Stratigraphy of the region between Lago Argentino and Lago Viedma (49° 40' - 50° 10' S lat.), Santa Cruz Province*

P. E. KRAEMER[1] and A.C. RICCARDI[2]

[1] *Faculty of Exact, Physical, and Natural Sciences, National University of Córdoba, Av. Vélez Sársfield 299, 5000 Córdoba*
[2] *Museum of Natural Sciences, Paseo del Bosque (no number), 1900 La Plata*

Introduction

The region analyzed in this work is part of the Southern Patagonian Cordillera (Riccardi and Rolleri 1980) and the western border of the Southern Basin (Russo et al. 1980) (Fig 1). The majority of geologic research in the Southern Patagonian Cordillera, from the end of the last century up to today, are center both in the northern section (lakes Pueyrredon, Belgrano, and San Martin) and in the south (region of Ultima Esperanza, Río Turbio, and the southern margin of Lago Argentino), leaving aside the region between lakes Viedma and Argentino, which is comparatively less studied.

From the geologic point of view, the sector between lakes Viedma and Argentino, links the northern and southern regions, respectively, with particular traits. Among the most notable differences between these regions, it is important to mention the following:

a) Development of basic magmatism south of Lago Argentino (51° S lat.) from the Late Jurassic to Early Cretaceous time, whose rocks are included in the Sarmiento Complex (Dalziel 1981; Allen 1982; Barker and Dalziel 1983; Stern *et al.* 1991) and are absent north of the stated latitude.

b) Presence of deep-marine turbidites south of Lago Viedma (49° 40' S lat.) in the Late Cretaceous (Arbe and Hechem 1984a; Wilson 1991), compared to primarily platform, coastal, and continental sediments north of this latitude (Riccardi and Rolleri 1980; Arbe and Hechem 1984b; Arbe 1987,1988).

c) Evidence that the western clastic source was divided in the Late Cretaceous into a reactivated orogeny north of 49° S lat. and a magmatic arc to the south (Manassero 1988, 1993; Macellari et al. 1989; Manassero at al. 1990).

d) Existence of a pronounced deepening, in staggered form, of the basement of the basin in a north-south direction (Riccardi and Rolleri 1980; Biddle *et al.* 1986) coinciding with lakes Argentino and Viedma (Kraemer 1991).

e) Increasingly restricted participation of the Paleozoic (?) basement in the structures of the fold-and-thrust belt south of Lago Viedma (Kraemer 1993). [p. 334]

These characteristics indicate that the region is important for understanding the evolution of the strata and tectonics of the Southern Patagonian Cordillera.

The objective of this work is the analysis of the stratigraphy between lakes Viedma and Argentino. That is why we created an east-west diagram of columns

---

* Original citation: Kraemer, P. E. and A. C. Riccardi. 1997. Estratigrafía de la region comprendida entre los lagos Argentino y Viedma (49°40'-50°10' lat. S), Provincia de Santa Cruz. *Revista de la Asociación Geológica Argentina* 52:333–360. Unknown translator, edited by Matthew Carrano, Smithsonian Institution, April 2014.

correlated based on the 1:100,000 scale map of the region, measurements of 16 stratigraphic profiles, and identification of 14 fossiliferous levels.

The interpretation of 570 Km of seismic lines of reflection, and data from an exploration well (YPF-SCA-Cfo-es-l), allowed us to correlate the surface units with 5 seismic sequences S1-2-3-4-5 separated by discontinuities of regional significance.

This work synthesizes studies executed by the first author (PEK) in his doctoral thesis (Kraemer 1991), supplemented with a biostratigraphic analysis by the second author (ACR), and additional observations from both (See Kraemer and Riccardi 1996 and Riccardi and Kraemer 1996).

The fossil material illustrated is deposited in the Museum de La Plata (MLP).

Location of the area

The region we studied is located in the southwestern part of Santa Cruz province, between 49° 40' and 50° 10' S lat. and 72° and 73° 30' W long. The region is limited on the north by Lago Viedma, on the south by Lago Argentino, on the east by the Río Leona, and on the west by a line of high mountain ranges (Fig. 1). Access to the area is not very difficult in the summer. National Route No. 40 constitutes the main trunk road in the north-south direction, from which detach numerous provincial roads to the west that permit access to the foot of the mountain range.

Previous investigations

Geologist E. Feruglio carried out the first stratigraphic works in the region. He was part of the expedition of Padre De Agostini, between the years 1931 and 1932. He contributed basic work to the knowledge of the region (Feruglio 1938, 1944, and 1949-1950 among others). The analysis of samples, collected by this author, was carried out by Conci (1935) and Zuffardi (1944).

Subsequently, Piatnitzky (1938) studied the stratigraphy of the region of lakes San Martin, Cardiel, Río Sehuen or Chalia, Río Leona, and the mouth of Río Guanaco. By order of Yacimientos Carboniferos Fiscales, he carried out explorations in the region of lakes Argentino and Viedma (Galante 1953, 1955), and during the summer of 1955 G. Furque created the Lago Argentino geological sheet for the National Agency of Geological Mining. The results were published later (Furque 1971, 1972, 1973).

Flores and Perrot (1961), Bianchi (1967) and Di Benedeto (1973) carried out stratigraphic profiles and collected fossil material in the Cretaceous–Tertiary sequences of the region of lakes Argentino and Viedma.

A. F. Leanza (1972) identified ammonites not mentioned in the past and created a scheme of biostratigraphic zonation, proposing the existence of discontinuities in the Cretaceous succession.

Subsequently, the stratigraphic diagrams of the region were modified with the contributions of Blasco *et al*. (1979, 1980) and Nullo *et al*. (1981a, 1981b); This is discussed by Riccardi (1983). Finally, Riccardi and Aguirre Urreta (1988) and Riccardi and Kraemer (1996) analyzed the biostratigraphy of the Upper Cretaceous of the region of Lago Viedma.

The works of Vilela and Csaky (1968); Arbe and Hechem (1984a), Arbe (1987), and Macellari *et al*. (1989) focused the study of the Cretaceous succession from the sedimentological point of view.

Biddle *et al*. (1986) analyzed the filling of the central and westem zones of the Southern or Magellanic Basin, using seismic-stratigraphic information, and more recently, Manassero (1988), Manassero *et al*. (1990), and Manassero and Merodio (1993) studied the origins of sandstones and clay minerals of the Cretaceous–Tertiary series south of Lago Viedma.

Stratigraphy

The oldest rooks, which constitutes the basement of the region, are represented by Paleozoic sediments and metasediments cropping out in the cordilleran section. Above follows a thick succession of volcanic sediments from the Jurassic age, and marine and continental sediments from the Cretaceous and Paleocene, rising in the pre-Andean and extra-Andean sector with a maximum height of 3700 m (Figs. 2 and 3).

Bahia de la Lancha Formation (Shell CA.P.S.A 1965; Borrello 1967)

Distribution and stratigraphic relations: Rocks belonging to this unit crop out on both margins of the Viedma Glacier, the west flank of the Masters chain, and the right bank of Upsala Glacier (Fig. 2).

The base of this formation has not been observed, while its roof constitutes angular and erosive discordances (Fig. 3) supporting the volcanics of the El Quemado Complex at the junction of Río del Bosque and Río de las Vueltas, north of Lago Viedma.

Thickness: The thickness is difficult to determine because of the faulted and folded complex affecting the unit.

Lithology: Two very different lithographic types were identified on the right margin of Chico Glacier, at the source of the Río Diablo (south of Lago San Martín), on the eastern margin of the Viedma Glacier, in the Viento saddle, and in the Las Vacas Valley (Fig 2, locality 1), on the western margin of the Upsala Glacier.

Lithology 1: Characterized by its sedimentary aspect, formed of altemating sandstones and mudstones with benches whose thickness varies between 0.2 and 2 m. The sediments are of light gray to brownish gray color, massive, with thickness varying between 0.1 and 0.5 m, up to more than 1 m, with granulometry including from coarse conglomeratic to fine sand. The mudstones are of dark gray color and appear intercalated with the sandstones in fining cycles, with thickness varying from a few cm up to 3–4 m. Locally, the sandstone bodies adopt channeled forms with a erosive base. Flow tracings are frequent in the sandstone base, and wavy lamination is present internally. They are interpreted as turbidite deposits.

Lithology 2: Described as phyllites, they are characterized by a progressive loss of sedimentary features, appearance of foliation planes with glossy bright and green to gray color. The injection of white quartz veins and microfolds are common. In the Río Diablo, the phyllites (lithology 2) are found topographically below the sedimentary layers, while on the eastern margin of the Viedma Glacier and the western margin of Upsala Glacier, they appear intercalated between shearing zones.

Paleontology and age: In this formation, the few paleontological discoveries were made in the region of Lago San Martín. Frenguelli (1941) found one impression questionably referable to *Ulodendron*, while Casamiquela (1965) studied ichnites that he attributed to ?*Orchesteropus* sp.

Bonarelli and Nágera (1921) mentioned the presence of dubious impressions and forms related to *Cylindrites*. Similar traces were found in sedimentary rocks on the right margin of the Viedma Glacier (Fig. 3, level n_1) which were tentatively equated to *Palaeophycus tubularis* Hall (Pemberton and Frey 1982). In the Cancha Rayada peninsula (Lago San Martín), Parma (1980) noted fungus, unicellular forms, and carbonaceous remains of vascular plants.

Shell C.A.P.S.A. (1965) mentioned the discovery of pollen, this being the only valid indicator for assigning the age of this formation, which would be from Late Devonian to Early Carboniferous.

