SIMPOSIO

" EXPLORACION PETROLERA EN LAS CUENCAS SUBANDINAS "

REGIONAL GEOLOGY AND TECTONIC EVOLUTION OF THE SUBANDEAN BASINS FROM THE BARINAS BASIN (VENEZUELA) TO THE NAPO RIVER (ECUADOR)

By

ARMANDO ESTRADA M.

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ABSTRACT

The Subandean basins form a long wedge - shaped belt of marine and continental sedimentary rocks covering a broad stratigraphic range from Cambrian to Recent. Crystalline basement of Precambrian age underlies the Barinas and LLanos basins but in Putumayo and Ecuador the crystalline basement is pierced by plutonic and volcanic rocks of Jura- Triassic age .

Major geotectonic elements structurally involved in the tectonic framework and evolution of the Subandean basins, are as follows :

Cratonic element :	A stable and rigid element occupying the western part of the Guiana Shield .
Pericratonic element:	A rigid slab of crystalline Precambrian rocks peripheral to the craton and gently inclined toward the Andean orogen ; it was subject to oscilatory mouvements .
Andean orogen :	A mobile belt that has undergone the most dynamic folding and faulting , metamorphism and magmatism during several orogenic episodes and uplift . This belt forms the western boundary of the Subandean basins .

The long geologic history of the Subandean basins practically started around 1100 to 1300 m.y. ago when a regional metamorphic event, which affected all of Colombia and the Guiana and Brasilian shields, began to split apart creating The Amazonas basin . The analisis of regional geology since Precambrian time allows a better understanding of the tectonic evolution outlining the interaction of the Andean province and the Guiana Shield, as follows :

— The Precambrian craton extended to the west as far as the present Cordillera Central. Isochron contours show increasingly younger ages from the craton to the Andean front.

- The most extensive marine invasion took place during Cambro- Ordovician time but a great part of the sedimentation to the west belongs to a Precambrian mio-geocline .

- The best documented orogeny of the Early Paleozoic occurred during Silurian time creating the first Andean feature herein called the Dorsal Bolivariana. Subsequently, the eastern Andes and the Pericratonic belt became the site of complex longitudinal basins with reverse axial polarity of sedimentation.

- During Jura- Triassic time a rift valley developed along the Magdalena depression extending southward toward Ecuador and Peru along the Subandean basin masking the geologic features of the Cordillera Oriental .

- A second marine invasion took place during the Middle Cretaceous developing different characteristics in each Subandean basin . The Tertiary cover includes marine, terrestrial and brackish sedimentation .

- Accumulated Andean uplift since Eocene totals about 6 kilometers, west of the Putumayo basin .

The Subandean basins can be divided in three units with different tectonic styles :

a. The Fold Belt : Located at the Andean foothill, form a distinctive belt 15 to 40 km wide, with varied asymmetrical folds. It is usually bounded by two major thrust faults inclined to the west .

b. The Subandean Trough : Zone of maximum sedimentary thickness located between the Fold Belt and the Platform.

c. The Platform : Extends over a flat area of 100 to 250 km wide, east of the Andean foothills . Sedimentary layers are subhorizontal or gently inclined to the west . Strata are only minorly affected by faults and folds, and have scaped the effect of orogenic events. Sandy facies increase to the east .

Oil Potential : Hydrocarbons were generated mainly from Cretaceous sedimentary rocks with minor contribution of Tertiary sediments, Paleozoic strata deserve attention . Migration occurred in various stages influenced Andean orogenies, folding and uplifts.

Better possibilitie for large oil fields are within the platform belt. Traps are ample with large radial folds . Fault and stratigraphic traps are very attractive .

Confirmed presence of oil fields exist in the fold belt . However , younger folding and faulting has fragmented and dispersed the previously entrapped oil into medium to small size oil accumulations . The hydrodynamic effect of waters washing in from the Andean front helped to move and displace oil from highly permeable layers.

ARMANDO ESTRADA MEJIA

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I INTRODUCTION

About half of Colombia's land area in the east and southeast, lies within the Llanos-Amazon plain, which slopes gently to the east and southeast and is drained by tributaries of the Orinoco and Amazon rivers whose long courses both discharge into the Atlantic.

This huge territory, lying between the Andes Cordillera and the Guiana Shield, has been the depositional site of a long wedge-shaped belt of marine and continental strata known as the Subandean basins. Time range of the stratigraphy embraces all periods from the Cambrian to Recent and presents a complex tectonic and sedimentologic evolution tied to the interaction of the Precambrian crystalline basement with the Andean orogen.

Several oil discoveries within this extensive and poorly explored territory have attracted the industry's interest in recent years. Most oil exploration covers only the Tertiary and Cretaceous strata with little attention to older events. Many stratigraphic structural and sedimentologic questions arise from the only partial knowledge of the tectonic evolution since Precambrian time.

Cratons, rather than being completely immobile, stable or undeformed, have been subject to episodes of deformation of varying degree, including localized vertical displacements of several kilometers.

The cratonic continental margins and the Andes have shared dual roles as sediment sources and sediment traps, resulting in a more complex history than that of the Atlantic margin of South America. However a comprehensive tectonic history, especially along the Andean front, is obscured by the multiplicity of events. Historical reconstruction depends on the dating of intrusive or thermal events that produce a complex tectonic history and the identification of facies responses as evidenced in the preserved sediments, as well as an understanding of extrusive, intrusive and metamorphic events and vertical movements ranging from epeirogenic to orogenic in scale. As a result, the tectonic evolution of the Subandean basins cannot be fully understood without going into the older chapters of geologic history and to the Precambrian roots which provide the foundation for the entire subsequent geologic evolution.

This paper emphasizes the geologic events of the Precambrian, Paleozoic and Early Mesozoic in Colombia, encompassing a regional approach which covers parts of Venezuela and Ecuador. Most of the ideas expressed in this paper were developed by the author ten years ago (Estrada, 1972) and are revived here with the purpose of stimulating new thinking and approaches to exploration models, in the hope that this contribution may help to complement the geologic knowledge of the Subandean basins.

II GENERAL GEOLOGY AND GEOTECTONIC BOUNDARIES

The geotectonic boundaries suggested here for the Subandean basins are based on concepts of the relative stability of the crustal segments, the nature of major orogenic belts, the genetic implications of magmatic events and petrotectonic assemblages, considering possible correlation of major sedimentary units with low grade metamorphic rocks that may be stratigraphically equivalent. Only two major geologic provinces have been distinguished in Colombia by most geologists : the Andean Cordillera and the Guiana shield. By recongnizing the four geotectonic elements a better understanding of sedimentation , tectonic evolutiòn and boundary framework of the Subandean basins is achieved.

The term ' geotectonic element ' refers to a unit with a common assemblage of structural and petrological features with defined tectonic style within a belt of regional significance in terms of geologic history and sedimentation. As thus defined, the geotectonic elements involved in the Subandean basins bear a close relationship to the major geomorphic features of Colombia, Venezuela and Ecuador. The areal distribution and general features of the tectonic elements are illustrated in Figures 1 and 2 .

II.1 Guiana Shield

The crystalline terrain in the Llanos area is a part of the main Guiana Shield which extends west into the Andes in fragmented slabs as far as the Cordillera Central and consists of crystalline rocks of Precambrian age representing typical old continental crust. This geological province contains two geotectonic elements termed cratonic and pericratonic , described as follows :

II.1.1 Cratonic Element

The Cratonic element consists of Precambrian crystalline rocks which are exposed in small hills in the easternmost Llanos region , and extends north from the Amazon basin to the Guiana Craton proper . This geotectonic element, which forms the eastern boundary of the Subandean basins, has been a tectonically stable and rigid element unaffected by orogenic events at least since Cambrian time , and has little or no sedimentary cover. Its geology is poorly known in Colombia ; however , substantial contributions from the PRORADAM PROJECT (Galvis et al , 1979 ; and Priem et al , 1980)have provided a better understanding .

Migmatites, quartz feldepatic gneisses and anatectic granites are the predominant rocks types together with amphibolites, paragneisses and a variety of metasomatic banded rocks derived from sedimentary - volcanic events. A sequence of partially metamorphosed quartzose sandstones and conglomerates indicates that the last sedimentation took place at least 1200 m.y. . Microcline is a conspicuous mineral present in almost all rock types. Gradational changes and transitions between rock types and minerals going from mafic assemblages into more acidic or granitic rock types is a rather common feature and suggests potassium metasomatism. Radiometric datings (Priem et al , 1980) show ages around 1500 m.y. which gradually decrease in age toward the Andean front, where crystalline Precambrian appearing rocks are dated as 1100 m.y. or younger .

II.1.2 The Pericratonic Element

The Pericratonic Element forms a distinctive belt between the Craton and the Andes Mountains, but still is made up of typical Precambrian continental crust. This belt forms the Subandean region along which a longitudinal basin runs through Peru, Ecuador, Colombia and Venezuela and borders the stable craton. The most important part includes a wedge-shaped cover of sedimentary rocks of Cambro-Ordovician age resting on the depressed western border of the belt and overlain by sediments of Late Cretaceous and Tertiary age. Slight metamorphism has effected the Ordovician sedimentary rocks in the Macarena area without significant deformation, but younger sedimentary rocks in the same area lack of metamorphism . Absolute age determinations within the Pericratonic Element vary between 1100 and 1300 m.y. . However, some syenitic intrusions and pegmatites of Early Paleozoic age are present toward the middle part of the pericratonic area.

The crystalline substrata of the Pericratonic Element behave like a rigid slab gently tilted to the west along the Andean boundary where it has been subject to oscillatory movements and has accumulated the maximum thickness of sediments .

Faulting is a common feature and is aligned in two main directions; one almost parallel and the other perpendicular to the Andean front. Horsts or basement highs following a north west direction abut against the Andean fold belt and reflect the old tectonic trends of the cratonic terrain, thus tending to divide the local Sub andean basins.

II.2 Andean Province

The Andes is the most complex part of Colombia and is the zone that has undergone the most dynamic folding , faulting, uplift and magmatism during several orogenic episodes. It includes the transition zone between continental and oceanic crust and was the site of complex longitudinal basins where thick sequences of Mesozoic sedimentary rocks accumulated in two major environments: miogeosynclinal and eugeosynclinal . On the east, fossiliferous Paleozoic and Mesozoic sedimentary rocks make up the bulk of the mountains. On the west, metamorphism has obscured most stratigraphic relations, and correlations with units to the east are difficult or impossible. Better correlations are feasible along individual belts oriented north-south .

Metamorphic rocks in paired belts, chains of batholitic intrusions, young volcanic rocks and strong seismic activity are characteristic of the Andean province. This mobile belt is here divided into three geotectonic elements which coincide with the three main ranges of the Colombian Andes : Cordillera Oriental, Central and Occidental. Along both sides of the Cordillera Central two intra-Andean depressions, the Magdalena and Cauca valleys, separate the main ranges and form two other important geotectonic elements within the Andean province.

II.2.1 Cordillera Oriental

This Cordillera lies between the Llanos area and the Magdalena Valley and trends about N 37 E. The highest point, near the Santander Massif, is about 5490 meters above sea level and is made up of sedimentary rocks. The range extends into Venezuela as two main branches : the Merida Andes toward the northeast and the Perijá Range to the north.

The Cordillera Oriental is the external zone of the Andean mobile belt and consists of a thick accumulation of marine Cretaceous sedimentary rocks overlying continental molasse, redbeds, and some volcano- plutonic rocks of Jura- Triassic age. Devonian and other upper Paleozoic sedimentary rocks crop out in discontinuous patches along the central part and on the eastern flank. All the known pre- Devonian rocks show effects of regional metamorphism, although Silurian sedimentary rocks have not been found. The Cretaceous sequence was deposited unconformably on the older rocks in an area nearly coincident with The Jura- Triassic basin. No significant metamorphism of the Mesozoic sedimentary rocks has been reported and evidence of igneous activity during Cretaceous and Tertiary time is very scarce.

The Cordillera Oriental in Colombia and the Merida Andes in Venezuela share very similar geological characteristics and mark the western boundary of the Subandean basins. The Cordillera Oriental, as the geotectonic element conceived in Colombia, doesn't exist in Ecuador or it is minorly represented by the incipient Cordillera Cutucú and the Napo Uplift, so the western boundary of the Subandean basin in Ecuador exhibits different tectonic characteristics.

II.2.2 Cordillera Central

This Cordillera lies between the two Intra- Andean depressions and trends north-south, decreasing in altitude and dying out toward the north. Several snow- crested, dormant volcanoes are present in the central part and rise to an elevation of 5750 meters.

The Cordillera Central consists mainly of crystalline, generally folded metamorphic rocks . Those of the eastern flank, which are mainly in the amphibolite facies, are more feldspathic and commonly include quartzite and marble ; whereas those of the western flank, which are largely of greenschist facies, are more pelitic and are associated with tuffaceous and submarine volcanic rocks. The metamorphic rocks have been considered to be Paleozoic, but may include rocks of Late Precambrian and Mesozoic age. Late in the Cretaceous, batholiths of quartz diorite were emplaced along the axial core of the Cordillera where they intrude rocks as young as thin patches of Albian to Aptian marine sedimentary strata which rest uncomformably on the metamorphic rocks at intervals along the crest of the Cordillera. A discontinuous belt of ophiolitic rocks parallels the western flank of the Cordillera Central close to marine sedimentary and volcanic rocks of Cretaceous age. Along the same side of the Cordillera, active andesitic volcanism later took place from Middle Miocene to Pleistocene time. According to Case (1971), the Cordillera Central represents a transition zone between continental and oceanic crust. Some of the most typical geological units of the Andean domain, such as the batholiths, the paired metamorphic belt and the andesitic chain, are present in the Cordillera Central.

The geologic framework of the Cordillera Central of Colombia bears a close relationship with the Cordillera Real of Ecuador and can be considered as the same geotectonic element. The Subandean basins in Ecuador are bounded on the west by the Cordillera Real and contrast in geotectonic setting when compared with the Subandean basins of the Llanos and Venezuela which are bounded by the Cordillera Oriental and the Merida Andes.

II.2.3 Magdalena Valley Depression

The Intra-Andean depression of the Magdalena Valley, between the Cordillera Central and Oriental, is a rift valley which extends from southern Colombia northward through the Cesar Valley and to the Caribbean coast. The rift walls are formed by a system of block faults or other steep faults. Rifting started during Early Mesozoic time with initial basaltic and acidic volcanism piercing the crystalline basement. The basin was partially filled with volcanoclastic products and redbeds, as well as with local marine sediments and evaporites of Jura-Triassic age covered later by Cretaceous and Tertiary sediments. Gravimetric measurements by Case et al (1971) indicate positive gravity anomalies suggesting a thin crust or shallow rocks in the subsurface. Crystalline basement rocks along the valley consist mainly of epizonal batholiths of Jurassic age and remnants of Precambrian rocks. The rift and the magmatic activity extend southward into Ecuador and Peru, covered there by the Cretaceous and Tertiary sedimentary rocks of the Subandean basins.

