Evidence for a Stratigraphic Basis for the Anthropocene

Colin N. Waters, Jan Zalasiewicz, Mark Williams, Simon J. Price, Jon R. Ford and Anthony H. Cooper

Abstract The Anthropocene was proposed as a term (Crutzen and Stoermer 2000) before consideration was given to the nature of the key signatures, contrasting with standard procedures for defining such units. The term is being widely used in both popular and scientific publications before a decision is made as to whether it warrants formalisation and definition of a Global Stratigraphic Section and Point (GSSP). The deliberate human modification of the landscape and its subsurface, and the creation of human-generated novel sedimentary deposits, minerals, and landforms, are characteristic features of the development of Earth's surface and near surface, which has accelerated in the past two centuries. The large-scale intentional excavation, transportation, and deposition of mixtures of rock and soil to form anthropogenic deposits and landforms represent a new geological process that could be used as a diagnostic signature of the Anthropocene.

Keywords Anthropocene · Stratigraphy · Anthropogenic deposits

Stratigraphic Issues Related to Anthropogenic Deposits

The ground surface and deposits immediately beneath are an open system prone to modification through urban redevelopment, agricultural ploughing, and soil formation. This system may be the product of several phases of ongoing evolution and therefore dating this interval is problematic. The history of excavation in

C. N. Waters (✉) · S. J. Price · J. R. Ford · A. H. Cooper
British Geological Survey, Environmental Science Centre, Keyworth,
Nottingham NG12 5GG, UK
e-mail: cnw@bgs.ac.uk

J. Zalasiewicz · M. Williams
Department of Geology, University of Leicester, Leicester LE1 7RH, UK

archaeology helps to determine the timing of events, analogous to the use of geological unconformities through allostratigraphy (Ford et al. 2014). The complex unconformities, of value at a local scale for dating the relative age of deposits, do not permit regional-scale correlation of these surfaces to be made. The only unconformity that can be certainly correlated is the contact between basal artificial deposits and the underlying natural deposits that pre-date human modification of that landscape; this bounding surface is highly diachronous.

Ford et al. (2014) recognise that human artefacts, used as indicators of age in archaeological investigations, are equivalent to geological "type-fossils" and that modification of the landscape (anthroturbation) may be considered as human-produced trace fossils. Both are functions of technological evolution, with certain technologies replacing older ones because they are better adapted, comparable to natural selection controlling biostratigraphic signatures. Artefacts evolve from invention (equivalent to First Appearance Datum) to global distribution (or biostratigraphic acme) and then to obsolescence (or biostratigraphic rarity) within years or decades as a function of the globalisation of trade. These artefacts and compositional variations in human waste can provide a very high-resolution tool for dating deposits. Their long-term preservation potential is controlled by the material composition, moisture content, temperature, redox potential, and pH of the deposits, and in the distant future relatively few distinctive artefacts may be recognisable (Ford et al. 2014).

Potential Ages for the Start of the Anthropocene

Three main suggestions have been proposed as to potential ages for the start of the Anthropocene, namely, a pre-Industrial Revolution (Holocene) age, an industrial revolution age, and a mid-twentieth-century age, discussed in turn below.

Pre-industrial Revolution (Holocene) Age

The Holocene Epoch is a time during which there has been a progressive increase in the prominence of humans as an agent influencing natural environments and processes, making this epoch distinct from previous Pleistocene interglacials. The human influence is principally associated with deforestation, the domestication of land for food production, the introduction of irrigation schemes, localised mineral workings, and the development of small-scale and simple urban settlements. The earliest development of artificial deposits approximates to the onset of the Holocene. Many contemporary cities record hundreds or thousands of years of occupation, so it is not the onset of urbanisation that should be considered indicative of the start of the Anthropocene.

Industrial Revolution Age

The start of the Industrial Revolution was associated with the increased burning of fossil fuels and rapid urbanisation, resulting in large-scale land transformation as populations grew and generated more wealth. This resulted in a marked change in the characteristics of anthropogenic deposits. These include increases in the use of building and construction materials, in the exploitation of surface deposits, in the inclusion of processed metals and associated manufactured goods, and in human activities at depth for mineral exploitation or subsurface infrastructure (Ford et al. 2014). Although this process started at around 1800 CE in Europe and North America, the global impact of the Industrial Revolution was diachronous. Williams et al. (2013) recognise a radical change in the urban environment during the mid-nineteenth century with the inception of London as the first "megacity". Here, the scale of the conurbation resulted in the need to evolve subsurface transport and sewerage systems, setting the pattern for many, though not all, large cities in the twentieth and twenty-first centuries.

Mid-Twentieth-Century Age

Using key commodity indicators (e.g., coal and iron ore) and anthropogenic materials flows associated with urbanisation (e.g., the use of cement and concrete, engineered infrastructure development, and waste disposal), distinct trends in rates and volumes of anthropogenic flux are observed. These show a significant change in the nature and volume of artificial anthropogenic deposits from 1945 onwards. These include a dramatic rise in overburden and spoil ratios related to mineral extraction and in the volumes of material worked and used for construction, driven by an extraordinary growth of cities and major infrastructure projects (Ford et al. 2014). It coincides with the "Great Acceleration" in global economic activity following World War II (Steffen et al. 2007). This time interval is characterised by electronic equipment, extensive concrete manufacture, deep mining, and the generation of vast amounts of waste. These stratigraphic signals are both sharp (to decadal level) and globally widespread (Zalasiewicz et al. 2014).

Zalasiewicz et al. (2013) recognise a suite of minerals contained in fired brick, ceramics, cement, and concrete that are present in archaeological times, but which have become significantly more common since the mid-twentieth century. These minerals are sufficiently stable to provide a lasting signature. There are also new metal alloys, mineraloid glasses, semiconductors, synthetic "minerals", and emerging nanomaterials that may be indicative of the Anthropocene. However, Zalasiewicz et al. (2013) argue that the process of mineral classification excludes anthropogenic/biogenic minerals and without classification it is difficult to quantify the evolution of these novel "minerals", hindering their usefulness for characterising a new epoch.

Definition of a Global Stratigraphic Section and Point (GSSP)

International stratigraphic practice requires that major chronostratigraphic subdivisions are defined with reference to boundary stratotype localities in sedimentary successions, designated as GSSPs. However, directly deposited terrestrial anthropogenic deposits are markedly diachronous and laterally impersistent, and may include numerous disconformities. They have a propensity for reworking by continued human landscape modification and ultimately a relatively low preservation potential in the geological record; furthermore, they are commonly associated with poor or often temporary exposures (Ford et al. 2014). These factors do not make artificial deposits a suitable succession in which to place a GSSP, despite being the sedimentary deposits most directly related to anthropogenic modification of the planet.

With the definition of the base of the Anthropocene likely to be at a time of tens to hundreds of years before present, the resolution of dating techniques needs to be at least decadal, if not annual, and the definition of a Global Standard Stratigraphic Age (GSSA or numerical age) needs to be made at a specific year. This could be based upon a spectrum of chemical, biological, and lithological signatures, a process arguably preferable to using a proxy indicator in a single section based upon the evolution of a specific indicator faunal/floral species.

Williams et al. (2013) promote a GSSP based on the increased complexity developed by the urban environment, analogous to the increasing complexity of the trace fossil used to define the base of the Cambrian. Those authors use a particular criterion to define the start of the Anthropocene—the 1863 inception in London of the first Metro system. Comparisons are made with the definition of the base of the Cambrian; here, increasing biological complexity required that one ichnospecies was chosen to represent this changing complexity. This first appearance has ultimately proved diachronous for the base of the Cambrian, with few observed sections. The complex urban environment has taken decades (rather than hundreds of thousands of years for the Cambrian basal facies) to promulgate globally. It represents a subordinate depositional environment (about 3 % of Earth's surface), but this is large compared with the small number of Cambrian sections, suggesting dual standards compared with the definition of existing chronostratigraphic units.

Conclusions

The nature of anthropogenic deposits could be used as a signature for the start of the Anthropocene. The start could be fixed to 1863 and the increase in the complexity of the evolution of urban areas, or to 1945, when the rate of change in and volume of production of anthropogenic materials and the generation of new

minerals and lithologies in the sedimentary cycle are so significant and novel. Ultimately, any decision needs to be made in light of a broad spectrum of physical, geochemical, and biological signatures.

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Stratigraphy of the Caspian Sea Neopleistocene, Based on *Didacna* Eichwald Molluscs

Tamara Yanina

Abstract The stratigraphy of the Caspian Neopleistocene (comprising the Middle and Upper Pleistocene according to the International Stratigraphic Scheme) is based on changes in the evolutionary patterns and ecological assemblages of the mollusc genus *Didacna* Eichwald. The molluscan faunas represent a complex hierarchical system of faunal assemblages with different taxonomic compositions and at different taxonomic levels: faunas, complexes, subcomplexes, and associations. Based on the molluscan fauna, namely, on faunal units distinguished at different hierarchical levels, this work presents a regional biostratigraphic (ecostratigraphic) scheme of the Neopleistocene of the Caspian, supplementing the existing schemes.

Keywords Caspian Sea · Neopleistocene · Molluscs · *Didacna* Eichwald · Biostratigraphy · Type sections

Introduction

The biostratigraphy of the Caspian Neopleistocene is based on changes in the evolutionary patterns and ecological assemblage changes of the mollusc genus *Didacna* Eichwald. Here, thorough analyses were conducted on virtually all known sites containing Caspian fauna, which included the revision of a large collection of *Didacna* shells together with analyses of their spatial and stratigraphic distributions in sediments of the Caspian region. Faunal groups of different taxonomic composition were distinguished at different taxonomic levels. The study has allowed existing biostratigraphic schemes to be revised and

T. Yanina (✉)
Faculty of Geography, Moscow State University, Leninskie Gory, 1, Moscow 119991, Russia
e-mail: didacna@mail.ru

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supplemented, stratigraphic units to be systematically organized, and reference sites for all the described faunal assemblages at different taxonomic levels to be proposed.

