Lingulid shell beds from the Ordovician of Argentina, with notes on other peri–Gondwanan occurrences

Guillermo F. Aceñolaza1, Christian C. Emig2 and Juan Carlos GutiérreZ–Marco3

1 INSUGEO–CONICET, Facultad de Ciencias Naturales e I.M.L., Universidad Nacional de Tucumán, Miguel Lillo 205, 4000 Tucumán (Argentina). E–mail: acecha@unt.edu.ar

2 CNRS UMR 6540, Centre d'Océanologie, Rue de la Batterie–des–Lions, F–13007 Marseille (France). E–mail: emig@com.univ-mrs.fr

3 Instituto de Geología Económica (CSIC–UCM), Facultad de Ciencias Geológicas, E–28040 Madrid (Spain) and Academia Nacional de Ciencias, Casilla de Correo 36, 5000 Córdoba (Argentina). E–mail: jcgrapto@geo.ucm.es

Key words: Shell beds. Lingulids. Gondwana. Ordovician. Northwestern Argentina.

Introduction

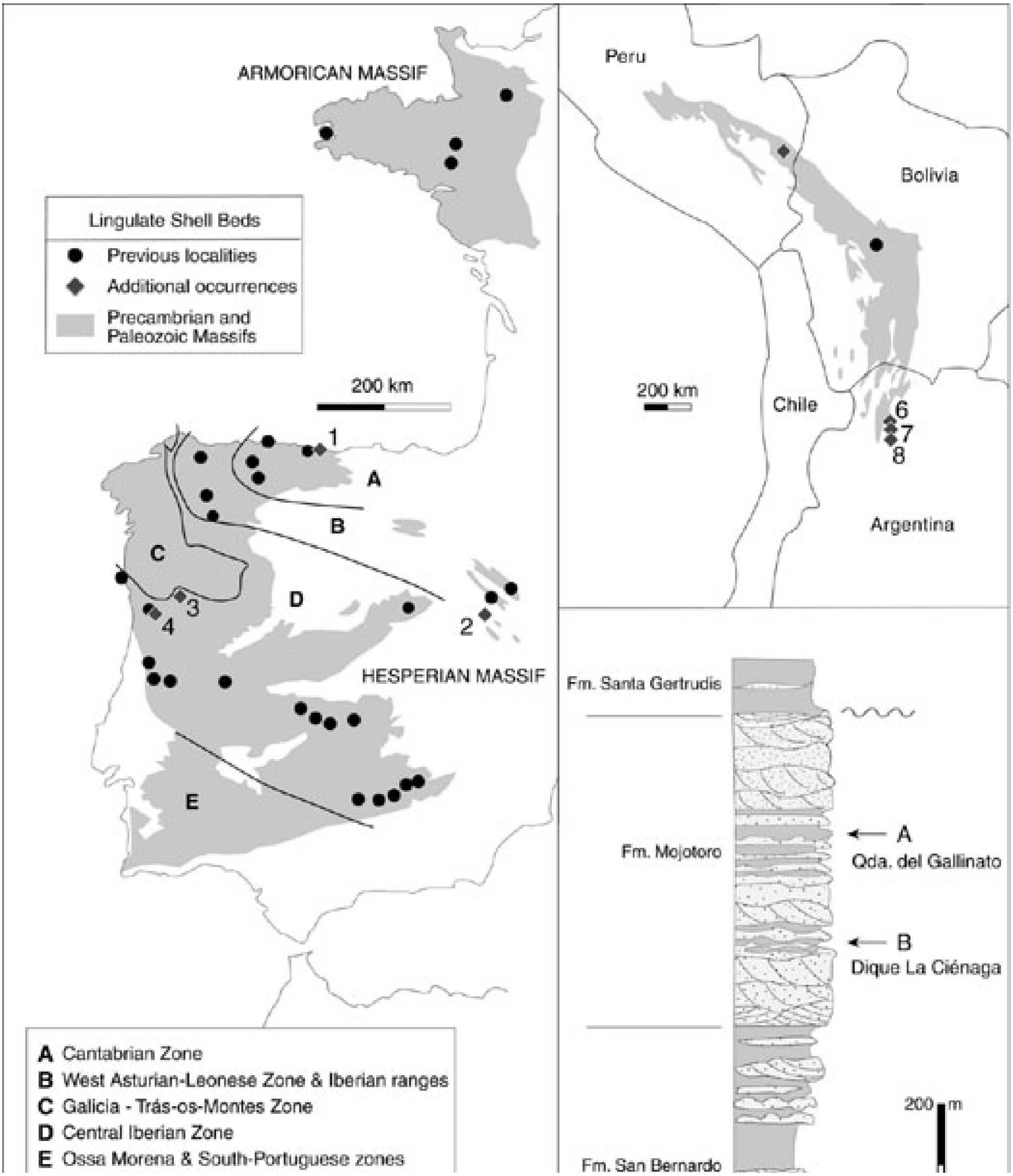
Ordovician shell beds have been classified from different points of view, considering their genetic processes (Kidwell *et al*., 1986), their stratigraphic features and concentrating processes (Kidwell, 1991), their sedimentation patterns (Davies and Miller, 1992), the shell concentrating processes (Fürsich and Oschmann, 1993), and on the basis of the taxonomic composition of their shell concentrations (Li and Droser, 1999).

