin Islands (Nivia, 1989), and the similarly geochemical characteristic that point out lavas of high temperature related to primitive or primary magmas that are presented such as in the Caribbean plate as in the Ontong Java plateau during Cenomanian - Turonian lapse insinuates the correlation of these crusts with a common source in its origin, or a tectonic special dynamics too, that produced an extreme thinned of upper lithosphere, so that these lavas were presented contemporarily in both igneous provinces. It is also necessary to emphasize that these lavas are exceptional for the Phanerozoic and apparently they are only presented in these two igneous provinces in the planet (Kerr, 2003).

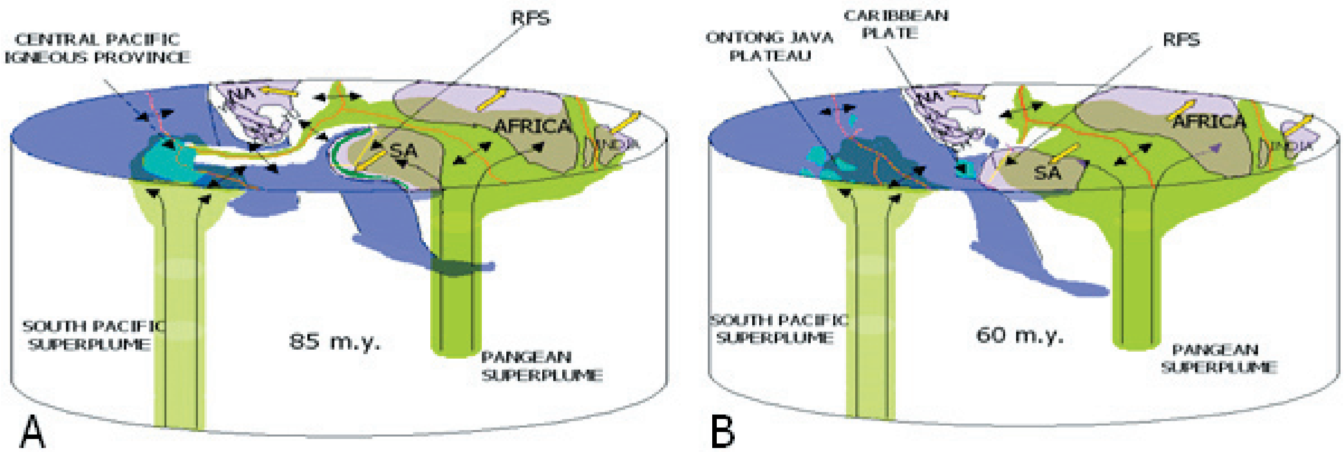

Fig. 5. A. Global Geodynamic panorama from west hemisphere for Late Cretaceous and B. Paleocene., showing the source possible for Caribbean plate. See text for more details

Considering this it is possible to mention that during Aptian - Turonian lapse both conformed a single igneous province and that after this lapse they get separated (Figs. 5 A and B). Such as the Caribbean plate as the Ontong Java plateau showing by geophysical evidences high thickness crust (Kerr, 2003; Maloney et al., 2001; Mauffrett and Leroy, 1997). It is possible that here it was a single great Cretaceous igneous province, and that a triple joint produced this exceptional extrusion with lavas that represent a primitive magma. This triple joint would be conformed by Oriental Pacific ridge and possibly west extension of one ridge defining the triple joint rift - rift - rift that separated in Triassic - Jurassic North and South America.

The Caribbean plate accreted in Campanian at the western margin of the northwestern South American corner. Dynamic metamorphism increment in shears of RFS due to the effect of this collision (Fig. 6 A). Previous to this, Amotape and the Chaucha - Guamote terranes accreted with the Ecuadorian continental margin (Jaillard et al., 1999; Aspden and Litherland, 1992 a). These accretions produce decrease in the magmatism product of a developed subduction zone from the Late Jurassic in the continental margin (Ordóñez et al., 2001; Maya, 1992; Aspden et al., 1992 b, 1987 b). Spikings et al. (2002, 2001 and 2000), show by modeling with fission tracks in apatite, zircon and white mica for Ecuador the increment of the cooling rates in the continental lithosphere, being observed a period of cooling for the Cordillera Real and the Amotape terrane. A first event for Maastrichtian – Paleocene lapse is coincident with the accretion of the Pallatanga terrane in the continental margin of Ecuador and a second event for Middle Eocene with the accretion in this margin of the Macuchi terrane (Aspden and McCourt, 2002; Kerr et al., 2002). Equally these authors show for the Cordillera Occidental in Ecuador, a fall in the heating, but its not as constant as in the other regions in both cases, because its represented a jump in the subduction zone and magmatism indicates the presence of a volcanic arc in this sector of the continental frontier (Aspden and McCourt, 2002; Kerr et al., 2002; Reynaud et al., 1999). The collision in its first phase produced the ascent and exhumation of the deep geologic units of Cordillera Real generating the inversion metamorphism and shear of these rocks in Loja and Salado terranes (Spikings et al., 2001). In Colombia this accretion was take place gradually toward north until the Middle Eocene (Fig. 6 B) producing a first order unconformity for this sector of the northern Andes and Colombian Caribbean platform when accreted the PLOCO and San Jacinto accretionary wedge (Nivia, 1996; Duque, 1984, 1980).