Materials and Methods

A malacological study was conducted in the following areas: the Lenkoran coast, the Kura Depression, the Apsheron Peninsula, the Azerbaijan and Dagestan coasts of the Caucasus, the Manych Depression, the Lower Volga region, the Volga–Ural interfluve, the Ural River valley, the Mangyshlak Peninsula, and the Iranian coast. The investigation included the taxonomic composition, taphonomy, biostratigraphic distribution, evolution, phylogeny, and biogeography of molluscs. The main focus was placed on brackish-water species of the genus *Didacna* Eichwald, because members of this genus are index species for the Caspian Sea and are endemic for the Pontian–Caspian region. This genus is known for its high evolutionary rates at the species and subspecies levels, which highlight its significance for establishing the stratigraphy of the marine Neopleistocene of the Caspian region. A multimethod approach was used, implying the use of geomorphological, lithological, facies, spore and pollen, and geochronological analyses for the study of recent sediments; these different tools complement each other in this stratigraphic study.

Results

An analysis of shells of *Didacna* Eichwald from the Neopleistocene deposits of the Caspian region revealed that they represent 74 species and subspecies. In the distribution of *Didacna*, the following faunas were identified: Baku, Urunjik, Early Khazar, Late Khazar, Khvalynian, and New Caspian. Each of the faunas is characterized by a particular ratio of major *Didacna* groups (crassa, trigonoides, and catillus), as well as by the taxonomic composition of each faunal group with its own index species and affiliation to a particular interval in Caspian sediments, separated from under- and overlying sediments by traces of unconformity or washout. In the Baku fauna, the crassa and catillus groups are abundant. The Urunjik fauna is characterized by the predominance of the crassa group, whereas the Early Khazar fauna is dominated by the trigonoides group. The Late Khazar fauna, in contrast, is dominated by the crassa group of *Didacna*. The Khvalynian fauna is characterized by the trigonoides and catillus groups, and the New Caspian by abundant crassa and trigonoides *Didacna*. There are, therefore, clear distinctions between the faunas together with their linkages. In the palaeogeography of the region, these faunas reflect major transgressive epochs in the history of the Caspian.

Stratigraphical scale	Biozone	Horizons	Groups of Didacna			Subzones (Faunas)	Index-species, characteristic species	Subhorizons	Interval zones (Faunal complexes)	Layers	Subcomplexes	Reference sections
			crassa	trigonoides	catillus							
Holocene		New Caspian				crassa-trigonoides (New Caspian)	Cerastoderma glaucum D. crassa D. baeri D. trigonoides			modern	Mytilaster	Turali (Dagestan)
										middle New Caspian	Cerastoderma	
										lower New Caspian	D. crassa-D. trigonoides	
Pleistocene (Neopleistocene in Russia)	Upper	Khvalynian				trigonoides-catillus (Khvalynian)	D. ebersini D. praetrigonoides D. parallella D. protracta	Upper Khvalynian	Late Khvalynian D. praetrigonoides			Enotaevka-Kopanovka-Tsagan-Aman (Lower Volga region)
								Lower Khvalynian	Early Khvalynian D. parallella-D. protracta			
		Upper Khazar				crassa (Late Khazar)	D. surachanica D. nalivkini	upper Upper Khazar	late Late Khazar D. surachanica-D. nalivkini			Seroglazovka (Lower Volga region)
								lower Upper Khazar	early Late Khazar D. nalivkini			
	Didacna Eichwald	Lower Khazar				trigonoides (Early Khazar)	D. subpyramidata D. paleotrigonoides D. shuraosenica	upper Lower Khazar	late Early Khazar D. paleotrigonoides-D. nalivkini			Seroglazovka Kopanovka (Lower Volga region)
								middle Lower Khazar	middle Early Khazar D. paleotrigonoides-D. sybpyramidata-D. shuraosenica			
								lower Lower Khazar	early Early Khazar D. subpyramidata			
	Middle	Urundjik				crassa (Urundjik)	D. celekenica D. eulachia D. kovalevskii D. pravoslavlevi			Late Urundjik	D. kovalevskii	Nephtyanaya Balka (Kura depression)
										Early Urundjik	D. eulachia	
		Baku				crassa-catillus (Baku)	D. parvula D. catillus D. rudis D. carditoides			Late Baku	D. rudis-D. carditoides	Gora Bakinskogo Yarusa (Apsheron peninsula) Nephtyanaya Balka (Kura depression)
										Early Baku	D. parvula-D. catillus	

Fig. 1 Biostratigraphic subdivision of the Caspian Sea marine Neopleistocene deposits

Each fauna is represented by closely related faunal complexes, characterizing sediment members of different age, and corresponding to separate stages in the development of transgressions. Complexes have particular taxonomic compositions of *Didacna* with characteristic species. The Baku, Urunjik, and New Caspian faunas each have a single *Didacna* complex, the Early Khazar fauna includes three complexes, and the Late Khazar and Khvalynian include two each. Most of the faunal complexes, based on variability within one sediment member, are subdivided into subcomplexes, usually characteristic of separate stages of the transgression. Some areas of the Caspian coast are characterized by faunal complexes (and subcomplexes) that differ from others and are defined as faunal associations. The faunal assemblages distinguished at different taxonomic levels are used as a basis for the biostratigraphy of the Neopleistocene of the Caspian region (Fig. 1).

The main taxonomic unit of regional biostratigraphic schemes is a biostratigraphic zone, defined as an interval of geological strata that spans the entire stratigraphic interval of taxon distribution. The Neopleistocene of the Caspian belongs to the *Didacna* Biozone. According to the development of the major *Didacna* groups that form faunas, the zone is subdivided into six subzones, which are fundamental for establishing the main regional stratigraphic unit, namely, the horizon (or regional stage). The following horizons are recognized: Baku, Urunjik, Lower Khazar, Upper Khazar, Khvalynian, and New Caspian. An analysis of the distribution of major *Didacna* groups in the section points to their high accuracy for identifying different sediment members in the Caspian on the basis of the evolutionary development of *Didacna*. From the point of view of historical geology, these horizons correspond to transgressive epochs in the history of the

Caspian history. For each of the horizons, index and characteristic (controlling) species are distinguished.

Higher-resolution stratigraphic units are interval zones, and are used to identify the subhorizons. From the point of view of historical geology, they correspond to major transgressive stages, separated by regressions, within the transgressive epochs. The Lower Khazar horizon is subdivided into lower, middle, and upper subhorizons, characterized by corresponding faunal complexes. The Upper Khazar horizon is subdivided into lower and upper subhorizons. The Khvalynian horizon is subdivided into lower Khvalynian and upper Khvalynian subhorizons. The subhorizons are linked to the presence of characteristic species.

A minor stratigraphic unit identified is the bed. Beds were distinguished based on the mollusc subcomplexes, and record the initial and end phases of the transgressive stages. Beds are linked to presence of characteristic species. Members, constituting the smallest stratigraphic unit, were defined within some of the subhorizons and beds. Members are characterized by malacological faunal assemblages, showing low-range oscillations of the basin reflected in variable facies. Mollusc associations, which were distinguished for faunal units at different taxonomic levels, reflect the spatial diversity of palaeoecological environments in the basin and show the variety of facies of the horizons, subhorizons, and beds. All stratigraphic units distinguished are related to palaeogeographical events at various hierarchical levels (transgression, stage, and phase) in the development of the basin. Type localities for faunas, faunal complexes, and subcomplexes are suggested for the stratigraphic units distinguished. All of them are located in well-stratified sections, are available for investigation, and have been previously thoroughly studied. Besides malacofauna, the sections contain other fossil remains (including ostracods, foraminifers, pollen, and carpological material); data on all these fossils, as well as on palaeomagnetism, absolute chronology, lithology, and geomorphology, were taken into consideration for their selection.

Potential Formalization of the Anthropocene: A Progress Report

Jan Zalasiewicz, Colin Waters and Mark Williams

Abstract The geological rationale for a potential formal Anthropocene Epoch includes evidence of lithostratigraphic, biostratigraphic, and chemostratigraphic change. These changes represent the early stages of what will be a long-lasting geological event, and at present range from substantial (e.g., lithostratigraphic changes and species invasions) to minor (e.g., sea-level rise), while some (e.g., new mineral species) are geologically novel. On current evidence, a practicable base for an Anthropocene Series may be placed around 1950 CE, coincident with global chemostratigraphic and other changes. This possibility needs examining via the assembly and debate of further stratigraphic evidence, and consideration of the utility of the term as a formal unit.

Crutzen and Stoermer (2000; see also Crutzen 2002) proposed that human influence has driven Earth to a new phase of its history, the Anthropocene. This represents the most recent suggestion made since the beginning of organized stratigraphy (Roger 1962). Earlier suggestions were not generally accepted by geologists (e.g., Berry 1925), because human influence on Earth seemed too minor and too ephemeral to be compared with forces such as volcanism and tectonics acting over millions of years.

However, Crutzen and Stoermer's proposal was made when it was realized that human influence, albeit geologically brief, may have significant, long-term impacts on Earth system processes. The term has now entered general circulation both within the Earth Sciences community (e.g., Steffen et al. 2004) and beyond.

J. Zalasiewicz (✉) · M. Williams
Department of Geology, University of Leicester, University Road,
Leicester, LE1 7RH, UK
e-mail: jaz1@le.ac.uk

C. Waters
British Geological Survey, Keyworth NG12 5DP, UK

The Stratigraphy Commission of the Geological Society of London analysed the term and considered that there was geological substance to it, with potential for formalization (Zalasiewicz et al. 2008). An Anthropocene Working Group of the Subcommission on Quaternary Stratigraphy was formed, and is examining the topic and detailing the evidence (Williams et al. 2011; Waters et al. 2013). Key considerations include: the further development of the geological rationale, with attention to factors that speak both for and against formalization; where the beginning of a potential Anthropocene time unit should be placed, how it should be placed (i.e., GSSP or GSSA), and on what stratigraphic criteria it should be defined; at what hierarchical level it should be (i.e., Age, Epoch, or Period—it is currently considered mainly as a potential Epoch); and what is the use of formalization, and for whom. The aim is to publish opinions on these questions in 2016 for the next International Geological Congress.

Several proposals for the start of the Anthropocene have been made, and range from the beginning of the Industrial Revolution (ca. 1800 CE), to various times in the early to mid-Holocene associated with the early spread of farming (Ruddiman 2003), and to the mid-twentieth century associated with the "Great Acceleration" of the post-war economy (Steffen et al. 2007). These and other proposals remain under consideration, but currently the mid-twentieth-century level seems most defensible in stratigraphic terms (although see Gibbard and Walker 2013). The question of a GSSP or GSSA remains open, and either would be practicable.

