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STRATIGRAPHY OF LATE CRETACEOUS-EARLY EOCENE, SENO SKYRING-STRAIT OF MAGELLAN AREA, MAGALLANES PROVINCE, CHILE

BY

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Stratigraphy of Late Cretaceous-Early Eocene, Seno Skyring–Strait of Magellan Area, Magallanes Province, Chile[1]

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Abstract Five surface sections and one subsurface section of Late Cretaceous–early Tertiary sedimentary rocks were studied in the Punta Arenas-Strait of Magellan area, southern Chile. The rocks range in age from middle Maestrichtian to early Eocene and consist of the following formations from base to top: Santa Ana Beds, Río Blanco, Carrera, Chorrillo Chico, San Jorge, and Agua Fresca (eastern Brunswick Peninsula area); and Fuentes, Rocallosa, Chorrillo Chico, San Jorge, and Agua Fresca (Seno Skyring area). The Cretaceous-Tertiary boundary is in the Chorrillo Chico Formation which covers the entire area.

The rocks studied are varieties of graywacke, siltstone, and argillite. Heavy-mineral studies indicate a varied source area including silicic plutons, metamorphic and gneissic rocks, and some volcanic terrane.

Lithologic, paleoecologic, and geochemical data show that the transition from middle Maestrichtian to early Eocene was gradual. Generally, the depth of water in which the stratigraphic units were deposited decreased continually through time.

Geochemical element analyses were made in an attempt to correlate the pre-Chorrillo Chico units in the Seno Skyring and Brunswick Peninsula areas. The study was limited and the results were not decisive. However, evidence was found to support correlation of the middle Rocallosa Formation with the Carrera Formation. The results obtained warrant further geochemical studies to aid correlation in the area.

All evidence collected indicates that, before deposition of the Chorrillo Chico Formation, the Late Cretaceous basin in this area was bisected by a northeast-southwest-trending topographic ridge. Because of the presence of this ridge, the sedimentation histories in the northwestern and southeastern parts of the area differ, and units deposited on either side of the ridge are difficult to correlate.

Introduction

The original purpose of this work was to determine paleontologically the position of the Cretaceous-Tertiary boundary. Subsequently, additional problems related to the correlation of the strata studied arose, and solutions by means of paleoecologic, sedimentologic, and geochemical methods have been attempted.

Five stratigraphic sections that include the Cretaceous-Tertiary boundary were studied during the first 4 months of 1964. The sections were measured by plane table and mapped at scales of 1:5,000 and 1:3,000. Cores and cuttings of the El Ganso No. 1 well, drilled by Empresa Nacional de Petróleos (ENAP), the Chilean State Petroleum Company, also were used (Fig. 1).

Previous work.—The area in which these sections are located has been studied for more than 125 years, beginning with the scientific expeditions of such naturalists as Darwin, d'Orbigny, and Grange (*e.g.*, Darwin, 1846). Studies during the present century were made by Felsch, Bonarelli, Decat and Pomeyrol, Keidel and Hemmer, Hollister, Shaw and Mohr, and Thoms (*see* Léxique Stratigraphique International, 1957). These authors outlined the stratigraphy of the region, but Thomas (1949) and von Goetsche (1953) established the definitive stratigraphic subdivision which is still accepted. Thomas described the Seno Skyring area and von Goetsche the Brunswick Peninsula.

Later studies introduced only slight modifications of the basic outline of the stratigraphy. Cecioni (1955, 1957) made most of the regional correlations throughout the province. Katz (1961) found possible evidence for an orogeny equivalent to the Laramide. Finally, Hauser (1964) studied the subsurface strata which are equivalent to those studied by the writers.

Among paleontologists who classified the Magallanes fauna are Reeside (1950), Todd and Knicker (1952), and Robles and Gómez (1956).

Geologic outline of area.—The geologic units of this province crop out in long parallel bands; the ages and intensity of folding decrease eastward (Fig. 2). The westernmost

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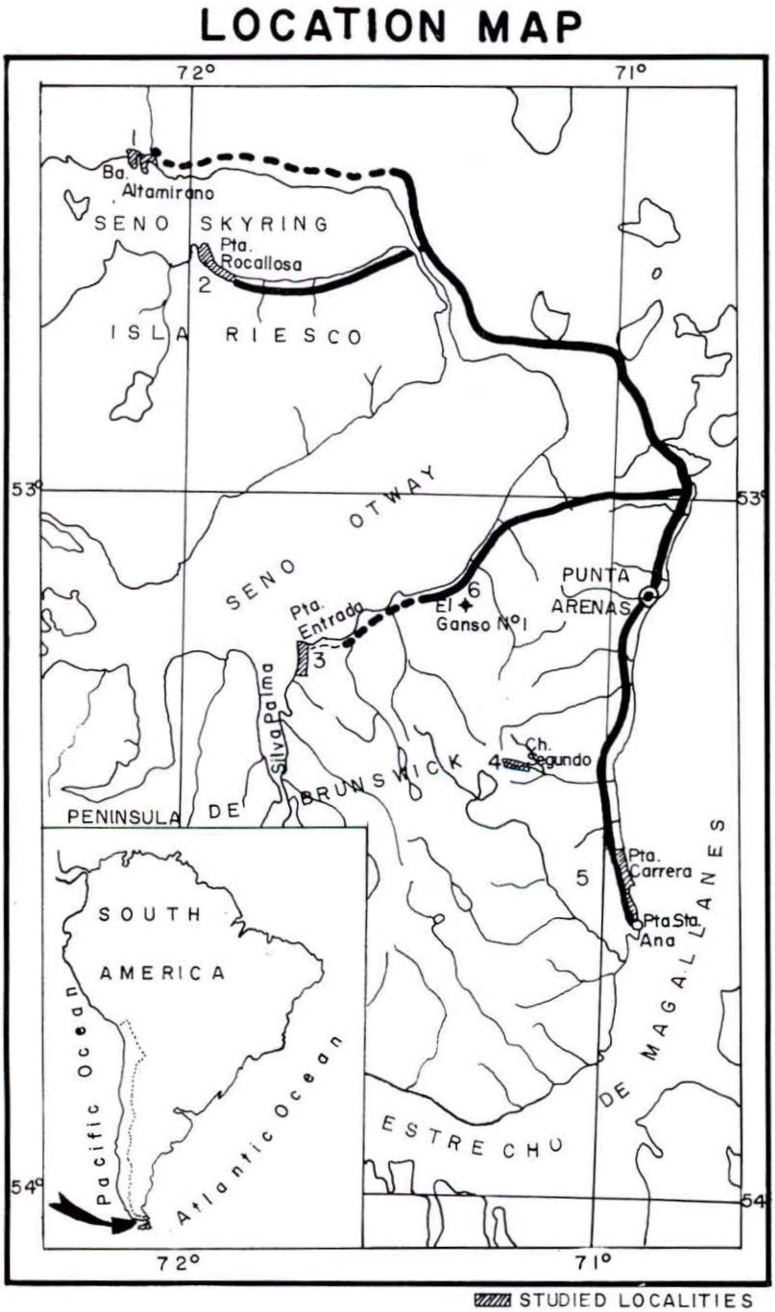
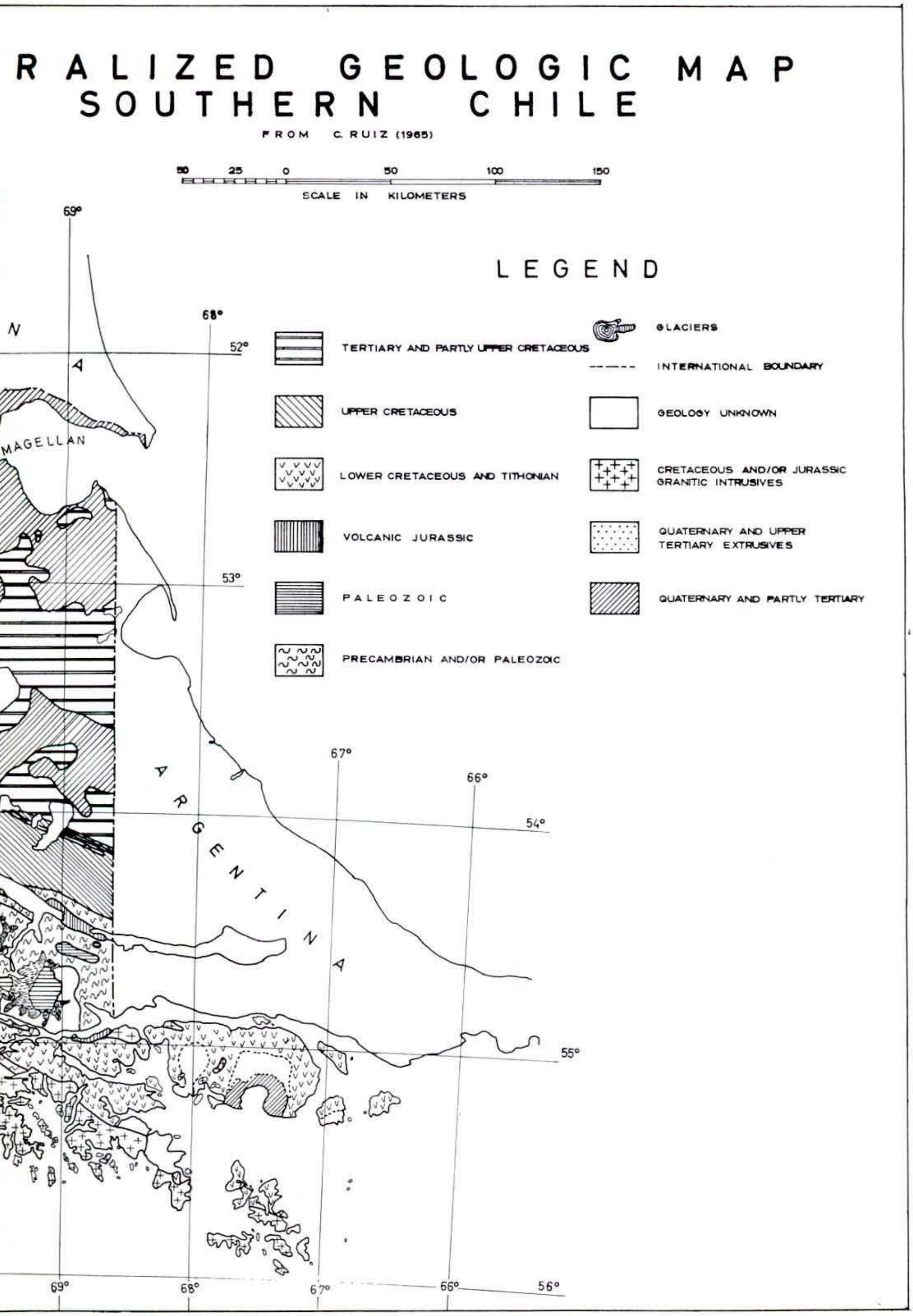


FIG. 1.—Location map. Strait of Magellan area, southern Chile. Numbers are sections studied. See Figure 3.



map, southern Chile.

