STRATIGRAPHIC AND MICROPALEONTOLOGIC OBSERVATIONS FROM THE GOLFO DE PENAS-TAITAO BASIN, SOUTHERN CHILE

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ABSTRACT

New stratigraphic and micropaleontologic findings are described from Cenozoic strata exposed in the Golfo de Penas region of southern Chile. These strata include: the Puerto Good and Tres Montes sequences, successions of carbonaceous clastic beds of probable Middle Eocene age; the Grupo Chaicayán sequence, a post Middle Eocene to Late Miocene succession of shallow marine terrigenous strata; the Seno Hoppner sequence a Pliocene-Pleistocene marine succession of volcanic, volcaniclastic, and terrigeneous clastic beds; and the Isla Javier sequence, a Neogene, probably Quaternary, succession of glacial, glacio-marine, glacio-fluvial, and marine strata of poorly consolidate mudstone, silt, sand, conglomerate, and till. The older Puerto Good, Tres Montes and Grupo Chaicayán sequences likely correlate with portions of the strata defined by multichannel seismic profiles from the Golfo de Penas where 2 to 4 km of sedimentary strata lie buried under the shallow floor of the gulf.

RESUMEN

En este trabajo se dan a conocer nuevos hallazgos estratigráficos y micropalentológicos efectuados en los estratos cenozoicos, que se exponen en la región de Golfo de Penas. Los mencionados estratos incluyen a las secuencias de Puerto Good y Tres Montes, series clásticas de probable edad eocena media; la secuencia del Grupo Chaicayán, una sucesión post-eocena media-miocena superior, formada por sedimentos marinos terrígenos, de aguas someras; la secuencia de Seno Hoppner, una sucesión marina, plioceno-pleistocena, de capas terrígenas, volcánicas, volcanoclásticas y clásticas; y la secuencia de Isla Javier, sucesión neógena, probablemente cuaternaria, constituida por capas de origen glacial, glaciomarino, glaciofluvial y marino, formada por fangolitas mal consolidadas, limos, arenas, conglomerados y till. Las secuencias más antiguas (Puerto Good, Tres Montes y Grupo Chaicayán) son, posiblemente, correlacionables, en parte, con los estratos observados en los perfiles de sísmica marina efectuados en Golfo de Penas, donde se reconoce una secuencia sedimentaria, probablemente cenozoica, de 2-4 km de espesor.

INTRODUCTION

Since 1981 three separate geologic expeditions have been conducted in the Chilean archipelago that permitted surveying of the coastal rocks exposed in the region of the Golfo de Penas (see figure 1). This work has led to new discoveries of Tertiary and Quaternary strata in the area. This report summarizes the field relations and new micropaleontologic findings of these Cenozoic sequences.

In southern Chile the Golfo de Penas forms one of the largest embayments along the coast, and brings the open Pacific 120 kilometers into the in-

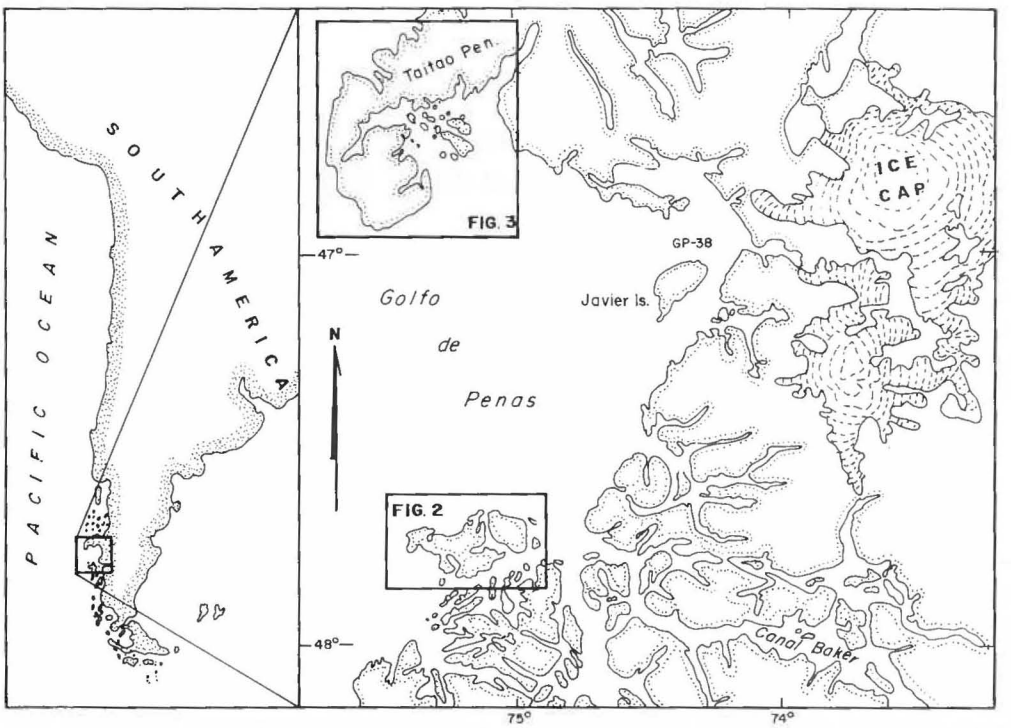

FIG. 1. Location map of the study area. Cenozoic strata are described here from the two areas boxed in on the right, and from Javier Island.