The oblique collision and the dextral displacement of the Caribbean plate toward the NE in this margin during Paleogene (Figs. 6 A and B), develops an regional unconformity and produced a gradual exhumation of the RFS rocks and in several sectors the milonytes belts development mainly in the faults that constitute and correspond to limit between the subduction zone and the Early - Late Cretaceous volcanic arc, represented by San Jerónimo and Silvia - Pijao faults of Cordillera Central in Colombia. This process produces the metamorphism retrograde in the rocks that form this shear zone producing reactivation or the development of first order faults like Pallatanga, Pujilí, Calacalí and Peltetec in Ecuador (Kerr et al., 2002; Spikings et al., 2001; 2000), Cauca – Almaguer fault in Cordillera Central in Colombia and Romeral Lineament in Colombian Caribbean platform. The accretion of the oceanic terranes to the west of the RFS defines structural limits of first order like Cauca – Patía Fault zone in Colombia and San Isidro - The Angel, Canande, Daule - Apuela, Pallatanga, Calacali, Pujuli and Chimbo - Toachi Lineament among others in Ecuador.

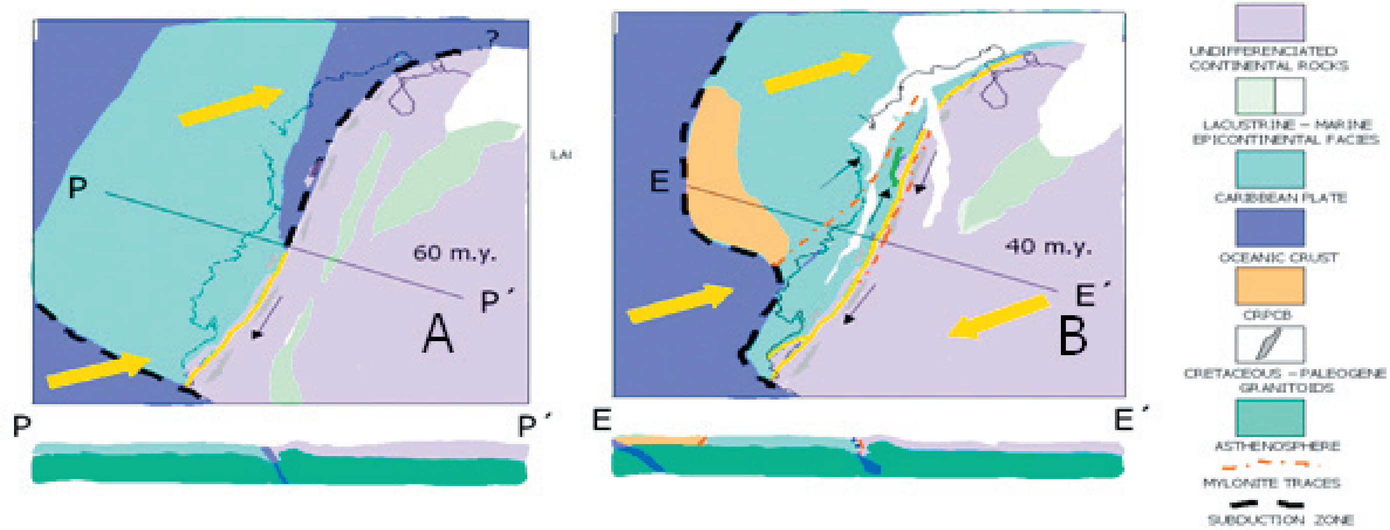

Fig. 6. Local geodynamic view for the northwestern South American corner in Paleocene with cross section P – P¨ (A), and Middle Eocene with cross section E – E¨ (B). See text for more details.