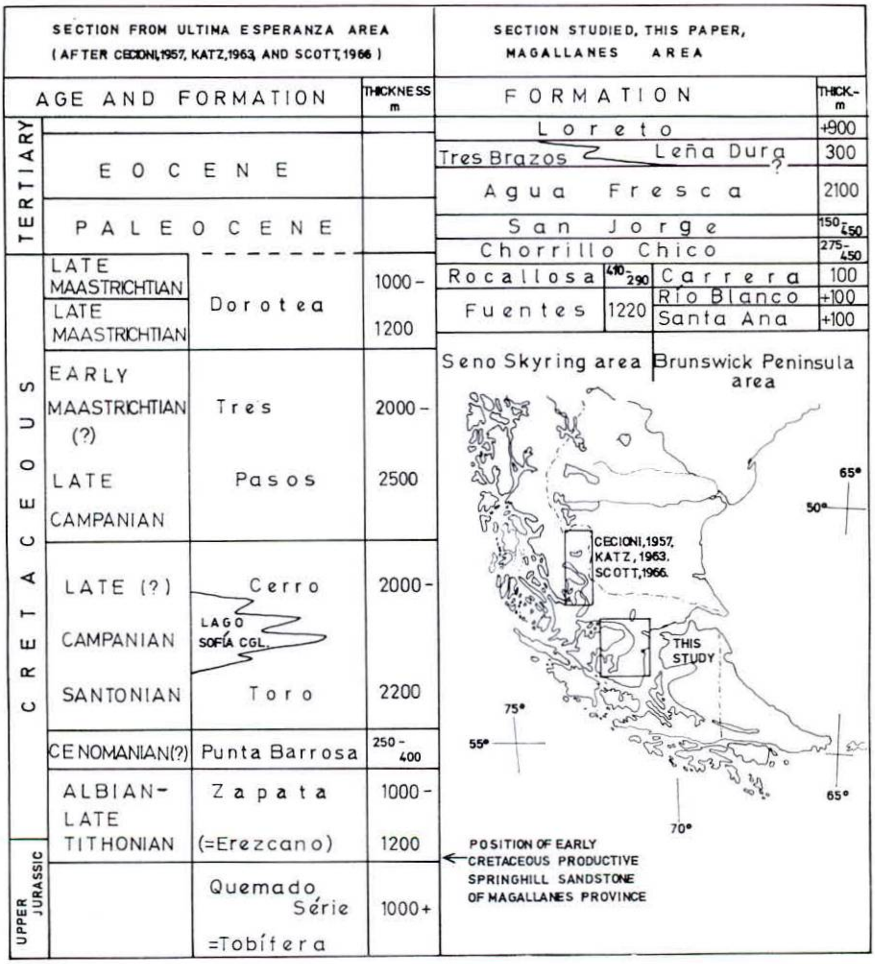


FIG. 3.—Stratigraphic correlation chart, southern Chile, generalized. Shows section described by Cecioni (1957), Katz (1963), and Scott (1966) and its relation to section described in present study.

strata are Paleozoic and are bordered on the east by the granitic core of the Austral Andes. East of the granitic core is a band of Paleozoic and/or Precambrian metamorphic rocks, bordered on the eastern side by Jurassic volcanic rocks, the Serie Tobífera. The last unit consists of porphyritic tuff, volcanic breccia, and sericitic slaty shale. Overlying the Jurassic is a thick marine sequence of shale, siltstone, sandstone, and conglomerate. This sequence was deposited in a marine basin which formed between latest Jurassic and middle Cretaceous times. The basin was an active site of deposition until the Oligocene. Some of the deposits are flysch type (middle and Late Cretaceous Erezcano, Punta Barrosa, and Cerro Toro Formations) and others are molasse type (Tres Pasos and Dorotea) (Cecioni, 1957; Katz, 1963; Scott, 1966; Fig. 3).

Despite numerous studies of the sedimentary rocks, correlation of the units from south to north within the study area is uncertain. Specifically, there is no agreement concerning the relations between the formations that crop out in the Seno[4] Skyring area with those of the east coast on the Brunswick Peninsula. A schematic succession of the marine formations studied in both areas follows (Fig. 3).

[4] *Seno* is a Spanish word meaning cove; in southern Chile and Argentina, the word refers to the deep glacial valleys and fiords occupied by arms of the sea, some of which cross Chile into Argentina.

Seno Skyring	Eastern Brunswick Peninsula
Agua Fresca Formation	Agua Fresca Formation
San Jorge Formation	San Jorge Formation
Chorrillo Chico Formation	Chorrillo Chico Formation
Rocallosa Formation	Carrera Formation
Fuentes Formation	Río Blanco Formation
	Santa Ana Beds

Succeeding these marine formations are the Leña Dura Formation and the coal-bearing strata of the Oligocene Loreto Formation; a disconformity separates the Loreto and older rocks from the continental Miocene Palomares Formation. The Palomares was covered and eroded by extensive Pleistocene ice sheets, which sculptured the present landscape.

During the Quaternary, basaltic lava flows and other basaltic extrusive materials covered areas in eastern Chilean Patagonia.

Stratigraphy

The units that crop out in the Seno Skyring area are the same as those along the south coast of Seno Otway, but differ from those studied in the eastern part of the Brunswick Peninsula (Fig. 4). However, in both regions the stratigraphic succession is the same from the Chorrillo Chico Formation upward.

The formations in the Seno Skyring area below the Chorrillo Chico Formation are, from base to top, the Fuentes and Rocallosa.

Seno Skyring Area

Fuentes Formation

Hollister (1943–1944, *in* Léxique Stratigraphique International, 1957) gave the name Fuentes to the shaly sedimentary rocks at Bahía Fuentes along the north coast of Isla Riesco, Seno Skyring. The first detailed description was made by Thomas (1949), and García (1952) raised the unit to formation rank. García distinguished three members, a lower shale, a middle sandstone, and an upper shale; he measured a complete thickness of 1,220 m.

Only the uppermost strata of the formation were studied by the writers. At the type locality, these beds are sandy siltstone and dark-gray shale in beds about 60 cm thick.

In other localities where the formation was studied (north coast of Seno Skyring, south coast of Seno Otway, and the El Ganso No. 1 well), the upper beds have almost the same characteristics as in the type locality.

The contact with the overlying Rocallosa Formation at the type locality of both formations is characterized by a distinct lithologic change. The dark-gray shale of the Fuentes is covered by a coarse-grained, yellow-green arenite ("arenite" is used here in the broad sense of Grabau; Pettijohn, 1957, p. 234). This contact, in the opinion of the writers, is conformable, even though Thomas (1949) wrote that the Rocallosa Formation ". . . lies unconformably above the Fuentes shale."

Along the north coast of Seno Skyring the contact between the formations is gradational.

The faunal content is listed below.

Gunnarites antarcticus (Weller)
Gunnarites kalika (Stoliczka)
Gunnarites bhavaniformis (Kilian and Reboul)
Maorites tenuicostatus Marshall (*fide* A. Cañón, ENAP)
Hipophylloceras nera (Paulcke)
Thyasira townsendi (White)
Voluta aff. *triplicata* (Sowerby)
Serpula occidentalis Leanza and Castellano
Rotularia tricarinata (Wilckens)

Additional foraminiferal species were collected from samples along the south coast of Seno Otway.