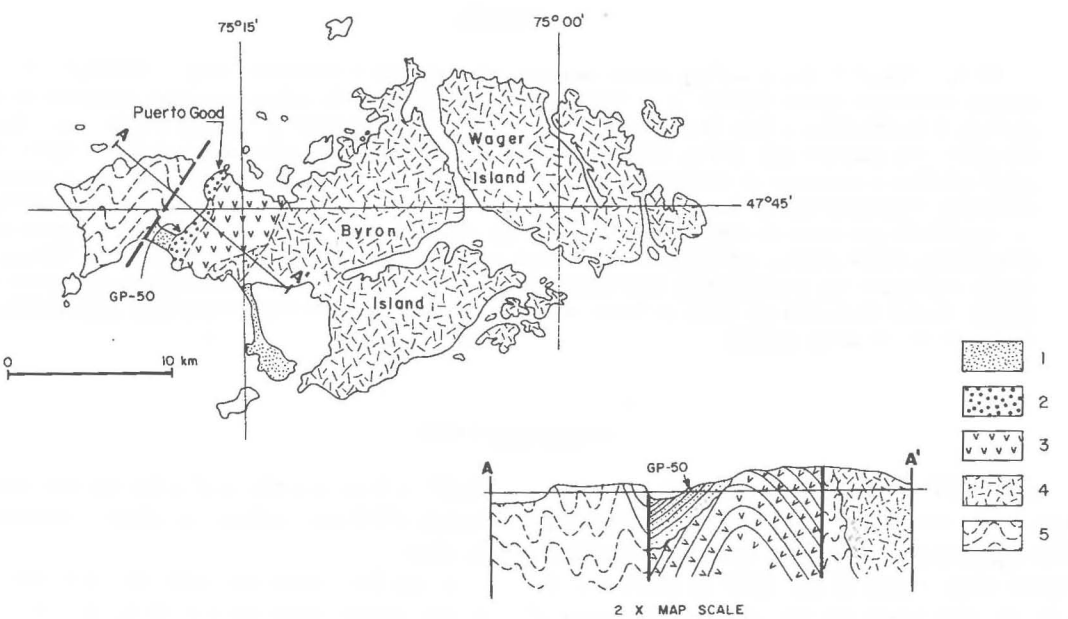

FIG. 2. Reconnaissance map of the islands on the southwest border of the Golfo de Penas. Units are: 1. Surficial cover; 2. Puerto Good sequence (Middle Eocene) 3. Pre-Middle Eocene volcanic and volcaniclastic strata; 4. Plutons of the Patagonian Batholith; and 5. Tightly folded metasedimentary rocks of probable pre-Late Jurassic age.

