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Hettangian and Sinemurian (Lower Jurassic) biostratigraphy of Argentina

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Abstract—On the northern bank of the Río Atuel, Mendoza province, Argentina, the marine fossiliferous Mesozoic is now known to begin with Hettangian-lower Sinemurian strata. Traditionally, the marine Jurassic sequence in the area was believed to start with upper Sinemurian levels. Representatives of the genera *Psiloceras* Hyatt, *Caloceras* Hyatt, *Alsatites* Haug, *Waehneroceras* Hyatt, *Schlotheimia* Bayle, *Sulciferites* Spath, *Badouxia* Guex and Taylor, *Vermiceras* Hyatt, *Coroniceras* Hyatt, *Agassiceras* Hyatt, *Euagassiceras* Spath, and *Arnioceras* Hyatt thus indicate the presence of beds equivalent to the Planorbis, Liasicus, Angulata, Bucklandi, Semicostatum, and Turneri zones of the standard international chronostratigraphic scale. Hence, in Argentina, the marine Hettangian, Sinemurian, and lowermost Pliensbachian have been proved only in the neighborhood of the Río Atuel region, where marine Triassic could also be represented. Elsewhere in Argentina, the oldest Jurassic ammonite-bearing levels usually belong to the upper lower or the upper Pliensbachian. Regionally, these findings imply a substantial modification to previous paleogeographic reconstructions for the Early Jurassic of South America.

Resumen—En la margen norte del río Atuel, Mendoza, Argentina, la sucesión fosilífera marina del Mesozoico comienza con niveles del Hettangiano y Sinemuriano inferior. Tradicionalmente se había considerado que en la región el Jurásico marino comenzaba con el Sinemuriano superior. Representantes de los géneros *Psiloceras* Hyatt, *Caloceras* Hyatt, *Alsatites* Haug, *Waehneroceras* Hyatt, *Schlotheimia* Bayle, *Sulciferites* Spath, *Badouxia* Guex y Taylor, *Vermiceras* Hyatt, *Coroniceras* Hyatt, *Agassiceras* Hyatt, *Euagassiceras* Spath y *Arnioceras* Hyatt, indican la presencia de estratos equivalentes a las zonas de Planorbis, Liasicus, Angulata, Bucklandi, Semicostatum y Turneri de la Escala Cronoestratigráfica Internacional. Así en Argentina el Hettangiano, Sinemuriano, y Pliensbachiano basal marinos solamente han sido comprobados en proximidades de la región del río Atuel, donde también podrían hallarse representados niveles de Triásico marino. En el resto de Argentina los niveles más antiguos portadores de amonites del Jurásico corresponden generalmente al Pliensbachiano inferior alto o Pliensbachiano superior. Desde el punto de vista regional estos hallazgos determinan una modificación substancial en la paleogeografía del Jurásico temprano de América del Sur.

INTRODUCTION

THE LOWER JURASSIC stratigraphy and paleontology of the northern bank of the Río Atuel has been briefly described by Burckhardt (1900, 1903), Jaworski (1914, 1915, 1925), Gerth (1925), Groeber (1947), and Groeber *et al.* (1953). According to these authors and to more recent studies (Stipanicic, 1969; Stipanicic and Bonetti, 1970; Volkheimer, 1978; Rosenfeld and Volkheimer, 1980, 1981; Hillebrandt, 1973, 1981, 1987; Damborenea, 1987a), the Jurassic of the area has been considered to include the following (Riccardi 1983): below, 900 meters of a mainly conglomeratic unit, the El Freno Formation, lacking fossil invertebrates and questionably dated as Hettangian; above, about 300 meters of marine sandstones, the El Cholo or Puesto Araya Formation. Fossil invertebrates found at different levels of the Puesto Araya Formation indicated (?early) late Sinemurian to late Pliensbachian ages (Stipanicic, 1969; Riccardi, 1983). This succession was believed to document the earliest marine Mesozoic of Argentina because in other areas the first marine fossils are dated as late early Pliensbachian (Riccardi, 1984).

In South America, marine Hettangian and lower Sinemurian strata have been previously recorded in Chile (Cecioni, 1960; Thiele, 1967; Cecioni and Westermann, 1968; Minato, 1977; Escobar, 1980; Hillebrandt, 1970, 1973, 1981, 1987, 1988; Quinzio, 1987), in Peru (Hyatt, 1889; Lisson, 1911; Tilmann, 1917; Schindewolf, 1957; Geyer, 1979; Prinz, 1983, 1985a,b), in Ecuador (Geyer, 1974), and in Colombia (Geyer, 1973, 1976).

The marine Hettangian and the lower Sinemurian of central Chile are restricted to the Coastal Cordillera between Vichuquén and Batuco (35-35°15'S; Thiele, 1967; Corvalán, 1976, 1982; Minato, 1977; Escobar, 1980) and between Los Vilos and Los Molles (32-32°15'S; Fuenzalida, 1938; Cecioni, 1960; Cecioni and Westermann, 1968). In the Principal Cordillera of Argentina, the Sinemurian dating of the earliest marine Jurassic of the Río Atuel area was supported until quite recently by Hillebrandt's studies (1989).

The Pliensbachian stratigraphy of the Río Atuel area was studied by three of us in 1973 (ACR, SED, MOM; field samples 346-371), and the upper Sinemurian and Pliensbachian by two of us in 1983 (SED, MOM; field samples 1251-1276). In 1986 (field

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samples 1384-1477), we undertook field studies over the whole region in order to find and date the beginning of the marine Mesozoic. Four selected sections were studied from west to east along the northern bank of the Río Atuel between Laguna El Sosneado and Arroyo Blanco (Figs. 1 and 2). These studies documented for the first time the existence of marine Hettangian and provided a rich fauna of early Sinemurian invertebrates. Supplementary sampling (1693-1732) and field observations were conducted in 1988 (Riccardi *et al.*, 1988).

In classifying the fossiliferous succession on the basis of its ammonites, we follow Riccardi *et al.* (1990b) and distinguish three levels of stratigraphic units. The lowest level of classification is the "faunal horizon," the next is the "assemblage zone," and the third level of classification is the "standard chronozone." In the correlation of these units with the European standard zonation (Fig. 3), horizontal divisions are shown as not coinciding in order to avoid implying exact time correlation. Donovan's generic ammonite systematics were used (Donovan *et al.* 1981). Fossil specimens, labeled MLP, are in the collections of the Museo de La Plata.