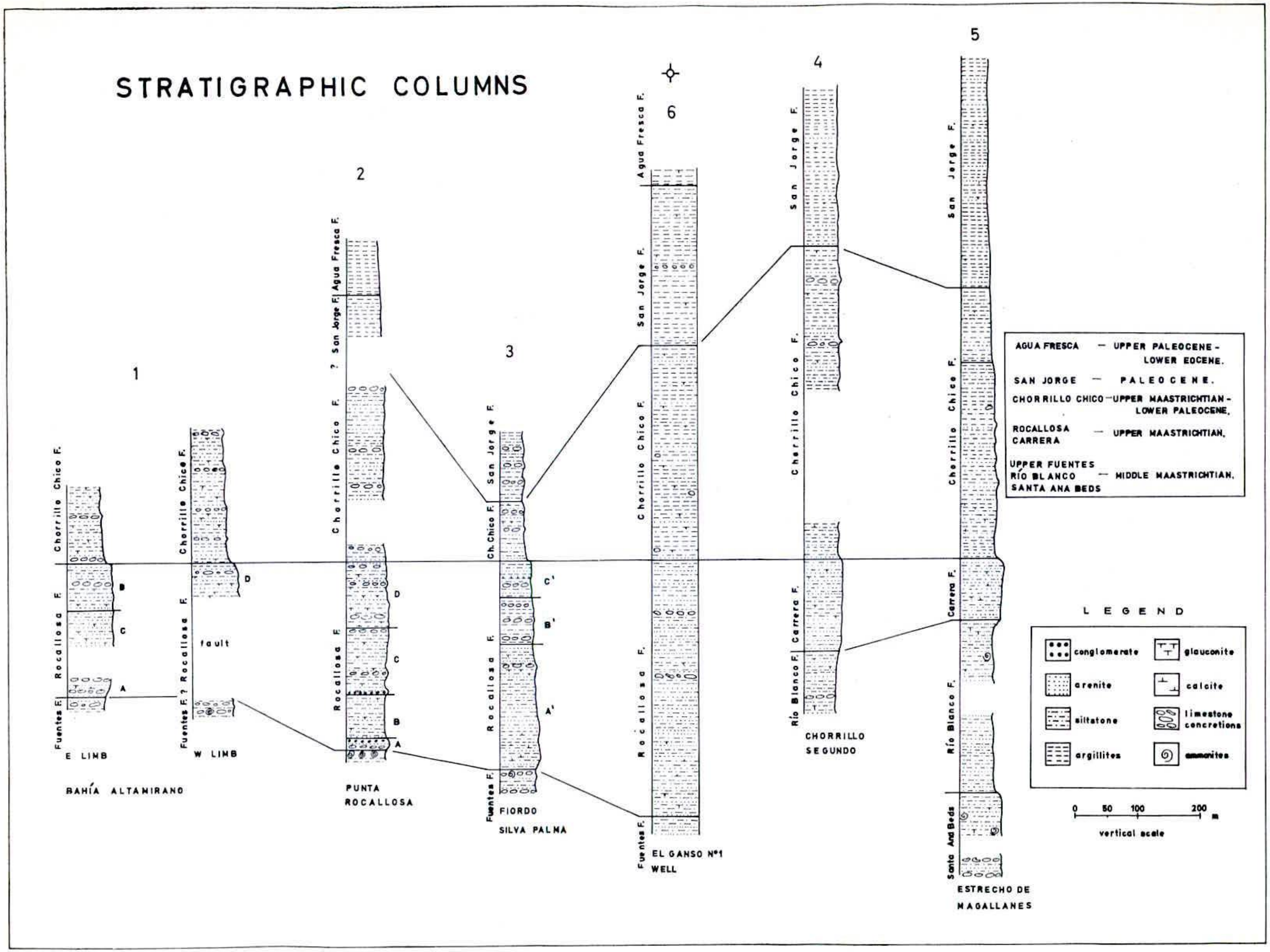
Racemigümbelina sp.
Gümbelitria sp.
Gümbelina ultimatumida Cushman *non* White
Gümbelina striata (Ehrenberg)
Gümbelina globulosa (Ehrenberg)
Gümbelina sp.
Rugoglobigerina rugosa (Plummer)
Rugoglobigerina beldingi Gandolfi
Rugoglobigerina aff. *loeterlli* (Nauss)
Rugoglobigerina circumnodifer (Finlay)
Globigerinella messinae messinae Brönnimann
?Globotruncana mayaroensis Bolli
Globotruncanella havanensis (Voorwikj)
Bolivinoides draco dorreeni Finlay

The presence of these species indicates that the upper part of the Fuentes Formation is of late Maestrichtian age.

Rocallosa Formation

The name Rocallosa also was introduced by Hollister (1943–1944, *in* Léxique Stratigraphique International, 1957) for strata at Punta Rocallosa on the north coast of Isla Riesco. In the *Léxique Stratigraphique*, ENAP geologists are credited with raising this unit to the rank of formation; however, Thomas (1949) already had done so.

The thickness measured by the writers at the type locality is 290 m, whereas Thomas (1949) measured 340 m and García (1952) 227 m. The formation was recognized in four of the six sections studied. On the south coast of Seno Otway, the Rocallosa has somewhat different lithologic characteristics than in the other sections.


STRATIGRAPHIC COLUMNS
1
2
3
4
5
6
Chorrillo Chico F.
Rocallosa F.
Fuentes F.
E LIMB
W LIMB
fault
Fuentes F.? Rocallosa F.
BAHÍA ALTAMIRANO
Agua Fresca F.
? San Jorge F.
PUNTA ROCALLOSA
San Jorge F.
Ch. Chico F.
FIORDO SILVA PALMA
EL GANSO Nº1 WELL
CHORRILLO SEGUNDO
Carrera F.
Río Blanco F.
Santa Ana Beds
ESTRECHO DE MAGALLANES
A
B
C
D
A'
B'
C'
AGUA FRESCA — UPPER PALEOCENE - LOWER EOCENE.
SAN JORGE — PALEOCENE.
CHORRILLO CHICO — UPPER MAASTRICHTIAN - LOWER PALEOCENE.
ROCALLOSA CARRERA — UPPER MAASTRICHTIAN.
UPPER FUENTES RÍO BLANCO SANTA ANA BEDS — MIDDLE MAASTRICHTIAN.
LEGEND
conglomerate
arenite
siltstone
argillites
glauconite
calcite
limestone concretions
ammonites
0 50 100 200 m
vertical scale

The writers subdivided the formation at the type locality into four members, A, B, C, and D, from bottom to top.

Member A.—At the type locality member A is 20 m thick. The thickness increases northward. The member consists of hard, glauconitic, medium- to coarse-grained arenite which contains some carbonaceous fragments and is somewhat calcareous. In this member are numerous concretion beds and limestone strata; the limestone beds possibly are formed by "anastomosing," connected concretions. They do not contain terrigenous detrital material, a fact which possibly shows that they are a precipitate of $CaCO_3$ from seawater.

The basal parts of beds in the upper strata of this member are irregular and conglomeratic. The pebbles are spherical or ellipsoid and reach 10 cm in diameter. The clasts include fragments of shale, biotite granite, and rhyolite. The fact that some are impressed into the subjacent bed indicates that a short time elapsed between the deposition of the two layers. Calcareous fragments in the upper bed are chaotically distributed, whereas those in the subjacent bed are parallel with the bedding planes. The terrigenous detrital material within the fragments is finer grained than that of the sediment surrounding the fragments, which indicates that they are not concretions formed *in situ,* but transported blocks.

Upward in the member, pebbles are scarce and near the top the arenite is cross-bedded. Cross-bedding measurements (in one plane) seem to indicate flow toward the north-northwest (Fig. 5). In the same strata where cross-bedding is present, oscillation ripple marks were observed.

The arenite of this member is graywacke (as defined by Pettijohn, 1957), which contains angular and subangular unsorted grains ranging in size from 0.06 to 1.0 mm.

In order of decreasing importance, the grains consist of quartz, glauconite, plagioclase (andesine), andesitic lava, shale, foraminiferal tests filled with opal, opaque minerals, chlorite, biotite, zircon, and garnet. The matrix is mainly clay which is somewhat calcareous and partly chloritized.

FIG. 5.—Cross-bedding: member A of Rocallosa Formation at Punta Rocallosa.

Member A also crops out along the north coast of Seno Skyring, where its thickness is somewhat greater than at the type locality. Along the north coast, the contact with the Fuentes Formation is gradational. South of Seno Skyring, member A wedges out and disappears.

This sandy and partly conglomeratic member seems to have been deposited catastrophically as a lens of limited areal extent. García (1952) could not find it in the central part of Isla Riesco, south of Punta Rocallosa. The writers did not find it in the Seno Otway area and observed only a northward increase in thickness. It is suggested that the formation of these graywackes took place locally and during a short time interval while the Fuentes Formation was being deposited.

Member B.—In the type locality of the Rocallosa Formation, member B is 60 m thick. Along the north coast of Seno Skyring at Bahía Altamirano, it does not crop out.

Bahía Altamirano occupies the trough of a syncline. Each limb of the syncline forms a prominent cuesta held up by hard Rocallosa arenite. Member B was not observed in these cuestas because in the western limb a thrust fault brought the Fuentes Formation to the same elevation as member D of the Rocallosa Formation, and in the eastern limb its outcrop is covered by modern beach deposits.

At Punta Rocallosa member B is a reddish-brown sandy shale consisting of 60 percent cal-

FIG. 4.—Stratigraphic columns of six studied sections, with indication of lithology. Lines between columns indicate contacts of formations. Horizontal line corresponds to base of Chorrillo Chico Formation, only contact observed at each locality. Numbers at top of columns correspond to numbers in Figure 1.

careous shale matrix. The sand grains are angular to subrounded and poorly sorted. They consist, in order of decreasing importance, of plagioclase (andesine), andesitic lava, shale, quartz, glauconite, opaque minerals, foraminiferal tests filled with calcite or silica, biotite flakes, chloritized amphibole, and tiny zircon crystals. The carbonate content of the matrix diminishes upward.

Martínez (1965) found in this member a very well-preserved specimen of *Bolivinoides draco dorreeni* Finlay, on the basis of which a late Maestrichtian age is assigned.

Lithologically, member B is similar to the upper strata of the Fuentes Formation. If one considers, however, that member A probably was deposited catastrophically and that its areal extent possibly is restricted, the lithofacies of member B should be a repetition of the Fuentes Formation lithofacies.

The upper contact of member B with member C is sharp.

Member C.—At the type locality of the Rocallosa Formation this member is 100 m thick. Along the north coast of Seno Skyring the upper part of the member crops out only in the eastern limb of the syncline.

Member C consists of greenish siltstone with argillaceous graywacke intercalations showing graded bedding, coarse-grained arenite lenses, and limestone-concretion layers. The concretions reach diameters of 60 cm.

The angular grains composing the siltstone range from 0.02 to 0.4 mm in diameter. The grains, in order of decreasing importance, are quartz, lithic fragments, plagioclase (andesine), foraminiferal tests, biotite, zircon, and chlorite. Approximately 65 percent of the matrix is calcareous.

At Punta Rocallosa the lowest unit of the member is a 2-m bed of medium-grained arenite which is conglomeratic at the base. The bed also contains glauconite and carbonaceous remains. A similar layer, not conglomeratic, was observed several meters stratigraphically higher.

A layer of limestone "concretions" of very diverse shapes forms the top of the member. The "concretions" are so abundant that they almost constitute one stratum; a limestone bed, 1 m thick, is present several meters below the "concretions" bed.

Foraminifera found in the samples collected along the north coast of Seno Skyring are *Rugoglobigerina rugosa* (Plummer), *Rugoglobigerina* aff. *loeterlli* (Nauss), and *Globigerinella messinae messinae* Brönnimann. These species indicate a Late Cretaceous age.