The future duration of "Anthropocene" phenomena is uncertain, and depends on the nature and duration of anthropogenic driving forces and the interplay of both natural and anthropogenic feedback mechanisms. However, some effects (e.g., the perturbation of the carbon cycle; Tyrrell 2011) will last tens of thousands of years, while much biotic change will have permanent repercussions. It is clear that we are in the early stages of a significant geological event, no matter what the pattern of human forcing takes from now. Being at a very early stage in this unfolding geological event is a factor in the consideration of formalization.

The rationale has developed significantly, though much remains to do. Contemporary "environmental" phenomena need be considered in stratigraphic terms, with consideration of the environmental history of a potential Anthropocene Epoch and of the resulting deposits of a parallel potential Anthropocene Series. Some stratigraphic signals are already of considerable scale (with some being unprecedented in Earth's history), whereas others are still geologically insignificant; the evolving and partly diachronous pattern of geologically significant change in time and space is a further factor to be considered in formalization.

Humans have produced novel mineral types, from metals not found in nature to minerals such as tungsten carbide and "mineraloids" such as plastic and glass, amounting to a new phase in Earth's mineral evolution (cf. Hazen et al. 2008). Novel and existing minerals are combined in new rock types (concrete, brick, and ceramics), and human modification of the landscape has given rise to an order-of-magnitude increase in terrestrial erosion and sedimentation (Wilkinson 2005) and has produced mappable rock units of artificial deposits (Ford et al. 2013). Such

anthropogenic strata are strongly diachronous across the Holocene, but a clear expansion in distribution took place from the mid-twentieth century.

The biostratigraphic signal is complex, and its study needs comparison of ancient palaeontological and modern biodiversity data. Elevated levels of extinctions, present since the beginning of the Holocene, have accelerated over the past century. A sixth (period/era-scale) mass extinction has not yet taken place, although is likely over the next couple of centuries (Barnosky et al. 2011). Ongoing species invasions around the world have altered biological assemblages considerably (McNeeley 2001; Barnosky 2013). The increase in large terrestrial vertebrate biomass and its skewing towards humans and domesticated animals is a striking, if likely transient, feature.

Chemostratigraphic signals include carbon (Al-Rousan et al. 2004) and nitrogen (Holtgrieve et al. 2011) isotope ratios changed globally as a result of burning fossils fuels and the operation of the Haber–Bosch process, respectively, the latter showing a clear inflection in the mid-twentieth century, coincident with the spread of radioactive isotopes from above-ground A-bomb tests (Hancock et al. 2011).

The climate signal is significant locally, especially at high latitudes, but does not yet exceed previous interglacial peak temperatures. Projected temperature rises (IPCC 2007), if realized, will clearly go beyond Quaternary norms. Sea-level rise to date remains geologically insignificant, and would be expected to lag temperature rises by centuries to millennia.

Overall, there is a cluster of stratigraphic signals reflecting major and developing global change at $\sim$1950 CE, and may provide a basis for a workable Anthropocene time unit. However, further analysis is needed, and the question of the utility of a formalized Anthropocene to both earth scientists and others needs debate.

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Part XVIII
Theme C: Applied Stratigraphy

Fossil Vertebrates in Stratigraphy

cnw@bgs.ac.uk

Stratigraphic Distribution of Large Flightless Birds in the Palaeogene of Europe

Eric Buffetaut and Delphine Angst

Abstract Three main groups of large flightless birds are known from the Palaeogene of Europe: Gastornithidae, Ratitae, and Phorusrhacidae. Gastornithids have the longest and most complete record (Selandian to middle Lutetian). Ratites have a patchy record (Thanetian and Lutetian). Phorusrhacids are known only from the late Lutetian. Gastornithids probably originated in Europe, whereas phorusrhacids probably reached Europe from Africa.

Keywords Aves · Gastornithidae · Phorusrhacidae · Ratites · Europe · Palaeogene

Large flightless birds have been known from the Palaeogene of Europe since the nineteenth century. The first taxon to be identified was *Gastornis*, originally described in 1855 from the lower Eocene of Meudon, near Paris, and since then reported (sometimes as *Diatryma*) from various Palaeocene and Eocene localities in France, Belgium, England, and Germany. Ratites are less well represented, although they are known from the Palaeocene of France (*Remiornis*) and the Eocene of Germany (*Palaeotis*). Recently, remains of Phorusrhacidae, a group otherwise known mainly from South America, have been identified from Eocene localities in France (Angst and Buffetaut 2012) and Switzerland. For a better understanding of the evolutionary history and possible ecological interactions of these terrestrial birds, it is important to establish their stratigraphic distributions as accurately as possible. The fossil record of the above-mentioned taxa is presented

E. Buffetaut (✉)
UMR 8538, Laboratoire de Géologie de l'Ecole Normale Supérieure, Centre National de la Recherche Scientifique, 24 rue Lhomond, 75230 Paris Cedex 05, France
e-mail: eric.buffetaut@sfr.fr

D. Angst
CNRS UMR 5276, Laboratoire de Géologie de Lyon, Terre, Planètes et Environnement, Université Claude Bernard Lyon 1 et Ecole Normale Supérieure de Lyon, 2 rue Raphaël Dubois, 69622 Villeurbanne Cedex, France
e-mail: angst.delphine@gmail.com

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Fig. 1 Stratigraphic distribution of large flightless birds in the Palaeogene of Europe
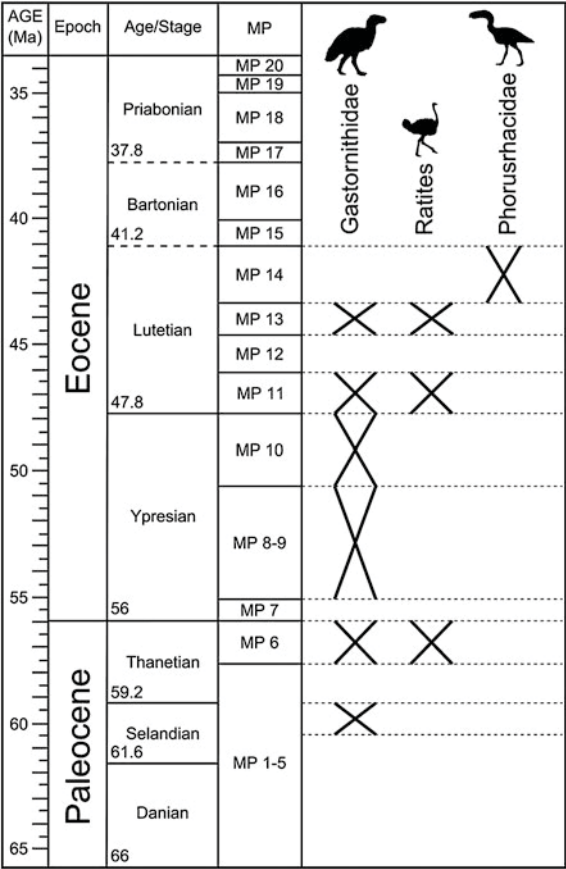
below (see Fig. 1). Stratigraphic correlation of the mammal-based MP reference levels follows Vandenberghe et al. (2012).

1. Gastornithidae

The family seems to be represented in Europe by the single genus *Gastornis* Hébert (1855) (*Diatryma* Cope 1876 being considered as a junior synonym). This very large bird is known from the following levels and localities:

Palaeocene

Selandian

MP5: Walbeck (Germany)
Thanetian

MP6: Cernay, Berru, Rivecourt (France); Mesvin (Belgium).

Eocene

Ypresian

MP8–9: Meudon, Saint-Papoul (France); Croydon (England).
MP10: Monthelon (France).
Lutetian

MP11: Messel, Geiseltal Unterkohle (Germany).
MP13: Geiseltal Obere Mittelkohle (Germany).

The record of *Gastornis* thus appears to be nearly continuous from the Selandian to the middle Lutetian, the only gaps being in the Palaeocene (although the Selandian age of the Walbeck locality is somewhat uncertain), in the lowermost Eocene (MP7, for which rather few localities are known), and in the middle Eocene between MP11 and MP13.

2. Ratites

The record of ratites in the Palaeogene of Europe is much patchier than that of gastornithids. They are represented by two relatively small-sized genera, *Remiornis* in the Palaeocene and *Palaeotis* in the Eocene, the relationships between these taxa being obscure. Their distribution is as follows:

Palaeocene

Thanetian

MP6: Cernay, Berru, Rivecourt (France): *Remiornis*.

Eocene

Lutetian

MP11: Messel (Germany): *Palaeotis*.
MP13: Geiseltal Obere Mittelkohle (Germany): *Palaeotis*.

3. Phorusrhacidae

Although previous reports of this family in Europe have been dismissed, recent research has shown that it is indeed present at a few upper Lutetian localities, with probably a single, middle-sized, genus, *Eleutherornis* Schaub (1940). Its distribution seems to be limited to:

Eocene

Lutetian:

MP14: Lissieu (France), Egerkingen (Switzerland).

In addition, abundant eggshell fragments attributed to giant birds (Gastornithidae?) are known from several Palaeogene levels in southern France (Provence and Languedoc). They are currently being restudied and the earliest occurrences appear to be Thanetian (thin-shelled eggs) and the latest records Ypresian (thick-shelled eggs). Very large bird footprints from the gypsum beds of the Paris region (MP19, Priabonian) have problematic affinities (Buffetaut 2004).

This review shows that gastornithids were present in Europe for at least 15 Myr, from the middle Palaeocene to the middle Eocene. Their known records in North America and Asia are shorter, being limited to the upper Eocene, which may suggest a European origin for the family (Buffetaut in press). The ratites from the Palaeogene of Europe are still poorly known and their relationships with living forms are unclear, but *Remiornis* and *Palaeotis* may form a clade (Mayr 2009), in which case their stratigraphic record may suggest a fairly long temporal range in Europe, from the late Palaeocene to the middle Eocene. On the other hand, European phorusrhacids were apparently restricted to the late Lutetian. The family is otherwise known mainly from the Cenozoic of South America, with upper Cenozoic representatives in North America, and a single African record from the lower to middle Eocene of Algeria (Mourer-Chauviré et al. 2011). Their rather isolated occurrence in the Lutetian of Europe may suggest dispersal from elsewhere, probably Africa, followed by extinction on the European continent. There is currently no evidence that they coexisted with gastornithids, which rules out competition between the two groups (which in any case showed significantly different adaptations).