El Quemado Complex (Feruglio, in Fossa Mancini *et al.* 1938; Riccardi 1971)

Distribution and stratigraphic relations: This volcanic-sedimentary complex crops out extensively in the Masters chain. To the north the outcrops are expanded, but in the south they tend to disappear east of the channel of the Olla, the northern arm of Lago Argentino (Fig. 2).

Lying uncomformably on the Bahía de la Lancha Formation (Nullo *et al.* 1978) (Fig. 3), although they intercalate in some locations (Lago San Martín or the Río de las Vueltas basin, north of Lago Viedma), uncomformably on said formation, and in the gradual passage to the El Quemado Complex, the red clastic levels called the Arroyo de la Mina Formation (Riccardi 1971). At the headwaters of the Río Guanaco (Figs. 2 and 10, locality 4), it is covered paracomformably by the Springhill Formation or, missing this, the Río Mayer Formation, while in the El Quemado locality (Fig 2, locality 2) (Feruglio 1944; Furque 1973), the upper course of Arroyo Las Hayas and Laguna Pearson or Anita (Fig. 2, locality 3), north of Bahía Cristina, averages a transitional interval in which sedimentary and volcanic layers alternate.

Thickness: The thickness of this unit varies according to location. Katz (1963) mentioned more than 1000 m for the Ultima Esperanza region (Chile); Feruglio (1944) assigned more than 500 or 600 m in the [p. 337] Lago Argentino region, while Furque (1973) mentioned more than 1000 m for the same region. Riccardi (1971) observed between 150 to 500 m as maximum in Lago San Martín. According to observations made in the Masters chain, the thickness of this unit varies frequently because of tectonism affecting it.

Lithology: In the region of Lago San Martín, north of Lago Viedma, Riccardi (1971) and Nullo *et al.* (1978) recognized two sub-units or informal members. One lower, of volcanic nature, composed of andesites, dacites, and riodacites, agglomerated andesitic volcanics and mesosilicic tuffs with predominant purple color, and another, upper pyroclastic, composed of volcanic and tuffaceous sandstones, glassy and crystalline-glassy tuffs, tuffites, and dacitic ignimbrites of clear, brownish gray, and yellowish white color. In the region we studied the lower member is well represented although we have not recognized the upper unit. In the zone of the EI Quemado location, thick pyroclastic beds crop out with limited lateral continuity. Also, in the upper course of the Río Guanaco, levels formed by mantles of dacite and riodacite show an increase in pyroclastic participation toward the top (Becchio 1990).

The emergence of this unit is easily recognized from the yellowish, orangey, and whitish colors of the volcanic layers, which contrast with the darker tones in the units below and above. They have a thick tabular nature recognizable from a distance, and its erosive morphology consists of sharp, abrupt escarpments that limit hills with variable slopes on which are usually preserved remains of the sedimentary cover.

Age: In the upper limits of the El Quemado Complex, Feruglio (1944) mentioned politic intercalations between the porphyric levels, with remains of brachiopods, bivalves, and cephalopods. According to the fauna described (Feruglio 1936–1937), that author assigned an early Tithonian age in the last porphyric levels. On the other hand, Blasco *et al.* (1979) described a section in Arroyo de los Loros, immediately above the porphyrites of the El Quemado Complex, bearing a fauna of early to middle Tithonian age.

A riodacite from the Cancha Rayada peninsula (Lago San Martín) showed an age of 166 ± 10 Ma (Parma 1980). Radiometric dating of the upper levels of the El Quemado Complex, in the Sierra de Sangre (north of Lago San Martín) showed an age of 158 ± 10 Ma (Nullo *et al.* 1978). These values are attributable to the Bathonian and Callovian, respectively, according to the scale of Cowie and Basset (1989). Rb/Sr geochronological studies by Pankhurst *et al.* (1993) indicate isochrones of 136.6 Ma for rocks from the El Quemado Complex in the zone of Lago Pueyrredon, and of 168.2 Ma from the "Chon Aike Complex."

Dating of vulcanites and pyroclastics from the Bahía Laura Complex, cropping out in the Gran Bajo de San Julian, show ages of 161–160–157 and 149 ± 10 Ma (Bathonian–Callovian) (Spalletti *et al.* 1982). Dating realized by de Barrio (1993) corroborated the values attributed to the Bahía Laura Complex.

According to the available data, the El Quemado Complex could have a Middle to Late Jurassic age, and the youngest beds correspond to the Tithonian in the region of Lago Argentino

.

Springhill Formation (Thomas 1949b)

Distribution and stratigraphic relations: This formation was observed for the first time in the region by Blasco *et al.* (1979) in Arroyo de los Loros. New outcrops belonging to this unit were detected in Lago Tanhauser (Fig 2, locality 5), headwaters of Río Cóndor (Fig. 2, locality 6), west of Perez valley (Fig. 2, locality 5), headwaters of Río Guanaco (Fig. 2, locality 4), and Lago Pearson or Anita (Fig. 2, locality 3).

This formation lies paracomformably or uncomformably on the rock of the El Quemado Complex, and over this the mudstones of the Río Mayer Formation lie comformably. The pronounced lateral wedging observed in the outcrops of the headwaters of Río Guanaco could be a consequence of sedimentation in depressions associated with normal faulting (Fig. 10). In the central zones of major subsidence, the Springhill Formation lies paracomformably on the El Quemado Complex, while toward the high structures the paracomformable or uncomformable relationship would suppression the lower levels.

Thickness: The thickness measured in Arroyo de los Loros by Blasco *et al.* (1979) is 98 m, while in Perez valley a minimum of 70 m was measured (Fig. 3).

Lithology: The outcrops west of Perez valley, above de volcanics and tuffs of the El Quemado Complex, begins a succession of calcareous sandstones, fetid, dark gray, of medium to coarse grain, that alternates with mudstones and fine sandstones, with lower resistance to the erosion that form the bench up to 15 meters thick. Remains of bivalves, plants, and ammonites of large dimensions are frequent in the basal levels.

The Arroyo de los Loros succession, described by Blasco *et al.* (1979), is made up of brightly colored sandstones with intercalations of coal at the base, [p. 338] [p. 339] levels of silty claystones and sandstones above that intercalate with dark gray claystones, passing suddenly to mudstones of the Río Mayer Formation. The upper course of Arroyo las Hayas consists of an association of sandstones and silty claystones with plant remains and pyroclastic levels (Arbe 1988).

Paleontology and age: In the section measured to west of Perez valley, we found ammonites close to the base of the sequence: (Fig. 3, Level n_2) *Aspidoceras* cf. *andinum* Steuer (Fig. 4.1a, b), *Aulacosphinctoides* cf. *smithwoodwardi* (Uhlig) (Fig. 4.2a, b), *Aulacosphictoides* sp., *Choicensisphinctes* cf. *erinoides* (Burkhardt), some of these last are large, with 70 meters from the base. (Fig, 3, level n_3) *Subplanites* sp. (Fig. 4.3).

The collection could be referred to the upper level of the early to middle Tithonian (Figs. 3 and 12). In Arroyo Los Loros, this unit bears a cephalopod fauna that, according to Blasco de Nullo *et al.* (1979), includes *Aspidoceras* cf. *haupti* Krantz, *Aulacosphinctoides* sp., *Virgatosphinctes* sp., and bivalves such as *Geukensia*? sp. that allow assuming an early to middle Tithonian age.

In Bahía de la Lancha, Lago San Martín, the Springhill Formation was attributed to the Berriasian (Ricardi 1976, 1977) on the basis of the presence of the genera *Jabronella* Nikolov, *Delphinella* Le Hegarat, and *Neocosmoceras* Blanchet. Micropaleontological studies in levels this formation in Bahía de la Lancha and well Y.P.F.SCA.C.So.39 (Canadón Salto) to the south of Río Coyle, on the eastern border of the Southern Basin, indicate a Valanginian age (Kielbowicz *et al.* 1983). The different ages found are explained by proposing an transgression that started in the Oxfordian–Kimmeridgian, in the south of the basin, and that would have had younger ages toward the north and northeast (Ricardi and Rolleri 1980).

Río Mayer Formation (Hatcher 1897; *nom. subst.* Riccardi 1971)

Distribution and stratigraphic relations: This unit is found widespread in the Southern Patagonian Cordillera, cropping out in the region studied mainly on the flanks and extreme south of the Masters chain, sectors adjacent to the Upsala Glacier, Bahía Clistina, and Spegazzini canal (Fig. 2). It lies paracomformably on the volcanics of the EI Quemado Complex in some sectors, and in others comformably or paracomformably on the clastic levels of the Springhill Formation. The Cerro Toro Formation lies on it paracomformably (Arbe and Hechem 1984a).

Thickness: The thicknesses of this unit are variable regionally. Furque (1973) measured 450 m on Cerro Hobler, while in the headwaters of Río Guanaco he measured a section of 400 m of mudstones but without reaching the contact with the Cerro Toro Formation. If reflectors d_2 and d_3 (Figs. 9 and 11) are equated with the base and top of this unit, the thicknesses vary between 350 and 500 m, similar to those obtained in well Y.P.F.SCA. Cfo. es-1 (Fig. 7).

In Lago San Martín, Riccardi (1971) assigned a thickness of 700 m; while south of Lago Argentino, in the region of Payne (Chile), Soffia and Harambour (1988) indicated for equivalent rocks a thickness varying between 800 and 1200 m.

Lithology: There are laminated dark gray to black mudstones with marked fissility. In the lower levels, with splintery fractures and abundant intercalated calcareous banks with thickness up to four cm, with alternating colors of brownish-red and positive relief. Often the upper levels are concretions of varying sizes, reddish brown color alterations and gray fresh surfaces. These characteristics are observed up the westernmost outcrops of the right margin of the Upsala Glacier.