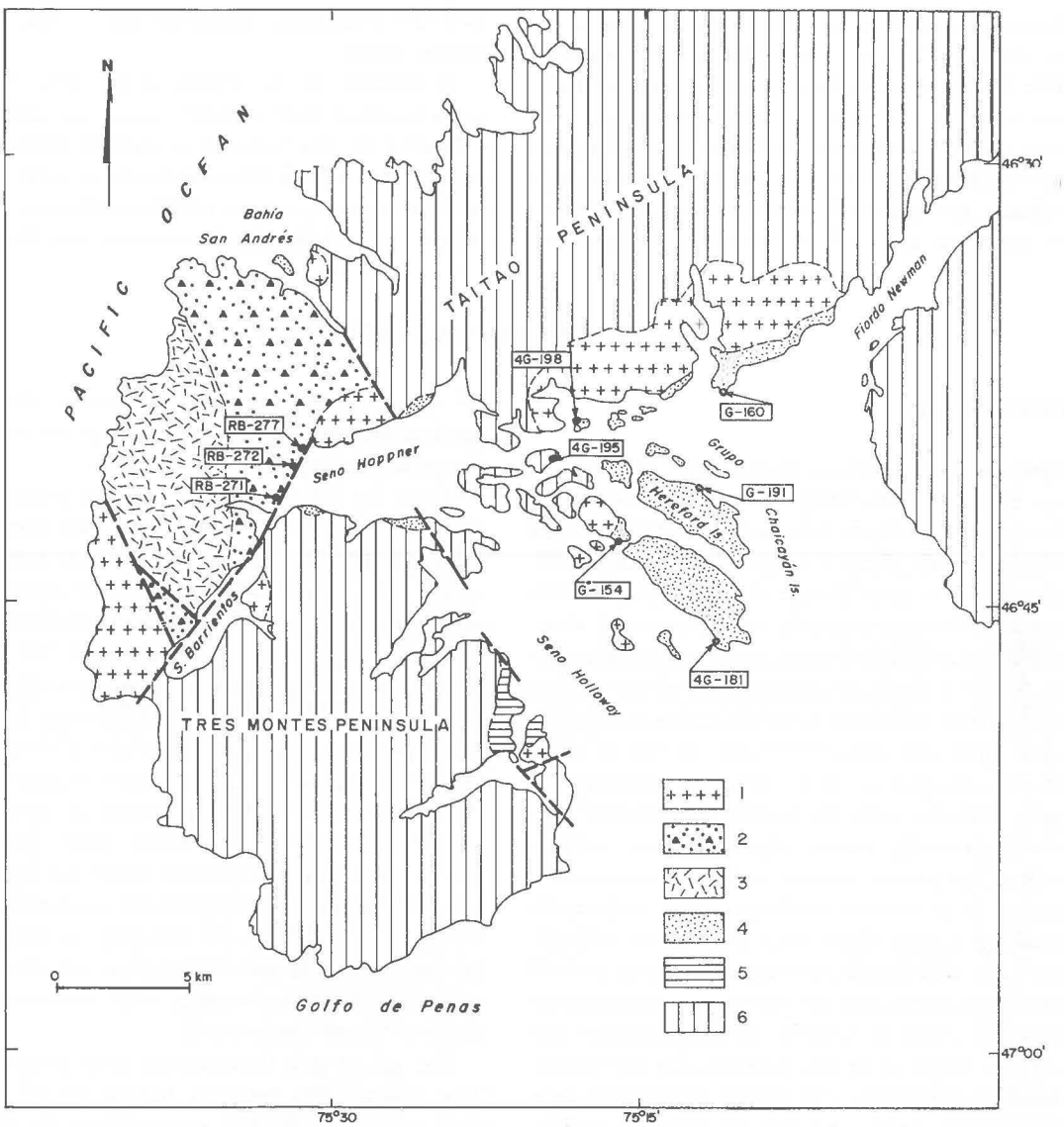

FIG. 3. Reconnaissance map of the Tres Montes and Taitao Peninsulas. Units are: 1. Areally distributed plutons, stocks and volcanic breccia of Pliocene age; 2. Volcanic and marine terrigenous strata of the Seno Hoppner sequence that forms the upper stratiform portions of the Taitao Ophiolite; 3. Serpentinized ultramafic rocks, gabbro and dikes of the Taitao Ophiolite; 4. Marine strata of the Grupo Chaicayán sequence; 5. Strata of the Tres Montes sequence that is correlated with the Eocene Puerto Good sequence; and 6. Tightly folded metasedimentary strata, and phyllitic schist of the pre-Late Jurassic basement. Sample localities are labeled that yielded age diagnostic foraminifera.

terior of the Andes, essentially to the base of the North Patagonian Ice Cap. Within the gulf, recent geophysical surveys made for the Empresa Nacional del Petróleo of Chile (Mordojovich, 1981) have revealed that under the shallow (<150 m) waters of the gulf lie buried over 2 to 4 kilometers of sedimentary strata. Since no drilling has yet been done in the gulf, the age and lithologic nature of these buried strata remains a mystery. At the present time the Cenozoic strata exposed along the shores provide the only clues to what may be buried under the gulf floor.

The strata that have been studied in some detail come from three regions: on Byron Island (Fig. 2) along the southern margin of the gulf, in the eastern limit of the gulf (Javier Is., Fig. 1), and in the northwest area along the coasts of Peninsulas Taitao and Tres Montes (Fig. 3). In discussing these

Cenozoic sequences, all older units of the area can be viewed as part of a pre-Cenozoic "basement" This basement collectively includes metasedimentary units of probable pre-Late Jurassic age, plutons of the Patagonian Batholith, and deformed and indurated sequences of silicic and intermediate volcanic and volcaniclastic strata that are likely to be remnants of an extrusive cover that once covered the Patagonian Batholith (Serv. Nac. Geol. Miner., 1982).

In addition to the results of the three expeditions reported here, a short report has also been published by De Vries *et al.* (1984) following a geologio expedition they conducted In 1983. They reported the occurrence of (?)late Miocene invertebrate fauna from the Tres Montes area (Fig. 3).

