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ABSTRACT

The mio-pliocenic Navidad Formation, and the eocenic and cretaceous sediments, show significant promising features, taking into account the repeated oscillations within the southward closed basin, of the ancient shore-lines. Upwards, the area was stratigraphically covered by more extensive seas, decreasing its energy. Near the pacific coastal line, the sediments are much tectonicaly disturbed; in turn, east and northwards, the embayment is nos affected by great disturbance. Some types of stratigraphic traps, as eolian sandbeaches atractive reservoires are expected.

INTRODUCTION

New areas have continually been opened up where new oil fields may be discovered, if there are some probabilities considering historical events and traps, although the sedimentary basin was not extended and thick.

B. F. GROSSLING (1975) pointed out that "Latin America holds 19% of the world's potential area for petroleum; however it is currently producing only 9% of the total oil"; and regarding petroleum perspective areas, "Chile offers $58x10^3$ sq. miles onshore and only 5% offshore".

The Navidad sedimentary basin is located 130 km. SW of Santiago and present a N-S trend of 70 km, and an E-W width of 30 km. An inadequate gravimetrical profile (DRAGUICEVIC, 1970) permits us to assume a 500-1000 m thickness. However, the geology of this basin shows some important stratigraphical and structural traps.

Since DARWIN'S original description of the "Sandstone formation at Navidad" in 1846 (1) (HOFFSTETTER *et al.*, 1957) scarce geological work has been done in this area.

(1) DARWIN's type locality is not located at Navidad but in Topocalma Bay at 34° 08' S. L. and 72° W. L. (CECIONI, 1970).

CONCHA Y TORO (1869) referring to the tertiary sediments between Santo Domingo and Topocalma puts in evidence the existence of a marine formations transition towards lacustrine formations; a 400 m thickness is estimated. He points out the presence of coal at Topocalma, not at Navidad, as DARWIN did.

BRÜGGEN (1950) published and structural sketch of the Topocalma Bay.

In 1967 the present author started working sporadically in this area, in close association with F. GARCÍA, geologist of the Chilean National Oil Co. (ENAP). The initial aim of the field work was to stablish the general stratigraphic framework. However, this goal was changed later to the geological mapping of the Cretaceous - Cenozoic angular unconformimity, in colaboration with Prof. J. FRU-

(*) Professor of Geology at the University of Chile.

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TOS, in order to prove the presence of cretaceous rocks in the Topocalma Bay, previously stablished by Prof. TAVERA, but subsequently disregarded (in the second edition of the Geological Map of Chile), because of the prevailing opinion that the cretaceous fossils were reworked forms in cenozoic sediments.

Since 1968 a detailed geological mapping was undertaken at the scale 1:25.000, also by means of a plane- table whenever it was necessary; detailed work was done at different scales ranging from 1:500 to 1:10.000. The upper structure of the sequence was controlled by means of two key benches of Middle Pliocene age. The lower one ranges in thickness from 0,5 to 1 meter and the upper one, wich shows better outcrops in the southern part of the area, averages 15 m in thickness.

The sedimentary beds show gentle angular unconformities associated to the Cretaceous-Eocene and Eocene-Miopliocene contacs. Lithologically the cretaceous and eocene deposits, located along the southern central cliffs are similar and both are clearly distinct from the miopliocene beds.

Pleistocene lahar deposits mantling upper pliocene continental and marine sediments crop out at the eastern area. However, coastal laharic deposits, including scattered volcanic boulders up to 5 m in diameter, suggest recent deep erosion of the upper cenozoic deposits. The boulders were previously interpreted as glacial deposits (BRÜGGEN, 1950; CECIONI, 1970).

The sedimentary sequence rests unconformably over a paleozoic basement which consists of a metamorphic complex including gneisses, schists, metagranites with associated granitoids. Along the coastal cliffs the basement outcrops consist mainly of normal transcurrent and reverse metagranitic ridges, locally superposed on miocenic and pliocenic beds. In the southern area, where the basement uplift was greater, the prevailing rocks are gneisses and schists, wich gave a Rb/Sr radiometric age of 342±5 m.y. (whole rock, MUNIZAGA, 1973).

The tectonic pattern of the area changes gradually in intensity from western coastal area to the eastern highlands. Strong reverse faulting on the west grades to a simple normal faulting to the east, and the fracture orientations suggest an older northeast stress on the coastal area and a younger northward stress in the eastern area. Clearly preserved horizontal slickensides in vertical granitic cliffs allow us to infer an east-west oriented left hand transcurrent faults.

PHYSIOGRAPHY

The eastern region, outside of the studied area, shows a mature landscape, carved over the cristalline basement. From east to west, hills are gradually replaced by isolated granitic mounds, protruding the main alluvial terrace. Still farther west, below the alluvial terrace, there are subhorizontal marine deposits. Here a dendritic drainage pattern is observed.

Around the coastal area, near the mouth of the Rapel river, the drainage pattern is characterized by a 90º structural controlled bend of water courses, some valley meanders and gorges. This pattern is due either to carving or equilibrium but do not represent filling as the one observed a Yaly river wich is located at the northern tip of the studied area.

Creeks flowing into the sea are scarce. When present, they appear separated by dune ridges and tombolos. Bars and tombolos can be destroyed during spring time. The coastal landscape shows high, prominent, hard cliffs in areas where the crystalline basement crops out, but it is concave seawards when sediments are present. Granitic stocks and rocks alignements, structurally controlled, are frequent towards the sea.

Reactivation of river erosion is due to the recent lowering of sea level which during the lower stand originated the low 2 m high fossiliferous marine terrace. At present this terrace includes remains of Diaguita and Los Molles indian culture, According to HERM and PASKOFF (1967), this feature might be equivalent to the european Flandrian (now Versilian). Old and young dunes are also present. The later one covering the above mentined terraces and indian culture.

STRATIGRAPHY

On the following paragraphs, the stratigraphy of the area is described from bottom to top. No emphasis will be given to the discussion of the Miopliocene fauna, and the Holocene deposits are disregarded.

Metamorphic basement

The metamorphic complex consists of schists (Lower Carboniferous in age, MUNIZAGA, 1973; GONZÁLEZ - BONORINO, 1970) intruded by mainly pre-mesozoic crystalline rocks (coastal Batholit, MUÑOZ CRISTI, 1964), grading from adamellites in the south and tonalites in the north. Only one lower jurassic (CORDANI *et al.*, 1976) lamprophyric-dike cuts all these ancient rocks of Huehinco creek. The diverse diaclase sets have been studied, but disregarded in the present paper.

Cretaceous

At Topocalma Point there are 10-15 m of basal conglomerate with boulders and pebbles with some calcareous sandstones intercalations, with well rounded and often great quartz grains on the top. Westwards these intercalations grade to piritous limestones. Thickness and permeability increase towards the east and north, but the size of the grains decrease. Permeable uppermost quartz sandstones present here and there often with deltaic crossbedding put in evidence a directional transportation towards the ENE. The quantity of iron and manganese oxides increases towards the east revealing perhaps reducing epicontinental seawaters beyon the eastern ancient coastal line of the cretaceous embayment.

Sandstones often present silicified great tree trunks elongated N10ºE; these beds often grade to siltstones towards the east.

Abundant fossil fauna has been collected, consisting of *Pachydiscus quiriquinae*, *Gunnarites* sp., *Grossouvrites* sp., *Cardium acuticostatum*, *Trigonia hanetiana*, *T. cazadoriana*, wich indicate an uppermost campanian or lowermost maastrichtian age. Sandstones bearing tree trunks are often associated with lacustrine light siltstones, containing unclassified monocotyledonies.

The thickness of cretaceous sediments is very variable, reaching up to 150 m. The base with some thin coquine beds, is paleotopographically very irregular. Where thickness is greater (Topocalma area) very good measurements have frequentely been done, wich indicate a depositational direction towards the north and mainly towards the NE. At the southward area of cretaceous outcrops (Quebrada del Deslinde) some coal bearing sandy beds are present and in some beds, along a normal fault and near a transcurrent fault, hydrocarbure odor has been detected.

It is remarkable that near the cretaceous and eocenic outcrops the lowermost member of the miopliocene sequence is not present; but north of Pupuya at the local lowermost deltaic cross-bedding and conglomeratic series of the Navidad Formation, a pebble with cretaceous *Trigonia hanetiana* has been collected.

At the rigth hand side of the Topocalma river, where this arrives to the alluvial plain, a 20 m thick outcrop was observed (basal layer is not exposed) which consists of clearly cross-bedded yellow sandstones and conglomeratic lenses. The series rests under yellow silty sandstones including abundant specimens of *Trigonia hanetiana*. Only the specimens of the lower layers are manganese coated.

The change of lateral facies, the variability of thickness and the directional contribution to the cretaceous depositation, indicate that the western shoreline of this mesozoic embayment was located towards the west of the present pacific coast; that towards the NE cretaceous sediments were thicker and may be not much affected by erosion, Towards the south, deltaic cross-bedding is observed. The basin was closed to the south and to the east, where no cretaceous sediments are present at the surface, perhaps covered by the uppermost miopliocenic marine sediments, sometimes covered by pleistocenic sediments and lahar.

One normel fault is present only in the basal cretaceous beds, 1 km southward of Topocalma Bay, but this fault does not reach the uppermost visible cretaceous sediments.

At Topocalma Point, a discontinuous uppermost quartz sandstones, usually showing cross-bedding, silicified tree-trunks, a lagoonal ligth coloured unclassified plant bearing siltstone was found along the traverse. Paleocurrent indicators, such as cross-bedding, elongations of tree-trunks and imbrication, show that depositation occurred towards the ENE, N50°E, N and NE respectively, suggesting a fan like sedimentation structure.