III CHARACTERISTICS OF THE SUBANDEAN BASINS

The Subandean basins in Colombia, Ecuador and Venezuela present similar tectonic and sedimentologic features :

- The sedimentary cover rests on Precambrian crystalline basement gently tilted toward the Andean belt where sediments achieve their maximum thickness.
- Structural profile is strongly asymmetrical showing a tectonic and faulted contact with the Andean mountains, bordered on the east by a fold belt that exhibits decreasing deformation eastward. On the platform folding tends to disappeat resulting in subhorizontal strata.
- Sandstone and coarse clastics tend to increase toward the cratonic area where most of the sedimentary marine formations develop littoral facies almost without fossils. The hinge line between fold belt and platform for each formation is represented by a wide range of lithologies for different formations covering a broad stratigraphic range thus creating confusion for an adecuate stratigraphic separation. The division of Subandean basins is illustrated in Figure 3 .

III.1 Barinas-Apure Basin (Venezuela)

The Barinas - Apure basin is a structural depression in the Precambrian basement filled with Cretaceous and Cenozoic sediments to a depth exceeding 5000 meters.

- Boundaries : To the west and northwest it is fault contact with the Venezuelan Andes ; to the east and northeast by the Baul Arch which has been apparently uplifted since Permian time; to the southeast by the Guiana craton ; and the south and southwest by a gravity high between the Apure and Arauca rivers which separates this basin from the Llanos basin in Colombia .

- Areal Extent : Prospective petroliferous areal extent is about 9.000 km using an arbitrary isopach line greater than 3.000 meters of sedimentary thickness .

- Oil Potential : The Merida Arch, which has a northwest orientation, separates the area in two sub-basins. Oil fields are located on the northeast flank of the Arch. Source rocks are the Upper Esperanza formation of Late Cretaceous age, the Pagüey formation of Upper Eocene and the Parangula formation of Oligo-Miocene age.

Sands of the producinghorizons are derived from the clastic basal sequence of the Cretaceous Fortuna formation.
Figure 4 is a generalized stratigraphic column of the basin.

III.2 Llanos Basin (Colombia)

The Llanos basin is an elongated structural depression oriented N 37 E and parallel to the Cordillera Oriental. It is filled with Cenozoic, Mesozoic and Paleozoic sediments resting on Precambrian crystalline basement to a depth exceeding 7000 meters.

- Boundaries : To the west the basin is in tectonic contact with the Cordillera Oriental for more than 400 kilometers. To the north it is limited by the Arauca Arch, a gravity high, wich separates it from the Barinas basin. To the east is the Guiana craton and the pericratonic area with a structural slope of 10 to 15 degrees to the west. On the south the Macarena area and the Vaupes Swell separate the Llanos basin from the Putumayo basin.
- Areal Extent : Prospective petroliferous areal extent, considering a minimum sedimentary thickness of 3.000 meters, is about 45.000 km.

- Oil Potential : Recent oil finds have attracted the considerable interest of various oil companies. Source rocks are mainly within marine Cretaceous strata and the neritic marine shales of Oligocene age. Paleozoic sedimentary rocks and the lower Cretaceous strata have not been tested. The excellent sandstones of the Mirador formation are considered to be the best and are very attractive. Heavy oil plays occur to the south near the Macarena area.

A generalized stratigraphic column of the basin appears as Figure 5 .

III.3 Putumayo Basin (Colombia)

The Putumayo basin can be considered as the northern end of the Ecuador basin. It is an elongated depression, oriented N 40 E , filled with Middle Cretaceous and Cenozoic sediments to a maximum depth of 4000 meters. Basement consists of crystalline Precambrian rocks pierced by intrusive and volcanic rocks of Jura- Triassic age.

- Boundaries : To the west the basin is in tectonic contact with the volcano-plutonic belt of epizonal intrusives of the Magdalena rift valley. To the north it is defined by the Precambrian rocks of the Garzon Massif . To the east is the Pericratonic area and the Vaupes swell which separate this basin from the Llanos Basin. The basin plunges very gently southward forming a single unit with the Napo - Pastaza basin.

  For practical purposes the Putumayo basin will herein be limited to the south by the geo-political boundary between Colombia and Ecuador.

- Areal Extent : The most prospective area is about 12300 km, based on an arbitrary minimum sedimentary thickness of 3.000 meters.

- Oil Potential : The discovery of the Putumayo oil field in 1965 led to the discovery of the large Ecuadorian oil field. Source rocks are undoubtedly the Cretaceous shales of the Villeta formation.

The basal clastic sequence of the Cretaceous Caballos formation is the most important reservoir, together with some intraformational sandstones and limestones within the Villeta formation. Sandstones of the Eocene Pepino formation yield some oil, and in the northern part of the basin in the Florencia area the reservoirs are heavily impregnated with tar and heavy oil.

Figure 6 is a generalized stratigraphic column of the Putumayo basin.

III.4 Ecuador Basin (Ecuador)

The Ecuador basin taken as a whole is the largest of the Subandean basins because it widens and deepens toward Peru and the Amazon intracratonic depression . Basin fill remained entirely marine up to the Maestrichtian . From then on , and up to the present time , the deposits were at first brackish with marine incursions , and then continental . Basement consists of crystalline Precambrian rocks pierced by intrusive and volcanic rocks of Jura - Triassic age. Sedimentary thickness is about 4000 meters in the Rio Napo - Lago Agrio area, and exceeds 6000 meters in the Pastaza - Marañon area.

- Boundaries : To the west the Ecuador basin is separated from the Cordillera Real by a high angle thrust fault. Adjacent to this contact exists the Cutucu - Mirador - Napo uplifts which could represent incipient development of the equivalent Cordillera Oriental of Colombia. The basin extends as a continuation of the Putumayo basin. To the northeast it is bounded by the basement of the Vaupes Swell, and to the east is the crystalline basement.

IV. STRATIGRAPHY AND GEOCHRONOLOGY

Petrologic aspects are emphasized for a better interpretation of paleogeologic environments and petrotectonic assemblages. Lithostratigraphis concepts are used to describe the stratigraphy together with the geochronology. Fossil descripsions are intentionally avoided, but readers can find full description in the references .

IV.1 Precambrian

The Precambrian rocks of Colombia include igneous and metamorphic rocks and are considered as the northwest limit of the Guiana Shield .

They form a continuous body involving the Cratonic and Pericratonic elements where better exposures exist. Slabs and megafragments of Precambrian rocks together with complex assemblages of metamorphic rocks occur within the Andean province , making it difficult to construct an orderly stratigraphic sequence.

IV. 1. 1. Guiana Shield Province

In the southeast Llanos area between Guaviare and Caquetá, Galvis et al (1980) describe, within the Cratonic element , the following lithostratigraphic units :

Mitú Migmatitic Complex: Includes gneisses, migmatites and anatectic granites derived from arenaceous and pelitic metasediments, together with mafic and quartz - feldspathic meta - igneous rocks. All the known rock types exhibit potassic meta -

somatism with secondary growth of microcline and biotite replacing the amphiboles.

Radiometric dating for the Mitu comples varies from 1450 to 1560 m.y. and overages 1500 m.y. (Priem et al, 1980). The different ages represent reconstitution stages of older crustal material and high grade metamorphism during the Parguazan event. Isochron extrapolation of Rb- Sr data portray relict ages of at least 1780 to 1850 m.y. which correlate with the late transamazonic event. Around 1100 to 1300 m.y. the Mitu complex was effected by an extensive thermal event that reset the micas.

La Pedrera Formation : Composed of coarse arenaceous meta sediments including quartz conglomerates and pelitic sediments. It is located near the village of La Pedrera on the Caqueta River close to the Brazilian border. This formation rests unconformably on crystalline rocks of the Mitu Complex and has been effected by slight metamorphism. Thickness is not well known but exceeds 300 meters.

Roraima Formation : Composed of folded arenaceous sediments, mainly light colored quartzitic layers and conglomerates in the basal part. This formation has been tentatively correlated with the Roraima Formation of Venezuela (Galvis et al, 1980)but it apparently represents a younger period of sedimentation related with La Pedrera Formation . Thickness is not well known but exceeds 800 meters .

The Pedrera and Roraima Formations are cut by diabase dikes 1200m. y. old and have been unconformably deposited on the Mitu Complex which averages 1500 m. y.

Piriparaná Formation : This volcanic sequence is found along a narrow north – south belt about 250 km long from the Caquetá River to Mitú . The formation includes dark red arenaceous sediments and pyroclastics together with rhyodacitic lava flows . Thickness is not well known . Rb– Sr whole – rock dating suggest an initial extrusion age of about 920 m.y. (Priem et al , 1980).

In Venezuela , near Puerto Carreño , the absolute age determination closest to the Colombian border, ages between 1825 and 1440 m.y. have been determined for the Parguazan alcalic granites (Hurley at al, 1967) .

IV . 1 . 2 Andean Province

Microcline and perthitic feldspar are common constituents in rocks of the Guiana Shield . Most of the rocks within the Andean Province that have been dated as Precambrian also contain substantial amounts of microcline and perthite . A cautious use of this indirect line of evidence may help identify unrecognized Precambrian rocks. However tectonic, magmatic and metamorphic episodes have effected these rocks and give younger ages.

Geochronology

The oldest known rocks are amphibolites found in the Cordillera Central and are dated as 1670 m.y. (Restrepo et al, 1978) and 1360 m.y. (Barrero et al, 1976). In the Sierra Nevada of Santa Marta the Rb-Sr dating of whole -rock samples in granulites is very consistent, yielding ages of 1300 to 1400 m.y. . On the other hand, dating which is more sensitive to heating, suggests that the same Precambrian rocks have been reheated during subsequent geologic events, around 940 and 250 m.y. Other radiometric dates of Precambrian age in the Cordillera Oriental are 945 and 680 m.y. for the Bucaramanga gneisses which however have also been dated around 450 m.y. and 200 m.y. A similar situation occurs in the Cordillera Central where Precambrian like rocks yield absolute ages around 560, 420, 230 and 200 m.y. , which correspond to several tectonomagmatic episodes.

Good agreement exists in Colombia for an orogenic event around 1200 to 1350 m.y. : dates from rocks on the Guaviare River, of 1205 $\pm$ 60 m.y. (Pinson et al , 1962) and dates from the Guajira area of about 1200 m.y (Mac Donald , 1972) suggest contemporaneity . This episode may have some connection with da tes of 1300 to 1400 m.y. in the Santa Marta Massif.

Absolute age determinations in the Garzon Massif (Alvarez, 1971) indicate 1110, 1150 and 1180 m.y. for granulites. This event is also hamed the Nickerie thermal episode and is apparently effecting the micas of the Mitú Complex.

Regional correlation of Precambrian radiometric dates display a general tendency to decrease from the eastern Cratonic province at 1500 m.y. to the western Andean Province, where Precambrian rocks effected by various orogenic events have reset the timing of minerals to younger ages. Most of the schistose rocks of medium to low grade metamorphism were originally developed as the sedimentary fill of a prominent geocline during late Precambrian time, the thickest accumulation being along the present Cordillera Central but diminishing toward the Cordillera Oriental and the Pericratonic area.

Precambrian rocks in the Venezuelan Andes are represented by the Iglesias Group which is divided by Shagam (1971) as follows :

Sierra Nevada Facies , includes gneisses and coarse grained schists predominantly of quartz- feldspathic composition.

Intercalations of amphibolite are common toward the middle of the unit. Tostos Facies, includes micaceous quartz- chloritic schists intercalated whit fine grained siliceous rocks within the green schist facies. Bella Vista Facies , it looks lithologically very similar to the Tostos Facies but amphibolites or actinolitic layers are not pre - sent here.

Radiometric dating of the Iglesias Group including some granites yields ages of 660, 400,380 and 230 m.y. , which suggest several igneo- metamorphic episodes with remobilization and resetting of minerals extending to the intrusion of some Mesozoic granites.

In the Perija Range, metamorphic and granitic rocks effected by different igneo - metamorphic episodes are known as the Perijá Series which includes the Perijá Groups formed of reddish brown quartzites alternating with dark gray schists with two types of micas.

Granites and gneisses of the Perijá Series yield absolute ages of 800, 370, 300,200 and 100 m.y. , indicating a complex history of metamorphism and magmatic remobilization which is in agreement with similar events within the Andean Province.

In the Ecuadorian Andes,Precambrian rocks are formed along the

Cordillera Real which bear similarities to the Cordillera Central of Colombia. Common rock types are green schists, quartzites, gneisses, migmatites and granites. Radiometric dates are not available.

IV.2 Early Paleozoic.

The most extensive accumulation of Paleozoic sediments in Colombia took place during Cambro-Ordovician time, invading most of the Pericratonic area. Maximum thickness is on the order of several thousand meters; however, a clear reconstruction is obscured by structural complexities from pre-Devonian orogenies. Some of the metamorphic rocks in the Cordilleras Oriental and Central were formed from Lower Paleozoic and Upper Precambrian sediments. The lithology of unmetamorphosed Lower Paleozoic rocks is rather uniform throughout, and represents an epicontinental marine facies. The strata consist of dark grey micaceous siltstone and sandstone with some sandy limestone and shale intercalations; conglomeratic beds occur locally. Deeper water facies containing graptolites occur to the north and west.

Silurian strata are missing in Colombia, but in the Merida Andes they are exposed together with Ordovician sediments. In both areas evidence of Upper Ordovician sedimentation is lacking. An igneo-metamorphic event about 460 $\pm$ 25 m.y. may have first defined the Andean orogenic trend.

IV.2.1 Cambro-Ordovician

On the Magdalena River, 25 kilometers southwest of Puerto Berrio, the Cambro-

Ordovician sedimentary section consists of dark micaceous shale and argillite alternating with quartzite ; thin lenticular bodies of marble are common. A rough estimate of the thickness here is a few thousand meters. The shale contains graptolites that indicate an Arenigian age (Harrison, 1930) . Ordovician rocks overlie Precambrian gneisses and were intruded by Jurassic granodiorite.
Along the eastern side of the Cesar Valley and on the west flank of the Perija Range Tschanz et al (1969) assign a Cambro- Ordovician age to a series of low grade metamorphic rocks (conglomerate, quartzite, phyllite, dolomite and arkose are the most common rock types) that are overlain by fossiliferous Devonian strata.

The presence of Ordovician sedimentary rocks in the Merida Andes of Venezuela (Shell and Creole, 1964) suggests that the basin extended along the Cordillera Oriental toward the northeast, continuing into the Merida Andes and that sedimentation persisted in this particular area until upper Silurian time.