BIOSTRATIGRAPHY

Ammonite Zonation

Psiloceras Assemblage Zone (I on Fig. 2). This zone was defined by Riccardi *et al.* (1988) in the Arroyo Malo section (Fig. 2A). The beds are about 45 meters thick and overlie 300 meters of unfossiliferous turbidites (base not exposed). The zone is characterized near the base (levels 1384-1385) by *Psiloceras* cf. *tilmanni* Lange (Fig. 4, nos. 1-2), and in the upper parts (levels 1389, 1701) by *Caloceras* cf. *peruvianum* (Lange) (Fig. 4, nos. 3-5). The middle part of this interval (levels 1386, 1699) yields *Psiloceras* cf. *rectocostatum* Hill. (Fig. 4, no. 6) and a loose fragment of *?Alsatites* cf. *liasicus* (d'Orb.).

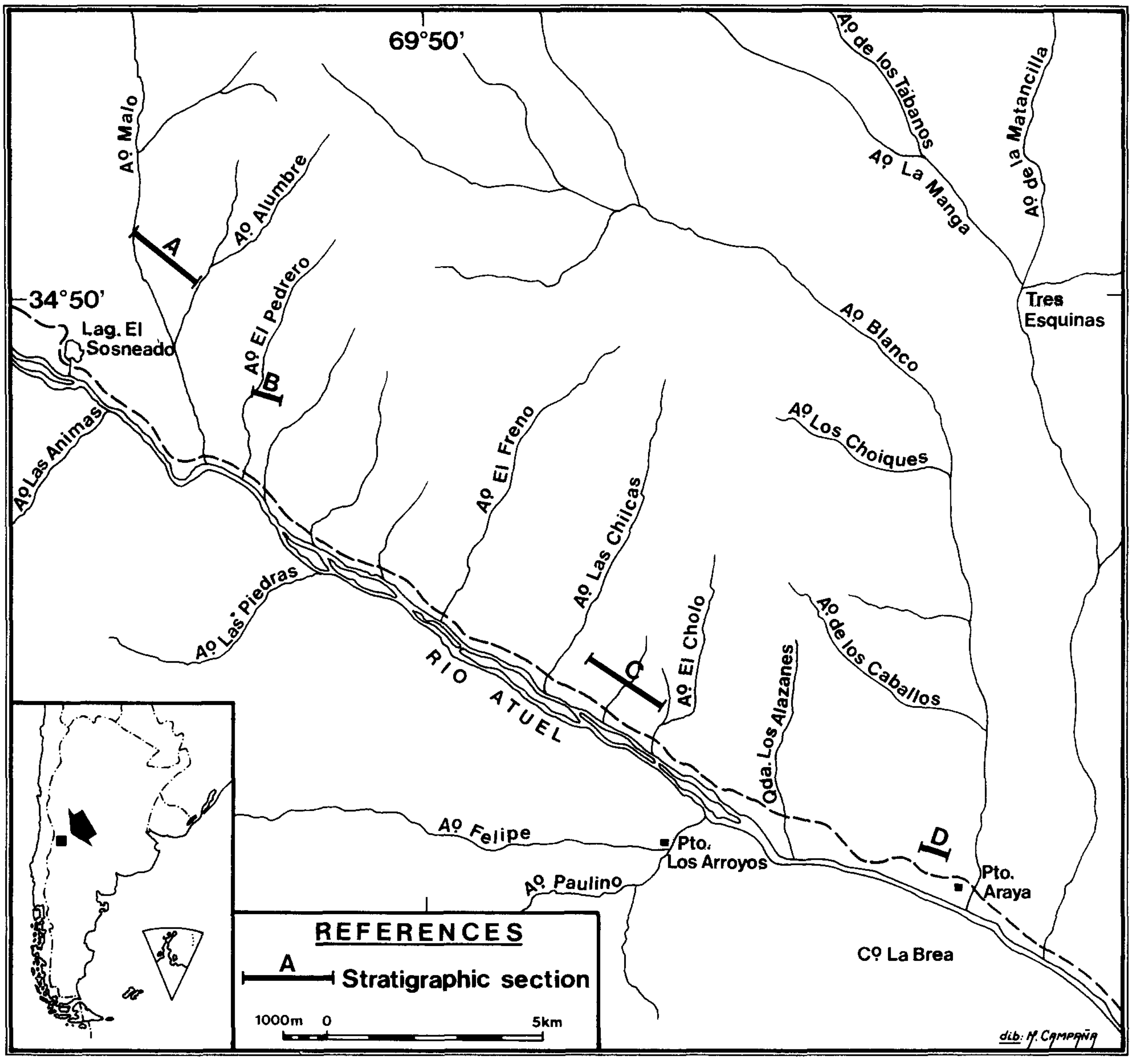

Fig. 1. Index map to sections in the Río Atuel area.