At Cerro Candelero, and near the mouth of Maitenlahue river, unfossiliferous dark calcareous shale are present; at its base a thin pebbly conglomerate frequently is present; these sediments are covered discordantly by eocenic sediments and may be cretaceous in age; thickness is 6 m at least. These beds are dipping 20° to the SSE or 15° eastward.

Eocene

Eocenic sediments. recognized at now for the first time, of limited areal extension, are present at Cerro Candelero, to the north, at El Alamo Gorge and Topocalma river to the south.

Southward of Cerro Candelero, eocenic sediments rest discordantly over a 5 m thick dark calcareous shales, perhaps cretaceous in age.

Northward of Cerro Candelero the series rests over tonalite: at the base a thin conglomerate with little pebbles of tonalite and quartz is present. The maximun thickness observed reaches only 50 m. It is a quartz sandstones series with yellow calcitic cementation in the upper part; in the lower sequence black shales are present, bearing autochthonous coal thin layers. Some brown siltstones, gray sandstones with interbedded microconglomeradic thin beds are also present. The pebbles of the microconglomerates are of rhyolitic and andesitic composition; however granitic or tonalitic pebbles are not present in the upper lenticular conglomerates. The higher member of the miopliocenic series rests over eocenic deposits.

The fauna is well represented by coral forms such as *Caryophillia sebastiana* and *Lithomices costellatus* as well as by some ephebic *Cardium acuticostatum*. This later form is cretaceous in age but in this area it represents a reworked fossil. The mentioned coral forms are common in Eocene deposits of the Magellan basin, in the Boquerón, Loreto and Agua Fresca Formations (HOFFSTETTER *et al.*, 1957).

At base (232 m) of San Enrique N° 1 Well, perforated by ENAP, some thin coal bearing microconglomerates were found upon granite; this lowermost series may be eocenic in age.

In the uppermost part of the Quebrada El Alamo some brown coal bearing siltstones covered in angular unconformity by the uppermost member of the miopliocenic series are observed. Fossils were not found. The lithology of this area is the same as that of part of the sediments of the lowermost part of the eocenic series of Cerro Candelero; a tentative eocenic age is considered for these sediments.

Quartz sandstones with scarce cementation and good permeability are present at Topocalma river, showing interbedded autochthonous coal bearing layers, without economic significance: they consist of a high density resinous luster, sub-bituminous lignite which suggests a deeper burial depth than the actually observed.

A northward input of sediments is inferred from these outcrops on the basis of well developped deltaic crossbedding. The maximum thickness observed in this series reaches only 50 m.

Interbedded in the quartz sandstones there are three calcareous beds, 10 cm thick, containing abundant forms of *Turritella* (*Melania*) *araucana* of eocenic age. At Topocalma Point the same sequence was observed unconformably over cretaceous deltaic cross bedding sandstones and conglomerates including manganese coated cretaceous *Trigonia hanetiana.*

The eocenic sandstones are unconformably under a miopliocenic sequence and over both adamellite (and associated rocks) and createaceous sediments. The angular relationships indicate a northward 20º tilt of the granitic basement in agreement with the 10º to 15º tilt observed between eocenic and cretaceous beds.

Pollen found in this coal has been considered synchronous with that of the "Piso de Concepción" coal of Paleocene or Lower Eocene age (FRUTOS, oral communication).

This pollen, according to FRUTOS, consists mainly of Betullacea and Myrtacea forms indicating a rain temperature warm paleoclimate. with an annual average temperature of 10º to 14º C.

In Chile coral forms are very scarce along the whole territory. However the unusual abundance of these forms coincides with the palinological results. Furthermore, the coral abundance suggests a low input of fresh water in the embayment after the sedimentation of the lower part of the series at Cerro Candelero.

During the Eeocene, the Cerro Candelero area was the NE coast of the southward closed embayment. This statement is supported by the strange presence of slate and flysch pebbles in the conglomerates of the lowermost outcrops of miocenic sediments, deposited in the opposite coast of the embayment.

Synsedimentary folds found at Topocalma have an E-W oriented axial planes dipping to the north. An uplift of the southward edge of the embayment or sinking of the northward area is inferred from these observations.

In is interesting to emphasize that DARWIN's description of the series present at Topocalma (perhaps Topocalma was called Navidad at that time, or could belong to a politic district or province of Navidad) is quite similar to those described in the present work. DARWIN neither recognized the slight angular unconformity nor found the ammonites, present practically at the same levels including silicified tree trunks. DARWIN states: "that the whole series, or the sandstones formation at Navidad... belongs to nearly the same epoch, which... must be a very ancient tertiary one" (HOFFSTETTER *et al.*, 1957). According to this it maight be concluded that the Navidad Formation is a comprehensive group, including cretaceous, eocene and, as we shall see, miopliocene sediments separated by two angular unconformities.

On the basis of this last statement it is proposed to change the hierarchy of DARWIN's Navidad Formation to the range of Group.

If the present author proposal is accepted, the Navidad Group consists of the following 4 formations: Punta Topocalma (Cretaceous), Río Topocalma (Paleocene-Lower Eocene), and miopliocene sedimentary sequence for wich the name of Punta Perro - La Era Formation is proposed (described in the following lines) and the already known uppermost pliocenic La Cueva Formation (BRÜGGEN, 1950).

Punta Perro - La Era Formation

Considering that the comprehensive series of Topocalma area were informally designed by "DARWIN's formation of Navidad" and "Sandstone at Navidad", most of the later research was restricted to the nearby areas such as Navidad (Matanza, Punta Perro) where DARWIN could not go ashore.

As DARWIN states, Topocalma is the only site where a 250 m cliff exists. None of the remaining areas show a similar feature. DARWIN debarked in Concepcion where he stablished the "Concepción formation". According to D'ORBIGNY and FORBES paleontological determinations, this stratigraphic unit is considered as Lower Eocene-Upper Cretaceous. However DARWIN suggests that the ammonites and baculites forms found in this unit, indicate a younger span of live than the one observed for the same forms in the northern hemisphere.

This "famous geologist", after debarking at Navidad, recognized that the lower tertiary marine sediments had been accumulated in coastal basins, generated by submarine ridges paralleling the older coast of the continent.

In respect to the paleoclimatology, DARWIN accepts, but hesitantly, that the fauna should have lived between 1 and 10 fathoms (2-20 m), having characteristics of higher latitudes than the one observed at present.

After DARWIN's work, people mixed the faunistic with lithological concepts. In this way, his formation was assigned to "stage", "stufe" because of the incapacity to grasp the rocks-correlation and time equivalence concepts. Finally the Navidad formation was recognized as present from Chiloe to Valparaiso (HOFFTETTER *et al.*, 1957).

The area where the Navidad Group crops out was completely surveyed. However there is no type section for the miopliocene strata. The basal layers of Punta Perro-La Era formation are located on the western coast of Punta Perro peninsula. However the higher and thicker beds of this unit are better exposed at La Era. The sediment types present in both areas allow a close correlation of them. On this basis it is possible to reconstruct a correct integrated series, perhaps including an insignificant error in the thickness, due to natural changes of this shallow sedimentation in no-oceanic epeiric sea.

The base of the Punta Perro - La Era Formation (formal proposition) is the granitic complex or the unconformity which separates this formation from Rio Topocalma Formation or Punta Topocalma Formation. The overlyng unit is a conglomeratic sequence over which rests La Cueva Formation as inferred from areal correlation. However La Cueva Formation rests also over the granitic basement in the nearby surroundings of its type locality.

The thickness of Punta Perro - La Era Formation is 40 m at Punta Perro (only Member I) and 174 m at La Era area, where the base is not exposed. This formation was subdivided in four members which from bottom to top are as follows:

MEMBER I: basement: granite; top: yellowish sandstones including calcareous concretions that correspond to the basal layers of Member II. At Punta Perro there are 40 m of well exposed sediments without the lower or upper layers. The basal layers of this member are better exposed in the Polcura area, 8 km. to the SW of La Era.

At Punta Perro a basal 2 m thick conglomerate was observed. It shows granitic boulders up to 2 m in diameter. The major axis of these boulders is directed to N20º E. The granitic outcrops are found seaward at the reef like stocks exposed by transcurrent faulting.

In those outcrops where the contact is well exposed, the basal conglomerate shows a maximum observable thickness of 2,50 m. At Punta Perro this basal conglomerate shows marine clay lenses. The microfauna is composed of quite frequent globigerinoides individuals. This fact was also stressed by Dr. DREMEL (in HERM, 1969) who assigns these forms to the Lower Miocene (Burdingalian).

These clay lenses are different from those clay layers (6,25 m in thickness) found 500 m northward, at the very same Punta Perro, clay which belong to the uppermost beds of Member I.

South of Boca de Pupuya the conglomerate splits in two branches: the lower one consists of granitic boulders and subordinate lamprofires. The upper one shows granitic. flysch, slate, lignite and *Balanus* specimens. The conglomerate layer pinches out to the south.

Over the conglomerate there are 5 m of

sandstones, part of which are eolian. They show abundant veins of gypsum and magnetite. These sandstones, when consolidated, were broken as suggested by the chaotic disposition of the blocks, which evidence an average gravity sinking to the north. Upwards there are 10-12 m of cross -bedding heterogeneous sandstones including microconglomerates and clay lenses. Its basal 2 m thick sandstones are eolian and show magnetite veins. Further upward there is a brown yellow coarse grained sandstone and interbedded ashes. The strata include wood fragments drilled by *Teredo*. The thickness of this sequence is 16,25 m. Still upwards the sandstone facies change sharpely to a 6,25 m thick sequence of gray fossiliferous clay interbedded with thin yellowish white ashes and basal well cemented quartz microconglomerate. Its top is a local angular unconformity over wich rests the Member II of the formation. A maximum tilt of 10º of the lower beds is inferred from the angular relationship between the ash lamination and the member II stratification.

In the Punta Perro area, a normal fault dislocates the lower member. The upper Member II is not displaced. (northern block lowering).