The basal levels are differentiated from the Springhill Formation by their positive erosive relief, reddish colors, and great lateral continuity (Fig. 5), while the upper levels have dark colors and smooth, negative erosive relief relative to the suprajacent Cerro Toro Formation.

Paleontology and age: This unit is characterized by having an abundant cephalopod fauna corresponding to different levels of the Lower Cretaceous. Nullo *et al.* (1981a) mentioned Berriasian forms in the outcrops of Lago Tanhauser (Fig. 2, locality 5), while Riccardi and Rolleri (1980) noted associations characteristic of the Hauteriavian–Barremian, Barremian–Aptian, Aptian–Albian, and Cenomanian for the region north of Lago Argentino.

In a section measured west of Perez valley, 2 fossiliferous were identified, one lower: (Figs. 3 and 12, level n_4) *Berriasella* cf. *behrendseni* Burckhardt (Fig. 5.1), *Jabronella* cf. *michaelis* (Uhlig) (Fig. 5.2), *Subthurmannia* sp., *Phyllopachyceras aureliae* (Feruglio) (Fig. 5.3) from the late Berriasian, and another upper: (Figs. 3 and 12, level n_5) [p. 340] [p. 341] *Kilianella* sp. (Fig. 5.4), *Neocomites* sp., ?*Subthurmannia* sp., *Busnardoites*? cf. *campylotoxus* (Uhlig) (Fig. 5.5) from the early Valangianian.

Arbe and Hechem (1984a) referred the top of this unit to the late Albian on the basis of fossils coming from Arroyo de las Hayas. The material includes the ammonite *Mortoniceras* cf. *arietiforme* (Spath) (Fig. 6.1) which certifies the age.

Cerro Toro Formation (Cecioni 1955; Katz 1963)

Distribution and stratigraphic relations: This unit is widely distributed in the basins of the Cóndor and Guanaco rivers, while its best exposures are found on the west slope of the Masters chain and the eastern margin of the Upsala Glacier (Fig. 2). It lies paracomformably on the Río Mayer Formation and has an identical underlying relationship to the Alta Vista Formation.

Thickness: The thickness measured on Cerro Horqueta is 1050 m (Arbe and Hechem 1984a), while the thickness measured on the eastern and western margins of Arroyo La Sola (Fig. 2, locality 8) reaches a minimum of 880 m (Figs. 3 and 12).
[p. 342]

Lithology: 4 lithofacies were identified.

Lithofacies CTO 1

These are dark gray mudstones, massive, in banks of 0.4 to 1 m thickness, alternating with dark greenish gray sandstones of 0.01 to 0.02 m thickness with micro-cross-stratification. The ratio of mudstones/sandstones is always greater than 4. In the mudstone levels, it is frequent that ovoid concretions, reddish brown, and algal structures with calcareous cement, are entirely crossed by clastic dikes of 0.05 to 0.10 m size. In this lithofacies are included the "lithofacies of cyclic claystones and siltstones" and the "lithofacies of laminated claystones" of Arbe and Hechem (1984a).

The intercalations of levels of light gray color, calcareous, tuffaceous in this lithofacies, allow rapid identification of the basal levels of this unit on the eastern slope of the Masters chain.

Lithofacies CTO 2

This is characterized by an alternation of mudstones with thickness from 0.20 to 0.50 m and sandstones with thickness from 0.05 to 0.10 m. These latter present micro-cross-stratification, tabular stratification, and base-plane erosion onto the mudstones, in cycles from 0.2 to 0.5 m. The ratio between mudstones and sandstones is greater than 2.

In the west section of La Sola were observed levels with synsedimentary deformation, that partially bevel this lithofacies. They are usually present associated with lithofacies CTO 1, vertically and laterally. It is equivalent to the "thin turbidites" lithofacies of Arbe and Hechem (1984a).

Lithofacies CTO 3

These are composed of sandstones in benches up to 0.20 m with positive gradation and micro-cross-stratification, finishing with pelitic levels with parallel-plane laminations. They form cycles of decreasing grain size from 0.2 to 0.5 m with frequent intraclastic mudstones at the base. There are often bioturbations. Arbe and Hechem (1984a) mention bioturbations "of *Zoophycus*, *Helminthoudes, Poliphyllum, Chondrites,* etc. type together with limited remains of *Inoceramus* cf. *steinmanii*." This lithofacies is equivalent to the "classic turbidites" of the same authors.

Lithofacies CTO 4

Formed by yellowish, whitish sandstone with thickness up to 1 m. They have regular internal gradation, with an erosive base with intraclasts, reaching a granulometry of thick sand to fine gravel. Amalgamations that increase the strength of the banks are frequent. The cycles usually end with thin levels of gray mudstones. The most common internal structures are micro-cross-stratification and water escape structures. This lithofacies could be equivalent to the "graded sandstones" and the "sandstones with water escape" of Arbe and Hechem (1984a). The "siltstones and marls" and "massive green sandstones" lithofacies described by these authors were not identified in the Arroyo La Sola section.

The association of lithofacies allows defining four sequences of ascending grain and strata (Fig. 12). The first two could correspond to a lower member of the Cerro Toro Formation *sensu* Arbe and Hechem (1984a) while the other two could be correlated with the upper member.

The upper and lower members of the Cerro Toro Formation are correlated with seismic sequences S3 and S4, limited by discordances d3, d4, and d5, respectively (Figs. 9 and 12).

This unit is recognized by its dark gray colors and a typical profile of alternating hard-soft erosion, and the positive relief relative to the underlying unit (Río Mayer Formation). To the east the erosive morphology is softer because of the lesser samitic participation.

Paleontology and age: Various fauna-bearing levels have been identified. Associated with lithofacies CTO 1 in Arroyo la Sola (Figs. 3 and 12, level n_6) (Fig. 2, locality 8) were found *Birostrina*? cf. *concentrica* (Park) (Fig. 5.6). This species is found in the middle–late Albian and could reach the early Cenomanian. Above were found several levels bearing *Inoceramus* sp. (Fig. 12, level n_7). Associated with lithofacies CTO 1 and CTO 2, but in a higher stratigraphic position, was found an ammonite of large dimensions (Fig. 12, level n_8), identified as *Pachydesmoceras*? sp., whose age was in early Cenomanian–Coniacian time. Above and on the eastern margin of the Arroyo La Sola (Fig. 2, locality 8) were found remains of bivalves and ammonites (Fig. 12, level n_9) that could correspond to ?Pachydiscidae indet. and *Gauthiericeras* cf. *santacrusense* (Leanza) (Fig. 8.1), referable to the middle–late Coniacian.

In a similar stratigraphic position, but in the Los Kaikenes valley (Fig. 2, locality 9), [p. 343] [p. 344] were identified (Fig. 12, level n_{10}) ?*Eupachydiscus* sp. and *Gauthiericeras* cf. *santacrucense* (Leanza), referred to the middle–late Coniacian.

Above, both on the eastern margin of the Arroyo La Sola (Fig. 2, locality 8) and the Los Kaikenes valley (Fig. 2, locality 9), were identified (Fig. 12, level n_{11}) *Inoceramus* cf. *steinmanni* Wilckens, *Inoceramus* cf. *andinus* (Wilckens), and *Sphenoceramus* cf. *lingua* (Goldfuss) (Fig. 8.3). This last species indicates the late Santonian–early Campanian in Europe. In Estancia Nídaros (Fig. 2, locality 14) were found *Neopuzosia*? cf. *guanaquesis* Blasco de Nullo *et al.* 1980, *Mesopuzosia*? sp., and *Gaudryceras glaneggense* (Redtenbacher). To the west of Estancia La Herradura (locality 13, Fig. 2) was found a large ammonite *Mesopuzosia*? sp., and *Gauthierceras* cf. *santacrucence* (Leanza) referred to the middle–late Coniacian.

In Estancia Los Hermanos, on the eastern margin of Arroyo Mylodon (Fig. 2, locality 15), were found *Puzosia* sp., and above *Austiniceras* cf. *A.*?*magellanicus* (Leanza) (Fig. 7.1) and *Scaphites* cf. *obliquus* J. Sowerby (Fig. 7.2), this latter species being of Cenomanian age.

Arbe and Hechem (1984a) mentioned the presence of indeterminate ammonite remains and considered that the discovery of *Calycoceras* sp., described by Riccardi (1979), came from basal levels in this formation, associated with the "lithofacies of claystones and cyclic siltstones." They assigned a Cenomanian–Turonian age to the lower member of this formation based on the presence of *Calycoceras* sp. and *Inoceramus* cf. *hobetsensis* Nagao, while considering the upper member as of Conician–Santonian age.

In this work, the ammonites and bivalves found in the lower section of this formation (levels n_6–n_7–n_8) attest to an age between late Albian–early Cenomanian and early Coniacian for the lower member; while the discoveries in the upper levels permit assigning a middle–late Coniacian (levels n_{9-10}) to late Santonian–early Campanian (level n_{11}) age.

The fauna found in the lower member corresponds stratigraphically with that of the middle and upper levels of the El Alamo section, northern margin of Lago Viedma (see Riccardi and Aguirre Urreta 1988), which in its highest part contains *Pachydesmoceras* cf. *linderi* de Grossouvre (Fig. 7.3a-b) of late Turonian age (Riccardi and Kraemer 1996).

The faunas of these levels, corresponding to the *Anapachydiscus steimnanni* Association Zone, was referred to the lower Santonian–Campanian by Blasco de Nullo *et al.* (1980), Riccardi (1984), Arbe and Hechem (1984), and Kraemer (1991). Riccardi and Aguirre Urreta (1988) and Riccardi (1988) relocated this zone in the Turonian–Coniacian, considering that it belonged to the fauna of the highest levels of the El Alamo section, northern margin of Lago Viedma. Later, Riccardi and Kraemer (1996) corrected this equivalence, attributing the fauna of this last locality to the *Pachydesmoceras* Association Zone (upper Turonian) and supporting the Santonian– early Campanian age of the *Anapachydiscus steimnanni* Association Zone.