The thickness of Ordovician sedimentary rocks in the pericratonic area of Colombia is on the order of a few hundred meters. The thickest section is present in the Venezuela Andes : 1670 meters represented by the Caparo formation (Arnold, 1966). Other Ordovician sections in nearby areas are only 280 meters thick. West of this belt, in the Perija Range and Cordillera Central, all the pre- Devonian rocks are metamorphosed. The Perija Group and the Silgara formation in the Santander Massif all seem to be metamorphosed debris from Cambro- Ordovician and Precambrian sediments.

In Ecuador a thick series (1000 meters) of dark grey to black, slightly phyllitic slates and fine to medium grained quartzitie sandstone, named the Margajitas Formation by Tschoop (1953), can be tentatively assigned to the Cambro- Ordovician sequence.

Igneous Rocks. Near San Jose del Guaviare in the Llanos area, five samples of syenitic pegmatite and fine grained syenite were dated by the K- Ar method as being close to the K-Ar age of 457 $\pm$ 13 m.y. that Goldsmith et al (1971) reported for a pegmatite in the Santander Massif.

In the Merida Andes of Venezuela, granitic bodies that have intruded into Ordovician strata have been dated at 460 $\pm$ 15 m.y. (Arnold, 1966).

IV.2.2 Silurian

No evidence has been found yet that indicates rocks of Silurian age are present in Colombia. Sedimentation apparently was interrupted from the Middle Ordovician to the Early Devonian. However, in the Caparo formation of the Merida Andes in Venezuela, fossiliferous Silurian beds (Llandoverian) have been reported (Boucot et al, 1968). In that area, Arnold (1966) suggests an unconformity between fossil-bearing

Siluran strata and underlying Middle Ordovician rocks. The Silurian strata locally contain conglomerate which postdates a granitic intrusion that cuts the Ordovician strata. This intrusion has been dated at 469 $\pm$ 15 m.y. Granitic pebbles within the Silurian strata are very similar to those of the granitic intrusive body (Arnold, 1966).

IV.3 Late Paleozoic.

Sedimentary rocks from Middle Devonian to Early Permian record a second important cycle of Paleozoic sedimentation. These sediments were deposited in uniform epi-continental seas in Devonian and Permian time, but during the Carboniferous a more irregular sedimentation took place with frequent fluctuations between marine and continental conditions. The whole sequence of sediments probably attained a maximum thickness of 4000 meters. The Upper Paleozoic sedimentary rocks crop out in the Cordillera Oriental and the Perijá Range of Colombia and continue into Venezuela in the Merida Andes, where Devonian rocks appear to be absent. Southward, Carboniferous and Devonian rocks have been recognized in Ecuador in both the Cordillera Oriental and the Subandean Pericratonic region. The whole sedimentary sequence is continous with the exception of a minor unconformity near the base of the Carboniferous section which represents an intraformational erosional hiatus.

IV.3.1 Devonian

Devonian sedimentary rocks are well known in the Cordillera Oriental where they are known as the Floresta Formation. They extend from the Garzon Massif up to the northern Perija Range. The lower part of the Devonian sedimentary sequence is sands tone, and a thin basul conglomerate commonly is present. The strata rest locally on gneiss and amphibolite of Precambrian age, but usually on metasedimentary rocks and other schists of Cambro- Ordovician age. In some places they rest on the eroded sur face of pre- Devonian granite. The thickness of the basal sandstone and conglomerate at the type section (Floresta Massif) varies from 30 to 70 meters.

In the Merida Andes, Shagam (1971) considers that the Mucuchachi formation is mostly of Pennsylvanian age and that the Devonian section is absent.

The Pumbuiza formation in Ecuador, (Tschopp, 1953) is composed of dark grey to black thin-bedded slates, inplaces graphitic, and hard fine-grained quartzitic sandstones. The slates are highly folded and faulted. Thickness estimates are not reliable but, based on its stratigraphic position below the Macuma formation (Pennsyl vanian), it is probable that the Pumbuiza belongs to the Devonian. Some unidentified Lingula specimens were found in a loose block apparently derived from this formation.

IV.3.2 Permo-Carboniferous

Sedimentary rocks of Carboniferous age are mostly redbeds with abundant sandstone and local conglomerates. Permo-Carboniferous deposits are present along the Cordillera Oriental and continue southward into Ecuador, and in Peru they reach their maximum thickness of 10000 meters. In the Quetame Massif, Carboniferous rocks (Gachala formation) consist of more than 2000 meters of quartzitic sandstone, hard argillite in bright red and green colors and neritic limestones at the top (Bürgl, 1961) . In the Floresta Massif, the Carboniferous strata are cream-colored shales interbedded with thin layers of reddish-violet shale and overlain by sandy siltstone, reddish-violet sandy shale and hard sandstone. Above this are about 100 meters of cream - colored siliceous shale and siltstone exhibiting regular banding. The entire thickness is about 400 meters .

In the Santander, Santa Marta, Quetame, and Garzon Massifs , calcareous rocks and limestone have been reported by several geologists . All paleontologic data indicate that whereas some of the rocks are uppermost Carboniferous in age, most are of Permian age (Wolfcampanian , Leonardian and Guadalupian). The thickest section, 1200 meters , is reported by Stibane (1966) in the Quetame Massif. At other localities the thickness is only a few hundred meters. Deposition of Permian limy rocks seems to have lasted to the end of the Guadalupian.

In the Merida Andes of Venezuela, Arnold (1966) describes an abruptly thinning wedge of sediments with a lower clastic member 1880 meters thick and an upper redbed member 1480 meters. Paleontologic data indicate a Carboniferous and perhaps Permian age for these rocks. The Palmarito formation in Venezuela is marine with with some sandstone at the base (Arnold, 1966) . It unconformably overlies the Sabaneta formation (Permo- Carboniferous) and grades upward to sandy siltstone , calcareous siltstone, silty shale and limestone containing interbedded marls. Fossil evidence yields a Lower Permian age. The Mucuchachi facies includes metasedimentary rocks of Upper Paleozoic age, apparently grading into Palmarito and Sabaneta formations.

The Macuma formation in Ecuador, as described by Tschopp (1953) , comprises at the base about 150- 200 meters of dark blue- gray, mostly siliceous and thin-bedded limestone, alternating with black shales and slates. The upper Macuma consists of white to dark gray limestones with shale intercalations. The thinner limestones are siliceous and dark in color; they grade into marls and non- calcareous claystones. Gradations from sandy limestones to pure greenish - brown sandstones are common. Estimated thickness for the upper Macuma is 1250 meters . Abundant fossil evidence places the Macuma in the Upper Carboniferous (Pennsylvanian) and probably ranges into the Permian.

Crystalline Rocks . Tschanz et al (1974) reported an age of 250 m.y. for a metadio rite in the Santa Marta Massif. In the same area, MacDonald and Hurley (1969) obtained an anomalous date of 250 m.y. in Precambrian gneiss which was interpreted as a loss of argon in the parent gneiss during later heating. It is assumed from the interruption of deposition and by the occurrence of local conglomerate beds that during the uppermost Permian, orogenic events were taking place but were not fully expressed until Triassic. However, in the Merida Andes, Bass and Shagam (1960) report ages of 285 to 277 m.y. and 230 to 242 m.y. for metamorphic rocks. Recent radiometric dates in the Cordillera Central indicates five different ages varying from 227 to 270 m.y. . These data suggest a thermal event or events in the Late Paleozoic.

IV.4 Mesozoic .

The most important events in the Andean province took place during the Mesozoic era. Two major time divisions characterized by different geologic behavior can be recognized : the Early Mesozoic or Jura-Triassic; and the Late Mesozoic which includes the Cretaceous and part of the Paleocene . Jura-Triassic time was characterized mainly by tectonic rupture of a somewhat rigid terrain and magmatic activity, together with epiclastic sedimentationof mostly redbeds and deposition in local marine basins of evaporites.

Cretaceous time was characterized by the development of large marine basins of sedimentation which covered almost the entire surface of the country including the pericratonic region. Regional warping formed an elongate basin along the Cordillera Oriental, a linear uplift along the Cordillera Central, and a deep depression to the west in the Cordillera Occidental. While the sequence of Mesozoic events along the Cordillera Oriental and the Magdalena Valley can be clearly elucidated, those in the Cordillera Central and areas farther west are controversial, owing to the scarcity of fossils, complex structures and metamorphism.

IV.4.1 Triassic and Jurassic

Triassic sedimentary rocks crop out along the intra-Andean depression of the Magdalena River in small isolated basins as shallow marine deposits in the Upper and Middle Magdalena Valley, in the Santander Massif and in the Cesar Valley where volcanic activity was also important. Sedimentary Triassic is also reported on the eastern side of the Perija Range and in the Merida Andes (Lower Quinta formation). Volcanic rocks are present too, but they decrease in importance toward the Merida Andes.

The Jurassic period is characterized by an accumulation of continental redbeds in the Cordillera Oriental and the Magdalena Valley. Intercalations of littoral to lagoonal sediments indicate temporary marine invasions (Bürgl, 1967). Some local evaporites have been found to the south in Ecuador (Tschopp, 1953).

Volcanism is also very characteristic of the Jurassic period, occurring in a belt along the Magdalena Valley and southward into Ecuador where it changes from acidic types in the pericratonic or continental areas to diabase and porphyrite toward the Pacific in the west. A plutonic belt of quartz monzonites and granodiorites associated with the volcanic rocks is characteristic of this period.

Sedimentary and Volcanic Rocks

Asequence of sedimentary and volcanic rocks has been identified in the Guajira, Santa Marta, Laguna Morrocoyal and San Lucas Ridge localities. This sequence also outlines the Magdalena Valley depression in Tolima and Huila and continues southward with similar characteristies to the Mocoa and Putumayo areas and into Ecuador.

A group of sedimentary rocks near the village of Payande in the Upper Magdalena Valley is the most classical sequence of Jura-Triassic sedimentary-volcanic rocks and was described by Nelson (1957) who divided it into three formations :

The pre-Payande Formation or lower unit is made up of conglomerate, graywacke and ferruginous shale of redbed affinities. The debris consists of fragments of granodiorite, dacite, rhyolite, porphyrite and metamorphic rocks. This formation is about 300 - 400 meters thick.

The Payande Formation consists of a series of grayish - blue to dark limestones interbedded with slaty shale and black chert. Calcareous breccia, nodules of black chert and coral material are common. The limestone is frequently arenaceous with terrigenous admixtures which grade into pure sandstone. Feldspar is abundant in the terrigenous grains but volcanic activity seems to be absent. This formation is about 600 meters thick.

The lower part of the Payande Formation in the Cordillera Central probably rests partly on crystalline rocks and partly on Precambrian rocks. The upper part is overlain by continental beds containing volcanic material of Jurassic age (post- Payande Formation). The Payande Formation has been extensively intruded by granodioritic rocks of Jurassic age with intense thermal contact metamorphism (Nelson, 1957 ; Barrero, 1969).
The Payande formation is locally rich in fossils which indicate that its lower part is of Carnian age and the upper part of Norian age.

The post- Payande Formation consists of a series of volcanic rocks resting on the Payande formation. The exposed thickness is about 500- 600 meters. To the south the volcanic strata are conformably overlain by loose conglomerates , graywackes and arkosic sandstone of redbed type which pass gradationally into quartzitic sandstone of Aptian age (Nelson, 1957).

On the west side of the Santander Massif, Cediel (1968) describes the Giron Formation as a series of sandstones with cyclic intercalations of lutitic redbeds which were deposited principally in a fluvial or limni- fluvial environment. Upward they pass gradually into a blanket of marine protoquartzite of Early Cretaceous age.

Thickness at the type section, according to Cediel (1968) is 4650 meters. The Giron formation is apparently devoid of volcanic material, and according to Ward, et al (1969) it is of Jurassic age.

Venezuela

On the southeast side of the Perija Range, facing toward the Maracaibo basin, Hea and Whitman (1959) describe sedimentary units consisting of dark grey pseudoolitic limestone and medium to coarse-grained olive-grey sandstone, olive-grey carbonaceus siltstone and varicolored lithic tuff. Intercalations of volcanic rocks are common in the upper part. This unit, known as the Macoita Formation, is about 2400 meters thick. Paleontological data indicate a Permian to Triassic age.

Redbed type sediments, equivalent to those of the Giron Formation, crop out over large areas of Venezuela, including the Merida Andes where they are commonly known as the La Quinta Formation. This formation has conglomeratic sandstone in the lower part; green and red varicolored siltstone and sandstone in the middle part; and red sandstone in the upper part.

In the Perija Range, the La Quinta Formation is locally penetrated by dikes, lenses and sills of quartz diorite and porphyric to vitrophyric diabase (Sutton, 1946). Here the whole sequence is 3000 meters thick. It is worth noting that in Venezuela, the La Quinta Formation usually includes beds of Triassic age.

Ecuador

In eastern Ecuador, Tschopp (1953) describes the following Jurassic formations :

The Santiago Formation comprises a monotonous sequence of thin -bedded dark- gray to black, siliceous limestones alternating with calcareous sandstones with intercalations of sandy micaceous black shales. Minor amounts of intraformational breccias and thin sandy tuffs and tuffaceous shales are present.
West of the Cutucú Mountains, the Santiago limestones and shales contain abundant intercalations of volcanic breccias which grade laterally into green sandy tuffs and bentonitic shales. The whole sequence is intruded by dikes, sills and larger intrusions of green, porphyritic, gray to green, felsitic and diabasic igneous rocks.
The intraformational pyroclastics indicate that submarine volcanic activity took place during Santiago time and that part of the intrusions must be contemporaneous.
Thickness estimates range from 1500 to 2700 meters. Fossil determination indicates a Lower Liassic age.

The Chapiza Formation represents on the whole a continental redbed formation that can be divided in three members :

The Lower Capiza consists of alternating shales and sandstones where gray and pink colors may locally dominate over red-brown, brick-red and violet hues. This member contains thin layers of anhydrite, thick veins of gypsum, concretions of dolomite and a few salt-water springs.

The Middle Chapiza comprises a sequence of alternating red shales and sandstone (the so-called "Red Chapiza") but without evaporite intercalations.

The Upper Chapiza contains, besides red shales, sandstones, and conglomerates, a characteristic but varying amount of gray and green feldspathic sandstone and violet tuffs, tuffaceous sandstones and breccias.

Intrusions of porphyrite and diabase occur throughout the Chapiza, but lavas and pyroclastics are restricted to the Upper Chapiza (known also as "Misahualli" volcanic member).

Thickness for the entire formation varies within wide limits but in the type area totals between 2300 and 4500 meters. Stratigraphic relationships place the Chapiza between the under lying Santiago (Liassic) and the overlying and overlapping, Hollin formation.