In the upper clay the author collected microfossils which, according to Dr. THALMANN (1960, oral communication) are assigned to a Tortonian age; this fauna does not present the exceptional abundance of Globigerinoides observed in the lowermost marine clay lenses, interbedded in the basal conglomerate and Lower Miocene in age.

An orogenic Attican phase migth be inferred from the unconformable relationship between the Members I and II.

MEMBER II: Obove the mentioned 6,25 m thick clay sequence, belonging to Member I there is an unconformable (10º tilting) yellowish gray medium to fine grain sandstone including limonitic veins near the basal contact; quite hard and big calcareous concretions were also observed. Their longest axis is subparallel to the stratification and the maximum diameter is 1 m. The concretions shows characteristic bombs at the extremities. At Punta Perro this sandstone is 8 m thick and the upper layers are missing south-westward of Punta Perro, south of Boca Pupuya and south of Navidad town. There is a 30 cm thick bench below the concretion level; the bench includes abundant gastropods; in Matanza area the same bench shows interbedded beds which includes abundant dicotiledoneas remains.

Cross-bedding sandstone were observed in a furrow carved on the uppermost clay of Member I. In those areas where this clay is missing, the series is continuous and the concretions level marks the base of the Member II.

At La Era area the sandstones with big concretions reach 19,5 m thickness; yellow sandstones, 30 m thick, rest over the concretions; these sandstone graded from south to north from 5,20 m to 60 m in thickness. Still upward follows a white volcanic ash (12,40 m thick) over which rests a characteristic gray sandstone pinching out from the north from 22 m to 12,80 m in this area and in the area of Navidad; these gray sandstones, with or without cross-bedding, are very well extended in all eroded outcrops; it presents a 0,20 m thick conglomeradic ample lense; but in the Polcura area the same sandstone shows coarser grain and abundant conglomeradic lenses.

At Los Gauchos area the gray sandstone is absent. There are some evidences that the immediate lower volcanic ash was eroded, as suggested by the ash boulders found in the cross - bedding conglomeradic sandstone of Member III.

The Member II increases in thickness to the E, excepting those areas where it is not present, but granitic reefs outcrop instead. From east to west the ash bench decreases in thickness, but always including marine fossils. However to the east it has pumice fragments, lignite and crabs; finally at Boca Pupuya shows quite abundant echinoderms fossils resting as live specimens. For all the chilean stratigraphic colum this echinoderm abundance is quite an exception. To the east of Boca Pupuya the ash shows cross-bedding.

The presence of this echinoderms (CECIONI, 1970) might indicate a pliocene age for the Member II. Its top is the base of the Member III.

MEMBER III: It is a 1 m thick fluvial marine conglomerate, with a very well giantic *Venus* specimens; in spite of this small thickness it is here assigned as "mappeable" member; the cobbles are volcanic in an iron stained sandstone matrix; which becomes calcareous to the east of La Era. The Member pinches out to the SE of La Era. The Polcura area shows the same pattern, but at Los Guachos it shows a thickness of a few meters and abundant cross-bedding.

Member III was also observed in both sides of the Rapel river between the Rapel and Navidad towns. Northward of this area the unit disappears, being replaced by the uppermost gray sandstone of Member II, over which rests the Member IV. The areal distribution of this significant key-bench is as follows: from the SW (Los Guachos) to the NE (Rapel river meanders), it is quite frequent but disappears to the north, on the eastern and western areas. Its thickness decreases to the NW. On the eastern side of Rapel town rests over granite reefs with an interposed Balanus layer; to the SW of Pan de Azucar Hill rests over schists and tonalite.

Fossils of this member are extraordinarily abundant in the uppermost level where they show a chaotic appearance.

MEMBER IV: it rests over the Member III and its top is a conglomerate which is the base of La Cueva Formation, as established by correlation and equivalence. At La Era its top is missing. The Member IV is represented here by a 31 m thick yellowish sandstone; it shows a 0,20 m thick interbedded conglomerate and a 0,50 m thick ferrouginous concretions bench towards the top. To the SW a crossbedding bench increases from 0,50 to 2 m in thickness, but farther to the SW the thickness decreases and the conglomerate disappears. South of La Era (6-7 km) there is a microconglomeratic sandstone over the top of Member IV. Upwards a dark gray shale is found under a yellowish silty sandstone quite similar to the one outcropping at the type locality of La Cueva Formation; the contact is gradational. The maximum thickness of the Member IV is found to the NE of La Era, at Pan de Azúcar Hill, where it reaches 150 m. Here, upwards is followed by a 1 m thick conglomerate and 8 m of yellowish silty sandstone similar to those of La Cueva Formation. According to Prof. V. COVACEVICH, the fossil content of this uppermost unit at Pan de Azúcar Hill shows a significant percentage of forms characteristic of La Cueva Formation; the remaining fossil forms are related to those of the Member IV. On this basis La Cueva Formation at Pan de Azúcar Hill is older than at La Cueva type locality, where the fauna is Upper Pliocene in age (BRÜGGEN, 1950; HERM, 1969) indicating a southward ingression.

At Cerro Candelero the Member IV rests directly over Rio Topocalma Formation, eocenic, and tonalites.

At San Enrique Nº 1 Well a sedimentary sequence, 220 m thick was found. The upper 55 m are silty-clay deposits correlated to those of the Member IV, 6-7 km south of La Era. The remaining column is correlated to the Member II; the Member III is missing in this well; the lowermost coal bearing microconglomerate may be eocenic in age. The electric log indicate impervious layers in the Member IV sequence, and some permeability in the beds of Member II.

The Member IV presents homogeneous lithology, erosion pattern and the widest geographic distribution. It shows also a slight tilt to the north. At the most eastward outcrops, along the Rapel river, this member includes 2 sedimentary sandy dikes, which were cemented by calcium carbonate rich solutions. Dikes trend N10º E; they indicate an E-W tension stress synchronic with the sedimentation of the lower sequence's member.

South of Pan de Azucar Hill, along the road of the left river side, a slender synsedimentary fold was observed, showing an E-W axis and a greater slope to the north. It is interpreted as a submarine sliding to the north.

La Cueva Formation

Along El Ganso Creek there is a hilly area where Brüggen (1950) found the following sequence from bottom upwards: a) 20-30 m thick sandstones and conglomerate; b) upper pliocene marine sandstones (unknown thickness); c) 10 m thick dark sandstones; d) 6 m thick conglomerate including pumice; e) 15 m thick dark sandstones; f) 4 m thick glacial conglomerate. BRÜGGEN did not give a formal designation to this sequence with conglomerates at its base, which rests over the Punta Perro - La Era Formation.

Locally the La Cueva Formation rests over the whethered adamellite. It is an agglomerate of pumice, ash and big boulder which are the remmants of laharic deposits coming from the andean cordillera.

At the type locality the formation thickness is approximately 50 m. At level c) a whale bone was recently found.

HERM (1969) studied the fossil content of a yellowish silty sand located 5 m over the base. On the basis of this study the author gives a best support to the upper pliocene age, formerly assigned to this unit by BRÜGGEN. Certain fossil forms indicate a warm climate. Since 20 years ago several paleontological studies have been started but never ended in a published report.

South of La Era (6-7 km) there are some outcrops of silty clays showing a thickness of a few meters. Fossiliferous silty sandstone, which grade to a dark silty clay; this later resting over a microconglomerate. The last one could be correlated with the conglomerate of the base of La Cueva Formation located at Pan de Azúcar Hill and to the BRÜGGEN's level a) of La Cueva Formation type locality. Here, over the silt beds rest fossiliferous marine yellowish silty sandstone, that is correlated with the 8 m of the upper sandstone at Pan de Azúcar Hill.

On the basis of the above lithological correlations and paleontological equivalence, it is possible to define La Cueva Formation as a yellowish silty series. Sometimes showing a few meters of dark silty clay near the basal contact, represented by a conglomerate (decreasing size of cobbles to the south). The top is the base of Los Peumos Formation, defined in the present paper.

La Cueva Formation is located on the eastern margin of the area, overlapping granitic outcrops in the surroundings of Pan de Azúcar Hill. Eastward, 10 km SE of Central Rapel, a few meters of la Cueva Formation rest over the Member III, here 15 m thick.

At the head of Pupuya gorge the same dark silty clay was observed. It includes abundant microfossils of apparently pliocene age. As in the type locality it shows upwards a yellowish silty sandstone. Here a tensive stress opened the compacted clay, while under marine conditions. The fracture is 1-2 m wide and it shows funnel like folding of the upper yellowish silty sandstones. The fracture trends approximately N20ºE being on the average parallel to the similar fractures observed in the Member IV of Punta Perro-La Era Formation. The avalanche of 1975 destroyed this didactic structure.

At Matanza town, 1 km SW of this town, near Lagunilla hamlet, an unconformity of erosion was observed at the higher part of the coastal cliff. There the yellowish sand of the Member II of Punta Perro- La Era Formation appears eroded in two sites that are interpretad as older gorges. To the north there is a white fine silt including abundant dicotiledoneas leaves. To the south dark coarse sand sediments were observed showing slight compactation and very good permeability. The north site deposit are tilted 36º to the NW, and the south one 32º to the WSW. however the member II rests almost horizontally. Both series rest over brown paleosoil. The thickness of the two sequences ranges from 10 to 15 m. These deposit can not be correlated to any unit of the area. Tentatively they are considered as equivalent to those of La Cueva Formation. If so, they represent continental deposits of the westward embayment, and were generated between both Punta Perro-La Era and La Cueva marine regression. Being the outcrops of very limited areal extension, the present author suggests a great cross bedding which may indicate a peleoslope of the gorges to the NW and to the WSW.