Cloos (1993) indicates that for the collisions in the active margins, in the jump of a subduction zone a displacement of the magmatic arcs is presented. In our case that is presented toward the west of the collision area that is represented by the RFS. It was also presented the development of a shears zones accompanied by heating as a result of a strong dextral displacement which produced the dynamic metamorphism in this collision area, as a result of a series of the phenomena that's conjugate a panorama of lithosphere delamination (Schott et to the., 2000; Schott and Schmeling, 1998). Development of this panorama over the low lithosphere can present the separation or the partial disintegration of the old subducted slab.

FIFTH THERMAL EVENT

This event begins at Early Miocene in Colombia (Risnes, 1995; Maya, 1992; Aspden et al., 1987 b). This calc - alkali magmatism showed under the continental margin in the Cauca - Patía basin and in Cordilleras Central and Occidental in Colombia. The long activity in the time of this magmatism obeys to convergence development of Nazca plate under South American northwestern margin from Early Miocene resulting of the Galapagos triple junction located in this sector of the Oriental Pacific (Georgen and Lin, 2002; Hey, 1998, 1977). The partition of the Farallon plate in Cocos and Nazca plates starting from this triple junction caused that Caribbean plate moved with tendency ENE in contact with South American northwestern margin until getting inserted between North America and South America during Neogene (Figs. 7 A - C and 8). The final consequence of this convergence is the accretion and collision in the Late Neogene of Costa Rica - Panama - Choco Block (CRPCB) in Colombia northwestern corner, together with accretion of Sinú accretionary wedge in Colombian Caribbean platform (Chicangana and Vargas, 2003; Chicangana et al., 2002; Duque, 1990 a and b, 1984, 1980, Escalante, 1990).

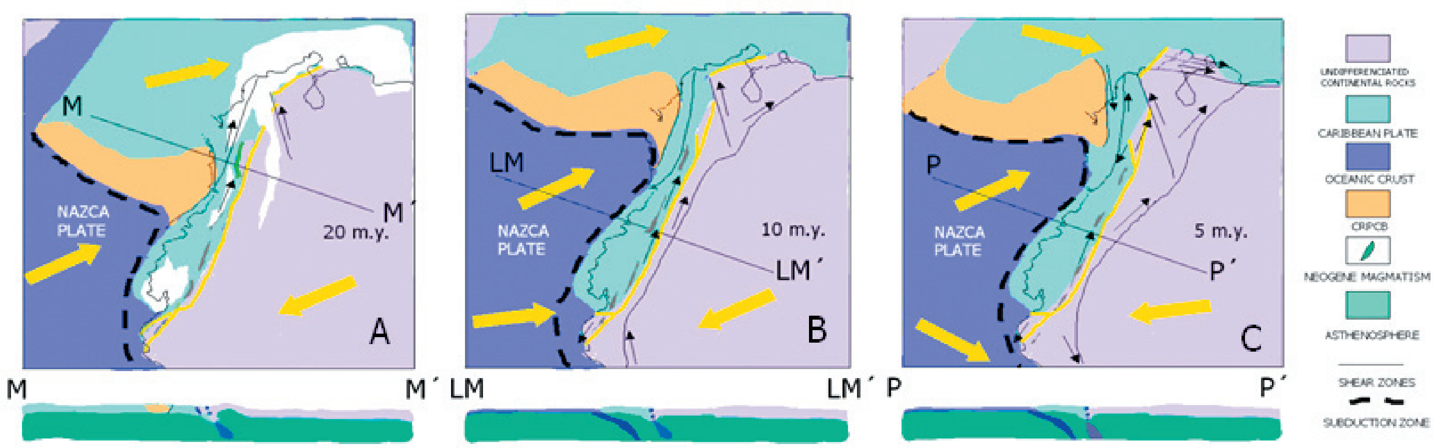

Fig. 7. Local geodynamic view for the northwestern south American corner and its cross section respectively. A. Early Miocene with cross section M – M¨. B. Late Miocene with cross section LM – LM¨. C. Early Pliocene with cross section P – P¨. Black arrows indicate cinematic tends of principal tectonic structures including RFS and cross sections to right left showing delamination lithospheric processes evolution in old slab due to subduction zone jump. See text for more details.