Plutonic Rocks

The plutonic rocks of Triassic age show a peculiar distribution along the marginal border of the main sialic platform and show signs of heat remobilization of Precambrian rocks along the same belt. Based on the few control points available, indica tions are that this belt exists on the west side of the Cordillera Central in Antioquia, the northwest corner of the Santa Marta Massif and in the Guajira Peninsula. Outside the belt, some plutonic rocks were intruded into the Santander Massif. Near Amagá Antioquia, on the west flank of the Cordillera Central, a mass of granodiorite yielded a K / Ar age of 210 m.y. (Perez, 1967).

A possible batholith belt of hybrid quartz diorite granodiorite composition was emplaced along the western side of the Santa Marta Massif. K/Ar determinations in hornblende give an age of 202 $\pm$ 13 m.y. (Tschanz et al, 1969). Other plutonic bodies of gabbroic composition, somewhat metamorphosed, were inferred to be Triassic or Upper Permian in age (202- 250 m.y.) on the basis of field evidence showing close relationship with the hybrid quartz diorite (Tschanz et al , 1969) .

In the Guajira area (Alvarez 1971) K/Ar dates from pegmatites cutting the Macuira Formation indicate an age of 195 $\pm$ 8 m.y. In the Santander Massif quartz monzonites and granodioritic batholiths were intruded around 194 $\pm$ 7 m.y. ago (Goldsmith et al 1971).

During the Jurassic time belts of epizonal, monzonitic to granodioritic batholiths were intruded along the Magdalena River depression in pulsating events related with volcanic activity. These plutonic bodies are characterized by their pinkish color, local textural and compositional variations, thermal aureoles, inclusions and assimilation of the country rock, lamprophyric dikes and a comagmatic volcanic cap. The emplacement of these epizonal igneous bodies started in the Middle Triassic with major activity during the Liassic, which extended into the Late Jurassic - Early Cretaceous when acidic volcanism (rhyolites and dacites) became the dominant type.

Metamorphic Rocks

Samples of amphibolite and gneiss taken within 1 kilometer of the contact with the batholiths of the Santander Massif are remarkably close in age about 198 $\pm$ 8 m.y. . The age is consistent with the plutonic event (Goldsmith et al , 1971). These differences would suggest that the cooling period for the batholiths took from 2 to 6 m.y.

Granitic gneiss at the northern end of the Cordillera Central yields ages within the Permo-Triassic limit in a very old looking terrain in the Puqui complex. Field evidence in Santa Marta, Guajira, Santander and in the Cordillera Central suggest regional metamorphism and thermal effects, mostly within Triassic time. It is also possible that pelitic metasedimentary rocks developed extensive belts containing porphyroblasts of andalusite.

IV.4.2 Berriasian to Barremian

Lower Cretaceous sedimentary rocks are best known along the Cordillera Oriental where deep local basins began to fill in Late Jurassic time. The Cundinamarca (Caqueza) basin is the area of maximum sinking which initiated in Liassic time depositing sandstones and conglomerates followed by limestones and black shales (Calizas del Guavio, Saname, La Calera, basal Caqueza Group) which yield Berriasian to Valanginian faunas. This sedimentary units probably extends to the Otanche area.

In the deepest portion of this basin, which underlies the area around Bogota, the euxinic shales (the " Lutitas de Macanal " of Ulloa and Rodríguez , 1979) of the Caqueza Group contain some gypsum, suggesting an evaporitic environment. Near the southern end of the Cundinamarca basin evidence of submarine sliding and turbidites was observed by Bürgl (1973). On the east flank of the Quetame Massif the Berriasian strata become more shaly and silty and the sandstones much more numerous and thicker.

During Valanginian time, tectonic uplift took place outlining the Santander Massif with a surrounding depression or furrow around it . The deposition of coarse clastics and arenaceous sediments started in the Hauterivian in the eastern Andes and part of the pericratonic area. At this time a main transgression was initiated when the Cordillera Oriental north of Bogota subsided in a narrow basin in which black shale was deposited and a connection was established between the Cundinamarca (Bogota) and the Venezuelan and Guajira basins.

Two important depressions in Venezuela, the Tachira furrow and the Machiques furrow (Zambrano et al , 1971), were active from the Hauterivian to the Barremian and were apparently connected with the Cundinamarca basins.

The terrain over which the Hauterivian sediments spread during transgression had an irregular relief. Variation in composition and thickness of the sedimentary rocks was common. In the lower part of the sequence, basal conglomerates and sandstones (Rio Negro formation) were deposited around Venezuela and northern Colombia. Southward in the Bogota and Middle Magdalena basins, the Caqueza, Esparso and Tambor sandstones were deposited. Most of the clastic material came from the re - working of Jurassic beds and the pericratonic area.

Resting on this basal clastic sequence is a thick accumulation of shales (Paja, Upper Caqueza and Apulo) which were gradually deposited in response to the progressive subsidence of the basins that extended to the Barremian time.

To the south, the Caqueta, Putumayo and Ecuador areas behaved like a positive element subject to erosion and peneplanation, with the main drainage flowing south and southeast toward the Amazonas basin.

The Vaupes - Caqueta Swell divided the pericratonic area in two parts, forming an elongated domal structure that acted as a watershed between the Llanos area to the north and the Amazon River basin to the south, the Amazon in Ecuador probably flowing to the west. At the same time the erosion of the cratonic area under a fluvial regime was producing substantial amounts of quartzose sandstone.

In Venezuela, The Merida Arch was a positive element precluding marine deposition over almost the entire Barinas basin. In addition the Arch was separating the Tachira furrow in the southwest from the Trujillo furrow in the northeast.

IV.4.3 Aptian to Santonian

The Aptian to Santonian interval can be considered as a second transgressive cycle. The central and southern part of Colombia, including the Putumayo basin and Ecuador, behaved like a platform where extensive sandstone blankets transgressed toward the southeast beginning in Aptian time. These sandstones are known as Caballos formation in the Putumayo and Upper Magdalena basin, and as the Hollín formation in Ecuador. Both are very good oil reservoirs .

Stratigraphic gaps in sedimentation as well as facies changes in the pre-Albian stages throughout the Cordillera Oriental indicate tectonic movements which at any rate, resulted in raising the east flank and lowering the west flank of the Cordillera (Bürgl, 1973). These tectonic movements probably resulted in the accumulation of the Ubaque and Une sandstones in the Quetame and Caqueza areas and along the Llanos front.

During Albian to Coniacian time the basal sandstones of the Caballos and Hollin formations in the south, as well as the Ubaque sandstone, were covered by a monotonous sequence of black marine shales with sporadic intercalations of sadstones and limestones mainly of Albian age. This sequence, known as Villeta formation in Colombia and the Napo formation in Ecuador, is one of the most important oil sources in the Subandean basins.

In the Barinas basin the Merida Arch was mainly a positive element in Aptian time, separating the two aforementioned sedimentary furrows that parallel the Merida Andes.

During the Albian transgression the Barinas basin was invaded by a basal clastic sequence called the Fortuna formation made up sandstones and conglomeratic sandstones derived from a cratonic source (Zambrano, 1971). The transgression initiated in the Albian and advanced from north to south developing a sandy littoral facies bordering the southern part of the Barinas basin, and a neritic facies (Lower Esperanza formation) in the Barinas depression proper. The sedimentary sequence continues with the accumulation of claystones and sandstones of the Upper Esperanza and Burgüitas formations .

At the end of Santonian time in Colombia an interruption of sedimentation took place which lasted a short period of time.

IV.4.4 Campanian to Paleocene

During the Late Campanian to Early Maestrichtian the sea covered the whole Andean area. From the Maestrichtian to the Paleocene the eastern Andean province gradually emerged and changed from a marine to a lagoonal and lacustrine environment (Bürgl, 1967). These gradational changes included some local unconformities and continued without major variations into the Paleocene. At the same time, important accumulations of coal beds took place in the Cordillera Oriental, north of the Quetame area.

The best known formations of this period in Colombia are the Umir formation in the Middle Magdalena Valley, the Guadalupe and Guaduas formations in the Cordillera Oriental, the Guadalupe and El Morro in the Llanos basin and the Rumiyaco formation in the Putumayo basin. In the Macarena area a distinctive scolithus sandstone layer is tentatively correlated with the Guadalupe formation which in turn is overlain by the Guayabero or Ciego formation of Paleocene age.

In eastern Ecuador an abrupt change in sedimentation took place from the euxinic marine facies of the Napo formation to the redbed facies of the Tena formation. The Vaupes swell separated the Llanos and Barinas basins in the north from the Putumayo and Ecuador basins in the south . The deposition of the Tena formatios was apparently interrupted during a short period prior to deposition of the overlying Tiyuyaco for - mation (Institute Francais du Pétrole, 1971).

In the Barinas basin, Paleocene sedimentary rocks are absent indicating a period of epeirogenic uplift and erosion .

It can be concluded that the widespread sedimentation characteristic of the Creta- ceous time was essentially terminated in the Paleocene, with brackish lagoonal facies in the east and a persistent cherty layer in the west (Cordillera Occidental), and a great part of the present Cordillera Central occupied by an emergent barrier.

Weathering and erosion of the emerged Cretaceous shales under atmospheric oxida- tion originated abundant redclays that were transported from the platform to the paludal basin to the west thus accumulating the characteristic redbeds of the Maestrichtian - Paleocene strata .

IV.5 Cenozoic

In Cenozoic time the Colombian Andes developed their present day configuration mostly through geomorphic mutations resulting from intense Andean faulting and uplift. These mutations were preceded by an important tectonic phase during the Eocene which changed the style of sedimentation from open marine basins connected with the Pacific in Cretaceous time to narrow restricted basins such as the Magdalena Valley and the Subandean basins parallel to the main Cordilleras and not connected with the Pacific Ocean, these latter being invaded by sea waters from the north (Venezuela) and from the south (Ecuador) .

When the marine connections were closed by Andean uplift the Subandean basins changed to brackish and continental environments during the Oligocene.

IV.5.1 Paleocene to Eocene

At the beginning of the Cenozoic, the tectonic framework operative in the Cretaceous changed significantly, beginning with a transitional stage during the Paleocene.

Manifestations of the new tectonic style began in the Early Eocene, but were strongest toward the Middle Eocene and were marked by a regional interruption in deposition which was followed by coarse clastic sedimentation such as the Tiyuyaco formation in Ecuador, the Pepino formation in the Putumayo basin, the Lozada or Mirador formation in the Macarena area the Areniscas del Limbo (Limbo Sandstone) or Mirador formation in the Llanos basin and the Gobernador formation in the Barinas basin. The above formations are predominantly arenaceous, conglomeratic, and quartzose and were formed in a variety of depositional environments such as deltaic, fluviatile and shallow marine.

IV.5.2 Oligocene

The clastic sedimentation initiated during the Late Eocene continued, but in the Middle and Late Oligocene rapid subsidence took place allowing a marine invasion from Lake Maracaibo to extend southward as far as the Macarena area. Additional connections to the Middle Magdalena basin existed via the Cundinamarca basin. This elongated body of marine water surrounded by land, with its axis of deposition through the Casanare area, can be named as the Gulf of Casanare.

Sedimentation commenced in the Llanos basin and in the intra-Andean Magdalena Valley and lasted throughout the Miocene. The result is a series of sediments of considerable thickness and monotonous lithology consisting of gray and greenish shales and laminated claystones with alternating cross-bedded sandstones and some coal seams.

The marine connection of the Llanos basin with the Maracaibo and Cucuta basins during the Oligocene permit correlation, and use of similar nomenclature, between the Cucuta basin and the main sedimentary formations in the northern Llanos basin.

Common stratigraphic names used in the Cucuta Basin are : Mirador (Eocene) , Carbonera (Eocene- Oligocene), Leon (Oligocene) and Guayabo (Miocene).

In the Barinas basin the Parangula formation consists predominantly of shales and varicolored claystones ranging from red, violet and orange to brown in color. This lithology persists from the Oligocene to part of the Miocene.

In the Llanos basin the Mirador formation is well known from the Macarena area to the Cucuta basin. The name San Fernando formation has a wide acceptance for Oligocene strata, mainly by government geologists.

In the Putumayo and Ecuador basins the residual marine facies gradually changed to brackish and fresh water facies, but in some places isolated ponds dried up forming gypsum layers. Marine connections to the north problably existed during Oligocene time, but in the Miocene the Vaupes Swell created a separation of the Llanos and Putumayo basins. The middle part of the Orito Group in the Putumayo basin and the Chalcana formation in Ecuador are the most representative lithologic units of Oligocene age.

IV.5.3 Miocene to Pliocene

The Miocene represents a strong orogenic period with faulting, uplift and volcanism. The sedimentary furrows were filled with an the accumulation of conglomerates, sandstones and claystones in a rapid succession of alternating periods of high and low energy transport. In the tectonic depressions a considerable thickness of sediments was accumulated and the positive areas were subject to intense erosion. Angular unconfor -

mities are also characteristics of Miocene deposits .

In the Barinas basin the Upper Parangula and Rio Yuca formations are very similar continental sequences with a common detrital source from the Andean front. To the west in the Cucuta basin, these sediments are included within the Guayabo Group.

In the Llanos basin the sandy to argillaceous and conglomeratic Caja formation , as described by Ulloa (1979) is considered of Late Miocene age. It rests on a sequence of alternating shale and sandstones known as the Diablo formation of Lower to Middle Miocene age.

In the eastern Ecuador basin, the Arjuno formation is made up of sandstones with stringers and lenses of pebbles, a few conglomerates and some intercalations of bentonitic clay , with abundant hornblende being the heavy mineral in the Llower part of the formation. The Arjuno correlates with the Ospina formation of the Putumayo basin (Middle to Upper Miocene age) which is characterized by the presence of volcanic products of the andesitic volcanism. Equivalent strata in the Llanos and Barinas basin are devoid of volcanic material .

The Chambira formation in Ecuador comprises medium to coarse grained sandstones , commonly conglomeratic, with clay pebble horizons and sandy , laminated clays. The upper part consists of tuffaceous sandstones and conglomerates . This formation is of Mio- Pliocene age and correlates with the San Miguel formation of the Putumayo basin.

The coarsely conglomeratic to sandy Corneta formation, as described by Ulloa (1979), is known as the Llanos formation in the Llanos basin. Its equivalents, the Guanapa formation in the Barinas basin and the Necesidad formation in the Cucuta basin, are of Plio-Pleistocene age and represent the final uplift and intense erosion of the Andean mountain chain. Terraces, alluvial fans, and volcanic lahars mark the culminating episode of the sedimentary record.

V STRUCTURAL FRAMEWORK

The structural configuration of the Subandean basins presents three well defined structural units, each of which apparently displays a different tectonic style.

V.1 The Fold Belt.