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The Neogene Terrestrial Chronostratigraphic Sequence of China

Tao Deng and Sukuan Hou

Abstract Seven terrestrial chronostratigraphic units, namely the Xiejian, Shanwangian, Tunggurian, Bahean, Baodean, Gaozhuangian, and Mazegouan stages, are recognized for the Chinese Neogene based on updated large and small mammalian faunas. In the past, the positions of the Chinese mammalian faunas in the chronological chart and their correlations to European faunas were determined mainly by the evolutionary levels of mammals because of the lack of accurate absolute ages. However, during the last three decades, great progress has been made in Chinese Neogene terrestrial stratigraphic studies. Most of the classic regions have been revisited, such as the Yushe and Baode areas in Shanxi, the Lantian area in Shaanxi, and the Tunggur area in Inner Mongolia. New discoveries have been made in well-exposed fossiliferous regions, such as Tongxin in Ningxia, central Inner Mongolia, the northern Junggar Basin in Xinjiang, the Linxia Basin in Gansu, and the Qaidam Basin in Qinghai. Magnetostratigraphic work has also been conducted in several regions. Despite this, large gaps still exist between China and its European and North American counterparts in terms of the accumulation of fossils as well as such basic tasks as the documentation of fossil occurrences and their biostratigraphic contexts. However, land mammal ages for China have now been better constrained by data from new localities and new taxa. The significance of these new data is that they are improving our understanding of mammal turnovers and boundary calibrations. The faunal components are thought to be stable throughout each chronostratigraphic unit, without large changes occurring. For each unit, series of species or genera are regarded as characteristic forms on the basis of correlation with the European taxa. Generally, the chronostratigraphic units deal with the first appearance datum of mammals at the generic level. Some of these genera are immigrants, and their entry into China often marks the beginning of a unit. The exact correlations between the Chinese and European mammalian ages based on more accurate dating will increase our ability to

T. Deng (✉) · S. Hou
Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences, Beijing 100044, China
e-mail: dengtao@ivpp.ac.cn

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recognize mammal migrations between China and Europe. Asia acted as a faunal dispersal centre for Europe during the Neogene, and the great majority of the exchanges were migrations from Asia into Europe. China was one of the main dispersal centres of the Neogene. In recent years, the Chinese Neogene mammal ages have become more accurate with the introduction of magnetostratigraphy, which has enabled ages to be calibrated and well dated at their boundaries. The increasing number of palaeomagnetic measurements has enabled a good calibration to be made for the correlation of Chinese Neogene mammalian faunas with their European and North American counterparts. A new Neogene chronostratigraphic framework is proposed, one that is more consistent with the reality of the state of research and conditions in China. This will provide a foundation for the establishment of a formal Chinese Neogene terrestrial chronostratigraphic system. Given that China possesses well-developed Neogene terrestrial strata that are richly endowed with fossil mammals, such a system should play a role in the establishment of an Asian Neogene terrestrial scheme in the future.

Keywords Chronostratigraphic unit · Stage · Mammal age · Magnetostratigraphy · Neogene · China

Since its establishment, the sequence of Chinese Neogene mammalian faunas has been frequently revised up to the latest discussion of Qiu et al. (2013). Based on a series of productive studies incorporating Li et al. (1984), Qiu and Qiu (1995), Deng (2006), and Qiu et al. (2013), a more accurately defined chronostratigraphic sequence of the Chinese terrestrial Neogene is proposed, including the Xiejian, Shanwangian, Tunggurian, Bahean, Baodean, Gaozhuangian, and Mazegouan stages (Fig. 1).

The stratotype section of the Xiejian Stage is located at Xiejia village in Huangzhong, Qinghai, where the Xiejia fauna are found. This fauna contains about a dozen large and small mammals showing a distinct early Miocene character. The lower boundary of the Xiejian Stage is in the upper part of the Mahalagou Formation of the Xiejia section and at the base of Chron C6Cn.2n with an age of 23.03 Ma.

The representative section of the Shanwangian Stage is located at Shanwang village in Linqu, Shandong, where the Shanwang fauna was found. Based on the evolution of mammals, this fauna is comparable to those of the European MN 4. The lower boundary of the Shanwangian Stage corresponds to that of the Burdigalian Stage close to the top of Chron C6 An with an age of 20.43 Ma.

The stratotype section of the Tunggurian Stage is located at Tairum Nor in the Tunggur area in Sonid Left Banner, Inner Mongolia, where the Tunggur fauna was found, traditionally referred to as *Platybelodon* fauna. The Tunggurian is correlated to the European Astaracian, and they share the same definition of the lower boundary at the base of the palaeomagnetic Chron C5Bn.1r with an age of 15.0 Ma. In the Tairum Nor section, this boundary is situated within the lower part of the Tunggur Formation.

Fig. 1 Division of the
Neogene terrestrial sequence
and distribution of Neogene
mammalian faunas in China

The representative section of the Bahean Stage is located at Shuijiazui village in Lantian, Shaanxi, on the southern bank of Bahe River, where the Bahe fauna was found. For the Neogene terrestrial strata of the Palearctic Province, the lower boundary of the upper Miocene is fixed at the first appearance of *Hipparion*. The lower boundary of the Bahean Stage is identical to that of the Tortonian at the base of Chron C5r.2n, and it occurs in the sedimentary sequence in the Linxia Basin,

with an age of 11.6 Ma, where the first appearance datum (FAD) of *Hipparion* is slightly higher than the boundary, with an age of 11.1 Ma.

The stratotype section of the Baodean Stage is located at Jijiagou in Baode, Shanxi, where the Baode fauna was found. The lower boundary of this stage is identical to that of the Messinian, and both boundaries are within Chron C3Br.1r with an age of 7.25 Ma. This boundary is near the base of the red clays in the Baode Formation at Jijiagou, and the FAD of *Hipparion forstenae* can be regarded as a biostratigraphic marker.

The stratotype section of the Gaozhuangian Stage is located at Taoyang village in Yushe, Shanxi. The Gaozhuang fauna corresponds to the European MN 14–15. The Gaozhuangian Stage is correlated to the Zanclean Stage, and they share the same definition of the lower boundary at the top of Chron C3r with an age of 5.3 Ma. At the Taoyang section in the Yushe Basin, this boundary is situated in the basal part of massive sandstones of layer 5 of the Gaozhuang Formation.

The Mazegouan Stage represents the terrestrial upper Pliocene, and its stratotype section is located at Zhaozhuang–Damalan in Yushe, Shanxi. The Mazegouan Stage is correlated to the Piacenzian Stage, and they share the same definition of the lower boundary at the base of the Chron C2An.3n, that is, the base of the Gauss Epoch, with an age of 3.6 Ma. At the Zhaozhuang section in the Yushe Basin, this boundary is situated in the middle part of the purple clays of the Mazegouan Formation in layer 6 of this section, marked by the first appearance of the rodent *Apodemus zhangwagouensis*. The Mazegouan age is correlated to the early Villanyian age or the early Villafranchian age of the European land mammal ages, and its mammalian fauna corresponds to the European MN 16.

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Triassic Timescale Based on Tetrapod Biostratigraphy and Biochronology

Spencer G. Lucas and Lawrence H. Tanner

Abstract The biochronology based on the global biostratigraphy of tetrapod fossils allows the Triassic System to be divided into eight land-vertebrate faunachrons based mainly on the first appearance datums of tetrapod genera. Temporal resolution may be improved by subdivision of these faunachrons. We note, however, that this biochronology is undermined by the use of cladotaxonomy. The Triassic tetrapod footprint biochronology has lower resolution, dividing the entire system into five footprint-based biochrons. The temporal resolution of this biochronology also may be improved through subdivision based on ichnotaxon range zones.

Keywords Triassic · Tetrapods · Footprints · Biochronology · Land-vertebrate faunachrons

The standard global chronostratigraphic scale divides the approximately 50 million years of Triassic time into three series, seven stages and 15 substages, based primarily on ammonoid and conodont biostratigraphy and biochronology. The global biostratigraphic distribution of Triassic tetrapod body fossils is the basis of a tetrapod biochronology that divides Triassic time into eight land-vertebrate faunachrons (LVFs) (e.g., Lucas 2010). The Triassic LVFs (Fig. 1) have boundaries defined by the first appearance datums (FADs) of tetrapod genera or, in two cases, the first appearance datums (FADs) of a tetrapod species: (1) the beginning of the Lootsbergian LVF = FAD *Lystrosaurus*; (2) the beginning of the Nonesian LVF = FAD *Cynognathus*; (3) the beginning of the Perovkan LVF = FAD

S. G. Lucas (✉)
New Mexico Museum of Natural History, 1801 Mountain Road, N.W, Albuquerque, NM 87104, USA
e-mail: Spencer.Lucas@state.nm.us