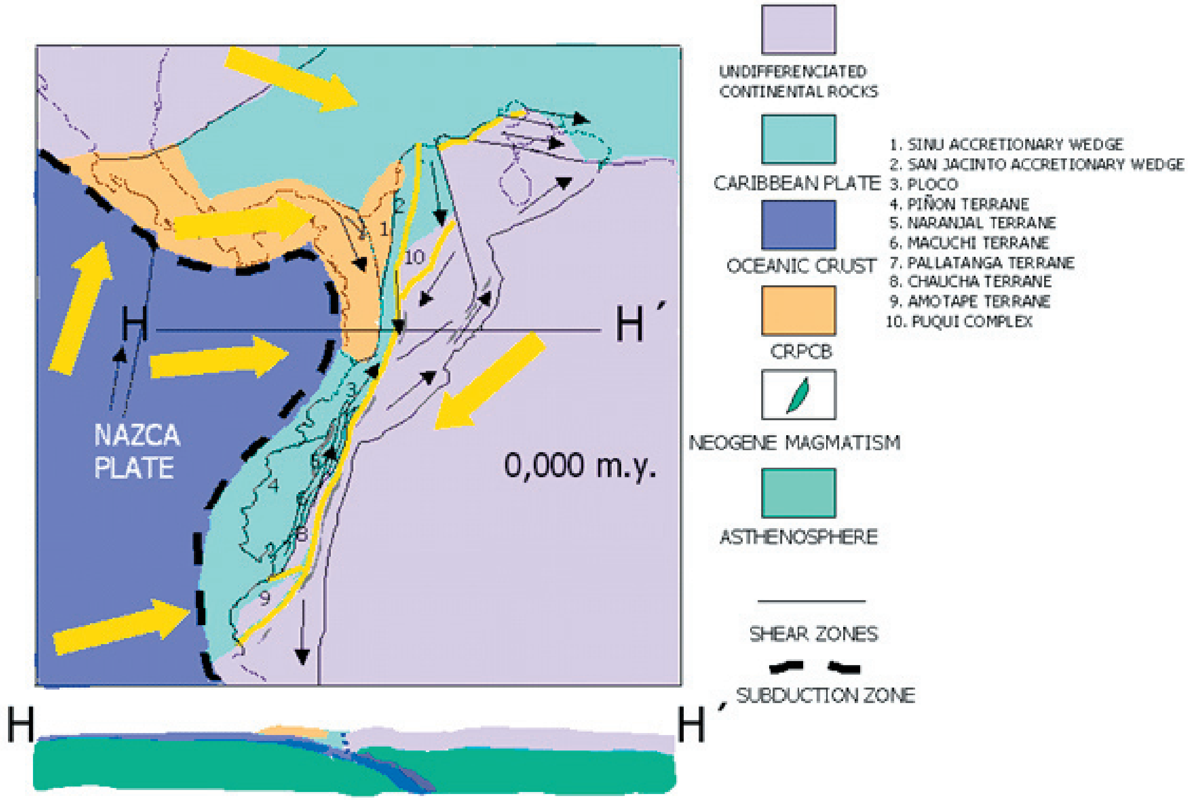

Fig. 8. Actually local geodynamic view for the northwestern south American corner in with cross section H – H¨ also showing allochthonous terranes and geologic units accreted during late Cretaceous – Paleogene lapse to west of RFS, and black arrows point out cinematic tends of main tectonic structures of this region at present time.

The development of Neogene's magmatism verified with geochemical indications showing in western Colombia from Middle Miocene a strong likeness with the mantle source (Ordóñez y Pimentel, 2001b). In Ecuador from Middle Miocene until present a cooling of the lithosphere besides an ascent and exhumation of deep rocks has verified (Spikings et al., 2002, 2001, 2000), additionally there is, a change is presented in the magmatic differentiation for Late Neogene causes a big affinity with a mantle source (Chiaradia and Fontboté, 2003). This likeness made the mantle also observed in recent basic extrusions in southwestern Colombia (Rodríguez and González, 2003).

The change in the magmatic differentiation of this thermal event in Colombia and Ecuador for the Late Neogene indicates a change under the conditions from the lithosphere at the end of this lapse. According to Schott et al. (2000) and Schott and Schmeling (1998), during a process of delamination in the ductile conditions of the lower lithosphere, big shears being developed originate a separation of subducted slab take place materials with smaller density that ascends while those of more density descend in the mantle. This condition is in function of the age of the detachment slab and the space left by this phenomenon, which is filled by the upward material of the mantle. When this kind of evolution occurs in the lowest lithosphere, the new disposition of the subducted slab to the west of RFS reconfigures this astenospheric wedge generating a thinned lithosphere. The interference of basic magmas took place in several cases when they were favored with the propagation of the big shears from the lowest to the superior lithosphere due to the regional extensive régimes that helped basic magmas emerge to the surface. Its observed that a strong extensive régime is presented as a result of the increment of tension of the upper lithosphere by the effect of the orogeny in the area of the collision that produced the activation of normal faulting in back arc basin to the east of the RFS during the collision of the Caribbean plate such in Colombia as in Ecuador. Toward final of the Paleogene and Early Neogene were originated big faults as result of a transtensive regional regime in this sector of South America. These faults in Colombia are the Santa Marta – Bucaramanga Fault (SMBF), Cesar Lineament and Tigre fault in the northeast (Etayo et al., 1986). Toward southwest big shear systems reactivate in the eastern piedmont of the Cordillera Central while that the RFS developed dextral pull apart basins as result of the displacement to the NE of the Caribbean plate (Figs 7 A and B).