Member D.—At the type locality of the Rocallosa Formation member D is 110 m thick, but it is only 65 m in the eastern limb of the Bahía Altamirano syncline. In the western limb of the syncline, only the upper part crops out because of the thrust fault mentioned.

At both localities member D consists of glauconitic, greenish-gray, sandy siltstone with coarse glauconitic arenite intercalations, in beds 10–20 cm thick. There are several beds of calcareous lenticular concretions measuring up to 2 m in diameter and several very glauconitic sandy lenses. The arenaceous intercalations decrease upward.

The siltstone contains, in order of decreasing abundance, angular grains of quartz, andesite fragments, plagioclase (andesine), glauconite, foraminiferal tests, biotite, zircon, apatite, and altered amphibole. The matrix principally clay with some chlorite and microcrystalline silica, comprises 60–70 percent of the sediment.

The intercalated graywacke is argillaceous with graded beds. The composition is similar to that of the siltstone, but includes a smaller percentage of matrix. Compared with member C, member D has a larger content of glauconite and thinner arenite intercalations.

The contact with the grayish-brown argillite of the Chorrillo Chico Formation is gradational.

In member D the fossils found are *Turritella ameghinoi* (von Ihering), *Dentalium cazadorianum* Wilckens, corals (not determined), and *Serpula occidentalis* Leanza and Castellano.

Rocallosa Formation along south coast of Seno Otway and in El Ganso No. 1 well

At Punta Entrada, at the east side of the mouth of the Silva Palma Fiord, a sandy siltstone unit crops out above the Fuentes Formation and below the Chorrillo Chico Formation. This unit, correlated lithologically with the Rocallosa Formation, is 345 m thick, and is divided into three members.

The lower member is 200 m thick and consists of greenish- or yellowish-gray, hard argillaceous arenite, with argillaceous graded beds and glauconite pellets. The middle member, 85 m thick, consists of brownish-gray, very hard, argillaceous siltstone. Limestone "concretions" of very peculiar shapes are common (Fig. 6). The upper member is 60 m thick and consists of yellowish-gray, fine- to medium-grained arenite and greenish-gray, sandy siltstone.

FIG. 6.—"Concretions," Rocallosa Formation at Punta Entrada. Very common structures in studied area at several stratigraphic levels.

The grains of the arenite (graywacke) and siltstone are, in order of decreasing importance, quartz, plagioclase (oligoclase and andesine), glauconite, foraminiferal remains, andesite, argillite, opaque minerals, biotite, titanite, zircon, and garnet. The matrix is principally argillaceous and contains some silica.

In the middle member a questionable specimen of *Globigerinella messinae messinae* Brönnimann was found.

In the El Ganso No. 1 well, the Rocallosa Formation was penetrated between the depths of 1,250 and 1,660 m, a thickness of 410 m.

The lower 30 m consists of greenish-gray graywacke grading upward into a light-gray siltstone possibly containing sandy intercalations; this siltstone grades into the Chorrillo Chico argillite.

Cuttings from the lower part of the unit (1,580–1,590 m and 1,520–1,530 m) contain the Late Cretaceous Foraminifera *Rugoglobigerina rugosa* (Plummer), *Gümbelina ultimatumida* Cushman *non* White, and *Heterohelix* sp.

Brunswick Peninsula Area

The lithologic units that crop out below the Chorrillo Chico Formation in the eastern part of the Brunswick Peninsula are, from base to top, the Santa Ana Beds, the Río Blanco Formation, and the Carrera Formation.

Santa Ana Beds

Hemmer (1935, *in* Léxique Stratigraphique International, 1957) gave the Santa Ana Beds name to the strata which underlie Punta Santa Ana on the east coast of the Brunswick Peninsula. Hemmer failed to observe that at this locality the formation is overturned.

The writers found the unit only along the coast of the Strait of Magellan, where the upper 150 m was studied. The strata consist of thin, dark-gray, poorly sorted arenite; some beds are glauconitic. Thin intercalations of dark-gray argillaceous siltstone, calcarenite, and calcareous siltstone also are present. Several limestone "concretions" of unusual shape were found.

The arenite is graywacke; the grain types include in order of decreasing importance, quartz, plagioclase (andesine), orthoclase, andesite fragments, glauconite, opaque minerals, zircon, biotite, foraminiferal tests, garnet, apatite, titanite, and epidote.

The matrix is argillaceous; about 35 percent of the sequence is calcareous.

A calcareous arenite bed, 40 cm thick and having conspicuous convolute bedding, was observed a few meters below the top of the unit (Fig. 7). Because the crests of the structures point southeast, that probably was the direction of flow of the depositing currents, although it is opposite to that indicated by the cross-bedding of member A of the Rocallosa Formation.

Along the Brunswick Peninsula coast are many vertical faults that strike northeast. Some strike-slip movement shifted the northern blocks northeastward, causing several repetitions of outcrops of the same beds along the

FIG. 7.—Convolute bedding in Santa Ana Beds, east coast of Brunswick Peninsula. Movement toward left side of photo.

coast. The coastline strikes almost north-south, but the beds strike northwest. An identical situation was observed farther north at Punta Carrera.

The Santa Ana Beds grade upward into the Río Blanco Formation.

The Maestrichtian fossils found are *Diplomoceras notabile* Whiteaves, *Maorites* cf. *tenuicostatus* Marshall, *Maorites* cf. *densicostatus* (Kilian and Reboul), *Pachydiscus* sp., and *Scalpellum* sp.

Río Blanco Formation

Von Goetsche (1953) gave the name Río Blanco Formation to a siltstone unit which crops out along the Río Blanco Valley, 50 km south of the city of Punta Arenas.

The writers studied the upper and lower parts of the formation along the east coast of Brunswick Peninsula. Along the Chorrillo Segundo Valley only the upper 100 m is exposed.

The formation consists of light-gray sandy siltstone. Intercalations of greenish-gray, medium- to fine-grained arenite, with argillaceous graded beds, are common. In this unit andesine plagioclase and andesitic lava grains are more abundant than quartz; orthoclase grains and glauconite pellets also are present. The grain size increases gradually upward to the Carrera Formation.

Fossils collected in this formation are *Maorites* cf. *densicostatus* (Kilian and Reboul), *Maorites* sp., and coral (not determined).

Carrera Formation

Von Goetsche (1953) gave the name "arenisca Carrera" to a unit that crops out at Punta Carrera, 55 km south of the city of Punta Arenas. This unit was raised to formation rank by Cecioni (1955).

At the type locality the formation is 100 m thick. It consists of brownish- and greenish-gray, medium- to fine-grained arenite, some of which is very glauconitic. Silty argillite intercalations and limestone-concretion beds are common throughout the formation. A conglomeratic bed in the upper part contains gastropod and pelecypod remains. The number of siltstone and argillaceous graded arenite beds increases upward.

Near the top of the formation asymmetric flame structures are present (Fig. 8), which have characteristics similar to those described by Prentice (1956, Fig. 3) and Sullwold (1959, Fig. 2). All of the "flames" point southeast. Small granulometric differences were observed in the sediment below and above the structures. Nevertheless, darker laminations within the "flames" permit the study of the structural details. The point of one of these "flames" is in contact with the next "flame" and envelops the sediment that accumulated in the depression between the two.

The writers believe that Prentice's (1956) two explanations for flame structures are applicable to the Carrera Formation: (1) slow turbidity-current flow could produce movements in both the viscous material just deposited and in that directly underlying it, and (2) the sedimentary overburden imposed by the younger sediments on those below could cause both to slide downslope. Thus, both the paleocurrent and/or the paleoslope can be interpreted from the direction toward which the "flames" point.

Some authors believe that flame structures originate where differential loading, caused by irregularities on the sedimentation surface, takes place on a bottom underlain by semiplastic, water-saturated sediment; such irregularities may be grooves, flutes, *etc.* Because of the greater accumulation of material in the depressions, the sediments deposited there sink differentially and cause flow of sediment toward the crests of the intervening high areas, thus forming the "flames" (Kelling and Walton, 1957). However, according to this explanation, the pressure is vertical, and therefore the crests or "flames" which are produced should be symmetrical (Kelling and Walton, 1957, Fig. 2).

The flame structures in the Carrera Formation are asymmetrical and evidently are not load structures. Therefore, the paleocurrent or paleoslope was toward the southeast. This interpretation is supported by the orientation of the convolute bedding in the upper part of the Santa Ana Beds.

The arenite in the Carrera Formation contains poorly sorted angular grains that range in diameter from 0.02 to 1.0 mm. In order of decreasing importance, the grains consist of quartz, andesitic lava, andesine (in places altered to calcite or clay), glauconite, opaque minerals, biotite, zircon, muscovite, and epidote. The argillaceous matrix, somewhat chloritized and calcareous, comprises about 30 percent of the unit.

At Chorrillo Segundo, the Carrera is similar to that at the type locality exposures.

The contact with the overlying Chorrillo Chico Formation is gradational.

Seno Skyring and Brunswick Peninsula Areas

Overlying the Rocallosa Formation at Seno Skyring in the north and the Carrera Formation at Brunswick Peninsula in the south is the Chorrillo Chico Formation. The lower contact in both areas is gradational. Above the Chorrillo Chico is the San Jorge Formation, and above it is the Agua Fresca Formation. Like the Chorrillo Chico, the San Jorge and Agua Fresca are present throughout the area.

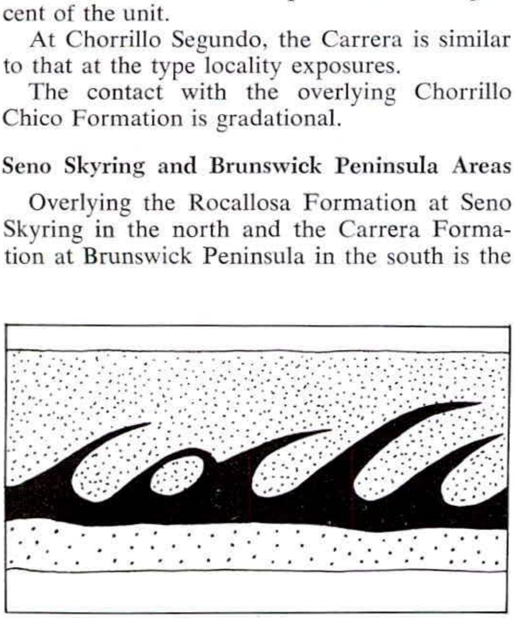


FIG. 8.—"Flame" structure in Carrera Formation. Paleocurrent or paleoslope at right of figure.