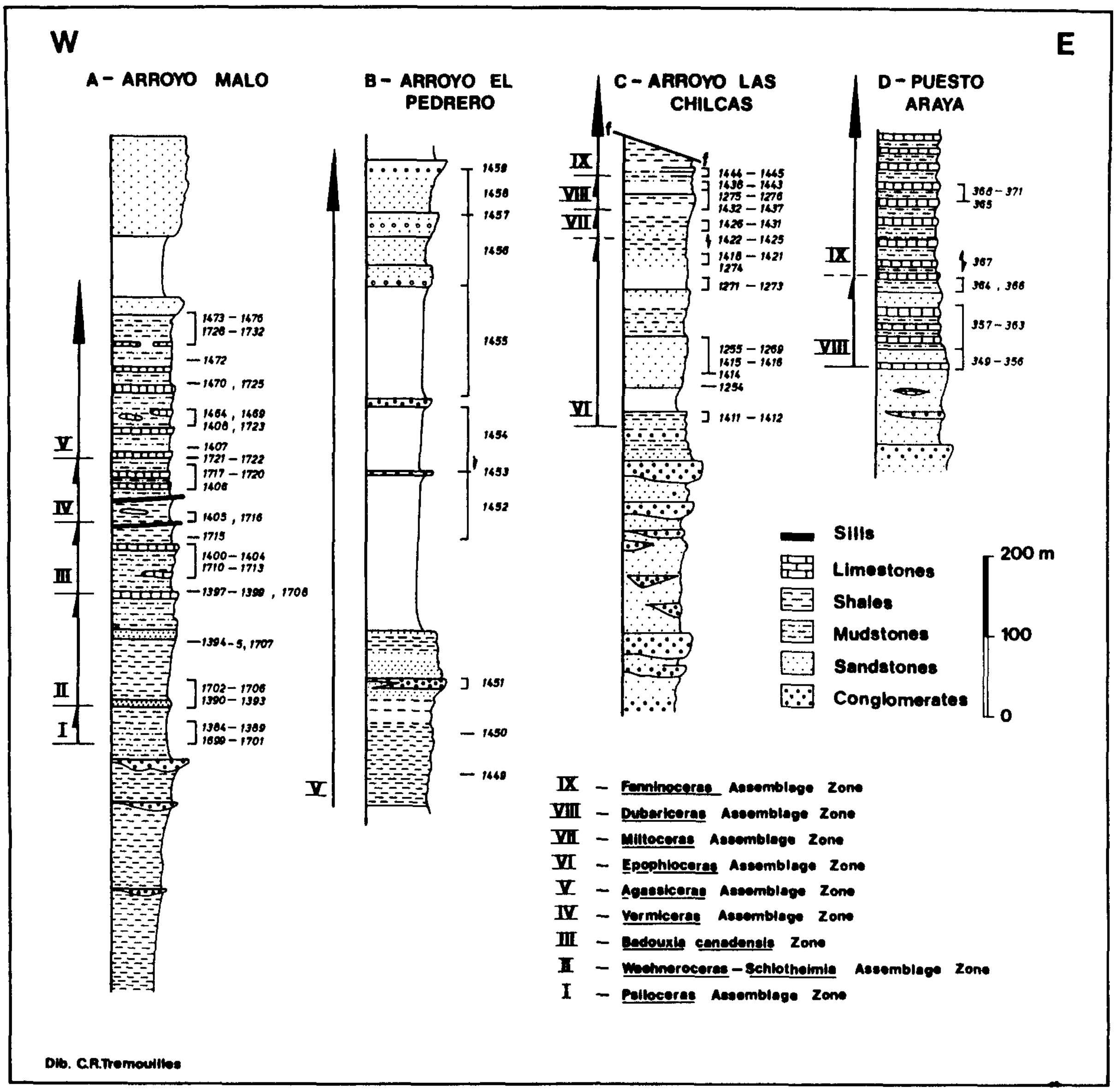

Fig. 2. Columnar sections at Arroyo Malo, Arroyo El Pedrero, Arroyo Las Chilcas, and Puesto Araya, with local zonation.

The fragmentary specimen identified as *Psiloceras* cf. *tilmanni* is similar to material from Peru (Tilmann, 1917, pl. 22, fig. 1) included in *P. tilmanni* Lange (1925, p. 474). This species has recently been used as index of a "Zone of *Psiloceras tilmanni*" (Hillebrandt, 1988). *Caloceras peruvianum* resembles *C. johnstoni* (J. de C. Sowerby), a widely distributed species known from the Planorbis zone of Europe, Alaska, and Canada (Blind, 1963, pl. 1, fig. 4; Frebold and Poulton, 1977, pl. 1, figs. 3-8; Imlay, 1981, pl. 1, figs. 11-16). *Caloceras peruvianum* (Lange) is known from Peru (Tilmann, 1917, pl. 22, figs. 2-3; Prinz, 1985b, pl. 2, fig. 5), and Chile (Cecioni and Westermann, 1968, pl. 6, figs. 7-8; Hillebrandt, 1987, pl. 1, fig. 6; Quinzio, 1987, pl. 1, figs. 5-6). Some poorly preserved impressions were compared (Riccardi *et al.*, 1988) with *P. plicatulum* (Quenstedt, 1883-1885, pl. 1, fig. 11; Schlegelmilch, 1976, pl. 4, fig. 15) — a species previously recorded from Peru (Lisson, 1911, pl. 2). Material from Chile (? and Peru) previously compared with this species (Hillebrandt, 1981, pl. 1, fig. 1a-b; Prinz, 1985a, pl. 1, fig. e) has more recently been referred to *P. rectocostatum* and *P. primocostatum* Hillebrandt (1988, p. 63, 67).

In Europe, *P. plicatulum* and *C. johnstoni* are the index species of the middle and upper subzones of the Planorbis zone. The age of this assemblage is therefore early Hettangian, (?early to) late Planorbis zone (Fig. 3). The underlying 300 meters of unfossiliferous turbidites are probably Late Triassic to early Planorbis in age. Early Hettangian invertebrate faunas are known from Peru (Lisson, 1911; Tilmann, 1917; Geyer, 1979; Prinz, 1985a,b) and Chile (Cecioni and Westermann, 1968; Escobar, 1980; Hillebrandt, 1981, 1987, 1988; and Quinzio, 1987).

The *Psiloceras* assemblage zone is equivalent to the "Zones of *Psiloceras tilmanni* [?], *P. primocostatum*, *P. rectocostatum*, and *Caloceras peruvianum* [part]" proposed by Hillebrandt (1988) for Chile and Peru.

Waehneroceras-Schlotheimia Assemblage Zone (II on Fig. 2). This zone was introduced by Riccardi *et al.* (1988) for about 140-meter-thick shales at Arroyo Malo (Fig. 2A). The lower part of this zone (levels 1703, 1390) has yielded *Waehneroceras* cf. *longipontinum* (Fraas) (Fig. 4, nos. 7-8; cf. Elmi and Mouterde, 1965, pl. 9, fig. 1; Schlegelmilch, 1976, pl. 5, fig. 10) and *ex situ* material identified as *Schlotheimia* cf. *angulata* (Schl.)/*angulosa* Lange (Fig. 4, nos. 10-11; cf. Thiele, 1967, pl. 4, fig. 10a-b; Minato, 1977, pl. 6, fig. 4b; Escobar, 1980, pl. 4, figs. 1-3; see also Lange, 1951, pl. 1, fig. 6 and pl. 4, fig. 4), and perhaps the specimen of ?*Alsatites* cf. *liasicus* mentioned above (level 1386).

Higher up (levels 1704, 1705, 1706), this zone is characterized by *Schlotheimia* cf. *polyptycha* Lange/*complanata* Koenen (Fig. 4, no. 9; cf. Lange, 1951, pl. 3, figs. 4-5 and pl. 17, figs. 4-6; Geyer, 1979, fig. 5a), *Schlotheimia* cf. *stenorhyncha* (Lange) (Fig. 4, nos. 12-13; cf. Lange, 1951, pl. 16, fig. 3), and *Vermiceras* (*Paracaloceras*) cf. *coregonense* (Sow.).

Similar faunas have been found in Chile (Thiele, 1967; Cecioni and Westermann, 1968; Minato, 1977; Escobar, 1980) and in Peru (Geyer, 1979). In Europe, *Waehneroceras* is found in the Liasicus zone, whereas the species of Schlotheimiidae to which the South American material has been compared characterize the Angulata zone, the Extranodosa and Complanata subzones. Therefore, this interval seems to represent the middle-upper Hettangian — *i.e.* the Liasicus zone and part of the Angulata zone of the European zonation (Fig. 3).