Los Peumos formation

At Los Peumos the following sequence from bottom upwards can be observed: a) gray medium size yellowish sandstone including pumice pebbles; the top of this unit shows erosional gorges; its maximum observed thickness is 20 m; b) river conglomerate 3 m thick including cobbles up to 10 cm. c) gray cross-bedding sandstone wich indicate transport from NE to SW; the beds are well stratified and shows very fine grain size; this sandstone, 2 m thick, do not present yellowish color, nor erosion gorges. d) conglomerate beds wich thickness increases from 4 m at Los Peumos to 30 m at La Cueva; the conglomerate is normally graded showing upwards some boulders, cemented by volcanic ash, and chaotic agglomerates with fine material which constitute the abundant element at the top.

The basal sandstone a) belongs to the level d) of the La Cueva Formation; conglomerate infilling of gorges in this unit indicates erosion of the upper beds; this conglomerate is quite similiar to those found on the upper leve's of La Cueva Formation. The gray sandstone c) was originated by erosion and transported to the SW of the gray sandstones located over the Member II of the Punta Perro-La Era Formation. This gray sandstone immediately to the NE of Las Estrellas (16 km to the SE of Rosario del Solís) reach the maximum observed thickness of 15 m, and its cross bedding is very impressive, indicating a southward fluviatile current. The boulders of the unit d) are of andesitic, basaltic, granitic and schist composition. The cementing material, excluding the magnetite, consists of the following heavy materials: basaltic hornblende (95%), zircon (4%), epidote and olivine (1%) (three analyses).

These data suggest an andesitic-dacitic eruption which generated a lahar flow. It is also inferred that the andean volcanic centers are the most probable original formation on sites of this kind of lahar flows. A great amount of boulders bigger than 1 m in diameter were measured and located on a map. It was found that they are aligned preferentially along a NNW and NE trend. However the smaller boulders show a chaotic pattern. On this basis it seems that the lahar flow comes from the Andes from SSE towards NNW. It covered the sedimentation area following the slope of the Upper Pliocene northward marine regression. The lahar age is Pleistocene and could be lower Pleistocene.

However east of Rosario del Solís the lahar deposit rests directly over the adamellite.

After the avalanche of the lahar, the subsequent rivers found a wide basin on the granites of the Maitenlahue Creek-La Manga area. River sedimentation generates 4 benches of sedimentary magnetite, 0,50 m thick. two of which were detected by means of a magnetometer.

When the erosion destroys the thin uppermost fine layer of the lahar, where grass is abundant, the under sited boulders protrude. On the next erosion stage, boulders fall down. The landscape shows at this stage slope gorges greater than 30º. The irrational cultivation of wheat over these slopes induces a greater anthropic erosion and the subsequent disappearence of the agriculture production.

Rosario del Solís kaolinite

East of Rosario del Solís there are extensive outcrops of adamellite which show big plagioclase crystalls and scarce mafic minerals. These rocks are locally kaolinized. This economic mineral is under the lahar deposit of the uppermost Los Peumos Formation. The paleogeography pre-lahar seems to indicate that the kaolinization took place in lacustrine small basins (maybe containing hot water) during the depositation of the lahar beds of Los Peumos Formation. Efectively kaolinite was never observed in granitoid rocks covered by La Cueva Formation. Its age may be lowermost Pleistocene or uppermost Pliocene.

Rosario del Solís diatomaceous beds

Its thickness is quite variable but never greater than 5 m. These economic beds rest over yellowish sandstones of the Member IV of the Punta Perro-La Era Formation. The uppermost diatomaceous levels show sporadic beds of a very plastic gray silt which are very similar to the level c) of the Los Peumos Formation.

Thus apparently the diatomaceous beds were deposited while the kaolinnization process took place eastwards.

Synsedimentary disturbance seems to indicate that an upward stress and a sliding of the diatomaceous beds to the south was verified.

The paleontological content consist of fishes (verbal communication), fresh water ostracoda and very abundant diatoms.

Among these diatoms a great amount of *Denticula* aff. *lata* was reconized by Miss Irene Aracena. She also recognized the same form in the marine ash of the Member II of Punta Perro - La Era formation, evidently transported by rivers. The *Denticula lata* Freng. can be observed, according to Miss Aracena, in the El Loa Formation and between the Oxaya and El Diablo Formations, Arica area. All these formations are of pliocenic age.

At present it can be assumed that the diatomites are related to kaolinization phenomena in the Rosario del Solís area; thermal waters probably acted as catalytic agents in the potassic feldspars alteration, originating lacustrine waters rich in silica, where these diatoms live. At present there is a spring near Rosario del Solís area called "Hot Water", now cold.

STRATIGRAPHICAL CONCLUSIONS

Sediments present in this area should have been joined under the nominations of Navidad Formation and La Cueva formation; both of them rest over granitoid and schist rocks assigned to the Upper Paleozoic. Those sediments assigned to the Navidad Formation belong partly to the Cretaceous, Eocene and Mio-Pliocene. These three series are separated by two main unconformities. According to this, the name of Navidad Group, essentially marine, has been proposed, including the following formations: Topocalma Point, cretaceous; Topocalma river, eocenic; Punta Perro-La Era Formation, mio pliocenic, and La Cueva Formation upper pliocenic. The Punta Perro-La Era Formation has been subdivided, for mapping and paleographic reconstruction purposes, in four members of wich the first is assigned to the Burdingalian-Tortonian age, the second, unconformably over the first, is Middle Pliocene near the top; members III and IV appear also to be middle Pliocene. Actually, the marine La Cueva Formation, assigned to the Upper Pliocene. rest over Member IV of Punta Perro-La Era Formation. The series formely interpreted as a glacial agglomerate have been recognized as a wide areal extended lahar for wich the name of Los Peumos Formation is proposed. This includes continental sediments found at ist base. No estratigraphic name is proposed for the Rosario del Solís diatomites as these are locally limited; their stratigraphic relationships permit to affirm that they are equivalent to the lower part of Los Peumos Formation. The kaolinization of adamellite was temporarily verified.

SEDIMENTOLOGICAL SKETCH

Some data are here presented with the purpose of giving some ideas about this subjet. It has not been possible to estimate permeability and porosity. Argillaceous beds density should not have given enough security to support correlations, being frequently silty. Mineralogical analyses (heavy minerals, opaques and granulometry) are not complete; frequent lateral and vertical facies variations, sometimes very sudden, have to be considered.

Topocalma Point Formation

Calcareous benches, often with coarse quartz grains, contain much cubic pirite towards the W; this pirite is not present at Los Guachos. Sandstones become more thicker, granulometrically more uniform while permeability increases towards the north and east.

Iron and manganese oxides increase towards the east, indicating perhaps a reducing condition of these paralic sediments, originated in epicontinental sea waters away from the eastern shore line of the cretaceous basin. Sandstones often present silicified great tree trunks with a N10°W elongation at Topocalma Point; but southwards and eastwards the elongation gradually varies until reaching the E-W trend.

At Santo Domingo Point the isolated small cretaceous outcrops are quartzitic, microconglomeradic and enclosed in limited depressions within the granite, indicating the ancient coastal line as a cliff shape. In turn the coquine of Topocalma Point base, not completely compacted, with fossils in a generally chaotic disposition, sometimes reduced to fragments, indicate the nearness of a rather beachy coast. At Los Guachos area, fossils are better preserved, benches are more regular and grains selection is more uniform. At this area the marine series indicates a facies more separated from the coast, with continental supply, originating coal lenses, maybe in temporaneous inner lagoon in a typically paralic environment.

Topocalma River Formation

At the Cerro Candelero well rounded quartz grains indicate a long transportation and possible inheritance from coastal and eolian cretaceous sediments. They were deposited after a continental supply locally covering the granite. At its lower part, coarser, subrounded and rounded grains are present; few of them are angular; 66% are rhyolitic and a 33% are andesitic. To the top subangular grains predominate over the subrounded ones; 85% are rhyolitic and 15% andesitic (ETCHART, 1973). The presence of shales, siltstones, coal remains and rounded grains at the base, indicate a supply of mature rivers at their terminal course from the continent. The upper part of the series indicate a river reactivation mostly due to tremendous continental volcanism than to a significative lowering of the base level. A major supply of subangular material and from a farest source (rhyolites) is observed. In spite of its calcareous mosaic cementation, the upper part seems more permeable than the lower one. As these grains can not derive from a western land, constituted by other types of rocks, they are coming from the eastern embayment margin. It is possible to assume that while the lower part of Cerro Candelero was deposited, mature rivers should have supplied probable coastal dunes eolian grains. These must have filled the lower part plain the rivers longitudinal profile. Rivers being reactivated, fluviatile waters that reached the sea deflected the rivers mouth to the north, so that reached the sea deflected the rivers mouth to the north, so that corals could locally live. Finally the Cerro Candelero sediments indicate an open coast having no islands or peninsulas in front, that is to say, this area was not enclosed in the embayment during the Eocene.

The same facies of the lower part of Cerro Candelero is observed at El Alamo. More to the SW, at Topocalma river lower part, eocene basal sandstones are very similar to those of the Cretaceous. Unlike the Cerro Candelero-El Alamo sediments, the sandstones and conglomerates of this part of Topocalma River are scantily cemented and very permeable. A more grain uniformity is observed and it can be assumed that some quartz grains present there (idiomorphic, bipiramidal, with magmatic corrosion and/or liquid inclusions, evidently of rhyolitic origin) reflect the contemporaneous rhyolitic flows in the Main Andean Range (Farellones Formation).

Punta de Perro - La Era Formation

Among amphibolites, hornblende and actinolite are observed in basal sandstones. These proceed from the granitic and schistous basement. During Oligocene (of geocratic facies in Chile) erosion must have been very remarkable; the basement should have been digged up owing to the erosion of cretaceous and eocenic sediments. Thus, as in the other basal conglomerates, at this formation appear again turmaline, biotite (partially altered to chlorite), titanite, chlorite, and a few epidote and granate; the latter are very abundant and of a nut's size, at Polcura area. They have no economic interest. Opaque minerals piroxene (hiperstene and eustatite) and rutile decrease from the lower part to the upper one: they can be of intermediate to basic rocks and of metamorphic rocks.