Alta Vista Formation (Furque 1973; *nom. transl.* Arbe and Hechem 1984a)

Distribution and stratigraphic relations: This unit crops out exclusively east of the Masters chain to the north and south of Río Guanaco (Fig. 2). Lying paracomformably on the Cerro Toro Formation and overlying the Anita Formation comformably (Figs. 3 and 12).

Thickness: The thickness of the lower member is approximately 250 m between Arroyo Horqueta and Cañadón Hondo (Fig. 2, locality 10), while the upper member varies between 70 and 100 m in the lower banks of the stream El Turbio (Arbe and Hechem 1984a, b). The thickness measured west of the Los Kaikenes valley is on the order of 500 m for the lower member (Kraemer 1991).

This formation is recognized by the sudden appearance of strong benches of whitish-yellow sandstones and conglomerates, contrasting with the dark gray, thinly stratified mudstones and sandstones of the Cerro Toro Formation. It usually forms a landscape of hills and ravines similar to the Anita Formation in some places, but it differs by the limited lateral continuity of the benches due to wedging.

Lithology: Lower member: Lithofacies AVI1: Coarse to conglomeratic whitish-yellow sandstones that grade to medium to fine sandstones. Having lenticular stratification with an erosive base. Frequent amalgamations forming thicknesses up to 3 m, where mudstone levels are recognized fragmentarily, dismembered and encompassed in a sandy matrix. [p. 345] [p. 346]

Reducing the granulometry upward, mega-waveletes are frequent up to 0.20–1.5 m in wavelength, with plant remains. The cycles end in levels of gray mudstones with thicknesses of 3–4 m.

In the middle part of the lower member are observed conglomeratic levels with clasts up to 0.03 m in diameter, with a net erosive base and channel-fill morphology. They reach up to a width of 5 m with thicknesses of more than 2 m. Their axis has a north-south to northwest-southeast route. Re-transported fragments of valves of

Gervillaria sp. are frequent in the bases of the benches. The best outcrops are found south of the Río Guanaco in the upper channel of Arroyo EI Turbio. This lithofacies is equivalent to the "lenticular sandstones" of Arbe and Hechem (1984a).

Lithofacies AVI2: These are grayish-black mudstones, with intercalations of calcareous, yellowish-brown siltstones. In these rocks are often found remains of *Baculites* sp. Equivalent to the "black mudstone lithofacies" and "marls and sandstones lithofacies" of Arbe and Hechem (1984a). Lithofacies AVI1 and AVI2 appear together, forming fining-upward cycles on the order of hundreds of meters (Fig. 12).

Upper member: Lithofacies AVI3: These are grayish-black mudstones with thin parallel laminations in tabular benches. They intercalate with fine, greenish-yellow sandstones, in benches up to 0.1 meter thickness, with micro-cross-stratification. Levels of calcareous siltstones and concretions of up to 0.3 m thickness are common. Arbe and Hechem (1984b) called these rocks "Facies Y."

Lithofacies AVI4: These are dark gray and reddish-black siltstones, consolidated and siliceous, between which are intercalated fine, yellowish-green sandstones with thickness up to 0.3 m, with an erosive base plane. These are equivalent to "Faces Z" of Arbe and Hechem (1984a). Lithofacies AVI4 lies above AVI3 in fining-upward cycles in Arroyo EI Turbio (Fig. 12).

Paleontology and age: In the lower member of this unit, west of Los Kaikenes valley (Fig. 2, locality 9), levels with fragments of re-transported bivalves, *Gervilliara* sp., are frequent (level n_{12}) (Figs. 3 and 12).

In the upper member, at the source of Arroyo EI Turbio (Fig. 2, locality 11), are found *Anapachydiscus* cf. *hautali* (Paulcke) and *Argentoscaphites mutantibus* Blasco de Nullo *et al.* (level n_{13}) (Fig. 3 and 12). The following association was found on the lower channel of Arroyo EI Turbio (Fig. 2, locality 12): *Anapachydiscus* cf. *hautali* (Faulcke), *Dentalium* sp., *"Cytherea" rothi* Wilckens, *Cucullaea* (?) sp., *Cinulia pauper* Wilckens (?) (Level n_{14}) (Figs. 3 and 12). This association shows an early Campanian age. *Maorites* ? sp. was found in the same locality, but in a block coming from the upper levels of the Alta Vista Formation (level n_{14}).

In material collected by Arbe and Hechem (1984b) in the region Arroyo EI Turbio, Riccardi identified the following taxa: Facies Y: *Anapachydiscus* ? sp. and *Parabinneyites paynensis* (Fabre) (Fig. 8.6), Facies Z: *Anapachydiscus* sp. and *Placenticeras* cf. *santacrucense* Leanza (Fig. 8.5).

Riccardi (1983) referred levels of this unit to the early Campanian, which in Arroyo Centinela, on the southern margin of Lago Argentino, contain representatives of *Karapadites, Natalites* Collignon gen., and *Neograhamites* Spath. Based on the fauna found (levels n_{13} and n_{14}), the age of the upper levels of formation Alta Vista Formation could be early Campanian.

Name and correlations: Furque (1973) defined the Las Hayas Formation, composed of the Horqueta and Alta Vista members. Riccardi and Rolleri (1980) and Riccardi (1983) included the kosmaticeratid-bearing mudstones, which crop out on the southern margin of Lago Argentino below the Anita Formation, in the Cerro Toro Formation.

Blaco de Nullo *et al.* (1980) and Nullo *et al.* (1981a-b) included these levels in the Río Guanaco Formation. Arbe and Hechem (1984a) elevated the Alta Vista

Member *(sensu* Furque 1973) to the rank of formation, and divided it into two members; a lower one of 500 m thickness composed of deep marine environment facies, and another upper one of 250 m thickness and platform facies.

In this work, PEK shares the view of Arbe and Hechem (1984a), because both the Cerro Toro Formation and the Alta Vista Formation are mappable units with field characteristics that allow their differentiation and recognition. This unit corresponds with seismic sequence S_5, and its base with subsurface discordance d_5 (Fig. 9).

Anita Formation (Feruglio, in Fossa Mancini *et al.* 1938)

Distribution and stratigraphic relations: This unit crops out extensively both a the north and south of Lago Argentino. In the studied region it was possible to follow its outcrops in an almost continuously from the north coast of Lago Argentino, Arroyo EI Turbio basin, and the mouth of the Río Guanaco (Fig. 2).

This formation is recognized both north and south of Lago Argentino by its whitish-yellow benches that form abrupt reliefs and slopes that can be followed for kilometers because of their lateral continuity.

It lies comformably on the upper member of the Alta Vista Formation and is covered comformably by the Pari Aike Formation (Fig. 3).

[p. 347]

Thickness: Its thickness is from 40 to 50 m in the lower channel of Arroyo El Turbio (Fig. 2, locality 12), 130 m south of estancia La Herradura (Fig. 2, locality 16), and more than 255 m in Cañadón Hondo (Fig. 2, locality 10), which indicates a rapid increase in thickness from west to southwest (Fig. 12).

Lithology: Furque (1973) divided the Anita Formation into the El Barco and Cachorra members. Arbe and Hechem (1984b) divided the Anita Formation into four members, La Asunción, El Barco, La Irene, and Cachorro, the latter one recognized only south of Lago Argentino.

In this work the El Barco and La Asunción members are included in the Anita Formation north of Lago Argentino. The La Irene Member is considered to be stratigraphically disassociated from the previous two (see below).

The outcrops situated east of the studied region, on both margins of the Río Leona, correspond to the La Asunción Member. The outcrops west of Canadón Hondo (Fig. 2, locality 10) correspond to the El Barco Member of the Anita Formation *sensu* Arbe and Hechem (1984b). The rapid increase in thickness from east to west occurs as the lower ends of the Pari Aike Formation are replaced by thick sandy banks, typical of the Anita Formation (Fig. 12).

The outcrops of Arroyo El Turbio and Río Leona begin with siltstones and sandy siltstones associated with fine to very fine sandstones in inverse sequences of greenish- to yellowish-gray. Frequent load casts, flows, and levels with intraclasts are observed in the base of the sandstones. Its thickness varies from 0.5 to 1 m. Carbonized stems, poorly conserved and indeterminate bivalves, are found. These correspond to high-energy subtidal deposits ("Facies "Ñ" of Arbe and Hechem 1984b).

Above follows a succession of fine sandstone banks that grade from medium to thick, partly conglomeratic, yellow to yellowish-gray in color. They present a massive appearance from bioturbation, with thickness up to 4 m. Often finishing in calcareous levels, purple with ripple marks, generally bearing bivalves and remains of stems. There are frequent large-scale cross-stratifications. These are interpreted as high-energy subtidal to intertidal deposits ("Facies O" of Arbe and Hechem 1984) (Fig. 12).

In Cerro El Barco (Fig. 2, locality 17), this formation reaches 500 m in thickness, and in it 4 transgressive-regressive cycles are recognized of a deltaic environment referable to the El Barco Member (Arbe and Hechem 1984) (Fig. 12).

Paleontology and age; Riccardi and Rolleri (1980) cited the presence of bivalves and gastropods, and a unique ammonite found by Feruglio (1936-1937) 100 m from the base, "*Holcodiscus hautali* Paucke." This ammonite was later referred to the genus *Pseudokossmaticeras* Spath by Leanza (1968). Finally it was described by Riccardi (1983) as *Kossmaticeras* (*Natalites*) cf. *hautali,* so that the lower part of the Anita Formation should be early Campanian and not Maastrichtian as had been supposed.