DESCRIPTION OF CENOZOIC SEQUENCES

BYRON ISLAND

Puerto Good Sequence: On thc north shore of Byron Island, located along the east coast of Puerto Good and for a short distance (< 5 km) to the east of its entrance, there is a sequence of marine terrigenous clastic beds (Puerto Good sequence) which appear to lie depositionally over a sequence of indurated and folded volcanic and volcaniclastic strata. Figure 2 shows the distribution of the two sequences and their inferred relationships in a profile view. While the contact between the two is unexposed, attitudes of their respective bedding are quite different, with the underlying volcanic units having generally steeper dips and more variable strikes. Within the volcanic and volcaniclastic succession there are few sandstone beds, and in the overlying marine clastic beds there are no volcanic strata. In addition the lowestmost exposed beds of the Puerto Good sequence are coarse conglomerate beds with clasts of volcanic, metasedimentary and plutonic rocks. It is thus inferred that the Puerto Good sequence rests with angular discordance over the volcanic strata, and that the (?)basal conglomerate beds of the sequence were deposited over an erosional surface that exposed many of the pre-Cenozoic rock units of the Golfo de Penas region.

To the west of the Puerto Good sequence, along the western shores of Puerto Good are exposures of a tight to isoclinally folded sequence of metasandstone and pelite. In most of the shoreline exposures there is also present a semi-pervasive network of anastomosing brittle fractures and microfaults. The nature of the west shore of Puerto Good, the presence of highly fractured rocks along the shore, and the discordant attitude of bedding in the Puerto Good sequence, suggest that the Puerto Good sequence is faulted along its south-northeast trending contact with the metasedimentary rocks.

From the above field relations the sequence is estimated to be approximately 2 kilometers in thickness. Of this, the upper kilometer is not exposed. Near the base the sequence is composed of several hundred meters of massive to thick bedded strata of conglomerate and sandstone. The clasts range from cobbles to pebbles and are moderate to well rounded. Sandstones are dark-brown to grey, medium to coarse-grained, units with all but a few layers showing lenticular to planar crossbedding. The upper portions of the sequence are formed of moderately bedded strata within which there are only a few conglomerate beds. Here the sequence is mostly formed of interbedded sandstone and silstone. The siltstones are dark-grey to black and have abundant carbonaceous matter. However, no well preserved plant-remains, with the exception of a few "stems" were found.

The age of this sequence has been determined from foraminifera found in sample GP-50 taken from among the highest exposed beds in the sequence. This sample, when processed for extraction of foraminifera, revealed rather extensive recrystallization of foraminifera which rendered identification difficult. Identification utilizing serial thin-sections proved successful although recrystallization had completely altered many foraminifera. Foraminifera that can be recognized are mainly planktonic ones which suggests that parts of the Puerto Good sequence were deposited in an open marine environment. A Middle Eocene age is based on the occurrence of *Acarinina* sp., *Globigerinatheka* sp., *Morozovella lehneri, M. densa,* and *Truncorotaloides rohri* in sample GP-50.

PENINSULAS TRES MONTES AND TAITAO

This region includes three sequences of marine strata of Cenozoic age that are distinguished from each other on the basis of their age, lithologies, distribution and degree of induration. The three sequences are respectively exposed along the northeast shore of Peninsula Tres Montes, in the Grupo Chaicayán islands, and on the inner coast of Península Taitao along Seno Hoppner (see figure 3). Informally these will be referred to here as the Tres Montes, the Grupo Chaicayán, and the Seno Hoppner sequences. In addition to these three sequences one block of grey indurated siltstone was sampled along the east coast of the Taitao Peninsula, north of the Seno Barrientos inlet which yielded foraminifera of significantly older ages than those of the adjacent Seno Hoppner sequence (discussed below). The block does not appear to be in place or form part of any of the three main sequences exposed in the area. Since this block (Seno Barrientos Block) yielded the oldest ages of all Tertiary marine strata sampled in the Golfo de Penas region, the paleontologic findings from it will be discussed before describing the other three sequences.

Seno Barrientos block: The outcrop is limited to a few meters along the east coast of the Taitao Peninsula, and samples of the younger Seno Hoppner Sequence were collected only a few hundred meters to the south. The block is unlikely to be more than a few 100 m^2 in areal extent. The outcrop is composed of thinnly bedded buff-grey siltstone. Sample RB-227, taken from this block contains well preserved foraminera. The sample is Early Eocene in age, based on the presence of *Acarinina primitiva,*. cf. *A. pentacamerata, Planorotalites pseudoscitula, Morozovella subbotinae* and *Subbotina linaperta* (Stainforth *et al.*, 1975). A diverse assemblage of benthic foraminifera which includes the genera *Cassidulina, Chilostomella, Cyclammina, Globobulimina, Florilus, Lenticulina,* and *Sphaeroidina,* as well as the Eocene species *Abyssamina quadrata, Anomalina praecuta,* and *Melonis havanense* (Tjalsma and Lohmann, 1983), suggests a middle to upper bathyal enrivoment of deposition.