Along the Ordovician peri–Gondwanan shelves from high to intermediate paleolatitudes there are numerous occurrences of various types of shell beds, which are mainly intercalated in siliciclastic sequences. They are frequently monotaxic, *e.g.*, concentrations of articulated brachiopod shells, bivalve shells, bryozoan remains, echinoderm debris, etc. Polytaxic shell beds are mainly composed of trilobite sclerites combined with gastropod, bivalve and rostroconch shells. A typical monotaxic shell bed, widely recorded in the Darriwilian of SW Europe, is formed by lingulid brachiopods, which occur in tens of localities in the Armorican and Hesperian massifs (Figure 1), around the transition between the Armorican quartzite and the overlying fossiliferous shales (Tristani Beds) (Emig and Gutiérrez–Marco, 1997). The same type of lingulid concentration is recorded in various stratigraphic positions in the Ordovician of northwestern Argentina, where it has been considered for its economic potential as sedimentary phosphorite ore (Leanza, 1972; Mastandrea and Leanza, 1975; Fernández, 1984, 1987) as well as in a few localities from the Upper Ordovician of Bolivia (Suárez Soruco, 1976 with references; Gagnier, 1987).

The purpose of the present study is to consider the actual distribution of these lingulid shell beds, with detailed description of some typical occurrences in the Ordovician of Argentina. Apart from the peri–Gondwanan records, somewhat comparable lingulid shell beds have been previously described from the uppermost Cambrian sandstones of the Baltic area (Heinsalu, 1992; Puura, 1996) and along the present coast of Namibia (Hiller, 1993).

Description of the shell beds

Figure 1 summarizes the known occurrences of lingulid shell beds in the Middle Ordovician of Iberia and western France based on Emig and Gutiérrez–Marco (1997). Additional localities are cited in northern Portugal from the Valongo (Couto *et al*., 1999) and Marão (Coke and Gutiérrez–Marco, 2000) areas. Other new and unpublished Spanish occurrences have been discovered in the Rioseco nappe (Cantabrian zone, Torre section) and in the western Iberian ranges (El Pedregal locality in northern Sierra Menera) (Figure 1).