Badouxia canadensis Standard Zone (III on Fig. 2). The "*Psiloceras canadense* Zone" was introduced by Frebold (1967, p. 30-33) for the upper Hettangian of the Taseko Lakes, Canada. It was recognized in Argentina, as an assemblage zone, by Riccardi *et al.* (1988). The entire assemblage is quite homogeneous along the eastern Pacific margin. The base of the zone should be defined in North America.

This zone is about 90 meters thick in the Arroyo Malo section (Fig. 2A). It is characterized (levels 1397-1404 and 1708-1715) by *Badouxia canadensis* (Frebold) (Fig. 4, nos. 17-18), *Vermiceras* (*Paracaloceras*) cf. *rursicostatum* Frebold (Fig. 4, no. 22; cf. Frebold, 1967, pl. 7, figs. 1-2 and pl. 9, fig. 1; Imlay, 1981, pl. 6, figs. 1-11), *Sulciferites* cf. *marmoreum* (Oppel) (Fig. 4, nos. 20-21; cf. Frebold, 1967, pl. 3, figs. 1, 4; Imlay, 1981, pl. 3, figs. 1-10), and *Vermiceras* sp.

Badouxia canadensis ranges through different levels of this interval and is represented by several morphotypes showing a large variation in coiling and ribbing. As a whole, the Argentine representatives are similar to those figured by Frebold (1951, pl. 1, figs. 1-6, pl. 2, fig. 1, and pl. 3, fig. 1; 1967, pl. 1, figs. 1-4) and Imlay (1981, pl. 2, figs. 18-21, 24-28) from North America, by Hillebrandt (1981, pl. 1, fig. 5a-b) from northern Chile, and by Prinz (1985b, pl. 2, fig. 4) from Peru. In North America, *Badouxia canadensis* is also associated with *S. marmoreum* and *V. (P.) rursicostatum*.

The *B. canadensis* zone was correlated by Frebold (1967, p. 31) with the Liasicus and Angulata (lower part) zones of Europe. More recently, it was considered by Guex and Taylor (1976) as an equivalent of the Marmorea zone, which was placed at the base of the Sinemurian (see also Imlay, 1981). However, the International Subcommission of Jurassic Stratigraphy has ratified the traditional definition of the Sinemurian stage at the base of the *Conybeari* subzone (Bloos, 1988). Therefore, the age of this assemblage is late Hettangian, Angulata zone, although the presence of *Vermiceras* in the upper part suggests it could range into the Bucklandi zone of the early Sinemurian (Fig. 3).

Vermiceras Assemblage Zone (IV on Fig. 2). This zone was introduced by Riccardi *et al.* (1988) for an interval about 80 meters thick at Arroyo Malo (Fig. 2A, levels 1716-1721). The fossil assemblage is characterized by the presence of *Vermiceras* cf. *gracile* (Spath) (Fig. 5, nos. 1-2; cf. Guérin-Franiatte, 1966, pl. 63) and *Vermiceras* spp., and by the disappearance of *Badouxia*, *Vermiceras* (*Paracaloceras*), and *Sulciferites* cf. *marmoreum*.

The genus *Vermiceras*, including *V. gracile*, is restricted to the Bucklandi zone, *Conyberi* subzone of Europe (Guérin-Franiatte, 1966). The age of this assemblage is therefore early Sinemurian, partly or in total Bucklandi zone (Fig. 3). In South America, ammonites of the same age have been recorded from Peru (Lisson, 1911; Tilmann, 1917; Schindewolf, 1957) and Chile (Quinzio, 1987).

Agassiceras Assemblage Zone (V on Fig. 2). This zone was introduced by Riccardi *et al.* (1988) for a fossiliferous succession at least 170 meters thick at Arroyo Malo (Fig. 2A). The lower 120 meters are characterized by *Agassiceras* cf. *scipionianum* (Quenstedt) (Fig. 5, no. 6; cf. Quenstedt, 1883-85, pl. 14, fig. 1; Hillebrandt, 1981, pl. 2, fig. 1a-b), *Agassiceras* sp., and *Coroniceras* (*Paracoroniceras*) cf. *charlesi* Donovan. The upper 20 meters (Fig. 2A, levels 1475, 1729, 1730) yield rare *Coroniceras* (*Coroniceras*) cf. *alcinoe* (Rey.) (Fig. 5, nos. 7-8; cf. Guérin-Franiatte, 1966, pl. 82-84), and *Euagassiceras* sp.

This zone is probably present on the left bank of Arroyo El Pedrero (Fig. 1), with poorly preserved *Coroniceras (Eucoroniceras)* sp., *Euagassiceras* sp., ?*Pararnioceras* cf. *paolinae* (Reynés), and *Arnioceras* sp. (Fig. 2B, levels 1449 and 1451-1454). At the top of the section there is a horizon (1459) with abundant *Arnioceras* cf. *oppeli* Guérin-Franiatte.

In South America, *A. scipionianum* (Qu.) has been figured from Colombia (Geyer, 1973, 1976) and Chile (Hillebrandt, 1981), and *Coroniceras* (*Paracoroniceras*) Spath has been recorded from Peru (Prinz, 1985b, pl. 3, fig. 1); several species of *Arnioceras* have been figured from Peru (Tilmann, 1917; Geyer, 1973, 1979; Prinz, 1985b), Ecuador (Geyer, 1974) and Chile (Escobar, 1980; Quinzio, 1987). A close relative of *C.* (*C.*) *alcinoe* (Rey.), *C.* (*C.*) *gallicum* (Guérin-Franiatte), has been found in Chile (Escobar, 1980, pl. 5,

STAGES SUBSTAGES		AMMONITE STANDARD ZONES	LOCAL ASSEMBLAGES / ZONES		
			AMMONITES	BIVALVES	BRACHIOPODS
PLIENSBACHIAN	U	SPINATUM	Fanninoceras Ass. Z.	Radulonectites sosneadoensis Ass. Z.	Rhynchonelloidea cuyana Ass. Z.
		MARGARITATUS			Rhynchonelloidea burckhardti Ass. Z.
	L	DAVOEI		Otapiria neuquensis Ass. Z.	
		IBEX	Dubariceras Ass. Z.		
		JAMESONI			
SINEMURIAN	U	RARICOSTATUM	Miltoceras Ass. Z.		Gibbirhynchia dereki Ass. Z.
		OXYNOTUM	?		
		OBTUSUM	Epophioceras Ass. Z.		
	L	TURNERI	Agassiceras Ass. Z.	Otapiria pacifica Ass. Z.	[Lingula cf. metensis Beds]
		SEMICOSTATUM			
		BUCKLANDI	Vermiceras Ass. Z.		
HETTANGIAN		ANGULATA	Badouxia CANADENSIS Z.		
		LIASICUS	Waehneroceras - Schlotheimia Ass. Z.		
		PLANORBIS	Psiloceras Ass. Z.		