Chorrillo Chico Formation

The Chorrillo Chico type locality is on the eastern side of Punta Rocallosa (Thomas, 1949). According to the *Léxique Stratigraphique International* (1957), the ENAP geologists raised it to formation rank. Thomas (p. 1560), in the original description wrote ". . . at which locality the Chorillo Chico [brook] cuts across the formation," but he did not formally propose the unit as a formation, although he uses the term formation.

At the type locality, Thomas (1949, p. 1560) measured ". . . no less than 185 meters, but covered areas at that place extend 80 meters above and 60 meters below the exposed part." From this description the writers conclude that Thomas did not see the contact with the Rocallosa Formation. García (1952) measured at the same place 440 m of section, but the thickness includes what the writers consider to be member D of the Rocallosa Formation and part of the San Jorge Formation.

At the type locality the writers measured 275 m and observed a gradational contact with the Rocallosa. The lower covered 60 m, which Thomas (1949) mentioned, is slightly above the base of the formation. In the upper covered interval the writers measured 90 m of section normal to strike directly below the San Jorge Formation.

The Chorrillo Chico consists of very hard, light-brown, silty argillite of tuffaceous appearance. Thin glauconitic arenite intercalations, showing shaly graded beds, are common. Coarse glauconitic arenite lenses were found at some localities. Large lenticular limestone concretions, 6 m in diameter and 1.60 m thick, are characteristic of the formation.

Along the coast of the Strait of Magellan two members were distinguished. The lower member is more glauconitic and sandy than the upper. Furthermore, the lower member has more graywacke intercalations with argillaceous graded beds.

The argillite of the formation contains grains of quartz, plagioclase, biotite, and chlorite, ranging in size from 0.02 mm to 0.4 mm. The matrix is a reddish clay containing some calcareous cement. At Punta Entrada, a layer with abundant pebbles of carbonized wood was found near the top of the formation; the pebbles are 3–6 cm in diameter.

At Bahía Altamirano, along the north coast of Seno Skyring, 215 m of this formation was measured; the rest has been eroded. At Punta Entrada, on the south coast of Seno Skyring, the unit is only 100 m thick, but in the Strait of Magellan, it is 320 m. At the El Ganso No. 1 well, 340 m of this formation is present.

At Punta Entrada, a layer with abundant pebbles of carbonized wood was found near the top of the formation; these pebbles are 3–6 cm in diameter.

The upper and lower boundaries of the formation are gradational.

The fossil species found in the unit are *Turritella ameghinoi* (von Ihering), *Serpula occidentalis* Leanza and Castellano, *Balanocrinus* sp., corals (not determined), pelecypods (not determined), and gastropods (not determined).

The age of the formation is discussed in a subsequent section.

San Jorge Formation

Thoms considered the San Jorge unit to be the basal member of the Agua Fresca Formation, but von Goetsche raised it to formation rank (Léxique Stratigraphique International, 1957). The type locality is at Bahía San Jorge, along the east coast of the Brunswick Peninsula, 2 km north of Punta Carrera. The formation is present at all localities visited except at Bahía Altamirano, where it is absent because of erosion.

At Punta Rocallosa, only part of the formation crops out, but the unit could be 280 m thick. It consists of brown argillite that becomes semiplastic in water, and is assigned to the San Jorge Formation on the bases of lithologic characteristics and stratigraphic position.

Along the south coast of Seno Otway 140 m was measured; the upper part is eroded. At the type locality, Bahía San Jorge, approximately 450 m was measured. At that locality many northeast-striking faults are present. The northwest sides of the faults are displaced toward the east, causing much repetition of section along the coast. The same phenomenon was observed at the type locality of the Santa Ana Beds. In the El Ganso No. 1 well, 250 m of this formation is present.

Although in each locality the San Jorge Formation has somewhat different characteristics, it generally is a succession of soft brown argillite beds containing many limestone concretions. Some beds contain abundant glauconite. Thin siltstone or arenite intercalations with argillaceous graded beds are common.

Very few fossils were found in the formation and those collected are not useful for determining age even though there is an enrichment of the fauna in this formation relative to the older strata of the northern regions (see Herm, 1966, p. 78).

Agua Fresca Formation

Decat and Pomeyrol (1931, *in* Léxique Stratigraphique International, 1957) gave the name Agua Fresca to a unit including what now is considered to be the Chorrillo Chico, San Jorge, and Agua Fresca Formations. The Chorrillo Chico and San Jorge were separated by Thomas (1949) and von Goetsche (1953), respectively (Léxique Stratigraphique International, 1957). The type locality is along the lower part of the Agua Fresca River, in the eastern part of the Brunswick Peninsula.

The writers studied only the lower part at two localities, the north coast of Isla Riesco and the east coast of Brunswick Peninsula. In the El Ganso No. 1 well, only the lower 25 m was penetrated.

The planktonic Foraminifera of five samples from the two localities were studied. Four of the samples were collected by von Goetsche along the Brunswick Peninsula coast; the other sample was collected by the writers at Isla Riesco. All are from the lower part of the formation.

The species found are *Globigerina triloculinoides* Plummer, *Globigerina aquiensis* Loeblich and Tappan, *Globigerina spiralis* Bolli, *Globorotalia compressa* (Plummer), *Globorotalia membranacea* (Ehrenberg), *Globorotalia* cf. *quadrata* (White), *Globoanomalina pseudoiota* Hornibrook, and *Acarinina triplex* Subbotina. In the cuttings of the El Ganso No. 1 well, a specimen of *Globigerina triloculinoides* was found.

The fauna indicates a late Paleocene–early Eocene age for the lower part of the formation. Todd and Knicker (1952) assigned the whole formation to the late Eocene.

Some nannoplankton specimens were found in the samples that contained the Foraminifera. These forms are the first reported from Magallanes Province. Rubén Martínez classified them as *Rhabdosphaera scabrosa* (Deflandre), *Braarudosphaera bigelowi* (Gran and Braarud), *Discoaster tribrachiatus* Bramlette and Riedel, *Micrantholitus attenuatus* Bramlette and Sullivan, *Coccolithus grandis* Bramlette and Riedel, and *Zygolithus attenuatus* Deflandre.

Very few specimens of each species were found; however, the assemblage probably is early Eocene. The age is slightly younger than that indicated by the Foraminifera, but is less exact. This age determined for the lower part of the formation does not eliminate the possibility that the upper part could be late Eocene as was concluded by Todd and Knicker (1952) for the whole unit.

Petrography

A total of 130 samples was studied in thin section. All are terrigenous clastic rocks, except for some limestone that probably is of chemical origin. Classification of the lithic types was a problem because the specimens exhibit a complete gradation from graywacke to pure argillite.

Rock Types

Graywacke.—The graywacke specimens consist of very poorly sorted, angular or subangular grains ranging in size from 0.02 to 0.80 mm; the grains "float" in an argillaceous matrix. No pronounced size difference was noted between the framework grains and the matrix. Hence it was necessary to establish an arbitrary limit at 0.02 mm (Pettijohn, 1957; Gilbert, *in* Williams *et al.*, 1955).

The grain composition is principally quartz; however feldspar, fragments of andesitic lava and of argillite, glauconite, and biotite also are present. The matrix is argillaceous, and the microcrystalline material present may be of diagenetic origin. Minerals such as quartz, feldspar, chlorite, and sericite are present. The matrix comprises 20–75 percent of the samples. Apatite, chlorite, garnet, muscovite, titanite, zircon, pyroxenes, and amphiboles are accessory minerals.

The rocks are graywackes according to Pettijohn (1957) and it is used instead of Crook's (1960) classification of arenites (with which the writers agree) largely because it was not possible to determine whether the sediments were deposited by traction or turbidity currents. Because neither lithic nor feldspathic fragments appear to predominate, no further subdivision of the graywacke was justified.

Graywacke is the lithologic type of the Rocallosa, Santa Ana, and Carrera units.

Siltstone.—The term siltstone was applied to rocks containing more than 75 percent silt-size grains.

Sandy siltstone.—Siltstone with 10–25 percent sand-size grains was classified as sandy.

Argillite.—Rocks with more than 75 percent clay-size material were classified as argillite.

Silty argillite.—Silty argillite has 10–20 percent silt-size grains.

All siltstone and argillite in the samples studied contained sand grains, which were not considered in the rock classification if they did not exceed 10 percent of a sample. In general, the mineralogic composition of the graywacke is the same as that of the siltstone and argillite. The poor sorting, the slight alteration of the feldspar grains, and the great predominance of angular grains suggest rapid erosion, transport, and deposition.

The argillaceous graded beds in most of the graywacke sequences and the presence of grains "floating" in a matrix favor the idea that most of the rocks were deposited by turbidity currents or viscous-type flows.

Heavy Minerals

Very little has been written regarding the heavy minerals of the Magallanes basin. Although investigation was limited, the writers believed that some heavy-mineral studies would be of interest and might serve as a basis for future investigations in the area. The writers were particularly interested in determining whether (1) the heavy minerals of the Chorrillo Chico Formation are the same within the studied area and (2) the Rocallosa Formation could be correlated lithologically with the Carrera Formation. Eight samples were studied for heavy-mineral content.

The heavy minerals present are apatite, biotite, chlorite, garnet, hypersthene, titanite (sphene), topaz, and zircon. Lesser amounts of epidote(?), staurolite, fluorite, hornblende, muscovite, and palagonite were found. Although some slight differences were noted in the mineral content the general distribution is very uniform horizontally and vertically. Therefore, (1) the heavy mineral content of the Chorrillo Chico is everywhere about the same, and (2) heavy minerals could not be used to correlate the Rocallosa and Carrera Formations.