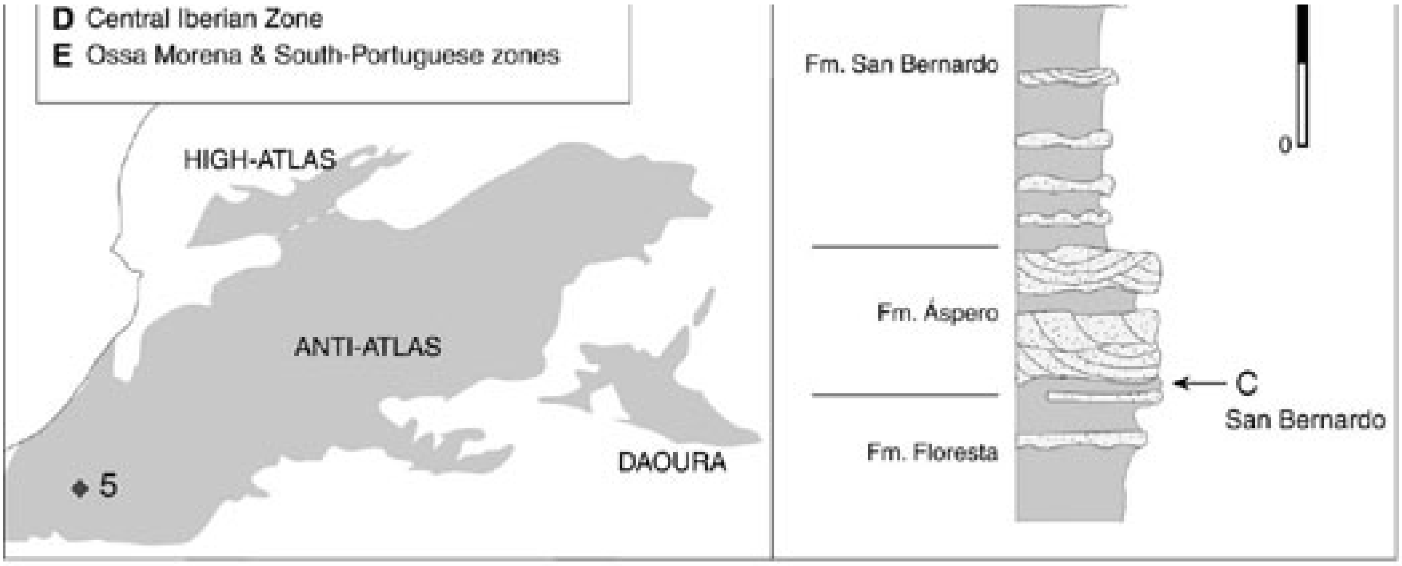


Figure 1. On the left: Geographical distribution of the lingulid shell beds in the uppermost part of the Armorican Quartzite Formation or at the base of the overlying unit of dark shales (Lower Ordovician) in southwestern Europe and North Africa (modified, from Emig and Gutiérrez–Marco, 1997). New localities have been added: 1, Torre, Asturias (unpublished); 2, El Pedregal, Guadalajara (unpublished); 3, Serra do Marão, Portugal (Coke and Gutiérrez–Marco, 2000); 4, Valongo area, Portugal (Couto *et al*., 1999); 5, Aouinet Torkoz – Messeied (Destombes, 1960). Zones A to E correspond to the subdivisions in structural zones of the Hesperian Massif. – Right square up: Geographical scheme of southern South America, showing the location of the main lingulate shell beds in Peru (Gutiérrez–Marco, unpublished), Bolivia (Suárez Soruco, 1976; Gagnier, 1987), and Argentina (Leanza, 1972; Mastandrea and Leanza, 1975; Fernández, 1984, 1987). The new Argentine localities are: 6, Dique la Ciénaga; 7, Quebrada del Gallinato and 8, San Bernardo. – Right square down: Schematic section of some Ordovician formations in Argentine Eastern Cordillera, showing the position of the studied lingulid shell beds (A to C).

In North Africa lingulid shell beds have been reported by Destombes (1960) and Gutiérrez–Marco *et al*. (2003) in the southwestern Moroccan Anti–Atlas (Figure 1), within a stratigraphic context closely comparable to the southwestern European occurrences (*i.e.*, a single horizon intercalated in shales directly overlying the Zini Sandstone, which is the local equivalent of the Armorican quartzite).

Ordovician data from lingulid shell concentrations in South America have been recorded from different localities in the Eastern Cordillera of northwestern Argentina and Bolivia, as well as in the Subandean ranges of southwestern Peru (Gutiérrez–Marco, unpublished). Three new Argentine localities are described below.

A) Quebrada del Gallinato (Province of Salta)

The shell bed, up to 4 cm in thickness, is intercalated in a quartzite unit corresponding to the Mojotoro Formation (= Arenisca 4 according to Moya, 1998), cropping out in the Quebrada del Gallinato, about 12–15 km northeastern of the city of Salta. In many respects the formation closely resembles the Armorican Quartzite facies, with *Cruziana, Skolithos* and others being abundant in many horizons. Acording to Mángano *et al*. (2001), the Mojotoro Formation represents subtidal environments, with heterolithic intervals changing upwards into tidal flat environments. There are several lingulid shell beds similar to those studied here, lying in these heterolithic facies which bear abundant ichnofossils and evidence episodic emersion. The age of the studied material is probably upper Arenigian.