It usually coincides with the Andean foothills which bound the Llanos region on the west, forming rolling topography of moderate to low relief. The fold belt varies in width from 15 to 40 kilometers and is usually bounded by two major thrust faults inclined to the west, establishing the transition zone between the pericratonic area or platform and the mobile orogenic belt.

The western fault puts Cretaceous or older rocks in contact with Tertiary rocks of the Subandean basin. The eastern fault cuts Tertiary rocks but to the east alluvium and Quaternary rocks are found at the surface. Between the two major faults folds are varied but are usually asymmetric and some of them present broad radial folding while others form synclinal , multiple folds.

In Ecuador the fold belt is rather wide with few gentle folds.

In the Putumayo basin the fold belt becomes narrow and somewhat complex due to the influence of the Garzon Massif and the volcano- plutonic belt of the Magdalena Rift.

In the Llanos basin, the Lengupa fault on the west and the Tauramena fault on the east define the fold belt, with a synclinal set of folds in between.

Major displacement of the faults took place during Upper Miocene to Pleistocene but the Lengupa fault apparently has a longer history .

V.2 The Subandean Trough

It is a zone of maximum sedimentary thickness and is located inmediately east of the eastern fault. The depo- axis can vary in position from being almost coincident with the fold belt to paralleling it a few kilometers to the east .

V.3 The Platform

The platform, or shelf, extends over a flat area 100 to 250 kilometers wide, east of the Andean foothills. Strata are subhorizontal or gently inclined to the west. They are only minorly effected by faults and folds and have escaped the effect of orogenic events.

The most important feature of the Pericratonic area is the " Macarena block ". This block is bounded on the west by a normal fault increasing in throw toward the north. The eastern part consists of sedimentary layers dippins 3to 4 degrees to the east. A direct connection between the Macarena block and the Andean foothills does not exist but there is some continuity with the Chiribiquete Ridge to the southeast in the Amazon region.

The Pericratonic belt has acted largely as an oscillatory platform subject to epeirogenic deformation that increases westward toward the Andean border where the belt is terminated by a high angle thrust fault zone dipping west. Structural relationship of the Pericratonic belt with the adjacent geotectonic elements is shown in Figure 10.

VI TECTONIC EVOLUTION AND GEOLOGIC HISTORY

The Cordillera Oriental, which limits the Llanos basin, occupies the position of a Cretaceous miogeosyncline whose axis of sedimentation lies sub- parallel to the main axis of a fault-bounded trough, the Magdalena rift valley.

The axis of the Cretaceous basin also coincides with the basins of sedimentation during Paleozoic and Lower Cenozoic time. Thus, the Cordillera Oriental is formed by a sequence of depositional basins extending into the Pericratonic area in vertical superposition where new axes of sedimentation are parallel or coincide with older ones. Synchronous multiple basins may exist, reversing the axis of sedimentation toward external areas. Reworking of sediments is very common, with production of sandstone.

The basement of the Cordillera Oriental consists of crystalline blocks of pre- Devonian age and the main tectonic features in this area are largely controlled by the relative movements of these blocks. The east and west boundaries of the Cordillera Oriental are marked by a high angle thrust fault zones, dipping toward the central axis of the belt.

VI.1 Precambrian Framework

The Precambrian terrain extended from the Guiana Craton to the western part of the Cordillera Central. The main reconstitution of older crustal material took place during the Parguazan tectonomagmatic episode between 1450 and 1560 m.y. and was accompanied by granitic plutonism and high grade metamorphism which obliterated the evidences of the Transamazonic event.

Uplift and erosion were common during the Parguazan event. A coarse clastic quartzose sequence (La Pedrera formation) was deposited in the eastern Llanos close to the Brazilian border, marking the oldest sedimentary record in Colombia between 1250 and 1450 m.y.

During 1100 to 1250 m.y. an extensive thermal event of low grade metamorphism effected all the micas of the Mitu Complex. This event was accompanied by tensional ruptures and injection of deabase dikes.

A local belt of volcanic and sedimentary rocks (Piriparaná formation) indicates volcanic rift type structure around 750 m.y. with a north – south orientation .
One of the gratest cratonic uplifts recorded around the world has been dated at the end of Precambrian time between 600 to 650 m.y. (Sloss, L. and Speed R. , 1974).
Radiometric dates in Colombia from 600 to 650 m.y. indicate that this event was probably present, especially during the formation of the known metamorphic rocks in the Cordillera Oriental .
Figure 11 illustrates the Precambrian Framework .

VI.2 Late Precambian Miogeocline and Cambro – Ordovician Transgression

Low grade metamorphic rocks of Quetame series have been correlated with the Cajamarca and Valdivia Groups of the Central Cordillera and with the Silgará formation in the Santander Massif.
Estimated thickness is 3000 meters for the Quetame series, 3700 meters for the Silgará formation in Santander, and about 13000 meters for the Valdivia and Cajamarca groups in the Cordillera Central .
Cambro– Ordovician sedimentary rocks in the Pericratonic area (Araracuara and Güejar formations) and Ordovician sedimentary rocks in the Magdalena Valley, are only a few hundred meters thick. Recently found fossiliferous Early Paleozoic rocks, probably of Ordovician age, in the upper range of the low grade metamorphic rocks in the Cordillera Central indicate that more than 70 percent of the low grade

metamorphic rocks were developed from a Late Precambrian sedimentary accumulation in an asymmetric miogeocline, and attain a considerable thickness to the west.

The correlation of the Quetame series with the Cambro- Ordovician sediments of the Güejar formation (Trumpy, 1943)is based only on the relative stratigraphic position and on similar lithology. This general statement has been accepted without objection by most geologists as an easy line of correlation.
The Quetame series belong to the continental rise accumulatation of Precambrian sedimentary rocks which culminated with an extensive period of sedimentation in epicontinental seas during Cambro- Ordovician time. Consequently the low grade metamorphism of the Quetame, Silgará, Perijá, in the Cordillera Oriental and the Tostos and Vella Vista Facies of the Merida Andes are likely to be metamorphosed debris from Late Precambrian sediments of a miogeocline basins.

The shore line of the Cambro- Ordovician transgression was located close to the Cratonic region. Exploratory wells Heliera- 1 and Negritos - 1 (Bürgl, 1973) drilled in the Pericratonic area revealed evidence of intervening Cambro- Ordovician sediments resting on basement.
The increase in thickness of the sediments to the northwest and southwest suggests a basin open to the west.
In the crystalline basement of the Macarena area mica schists and subordinate phyllites are cut by abundant quartz veins and intruded by pink granite with some quartz.

Angular quartz in the basal conglomerate of the Cambro- Ordovician section is mostly derived from the local quartz veins. Distribution of the Araracuara formation indicates that the Cambro- Ordovician transgression covered the Amazon region and extended into Brazil .

VI.3 Silurian Proto- Andes (Dorsal Bolivariana)

Pre- Devonian metamorphics form the core of the Cordillera Oriental. These rocks crop out in discontinuous massifs through the thick blanket of Mesozoic sedimentary rocks.

Gneissic rocks of Precambrian age are commonly present in the larger massifs.

This metamorphic belt has, apparently, a considerable variation in thickness and is bounded by crystalline cratonic terrain on both sides.

Metamorphism and folding seem to decrease on both sides of the belt, but metasomatism producing potassium feldspar in the lower part of the metamorphic sequence suggests that metamorphic intensity increases with depth and within a short lateral distance.

An increase of metamorphism toward the north is observed along the belt: slightly metamorphosed fossiliferous rocks in the Garzon Massif ; chloritic and sericitic phyllites in the Quetame Massif ; garnet and sillimanite bearing micaceous schists in the Floresta Massif ; and rocks of high amphibolite facies in the Santander Massif where even the Devonian sedimentary rocks are slightly metamorphosed .

The increase in metamorphism to the north could indicate that the lower part of the sequence has been gradually exposed by increased uplift northward. The Santander Massif particularly seems to have been uplifted by a considerable amount, thus exposing Precambrian rocks and high grade metamorphic facies.

Several granitic bodies were intruded along the metamorphic belt. Available radiometric dated cluster about the figure 460 ± 25 m.y.

The above considerations suggest that during the Late Ordovician and part of the Silurian there was an important orogenic event taking place in northwest South America, which coincides with the Taconic event in the Appalachian chain. The orogeny probably formed a large mountain chain following the trend of the several massifs in the Cordillera Oriental north to Venezuela thus creating a pre-Andean feature named by Estrada (1972) the ' Dorsal Bolivariana '.

This Paleozoic core within the Cordillera Oriental has effected the later development of the Colombian Andes and the Subandean basins.

During subsequent periods of sedimentation, the Dorsal has been only partially submerged. Upper Paleozoic, Mesozoic, and Cenozoic deposition produced conglomeratic and sandy facies near the Dorsal Region folding, faulting and other structural features are oriented parallel to its axis. During uplift the land derived material was transported from the Dorsal toward the Subandean basins producing continental accumulations during Silurian time.

A second marine transgression took place during Devonian time covering the dorsal ridge with a basal conglomerate which reflects an irregular topography. The Devonian seas penetrated into the Subandean basin to a limited extent, producing mainly sandy facies, marine dark shales with fossils and lesser amounts of marly and siliceous limestone. On Rio Blanco, east of Gutierrez, these shales reach a thickness of 1700 to 1900 meters (Bürgl, 1973).

Devonian sedimentary rocks are present in the Cordillera Central and throughout the Cordillera Oriental from the Quetame Massif to the Perija Range, exhibiting very similar characteristics which indicates deposition in shallow epicontinental seas.

In the Merida Andes Devonian sedimentary rocks have not been found.

VI. 4. Magdalena Rift Valley Evolution

In the uppermost Permian sedimentation was interrupted and an epeirogenic uplift in the shape of a large arch or dome, produced by heat - induced heaving of the mantle, apparently preceded the rifting stage . Rifting began with normal faulting and the accumulation of continental conglomerates in narrow prisms along these faults in such units as the pre- Payande formation and the Tiburon formation in Santander, and those formations located on both sides of the César Valley depression in the Santa Marta and Perija areas .

The steep faults of the rifting stage were oriented north and northeast and some of them gave access to magmatic extrusions . During subsequent tensional periods, northwest trending wrench faults were formed , creating sn irregular mosaic of rigid blocks .

The main rift broke into a zigzag pattern going south along the Magdalena Valley, and produced normal or very steep angle faults on both sides . These fault blocks were later subjected to lateral stresses that resulted in large horizontal displacements . Gravity highs are reported in the Puerto Berrio area and in the Putumayo region, both being along the axis of the rift . Case (1971) says that " east of the Andes , Bouguer anomalies range from - 50 to - 120 mgals over a Mesozoic basin of the Putumayo district, indicating that the crust is thinner or denser than it is beneath the central and eastern Andes " .

Volcanism accompanied the early rifting stage with spillites, diabases and very often acidic volcanic rocks piercing the crystalline basement largely made up of blocks of Precambrian age, and piling up in the lowest parts of the rift depression .

The beginning of the rifting was no later than Triassic, as suggested by the volcanic activity along the Cesar Valley , and apparently coincides with the early Atlantic opening.

Triassic rocks have not been found in Ecuador, but the Jurassic rocks are characterized by abundant volcanic material , acidic in the east and diabasic and porphyritic in the west. This may support the idea of a late opening in the south.

The variability of the volcanic products can be explained by the position of the volcanic centers with respect to the floor or the flanks of the graben. It is suggested that the gradual shift from acidic to basic volcanicity accompanies the progressive thinning of the continental crust. The earliest volcanics and those of the flank of the rift are acidic; graben floor or volcanoes over the accreting crustal margin become of basic character.

It is possible to understand why in Ecuador synchronous volcanicity changes from acidic and continental in the east to basic and marine to the west by assuming that the rift axis opened in a direction toward the Pacific ocean.

The Magdalena rift apparently did not reach a complete state of opening . In spite of the fact that spilitized basalts are reported in many places, ultramafic rocks have not been found, but wpizonal batholiths are very common, with a complex history related to the volcanicity western continental margin during Permo-Triassic time and were probably continuous from the Santa Marta Massif and Guajira, through the main nucleus of the Cordillera Central, and then southward to Ecuador in a narrowing strip which erosses the Cordillera Oriental and penetratis into the subandean basins . Later, rifting and wrench faults divided the rigid crystalline strip into several crustal blocks .

Active compressional forces during Cenozoic time have obliterated most of the characteristics of the rift valley proper which developed in the Jura-Triassic time.

The theory of marginal rifting is attractive . It can be suggested that the cratonic area extended west of the Magdalena Valley as a platform supporting a rather thin cover of Paleozoic sediments . Then during Premo-Triassic time, the rifting began and pulled apart a narrow strip of Precambrian rocks from the main Cratonic area , resulting in symmetrical distribution of Precambrian blocks on both sides of the rift . This hypothesis suggests the presence of cratonic slabs or microcontinents within the Andean Mobile Belt . In this regard Estrada 1972 postulated that the lowland of the Lower Cauca and Lower Magdalena region developed as a microcontinent or platform. This model is further described below .

<u>The Lower Cauca Microcontinent</u> . This particular region has been a very stable area with no apparent geomorphic connection to the Andean orogen . This stable area forms

a peneplain or the flat area of the Colombian coastal plain of about 40,000 Km^2; and is known as the lower Magdalena basin . It lies between the Santa Marta Massif, the northern end of the Cordillera Central and the Maria Mountains .

The entire basement complex forms a large sialic plate bounded on the east and southeast by major strike slip faults, the Santa Marta and the Espiritu Santo , respectively . The western limit follows and abrupt contact with oceanic type basalt and diabases of upper cretaceous age . Discontinuous patches of gabbroic and ultramafic rocks occur parallel to the western contact and continue toward the Caribbean region . Tertiary sedimentation along this contact is chaotic and suggests an unstable margin where submarine slump deposits were common (Chenevart , 1963) . Seismic data from the basament of the Lower Cauca region suggests large faults following an east - west direction .

The whole platform or better " The Lower Cauca Microcontinent " was a positive element from Cretaceous to Early Oligocene time at which time a basal transgressive sandstone was deposited and ultimately built up continental, deltaic and shallow marine deposits. The crystalline basement seems to be severely eroded after significant uplift and probably the crustal thickness is less than the average for the Andean region . It would be comparable with the Santa Marta Massif after complete erosional peneplanation .

The Lower Cauca Microcontinent was apparently affected by regional metamorphic events during Permo- Triassic time (Puqui Complex) and also volcano - plutonic activity during the Mesozoic .

Near the Laguna Morrocoyal (Lower Cauca) , the thick shallow marine and volcaniclastic sediments and intrusives of Liassic age probably accumulated on, or are related to, pieces of Precambrian rocks . A well core of granodiorite basement rocks from the Cicuco oil field gave 110 m.y. (Pinson et al, 1962) , indicating that plutonic bodies of this type intruded the sialic plate. This geologic picture resembles that along the Magdalena - Cesar graben and also is similar to that of Santa Marta Massif.