When the Caribbean plate trapped between North and South America during the course of Late Miocene to the Early Pliocene (the Fig. 7 C), a great left displacement take in FSMB that changes place the north end of the RFS displacing the Sierra Nevada of Santa Marta and La Guajira Peninsula regions toward NW for a great distance (Boinet et al., 1981). With the collision of the CRPCB from Late Pliocene in the northwestern Colombian corner (Figs. 7C and 8), a change is presented in the tendency of the displacement in the RFS become in left slip sense between the 4 and the 7,5°, while to the south of the 4° N until the 4° S in the Gulf of Guayas original right sense is conserved, while to the south of this latitude Jubones fault presents left slip (Steimann et al., 1999; Ego et al., 1996).

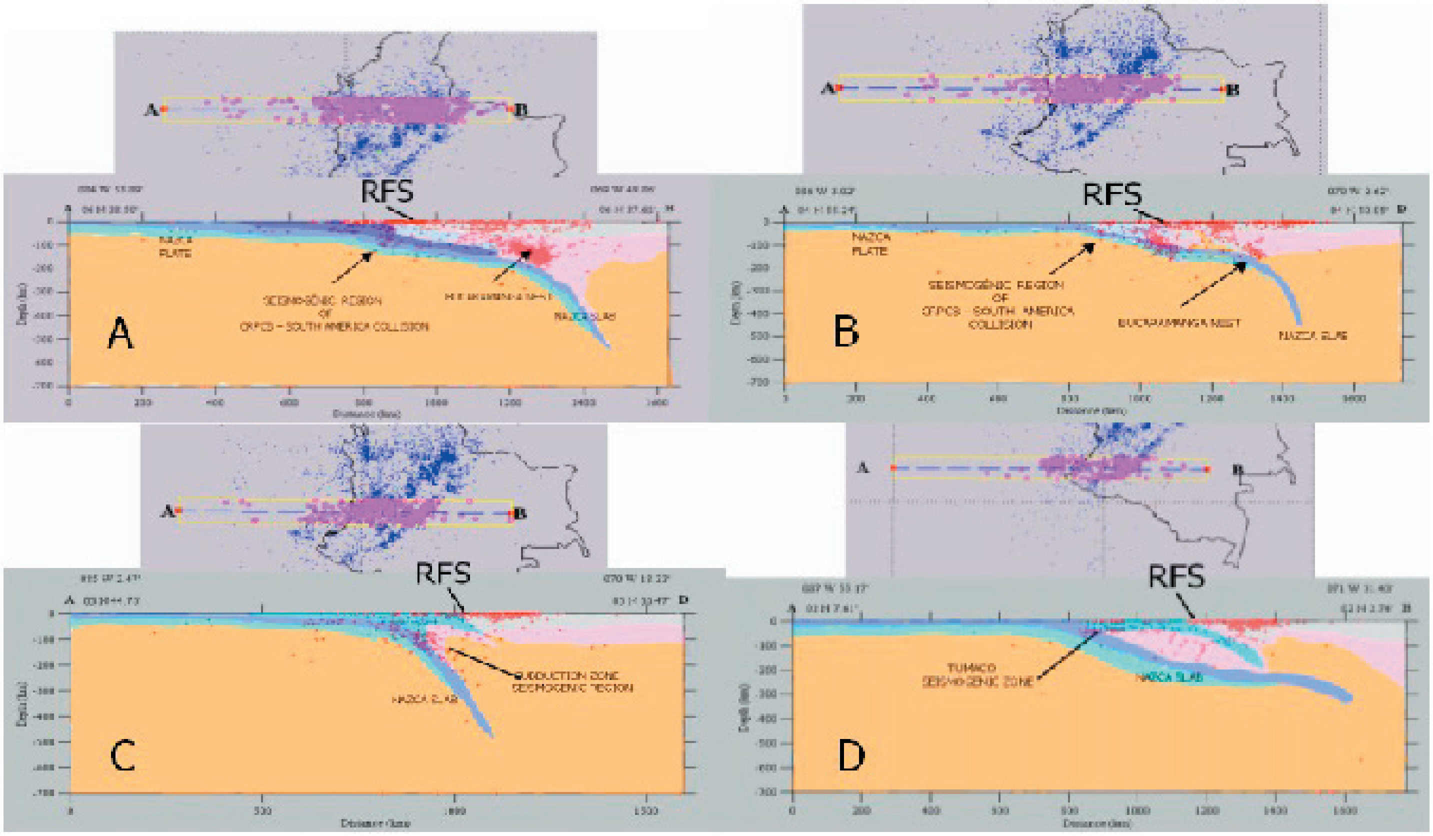