L. H. Tanner
Department of Biological Sciences, Le Moyne College, Syracuse, NY 13214, USA
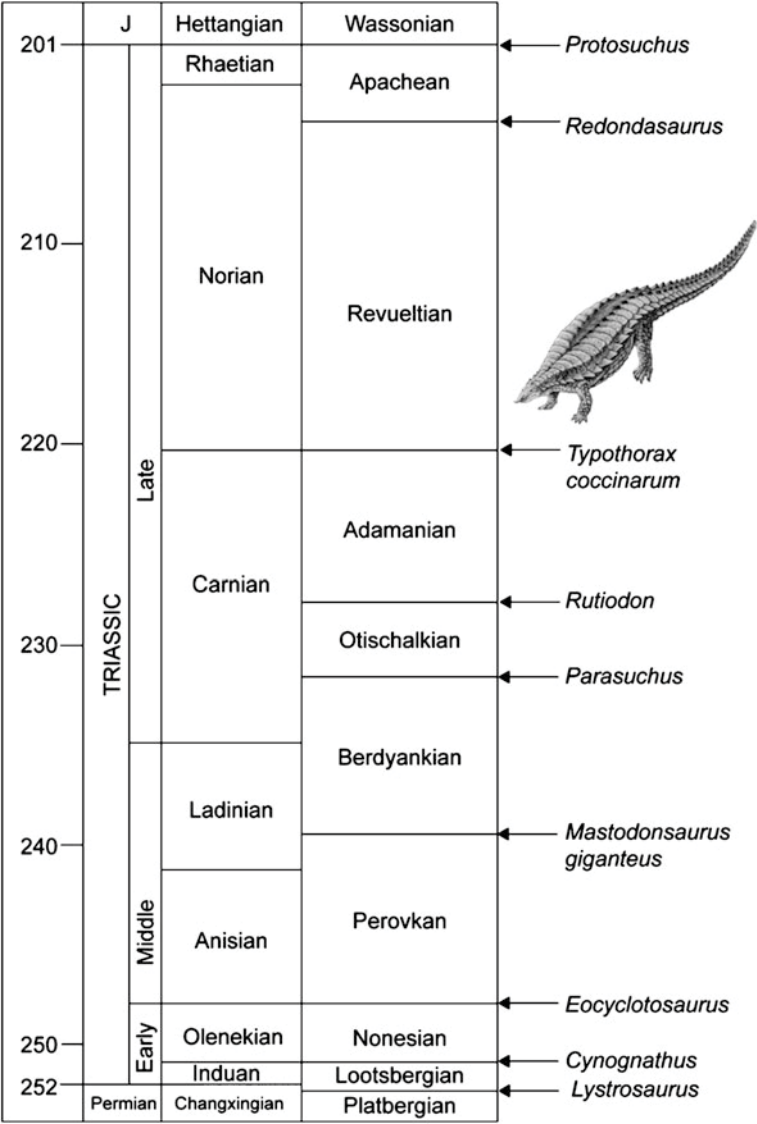e-mail: tannerlh@lemoyne.edu

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Fig. 1 The Triassic timescale based on tetrapod-body-fossil and footprint biochronology

Eocyclotosaurus; (4) the beginning of the Berdyankian LVF = FAD *Mastodon-saurus giganteus*; (5) the beginning of the Otischalkian LVF = FAD *Parasuchus*; (6) the beginning of the Adamanian LVF = FAD *Rutiodon*; (7) the beginning of the Revueltian LVF = FAD *Typothorax coccinarum*; and (8) the beginning of the Apachean LVF = FAD *Redondasaurus*. The end of the Apachean (= beginning of the Wassonian LVF, ~ beginning of the Jurassic) is the FAD *Protosuchus*.

Since the Triassic LVFs were introduced, several subdivisions have been proposed: the Lootsbergian can be divided into three sub-LVFs, the Nonesian into two, the Adamanian into two, and the Revueltian into three. The Triassic timescale based on tetrapod biostratigraphy and biochronology is a robust tool for the correlation of nonmarine Triassic tetrapod assemblages independent of the marine timescale.

Most criticism of the Triassic tetrapod-based biochronology focuses on differing correlations based on taxonomic conflicts. The genus is the operational taxonomic unit for Triassic tetrapod biostratigraphy and biochronology. This is because most species-level taxa of Triassic tetrapods are meaningless for correlation, as they are usually based on a single specimen or a local assemblage of well-preserved material and cannot be recognized at multiple localities. However, the rise of a type of alpha taxonomy based on cladistics (cladotaxonomy), what Feduccia (1999) aptly called the "jihad of cladism", is undermining many widespread and long-recognized Triassic tetrapod taxa useful to biostratigraphy. This is a major problem for vertebrate palaeontology, but we note here that the a posteriori reasoning inherent to cladistics renders it a questionable tool for alpha taxonomy, and what we refer to as cladotaxa have proven to be of little biostratigraphic utility.

The global distribution of Triassic tetrapod footprints (Klein and Lucas 2010) allows five distinct tetrapod-footprint-based biochrons to be recognized: (1) dicynodont tracks (Lootsbergian); (2) *Protochirotherium* biochron (Nonesian); (3) *Chirotherium barthii* biochron (Nonesian–Perovkan); (4) *Atreipus–Grallator* biochron (Perovkan–Berdyankian); and (5) *Brachychirotherium* biochron (Otischalkian–Apachean). Compared to the tetrapod body fossil record with eight biochrons, the five footprint-based biochrons provide lower temporal resolution, largely because ichnogenera and ichnospecies at best reflect families or higher biotaxonomic units, which have slower evolutionary turnover rates than do the genera and species used to delineate the body-fossil-based biochronology.

There is strong overlap of the Triassic tetrapod body fossil and footprint records, and the time intervals they discriminate are generally similar. Together, the tetrapod body fossil and footprint records resolve Triassic time about as well as do the Triassic stages. However, all but one of the Triassic stages (Rhaetian) are readily subdivided into substages, and further temporal resolution is achieved by reference to standard ammonoid and conodont zones. The next level of resolution in the tetrapod biochronology may be achieved by some of the subfaunachrons, although broad correlation of most of the subfaunachrons remains largely untested.

The footprint biochronology also may be subdivisible in part by using a strict taxon range zone approach instead of an assemblage-based biostratigraphy. For example, such an approach allows the subdivision of the *Atreipus–Grallator* biochron into an older interval with the co-occurrence of *Rotodactylus*, *Isochirotherium*, and *Synaptichnium*, and a younger interval with only *Synaptichnium*. However, the recognition of standard zones equivalent to even shorter intervals of Triassic time based on tetrapod body fossils and/or footprints is more difficult. This will require the recognition of tetrapod morphospecies whose temporal succession

can be established unambiguously (in stratigraphy) and whose temporal ranges are relatively short. Fortunately, this is now possible in some taxonomic groups, such as aetosaurs. The path forward in developing a more precise Triassic tetrapod biochronology is in placing tetrapod body and footprint fossils into stratigraphy and in basing their alpha taxonomy on the sound principles of evolutionary taxonomy.

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A New Early Middle Pleistocene Locality of Small Mammals (Lower Dniester River) and its Position in the Early Middle Pleistocene Sequence

Anastasia K. Markova

Abstract An important, new Eastern European locality of small mammals has been discovered near Levada station, Dniester Basin, 30 km east of Tiraspol town, Moldova. Small mammals found at the Levada locality include *Spermophilus* sp., *Lagurus transiens* Yanossy, *Eolagurus* sp., *Microtus (Terricola) arvalidens* Kretzoi, and *Microtus (Stenocranius) gregaloides* Hinton, amongst others. The species composition of this fauna indicates its close similarity to the fauna from the stratotype of the Tiraspolian Faunistic Complex described from the Kolkotova Balka locality (Terrace V of the Dniester River, Kolkotova Terrace, Moldova). These faunas could be correlated with the Ilinka Interglacial III and possibly with the Interglacial III of Cromer.

Keywords Middle Pleistocene · Small mammals · Eastern Europe

A new locality of small mammals has been discovered by A.L. Chepalyga and D.S. Zakharov near Levada station, 30 km east of Tiraspol town, Moldova (Chepalyga et al. 2013). This locality is related to the deposits of Terrace V of the Dniester River (Kolkotova Terrace) (Chepalyga 1962). The sequence exposed in this outcrop is about 20 m thick and includes four palaeosols interlayered with loess horizons. The morphological features and stratigraphic position of the lower fossil soil resemble the Vorona palaeosol, which corresponds to the Muchkap Interglacial (Shik 2005). The sequence is underlain by poorly sorted fluvial sand and gravel about 5 m thick, in which the remains of small mammals have been found.

The Kolkotova Terrace forms a wide plain on the left bank of the Dniester River from Tiraspol town to the mouth of the river. A rich fauna of mammals and molluscs

A. K. Markova (✉)
Institute of Geography Russian Academy of Sciences,
Staromonetny 29, 117019 Moscow, Russia
e-mail: amarkova@list.ru

was discovered in the fluvial deposits of this terrace near Tiraspol in the Kolkotova Balka section, and were described as Tiraspolian Faunistic Complex (Nikiforova 1971). The fluvial deposits in the Levada section are related to the upper part of the fluvial deposits in the Kolkotova Balka (A. Chepalyga, personal communication).

Small mammals found at the Levada locality include *Spermophilus* sp., *Lagurus transiens* Yanossy, *Eolagurus* sp*., Microtus (Terricola) arvalidens* Kretzoi, and *Microtus (Stenocranius) gregaloides* Hinton, amongst others. The species composition of this fauna indicates its close similarity to the fauna from Kolkotova Balka, described by Alexandrova (1976). However, it differs from the small mammal fauna found in the Vorona palaeosol in Kolkotova Balka, which contains *Lagurus transiens* Jannosy, *Eolagurus luteus volgensis* Alex., and *Microtus (Stenocranius) gregalis* Pall., amongst others (Markova 2007). This last species is more evolved than *M. (S.) gregaloides* found at Levada. This suggests that the Levada fauna are older than the fauna from the Vorona palaeosol in the Kolkotova Balka (Muchkap Interglacial = Interglacial IV of Cromer), and close to the fauna from fluvial deposits of the Kolkotova Balka with *Mimomys savini* Major, *Lagurus transiens* Yanossy, *Microtus (Terricola) arvalidens* Kretzoi, and *Microtus (Stenocranius) gregaloides* (Alexandrova 1976). The later fauna could be correlated with the Ilyinka Interglacial III (Interglacial III of Cromer) (Shik 2005).

The fauna from the Levada section is not the oldest early Middle Pleistocene fauna. There are several early Middle Pleistocene faunas described from the Russian Plain that have more ancient species compositions than that of Levada. They include *Mimomys pusillus* Mehely and *P. pannonicus* Kormos. These faunas are correlated with the older Ilyinka Interglacials I and II (Interglacials I and II of Cromer) and the Pokrovka cooling (Shik 2005).

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Part XIX
Theme C: Applied Stratigraphy

Fossil Invertebrates in Stratigraphy

cnw@bgs.ac.uk

Bivalves in Upper Devonian to Lower Mississippian Biostratigraphy

Michael R. W. Amler

Abstract Bivalves of the former "*Posidonia venusta*" group are widespread in Upper Devonian to lowermost Mississippian strata within low-latitude pelagic environments (Hercynian and Kulm facies). At present, these taxa are assigned to the bivalve genus *Guerichia* as determined by SEM observations of the shell microstructure. The form group can be subdivided into several taxa at the species level, which appear to be biostratigraphically important and indicate biostratigraphic zones in the pelagic Upper Devonian. Former attempts at a biostratigraphic zonation in Kazakhstan are successfully adopted in comparable facies in Europe. Close to the Devonian–Carboniferous (D–C) boundary of Hercynian (i.e., basinal) facies, *Guerichia venusta s. str.* characterizes the upper Famennian, whereas *Guerichia ratingensis* (= *G. venustiformis*) indicates the D–C boundary interval and *Guerichia mariannae* probably the lower Mississippian. Future correlation with conodonts will be performed soon.