Dib C R Tremouilles

Fig. 3. Correlation table of regional fossil assemblages and zones with the standard chronostratigraphic scale.

figs. 11-12) and a species of *Euagassiceras*, *E.* ex gr. *donovani* Guérin-Franiatte, is known from Colombia (Geyer, 1973, p. 49, fig. 19 and 1976, pl. 1, fig. 6). In Europe, these species occur in the Semicostatum zone and *A. oppeli* marks the lower Turneri zone.

This interval therefore seems to represent the upper lower Sinemurian, Semicostatum to Turneri zones of the European zonation (Fig. 3).

Epophioceras Assemblage Zone (VI on Fig. 2). This zone was proposed by Riccardi (1984; Riccardi *et al.*, 1988) for the "Fáunula de *Epophioceras*." This interval could reach 230 meters in thickness at Arroyo Las Chilcas (Figs. 1 and 2C) and is characterized (levels 1412-1414 and 1258-1267) by rather abundant *Epophioceras* cf. *cognitum* Guérin-Franiatte (Fig. 5, nos. 9-10; cf. Guérin-Franiatte, 1966, pl. 255, 226; Hillebrandt, 1981, pl. 3, figs. 2-3). Notice, however, that clear distinction of the homeomorph *Paltechioceras* Buckman is not possible as sutures are not well preserved.

At Arroyo Las Chilcas, the lower part of the interval yielded ?*Epophioceras* sp. and a fragmentary Polymorphitidae tentatively identified as *Microderoceras* cf. *birchi* (Sow.).

The age of this assemblage is therefore late early to late Sinemurian, late Turneri and Obtusum zones (Fig. 3).

Pliensbachian. At Arroyo Las Chilcas and Puesto Araya (Fig. 2C,D) the succession yielded Pliensbachian ammonites. They have been included, from below, in the *Miltoceras*, *Dubariceras*, and *Fanninoceras* assemblage zones (VII, VIII, and IX, respectively, on Fig. 2).

The *Miltoceras* assemblage zone is based on the "Fáunula de *Miltoceras*" of Riccardi (1984; Riccardi *et al.*, 1988) at Arroyo Las Chilcas. The zone is about 40 meters thick and is characterized (levels 1422, 1424-1425) by *Miltoceras* cf. *sellae* (Gemmellaro) and *Miltoceras* sp. This unit could be coeval to the latest Sinemurian and part of the Jamesoni zone (Fig. 3).

The *Dubariceras* assemblage zone was introduced by Riccardi *et al.* (1988). The interval is about 40-110 meters thick at Arroyo Las Chilcas and Puesto Araya (Fig. 2C,D). The lower part (levels 1433, 353-356) is characterized by *Tropidoceras* cf. *flandrini* (Dumortier) and *T.* cf. *stahli* (Oppel). The upper part (levels 1436-1440, 359, 361-362) is characterized by the fauna previously referred to "*Uptonia* cf. *obsoleta*" (Simpson) and "*U.* cf. *angusta*" (Quenstedt) (see Hillebrandt, 1981, pl. 5, figs. 1-3, 5), now included in *Dubariceras freboldi* Dommergues *et al.* (1984, p. 837) together with *Eoamaltheus meridianus* Hillebrandt. This zone has been considered coeval to part of the Jamesoni and Ibex zones (Fig. 3; Riccardi *et al.*, 1990a).