For their part, Arbe and Hechem (1984b) mentioned several levels bearing bivalves and gastropods in their Anita Formation, assigning, based on stratigraphic considerations, a Campanian to early Maastrichtian age.

In the outcrops of the north coast of Lago Argentino (Cañadón Hondo), levels of bivalves *Gervillaria* ? sp. (Figs. 3 and 12, level n_{15}) are frequent, similar to those found as fragments in the conglomeratic levels of the Alta Vista Formation.

Name and correlations: Feruglio (1944 and in Fossa Mancini *et al.* 1938) named the "Anita Strata" for the lower section of the "Sandy Complex of the Senonian," whose best expositions are found on the eponymous estancia south of Lago Argentino. He used the same name for the sandy levels found below the "Dinosaur Strata" or "Pari Aike or Aiken Strata" in the sections of Cerro Fortaleza, Barrancas Blancas, etc., north of Lago Argentino (Feruglio 1944).

Bianchi (1967) and Furque (1973) formalized the name used by Feruglio (in Fossa Mancini *et al*. 1938), giving it a formational rank. Furque (1973) divided his Anita Formation, from bottom to top into the EI Barco and Cachorro members, the latter corresponding to a transition between the marine sediments of the first and the continental origins of his Chorrillo Formation.

Riccardi and Rolleri (1980) maintained Feruglio's (1944) original concept considering the Anita Formation as a light-colored samitic assemblage, which back the pelitas [pellets""] attributed to the Cerro Toro Formation and below the continental sediments of the Pari Aike Formation.

Arbe and Hechem (1984b), while doing the stratigraphic analysis of the region, divided the Anita Formation into four members: EI Barco, La Asunción, La Irene, and Cachorro. In the region of the Río Leona, they considered that the La Irene Member was disposed above the the Cerro Fortaleza Formation whereas the La Asunción Member was below. Lately Macellari *et al.* (1989) gave the La Irene Member a formational rank.

In this work, we return to the concept of Riccardi and Rolleri (1980) and restrict the Anita Formation to the essentially sandy levels that lie over the sandy-pelitic marine [p. 348] sediments of the Alta Vista Formation or the Cerro Toro Formation *(sensu* Arbe and Hechem 1984b) (Arroyo EI Turbio and south coast of Lago Viedma, respectively), and are covered by pelitic sediments of the Pari Aike Formation *(sensu* Riccardi and Rolleri, 1980). It is excluded from the Anita Formation and considered the La Irene Member of the Anita Formation *sensu* Arbe and Hechem (1984b).

Pari Aike Formation (Feruglio, in Fossa Mancini *et al.* 1938).

Distribution and stratigraphic relations: It crops out widely in the region of the Río Leona, Arroyo EI Turbio, Cañadón Hondo, and lower stretch of the Río Guanaco (Fig. 2). It lies comformably on the sandstones of the Anita Formation (Furque 1973; Riccardi and Rolleri 1980; Arbe and Hechem 1984b), and is covered uncomformably (Macellari *et al.* 1989) on the La Irene Formation.

Thickness: The thickness is variable, 350 m in Cerro Fortaleza, 500 m on Barrancas Blancas (south coast of Lago Viedma) (Arbe and Hechem 1984b); while south of Arroyo EI Turbio minimal thicknesses varying from 175 to 300 m have been measured (Kraemer 1991). To the west, these are replaced by the Anita Formation (Arbe and Hechem 1984b) (Fig. 12).

Lithology: This unit is composed of more than 460 m of friable, dark gray claystones with a typical light-and-dark banding, and intercalations of yellowish to brownish-gray, barely cemented sandstones. Macellari *et al.* (1989) recognized a lower member constituted of fining-upward cycles of argillaceous sandstones that grade to grayish mudstones, with a thickness of 220 m. The upper member, more than 240 m thick, is formed of unconsolidated, olive green to purple claystones with rare intercalations of friable whitish sandstones. Often they present carbonaceous levels, silicified trunks, and remains of plants. A gradual replacement occurs to the west, by levels with greater clastic participation, in fining-upward cycles composed of basal conglomerations, with pelitic intraclasts that pass into sandstones with cross-stratification, and finally to reddish mudstones.

These deposits are interpreted as sequences of meandering rivers. The presence of carbonaceous levels in the upper levels, suggests the existence of fluvio-lacustrine intervals (Macellari *et al.* 1989). This unit is recognized by the typical "huaiquerias" or badlands landscape, of gray tones and with a classic light-and-sark banding in the region of the Río Leona. It contrasts with the rough hills that form the Anita and Irene formations, which lie below and above, respectively.

Paleontology and age: In this formation, Arbe and Hechem (1984b) mentioned remains of *Ostrea* sp., indeterminate bivalves and gastropods in their "Faces P" (Figs. 3 and 12, level N_{16}). In "Faces R" frequent remains of vertebra of dinosaur vertebrae and silicified trunks are indicated (level n_{17}).

Oviedo (1982) mentioned the following fauna, in levels equivalent to the base of this formation in the place La Asunción: *Ostrea ultima spei* Wilckens, *Melanopsis* sp., Pholadomydae (internal molds), and Ostreidae (internal molds) (level n_{16}). In the middle and upper levels were identified palynomorphs and a marine intercalation with microplankton (Oviedo 1982) (Fig. 12, level n_{18}). Based on the relations of the base and summit, Riccardi and Rolleri (1980) assigned an age between Aptian–Albian and Maastrichtian to the Pari Aike Formation.

Based on stratigraphic considerations, Arbe and Hechem (1984b) assigned the Cerro Fortaleza Formation a Campanian age, whereas Macellari *et al.* (1989) assigned a late Campanian age.

In the region of the Río Leona and east of Lago Viedma, the stratigraphic relations of the Pari Aike Formation indicate an age between late Coniacian and Maastrichtian.

Name and correlations: Feruglio, in Fossa Mancini *et al.* (1938), named the "Pari Aiken Strata" for 250 m of claystones, sandstones, and conglomerates with dinosaur bones that would be arranged above the "Mata Amarilla Strata" and below the "Man Aike Strata" in the valley of the Río Sheuén. Feruglio (1944) used the name "Pari Aike Strata" or "Dinosaur Strata" for the continental levels above the "Anita Strata" and below the "Man Aike Strata" in the region of the Río Leona, north of Lago Argentino. South of this lake, he used the name "Chorrillo Strata" for continental sediments in a similar stratigraphic position, that is to say, above the "Anita Strata" and below the "Calafate Strata."

Bianchi (1967), Turic (1967, 1968), Furque (1973), and Nullo *et al.* (1981a, b) used the name "Chorrillo Formation" to refer both to the "Chorrillo Strata" and to the "Pari Aike Strata" of Feruglio (1944). Leanza (1972) used the name Pari Aike Formation for continental strata south of the Río Shehuén.

Riccardi and Rolleri (1980) named the Pari Aike Formation for continental sediments cropping out in the localities of Pari Aike, Lago Cardiel, Lago Argentino, the left margin of the Río Leona, and the right margin of the Río Guanaco, which lies on sediments of marine origin. This unit is correlated with the "Chorrillo Strata" or "Chorrillo Formation" of Feruglio (1944), Leanza (1972), and Furque (1973). [p. 349]

Arbe and Hechem (1964b) maintained the name of Chorrillo Formation for the continental levels cropping out south of Lago Argentino, and proposed the name Cerro Fortaleza Formation for the surfacing cropping out between Barrancas Blancas and both margins of the Río Leona, a criterion that was subsequently endorsed by Macellari *et al.* (1989). This separation is based on that both would form "two lithographic units easily differentiated and associated with different depositional cycles" (Arbe and Hechem 1984b, p. 145).

For a question of priority and with the object of avoiding the proliferation of formational names between similar lithostratigraphic units, in this work the name Pari Aike Formation is used in the sense of Riccardi and Rolleri (1980).

La Irene Formation (Arbe and Hechem 1984b; *nom. transl.* Macellari *et al.* 1989).

Distribution and stratigraphic relations: Isolated outcrops of this unit occur on both margins of the Río Leona (Fig. 2).

Lying uncomformably on the Pari Aike Formation by mediating a marked sedimentological break, therefore the Man Aike Formation overlies it with a low-angle angular uncomformity.

Thickness: The thickness varies between 20 m in the zone of the Río Leona to more than 220 m in the Calafate locality (Macellari *et al.* 1989).

Lithology: This unit consists of fining-upward cycles of conglomerates with cross-stratification and well-rounded clasts up to 12 cm in diameter that grade to fine sandstones and pelites. The thickness of these cycles varies between 6 and 10 m, although frequently present amalgamations. The conglomerates present clastos of acidic volcanics, ignimbrites, basalts, andesites, diorites, quartz, quartzites, metamorphics, and chert. They are interpreted as high-energy fluvial deposits with rare fine material, typical of anastomosing rivers (Macellari *et al.*1989).

In the outcrops of Cerro post (Fig. 2, locality 18), this unit starts with sandy and conglomeratic levels with clasts of 3 to 4 cm in diameter, dark green colors, and an erosive base including remains of silicified trunks. This formation is easily recognized by a positive erosive relief and dark colors relative to the Pari Aike Formation.

Age: The presences of bivalves of Tertiary age *(Venericardia* sp.) in carbonate levels of the Calafate Formation equivalent to the Man Aike Formation of Feruglio (1944) (Macellati et a1. 1989, page 231), above the La Irene Formation in Cerro post (Fig. 2, locality 18), and the remains of dinosaur vertebrae in the underlying Pari Aike Formation, suggest a Maastrichtian age for this unit.