VI.5 Development of Cretaceous Basins

Lower cretaceous sedimentary rocks are known from the Cordillera Oriental where a deep local basin begal to fill in Late Jurassic time. In the deepest portion of this basin, which underlies the area aroun Bogota, the sedimentary succession contains Berriasian and Valanginian faunas and consists dominantly of euxinic shales, limestones, and sandstones. The Cretaceous deposits attain a total thickness of more than 12000 meters (Bürgl, 1961) .

Two main transgressions occurred during the Cretaceous. The first took place at the beginning of the Hauterivian, when the area of the Cordillera Oriental north of Bogota subsided in a narrow basin in which black shale was deposited and a connection was established between the Cundinamarca (Bogota) and Guajira basins (Bürgl, 1961). The second took place during Albian time and extended to the south and east into the

Pericratonic area, where the thickest and most extensive sedimentary sequence deposited since the Ordovician was deposited.

The terrain over which the Cretaceous sediments spread during the first transgression had an irregular relief. Variation in composition and thickness of the sedimentary rocks is common. Basal conglomerates and sadstones were generally deposited in the lower parts of the sequence, most of the clastic material coming from a reworking of Jurassic redbeds .

During a pre-Albian tectonic phase, the eastern portion of the east Andean region was uplifted while the western one subseded. This phase coincided with warping along the western border of the Cordillera Central which is outlined by an unstable marginal belt. It appears that the Cordillera Central together with the Santa Marta Massif formed a positive belt or island chain probably extending into the Caribbean region.

During the second transgression, the south central part of Colombia including the Subandean bsins of Putumayo and Ecuador, behaved like a platform where extensive sandstone blankets transgressed toward the southeast beginning in Aptian time, to be covered by marine black shale and limestone in the Albian. The sedimentation then continued over the whole area of deposition until Coniacian time. During the Cenomanian, the Cretaceous basin developed evaporitic facies in the vecinity of Bogota (Ujueta, 1968). During Early Maestrichtian, the sea covered the whole Andean region and the adjoining parts of the western.

Llanos - Amazon platform or Subandean basins, for the last time. Subsequently the eastern Andean province gradually emerged and changed from marine to lagoonal and lacustrine environments . These gradational changes included some local unconformities and continued without major variations into the Paleocene.

Applying plate tectonics concepts it appears that some tensional movements of the Pacific plate occurred during the Jurassic , forming a triple junction with the extension of the Caribbean opening. While the mid- Atlantic ridge was opening and some spreading occurred in the Pacific plate, the spreading vectors along the Caribbean were weakening and disappearing .

Most of the Cretaceous is characterized by a compressional phase.

The rapid spreading of the Pacific is evidenced by the abundant submarine volcanism in the west. It resulted in a compressional effect along the embryonic rigid Andes.

The compressional effect apparently produced large scala warping and two longitudinal basins : a miogeosyncline to the east and eugeosynclinal to the west. The Cordillera Central behaved like an arc separating the two basins. It was probably similar to the present to the present configuration of the west Pacific margin.

Periods of high spreading rates developed large-scale mid-oceanic ridges which displaced a considerable amount of water , thus producing marine transgressions. It is likely that the two major Cretaceous transgressions (Hauterivian and Albian) which invaded a great part of the Subandean basins were contemporaneous with periods of high spreading rates.

VI.6 Cenozoic Orogenies

After a calm period during the Paleocene, the compressional movements were strongly reactivated in the Eocene, as evidenced by the intense tectonism, dynamothermal metamorphism and intrusive activity .
These events suggest the sudden release of a strong and rapid rate of spreading, both in the Caribbean and in the Pacific domains.
Accreting mechanisms worked intersively , adding oceanic Cretaceous material to the Caribbean coast of Colombia and Venezuela . On land, evidence of this phase is marked by the uplift of the three main Cordilleras and the initiation of the molassic stage of sedimentation along the intra- Andean depressions and the Subandean basins.

The most important features in the morphology and structure of the present Colombian Andes were defined at the beginning of Tertiary time. In this regard the following points deserve consideration :

1. The Cordilleras Oriental and Central were uplifted , and the Pericratonic area and the Magdalena Valley remained as lowlands and became basins of rapid sedimentation, marking the beginning of Cenozoic molasse deposition .

2. Eocene paleocurrents in the Macarena region trend to the southeast, as noted by Paba and Van der Hammen (1958), indicating a reversed transport from the Cordillera Oriental toward the Pericratonic area, as opposed to the northwest direction of the Cretaceous currents.

3. Long prisms of coarse conglomerates occur along the zones of major faulting. Coarseness of the clasts appears to be proportional to the intensity of faulting. Local prisms in the Magdalena region may be more than 1000 meters thick , but a regional average is probably about 500 meters.

In the Ecuador and Putumayo basins the conglomerates are coarser (pebbles and cobbles) than equivalent strata in the Llanos and Barinas basins. It indicates that the tectonic uplift of the Cordillera Real or Cordillera Central was stronger than that of the Cordillera Oriental or the Venezuelan Andes.

During the Late Oligocene a rapid subsidence took place. The sedimentation commenced in the Llanos basin stablishim a marine conection through the Cucuta and Maracaibo basin which lasted throughout The Miocene. This sedimentary sequence develops a considerable thickness and monotonous lithology .

The Upper and Middle Miocene time is characterized in the Cordillera Central by strong andesitic volcanism.

There is no direct dating of the andesite volcanoes , but the sedimentary formations of Middle age, along the Putumayo and Ecuador Subandean basins, contain abundant volcaniclastic material of andesitic composition .

The andesite volcanic chain along the Cordillera Central is a very important episode which extends from the Middle Miocene to the present time . It is likely that this episode bears some relationship with plate tectonic mechanisms and could be coupled with a possible trench along the Atrato- San Juan depression during the Miocene. Howe ver , active trenches in recent times have not been recognized to be coupled with.

The final and regional uplift of the Colombian Andes took place during the Plio- Pleistocene . This regional uplift apparently affected the whole South American Continent, suggestin that by some unknown reason the southern part of the American plate was pushed up.

In the highest part of the Cordillera Central , along the Pasto- Mocoa road there are remmants of the Paleocene Rumiyaco formation (4000 meters elevation a.s.l.).

Down in the Putumayo basin, the Rumiyaco formation has been penetrated by exploratory wells at 2000 meters below sea level totalling more than 6000 meters of vertical displacement since Eocene Time .

Terraces, alluvial fans, lahaars and slump deposits are common features along the foothills of the Subandean basins.

VII OIL POTENTIAL

A detailed description of the several attractive oil plays and individual prospects in the Subandean basins is not undertaken here. In summary, however, it can be stated that conditions were favorable for hydrocarbon generation and accumulation .

From the descriptions presented in this paper, it can be seen that source rocks were formed during Paleozoic, Mesozoic and Tertiary time. Multiple cycles of sedimentation and reworking of sediments produced large amountsof good reservoirs whose areal distribution is controlled by the tectonic evolution .

A variety of hydrocarbon accumulations exist in the form of light and heavy oil , gas, asphalt, tarr sands and graphite- impregnating metaconglomerates. Likewise , the mechanism of oil migration and accumulation are varied and include upward and downward movements to different reservoirs and intraformational entrapment of oil .

ARMANDO ESTRADA M.

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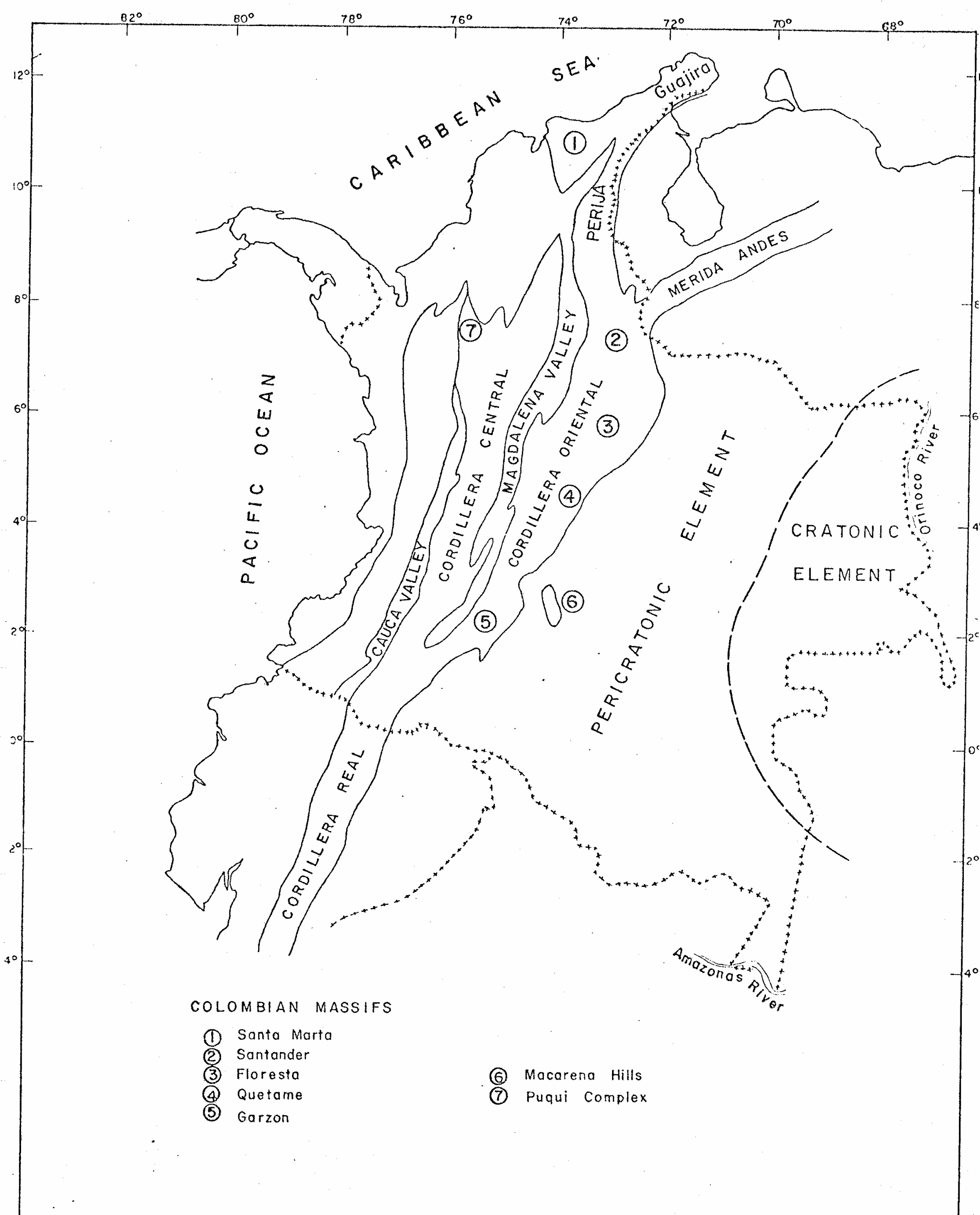