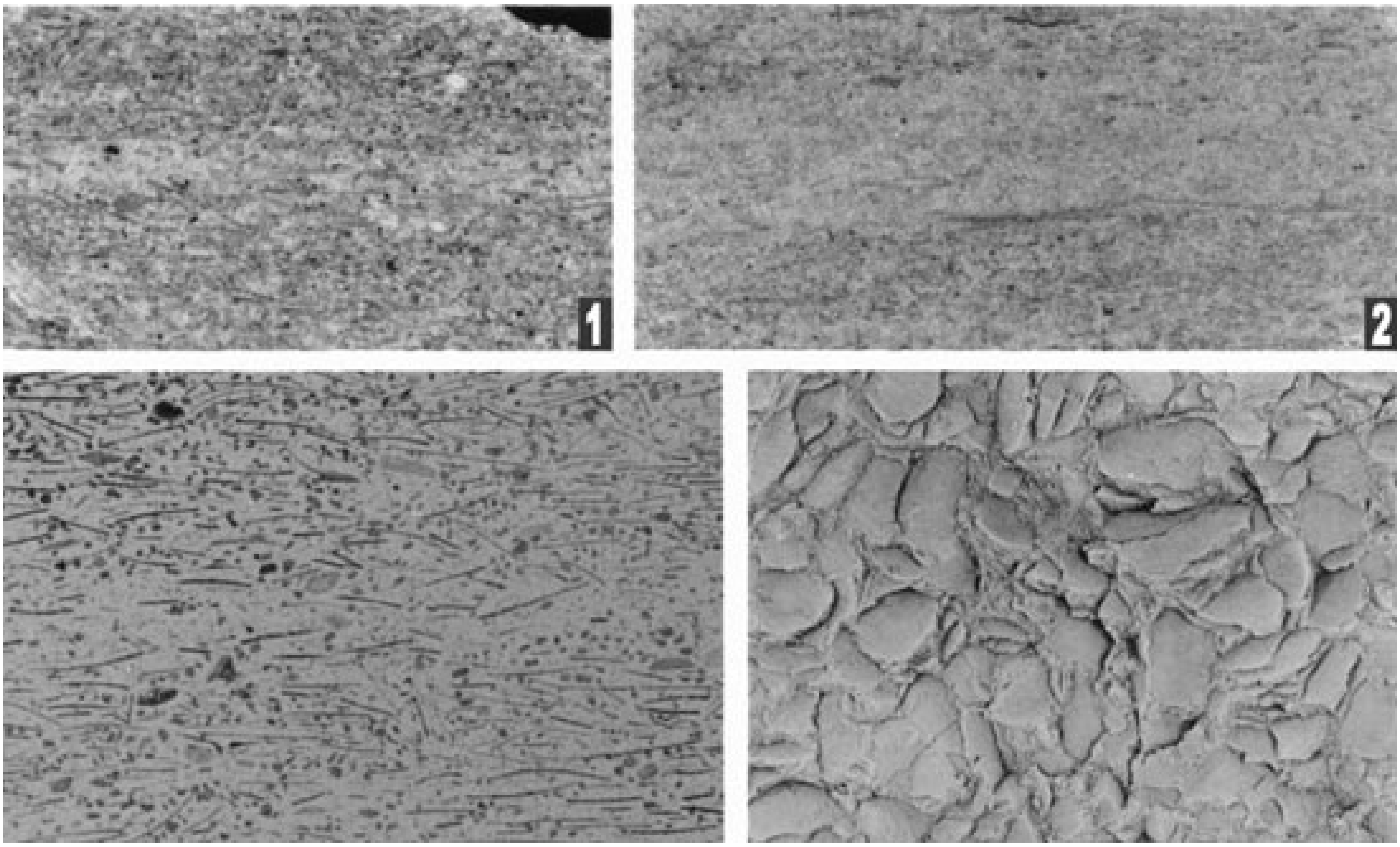
Lingulid shells are highly fragmented, and their remains define internal horizontal to slightly oblique lamination (Figure 2: 6). Larger lingulid fragments commonly occur on the basal and top surfaces of the fossiliferous horizon, displaying random orientation.

According to their shell characteristics, at least two different lingulid taxa can be recognized. The larger one (Figure 2: 9 and 10) corresponds to a very elongate form reminiscent of *Ectenoglossa*, which is a frequent element in similar facies of lingulid concentrations in the Ordovician of southwestern Europe, and particularly in the Armorican Quartzite facies (Emig and Gutiérrez–Marco, 1997, with references). The second taxon is smaller in size and has a thin and elongate shell of oval outline. The valves are longitudinally striated with a narrow median groove, which looks similar to *Dignomia muensteri* d'Orbigny, mainly identified in lingulid concentrations in nearshore littoral sandstones with *Cruziana* and *Skolithos* (Anzaldo Formation) from the latest Darriwilian–early Upper Ordovician of Bolivia (Steinmann and Hoek, 1912; Gagnier, 1987; Gagnier *et al*., 1996).

The studied shell bed can also be distinguished from the surrounding quartzite layers by its coarser granulometry, which consist mainly of large rounded quartz grains mixed with shell fragments of various sizes and with dark grains probably of phosphatic nature.