Tres Montes Sequence: This sequence es exposed along the northeast shore of Peninsula Tres Montes, for approximately 6 to 7 kilometers (see figure 3). Along this shore the sequence is bounded to the east by a columnar jointed porphyritic intrusion. While the contact is not exposed it is probably intrusive since dykes of the porphyre are seen cutting the sequence near the contact. The sequence is bounded to the south and west by metasedimentary rocks of probable pre-Late Jurassic age. Neither the southern nor western contacts are exposed. The contact zone on the west is marked by highly cataclastized rock of either the basal units of the sequence or the underlying metamorphic basement. On the south, the first outcrops of the sequence are conglomerate beds with well to moderately rounded cobbles of the underlying metamorphic basement.

The strata exposed along the north shore generally have north to northeast strikes, with dips ranging from 5 to 45 degrees. A few reversals in dip suggest that a few minor folds or faults may be present, however, no cleavage is developed. While outcrops permit only approximately 10 percent of the sequence to be seen, the sequence is likely to be approximately 2 to 3 kilometers in thickness.

The Tres Montes sequence is a rythmically interbedded succession of conglomerate, sandstone, siltstone and shale. Conglomerate, being the most resistent unit, is the most visible in the shoreline outcrops. The base is marked, as mentioned above, by a conglomerate with clasts of the underlying basement. The rest of the sequence is thick to moderately bedded with monotonous variations of pebble conglomerate, cross bedded sandstone, and carbonaceous siltstone and shale. All lithologies are dark grey to brown, and many of the beds have poorly preserved plant remains. In some beds small seams (<1 cm thick) of bituminous coal are present (Fig. 4).

The age of the sequence is based on correlation with the Puerto Good sequence. The degree of induration of these units prevented extraction of foraminifera; a few glauconitic beds, however, confirm that it is, in part, marine. The lithologies, and degree of induration in this sequence are identical to that seen in the Puerto Good sequence. On the basis of this correlation it is suggested to be probably Middle Eocene in age.

The Grupo Chaicayán Sequence: This sequence is exposed principally in the Grupo Chaicayán islands and islets which are located in the interior bay between the Taitao and Tres Montes Penínsulas (see figure 3). However, exposures of the se-