FIGURE 1 : SCHEMATIC DISTRIBUTION OF GEOTECTONIC ELEMENTS

SCHEMATIC GEOLOGICAL PROFILE OF COLOMBIA

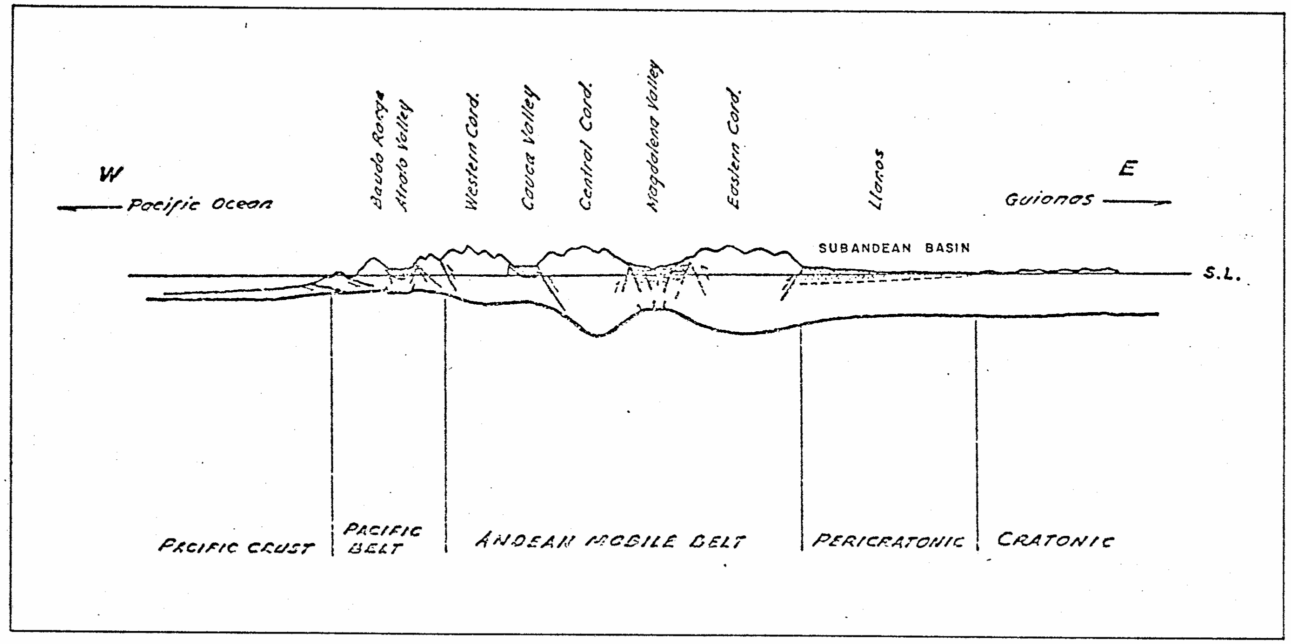


FIGURE 2 : POSITION OF THE SUBANDEAN BASIN IN RELATION TO GEOTECTONIC ELEMENTS ABOUT LATITUDE 5° N AND NOT AT SCALE

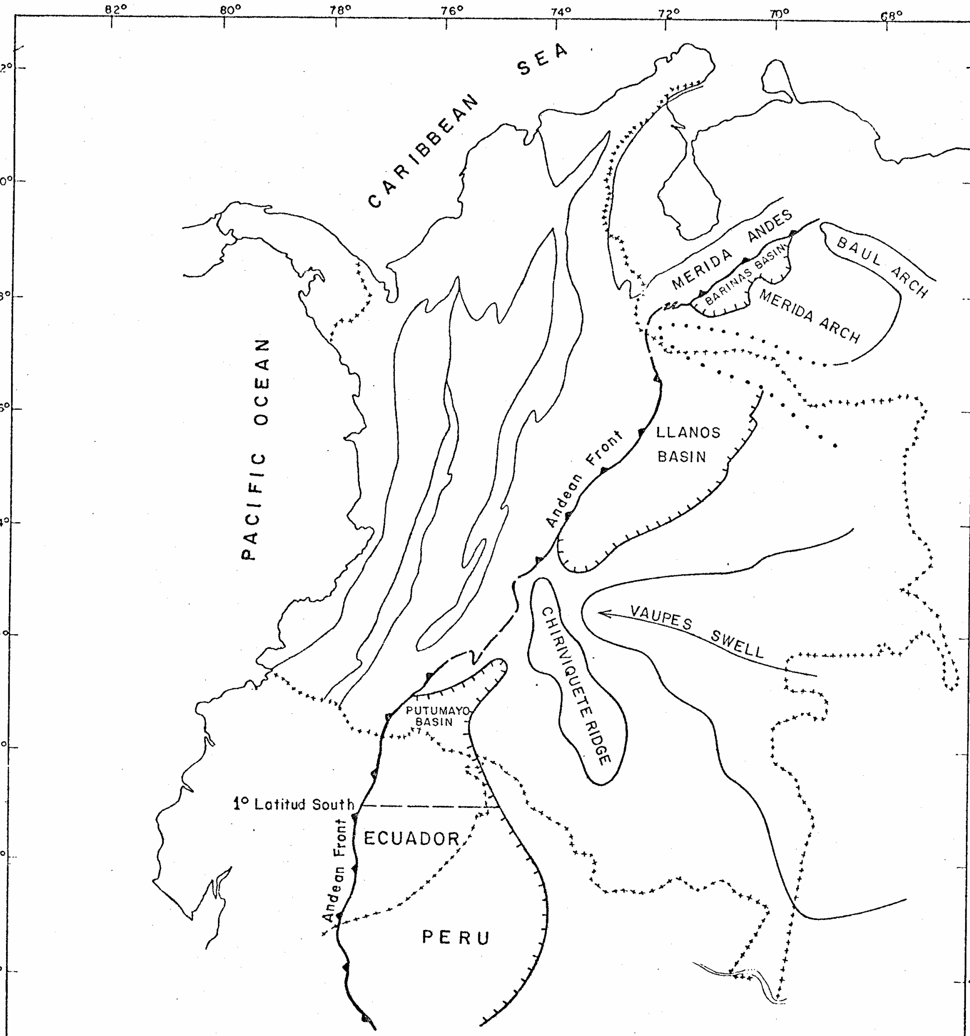
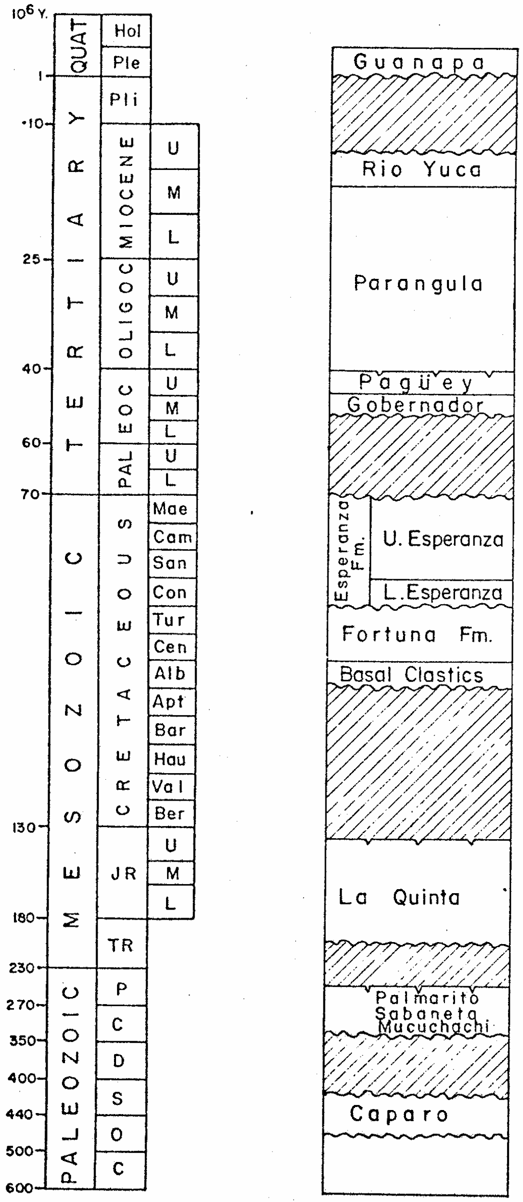