Names and correlations: The conglomeratic levels above the Pari Aike Formation, north of Lago Argentino, were included in the Man Aike Formation by Furque (1973), Leanza (1972), and Riccardi and Rolleri (1980), whereas Nullo *et al.* (1981a) included them in the Calafate Formation. Arbe and Hechem (1984b) considered this unit as the La Irene Member of their Anita Formation, whereas Macellari et al. (1989) assigned a formational rank.

The criterion followed by Arbe and Hechem (1984b) presents the formal and practical inconvenience of separating two members of a single formation (La Irene and La Asunción members) by the Cerro Fortaleza Formation. The criterion of Macellari *et al.* (1989) for giving a formational rank, followed in this work, is based in the clear uncomformity and marked facies change that this unit present relative to the limit, although not necessarily shared in the correlations of units between the north and south of Lago Argentino.

Man Aike Formation (Feruglio, in Fossa Mancini *et al.* 1938).

Distribution and stratigraphic relations: North of Lago Argentino, the outcrops of this unit can be followed almost continuously on both margins of the Río Leona (Fig. 2). The Calafate Formation, partially equivalent to the Man Aike Formation of Feruglio (1944), Macellari *et al.* (1989, p. 231), lies uncomformably on the La Irene Formation, north of Lago Argentino. The Río Leona Formation lies in apparent conformity on the Man Aike Formation (see Riccardi and Rolleri 1980; Arbe 1987) or by uncomformity (Russo et al. 1980).

The uncomformity at the base of the Man Aike Formation could be related to the uncomformity recognized by Riggi (1979) between the Maastrichtian and Eocene in the eastern sector of the Austral Basin, at *marker* G7 of the Chilean geologists (Soffia and Harambour 1988) of Maastrichitian age, recognized in the Austral Basin area or at the late Paleocene unconformity (Biddle *et al.* 1986) depending on the age assigned to this unit. Macellari *et al.* (1989) located the unconformity of the base of this unit in the Paleocene without many details.

Thickness: The thickness of this unit is on the order of 110 m in the the Río Leona valley (Feruglio 1944; Riccardi and Rolleri 1980), whereas Arbe and Hechem (1984b) indicated a thickness of approximately 100 m in estancia La Irene.

[p. 350]

Lithology: This unit consists of medium- to coarse-grained sandstone, generally with diagonal, intercrossed lamination, of yellowish-green color, with intercalations of fine conglomerates that disappear to the east (Riccardi and Rolleri 1980). Toward the top follow yellowish and greenish calcareous sandstones with remains of oysters with cross-stratification.

Paleontology and Age: This unit bears an abundant fauna of bivalves, gastropods, and brachiopods, teeth of selachians, and fragments of dinosaur bones. Based on the affinities of its abundant fauna, its age would be Maastrichtian–Paleocene (Riccardi and Rolleri 1980) or Maastrichtian (Arbe and Hechem 1984b; Manassero 1988). Nullo *et al.* (1981b) assigned an early Tertiary age to their Calafate Formation, without eliminating a Maastrichtian age, on the basis of the presence of palynomorphs and remains of fungus whose upper levels correlate to the Man Aike Formation north of Lago Argentino.

Macellari *et al.* (1989) proposed correlating the Man Aike Formation north of Lago Argentino with the upper levels of the Calafate Formation south of the same lake, composed of calcareous sandstones with abundant colonies of bryozoans, corals, brachiopods, and bivalves. The levels attributed to this unit in its subsurface could be of middle Eocene age, according to the microfauna (Malumián and Nañez 1988).

Given the transgressive character of this unit toward the north, a Paleocene age is adopted in this work for this formation, possibly reaching the Maastrichtian south of Lago Argentino (Calafate and Cerro Dorotea formations).

Name and correlation: The lower and upper limits of this unit could be the disconformities of the late Maastrichtian *(Marker G7* of the Chilean geologists) and late Paleocene, respectively, both identified by Biddle *et al.* (1986) in the subsurface of the Austral Basin. It could be correlated with the regionally recognized transgressive episode of Maastrichtian age, in the Argentine northeast, in the Atlantic basins of Colorado–Salado, Quiriquina Island in Chile, etc. (Riccardi 1987).

This transgression could also be related to the rise in sea level on a global scale, registered beginning at 68 Ma (late Maastrichtian), extending to the Paleocene, and which culminated with a fall in sea level at 58 Ma in the late Paleocene (Haq *et al.* 1987).

Feruglio (in Fossa Mancini *et al.* 1938), Feruglio (1944, 1949), and Piatnitzky (1938) named the "Man Aike Strata" or "Man Aike Sandstones" for a group of sandstones that crop out in the region of Río Shehuén and Río Leona above the "Pari Aike Strata" and below the "Río Leona Strata."

The same name, formalized, was used by Furque (1973), Leanza (1972), and Riccardi and Rolleri (1980). Arbe and Hechem (1984b) characterized the Calafate Formation as an identifiable unit north and south of Lago Argentino, equivalent to the "Calafate Strata" and partially to the "Man Aike Strata" of Feruglio (1944). North of this lake, Arbe (1987) located the Calafate Formation below the Man Aike Formation.

Furque (1973) considered that the Man Aike Formation rested conformably on the Calafate Formation, whereas Riccardi and Rolleri (1980) correlated the Man Aike Formation with the Cerro Dorotea Formation farther south, the same as Manassero (1988) and Macellari *et al.* (1989). Nullo *et al.* (1981a) correlated the Man Aike Formation with the highest end of the Calafate Formation.

In this work, we respect the original name, used for the northern sector of Lago Argentino by Feruglio (1944, in Fossa Mancini *et al.* 1938), alluding to the homonymous locality (estancia Man Aike) located 35 km northeast of Mata Amarilla, following the criterion of Riccardi and Rolleri (1980), and correlate this formation with the upper ends of the Calafate Formation south of Lago Argentino.

Seismographic interpretation and analysis of discontinuities.

570 km of seismic lines were counted for the interpretation, registered east and north of Lago Argentino, respectively, data from an exploratory well (YPF-SCA-CFo-es-1) and the rate law (Kraemer 1991). Two lines of good quality were selected (YPF 8111 and YPF 8124-25) with the object of showing the identified seismic sequences (Figs. 9 and 11).

Seismic sequence S_1

This sequence has external forms typical of depression fills (Mitchum *et al*. 1977), limited in the base and ceiling by disconformities. The basal disconformity d_1 is identified by the relation of *onlap* or filling truncation on a discontinuous and stepped reflector, which is interpreted as a substratum affected by normal faulting (Badley 1985). The ceiling unconformity d_2 corresponds to a strong reflector with high reflection amplitude and good regional lateral continuity in which are observed relations of *toplap* and/or erosive truncation (Fig. 9).

Internally the reflectors adopt forms of depression fills with divergent configurations developed in two sectors separated by a high (Fig. 9). The reflectors of the base of the sequence [p. 351] show little lateral continuity and low reflection amplitude, rising upward with a rapid lateral divergence toward the depressions, which would indicate sediments with uniform lithology originating in a high-energy environment (Mitchum *et al*. 1977) with limited contrast with respect to the basement. Upward, the largest lateral continuity and amplitude of the reflectors indicate deposits of [p. 352] [p. 353] a lower-energy environment. The rapid lateral wedging of the reflectors with typical forms of depression fills in the entire sequence suggests a strong structural control on sedimentation.

The reconstruction of unit S_1 by horizontalization of the ceiling reflectors (Fig. 9) shows an irregular paleotopography with depressions separated by highs that are evidence of a strong local subsidence controlled by normal faulting.

The faulting in the substratum and the characteristics of filling permit interpreting this sequence as deposits associated with local or hemigraben basins (Prosser 1993) similar to those associated with Middle-Upper-Jurassic volcanism of the El Quemado Complex described by Uliana *et al.* (1985) for the Austral Basin. Unconformity d_2 essentially marks the contact between the deposits associated with normal faulting (S_1) and the post-tectonic deposits (S_2).

The truncation of reflectors produced by sedimentation associated with the normal faulting are clearly observed in outcrops of the source of the Río Guanaco (Fig. 10) and in seismic (Fig. 9). Unit S_1 is assigned a Tithonian age based on the correlation of unconformity d_2 with the ceiling of the early to middle Tithonian Springhill Formation at the surface (Fig. 10). It is correlated with the "Springhill Transgressive Subcycle" of Arbe (1987, 1988).

Seismic sequence S_2

This sequence is limited by unconformities d_2 and d_3. Unconformity d_2 is a potent reflector recognized in all the interpreted seismic lines, in which toplap reflectors are observed.

Unconformity d_3 is a reflector with good lateral continuity in which *toplap* and *onlap* of reflectors are observed (Figs. 9 and 10). The reflection configuration is of parallel to sub-parallel type with lower amplitude and continuity in the base than in the ceiling, and is interpreted as originating in sediments of a platform environment with uniform subsidence.

The reconstruction of sequence S_2 through the horizontalization of ceiling reflectors, shows a paleotopography with greater regularity than that corresponding to unit S_1, indicating a general and uniform subsidence during its deposition, although respecting the inherited background configuration of the previous seismic sequence. The lateral correlation of the Cerro Fortaleza well through reflector d_2 (Figs. 9 and 12) permits equating unit S_2 with the Río Mayer Formation on the surface, formed by pelites in a platform environment (Fig. 12).