The oligocenic uplift permits a major erosion of the southward Pichilemu schists, until reaching a very smooth rivers longitudinal profile. Zircon (of granitoid and pegmatitic rocks) decrease from bottom to top. Observations indicate a short transportation of the Pichilemu schists to the mio-pliocenic embayment.

Light and magnetic minerals predominate now over the heavy ones. Gypsum exclusively appears at Member I, mainly marine and ingresive in stages. Afterwards there appears turbidity, much continental supply and even continental deposits with plants in Member II of the Matanza area are observed.

According to ETCHART (1973) the maximum sandstones size decreases to more than 2 mm (Member I), 1 mm (Member II), 0.5 mm (Member IV). Size locally also decreases from W to E.

The classification coefficient permits to establish that the Member II components are well classed, while fine parts are abundant in the Member IV; this allow us to point out that this silty member is impervious. With a so high base level, fluviatile supplies are of rather argillaceous material originating a scarcity of marine fauna and abundance of paralic facies, especially southwards.

Roundness values vary from 0,3 to 0,9 in Member I and in the remaining members vary from 0,5 to 0,7. Generally the sphericity/roundness ratio indicates a short fluviatil transportation. As some grains indicate a long transportation, it is possible to think of heritage phenomena.

Regarding semi-open or rhomboidal packing at Member I we have an intact skeleton and upwards partially intact. Members I and II present a high porosity; Member IV is impervious.

Magnetite decreases to the south and to the east at Member II

Elongated concretions, with apophisis and magnetite inside and outside, separating Member I from Member II (very rare in Member IV), indicate a coastal nearness with stationary waves, as suggested by Prof. E. VALENZUELA (oral communication) and temporarily related to short evaporation periods (Members I gypsum). As towards the south these concretions become benches without magnetite, it is deduced that towards the south the embayment was still more close and without stationary wawes; that is, it showed a low energy evironment with abundant organic substance which acids permitted the carbonate precipitation. After a negative oscilation of the base level the enviroment does not vary much: ingressive silty clay is present only along a narrow NW oriented area (La Cueva- Pupuya) with silty sediments specially at the Polcura and La Era areas, thats is on both embayment shorelines.

However, in the Lagunillas series of the Matanza area, if the above mentioned equivalence is correct, facies is totally continental, representing an island or western foreland which closes the embayment towards the W. Sediments are continental, sometimes with dicotyledoneous leaves. This vertical uplift is evident in the paralic sediments of this area and it was lifted during the "normal" Gauss period of the Geomagnetic History as a posthumous (Rhodanian) event of the Attican Main Orogenic event. Effectively, as an additional argument, the western land of the Matanza area may have been uplifted more than the remaining coastal zones as, a little more to the south, sandstones and conglomerates rest above the same granite. In this area the basal conglomerate only presents cretaceous sandstones pebbles with *Trigonia hanetiana*, pebbles of flysch and shales. At present these lithological types are unknown at this latitude; as here they are associated to coal pebbles their original source may not have been so far away.

SEDIMENTOLOGICAL CONCLUSIONS

Only at Candelero Hill area the Eocene upper series does not present fluviatil transportation evidences. Permeability decreases upwards. Member IV, covering 2/3 of the whole eastern area and La Cueva Formation are constituted by umpervious sediments. The Member I scarce eolian deposits (1 to 2 m) may perhaps be found in subsurface east of Candelero Hill, where great cretaceous and eocene deposits of this facies may be present. Effectively, this open beach area did not have peninsulas or islands in front, which could have prevented corals living, exclusively restricted to this small area.

Member III, constituted by fluviatile conglomerates, bearing abundant and extraordinarily great marine coastal bivalves, has a varying thickness between 0,50 and more than 3 m. This key-bench indicates a sudden sandy beach formation, originated by a quick sinking of some northern Rio Rapel block. Lower salinity adapted dwarf *Balanus* aff. *psittacus* (Dr. E. MENESINI, Pisa University, written communication) were incrusted along a granitic small inward peninsula which trend is NNW directed from Mesilla del Rapel to San Enrique Nº 1 Well. This sinking allowed an immediate increase of fluviatile gray sand towards the NW. The sea transgreded then towards this beach, originated by an extended mouth of one or more rivers, giving origin to some exuberant and giantic bivalves forms. Immediately afterwards, fluviatile erosion suddenly reactivated, bearing pebbles to the coast itself which chaotically mixed with fossils but occupying the conglomerate upper part due to a strong and prolonged dragging.

This conglomerate wedges in every direction but not at Los Guachos and at 20 km eastwards of Rosario del Solís, where it perhaps reaches 15 m in thickness.

At Los Guachos the river perhaps eroded Member II top and undoubtedly the ash cap. The most acceptable hypothesis is that after the northern block sinking a southern block uplifting was very soon verified approximately southwards of Los Guachos-Rosario del Solís area.

This hypothesis also explains why the Member II, so granulometrically heterogeneous to the south, to the north appears uniform medium grained. It is massive in exposed surface and with spheroidal fractures in fresh surface. South of Rapel River, where Member II has not been affected by the pre-Member III erosion, the Member II top is a conglomerate. North of Rapel River the top is a fine siltstone with vegetal remains. Thus an almost simultaneous marine ingression and a quick longitudinal profile change very near or in the river basin itself was verified.

Granitic reefs developped where the beach missed, over which *Balanus* lived and also in the granite diaclases opened by marine waves effects.

CLIMATE AND ENVIRONMENT

The most important changes in facies, thickness as well as unconformities between the different formations and some intraformational have been pointed out. Climate is now considered and afterwards environment.

CLIMATE

The present author stated in 1957 (HOF-

FSTETTER *et al.*, 1957) that at the end of Cretaceous, a warmer climate begins to develop in the South of the Americas due to the presence of corals, *Pliosaurus*, *Gleichenites* and *Nilssonia* in the Magallanes province. However the *Nothofagus* forest is developed in the continent (TRONCOSO, 1977).

Ammonites present at Topocalma Point Formation are the same as those found in Magallanes (Campanian - Maestrichtian limit); therefore it is possible to accept a similar climate at the Navidad area. At the same latitude, in the continent, also the *Nothofagus* forest develops (Abanico Formation; HOFFSTETTER *et al.*, 1957).

Climate tendency during the Paleocene-Eocene is to a tropical or subtropical transformation. At Coronel area, coal bears the southernmost remains of *Lygodium skottsbergii* HALLE, indicating a warm climate (ANDREWS, 1961). DOUBINGER (1972) found Nothofagidites at the lower eocenic Trihueco Formation.

The Topocalma River Formation pollen indicates a moderate warm (10°-14°) and rainy climate. In spite of the rain *Nothofagus* are not present. Isolated, non-colonial corals abundance, recognized at Cerro Candelero, confirms the former results, indicating also that marine waters were clean at that area.

Seas become cold due to the Humboldt Current presence in the Lower Miocene (HERM, 1969). The present author (CECIONI, 1971) considered that the mentioned current appeared since the Pacific Ocean did it, with different temperature waters and by Coriolis effects, thus stating that the Humbold Current "became cold" because since then the antarctic glacial cap began to develop.

At Cuya area, Arica province, a 21 m.y. age (Lower Miocene) ignimbrite (MORTIMER *et al.*, 1974) is present. Below this ignimbrite, lacustrine clays bearing *Chara* and fresh water *Ostracoda* indicate a cold climate but not an age, as these are new species (Dr. G. RUGGERI, Palermo University, epistolar communication).

In Member II, the present author found and determined the presence of abundant *Schizaster Jeanneti* MARTIN of the Sumbava Middle Pliocene and of *S. stalderi* WEAVER of the California and Mediterranean Pliocene (CECIONI, 1970). This genus is tropical and subtropical (GILL, 1961). Part of the "atlantic" fauna appears still upwards than HERM's estimation (1969) an the "tropically pacific" character definitely established during Pliocene.

The presence of *Cucullaea* in the Punta Perro-La Era Formation confirms also a tropical to subtropical climate (GILL, 1961).

It may also be observed that *Schizaster* is found in Middle Pliocene volcanic ash which fell down to the sea. However, considering the geochronological results (DRAKE *et al.*, in press) this ash age could be something older. Effectively, the rhyolitic acidic explosions of the Farellones Formation upper unities are of 5-4 million years ago (Prof. M. VERGARA, oral com.) and they correspond to the "reverse" Gilbert period, during which the posthumous vertical movement (Rhodanian) of the Attican Main Orogenic Event has been admitted here.

Thus, the postulate that acid explosions of the Farellones Formation second upper unit correspond to explosive phenomena which originated the Member II ash is accepted.

It is a very elegant problem in which small paleontological and/or radiometric errors are possibly joined or else we have to admit that the ash deposited 5-4 million years ago and that one million after ashy sediments uplifted with the posthumous Attican movement (Rhodanian).

It cannot be pointed out that *Denticula* aff. *lata* FER. belongs to a warm climate. The present author just observes that this form and the *Denticula lata* topotype located in the El Loa Formation (HOFFSTETTER *et al.*, 1957) has been found afterwards in the volcanic ash northward of Copiapó and at Rosario del Solís. This last diatomite is also here related to the plio-pleistocenic adamelite kaolinization, with the telethermal flows perhaps acting as catalytic agents; the silica liberation favored then diatoms living.