Keywords Bivalvia · *Guerichia* · *Posidonia venusta* · Upper Devonian · Lower Mississippian · Biostratigraphy

In contrast to cephalopods, foraminifers, or conodonts, bivalves only occasionally serve as biostratigraphic index fossils in the Phanerozoic. Halobiids in the Triassic or inoceramids in the Cretaceous are well known for their biostratigraphic potential, and for the Mississippian Kulm Facies a further example has been presented recently (Amler 2004a). In each case, pelagic, open-shelf taxa had a basin-wide distribution, whereas inner-shelf or near-shore groups were predominantly rather restricted to specific facies types or even habitats. Studies of Upper Devonian and lower Carboniferous bivalves, complementing previous observations of the last one hundred years, have shown that the Famennian to Tournaisian

M. R. W. Amler (✉)
Institute for Geology and Mineralogy, University of Cologne, Zuelpicher Str. 49a,
50674 Cologne, Germany
e-mail: michael.amler@uni-koeln.de

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succession across the D–C boundary can also be subdivided into biozones based on bivalves.

Devonian and Mississippian pelagic open-shelf facies (Hercynian Facies and Kulm Facies, respectively) are rich in peculiar, lesser-known bivalves introduced in several monographs from the nineteenth century. Despite their large specimen numbers in several different horizons, neither their taxonomy, nor their life habits or their correct stratigraphic ranges are well understood. Contrasting with bivalves of the Devonian and Carboniferous shelf facies, the pelagic taxa had a basin-wide distribution, partly driven by their mostly pseudoplanktic life habits, but also by their planktic larval stages. Thus, facies entity and phylogenetic continuity have enabled the study of the entire time span from the Frasnian–Famennian boundary (Kellwasser Crisis) until the end of the Mississippian.

The group of bivalves under study was introduced as *Posidonomya*? *venusta* by Münster ([1840](#)) from cephalopod limestones of Franconia (Germany). Subsequently emended into *Posidonia*, the "*Posidonia venusta*" group has been mentioned by many authors from localities throughout the Rhenohercynian and Saxothuringian domains in pelagic environments, for example, the *Cypridina* Shale, the *Clymenia* Limestone, and equivalents of Famennian age. As bivalve diversity drastically decreased after the Kellwasser Crisis ("Frasnian–Famennian Event"), reducing to about a dozen species, "*P. venusta*" still occurred unrestricted and widespread in almost every assemblage. In particular, the German mapping geologists, for example, Paeckelmann ([1913](#)), recorded various occurrences of "*P. venusta*" from Upper Devonian to lower Carboniferous sedimentary rocks all over the Rheinisches Schiefergebirge. In addition, faunistic studies conducted by Schindewolf ([1923](#)) and Schmidt ([1924](#)) offered detailed information on the co-occurrence of bivalves, goniatites, clymeniids, and trilobites.

The taxonomy of "*P. venusta*" sensu lato has never been studied in detail. Originally, the taxa had been assigned to *Posidonia* or *Posidonomya*; other species subsequently included in the group were named as *Sanguinolaria* or even *Macrodus* based on overall shape, but without any palaeobiological basis. Assignment to *Posidonia* was used until the 1980s, although Sadykov introduced the subgenus *Posidonia* (*Karadjalia*) for the group in 1962. As Weyer ([1968](#)) pointed out, *Karadjalia* is an objective junior synonym of *Guerichia* Rzehak ([1910](#)), which has been overlooked since the genus was "provisionally" established but valid according to the International Commission on Zoological Nomenclature. Consequently, the group under study is now assigned to *Guerichia* at the generic level.

In the 1980s, a fragmentary debate on the nature of guerichians as Bivalvia versus Conchostraca based on morphological similarities led to some misleading interpretations of the environmental nature of the host rocks. Bless et al. ([1988](#)), based on assumptions by Flajs and Feist ([1988](#)), considered the group estherian conchostracans, because guerichians grossly resemble conchostracans reported from the Pilot Shale (Upper Devonian–lower Carboniferous) from the US (Gutschick and Rodriguez [1979](#)). In fact, SEM observations of the shell microstructure in well-preserved specimens from the Refrath I borehole near Cologne (Fig. [1](#)) clearly indicate that the outer shell layer is regular, simple and prismatic,

Fig. 1 *Guerichia venusta* (Münster 1840), articulated valves ("butterfly preservation") Refrath I Borehole; GLA/NRW-Fa30; internal mould with fragments of shell material; Dasberg "Stage"; scale bar = ca. 5 mm

underlain by a nacreous inner layer (Amler 2004b), which was also independently discovered by D. Weyer (personal communication).

The basic shell characteristics of the guerichians (Figs. 1, 2 and 3) include small- to medium-size, variable shell outlines, ranging from transversely oval to rounded triangular, rounded valve margins, but some anteriorly nasute with tightly convex anterior margins, ventral margins usually slightly to moderately convex, and dorsal margins faintly convex or nearly straight. Umbos are minute, triangular, pointed, and faintly or not raised above the hinge margins, and the external shell surfaces have faint growth lines and five to eight comarginal undulations. Internal structures are not preserved or visible, but the hinge lines are obviously edentulous, and the ligaments appear to be external and amphidetic (Fig. 1). These characteristics are typical of thin-shelled, epibyssate, pelagic bivalves.

Overlooked for a long time, Sadykov (1962) presented a concept for separating different species from different stratigraphic horizons in the upper Devonian of Kazakhstan. Bartzsch et al. (1998, and references therein) noted that potentially similar results were likely for the central European Devonian–Carboniferous transition and demonstrated that the biostratigraphic approach is also applicable to European guerichians, if the morphological variants are correctly differentiated at the species level. The vertical distribution of guerichian bivalves is noted from the lower Famennian to lower Tournaisian in the pelagic facies. Sadykov (1962) showed that the evolution of this group as recorded in the Upper Devonian and lower Carboniferous of Kazakhstan is mirrored by a development from short,

Fig. 2 *Guerichia venusta* (Münster zu 1840), specimens preserved with shell material; Hartz Mountains, Elbingeröder Komplex, Hemberg "Stage"; scale bar = ca. 5 mm

Fig. 3 *Guerichia* sp., juvenile specimen (internal mould) from uppermost Devonian (Strunian) strata; Bergisches Land; coll. K. Weber; scale bar = ca. 1 mm

compact morphotypes in the Frasnian and lower Famennian (Fig. 3) [*Guerichia simorini* (Sadykov)] to elongate-triangular forms in the upper Famennian [*Guerichia venusta* (Münster); Figs. 1 and 2] and finally to elongate–triangular transversely oval in the uppermost Famennian to lowermost Mississippian taxa [*Guerichia venustiformis* (Sadykov)]. This trend is copied in central Europe by *Guerichia demaneti* (Maillieux), *Guerichia venusta eifeliensis* (Frech), and *Guerichia manipularis* (Richter) from the upper Frasnian to lower Famennian [including parts of the Hemberg "Stage"]. The above follows *Guerichia venusta* (Münster) sensu stricto present in the Hemberg and Dasberg "stages" only, whereas *Guerichia ratingensis* (Paeckelmann) occurs in the Wocklum "Stage", the Devonian–Carboniferous boundary interval, and lowermost Mississippian strata (Amler 2004a). In Kazakhstan, *Guerichia mariannae* follows *G. venustiformis* (Sadykov

1962), but *Guerichia mariannae* or an equivalent taxon is lacking in the lower Mississippian succession of central Europe, as the Hangenberg Formation and Kahlenberg Subformation (Liegende Alaunschiefer) hardly yield bivalves or have just been sampled insufficiently (Amler 2004a).

The biostratigraphic data are roughly confirmed by conodonts of the Middle *expansa* to Middle *praesulcata* Zone extracted by D. Weyer from the host rock of the *Posidonia venusta s. str.* lectotype (Amler 2004b). Furthermore, correlation of the *ratingensis* Zone with the *praesulcata* to *sandbergi* conodont zones is possible (see also Bartzsch et al. 1998). Further correlation of guerichians and conodont biozonation in cooperation with D. Weyer and colleagues from Münster University (Germany) is in progress and will be presented in the near future.

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Fossil Bryozoans in the Stratigraphy of Mongolia

Ariunchimeg Yarinpil

Abstract The taxonomic diversity and distribution of Palaeozoic bryozoans from well-studied Palaeozoic type sections in Mongolia are analysed, and 34 local biostratigraphic units with beds containing bryozoans are established.

Keywords Palaeozoic · Bryozoans · Mongolia

Bryozoans are one of the most widespread groups of benthic fauna in the Palaeozoic deposits of Mongolia. However, remarkably little had been published on Palaeozoic bryozoans until the beginning of the joint Soviet–Mongolian palaeontological expedition (Morozova et al. 2003).

The Palaeozoic deposits of Mongolia are divided into 21 regional stratigraphic units ranked as horizons. Incomplete bryozoan distribution in the sections makes it difficult to distinguish uninterrupted zonal sequences. In this study, Palaeozoic bryozoans from well-studied Palaeozoic type sections have been analysed and 34 local biostratigraphic units with beds containing bryozoans have been established.

The Ordovician bryozoans were collected from five type sections and consist of five beds with bryozoans: *Rhinidictya nekhoroshevae*, *Ulrichostylus aculeatus*, *Hallopora subnodosa*, *Cyphotrypa wilmingtonensis*, and *Fimbriapora plebei*. No bryozoans were recorded in the deposits of the Lower and Middle Ordovician. The most ancient assemblage was established in the lowermost beds of the Sandbian Stage in the Chigertei nuur section (Fig. 1, number 4). If Sandbian bryozoans' generic and species compositions are close to those of the coeval deposits of Baltoscandia and Canada, then the Katian Mongolian basin has a close connection with the epicontinental seas of the Siberian and North American platform (Kopajevich 1984). In Ordovician sediments, 59 species are described from 35 genera.