Unconformity d_3 of the ceiling of the unit is related to the first turbidite contributions in the basin represented by the base of the Cerro Toro Formation and unconformity C_1 of the Cenomanian, recognized by Biddle *et al.* (1986) in the subsurface of the Austral Basin. This correlation permits assigning a Berriasian–Albian age to unit S_2, which includes the Río Mayer Formation. Seismic sequence S_2could be correlated with the "Río Tarde Regressive Subcycle" of the "Río Mayer Cycle" and the "Arroyo Potranca Transgressive Subcycle" of the "Lago San Martín Cycle" of Arbe (1987, 1988).

Seismic sequence S_3

This sequence is defined by unconformities d_3 and d_4, the latter identified by the *onlap* of reflectors of the base of unit S_4 (Fig. 11) and by the rise in the reflection frequency of S_3 to S_4 (Fig. 9). The configuration of reflection is parallel to subparallel with continuity and growing amplitude toward the ceiling that would indicate an increase in clastic participation, which adds up a to a decrease in reflection frequency suggesting a parallel increase in the thickness of the upper levels (Fig. 9)

The reconstruction of the sequence by horizontalization of the ceiling reflectors, shows the background of a smooth basin, maintaining the subsiding tendency of the depressions defined early in units S_1 and S_2.

This sequence is related to the lower member of the Cerro Toro Formation sensu Arbe and Hechem (1984a) and the two turbidite sequences increasing in both grain and stratum of the base of the formation (Figs. 3 and 12), whose age could be Cenomanian–Turonian to early Coniacian. It is correlated with the Piedra Clavada regressive subcycle of the Lago San Martín Cycle and the Shehuén transgressive subcycle of the Mata Amarilla Cycle of Arbe (1987, 1988), linking the discontinuity between both subcycles with the boundary between the two turbidite sequences of the lower member of the Cerro Toro Formation on the surface (Fig. 12).

Seismic sequence S_4

It appears defined in its base ceiling by unconformities d_4 and d_5. Unconformity d_4 is clearly observed in the line of the western sector by the *onlap* of the basal reflectors of unit S_4 and an important lateral change of thickness (Fig. 6). Unconformity d_5 of the ceiling is observed in the line of the eastern sector, marked by an abrupt change in the reflection frequency (Fig. 9).

In this sequence, the reflection configuration is parallel to subparallel with good lateral continuity in sectors and decreasing reflection amplitude toward the ceiling. The decrease in reflection frequency suggests an increase in the thickness of the upper levels (Fig. 9).

The reconstruction of unit S_4 by horizontalization of the ceiling reflectors in the eastern sector [p. 354] shows a background with highs and depressions relatively similar to the previous sequences (Fig. 9). However, in the seismic located to the west (Fig. 11), the reconstruction of unit S_4 by horizontalization of the ceiling reflectors shows an important change in the paleotopography of the background of the basin. One sector that showed a subsiding behavior in the previous units is converted into a relative structural high that is interpreted as an episode of tectonic reactivation. [p. 355]

This rising episode could have generated a positive element located immediately west of Cañadón Hondo (Fig. 2). This is evidence of clear structural control of the basement in the sedimentary development of the basin, as already mentioned by Arbe and Hechem (1984b) based on stratigraphic analysis of the surface. If reflector d_3 is comparable to the base of the Cerro Toro Formation, reflector d_4 would be correlated with the boundary between the upper and lower members of Cerro Toro Formation, of Arbe and Hechem (1984a) which is interpreted as an unconformity (Figs. 9 and 11). The presence below d_4 of ammonites whose age is located in the late Cenomanian–early Coniacian span, and the medium–late Coniacian age above (Fig. 12), permits its correlation with the intra-Coniacian unconformity I10 of Biddle *et al.* (1986), recognized in the subsurface of the Austral Basin. The decreasing of thickness by *onlap* associated with unconformity d_4 permits explaining variations in the thickness of the Cerro Toro Formation on the order of 400 m in the east-west direction, estimated on the basis of the velocity law from well YPF-SCA-CFo-es-1.

The change in the configuration of the bottom of the basin associated with d_4, although it is evident west of the Río Leona (Fig. 11), is not recognized east of this river (Fig. 9), which suggests the existence of a tectonically unstable zone to the west during deposition of the Cerro Toro Formation.

This sequence is correlated with the "Pari Aike Regressive Subcycle" of the "Mata Amarilla Cycle" and the "El Alamo Transgressive Subcycle" of the "Lago Viedma Cycle" of Arbe (1987).

Seismic sequence S_5

This sequence appears partially defined on the seismic line of the eastern sector (Fig. 9). Its lower limit is unconformity d_5, a reflector with good lateral continuity and marking the passage of sequence S_4 to the low-frequency reflections of sequence S_5 (Fig. 9). This unit is linked with the lower member of the Alta Vista Formation which lies paraconformably and with a marked sedimentological break on the upper member of the Cerro Toro Formation (Arbe and Hechem 1984b).

Sedimentary-tectonic Evolution

Based on the characteristics of the subsurface and surface units and the discontinuities limiting them, it is possible to reconstruct the sedimentary-tectonic basin at this latitude, distinguishing three stages.

Rifting stage

The episode of regional extension that gave rise to Jurassic volcanism (Bruhn *et al.* 1978), represented in the cordilleran region by the El Quemado Complex, coincides with fundamental tectonic episodes such as the start of fragmentation of western Gondwana and the opening of the marginal basin of green rocks at the southern end of the Patagonian Andes (Dalziel 1981; Dalziel *et al.* 1987). This episode of extension, synchronic with the volcanism, appears registered in the rift-type depressions or seismic sequences S_1 in the subsurface (Fig. 9). The variations in the type of filling of the depressions or grabens must be related to the interaction between regionally synchronous phenomena such as the start and end of the extensional faulting and diachronous phenomena such as the inundation of the basin to the north and east, adding up to the irregular distribution of effusive centers.

A stage of general increase in sea level during the Late Jurassic and Early Cretaceous (Haq *et al.* 1987) explains the marked diachrony in the appearance of the first marine levels from south to north, Oxfordian–Kimmeridgian in the Ultima Esperanza region (Chile) (Soffia and Harambour 1988; Wilson 1991), early to middle Tithonian in the Lago Argentino region, late Berriasian to early Valanginian in Lago San Martín (Riccardi 1976, 1977; Kielbowicz *et al.* 1983), and late Valanginian to early Hauterivian in lakes Pueyrredon and Buenos Aires (Arbe 1988).

In the structural extensions observed in the subsurface (Fig. 9) and surface (Fig. 10), unconformities d_1 and d_2 mark the beginning and end of the stage of normal faulting, respectively, and limit the deposits of unit S_1 or the Springhill Formation. In the southern sector of the basin the sedimentation is essentially deep marine, as observed in the Ultima Esperanza region in Chile (Wilson 1991). In the intermediary sectors the deposits are shallow-marine and eventually continental environments at the base, as observed at the latitude of Lago Argentino (Arbe 1988), and both north and east of basin the deposits are essentially continental and the first marine levels are above unconformity d_2. The intercalation or not of volcanic and/or volcaniclastic levels in the syntectonic sedimentation depends on the proximity of the issuing centers. This explains that in region of Lago Argentino, levels of the same age (Tithonian) have volcanic and pyroclastic intercalations at El Quemado (Fig. 2, locality 2), while these are not observed at the source of the Río Guanaco (Fig. 2, locality 4).

Thermal subsidence stage

The end of normal faulting, localized sedimentation, and volcanism in the Late Jurassic marks the passage to a general subsidence by thermal cooling, with inundation of the basin.

The beginning of the stage appears registered with unconformity d_2 and in the transgressive episode beginning from the late Tithonian, is represented in the Lago Argentino region by platform-environment pelites of the Río Mayer Formation, or seismic sequence S_2 of the subsurface (Figs. 9 and 11). This stage extends from the Berriasian to the Albian, a range that includes the Río Mayer Formation.

Basin closure stage

This stage is characterized by a change in the polarity of sedimentation, registering the first regressive pulses in the north of the Austral Basin (48° S) during the Barremian (Aguirre Urreta and Ramos 1981; Arbe 1987). During the Aptian, the appearance of the first clastic input is produced from the west (Aguirre Urreta 1990) with the development of retrogradational sedimentary units from north to south (Biddle *et al.* 1986). To the south in the Ultima Esperanza region, the first evidence of input from the west constitutes the Punta Barrosa Formation, of turbidite nature with a late Albian–Cenomanian fauna (Riccardi 1988; Soffia and Harambour 1988). In Tierra del Fuego, the deformation of the marginal basin with green rocks would have occurred during the Albian–Cenomanian in the islands south of the Beagle Channel (Halpern and Rex 1972), coinciding with the first appearance of turbidite deposits on the eastern cordilleran border (Dalziel 1981; Barker and Dalziel 1983), deformation and metamorphism (Nelson 1982; Kohn *et al.* 1995), and with a peak of magmatic activity between 100 and 70 Ma in the Patagonian batholith (Nelson *et al.* 1988). During the Late Cretaceous–early Tertiary, strong subsidence is registered [p. 357] due to the load produced by the fold-and-thrust belt advancing from the west, with typical features of a foreland basin (Biddle *et al.* 1986).

The diachrony from north to south observed in the first appearance of clastic input from the west suggested to Arbe (1987) to postulate a collision migrating from north to south that would have occurred between the middle Aptian in the north and the Cenomanian in the south. It is probable that this diachrony also reflects changes in the magnitude and/or distribution of crustal stretching north and south of 50° S, respectively (Kraemer 1994). Due to a general compressive regimen during the Early Cretaceous, the sector south of 50° S, that reached to generate oceanic cortex, could support an important crustal shortening and thickening without increasing an emerging topography generating debris above sea level (Jamieson and Beaumont 1988). North of 50° S, the situation is reversed, because before the lesser crustal reduction that was produced in the stage of basin opening (did not generate ocean bottom), a relatively lesser shortening and thickening was sufficient to generate isostatic imbalance and subaerial topography generating debris, creating the change in polarity of sedimentation and input from the west in the Aptian, while south of 50° S there is no sedimentary evidence of western orogenic relief. This also explains the strong basement control in the distribution of sedimentary depocenters north of that latitude (Arbe 1988).