ENVIRONMENT

In Santo Domingo area the cretaceous beds are horizontally disposed over a very irregular adamelitic paleotopography. The Member II ash rests directly over the Cretaceous. At Topocalma the cretaceous basal conglomerate wedges towards the W; eastwards it grades to Alpha and Beta cross-bedding (HOYT 1971) with supplies mainly from the S and SW. Towards the W both benches bearing *Trigonia hanetiana* rest directly over the granite, lacking 100 m of sediments which are present towards the east. Above the *Trigonia* levels the trunks orientation indicates the SW embayment enclosing. At the El Deslinde area, both *Trigonia hanetiana* levels are found in conglomeradic near-shore facies; lamprophyre and coal pebbles are present. Here the Member II ash covers also the same two levels, missing at least the Eocene and part of the Pliocene. Towards the east the *Trigonia hanetiana* beds are underlying the Eocene by an angular unconformity.

During the Cretaceous at the Punta Topocalma, Los Guachos and west of Matanza areas, were of continental environment. The more deeper facies marine sediments should be located towards the east, partly eroded and buried by the Eocene and Miopliocene. To the east of Los Guachos, the granite must have been an uplifted land; the granite located to the NE of Los Guachos and the Santo Domingo granite seem to have been islands of the cretacous marine embayment.

In the Cretaceous base, whale bones are most abundant at the "Huesos de Ballena" place. In this same area, these bones are abundant in the Member II top. All these data indicate the southern cretaceous and pliocenic embayment close-tongue.

At mouth of Maitenlahue river area the probably cretaceous dark calcareous shales indicate a more deep facies. Unconformity planes angles separating the Cretaceous from the Eocene, or from the granite, have a northern 10º/15º inclination and a 20º inclination in the Topocalma area. However, towards the east the unconformity plane has a southward 30º: at this area cretaceous sediments constituted an island during the eocene sea; eocene rivers flowed into the embayment from south to north producing a Beta type cross-bedding dipping towards the north. At the El Alamo area the presumed Eocene shows scarce granite pebbles suggesting that the granite is locally covered by cretaceous deposits. At the same place, near the eocenic outcrop, these cretaceous sediments may have constituted a high paleotopography during the Miopliocene: effectively in this area the miopliocene cross-bedding is of a Beta type and with a northeast inclination.

Cross-bedding is of Alpha and Beta type in the whole Punta Perro-La Era Formation and shows a clear material convergence towards the Quebrada Pupuya-Mostazal area.

In Member I of the above mentioned formation, numerous shark teeth belonging to the *Lamna* genus of european seas planktofagus, pelagic and near-shore living forms are present. However these teeth are excesively smaller. Evidence of a major energy are also found here. Downwards a Nu type cross-bedding is observed; upwards, cross-bedding is Zeta or Eta type at the top. The angular unconformity plane has an eastern 10º inclination.

According to all these observation, it can be assumed that Member I (lower Miocene) deposited after the Oligocene geocratic phase; the eolian and marine sediments were deposited in an open coast (not in an embayment) with open sea in front; in the interland, to the east of the hills that constituted the coast, it may have presented a narrow depression through which the upper Miocene sea entered, depositing firstly the Member II in a southern closed embayment.

During the lower Miocene a general cooling of these seas is produced; however, in the upper Miocene-Pliocene embayment a tropical to subtropical climate is observed. This is a local microclimate because in other parts of Chile, where contemporaneous marine terraces are present, climate was cold.

It is possible that this microclimate has verified at the southern embayments detected in the chilean shelf and showing the same geography, oriented and opened to the N20°W (CECIONI, 1970, MORDOJOVICH, 1976).

At the Mesilla del Rapel area, between Member III and the pink and fractured granite, many *Balanus* specimens fixed over the granite are present. These are not young *Balanus psittacus* specimens but a variety of this form; they are dwarf specimens according to the reduced marine waters salinity; however, this waters was as clean as the eocenic water where corals lived. *Balanus* ended covered by fluviatile sandstones immediately before the conglomerate (Member III) depositation.

Certain giantic bivalves forms in the upper part of this conglomerate could indicate subtropical marine waters, as suspected by ARKELL (1956).

East of Rapel town, fluviatile sandstones below the conglomerate, present a Nu and Pi type cross-bedding indicating a major river energy; in the same member, at Los Guachos, a Beta type cross-bedding is observed.

To the SE of Rapel town, member IV present a thin bench with Alpha type cross-bedding and with a S to N supply. A synsedimentary fold is also present at the surroundings, indicating the same paleoslope. In this member cross-bedding practically misses, indicating a minimum energy.

According to ETCHART (1973) marine environment suffered a maximum reducing condition in the lowermost benches of each sedimentary cycle, just as in the more coastal environments, ranging from Eh - 0,5 to + 0,5. Ph values have been observed in the central part of the sediments and range from 7 to 7,8. This last value has been detected at places where concretions become calcareous benches, that is, at the embayment tongued closure. Reducing environments are specially verified at unconformity surfaces.

In the Los Peumos Formation type locality, an Alpha type cross-bedding with a SSW paleoslope is observed: some erosional furrows filled by pebbles and Zeta or Eta type cross-bedding, and with the same paleoslope are also present. Still more southwards, immediately to the NE of Las Estrellas, cross-bedding is much more developed, Beta type and showing a paleoslope to the south.

In summary, during the Cretaceous a moderate sea climate with a cooling and humidity tendence towards the continent can perhaps be assumed. During the Paleocene-Eocene climate is typically tropical to subtropical, always rainy. In the lower Miocene (Burdingalian) a cooling of the open sea developed. In the Tortonian-upper Pliocene lapse, a tropical to subtropical microclimate at the embayment and possibly much more cool at open sea is assumed. In the embayments the sea generally presented suspension particles due to numerous rivers supply. The sea is exceptionally clean at Candelero Hill, where corals developed and also to the east of Rapel town, where *Balanus* lived adapted to a lower salinity waters.

Tides at this embayment were of low magnitude, due to deltaic deposits abundance.

A reducing environment, specially at the angular unconformity areas, and in the marine sediments of the embayment western coast, is assumed and presenting a western rainy peninsula with forests and with a gentle slope. Its geological constitution indicates the existence of presently inexistent rocks such as slate and flysch.

Eolian deposits are only found in front of the open sea (Punta Perro); as the area where eocenic corals lived (Candelero Hill) did not have a peninsula or islands in front of it, it can be presumed that eolian deposits may have developed towards the east.

Energy clearly decreased since Cretaceous until Upper Pliocene; in the central part and to the embayment southern enclosure (Member IV and La Cueva Formation) argillaceous sediments sharply contrasting with the cretaceous and eocenic basal conglomerates were deposited.

PALEOGEOGRAPHY AND TECTONIC

Fossiliferous upper Cretaceous (Campanian-Maastrichtian) is found towards the SW part of the Navidad sedimentary basin: these are near-shore marine sediments with lacustrine intercalations; the most deeper facies is present to the east and perhaps to the north. These sediments do not crop out towards the south and east; adamelite and paleozoic schists are present towards the south; it is possible that it may not have deposited or else it was eroded. The Cretaceous embayment eastern shore-line is covered by pliocenic and pleistocenic sediments. Some western coastal sediments may have been eroded and only sandbeach remains in the subsurface may also be present. Towards the east of Candelero Hill cretaceous marine near-shore sediments may be present and buried eolian deposits may probably be found at its upper part.

Then follows the laramian diatrophism and a short erosion period during the upper maastrichtian - lower paleocene lapse. Paleogeographic conditions do not change with the eocenic marine ingression; it is only observed that at Candelero Hill, eocenic sediments have been deposited near the eastern coast embayment and that during this period eolian deposits may have accumulated towards the east: shore-face bars may also be present. Climate is now tropical to subtropical. Eocene show coastal facies at the Quebrada El Alamo area. Eocene may have deposited in the embayment eastern coast of the Candelero Hill-El Alamo area; islands or peninsulas within the same embayment were not covered by the sea or else their sediments were partially eroded (e. g. ENAP San Enrique Nº 1 Well).

Towards the west, scarce eocenic sediments deposited in the embayment western coast; some small islands may be presented.

Afterwards, the Pyrinean and/or Savian diastrophism is followed by a long erosion period. This took place during the whole Upper Eocene and Oligocene. The Member IV unconformable above the Candelero Hill Eocene, indicates a paleogeographic picture. At the beginning of Member II, the sea enters again into the embayment; a tropical to subtropical microclimate then developes. However in the open sea (Member I) a cooling process appears (Punta Perro's Burdingalian) and the main boulders direction indicates a western shore-line with a N20ºE trend.

The upper miocenic-middle pliocenic embayment appears to be wider than the former ones. Only in the northern part of this embayment an angular unconformity is observed, which maybe corresponds to the Attican diastrophism.

Acid explosions in the Andes occurred during the Middle Pliocene lower part (5 m.y.); these explosive ashes fell down into the sea where middle pliocenic fauna lived. Pumice stones (south of LaEra) transported by the embayment eastern side rivers extended along the same shoreline, together with carbonized trunks and crawfishes that lived in the high tide limit. Ash thickness decreases from W to E. A little after, the embayment western land slowly uplifts and lacustrine sediments are there deposited (Matanza area) where the Member I crops out again at the base. Something more to the south, in Polcura area, conglomerate intercalations are present at Member II; the Santo Domingo area appears to have been an island since the Cretaceous until it was covered by the Member II ash. Still more to the south (Los Guachos), the river which originated the conglomeradic Member III, eroded at least the Member II ash.

The remarkable blocks movements favoured the development of a marine sandbeach as well as the rivers flood that covered it with the Member III pebbles. Only the tensive fracture (down northern block) that affects the Member I and not the Member II, and the angular unconformity represent evidences of the Attican diastrophism, at Punta Perro.

A stagnant, closed sea, without energy, developes with the Member IV depositation. The shore-line drawsback to the NNW, developing then the ingressive basal conglomerate of La Cueva Formation. This event seems to correspond to the Rhodanian diastrophism.