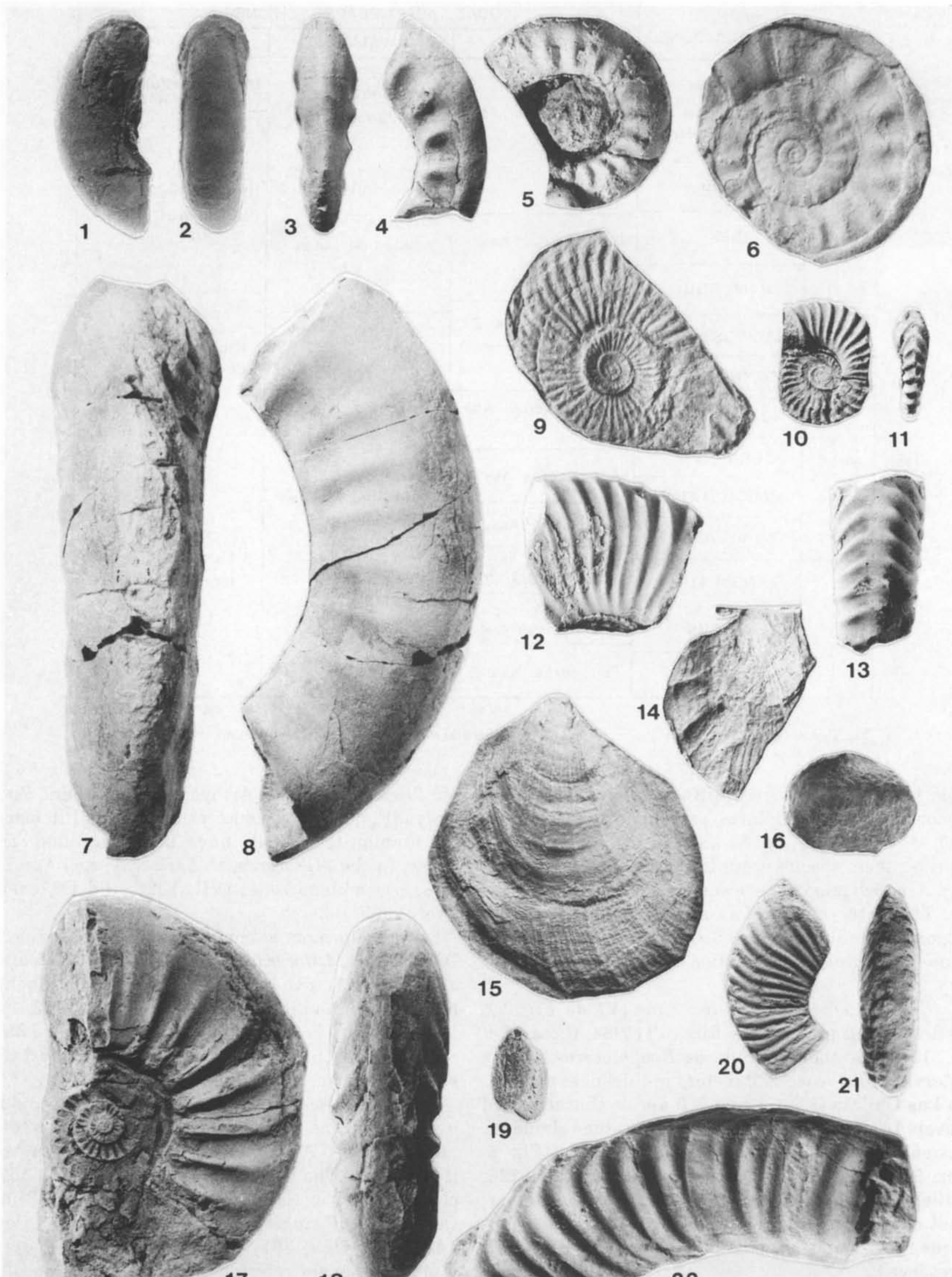

Fig. 4. Unless otherwise indicated, all of the figured fossils are from Arroyo Malo and are in the collections of the Museo de La Plata (MLP). All except nos. 16 and 19 were photographed at ×1, but the illustration has been slightly reduced for publication: 1-2, *Psiloceras* cf. *tilmanni* Lange (MLP 22245); 3-5, *Caloceras* cf. *peruvianum* (Lange) (MLP 22246, 22247); 6, *Psiloceras* cf. *rectocostatum* Hill. (MLP 22248); 7-8, *Waehneroceras* cf. *longipontinum* (Fraas) (MLP 22249); 9, *Schlotheimia* cf. *polyptycha* Lange (MLP 22250); 10-11, *S.* cf. *angulata* (Schl.) (MLP 22251); 12-13, *Schlotheimia* cf. *stenorhyncha* (Lange) (MLP 22252); 14, *Palmoxytoma* sp. (MLP 22253); 15, *Eopecten* cf. *velatus* (Goldf.) (MLP 22256); 16, *Ogmoconchella* sp. (MLP Mi702), ×42; 17-18, *Badouxia canadensis* (Frebold) (MLP 22255); 19, *Lingula* cf. *metensis* Terq. (MLP 22258), ×3; 20-21, *Sulciferites* cf. *marmoreum* (Oppel), from Arroyo Alumbre (MLP 22254); 22, *Vermiceras (Paracaloceras)* cf. *rursicostatum* Freb. (MLP 22257).