Most of the heavy minerals found in the samples could have been derived from a region of silicic plutonic rocks, their metamorphic aureoles, and metamorphic rocks such as gneiss and schist. The presence of hypersthene could indicate a volcanic source. Such a source is confirmed by the presence of numerous microscopic andesitic fragments. Similar conclusions were also drawn by Scott (1966) for the Ultima Esperanza region.

Some of the heavy minerals retain their original shape (idiomorphic), though others are angular. The presence of idiomorphic crystals proves a short transport distance. The rounded apatite grains with idiomorphic and angular grains of other minerals could indicate reworking or longer transport distance. However, the presence of chemically unstable minerals such as apatite, garnet, and hypersthene indicates that chemical weathering was not very intense and that erosion, transport, and deposition were very rapid.

Paleontology

Macropaleontology

Representatives of the phyla Annelida, Crustacea, Echinodermata, and Mollusca were found in the rocks studied. Study of the ammonites was particularly important because of their great usefulness in stratigraphic correlation. The descriptions of the species listed here will be the subject of another paper.

The ammonites found in the northern part of the area are from the Fuentes Formation; those found along the Strait of Magellan are from the Santa Ana Beds and the Río Blanco Formation. The Fuentes contained the following ammonites.

Gunnarites kalika (Stoliczka)
Gunnarites antarcticus (Stuart Weller)
Gunnarites zelandicus (Marshall)
Gunnarites bhavaniformis (Kilian and Reboul)
Hipophylloceras nera (Paulcke)
Maorites tenuicostatus (Marshall) (found by A. Cañón, ENAP, oral commun.)

The following species were found in the Santa Ana Beds and the Río Blanco Formation:

Diplomoceras notabile (Whiteaves)
Maorites densicostatus (Kilian and Reboul)
Maorites tenuicostatus Marshall
Gunnarites kalika (Stoliczka) (*fide* Léxique Stratigraphique)
Gunnarites zelandicus (Marshall) (*fide* Léxique Stratigraphique)
Pachydiscus sp.

O. Wenzel (personal commun.) found some ammonite fragments in member C of the Rocallosa Formation. They were observed by the writers, and may be either a *Maorites* or a *Grossouvrites*. Cecioni (1955, p. 5) subsequently found a *Gunnarites* fragment at nearly the same stratigraphic level.

The ages assigned to the genera listed depend on the opinions of the authors. Collignon (1955, p. 48) placed the genus *Maorites* in the early Campanian on the basis of his findings in Madagascar. The same author stated that in India and Antarctica the strata containing *Maorites* are the same age as those in Madagascar. Collignon believed that *Gunnarites* is the same age as *Maorites* because they occur together in India and Antarctica.

According to Spath (1953, p. 53), in Antarctica where these ammonites are very abundant, both genera are found in late Campanian beds and are associated with other ammonites that, in his opinion, could be early Maestrichtian. Cecioni believed that in Magallanes *Gunnarites* and *Maorites* are of Maestrichtian age, because he found them above the *Hoplitoplacenticeras* fauna (Léxique Stratigraphique International, p. 66, 310, 322), which generally is regarded as the top of the Campanian.

Outside the Magallanes area, *Gunnarites kalika* is known from Antarctica and India. In Antarctica it is present together with many other species of *Gunnarites* and *Maorites,* as well as with other ammonites. In India (in the Ariyaloor Group) only one *Gunnarites kalika* was found (Collignon, 1955, p. 48) and according to Spath (1953, p. 47), it was found with *Maorites aemilianus* Stoliczka.

Cotter (1938, p. 48), Haug (1909, p. 1346), and Stephenson (1941) assigned the Ariyaloor Group to the Maestrichtian; Collignon (1955, p. 80, 82), however, assigned to it an age ranging from late Campanian to early Maestrichtian because of the age he ascribed to *Maorites* in Madagascar. In New Zealand, Wellman (1956, p. 352) included *Maorites* and *Diplomoceras* in the Haumurian Stage, which he considered to be Maestrichtian. Hornibrook (1962) confirmed this age on the basis of microfossils.

In the Santa Ana Beds, *Diplomoceras notabile* (Whiteaves) was found with *Maorites tenuicostatus* and *M. densicostatus.* Usher (1952; *fide* Popenoe *et al.,* 1960, p. 1516) found this species in British Columbia in the Nanaimo Group (latest Campanian to early Maestrichtian), yet later restricted these ammonites to the Campanian (see Moore, 1957, p. L227) Matsumoto (1960) stated that *Diplomoceras* is not present in strata older than the late Campanian (*Hoplitoplacenticeras vancouverensis*) and that it lived until late Maestrichtian time, as in the Moreno Formation (Popenoe *et al.,* 1960, p. 1516).

In the upper part of the Fuentes Formation the genera *Gunnarites, Maorites,* and *Hipophylloceras* were found in association with Maestrichtian foraminifers; this would confirm the probability of a Maestrichtian age. However, the possibility that the genus *Maorites* has a greater age range is not excluded.

Micropaleontology

The planktonic microfossils found in the area and their stratigraphic positions are discussed briefly herein because a more detailed paper on the subject has been published (Charrier and Lahsen, 1968). This is the first study of the Cretaceous-Tertiary boundary in Magallanes Province by means of planktonic microfossils. The species form two age groups: one Cretaceous and the other Tertiary. The Cretaceous group is represented by the following species from the Fuentes and Rocallosa Formations.

Racemigümbelina sp.
Gümbelitria sp.
Gümbelina complanata Marie
Gümbelina ultimatumida Cushman *non* White
Gümbelina striata (Ehrenberg)
Gümbelina globulosa (Ehrenberg)
Gümbelina sp.
Heterohelix sp.
Rugoglobigerina rugosa (Plummer)
Rugoglobigerina beldingi Gandolfi
Rugoglobigerina aff. *loeterlli* (Nauss)
Rugoglobigerina circumnodifer (Finlay)
Globigerinella messinae messinae Brönnimann
Globotruncana mayaroensis Bolli?
Globotruncanella havanensis (Voorwijk)
Bolivinoides draco dorreeni Finlay

The Tertiary assemblage is from the lower part of the Agua Fresca Formation.

Foraminifera

Globigerina triloculinoides Plummer
Globigerina aquiensis Loeblich and Tappan
Globigerina spiralis Bolli
Globorotalia compressa (Plummer)
Globorotalia membranacea (Ehrenberg)
Globorotalia cf. *quadrata* White
Globoanomalina pseudoiota Hornibrook
Acarinina triplex Subbotina

Nannoplankton

Rhabdosphaera scabrosa (Deflandre)
Braarudosphaera bigelowi (Gran and Braarud)
Discoaster tribrachiatus Bramlette and Riedel
Micrantholitus attenuatus Bramlette and Sullivan
Coccolithus grandis Bramlette and Riedel
Zygolithus dubius Deflandre

The first group according to Brönnimann (1952), Gandolfi (1955), Bolli (1957), Edgell (1957), Herm (1962), van Hinte (1963), and others is of Late Cretaceous age.

Bolivinoides draco dorreeni Finlay is an index (Hornibrook, 1958 a, b, and 1962; Reiss, 1954) of the *Globotruncana mayaroensis* Zone assemblage, the uppermost zone of the Cretaceous. To date, however, no Maestrichtian *Globotruncana* has been found in the area.

B. draco dorreeni was found in the uppermost Fuentes Formation along the southern coast of Seno Otway; that is the third locality where it has been found in Magallanes. Martínez (1965) also found this species at the type locality of the Rocallosa Formation, in member B.

Late Cretaceous microfossils were found in member C of the Rocallosa Formation along the northern coast of Seno Skyring. The foraminifers include *Rugoglobigerina rugosa* (Plummer), *R.* aff. *loeterlli* (Nauss), and *Globigerinella messinae messinae* Brönnimann. In the southern part of the region almost no Foraminifera were found, hence the formations that crop out there could not be dated by microfossils.

The vertical distribution of several Tertiary microfossils is not the same as that of other species which are associated. This is true of both the Foraminifera and the nannoplankton. Therefore, it is not possible to date precisely the lower part of the Agua Fresca Formation, but it can be assigned to the late Paleocene–early Eocene. This age is older than that assigned previously to the whole formation by Todd and Knicker (1952).

Although species with different age ranges are together in the same samples, this is an isolated fossil assemblage in a region where the biostratigraphic column has not been worked out. Therefore, the relations of the faunas to older and younger species is not known, and the exact age of each foraminiferal association cannot be established exactly.

The *Globorotalia compressa* and *G. membranacea* were difficult to identify because descriptions differ slightly from those of the originals. However, they are practically identical with the drawings of Loeblich and Tappan (1957 b, Pl. 44, Fig. 11) and Subbotina (1953, Pl. XVI, Fig. 12, a, b, c), respectively.

Paleoecology

Some benthonic organisms found in the units studied indicate the environmental conditions that predominated in this basin from Late Cretaceous until early Tertiary time. Paleoecologic conclusions are based mainly on the work of Bandy (1964).

Although this study is brief some facts were found that previously were unknown. The strata studied were deposited in water which became increasingly shallow. The writers conclude that the Agua Fresca Formation, the youngest studied, was deposited in water not deeper than 100 m. In contrast, the upper Fuentes, Río Blanco, and Rocallosa Formations, lowest in the section studied, contain genera such as *Cyclammina* and *Allomorphina* which, according to Bandy (1964), typically have a bathyal depth distribution in modern seas.

In the Chorrillo Chico Formation samples, between the Agua Fresca and Rocallosa-Río Blanco-Fuentes, the genera *Cyclammina* and *Allomorphina* also were found, but with such genera as *Trochammina, Ammobaculites,* and *Haplophragmoides* which today characterize the inner shelf. The coexistence of genera typical of two different environments could be the result of an intermediate position of the Chorrillo Chico between the bathyal zone and the outer shelf during a period of decreasing depth of the sea bottom.

In the Agua Fresca, although certain species found are at bathyal depths today, most of the fauna belongs typically to a shelf environment. *Elphidium*, represented by five species, is the dominant genus in the unit (Todd and Knicker, 1952). According to Phleger (1960) and Bandy (1964) the presence of *Elphidium* indicates a very shallow sea, less than 80 m deep. They differ with Todd and Knicker (1952), who believed that the unit was deposited at great depth. At the type locality of the Agua Fresca, R. Martínez (personal commun.) found some very thin coal layers.