The Lago Argentino region presents intermediate characteristics between both sectors. The stage of loading subsidence appears equally represented in the south sector, by the first turbidite pulses of the lower member of the base of the Cerro Toro Formation of Cenomanian age (Arbe and Hechem 1984a), and the subsurface by unconformity d_3, the base of seismic sequence S_3, in which the configuration of the basin bottom is similar to that of the previous sequence, showing a general subsiding behavior, both east and west of the studied zone (Fig. 11).

The similarity in the configuration of the ancient basin bottom between units S_2 and S_3 (Figs. 9 and 11) would indicate that for the Cenomanian, the region was sufficiently remote from the active occidental edge that could not register an episode diastrophic of that age, except for an increment of the speed of the subsidiary basin, and the appearance of turbidite sediments contributed from the northeast.

However, associated with unconformity d_4, the base of seismic sequence S_4 (upper member of the Cerro Toro Formation), an important change is produced because sectors with a previously subsiding comportment suffer a process of tectonic reactivation, transforming them into relative structural highs. From the reconstruction of unit S_4 by horizontalization of the reflectors, we infer that the magnitude of vertical lifting localized during the Coniacian would be in the order of 400 m (Fig. 11), which indicates a strong basement control on the sedimentary development of the area.

Although seismic Fig. 1, does not permit defining which structural type generated the structural high, the observations of the phenomena of positive tectonic inversions (William *et al.* 1989) in the source of the Río Guanaco suggest that normal failing and its reactivation could have played an important role, both during the evolution of the basin and in the geometric control of the structures of the Cenozoic folded belt (Kraemer 1991, 1993).

Although they have common characteristics to both sectors suggesting a gradual passage, the abrupt influence of the Viedma and Lago Argentino guidelines the sedimentary thickness (Kraemer 1991), the change in the structural style of the folding belt (Kraemer 1993), variations in the gravimetric anomalies (Kraemer 1994; Kraemer *et al.* 1996), the segmentation of the area of sedimentary input at this latitude (Manassero 1988, 1993), and the disappearance of the basic rocks of the Sarmiento Complex (Allen 1982) suggest that a geological limit of regional importance is encountered at 50° S lat.

Conclusions

By mapping 1:100,000 scale, measurement of stratigraphic profiles, identification of 14 fossil levels (n_1 to n_{14}), seismic reflection and well data, an east–west stratigraphic scheme is established for the region between lakes Argentino and Viedma. 2 lithologic types are identified in the basement of the region (Bahía de la Lancha Formation). One sediment (turbidite) and another of metamorphic aspect (phyllites) are mentioned for the first time for the region of Lago Viedma, fossil traces tentative assigned to *Palaeophycus tubularis* Hall (fossil level n_1). The stratigraphic units of the surface, deposited above the vulcanites of the El Quemado Complex, were correlated with seismic sequences separated by unconformities of regional significance.

The Springhill Formation corresponds to deposits associated with normal faulting in the western sectors of the studied region. Ammonites found in this unit (levels n_2 and n_3) permit referring this unit to the upper part of the early and middle Tithonian. It is correlated with seismic sequence S_1, limited by unconformities d_1 and d_2, related to the rifting or basin-opening stage. The platform deposits of the Río Mayer Formation have a late Berriasian–early [p. 358] Valanginian (levels n_2 and n_3) to Albian age. It is correlated with seismic sequence S_2, limited by unconformities d_2 and d_3, corresponding to the thermal subsidence stage of the basin. The Cerro Toro Formation is divided in two members. The lower member has an age in the late Albian–early Cenomanian to early Coniacian interval (levels n_6–n_7 and n_8) and is correlated with the seismic sequence S_3, limited by unconformities d_3 and d_4. The upper member has an age in the middle–late Coniacian (levels n_9 and n_{10}) to late Santonian–early Campanian (level n_{11}) interval and is correlated with seismic sequence S_4, limited by unconformities d_4 and d_5. Unconformity d_4 separates both members and is interpreted as a Coniacian-age episode of tectonic reactivation of the basement of the basin. The Alta Vista Formation, of early Campanian age (levels n_{13} and n_{14}), is correlated with seismic sequence S_5, limited at the base by unconformity d_5.

The sector between the lakes Viedma and Argentino constitutes an important geological limit, because it separates regions, north and south of 50° S lat., with a different magnitudes or distributions of the crustal stretching during the basin opening stage. The identification of normal faulting in the Late Jurassic, with evidence of positive tectonic inversion, indicates that the structural extensions could have played an important role in the evolution of the region.

Acknowledgments

This work was done with thanks to the economic support of CONICET and the help of the mining industry of Santa Cruz Province. PEK thanks M. A. Hunicken and A. Mingramm for discussions on different aspects during the work of his doctoral thesis. Part of the fossil material used was collected by a Geological Commission of YPF directed by H. Harbe. We thank M. Macellari and H. Harbe for the revision of the manuscript and relevant suggestions.

We also thank the Yacimientos Petrolifieros Fiscales company for lending the seismic lines and information on the subsurface. Finally, the support of the settlers of the region permitted the successful development of the expeditions.

WORKS MENTIONED IN THE TEXT

[not included in translation]

Figure Captions

Figure 1. Location map. LV: Lago Viedma, LA: Lago Argentino, LS: Lago San Martín.

Figure 2. Geological map. 1: Las Vacas Valley, 2: El Quemado post, 3: Lake Pearson or Anita, 4: source of the Río Guanaco, 5; Lago Tanhauser, 6: source of the Río Condor, 7: Perez Valley west, 8: Arroyo La Sola, 9: Los Kaikenes Valley, 10: Cañadón Hondo, 11: source of Arroyo El Turbio, 12: lower course of Arroyo El Turbio, 13: estancia La Herradura west, 14: place of estancia Nidaros, 15: estancia Los Hermanos, 16: estancia La Herradura south, 17: Cerro El Barco, 18: Del Cerro place, 19: Cerro Fortaleza exploratory well, YPF-SCA-CFo-es-1.

Figure 3. Generalized stratigraphic column.

Figure 4: 1a–b, *Aspidoceras* cf. *andinum* Steuer, lateral and ventral views (MLP 27728); **2a–b**, *Aulacosphinctoides* cf. *smithwoodwardi* (Uhlig), lateral and ventral views (MLP 27729); **3**, *Subplanites* sp., lateral view (MLP 27730). West of the Perez Valley, Springhill Formation, early–middle Tithonian. All figures X1.

Figure 5: 1, *Berriasella* cf. *behrendseni* Burkhardt, lateral view (MLP 27731); **2**, *Jabronella* cf. *michaelis* (Uhlig), lateral view (MLP 27732); **3**, *Phyllopachyceras aureliae* (Feruglio), lateral view (MLP 27733); **4**, *Kilianella* sp., lateral view (MLP 27734); **5**, *Busnardoites*? cf. *campylotaxus* (Uhlig), lateral view (MLP 27735); **6**, *Birostrina* cf. *concentrica* (Park.), right valve (MLP 27736). Arroyo La Sola, Cerro Toro Formation, late Albian–early Cenomanian. All figures X1.

Figure 6: 1a–b, *Mortoniceras* cf. *arietiforme* (Spath), lateral and ventral views (MLP 19711).

Arroyo de las Hayas, Río Mayer Formation, late Albian. X1.

Figure 7: 1, *Austiniceras* cf. *A.* ? *magellanicus* (Leanza), lateral view (MLP 27737a); **2**, *Scaphites* cf. *obliquus* J. Sowerby, lateral view (MLP 27737b). Estancia Los Hermanos, Cenomanian. **3a–b**, *Pachydesmoceras* cf. *linderi* de Grossouvre, lateral and ventral views (MLP 27738), El Alamo place, Al Alamo Formation, late Turonian. Fig. a, X0.50; Figs. 2 and 3a–b, X1.

Figure 8: 1, *Gauthiericeras* cf. *santacrucense* (Leanza), lateral view (MLP 27739), middle–late Coniacian; **2**, *Baculites* cf. *kirki* Matsumoto, lateral and transverse views (MLP 27740); **3**, *Sphenoceramus* cf. *lingual* (Goldfuss), right valve (MLP 27741); **4a–b**, *Anapachydiscus* cf. *hauthali* (Paulcke), lateral and ventral views (MLP 20872); **5a–b**, *Placenticeras* cf. *santacrucense* Leanza, ventral and lateral views (MLP 16811); **6**, *Parabinneyites paynensis* (Favre), lateral and ventral views (MLP 16807), Arroyo El Turbio, Alta Vista Formation, early Campanian. All figures X1.

Figure 9. Seismostratigraphic interpretation of line YPF 8111.

Figure 10. Above. Panoramic vie of the source of the Río Guanaco (RG) interpreted. Normal faulting and stratigraphic units. QUE: El Quemado Complex, SPG: Springhill Formation, RMA: Río Mayer Formation, C: carbonate banks of the base of the Río Mayer Formation, PI: normal fault with positive inversion. The two faults situated to the west show little to no reactivation, whereas the two faults located to the east were reactivated with great intensity. d1 and d2: unconformities (see geographic location in fig. 2). **Below.** Panoramic view of the source of the Río Guanaco without interpretation.

Figure 11. Seismostratigraphic interpretation of line YPF 8124–25.

Figure 12. Diagram of correlated stratigraphic columns. See location of localities in Fig. 2.