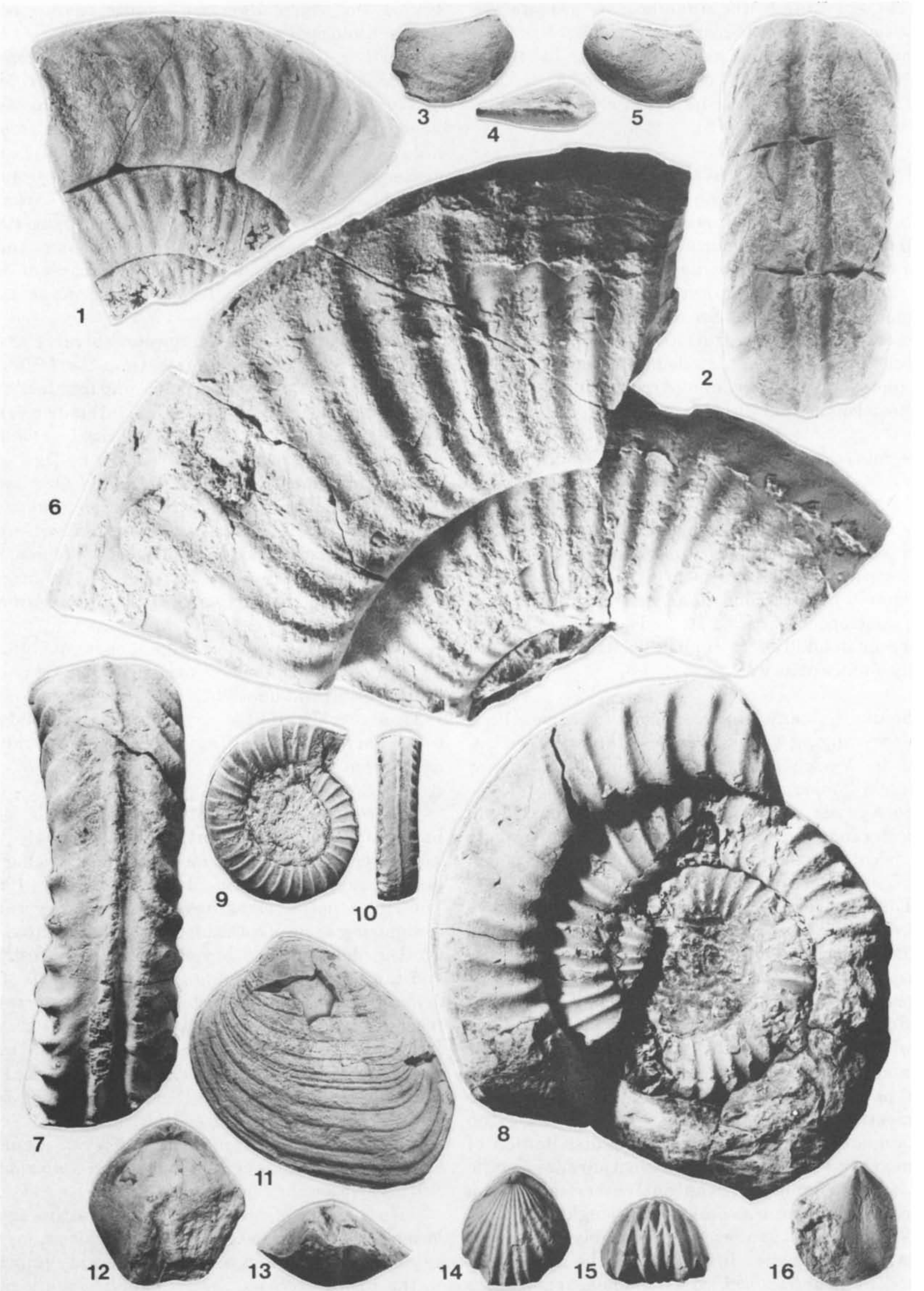

Fig. 5. Numbers 1-8 of the figured fossils are from Arroyo Malo, numbers 9-16 are from Las Chilcas; all are in the collections of the Museo de La Plata (MLP). Unless otherwise indicated, all were photographed at ×1, but the illustration has been slightly reduced for publication: 1-2, *Vermiceras* cf. *gracile* (Spath) (MLP 22259); 3-5, *Otapiria pacifica* Cov. & Esc. (MLP 22261); 6, *Agassiceras* cf. *scipionianum* (Qu.) (MLP 22262); 7-8, *Coroniceras (C.)* cf. *alcinoe* (Rey.) (MLP 22264); 9-10, *Epophioceras* cf. *cognitum* Guérin-Franiatte (MLP 22263); 11, *Cardinia* cf. *listeri* (J. Sow.) (MLP 24315), ×0.75; 12-13, ?*Peristerothyris reijensteini* Manc. (MLP 24486); 14-15, *Gibbirhynchia dereki* Manc. (MLP 24413), ×1.5; 16, *Spiriferina* cf. *ongleyi* Marw. (MLP 24483).

The beginning of the *Fanninoceras* assemblage zone (Riccardi, 1984; Riccardi *et al.*, 1988) has been documented at Arroyo Las Chilcas (level 1444) and Puesto Araya (level 367) on the basis of *F.* cf. *behrendseni* (Jaworski). This unit is latest early to late Pliensbachian in age (Fig. 3).

Toarcian-Bajocian. At the mouth of Arroyo Las Chilcas, a faulted block yielded *Phylloceras* cf. *trifoliatum* Neumayr, *Planammatoceras (Pseudaptetoceras) tricolore* Westermann and Riccardi, *Tmetoceras* sp., and *Puchenquia* cf. *malarguensis* (Burckhardt). This fauna indicates the *Puchenquia malarguensis* assemblage zone (Concavum and early Discites zones) of Westermann and Riccardi (1979).

Toarcian to Bajocian ammonite assemblages are well represented upstream of Arroyo Blanco (Fig. 1; see Westermann and Riccardi, 1972).

Other Invertebrates

In the Río Atuel area, the diversity as well as the abundance of benthonic invertebrates from successive assemblages tends to increase upward. This probably reflects a change from dysaerobic to well-oxygenated bottom conditions. Bivalves, brachiopods, gastropods, corals, ostracods, and scaphopods also occur in addition to ammonites; trace fossils are locally abundant as well.

Bivalves. Many bivalves belong to cosmopolitan and long-ranging genera such as *Chlamys* Röding, *Entolium* Meek, *Grammatodon* Branson, *Gryphaea* Lamarck, *Pholadomya* Sowerby, *Pinna* Linnée, *Pleuromya* Agassiz, and *Weyla* Boehm; they have long vertical ranges in the studied sections. Only some species with particular biostratigraphic and/or paleogeographic interest are commented upon here.

The bivalve fauna of the *Psiloceras* and *Waehneroceras-Schlotheimia* ammonite zones is very poor and is represented only by pectinaceans and ostreaceans. *Palmoxytoma* sp. (Fig. 4, no. 14) apparently ranges from the *Waehneroceras-Schlotheimia* zone to the *Badouxia canadensis* zone. It is comparable to coeval specimens from the early Aratauran of New Zealand (Trechmann, 1923, pl. 12, figs. 6-7) and to the the type species *P. cygnipes* (Y. and B.) from Europe (Dumortier, 1869, pl. 35, figs. 6-8). During the Hettangian-earliest Sinemurian, the distribution of *Palmoxytoma* included the southern circum-Pacific and boreal regions; it was not restricted to the northern hemisphere as previously thought.

The diversity increases considerably to about a dozen bivalve species in the *Badouxia canadensis* zone. The *Otapiria pacifica* assemblage zone, which extends up into the *Agassiceras* zone (Fig. 3), has recently been proposed by Damborenea (in Riccardi *et al.*, 1990a). In the Río Atuel region, *O. pacifica* Covacevich and Escobar (1979, pl. 1, fig. 3; Escobar, 1980, pl. 3, figs. 4-6) is recorded from the *canadensis* and *Vermiceras* zones (Fig. 5, nos. 3-5). The assemblage also includes *Eopecten* cf. *velatus* (Goldfuss) (Fig. 4, no. 15), *Chlamys* cf. *valoniensis* (Defr.), several limid species, and *Pleuromya* sp.

Further studies on the rich upper Sinemurian bivalve fauna (about thirty species) will probably lead to the recognition of one or more bivalve assemblage zones. Conspicuous elements are *Weyla alata alata* (v. Buch), *W. (Lywea) unca* (Philippi), and a species of *Cardinia* Agassiz (Fig. 5, no. 11) closely related to the type species, *C. listeri* (J. Sow.) from the early Sinemurian of Europe (Palmer, 1975, pl. 1, figs. 1-3) and clearly different from Pliensbachian Andean *Cardinia*. Limaceans, trigoniaceans, arcaceans, *Goniomya* sp., *Gresslya* sp., ?*Tancredia* sp. are accessory taxa.

Another diverse (*ca.* 35 species) bivalve assemblage zone has been recognized from the *Miltoceras* and *Dubariceras* zones and ranging up into the lowest part of the *Fanninoceras* zone (Fig. 3; Damborenea, in Riccardi *et al.*, 1990a). It is characterized by *Otapiria neuquensis* Damborenea (1987b, pl. 6, figs. 1-5), *Palaeoneilo patagonidica* (Leanza), and *Grammatodon costulatus* (Leanza). Furthermore, a local species of the south Pacific genus *Kalentera* Marwick forms part of this assemblage in the Río Atuel region. The specimens are very close to the type, *K. mackayi* Marwick (1953, pl. 13, figs. 5, 8, 9, 11, 12), from the Aratauran of New Zealand.

The next bivalve assemblage zone is equivalent to the rest of the *Fanninoceras* zone (Fig. 3). It is characterized by *Radulonectites sosneadoensis* (Weaver, 1931, pl. 28, fig. 169) — a widespread pectinid with north Pacific affinities first described from the Río Atuel area.

Brachiopods. A series of assemblage zones for the Lower Jurassic of Argentina has recently been worked out and formally named after rhynchonellid taxa (Manceñido, 1990, cf. also Riccardi *et al.*, 1990a). The Río Atuel sections have played a key role in recognizing some of these biostratigraphic units.