B) Dique La Ciénaga (Province of Jujuy)

This locality displays many similarities with the previous one because the lingulid shell concentration, about 10 cm thick, is also intercalated in quartzites belonging to the Mojotoro Formation and probably of upper Arenigian age. The locality is situated 5 km south of El Carmen and 30 km south of San Salvador de Jujuy



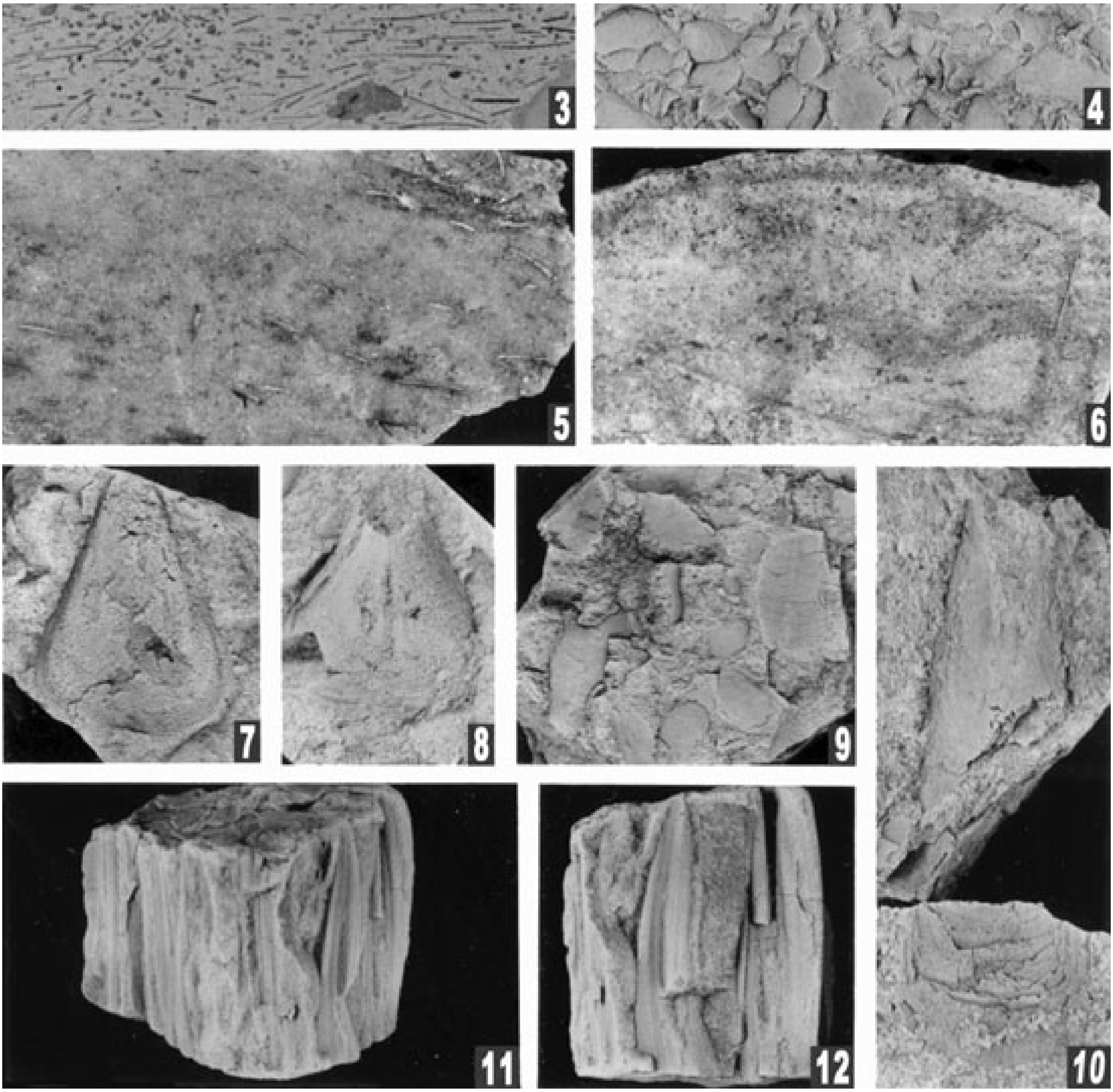


Figure 2. 1 and 2, sections of a lingulid shell bed of B type from the Cerro San Bernardo locality (respectively x 1.6 and x 1.2); 3, thin section showing details of 1, with abundant lingulid fragments, phosphatic grains and small pebbles (x 2.6); 4, horizontal surface of the lingulid shell bed (same locality), showing concentration of valve fragments (x 1.35); 5, coarse sandstone with oblique lamination indicated by the orientation of the larger lingulid fragments in La Ciénaga locality (x 1.5); 6, coarse sandstone bed with highly fragmented lingulid remains in the Quebrada del Gallinato section (x 1.3); 7 and 8? *Lingulepis* sp., internal moulds of respectively ventral and dorsal valves from La Ciénaga locality (both x 1.2); 9 and 10, accumulation of lingulid shell fragments, horizontal view (9, x 1.3) and a valve of *Ectenoglossa* sp. (10, x 2), both from the Quebrada del Gallinato locality; 11 and 12, *Daedalus* isp. in lateral views, demonstrative of its first record from NW Argentina, La Ciénaga locality (x 0.75 and x 0.8 respectively). The original samples are deposited in the collections of the Instituto Superior de Correlación Geológica –IML (Tucumán).