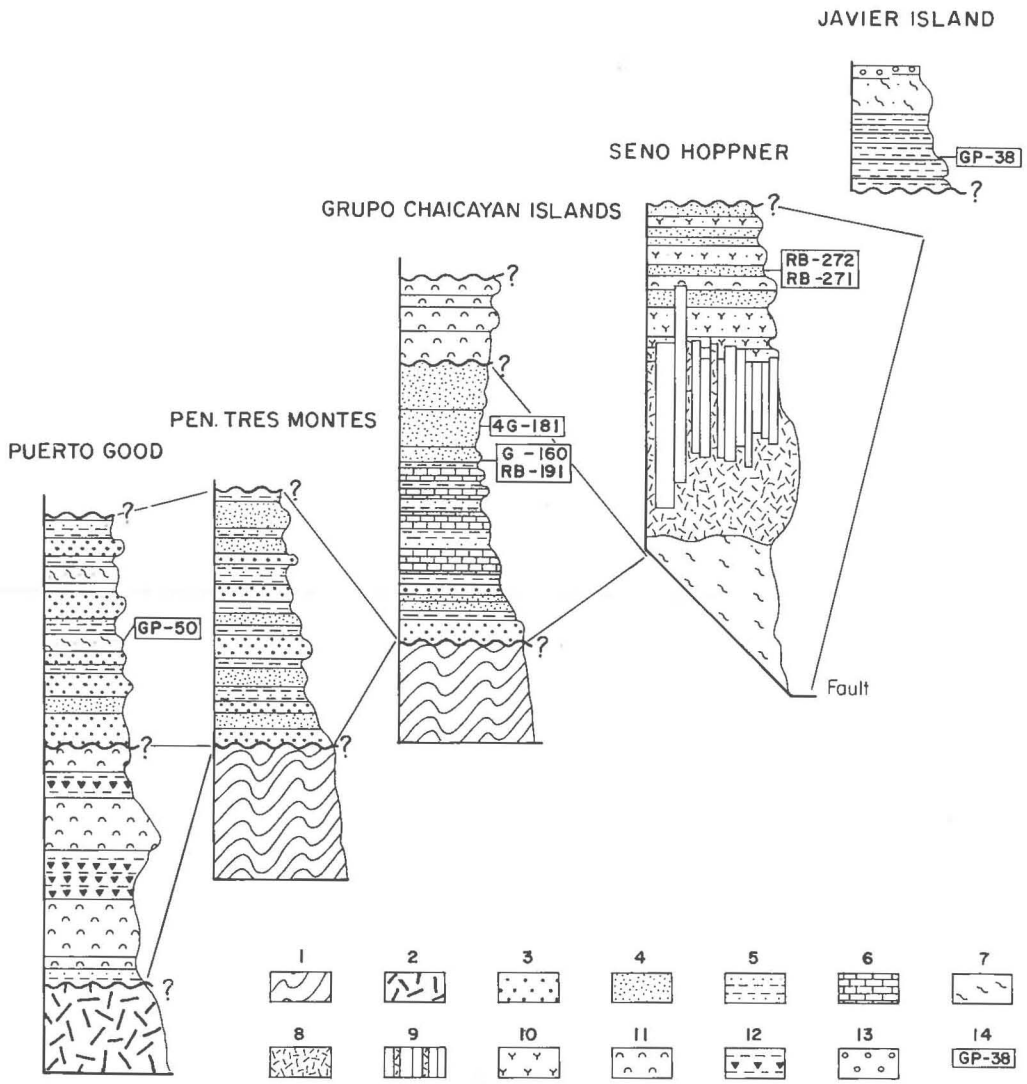

FIG. 4. Schematic columnar sections of the various Cenozoic sequences in the Golfo de Penas area. Lithologies are: 1. Metasedimentary rocks of the pre-Late Jurassic basement; 2. Plutonic rocks of the Patagonian Batholith; 3. Conglomerate; 4. Sandstone; 5. Interbedded sandstone and siltstone; 6. Calcareous units; 7. Serpentinized ultramafic rocks; 8. Gabbro; 9. Sheeted dikes; 10. Mafic pillow lavas; 11. Silicic volcanics; 12. Volcaniclastic strata; and 13. Till. Boxed numbers represent approximate location of foraminifera bearing strata discussed in this report.

quence are also seen to the north of the islands, along the south shore of the Taitao Península, and for 2 km into the interior of the unnamed bay directly to the north of Hereford Island. While the sequence has few exposed contacts, there appear to be three types. In places within the islands surrounding Hereford Island (Fig. 3) the sequence is intruded by porphyritic stocks or sills, with one of the unnamed smaller islands to the northwest of Hereford Island, having a good exposure of an intrusive contact (site 4G-198). In the unnamed bay outcrops of a volcaniclastic breccia separate outcrops of the Grupo Chaicayán sequence from outcrops of massive porphyre. Here volcaniclastic debris appears to have been preserved on the border of the porphyre (?)stocks. The volcaniclastic strata are thus likely to have covered at one time portions of the Grupo Chaicayán sequence. Lastly on one of the western islands of the group (site 4G-195, Fig. 3), there is a very coarse and poorly sorted massive conglomerate located at the contact zone between the sequence and the underlying metamorphic basement. The basement lithologies to the west of the sequence are generally of a high-

er metamorphic grade than those to the south; and chloritic and phyllitic clasts of schist in the (?)basal conglomerate appear to reflect this change and were likely derived from a western source. The basement clasts include angular boulders and cobbles supported in a finer matrix of pebbles, sand and silt.

Over the (?)basal conglomerate the sequence dips variably to the north and east. Beds in the west generally dip steeper than those to the east, with the latter dipping generally less than 5 degrees. Gravity data (Forsythe and Nelson, 1985) suggest that these strata continue to the southeast into the Golfo de Penas and likely correlate with the middle to upper portions of the sequence that is seen on the multichannel seismic profiles (Mordojovich, 1981).

The sequence appears to be entirely marine, and with the exception of one (5 meter) layer of volcaniclastic material (site G-154), is non-volcanic. The lower portions of the sequence, over the basal conglomerate are composed of thinnly to moderately bedded, grey-green sandstone and mudstone. Bioturbation and a few glauconitic layers indicate that the base of the sequence is marine. The middle portions of the sequence are formed of thin to moderately bedded siltstone, sandstone and conglomerate. The sandstone and conglomerate beds have shell material, and are calcite cemented. The conglomerate beds here differ from all other conglomerate beds in the region in their abundance of fragmental shell debris that is here mixed with moderately to well rounded lithic clasts. The upper portions of the sequence are composed of thick silty sandstone beds with occasional thin interbeds of siltstone. Conspicuous in the upper portions are calcareous concretions (up to 1 m in diameter) that are unevenly distributed in the upper sandstone units.

The age of the sequence is bracketed by regional relations. The sequence is intruded by porphyres which have been dated in several places as Pliocene in age (Mpodozis *et al.*, this vol.) In addition, it is unlikely to be older than Middle Eocene, since the Puerto Good and Tres Montes sequences are more indurated and of distinctly different lithologic facies.

Several samples (G-160, 4G-181, and RB-191) contain well-preserved foraminifera suggestive of a Late Miocene age. Age diagnostic planktonic foraminifera within this sequence include *Globigerina apertura, Globorotalia* cf. *acostaensis, G. conoidea, G. conomiozea, G. continuosa* and *Orbulina suturalis.* These species show that, ultimately, the Tres Montes sequence can be included in the biostratigraphic zonation of Kennett (1973) and Srinivasan and Kennett (1981). These species are also indicative of temperate water masses and are known from Upper Miocene levels in numerous Deep Sea Drilling Sites in the south Pacific and Atlantic Oceans (Kennett, 1978; Srinivasan and Kennett, 1981).