Geochemistry Applied to Stratigraphy

In the field and laboratory lithologic correlation of the pre-Chorrillo Chico formations presented several problems. Because conventional correlation techniques were useless, the writers attempted correlations based on *element analyses* (*i.e.,* comparison of the element contents of the different lithologic units).

It was reasoned that the different lithologic types of each unit should have a characteristic element content which should depend, qualitatively and quantitatively, on the kind of detrital material constituting the sediments and the physico-chemical and biologic environments that dominated during sedimentation and diagenesis. Assuming that some of these factors change with time, and knowing that the depth of water probably changed with time, the writers concluded that each unit should have its own suite of elements and that such suites could prevail in large areas, at least for a short time. A similar study was made by Cameron (1965), who in correlation fo an extensive area of Alberta, Canada, distinguished three units of different Na_2O content.

The writers used the finer sediment fraction for several reasons. First, an analysis of the whole sample would give a composition too closely related to the framework grains. Second, the clay and other constituents of the finer fraction certainly have a wider distribution in a sedimentary basin than other fractions. Third, the clay fraction has a greater metal content than the silt and sand fractions. Fourth, with use of the finer fraction, the interpretation of the results is not obscured by different clastic: clay ratios resulting from facies variations.

The writers are aware that this type of study has many limitations, both geologically and geochemically, but they wished to determine the validity of their reasoning.

A total of 53 samples was analyzed, including 10 cores of the El Ganso No. 1 well. All of them were analyzed for P, Pb, Cu, Co, Fe, Mn, Zn, Ni, Mo, V, and organic carbon. The Mo and V analyses were eliminated because they were not sufficiently precise. Lack of good equipment and shortage of funds prevented additional analyses. The analytic methods applied were taken from Ward *et al.* (1963). The precision obtained ranges from 10 to 20 percent, determined by repeating several analyses.

Each sample was analyzed nine times, once for each element. The resulting number of analyses for each sample was insufficient to permit the correlation of the different sections. Therefore, to make the data useful, the ratios among all elements were calculated. The values of these ratios depend on special conditions in the basin caused by many factors that acted interdependently. If these conditions lasted for a short time and were uniform throughout the basin, they could be recognized across a considerable distance. El Wakeel and Riley (1961) and Goldberg and Ahrrenius (1958, p. 181) have cited some ratios which have a very precise significance.

The nine analyses made possible 36 ratios, only 27 of which were used. Fe, Mn, Ni, Co, Pb, and Mo, according to Goldberg and Ahrrenius (1958), have similar behavior in seawater under a variety of environmental conditions. Hence, most ratios calculated with any pair of those elements would not change substantially. However, the Fe/Mn ratio was used because El

Table I. Values of Element Concentrations and Ratios which Determined Similarities Between Lower Rocallosa and Carrera Formations (Element Concentrations in ppm)

Formations	*Samples*	*Highest Values**									*Lowest Values**		
		P	*Mn*	*P/Ni*	*P/org.C*	*Mn/org.C*	*Mn/Zn*	*Mn/Ni*	*Cu/Ni*	*P/Cu*	*Pb*	*Fe/Mn*	*Pb/Ni*
SECTION 1													
Ch. Chico	ChL–262	1,480	200	78.8	3,654	493	3.3	1.6	1.3	59.2	95	25.0	5.0
Ch. Chico	260	1,180	200	26.2	3,089	523	2.0	4.4	0.6	47.2	—	20.0	—
Roc. m.D	259	80	200	2.1	384	961	3.3	5.3	0.7	3.2	—	45.0	—
Roc. m.D	256	580	600	464.0	2,283	2,362	8.0	461.5	20.0	23.2	100	16.0	80.0
Roc. m.C	252	880	800$^+$	880.0$^+$	3,651	3,319$^+$	13.3$^+$	800.0$^+$	25.0$^+$	35.2	75	7.5$^-$	75.0
Roc. m.A	245	1,480	300	51.0	4,032	817	4.6	10.4	0.9	53.8	80	26.7	2.8
Fuentes	241	280	400	12.0	903	1,290	4.4	17.3	1.1	11.2	38	15.0	1.6
Fuentes	276	280	600	11.2	1,513	3,243	10.0	24.0	0.6	18.7	38	8.3	1.5
SECTION 2													
Ch. Chico	ChL–199	580	200	77.0	2,006	692	3.3	26.6	3.9	19.3	55	25.0	7.3
Ch. Chico	177	580	140	11.6	1,355	327	2.3	3.0	0.5	23.2	—	32.1	—
Ch. Chico	148	1,480	200	91.0	3,195	431	3.3	12.3	1.5	59.2	50	27.5	3.0
Roc. m.D	142	1,480	400	29.6	2,930	792	6.7	8.0	0.5	59.2	—	15.0	—
Roc. m.D	120	2,350	1,100	62.0	7,912	3,703	10.0	28.9	2.0	32.6	—	8.2	—
Roc. m.D	100	1,750	800	65.0	6,603	3,018	6.4	2.9	1.8	35.0	105	10.6	3.9
Roc. m.C	279	580	800	464.0	5,043	6,956	11.9	615.3	20.0	23.2	50	11.2	40.0
Roc. m.B	130	280	600	280.0	833	1,785	8.0	600.0	25.0	11.2	55	8.3	55.0
Roc. m.B	87	580	3,200$^+$	464.0$^+$	1,946	10,737$^+$	64.0$^+$	2,461.5$^+$	25.0$^+$	19.3	38$^-$	2.8$^-$	30.0
Fuentes	84	480	800	392.0	3,809	6,349	7.3	61.5	20.0	19.2	38	7.5	30.0
SECTION 3													
San Jorge	ChL–310	580	140	12.0	1,901	459	1.9	2.8	0.5	23.2	100	4.3	2.0
San Jorge	308	280	350	5.6	353	441	5.8	7.0	0.5	11.2	—	14.2	—
Ch. Chico	304	580	4,000	464.0	2,109	14,545	53.3	3076.9	60.0	7.7	38	16.2	30.0
Roc. u.	301	80	200	4.2	869	2,173	2.7	1.6	1.3	3.2	38	25.0	11.0
Roc. m.	299	280	300	224.0	732	785	5.0	230.7	20.0	11.2	105	10.0	84.0
Roc. m.	298	80	150	2.1	363	681	3.0	3.8	0.6	3.2	—	26.7	—
Roc. l.	297	1,030	800	329.0	2,634	2,046	10.6	258.1	7.9	41.2	88	11.2	27.9
Fuentes	295	1,480$^+$	5,400$^+$	470.0$^+$	8,554$^+$	31,213$^+$	90.0$^+$	180.0	0.7	74.0$^+$	25$^-$	9.2	0.8$^-$
Fuentes	293	130	600	5.6	449	2,076	6.7	26.1	1.1	5.2	38	13.3	1.7
SECTION 4													
San Jorge	ChL–226	450	200	143.00	1,339.0	595	2.7	64.5	7.9	18.00	38	30.0	11.8
Ch. Chico	220	280	140	224.00	625.0	312	2.3	107.6	23.0	10.10	100	4.3	80.0
Ch. Chico	216	280	300	7.40	444.0	476	5.0	7.8	0.7	11.20	—	16.7	—
Ch. Chico	214	1	200	0.02	2.4	497	4.0	4.0	0.5	0.04	—	15.0	—
Carrera	213	280	400	11.20	972.0	1,388	—	16.0	—	—	—	15.0	—
Carrera	211	1,480$^+$	800$^+$	59.20	4,966.0$^+$	2,684$^+$	8.0$^+$	32.0	1.2	49.30$^+$	105	11.2	4.2
Río Blanco	204	450	450	10.90	1,567.0	1,567	4.1	10.8	0.5	18.0	38	14.4	0.9
SECTION 5													
San Jorge	ChL–235	280	140	224.00	2,393.0	1,196	2.3	107.6	20.0	11.20	38	2.8	30.0
Ch. Chico	76	280	200	11.20	589.0	421	2.7	8.0	2.0	5.60	—	10.0	—
Ch. Chico	73	80	100	64.00	155.0	193	1.3	76.8	20.0	3.20	95	40.0	77.7
Ch. Chico	51	80	600	16.00	193.0	1,452	8.0	12.0	0.5	3.20	—	8.3	—
Carrera	44	580	1,600$^+$	185.00	2,086.0	5,755$^+$	16.0$^+$	516.1	7.9	23.20	50	5.6	15.0
Río Blanco	69	880	600	704.00	1,666.0	1,136	6.9	461.5	20.0	35.20	100	15.0	80.0
Río Blanco	71	1	300	0.02	2.8	840	2.4	6.0	0.5	0.04	—	45.0	—
Río Blanco	4	1,750	400	40.00	3,234.0	739	6.7	9.1	0.2	70.00	38	20.0	0.8
Sta. Ana	19	1,480	200	74.00	3,785.0	511	2.0	10.0	1.3	59.00	38	30.0	1.9
SECTION 6													
San Jorge	T–4	1,750	200	108.0	2,380	272	2.7	12.3	1.6	70.0	75	30.0	4.6
Ch. Chico	T–5	550	400	440.0	1,041	757	5.3	615.3	20.0	22.0	100	15.0	80.0
Ch. Chico	T–6	550	200	36.6	1,261	458	3.3	13.3	1.6	22.0	113	20.0	7.5
Ch. Chico	T–7	550	100	440.0	2,083	378	2.0	76.8	20.0	22.0	38	10.0	30.0
Ch. Chico	T–8	1,750	200	60.9	4,117	470	2.7	6.8	0.8	70.0	100	20.0	3.4
Rocallosa	T–9	2,350	400	2,350.0	5,788	985	5.3	400.0	25.0	90.0	38	25.0	37.5
Rocallosa	T–10	550	200	88.0	2,500	900	2.4	31.7	4.8	18.3	71	30.0	11.0
Rocallosa	T–11	2,350$^+$	600$^+$	56.0	7,629$^+$	1,948$^+$	10.0$^+$	14.5	0.6	90.0$^+$	100	10.0	2.4$^-$
Rocallosa	T–12	1,750	350	60.9	6,340	1,268	4.7	12.1	0.8	70.0	105	2.9	3.6
Fuentes	T–13	1,150	300	1,150.0	3,733	974	2.4	300.0	30.0	38.3	105	26.7	105.0

* $^+$ or $^-$ indicates the highest or lowest values of each section that determined the correlation.