As in the former Argentine locality, the quartzites bear abundant ichnofossils, among them rare *Cruziana*, with dominant vertical structures such as *Daedalus* and *Skolithos*. Large *Rusophycus* are recorded in the shale–sandstone alternation below the main quartzite body.

The lingulid brachiopods are mostly fragmented in a horizon of coarse sandstone bearing iron oxide particles. Some rather complete valves have been recorded at the boundaries of the shell bed. In cross section, the larger shell fragments currently defined a low angle oblique lamination (Figure 2: 5).

According to the morphological characteristics of the lingulid remains, the bed appears monospecific. The best preserved specimens show a triangular outline and longitudinal striation in the exfoliated shell parts (Figure 2: 7, 8). They may be referred to ?*Lingulepis*, a common genus in the Armorican Quartzite facies of SW Europe (Havlícek, 1982, with previous references). In the same way the presence of the ichnogenus *Daedalus*, here reported for the first time from NW Argentina (Figure 2: 11, 12), also supports the biofacial relationships suggested by the brachiopods.

C) San Bernardo (Province of Salta)

The third shell bed occurs as a dense concentration of lingulid fragments in a fine silty matrix, about 30 cm thick, intercalated in a shale–sandstone sequence belonging to the lower part of the Áspero Formation (= Arenisca 3 of Moya, 1998). The studied locality lies in the classic section from Autódromo de Salta–Cerro 20 de febrero, eastwards to the city of Salta. According to Moya *et al.* (1994) and Moya (1998), the Áspero Formation is of upper Tremadocian age; these authors refer to the main quartzitic bodies as subtidal sand bars in a storm–dominated platform.

From a taxonomic point of view, the high fragmentation of the shells prevents identification of the different taxa involved in the accumulation; the lingulid forms have either smooth or striated surfaces. The packing of the lingulid fragments within the bed in not uniform but ordered in several microsequences enhanced by vertical changes in the bioclast concentrations, and internally by the orientation of the lingulid fragments, sometimes forming oblique to horizontal laminations. Phosphatic grains and small siltstone and ferruginous pebbles are frequent in the matrix (Figure 2: 1, 2, 3).

Interpretation and classification

Among the Paleozoic invertebrates the lingulid brachiopods show a low fossilization potential. Because of their structure and composition, shells with a high amount of organic matter are rapidly broken down by hydrolysis and the enzymatic actions of microorganisms. In tidal and subtidal zones, they are simultaneously exposed to mechanical abrasion by currents and wave movements. Lingulid shells are rapidly degraded and mechanically abraded with the central highly mineralized portion persisting longer. This explains why only catastrophic events lead to fossilization of lingulid shells (Emig, 1986).

For this reason the preservation of lingulid shell beds is different from those of other invertebrates and always appears as a consequence of event–concentrations of shell assemblages accumulated in a very short time period and transported for only short distances (Emig and Gutiérrez–Marco, 1997). Before this interpretation accumulations of shelly linguloid phosphorites in Portugal and Estonia were attributed to a combination of prolonged winnowing with the effects of bottom currents providing an immobile residuum of condensed sedimentation (Romano *et al*., 1986; Oja, 1995).

Most of the lingulid shell beds so far recorded in the upper Arenigian over a wide area in southwestern Europe and North Africa (Figure 1) have been interpreted as the probable result of tsunamis which affected the infaunal communities on shallow shelves where the Armorican sandy facies was deposited. Supposedly these tsunamis were related to explosive volcanism occurring at this time over the north Gondwanan platform (Emig and Gutiérrez–Marco, 1997).

The two first lingulid shell beds in Argentina, described above, belong to type A as described by Emig and Gutiérrez–Marco (1997). They probably originated through sedimentary floods of coarse particles, transported by rivers during periods of heavy rains which also induced large salinity decreases. In such coarse sediment the lingulids are unable to construct their burrows as well as to retract into the original burrow. Finally they leave the substrate and remain laying on the seafloor. The valve fragments behave like sedimentary particles in probable tidal flat environments.