The Seno Hoppner Sequence: This sequence is exposed on the outer and inner coasts of the central portions of the Taitao Peninsula. It forms the upper strataform portions of the Taitao ophiolite (Forsythe and Nelson, 1985). Exposures on the inner coast are very sparse, and those on the outer coast are almost inaccessible. The sequence is bounded on the south by the sheeted dike complex of the ophiolite, on the east by Pliocene intrusions or the metamorphic basement, and on the north by the metamorphic basement.

The thickness and internal stratigraphy is poorly known. Exposures along Seno Hoppner as well as on the outer coast in Bahía San Andrés indicate that it is a succession of interbedded marine sedimentary and volcanic rocks. Volcanic units include pillowed basalt and andesite, flow banded rhyolite, and a variety of volcaniclastic units. Interbedded with the volcanic units are thin to moderately bedded, grey to greenish-grey, sandstones, siltstones and shales. Some outcrops have thin, rhythmically bedded turbidites with graded and convoluted basal zones, cross laminated medial layers and planar laminated top intervals.

The age of the Seno Hoppner sequence is based on two samples from which foraminifera have been obtained, and several K/Ar age determinations. K/Ar ages are reported by Mpodozis *et al.*, this volume, and range from 2.5 to 4.6 m.y. B.P.

Samples RB-271 and RB-272 contain sparse assemblages of foraminifera. Sample RB-271 contain rare specimens of juveniles of the planktonic foraminifera *Globigerina,* as well as the planktonic species *Globigerinita glutinata,* and the benthic foraminifera *Cibicides lobatulus, C. fletcheri, Cassidulina subglobosus,* and *Eponides* cf. *antillarum.* The environment was probably middle to outer shelf.

RB-272 has the planktonic foraminiferal species *Globigerina bulloides, G. pachyderma* (left-coiling), *G. guinqueloba, Globoratalia* cf. *hirsuta, G. inflata, G. scitula,* and *G. pseudopachyderma.* A Late Pliocene to Pleistocene age is indicated by

this cool temperate assemblage (Stainforth *et al.*, 1975). The presence of *G. pachyderma* suggests that cold subpolar waters influenced this region, as well. RB-272 was collected only a few hundred meters to the south of RB-277 (Seno Barrientos block) where the Eocene fauna were found. The much younger Plicene age of the Seno Hoppner sequence, suggested by both K/Ar and foraminiferal data, argue for tectonic juxtaposition of the Seno Barrientos block with the Seno Hppner sequence.

JAVIER ISLAND

Isla Javier Sequence: In the terraced lowlands that border the Golfo de Penas on the north and east there are a few cliff exposures of poorly consolidated glacial, glacial-fluvial, glacio-marine and marine deposits of probable Quaternary age. These deposits have only been surveyed in reconnaissance and have not be sampled or studied in a systematic manner. In one area, that of Isla Javier (Fig 1), an approximately 70 meter section was traversed up a steep ravine on its eastern coast. This sequence has a marine, mudpebble, diamict exposed at sealevel. This basal diamict is covered by a 10 to 15 meter succession of interbedded, thin to moderately bedded sandstone and siltstone with small gastropods and pelecypods (as yet unidentified). This is in turn covered by a thick 20 meter sequence of sand and conglomerate with a lower zone of large eastdipping foreset beds of dominantly conglomerate and coarse sand. This is covered by a sandy and conglomeratic till which is in turn covered by 1 to 2 meters of peat.

Pollen from the upper contact of the till with the overlying peat suggest that this upper till correlates with the Llanquihue drift mapped further to the north in Continental Chiloé (C. Heusser, person. commun.). While foraminifera were not found in the samples taken directly from this exposure, a small exposure of marine sandstone and siltstone, that likely correlates with the lower portion of the sequence, was sampled on the north side of the island. Sample GP-38 from this exposure does not contain restricted, age-diagnostic, foraminiferal species. A Miocene to Recent age is based on the occurrence of typical Neogene benthic species such as *Buccella frigida, Cibicides lobatulus, Florilus mexicanum,* and *Cassidulinoides* cf. *tenuis* and suggests a middle to outer shelf environment.

REGIONAL CORRELATIONS AND CONCLUSIONS

The Cenozoic successions described above from the coasts bordering the Golfo de Penas are diagrammatically illustrated in Fig. 4. The oldest marine units discovered in the area are represented by the Lower Eocene strata of the Seno Barrientos block. The second oldest successions are represented by the Puerto Good sequence and its inferred correlatives of the Tres Montes sequence. These units are in part Middle Eocene and appear to have followed a period of uplift and erosion that had brought all pre-Cenozic units of the Patagonian Andes of this area to the surface by that time.