Wakeel and Riley (1961) attached considerable significance to it. The Cu content did not show vertical or horizontal variations, and therefore it was not used to calculate ratios.

Construction of curves for each stratigraphic section to show the vertical variations of the ratios was not possible because the samples were stratigraphically too far apart. Therefore the writers were compelled to find another method for comparing the sections. The highest and lowest ratio value, or the value of a single element content, was recorded at each section, because it was assumed that (1) those values represent extreme conditions, and (2) therefore they could be recognized easily from one section to the next.

All samples in the different sections that have the highest or lowest value for a particular ratio or element concentration were considered similar. Use of this procedure for each calculated ratio made it possible to determine which samples were the most similar between sections (Table I). It was also possible to unite with lines the similar samples of the different sections. A continuous line connected samples ChL-252, 87, 295, T-11, 211, and 44. Table I shows the values of element concentrations and ratios that determined this line. Ratios and element concentrations that did not indicate similarities between these samples are not included. Mn concentrations, and Mn:org.C and Mn:Zn ratios indicate better than the other values the similarities between samples. P:org.C value for sample ChL-211 was, for example, considered similar to sample T-11 because both have the highest values for the ratio in their sections. With this ratio, sample ChL-211 is not similar to sample Chl-44 although similarity is evidenced with other ratio values. In this same way many other lines were found but fail to unite all sections studied.

The wandering of the line from member B of Rocallosa Formation to the upper Fuentes, between sections 2 and 3, is in agreement with the suggestion that member A of the Rocallosa separates member B of the Rocallosa from the upper Fuentes—two units which have almost an identical lithofacies.

The similarities between these formations (member B of Rocallosa and the Carrera) could mean either that those units are correlative, or that they are of similar facies. It also suggests the possibility that this method may be useful in solving stratigraphic problems in that area.

The measured sections along the north and south coast of Seno Skyring, 10 km apart, could be correlated very precisely by the ratio values. This result also indicates that the method is useful, although it still needs much additional work to establish what factors affect its accuracy in a large area.

The average concentrations of each element analyzed in all the samples conform with those of silicic igneous rocks (Table II). This further strengthens the writers' conclusion that the rocks that were exposed and eroded during the Late Cretaceous–early Tertiary in the area were silicic plutons.

A marked difference in the average concentrations of the elements in pre-Chorrillo Chico sediments was observed between the areas north and south of the El Ganso No. 1 well (Table III). This suggests that a NE-SW-trending submarine ridge separated the two areas. The presence of such a ridge is supported by the very different types of pre-Chorrillo Chico sedimentation in the two areas.

The average concentrations of elements in the Cretaceous and Tertiary sedimentary rocks are almost the same, as are the heavy-mineral contents.

Between two close sections it was possible to draw several lines uniting similar samples. Most of these lines united samples of equivalent formations, a fact that shows that the method could be used in smaller areas. Each line was determined by different groups of elements and ratios. It seems, therefore, that at different stratigraphic levels the conditions changed and

Table II. Concentrations of Elements Analyzed Compared with Those of Igneous Rocks and Earth's Crust

	*Lutite**	*Igneous* Rocks**	*Mafic* Rocks**	*Felsitic* Rocks**	*Crust***	*Median Value of Studied Samples*
Co (ppm)	10–50	18	45	5	23	5
Cu (ppm)	30	70	140	30	70	25
Fe (%)	4.3	4.65	8.56	2.7	5.0	0.6
Mn (ppm)	—	1,000	2,200	600	1,000	350
Ni (ppm)	20–100	100	160	8	80	22.5
P (ppm)	—	900	—	—	1,180	580
Pb (ppm)	20	16	12	48	16	55
Zn (ppm)	50–300	80	130	60	132	75

* According to Hawkes and Webb (1962).
** According to Mason (1952).

Table III. Average Concentration of Elements for Samples Below Chorrillo Chico Formation (PPM)

	Bahía Altamirano	*Punta Rocallosa*	*Punta Entrada-Silva Palma*	*El Ganso No. 1 Well*	*Chorrillo Segundo*	*Punta Carrera-Punta Santa Ana*
Fe	7,250	7,500	5,666———	8,000	7,750	8,200
Mn	483	1,100	1,241———	370	625	620
Co	11	8	4	6	6———	10
Ni	19	18	19	16———	33	24
P	597	1,071	513	325———	965	938
C (org.)	0.260	0.277	0.257	0.304	0.292———	0.419
Cu	24———	36———	24	28	28	25
Zn	68	85	68	84———	105	95
Pb	66	57	59———	84	71	56

——— indicates the intervals with greater difference in concentration.

gave rise to different values of ratios and element concentrations. This was originally assumed by the writers.

Additional studies are necessary before definite conclusions can be established.

Cretaceous-Tertiary Boundary

Several authors have discussed the Cretaceous-Tertiary boundary in the region. Thomas (1949) tentatively considered the Chorrillo Chico Formation to be the youngest Cretaceous unit in Magallanes Province. Cecioni (1954) also assigned a Cretaceous age to the unit, but Robles and Gómez (1956) stated that the Chorrillo Chico was deposited during the Paleocene. Hauser (1964) did a subsurface study of the Springhill platform and concluded that the Cretaceous-Tertiary boundary in the subsurface is between the equivalents of the Rocallosa and Chorrillo Chico Formations.

Thomas (1949) mentioned an unconformity between the Fuentes and Rocallosa Formations. The writers believe that it is very unlikely because they did not observe any trace of an unconformity in the two localities where the contact is exposed, on the south and north coasts of Seno Skyring.

The ammonites of the upper Fuentes Formation in the Seno Skyring region and those in the Santa Ana Beds and the Río Blanco Formation along the Brunswick Peninsula coast are of Maestrichtian age. The planktonic microfossils in the upper Fuentes and those from members A, B, and C of the Rocallosa Formation indicate a late Maestrichtian age. The species found in the lower part of the Agua Fresca Formation, both in the Seno Skyring region and in the Brunswick Peninsula, are late Paleocene–early Eocene.

Between the Maestrichtian and Tertiary groups of planktonic Foraminifera is an interval where no fossils of index value were found. The Cretaceous-Tertiary boundary is in that interval. In the Seno Skyring area, this interval is in member D of the Rocallosa Formation, the Chorrillo Chico Formation, and the San Jorge Formation; together, it includes a stratigraphic section more than 650 m thick.

The writers believe that the Cretaceous-Tertiary boundary should lie in the upper part of the Chorrillo Chico Formation (Figs. 3, 4). The fact that there is an interval in which no planktonic Foraminifera are present does not mean that a "faunal break" also should be found in this region. The Cretaceous-Tertiary boundary is in a section which indicates gradational structural, lithologic, paleoecologic, and geochemical conditions.

Conclusions

1. The Cretaceous–Tertiary boundary in the region between Seno Skyring and the Strait of Magellan is in the upper part of the Chorrillo Chico Formation. On the basis of sedimentologic, structural, paleoecologic, and geochemical considerations, the passage from the Cretaceous to the Tertiary is completely gradational.

2. The following ages were determined for the formations studied:

Agua Fresca (lower part)	late Paleocene–early Eocene
San Jorge	Paleocene
Chorrillo Chico	late Maestrichtian–early Paleocene
Rocallosa and Carrera	late Maestrichtian
Upper Fuentes, Río Blanco, and Santa Ana Beds	middle Maestrichtian

3. The planktonic Foraminifera in the Cretaceous formations indicate that the genera *Maorites, Gunnarites,* and *Hipophylloceras* are in rocks of Maestrichtian age. The exact dating

of the microfauna is difficult because the range of those forms in the area is not known.

4. The paleoecologic features indicate that water depths decreased from the time of deposition of the Fuentes Formation (upper bathyal zone) to that of the Agua Fresca Formation (less than 100 m); this does not mean either an upheaval of the continent or a change in sea level, but certainly indicates filling of the marine basin.

5. Very rapid erosion, transport, and deposition are evident. Rapid deposition is indicated by the presence of many turbidity-deposited graywackes. These deposits are the result of a tectonic disturbance in more active tectonic sections of the geosyncline.

6. Extensive granitic masses were exposed to erosion at the time the formations studied were being deposited.

7. Member A of Rocallosa Formation (in its type locality) was deposited from south to north. In contrast, the Santa Ana Beds and the Carrera Formation were deposited from northwest to southeast. This may indicate the presence of a topographic ridge between Seno Skyring and the Strait of Magellan, which caused the detrital materials to travel in almost opposite directions. The geochemical data support the presence of a ridge between the two areas.

8. A geochemical study of the finer fraction of the sediments demonstrated that the element content of the fine fraction of samples of member B of the Rocallosa Formation (middle Rocallosa) is similar to that of the Carrera Formation.

9. Calculation of the average concentrations of the elements analyzed showed a sharp contrast between the Seno Skyring area and the Strait of Magellan area in the formations older than the Chorrillo Chico. The younger units do not show such differences. This confirms the supposition that a topographic elevation was present between the northern and southern areas of the region studied before the deposition of the Chorrillo Chico Formation. The large quantity of sediment deposited before the deposition of the Chorrillo Chico could have raised and leveled the basin floor before the deposition of the Chorrillo Chico.

10. The concentrations of the elements analyzed do not differ greatly from the concentrations of the same elements in silicic and/or intermediate-composition igneous rocks. The writers conclude that such igneous rock types and related metamorphic rocks supplied most of the detritus in the area for the units studied. A volcanic terrane was exposed. These conclusions are in accordance with those obtained from the heavy-mineral studies.

11. No substantial change in element content or heavy-mineral content is found between the Cretaceous and the Tertiary sediments.

12. Geochemical methods of study should prove to be useful in correlating lithologic units in the area, though the method needs refinement before its results can be used with confidence.

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