The third class of Argentine shell beds described here belong to type B, the most common in the high–latitude peri–Gondwanan areas, but also recorded in the Anzaldo Formation (late Middle–early Upper Ordovician) of Bolivia (see references above). It consists of a silty to sandy matrix, displaying large concentrations of fragments of lingulid valves, with some phosphatic and sideritic pebbles and heavy minerals. It originated during very short catastrophic events which induced unconformable deposits of valve fragments in the littoral zone, probably deposited during violent storms (hurricanes), and even related to tsunamis produced by earthquakes or explosive volcanism. However, some of the Bolivian records of the same type of lingulid shell beds have been interpreted by Gagnier (1987) as probably due to salinity crises induced by repeated fresh water fluxes in a deltaic environment.

The peri–Gondwanan record of the lingulid shell beds in the studied examples is clearly related to shallow marine sediments (*Cruziana* and *Skolithos* ichnofacies) which include the typical Armorican Quartzite in a large area of SW Europe, ?Eastern Europe (Serbia) and NW Africa, as well as some formations resembling the former in the Argentine Eastern Cordillera (Áspero and Mojotoro formations: Tremadocian to late Arenigian). Bolivian records of lingulid shell beds come from a comparable younger quartzitic unit (with *Cruziana* and *Skolithos* ichnofacies), the Anzaldo Formation, of the Eastern Cordillera of Bolivia (Cochabamba region).

According to the classification of the Ordovician shell beds primarily based on their taxonomic composition by Li and Droser (1999), Brachiopod Shell Beds are usually referred to as monotaxic (brachiopods–only) and polytaxic (brachiopod–dominated, brachiopod–ostracod, brachiopod–trilobite) shell beds, always with a predominance of orthids or other articulated brachiopods. Although our examples belong to the category of Brachiopod Shell Beds, the peculiar circumstances that involve the accumulation and preservation of Ordovician lingulate brachiopods are different from those described by the authors cited above. Thus we proposea new category, Lingulate Shell Beds, to accommodate these particular phosphorite–rich horizons. Individually they can be traced for tens to hundreds of kilometres, have sharp contacts with the underlying and overlying strata and are related to exceptional sedimentary events.

Acknowledgements

We thank Prof. Cristina Moya and Julio A. Monteros, Universidad Nacional de Salta (Argentina) for guidance and help in the field work, to Carlos Alonso (Madrid) for photographs, to Gilberto Herrero (Madrid) for the thin sections, and to Dr. Art Boucot, Oregon State University (USA) and Florencio G. Aceñolaza (Tucumán, Argentina) for helpful comments on the manuscript and improvements in the English of the last version. This work is a research contribution supported by the Fundación Antorchas and the INSUGEO (CONICET–UNT, Tucumán). The collaboration of J.C. Gutiérrez–Marco and C.C. Emig was granted by the French–Spanish exchange program CSIC–CNRS.

References

Coke, C. and Gutiérrez–Marco, J.C. 2000. Descoberta de lumachelas com lingulídeos no Ordovícico da Serra do Marão (Norte de Portugal). *I Congresso Ibérico de Paleontologia*, Évora: 189–190.

Couto, H., Gutiérrez–Marco, J.C. and Roger, G. 1999. Níveis fosfatados com lingulídeos do Arenigiano (Ordovícico) do Anticlinal de Valongo (Portugal). *Temas Geológico–Mineros,* Instituto Tecnológico Geominero de España, 26 (2): 410–458.

Davies, D.J. and Miller, M.F. 1992. Paleocommunity information retrieval vs. shell accumulation mode in Paleozoic carbonates: Examples from the Lebanon Limestone (Middle Ordovician), Tennessee, U.S.A. (Abstract). *5th North American Paleontological Convention,* Abstracts and Programs: 81.

Destombes, J. 1960. Stratigraphie de l'Ordovicien de la partie occidentale du Jbel Bani et du Jbel Zini, Anti–Atlas occidental (Maroc). *Bulletin de la Société Géologique de France*, 7 (2): 747–751.

Emig, C.C. 1986. Conditions de fossilisation du genre *Lingula* (Brachiopoda) et implications paléoécologiques. *Palaeogeography*, *Palaeoclimatology*, *Palaeoecology*, 53: 245–253.

Emig, C.C. and Gutiérrez–Marco, J.C. 1997. Signification des niveaux à lingulidés à la limite supérieur du Grès Armoricain (Ordovicien, Arénig, Sud–Ouest de l'Europe). *Geobios*, 30 (4): 481–495.

Fernández, R.I. 1984. Bioestratigrafía y mineralogía de nuevos yacimientos de rocas fosfóricas en la Provincia de Jujuy, República Argentina. *I Conferencia Latinoamericana de rocas fosfóricas* (GLIRF–AGID), Cochabamba, 1: 61–70.

Fernández, R.I. 1987. Wavellita en fosfatos sedimentarios ordovícicos de la provincia de Jujuy, República Argentina. *X Congreso Geológico Argentino,* Tucumán, 2: 257–260.