Pliocene regression coincides with the Walachian diastrophism (1,8 m.y.). An axial NE-SW sinking, flanking the Los Pololos anticlinal, is developed only in the Matanza area during the Rhodanian diastrophism. In this depression continental sediments, here considered equivalent to the La Cueva Formation, were deposited. These are just two outcrops towards the W of Lagunilla Hill. This same area uplifts again during de Walachian diastrophism. This equivalence will have to be solved through palinological studies as it cat not be omitted that the mentioned sediments may be equivalent to the Member III or IV. This is not a pure scientific problem: these movements may have once more affected the eventual oils migration. Therefore, the Rhodanian uplift, early and /or late, produced an embayment central part displacement to the east of the Member IV and of La Cueva Formation, which shoe a declining energy.

At these embayments, where the Navidad Group deposited, three common factors are observed: 1) the deepest part of them, since Cretaceous to Pliocene, displaces towards the east while sediments become more argillaceous. This is the area of maximum depositation within the basin (depocenter). 2) Axes are NNW oriented and facies is more deep to the north. 3) All conglomerates present andesite pebbles and these clasts percentages increase from bottom to top, evidencing volcanic events in the Main Andean Range.

STRUCTURES AND INTERPRETATIONS

The different structures distribution studied in the present paper appears very clearly shaped.

1) Tectonics is more complicated at the coastal area and it consists of a transcurrent fault along the coastal line, cut by other transcurrent faults which trend varies, from north to south, approximately from NW to NE; at the Poicura area the trend is E-W. These are all left-hand transcurrent faults. In turn, the coastal transcurrent fault is right-hand. At the northern area this fault is flanked by another rigth-hand transcurrent and parallel fault although it shows a wide "S".

The coastal fault had always been interpreted as a thrust fault (granite overlies the sediments). However, two reasons make us think of a transcurrent fault; A) At Topocalma Point, schists and gneisses are present (these are exclusively found at this point through the whole mapped area); they are paleozoic schists intruded by the granitic complex and well exposed in the Pichilemu area, 15 km to the south of Topocalma Point. B) Tortonian clays present immediately to the SW of Matanza town appear in direct contact with the granite without tectonic disturbances, evidencing only a higher density. This coastal transcurrent fault is surely previous to the other radially disposed transcurrent faults, with an approximate convergence at the X point (see map), 10 km to the SE of Rapel town. At this point, N-S right-hand transcurrent faults are predominant. Convergence angle is a bit more than 90º opened to the W. On the other hand, the convergence angle between the coastal and easternmost faults is 60º and opened to the S (map "Y" point).

2) Axial folds with NW or WNW pitching are the most frequent. Only the Los Pololos anticline presents a both NE axis and pitching. The northern anticline limbs dip more than the southern limbs; in turn, the few synclines present a more dipping southern limb. Inclinations are very gen-

tly and a approximately 5º difference between both limbs is observed. An exceptional small anticline near Matanza area is here mentioned: its southern limb presents a SW 20º dip and a 70º NE dip. This extreme beds inclination value is again observed along the Rapel river, very near the granite and the transcurrent fault.

3) Thrust faults (southern block uplifts over the northern block) are exclusively found in the faulted area. This area constitutes an arc which from Qda. Los Cerrillos (south of Boca de Pupuya) crosses the Maitén Fault (El Parrón) through which the member II overlies the Member IV. Still more towards the east, along the Rapel river, the Member III overlies the Member IV. Thus, the Maitén perimeter, concave towards the south, has been drawn.

4) North of Río Rapel area, normal faults with an average 25 m net-slip, always down the northern block, are present. These are "en échelon"; as an exceptional feature, between the El Parrón and Rio Rapel areas, a normal fault reaches a 100 m net-slip. These southernmost faults, towards the north of the El Parrón perimeter, constitute another perimeter, rather parallel to the first one and it will be referred to as Lago del Rey perimeter.

5) Two well shaped grabens are observed: the Pupuya graben, with a N-S trend, with a 100 m net-slip, lifted and mapped in detail in 1968; the other east of Pupuya, presents a minor displacement, maybe of 40 m.

6) Tensional cracks with a NNE trend, as the lateral graben west of Pupuya graben, are present.

7) In less tectonically disturbed areas, wide monoclines are present. 1º the Rio Yaly monocline; 2º the one located towards the SW of San Enrique Nº 1 Well; 3º the Rosario del Solís area. The latter appears to be constituted by a thin sedimentary cover (Member IV and La Cueva Formation) superficially very extense.

It is not this paper purpose the discussion of these kinematic and dynamic structures. That is a totally theoretical matter and objetive of well received criticism. The present author opinion is that the whole area tectonics adjusts, with some differences, to the two theoretical HAARMANN models (1930).

Observations here presented allow us to point out that in this zone two areas or "geotumours" (CAREY, 1976) where uplifted: the coastal and the meridional areas.

The meridional one shows the transcurrent faults converged to "y"; its most lifted point at the bisectrix, is La Cueva. The western area or "geotumour" produced the transcurrent faults convergence at the "x" convergence point, as well as the NW and E-W axial folds. All this perfectly coincides with the sedimentological patterns.

Seismic - tectonic parameters (b) and liberated energy values are very low at the whole Navidad area; besides the structural curves of the seismic association surface is of 50 km at the Navidad area; here is a very narrow one and opens itselfs sinking towards the "X" point, forming a "bowing" or "chute" some 30 km towards WSW of Topocalma (GALLARDO, 1973), suggesting that transcurrent faults converging towards the "X" point may still be active.

The Matanza area vertical movement seems to have been lower than those of La Cueva Formation.

At the southern "geotumour", it may be observed: 1º) the Los Pololos anticline could be interpreted as "décollement" effects; 2º) the El Parrón tectonic perimeter presents thrust faults and among normal foults some present an exceptional displacement, considering the whole unit; 3º) the most withdrawn and northernmost Lago del Rey perimeter shows only normal faults of small displacement. 4º) grabens and extensive fractures are divergently presented and extending towards the north, suggesting a parallelism with the arching slope of the continuosly ascending "geotumour".

While until Pliocene inclusively, the rivers drainage way was directed towards the embayment, during the Pleistocene the depositation of the Formación Los Peumos basal part drainage-way trend was towards the south; the "geotumour" thus uplifted at the Rosario del Solís area.

The western "geotumour" (of the western paleoeographic peninsula) produced: 1) transcurrent faults converging to the "Y" point. 2) NW and EW axial folds, wich could be interpreted as a "décollement" product. 3) the Burdingalian, Eocene and Cretaceous were uplifted.

As the converging angle towards "Y" is minor than the converging angle towards "X", a major and more concentrated energy in the southern uplifted area can be presumed. The uplift of the western area was originated with a greater energy dispersión; gentle anticlines and indistinctic perimeters of arbitrary delimitation were originated.

Both "geotumours" uplift, the peninsula origin and the embayment "close-tongue" should be related to a common cause.

It must be pointed out that during the Mio-Pliocenic depositation, a continuous uplift has taken place and contemporarily the South East Pacific Ridge continuous expansion mas verified (CHARRIER, 1973). If a cause-effect relation between both phenomena exists, the geotumours uplift might be due to the chemical interaction between the oceanic plate and the continental crust, with a 20% volumetric increase.

According to this, the anti - isostatic uplift could represent the resultant and the compression structures might be due to the local lateral components.

In both geotumours transcurrent faults migth be due to an upwards arching type uplift, representing the shear effort; the uplift must have developed with a rather uniform helicoidal rotation around the axic and with a same axis direction removing. Rotation may have began at the same area where older sediments (Topocalma) are at present observed; being the rotational helicoidal movement contemporaneous, the southern geotumour may have rolled from W to E and the other one from South to North. In this way, effects are superimposed and the old HAARMANN model may present many variants, both in time and space.

According to the embayment surface exposure opened towards the N.N.W. and hanging in the chilean shelf, kinematics is not new; this kinematics is also observed at a microscopic scale, but certainly less complicated, in the plutonic rocks crystalls; this is the protoplastic structure verified at the plutons edges when these plutons uplifted with an helicoidal movement.

Perhaps due to the oceanic plates horizontal pressure against the continental block, it is possible that small displacements towards the NE are being or have been verified in South America. Embayments due to break-away, and opened towards the NNW, should developed at the East Pacific coast (CECIONI, 1970). It is also possible that these embayments, at a continental margin, may represent an effect due to the continuous earth expansion which reduced to fragments the primitive continent (CAREY, 1976), or the exudate sialic cover of the Proto-planet (MOURITSEN, 1975); in this way, we should have a continents "moving away" and not "drift".

The kinematic "geotumours" interpretation should then be taken into account, whereas the effects that these complex movements may have performed over the probable hydrocarbons migration.

MANIFESTATIONS AND TRAPS

At San Enrique Nº 1 Well, smelling gas came out from the Eocene (?). The Member II sandstones are fetid along the Boca de Pupuya transcurrent fault. Along the Quebrada del Deslinde transcurrent fault, some sandstones (Member II) are also fetid. Lowermost sediments of each interne marine sedimentary cycle reduction environments offer naftogenic possibilities. Sediments thickness between each marine cycle, before the erosive period, may have been remarkable, considering the coal bearing levels compaction. Lithostatic pressure, beside the other climatic factors, may have neutralized the low naftogenic deltaic environment.

Probable accumulations in reservoir rocks cut by unconformities are more difficult to find at subsurfaces; these unconformity planes must be well developed at subsurface. True stratigraphic unconformity and (in buried sedimentary hills) paleogeomorphic-traps might be present in this basin.

Coral beds are atractive features, as well some sandy lenticularities.

The possibilities to find dune fields as reservoires are restricted to the Estero Yaly area.

CONCLUSIONS AND RECOMMENDATIONS

Seismic profiles in precedence order will have to be done at: 1º) Estero Yaly; 2º) Pupuya graben; 3º) San Enrique Well western area; 4º) Los Pololos anticline.