The oldest marine deposits are areally restricted and their brachiopod faunules appear to be of low diversity, although still poorly known. Impressions resembling *Calcirhynchia* have been observed in the *Waehneroceras-Schlotheimia* interval, and the inarticulate *Lingula* cf. *metensis* Terquem (Fig. 4, no. 19; cf. Terquem, 1851, pl. 1, fig. 9; Möricke, 1894, pl. 5, fig. 10) has been recorded already in latest Hettangian beds belonging to the *Badouxia canadensis* ammonite assemblage zone, lowermost part of the *Otapiria pacifica* bivalve assemblage zone (Fig. 3).

The paucity of brachiopods persists through the lower Sinemurian up to the *Agassiceras* ammmonite assemblage zone, and articulates become important in the *Epophioceras* zone. A *Gibbirhynchia dereki* brachiopod assemblage zone has been established. In its lower part, endemic terebratulids [?*Peristerothyris reijensteini* Manc. (Fig. 5, nos. 12-13; Manceñido, 1990, figs. 1.6a-7c)] are abundant, whereas representatives of the subtethyan genus *Gibbirhynchia* Buckman are subordinate. Higher up, and close to the incoming of the *Miltoceras* ammonite assemblage zone, the local index species *G. dereki* (Fig. 5, nos. 14-15; Manceñido, 1990, figs. 1.1a-c) predominates. It is associated instead with a *Zeilleria* of the *perforata* group and with smooth to faintly ribbed *Spiriferina* (Fig. 5, no. 16) reminiscent of *S. ongleyi* Marwick (1953, pl. 15, fig. 18) from the Aratauran of New Zealand. The assemblage as a whole is thus compatible with a late Sinemurian age (Fig. 3).

A different brachiopod assemblage appears within the *Miltoceras* ammonite assemblage zone and becomes richer in the *Dubariceras* and *Fanninoceras* zones. The *Rhynchonelloidea burckhardti* brachiopod zone has been erected and includes the so-called "Brachiopodenkalke" of Jaworski (1914, 1915). Characteristic taxa have close European relatives, especially from Gresten-like facies, such as the index *R. burckhardti* Manceñido (1990, figs. 2.1a-c), *Tetrarhynchia* ex gr. *subconcinna* (Dav.), *Spiriferina hartmanni* (Ziet.), *Zeilleria* (*Z.*) cf. *sarthacensis* (d'Orb.), or *Squamiplana* (*Cuersithyris*) *davidsoni* (Haime). The latter is a guide fossil in southern France and a member of a conspicuous lineage spread from the Iberian Peninsula to the Carpatho-Balkans in the lower Pliensbachian. Therefore, this fauna, which partly overlaps with the *Otapiria neuquensis* and *Radulonectites sosneadoensis* bivalve assemblage zones, can be dated as Pliensbachian (Fig. 3).

Evidence for the next younger brachiopod assemblage (Fig. 3) is not conclusive in the logged sections. Although the occurrence of *?Exceptothyris bodenbenderi* Manc. toward the top of section D (Fig. 2D) may be a hint of this latest Pliensbachian-earliest Toarcian zone, the index *Rhynochonelloidea cuyana* Manc. has not yet been found.

Microfossils

Thus far, microfossils have been recorded only in the upper Hettangian of the Arroyo Malo section. Representatives of the healdiid ostracod genus *Ogmoconchella* Gründel (Fig. 4, no. 16) have been found in three levels (1395, 1399, 1401) within the *Waehneroceras-Schlotheimia* and *Badouxia canadensis* ammonite zones. All specimens are closely related to *Ogmoconchella ellipsoidea* (Jones), a species well represented in the Hettangian-Sinemurian of central and western Europe (see Jones, 1872, p. 146; Lord, 1971, p. 658, pl. 123, figs. 9-13 and 1978, p. 196, table 1 and pl.1, figs. 1-3; Donze, 1985, table 5 and pl. 21, fig. 10; Herrig, 1988, fig. 1; Ainsworth, 1989, p. 141, pl. 4, fig. 25). The species was also recorded in the offshore upper Rhaetian-lower Sinemurian, southwest of the British Isles (Bennet *et al.*, 1985, p. 259) and south of Ireland (Ainsworth *et al.*, 1987, p. 620-621).

STRATIGRAPHY AND PALEOGEOGRAPHY

The ammonite assemblages found at Arroyo Malo have documented for the first time the existence of marine Hettangian in Argentina. The same section has also provided the best fauna of early Sinemurian invertebrates in the Río Atuel area. Furthermore, the existence, below the fossiliferous Hettangian, of 300 meters of turbidites (with base not exposed) could also imply the first record of marine Triassic for Argentina.

The studied sections show that the boundary between the Puesto Araya and El Freno Formations is diachronous from west to east. Thus, in Arroyo Las Chilcas the oldest marine levels belong to the *Epophioceras* assemblage zone, in Puesto Araya to the lower Pliensbachian *Dubariceras* assemblage zone (Fig. 2C,D). Furthermore, the conglomerates of the El Freno Formation appear to decrease in thickness toward the west where they change to, or interfinger with, marine levels of the Puesto Araya Formation.

Rosenfeld and Volkheimer's (1980, 1981) contention (supported by Hillebrandt, 1989) that, at Arroyo El Pedrero and westward, thick fluviatile conglomerates and sandstones (El Freno Formation) underlie sandy to shaly beds with Sinemurian fossils (Puesto Araya Formation) is not in agreement with our data. Instead, interfingering of relatively thinner submarine conglomerates and much older (Hettangian) ammonitiferous beds occurs.

Small-sized traces belonging to the ubiquitous ichnogenus *Chondrites* are widespread throughout most of the Hettangian-Sinemurian succession. In certain cases, the bottom of fining-upward beds bear hypichnial graphoglyptids of very simple, radiating pattern, indicating distal turbiditic, relatively deep-water environments. Shallowing trends are usually evidenced by an increase in abundance of subhorizontal, randomly oriented *Rhizocorallium* burrows with well-developed "spreite," characteristic of well-sorted sediments. Locally, *Thalassinoides* burrow systems, with typical "Y" junctions and without pelletal lining, occur in the upper Sinemurian. This is probably related to further shallowing from subtidal to even intertidal conditions.

The presence of marine Hettangian, and ?Triassic in the Río Atuel area (34°50'S, 69°52'W) on the eastern slope of the Principal Cordillera implies a substantial change in paleogeography. Previously, the easternmost evidence of marine Hettangian at about this latitude was recorded in the Coastal Cordillera, between *ca.* 70°30'W (Los Vilos-Los Molles) and 71°45'W (Vichuquén-Tilicura, Hualañe-Curepto). Thus, without considering the amount of shortening involved in the present-day outcrop distribution, the Hettangian coast should be placed more than 120-170 km to the east.

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