Fürsich, F.T. and Oschmann, W. 1993. Shell beds as tools in basin analysis. The Jurassic of Kachh, western India. *Journal of the Geological Society,* London, 150: 169–185.

Gagnier, P.–Y. 1987. *Sacabambaspis janvieri,* un heterostráceo del Ordovícico Superior de Bolivia.

IV Congreso Latinoamericano de Paleontología, Santa Cruz de la Sierra, 2: 665–677.

Gagnier, P.–Y., Blieck, A., Emig, C.C., Sempere, T., Vachard, D. and Vanguestaine, M. 1996. New paleontological and geological data on the Ordovician and Silurian of Bolivia. *Journal of South American Earth Sciences*, 9 (5–6): 329–347.

Gutiérrez–Marco, J.C., Destombes, J., Rábano, I., Aceñolaza, G.F., Sarmiento, G.N. and San José, M.A. 2003. El Ordovícico Medio del Anti–Atlas marroquí: paleobiodiversidad, actualización bioestratigráfica y correlación. *Geobios*, 36 (2): 151–177.

Havlícek, V. 1980. Inarticulate brachiopods in the Lower Ordovician of the Montagne Noire (South France). *Mémoires de la Société d'Etudes Scientifiques de l'Aude*, 1: 1–11.

Heinsalu, H. (ed.) 1992. *Geologiya rakushechnykh fosforitov Pribaltiki*. Tallinn: 1–132.

Hiller, N. 1993. A modern analogue for the Lower Ordovician *Obolus* conglomerate of Estonia. *Geological Magazine*, 130 (2): 265–267.

Kidwell, S.M. 1991. The stratigraphy of shell concentrations. *In*: Allison, P.A. and Briggs, D.E.G. (Eds.), *Taphonomy: realising the data locked in the fossil records*. Topics in Geobiology, Plenum Press, New–York: 211–290.

Kidwell, S.M., Fürsich, F.T. and Aigner, T. 1986. Conceptual framework for the analysis and classification of fossil concentrations. *Palaios*, 1 (3): 228–238.

Leanza, A.F. 1972. *Prospección de rocas fosfáticas en la Argentina para la fabricación de fertilizantes*. IDIA, 291, Buenos Aires.

Li, X. and Droser, M.L. 1999. Lower and Middle Ordovician shell beds from the Basin and Range Province of the Western United States (California, Nevada, and Utah). *Palaios*, 14 (3): 215–233.

Mángano, M.G., Buatois, L.A. and Moya, M.C. 2001.Trazas fósiles de trilobites de la Formación Mojotoro (Ordovícico Inferior–Medio de Salta, Argentina): implicancias paleoecológicas, paleobiológicas y bioestratigráficas. *Revista Española de Paleontología*, 16 (1): 9–28.

Mastandrea, O. and Leanza, H.A. 1975. Los estratos con *Lingula* del norte argentino y su importancia como fuente de fosfatos. *II Congreso Iberoamericano de Geología Económica*, Buenos Aires, 2: 445–460.

Moya, M.C. 1998. El Paleozoico Inferior en la Sierra de Mojotoro, Salta – Jujuy. *Revista de la Asociación Geológica Argentina*, 53 (2): 219–238.

Moya, M.C., Malanca, S., Monteros, J.A. and Cuerda, A. 1994. Bioestratigrafía del Ordovícico Inferior en la Cordillera Oriental argentina basada en graptolitos. *Revista Española de Paleontología*, 9

(1): 91–104.

Oja, T. 1995. *Morphology of clastic constituents in the phosphate–bearing Kallavere Formation (North Estonia) with respect to depositional environments*. MSC thesis, Geology, University of Tartu: 1–61.

Puura, I. 1996. *Cambrian–Ordovician lingulate brachiopods from Estonia and northwestern Russia*. Doctoral thesis, Uppsala University, part 1: 1–136.

Romano, M., Brenchley, P.J. and McDougall, N. D. 1986. New information concerning the age of the beds immediately overlying the Armorican Quartzite in central Portugal. *Geobios*, 19 (4): 421–433.

Steinmann, G. and Hoek, H. 1912. Das Silur und Kambrium des Hochlandes von Bolivia und ihre fauna. *Neues Jahrbuch für Geologie, Mineralogie und Paläontologie*, 34: 176–252.

Suárez Soruco, R. 1976. El sistema Ordovícico en Bolivia. *Revista Técnica de Yacimientos Petroliferos Fiscales Bolivianos*, 5 (2): 111–223

Received: February 15, 2003

Accepted: June 15, 2003