Fig. 9. Hypocentral Cross sections using 1993 – 2001 local seismological data from the National Seismological Network of Colombia (RSNC) (Ingeominas, 2001), with 1° of wide of section in these 7819 earthquakes were applied registered in more than 4 seismographic stations network. A. Flat slab between 5,5° - 7,5° N. B. Steep slab between 4,5° – 5,5 ° N. C Steep slab between 3,5° – 4,5° N. C. Steep slab between 0° – 3,5°. RFS indicate localization of Romeral Fault System zone. No vertical exaggeration.

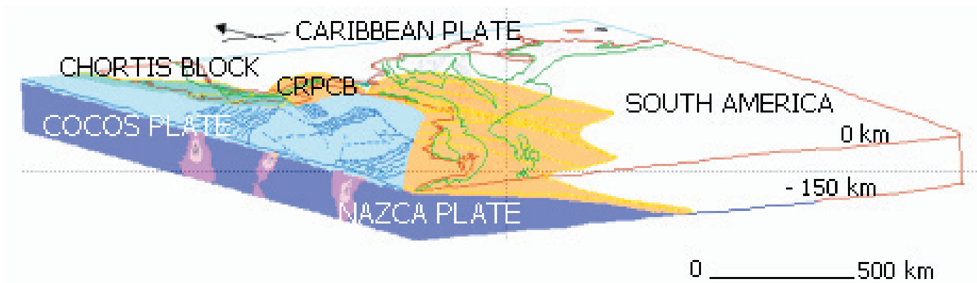

Fig. 10. 3D hypothetic topographic view of slab subducted surface below northwestern South American corner from RSNC database.

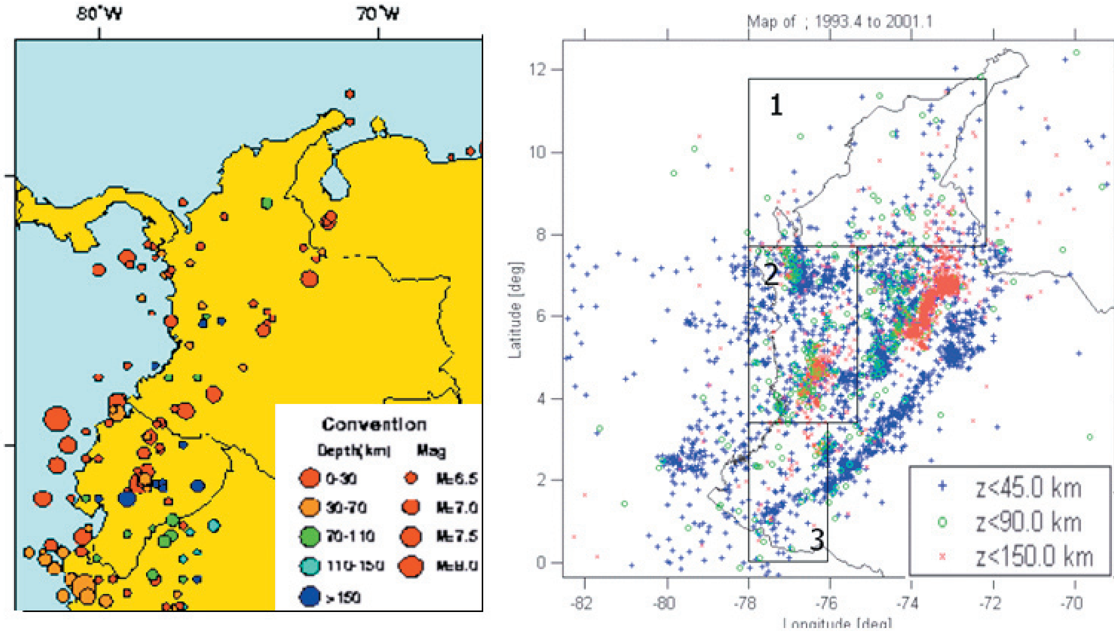

Fig. 12. Left, historical seismicity 1471 – 1991 report data SISRA (NEIC, 2000), with MS > 6,5 events only. Right, 1993 – 2001 local seismicity report by National Seismological Network of Colombia (RSNC). 1. Colombian Caribbean platform. 2. Between 3,5 - 7,5° N, and 3. Between 0 - 3,5° N. See text for more details.