Cape-rocks are well developed in the central and eastern areas. It is probable to find better selected eolian sediments at the Estero Yaly area; these sediments may have deposited near the embayment entrance; probable hydrocarbons migrations towards them may have verified. These hydrocarbons migth proceed from many reductive environments of the southern area. These possible migrations might have been favoured by the rotational helicoidal movement of both uplifted blocks ("geotumours").

It is evident that the SE Pacific coast is constituted by cenozoic sediments with a low temperature gradient. This is also present in deltaic waters.

In spite of this, having being pointed out that the Navidad Group developed through the times, as perceived by DARWIN'S genie, in a temperate climate embayment and in a subtropical to tropical microclimate, this environment favoured an exuberant living conditions, favourable to the oil formation.

In this case, the abundant deltaic environments detected represent naftogenic favouring elements, as organic matter transported by rivers within a hot climate embayment, bearing abundant marine fauna, may have been precipitated by the suspension particles.

All these critical factors can not be surely evaluated without an extensive drilling in the Navidad area.

It is assumed that the base of the continental margin slope represents the world's greatest thickness of sediments with a promissing petroleum prospect; but sediments of these areas are not considered as pay-rocks in the next few years, owing to the tremendous costs involved in drilling operations.

Tre Navidad Group may be economic if in some area a 1000 m thickness might be obtained, so that with the local geothermal gradient a favourable generating temperature (50º to 150º C) might have been reached in the buried sediments.

If this minimum thickness was not attained, the second possibility will perhaps be presented by the oceanward side of the slope base. This may have a high petroleum potential. Organic matter derived from both terrestrial and marine sources is here in a natural petroleum producing laboratory. If the marine slope presents at least a secundary permeability, it is possible that the eventual lighter petroleum, in response to compaction pressure and other expulsive force, have migrated upwards from the slope base to the shelfedge's sea entrance of the DARWIN's Navidad Group embayments.

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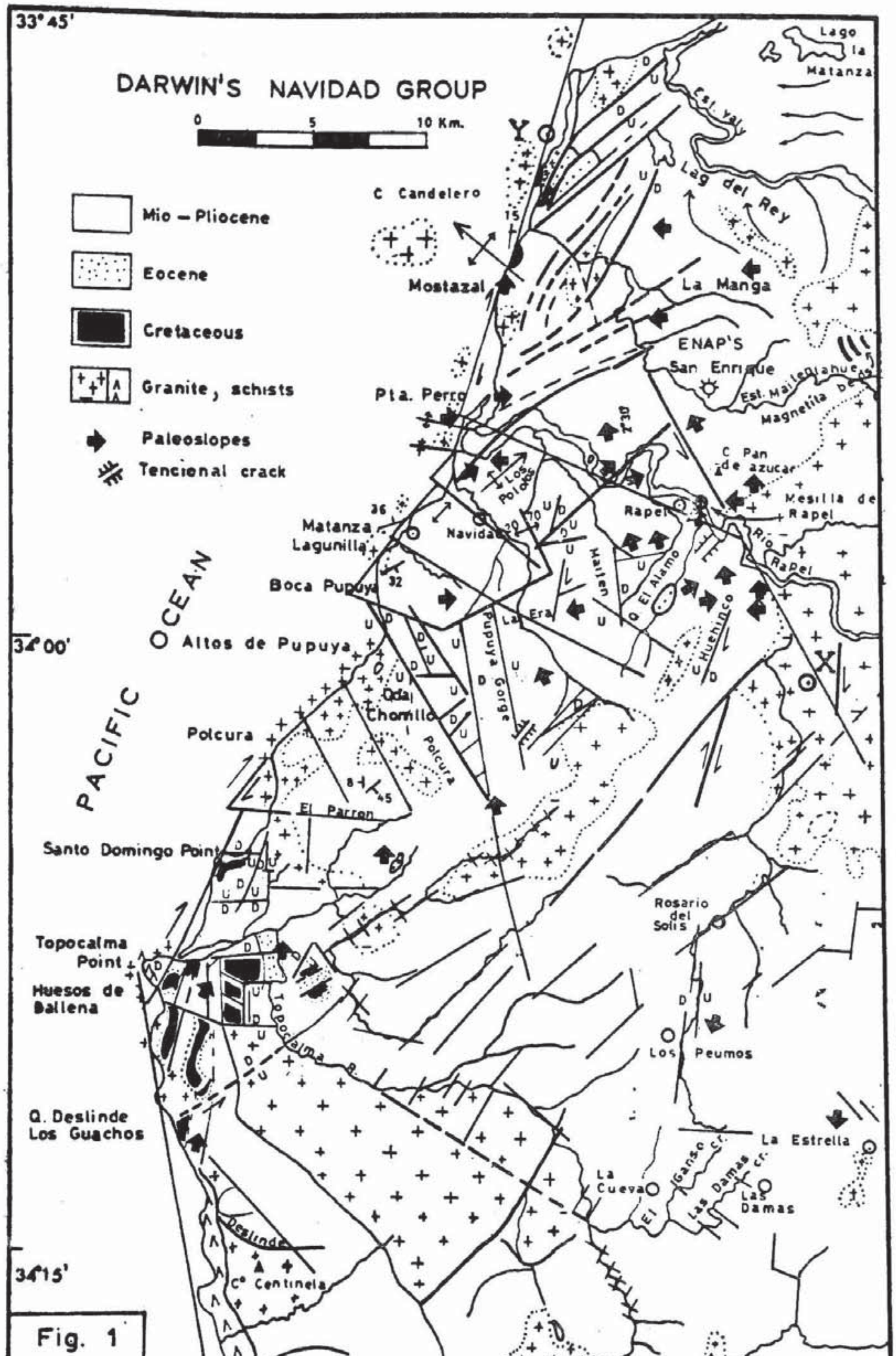

Fig. 1

Geological sketch of the coastal area between Estero Yaly and La Cueva.

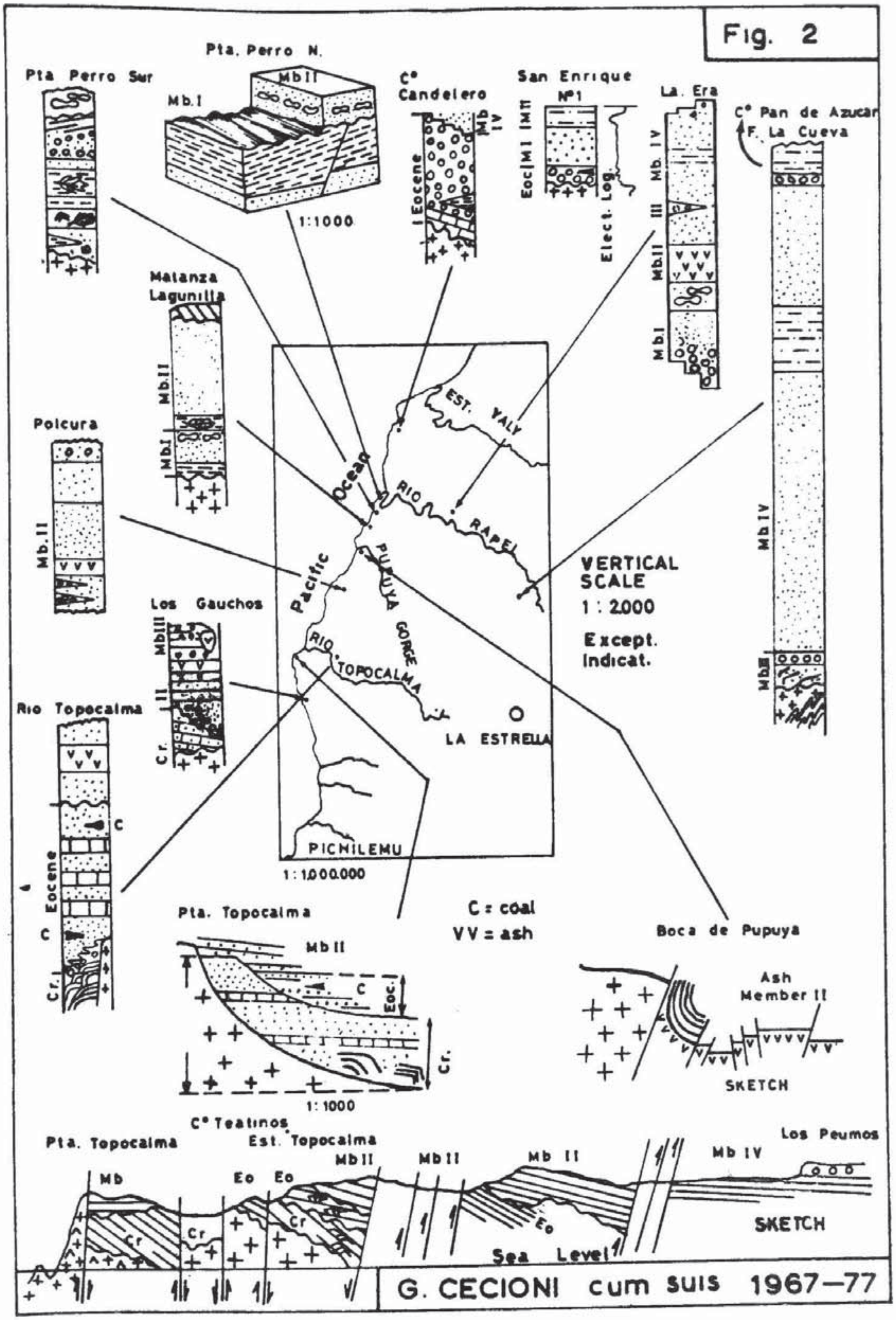

Fig. 2

Geological columns and perfiles. (reduced 10%).

CONTENT

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