A. Yarinpil (✉)
Paleontological Center, Mongolian Academy of Sciences, Enkhtaivan Avenue 63, Bayanzurkh District, 13343 Ulaanbaatar, Mongolia
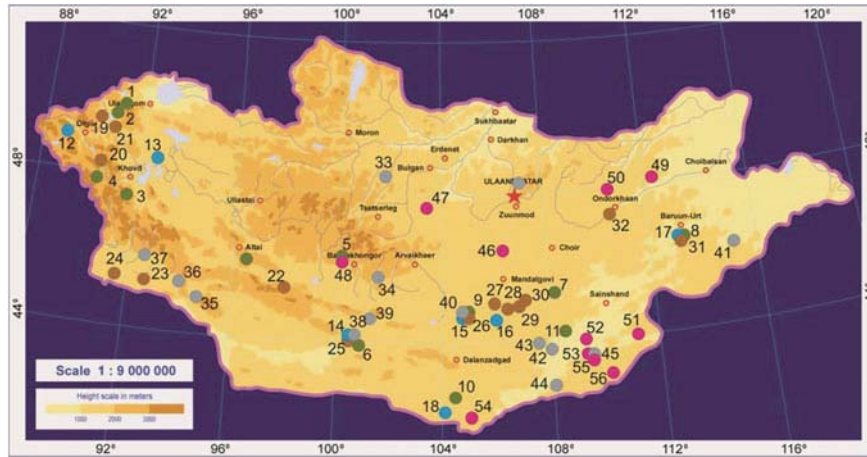e-mail: ariuna_ya@magicnet.mn

Fig. 1 Main bryozoan localities in Mongolia: Ordovician (*1–11*), Silurian (*12–18*), Devonian (*19–32*), Carboniferous (*33–45*), and Permian (*46–56*)

The late Katian event was caused by the Late Ordovician glaciations, which resulted in mass extinction affecting all known groups of organisms, including the development of Mongolian bryozoans at that time. Seven Silurian localities with bryozoans are known (Fig. 1, numbers 12–18) and five beds with bryozoans are established: *Rhinidictya salhitensis*, *Eridotrypa callosa*, *Lioclema subramosa*, *Ensipora astrovae*, and *Phaenopora bayangolica*. The diversity of Silurian bryozoans during the late Llandovery was perhaps related to the transgression in the Telychian. The bryozoans of the upper half of the Silurian are close to the bryozoan assemblages of Tuva and Altai Sayan regions of Russia.

Among the Devonian benthic organisms, bryozoans occupied an important position and eight beds with bryozoans, many of which are found together with conodonts, are established based on collections from 12 sections: *Eridotrypa minuta* (Lochkovian), *Lioclema netshlavense* (Pragian), *Amurodictya tsahirensis*, *Mongoloclema ignota* (Emsian), *Reteporina coalescens* (Eifelian), *Minussina maculosa* (Givetian), *Sulcoretepora consona* (Frasnian), and *Intrapora lanceolata* (Famennian). In Devonian sediments, 127 species from 66 genera are distinguished.

Based on updated information on the ranges of the Carboniferous bryozoan genera and species from 11 sections, the bryozoan assemblages are reinterpreted as follows: six major faunal subdivisions are distinguishable in the sequence of Mississippian assemblages, namely beds with *Nematopora afgana*, *Pseudobatostomella minima*, *Rhombopora simplex*, *Sulcoretepora minor*, *Paranicklesopora vera*, and *Lanopora eximia*, and two in the Pennsylvanian assemblages, namely *Mongolodictya insperata* and *Shulgapora aguiulensis*. In Carboniferous sediments, 142 species from 63 genera are recognized.

Permian bryozoans are reported from 11 sections. A sequence of eight bryozoan assemblages is proposed for the Permian. Beds with *Cavernella asiatica*,
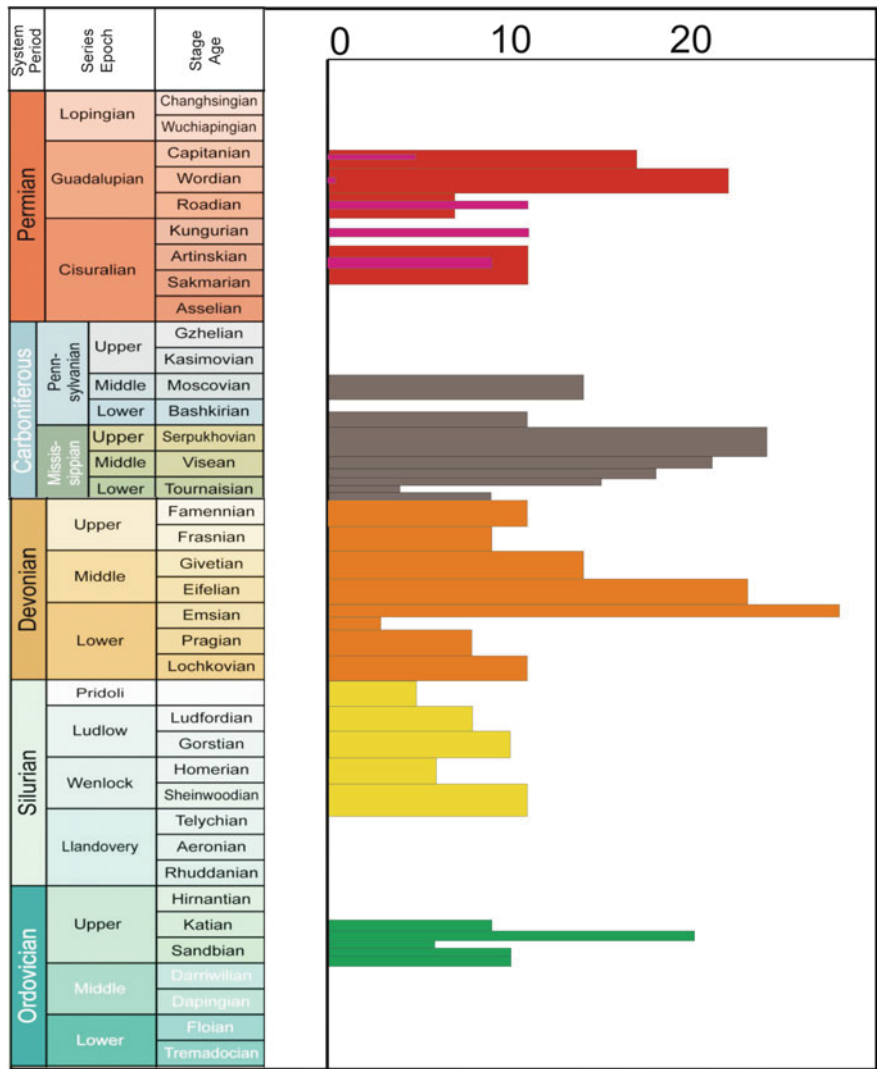
Fig. 2 Generic diversity of Palaeozoic Bryozoans of Mongolia

Prismopora morozovae, *Maychellina ornata*, and *Ogbinopora ninae* are recognized in southern Mongolia. Beds with *Pamirella secreta*, *Neorhombopora stellata*, *Timanodictya tenuis*, and *Shulgapora densa* are recognized in northern Mongolia. In total, 92 species from 53 genera are found, including the Tethyan genera *Prismopora*, *Ogbinopora*, *Etherella*, and *Araxopora*.

Thus far, 171 bryozoan genera containing 470 species have been reported from 13 Ordovician, 32 Silurian, 90 Devonian, 48 Carboniferous, and 31 Permian localities (Ariunchimeg 2010). The generic diversity of Palaeozoic bryozoans

shows that three fairly high peaks occurred in the Katian, Visean, and Wordian ages, and the maximum diversity is observed in the Emsian (Fig. 2).

Mongolia is subdivided into 44 terranes (Badarch 2002), and the presence of characteristic bryozoan associations in different tectonic terranes makes it possible to trace and widely correlate these bryozoan-bearing beds.

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Nautiloids From the Toarcian of the Iberian Peninsula, Spain and Portugal

Fernando Barroso-Barcenilla, María José Comas-Rengifo, Luís Vítor Duarte, Antonio Goy and Gemma Martínez

Abstract A study of the Lower Jurassic nautiloids held in the Universidad Complutense de Madrid and the Instituto Geológico y Minero, Spain, and in the Universidade de Coimbra and the Museu Geológico e Mineiro, Portugal, has revealed the presence of numerous and diverse representatives of the genera *Cenoceras*, *Ligeiceras*, *Ophionautilus*, and *Digonioceras* in the Toarcian of the Iberian Peninsula. Specifically, the taxa *Cenoceras robustum*, *C. fontannesi*, *C. semistriatum*, *C. astacoides*, *C. jourdani*, *C. toarcense*, *C. ciryi*, *C.? beirense*, *Ligeiceras fourneti*, *L. inornatum*, *L. anomphalum*, *L. jurense*, *L.? globulum*, *Ophionautilus* sp., *Digonioceras* sp. 1, and *D*. sp. 2 have been identified and described, and their stratigraphic distributions have been determined for this region of southwestern Europe.

Keywords Nautiloidea · Toarcian · Systematics · Biostratigraphy · Iberian Peninsula · Spain · Portugal

During the Early Jurassic, the Basque–Cantabrian and Iberian basins (Spain) and the Lusitanian Basin (Portugal) corresponded to shallow shelves connected to the open ocean that landwards progressively reduced in depth. Their structural layout and their particular palaeogeographical locations enabled eustatic cycles to be registered containing both Boreal fauna, derived from the Protoatlantic, and Meridional fauna, derived from the Tethys. Among this rich and diverse fauna, numerous Toarcian nautiloids have been collected and studied, being relatively

F. Barroso-Barcenilla (✉)
Grupo de Investigación IBERCRETA, Universidad de Alcalá de Henares,
28871 Alcalá de Henares, Spain
e-mail: fbarroso@geo.ucm.es

F. Barroso-Barcenilla · M. J. Comas-Rengifo · A. Goy · G. Martínez
Departamento de Paleontología, Facultad de Ciencias Geológicas,
Universidad Complutense de Madrid, 28040 Madrid, Spain

L. V. Duarte
Departamento de Ciências da Terra-IMAR-CMA, Faculdade de Ciências e Tecnologia,
Universidade de Coimbra, 3000-272 Coimbra, Portugal

abundant and diverse in the transgressive episodes of the sequences, which are composed mainly of marlstones.