When the collision was completed and the Isthmus of Panama emerges during the Late Pliocene (Duque, 1990 b), the Nazca plate in this sector presents besides with the CRPCB positive buoyancy, a left displacement is presented to the southeastern of Panama (Cowan et al., 1998) and flat subduction is observed between the 5,5 and the 7,5° N in Colombia (Monsalve, 1998) (Figs 9 A and 11). The limits of this accretion being faults as Uramita, Garrapatas, and the Sinú lineament that toward the south is called Monteria fault.

Equally as a result of this collision there are strike- slip faults system like the Ibagué fault and the reactivation of Espiritu Santo fault that belong to the RFS (Figs. 1 and 8). Lastly the development of this accretion produces a gradually rising of the Cordillera Oriental in Colombia, estimating that the propagation of the subduction of the Nazca plate to the 5,5° North and the convergence of the Caribbean plate, produced the rising of this orogenic context as Cordillera de Merida to the west of Venezuela, by activation of thrusting on the Falla Frontal de la Cordillera Oriental or Guaicaramo fault in Colombia and of the Piedemonte Oriental in Venezuela. The displacement on the Caribbean plate in this last sector produces right displacement in Boconó fault and kinematics tendency is observed from Cosanga fault in Ecuador (Eguez et al., 2003) until Boconó fault in Venezuela (Audemard et al., 2000), indicate a anticlockwise rotation of the South American plate in this lapse, situation that stays until today (Fig. 8).

Following the Colombia - Ecuador trench the Nazca angle slab increases until the 3° N (Figs. 9 B - C and 10), where again it decreases (See Fig. 9 D) until the 4° S due to the influence of the Carnegie ridge collision on this margin. On south of this latitude, again this angle is increased until the 5° S when it begins to decrease when presented the flat subduction of Nazca under the northwest of Peru (Gutscher et al., 1999). Its oblique convergence of the Nazca plate and Carnegie ridge to the south produced the successive rising of the Cordillera Occidental in Colombia and the final ascent of the Cordillera Real in Ecuador (Spikings et al., 2002, 2001, 2000).

The development of the adjustment of convergence during Late Pliocene to Early Pleistocene lapse took place in several sectors an effect tensional in big lithospheric shears that derive of the delimination lithosphere. These big shears favored the expulsion of the basic magmatism in the southwestern of Colombia and the presence of these basic magmas in the bodies of the Late Neogene porphyry bodies in Ecuador. On the contrary, to the north of the 5,5° N, observed that the magmatism was very restricted and by effect of cortical thinning product of the delamination its displaces toward to the east, this situation produced ignimbrites and tuffs volcanism activity in several sectors of the Cordillera Oriental during this last lapse (Garzón, 2003). His last situation seems that stays at the present time with the manifestation of hot springs in the Cundi - boyacence highlands and in the eastern flank of Cordillera Oriental (Fig. 8). Also by the effect of the delamination, takes place with this new collision the ascent of many relatively deep rocks of the upper lithosphere as the Mesoproterozoic basement and big igneous intrusions resultants of the Jurassic - Cretaceous arc like Antioquia batholith among others. North of the 7,5° with the adjustment of the Caribbean plate between North America and the South America plates together the subduction of the Cocos plate to the SW, this plate moves along the north margin of South America that collides with the continental crust in an oblique convergence in this sector.

In this continental margin are developed in E - W sense big strike slip faults like Oca and Cuisa faults. The lateral displacement of Caribbean plate in this sector produces a separated development pull apart basin in these E - W faults. This behavior continues from northeast Colombia until northeast Venezuela (Audemard, 1996). The development of this convergence produces clockwise rotation of the Sierra Nevada of Santa Marta with a strong ascent in this last orogen, operate as backstop the Tigre fault for produce a symmetrical orogen. In La Guajira peninsula the displacement that took place by this effect produced a total basement emergency to the north of Cuisa fault and the partial emergency between Cuisa and Oca fault.