During deposition of this Eocene succession, as well as for the younger Grupo Chaicayán succession in the area of the Tres Montes and Taitao Peninsulas, there are, with one exception, no signs of volcanic activity. This is perhaps explained by changes in the relative convergence along the margin at these times. As is shown in figure 5, much of the early Tertiary was a period of highly oblique convergence between the Nazca and South American plates (Pilger, 1983; Cande and Leslie, in press). It may also be that volcanism had migrated by these time to the east.

The strata of the Grupo Chaicayán sequence rest in places directly over the metamorphic basement, and as pointed out previously is likely to have a western provenance within the metamorphic basement. This suggests that a period of uplift is likely to have predated this Miocene succession, and have perhaps tilted and removed portions of the Tres Montes sequence.

The Pliocene-Pleistocene, Seno Hoppner sequence is part of the Taitao ophiolite. As discussed by Forsythe *et al.* (in press) the origin of the ophiolite remains enigmatic. The young intrusions distributed in the region, that intrude the other Cenozoic sequences, have yielded Pliocene ages consistent with the foraminifera discovered in the Seno Hoppner sequence. In addition these foraminifera indicate shallow water conditions. These arguments as well as geochemical ones discussed by Forsythe *et al.* (in press) suggest that the ophiolite was part of a shallow marine basin developed

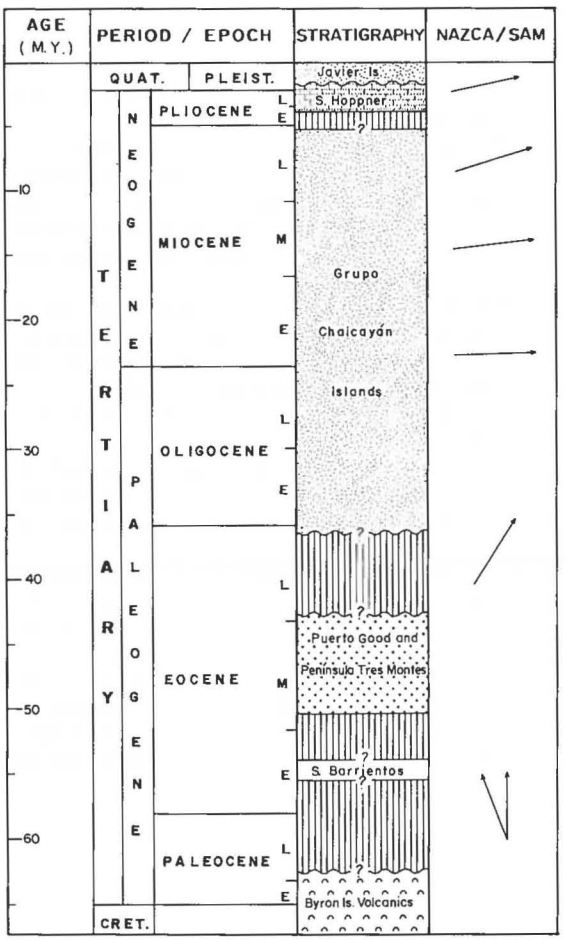

FIG. 5. Time stratigraphic section for Cenozoic deposition in the region of the Golfo de Penas. Four periods of uplift and erosion are indicated by the zig zag lines. The directions of relative convergence between the Nazca and South American paltes are shown on the left.

just seaward of the Miocene depocenter that is represented by strata in the Grupo Chaicayán islands. The timing of this Pliocene magmatism, approximately correlates in time with the collision of two segments of the active spreading center between the Nazca and Antarctic plates (Forsythe and Nelson,(1985).

The poorly consolidated glacial, glacio-marine and glacio-fluvial deposits that are locally preserved along the shore of the gulf do not contain volcanic beds, and since the Seno Hoppner sequence does not contain glacial units, it is assumed that these glacially related sequences are younger and of Pliestocene age. Considering the section seen on Isla Javier, the sequences are likely to include the last glacial, interglacial, and perhaps one earlier glacial interval.

The sequences in the regions surrounding the Golfo de Penas likely correlate with strata buried under the floor of the gulf, but how? Multichannel seismic lines reveal that portions of the gulf are still actively subsiding today, and have successions likely to be greater than 2 to 4 km thick. In other regions of the gulf large, 2 to 3 km, sections of sedimentary strata have been tilted eastward, and partially eroded along their western limit with their underlying acoustic basement. These western, tilted sequences are structurally in a similar setting to either the Tres Montes or Grupo Chaicayán sequences. Since the main outcrops of the Grupo Chaicayán strata appear to correlate with the gravity low associated with the actively subsiding zones in the gulf, it is suggested that the older, tilted strata in the gulf are likely to correlate with the Puerto Good or Tres Montes successions sequences.

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