FIGURE 3 : DIVISION OF SUBANDEAN BASINS

BARINAS BASIN



Modified from Zambrano et. al. 1971

FIGURE 4 : GENERALIZED STRATIGRAPHIC COLUMN OF THE BARINAS BASIN

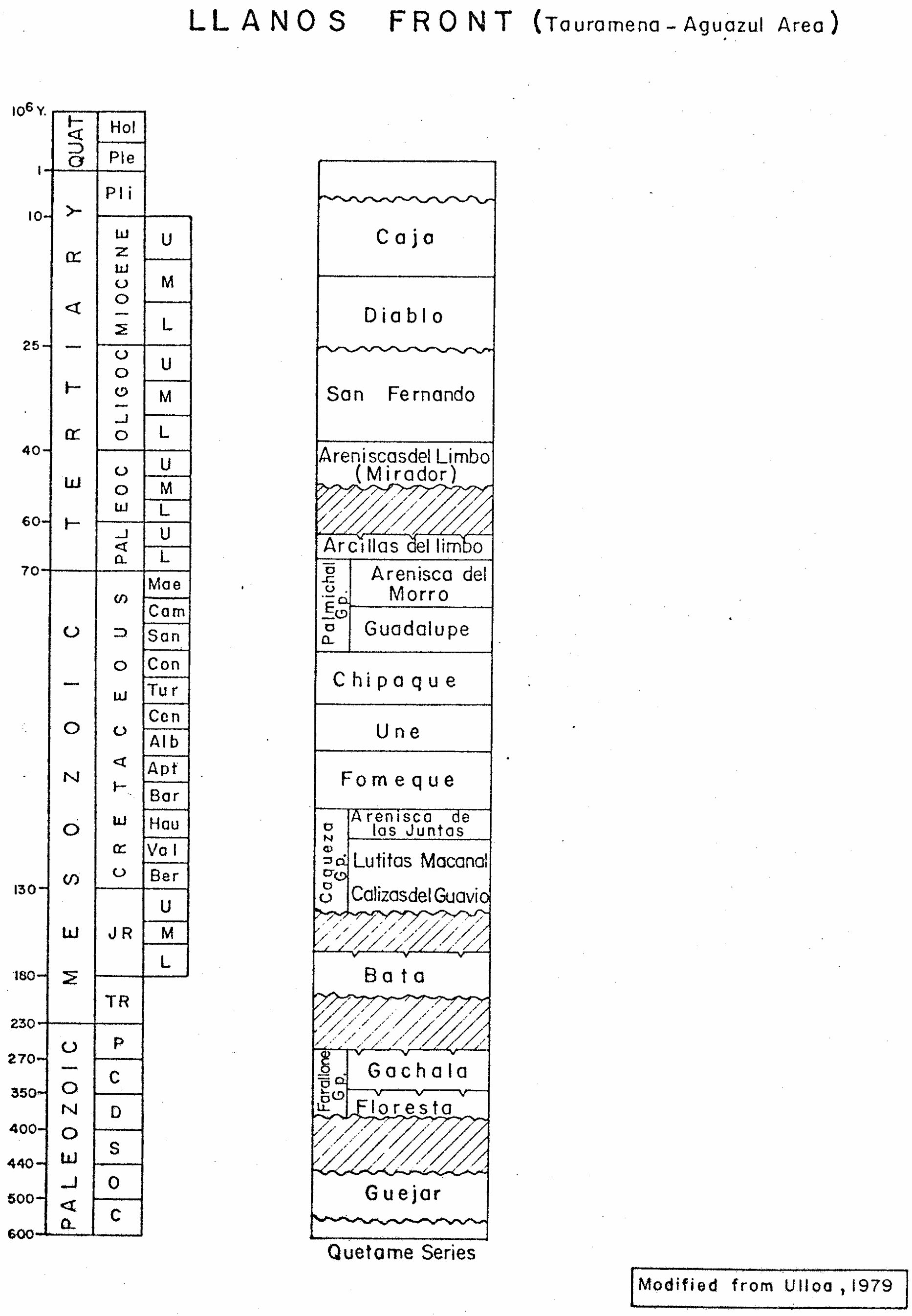


FIGURE 5 : GENERALIZED STRATIGRAPHIC COLUMN OF THE LLANOS BASIN

PUTUMAYO BASIN

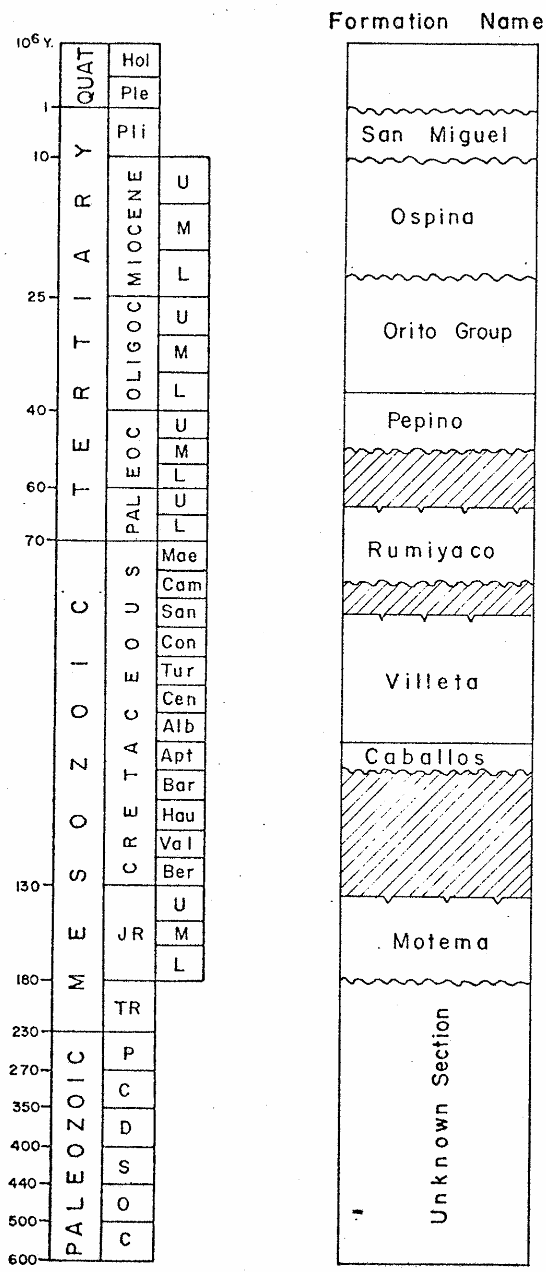


FIGURE 6 : GENERALIZED STRATIGRAPHIC COLUMN OF THE PUTUMAYO BASIN

ORIENTE ECUADOR BASIN

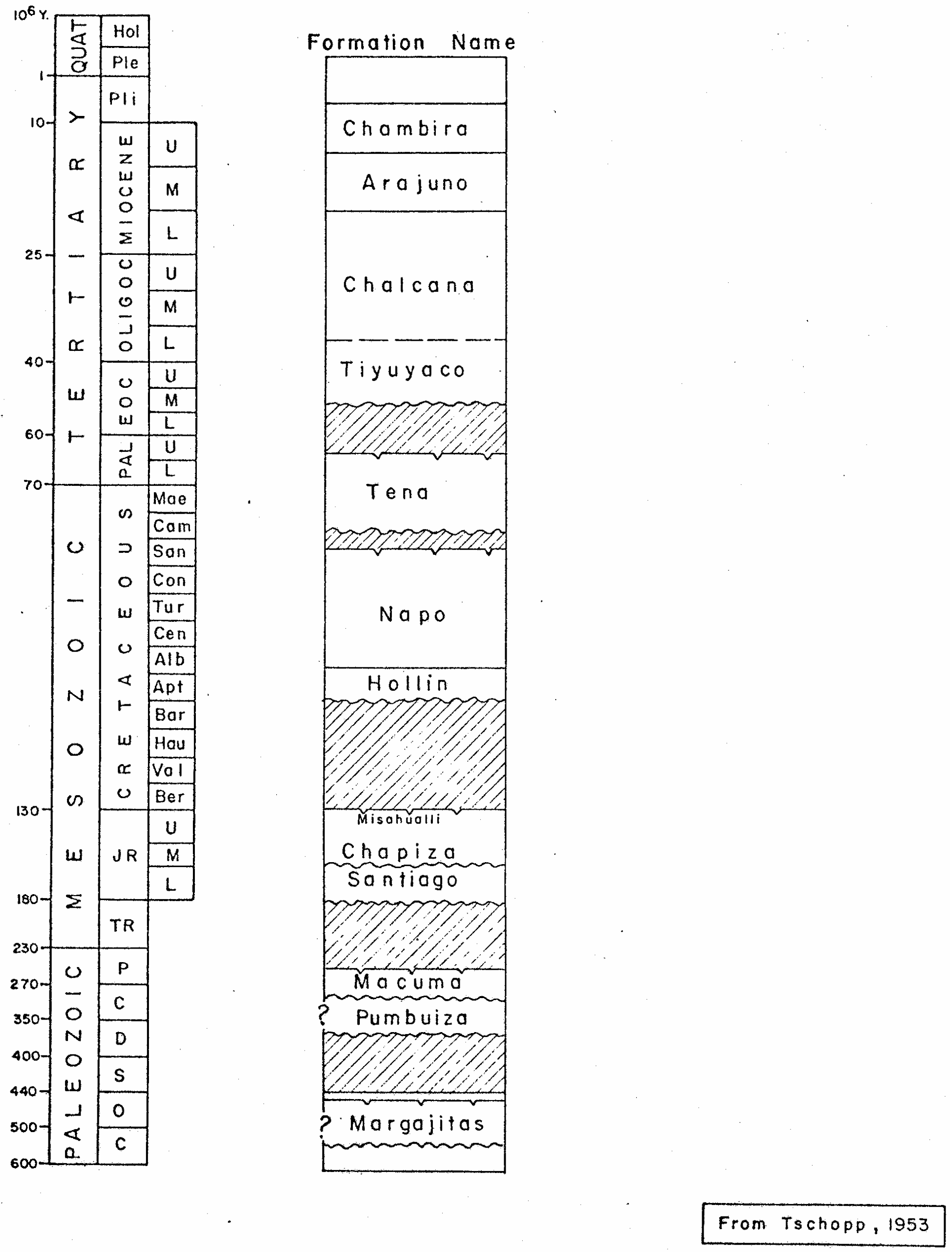


FIGURE 7 : GENERALIZED STRATIGRAPHIC COLUMN OF THE ECUADOR BASIN

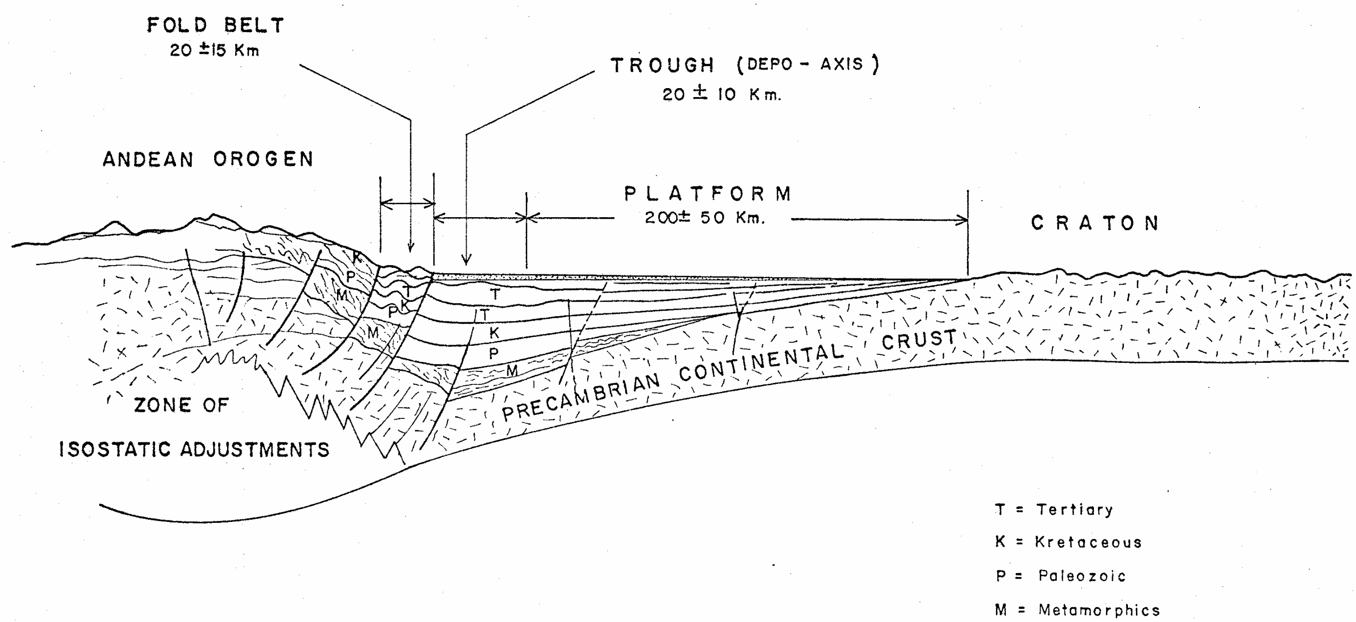


FIGURE 8 : SCHEMATIC STRUCTURAL FRAMEWORK
OF THE SUBANDEAN BASINS

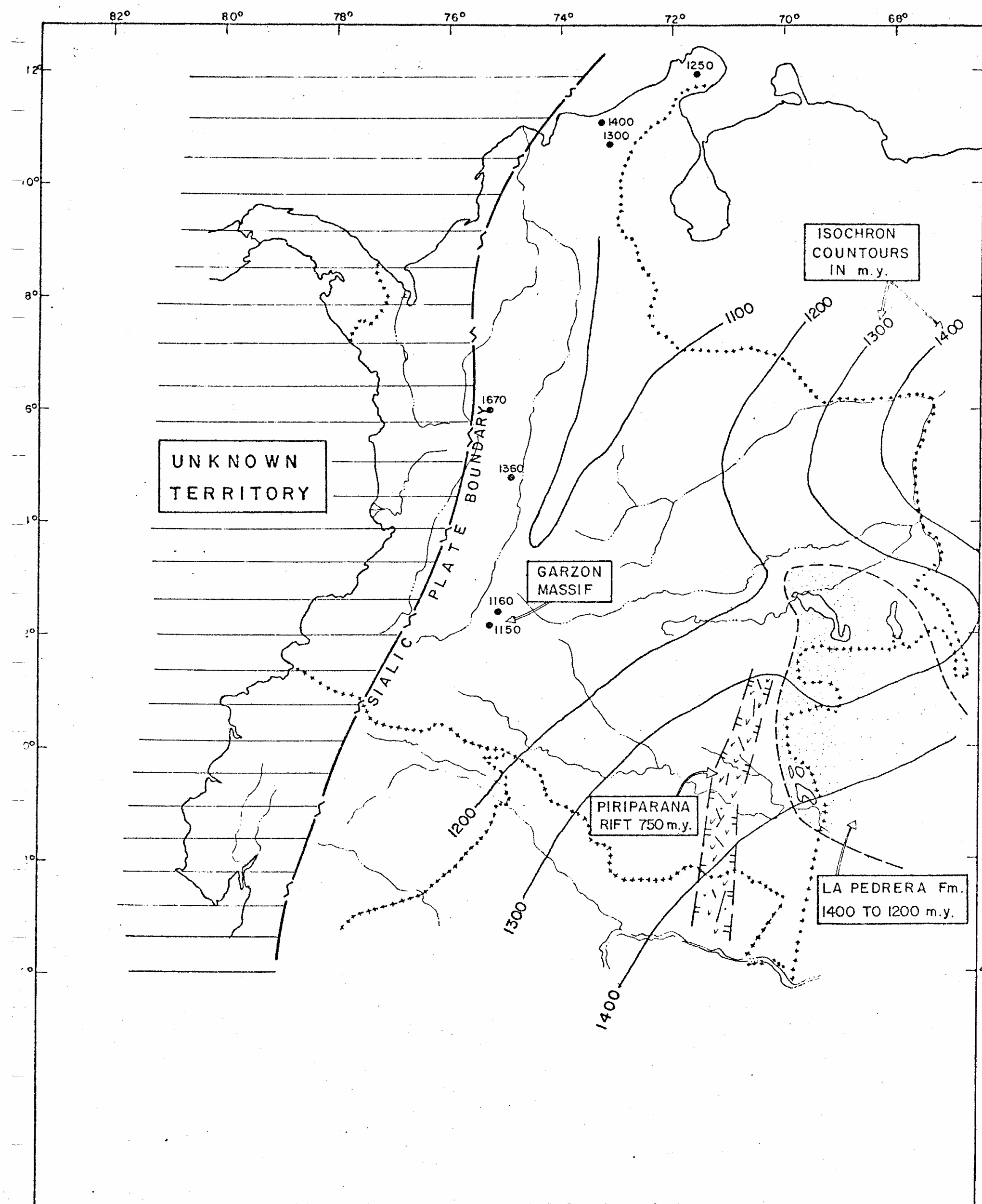


FIGURE 9 : PRECAMBRIAN
(PALEOGEOGRAPHIC MAP)

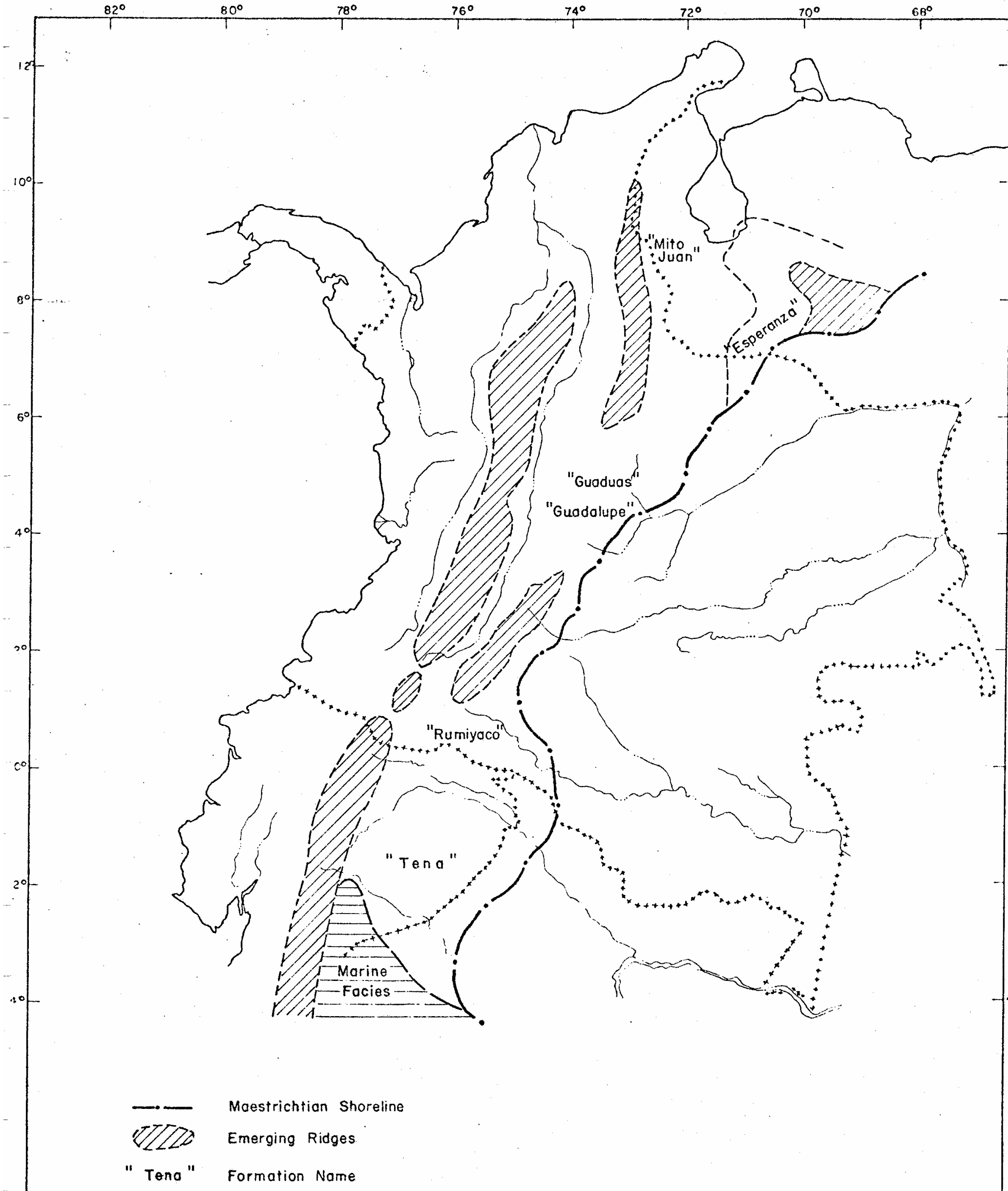


FIGURE 10 : MAESTRICHTIAN
(PALEOGEOGRAPHIC MAP)

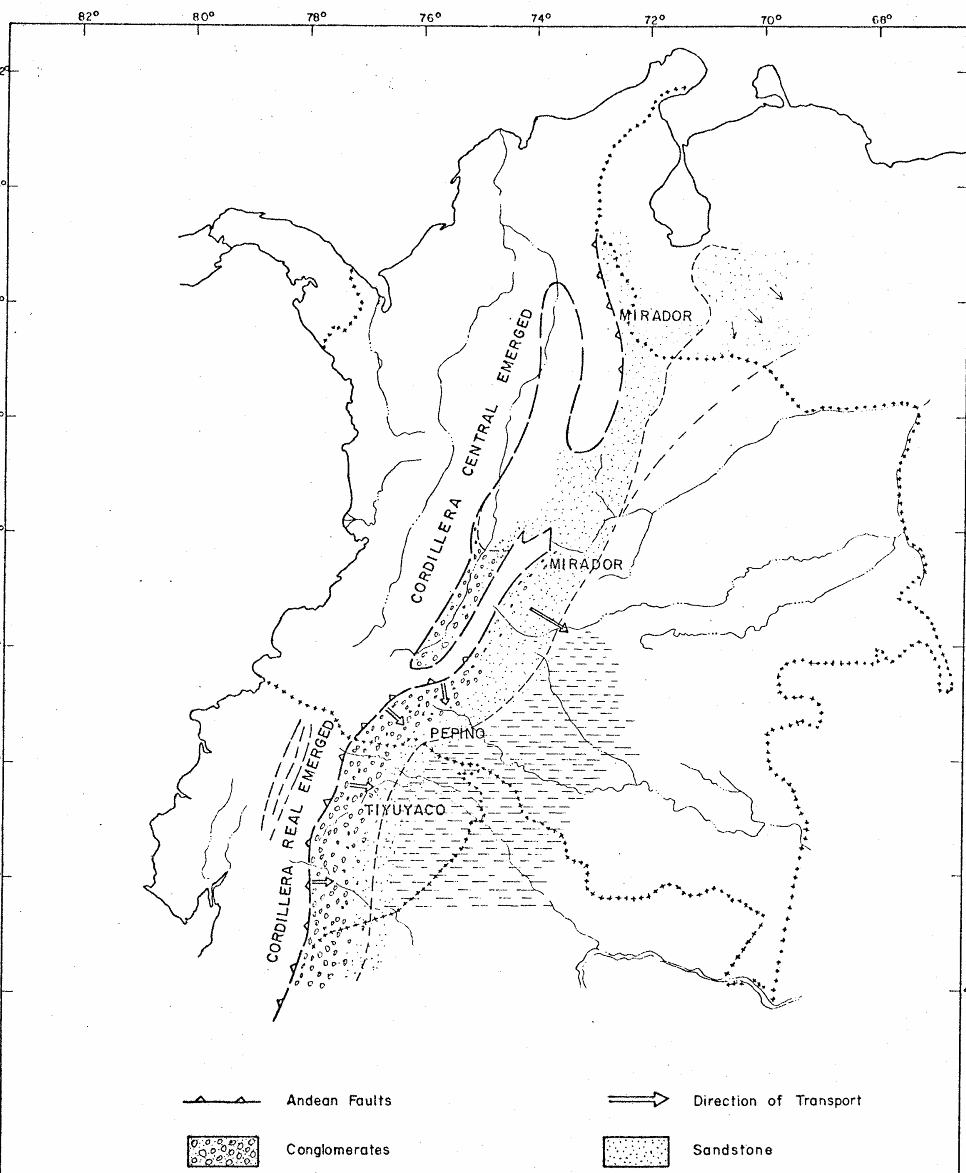


FIGURE 11 : MIDDLE EOCENE
(PALEOGEOGRAPHIC MAP)