SEISMOTECTONICS

The seismicity presented for the diverse sectors along the RFS in Colombia, is the result of the convergence of these plates from Late Pleistocene (Figs. 8, 9, 10 and 11). At Colombian platform between the 7,5 and the 11,5° N (Fig. 11), σ1 tend ESE take place a shallow seismicity with earthquakes ML ≤ 4,0 and an intermediate seismicity with earthquakes ML ≥ 5,0 (Chicangana and Vargas, 2004). Historically earthquakes have been observed with MS ≥ 6,0 for region of Sierra Nevada de Santa Marta. For this region an event of these characteristics with a depth hypocenter 58,3 km in this region registered by the National Seismological Network of Colombia (RSNC) in February of 2004 (Ingeominas, 2004). These events are possibly attributed to the Oca Fault activity (Paris et al., 2000). The registered of local seismological data in this region is unfortunately very poor due to the very low density of the seismographic RSNC stations and the registration of the events is taken mainly of NEIC. Because it is not possible to find studies of good quality on local seismic activity of this region, what helping to determine seismic areas and less for intermediate and long – term seismic hazard prediction analysis for this region of Colombia.

Between the 3 and the 7,5° N (Fig. 11), a drastic change is observed in the angle of Nazca slab (Monsalve, 1998). In this sector (Fig. 8) σ1 is predominantly NW - SW (Chicangana et al., 2003, 2002), with prevalence of high seismic activity that is observed in Colombia trench with MW ≥ 5,0 shallow events, Pacific coast platform and Cordillera Occidental. Equally a great intermediate seismicity associated to the subduction zone is observed where the scale goes from 3,5 and the 5,5° N a bigger rate of events is presented with MW ≥ 4,0. Many of these last earthquakes in some cases have produced destruction and lost human at historical times in Colombian Eje Cafetero region, as the events of November of 1979 and February of 1995. In the region along RFS two dozens of shallow events have been presented with MS ≥ 4,5 in near 450 years of historical data, and more recent was the earthquake MW ≈ 6,2 in January 25 1999 that destroy Armenia city.

Between the 0 and the 3,5° N (Fig. 11), with (Fig. 8), σ1 predominantly NE – SW (Ego et al., 1996), the subduction zone seismicity activity is lower than in north of the 3° N, but in the Colombian - Ecuadorian trench have happened MS ≥ 7,5 earthquakes with return rate of an event of this dimension in less than 20 years for this region such in Colombia as Ecuador (Fig. 11). Also historically the Falla Frontal de la Cordillera Oriental between 1 and 2° N, has presented several MS ≥ 6,0 earthquakes that have affected mainly the Colombia and Ecuador frontier region. The RFS presents in this region a higher shallow seismic activity that to north of the 3° N, being observed 40 earthquakes with MS ≥ 4,5 in 450 years of historical data and more recent important event was March 31 1983 earthquake that affected to Popayán city.

CONCLUSIONS

The modeling applied on this investigation starting from petrogenetic and geodynamic evolution of the lithospheres that constitute the RFS at the present time in western border of the northwestern corner of South America shows that the RFS originates initially as a product of a derived continental margin of North and South America separation from a triple junction joint rift - rift - rift during the Late Triassic – Early Jurassic lapse. Then under this margin was presented a subduction zone which was active from Middle - Late Jurassic until Late Cretaceous when it began to be truncated by Caribbean plate by effect of it collision with northwest margin of South America. From Paleogene until the present the RFS suffered the dynamic metamorphism and exhumation of its deep rocks as resulting mechanism in the upper lithosphere of slab separation at lower lithosphere by the effect of lithosphere delamination development by this collision that which takes place totally under this region of South America during Paleogene – Neogene lapse.

Also here is exposed a first attempt of direct correlation of Caribbean plate with the Ontong Java plateau considering secondary sources as the bioestratigrafic and petrogenesis, something that Reynaud et al. (1999), has been doing with the rocks of the of the Piñon terrane in Ecuador, this concepts are considering with a new sketch of the geodynamic that explains a lithosphere with the anomalous thickness in the Pacific's oceanic crust that tries to demonstrate the abnormal pulse of the Cretaceous Superplume proposed by Larson (1991), as the origin of the oceanic crust that represents the Caribbean plate in present. This correlation also explains many of the tectonic and stratigraphic phenomena that are observed in the RFS that derived mainly of the accretion and collision of this oceanic crust of anomalous thickness in this subduction zone in northwestern South America.

The consumption of the lithosphere in this continental margin derived from delamination and the later convergence of the plate of Nazca plate during the Neogene has left an area of cortical weakness (RFS) trapped between two rigid crust represented by a continental to the east and an oceanic to the west. This convergence for Late Neogene defines the three different stress fields tends in Colombia. The analysis of these stress fields and the seismological behavior of each one of these areas, show a rate seismicity increase from this shears zone to the south 3° N than to the north. Finally it is observed that the change on Nazca plate slab angle, under Eje Cafetero region to western Andes (3,5° - 5,5° N) increase of the intermediate seismicity activity. This last seismogenic source historically has been responsible for big earthquakes that have affected specially this region of Colombia.

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