An initial revision of the Lower Jurassic nautiloids from the Iberian Peninsula was made by Barroso-Barcenilla et al. (2011), using specimens belonging to various collections. These collections included the Antonio Goy and María José Comas-Rengifo and Luís Vítor Duarte collections, now held in the Universidad Complutense de Madrid, Spain, and the Universidade de Coimbra, Portugal, respectively, and to the Instituto Geológico y Minero de España (Martínez and Rábano 1999, and unpublished specimens), Spain, and the Instituto Geológico e Mineiro de Portugal (Tintant and Courbouleix 1974, and unpublished specimens), Portugal. The present study reports new data on the Toarcian representatives of these cephalopods in this region, reporting the taxa *Cenoceras* [*C. robustum* (Foord and Crick 1890), *C. fontannesi* (Tintant and Courbouleix 1974), *C. semistriatum* (Orbigny 1843), *C. astacoides* (Young and Bird 1828), *C. jourdani* (Dumortier 1874), *C. toarcense* (Orbigny 1850), *C. ciryi* (Rulleau 2008), and *C.? beirense* (Tintant and Courbouleix 1974)], *Ligeiceras* [*L. fourneti* (Dumortier 1874), *L. inornatum* (Orbigny 1843), *L. anomphalum* (Pia 1914), *L. jurense* (Quenstedt 1846–1849), and *L.? globulum* (Rulleau 2008)], *Ophionautilus* [*O.* sp.], and *Digonioceras* [*D.* sp. 1 and *D.* sp. 2].

Although some of these genera and species have already been cited in the literature, most of them have never been previously clearly described or illustrated, and their stratigraphic distributions have not been determined for Spain and Portugal as accurately as has been done here. In addition, many of them broadly coincide with those taxa recognized in the Toarcian of France by authors such as Chirat (1997) and Rulleau (2008), affording the present work significance in classifying and determining with precision the biostratigraphic range of these scarcely-known Toarcian cephalopods in southwestern Europe.

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Morphological Evolution of *Claraia* Species from the Late Permian (Changhsingian) to the Early Triassic (Induan) and the Response to the Permian–Triassic Stressed Environment

Weihong He, Kexin Zhang, Tinglu Yang and Shunbao Wu

Abstract *Claraia* ranged from the late Permian to the Early Triassic. From the early Changhsingian to the Induan, byssal notches of *Claraia* species became narrower, and gradually changed from being ventrally extended to being horizontally extended. As the byssal notches narrowed, many *Claraia* species also lost most of their radial ornamentation. This resulted in a higher ratio of *Claraia* species with only concentric ornamentation to *Claraia* species with both concentric and radial ornamentation. *Claraia* experienced a rapid diversification and geographical expansion from the early Changhsingian to the Early Triassic. The rapid diversification of *Claraia* during the Permian–Triassic transition is related to a change in the genera's morphology, making *Claraia* better adapted to the stressed environment near the Permian–Triassic Boundary (PTB), and as a result leading to *Claraia* being a successful disaster genus.

Keywords *Claraia* · Morphological evolution · Permian–Triassic

Introduction

Numerous papers have discussed the evolution or definition of *Claraia* in terms of ears and sculpture (Leonardi 1935; Ichikawa 1958; Zhang 1980; Yang et al. 2001; Fang 1993, 2003, 2010; Chen and Komatsu 2002; Kotlyar et al. 2004; He et al. 2007). *Claraia* was previously considered to be an index fossil of the Early Triassic. However, accumulating evidence indicates that *Claraia* occurred from the

W. He (✉) · K. Zhang · T. Yang · S. Wu
State Key Laboratory of Biogeology and Environmental Geology, China University
of Geosciences, Wuhan 430074, People's Republic of China
e-mail: whzhang@cug.edu.cn

late Permian. Characteristics of the byssal notch of *Claraia* are important not only for taxonomic purposes, but also for research on the life habitat of *Claraia* and related palaeoecological implications. Here we discuss the morphological changes of *Claraia* particularly with respect to the byssal notch.

Results and Discussion

In the early Changhsingian, *Claraia* species included *Claraia zhiyunica*, *C. primitiva*, and *C. diana*. These species had wide and deep byssal notches, with the inner ends of the notches extending to the ventral margins of the right valves and expanding into a circle. *Claraia bioni* and *C. liuqiaoensis* arose during the late Changhsingian. They had wide, deep, rectangular and near-horizontally extended byssal notches. In addition, *C. zhiyunica*, *C. primitiva*, *C. labensis*, and *C. diana*, with wide, deep and ventrally extended byssal notches, continued to appear. During the Induan, many *Claraia* species arose, such as *C. wangi*, *C. griesbachi*, *C. dieneri*, *C. clarae*, *C. tumida*, *C. stachei*, *C. hubeiensis*, *C. painkhandana*, *C. aurita*, and *C. intermedia*, whereas *C. liuqiaoensis* persisted from the Changhsingian. Among these species, *C. wangi*, *C. griesbachi*, *C. dieneri*, *C. clarae*, *C. hubeiensis*, *C. intermedia*, and *C. aurita* had narrow, conspicuous, and horizontally extended byssal notches, and *C. painkhandana*, *C. tumida*, *C. stachei*, and *C. liuqiaoensis* had wide, deep, rectangular, and near-horizontally extended byssal notches.

The morphological variation in byssal notches of *Claraia* described above suggests that the species studied herein displayed progressive morphological changes from the early Changhsingian to the Induan. Species in the early Changhsingian had ventrally extended byssal notches, whereas the species that first occurred in the late Changhsingian had near-horizontally extended byssal notches, which persisted to the Induan. In other words, from the early Changhsingian to the Induan, byssal notches of *Claraia* species became narrower, and gradually changed from being ventrally extended to being horizontally extended (He et al. 2007). As the byssal notches narrowed, many *Claraia* species also lost most of their radial ornamentation (e.g., *C. wangi, C. griesbachi, C. tumida, C. hubeiensis*, and *C. painkhandana*). This resulted in a higher ratio of *Claraia* species with only concentric ornamentation to *Claraia* species with both concentric and radial ornamentation.

Across the PTB, marine bivalves were decimated and the diversity of bivalves declined. However, *Claraia*, one of the pectinoids, experienced a rapid diversification (He et al. 2007) and geographical expansion from the early Changhsingian to the Early Triassic (Fang 2010). *Claraia* species increased from three species during the early Changhsingian to more than 30 species during the Early Triassic (Nakazawa 1977; Yin 1982; Guo 1985; Yang et al. 2001). In addition, *Claraia* species became more widespread, eventually attaining a global distribution (Yin 1985, 1990). The diversification of species and geographic expansion of *Claraia*

during the Early Triassic implies that *Claraia* may be regarded as a typical disaster or opportunistic genus during the Permian–Triassic crisis (Schubert and Bottjer 1995; Rodland and Bottjer 2001; Fang 2003).

Conclusion

The findings indicate that the trend towards narrower, horizontally extended byssal notches, and the loss of radial ornamentation in some species, coincide with the rapid diversification of *Claraia* species during the Permian–Triassic crisis. Although the life habit of *Claraia* is highly speculative, it has been suggested that the narrowing of the byssal notch indicates greater mobility in *Claraia* (Fang 1993), and that the reduction in radial ornamentation led to smoother shells that were also better for moving or even swimming (Newell and Boyd 1995). According to Yang et al. (2001), the smoother forms led planktonic lives attached to floating wood or sea algae. The increase in diversity of *Claraia* during the Permian–Triassic transition is related to a change in the genera's morphology, making *Claraia* better adapted to the stressed environment near the PTB, and as a result leading to *Claraia* being a successful disaster genus.

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Mississippian–Pennsylvanian Boundary Beds in the South Urals

Elena Kulagina, Svetlana Nikolaeva and Vladimir Pazukhin

Abstract This work presents a study of the Mississippian–Pennsylvanian (Serpukhovian–Bashkirian) boundary beds in the eastern regions of the Russian Platform and in the South Urals. The boundary beds have been studied in boreholes in the eastern Russian Platform and in the Pre-Uralian Foredeep, and in natural outcrops in the South Urals. In the Russian Platform, the upper Serpukhovian includes the Protvian and Zapaltyubian substages. The lower portion of the Bashkirian includes the Voznesenskian and Krasnopolyanian substages. In the South Urals, there are two subregional stratigraphic schemes for the lower Carboniferous, for the West Uralian and East Uralian subregions. The West Uralian Subregion includes the Cisuralian, West Uralian, and Central Uralian facies zones, and the upper Serpukhovian is subdivided there into the Protvian and Staroutkinskian (= Yuldybaevian in the Central Uralian facial Zone) regional substages, and in the East Uralian Subregion (Magnitogorsk Zone) into the Khudolazian and Chernyshevkian substages. This paper briefly summarizes features of the boundary beds in each of these regions, including ammonoids, conodonts and foraminifers.

Keywords Mississippian · Pennsylvanian · Serpukhovian · Bashkirian · Syuranian · Foraminifers · Ammonoids · Conodonts

E. Kulagina (✉) · V. Pazukhin
Institute of Geology, Ufa Scientific Centre, Russian Academy of Sciences,
Karla Marksa 16/2, Ufa, 450077 Russia
e-mail: kulagina@ufaras.ru

S. Nikolaeva
Borissiak Paleontological Institute, Russian Academy of Sciences,
Profsoyuznaya 123, Moscow, 117997 Russia

Introduction

In the Russian Platform, the Mid-Carboniferous boundary coincides with the boundary between Zapaltyubian (uppermost Serpukhovian) and Voznesenskian (lower portion of the Bashkirian) substages (Fig. 1). In most regions of the eastern part of the Russian Platform, adjacent to the South Urals, there is a gap between the Mississippian and the Pennsylvanian. The Serpukhovian is composed of lagoonal dolomites, which are unconformably overlain by the Bashkirian oolitic limestone. The gap corresponds to the Voznesenskian and Krasnopolyanian substages and, in some regions, also to the Akavassian Substage.

In the South Urals, sections are studied in five facies zones, as follows.

1. In the Cisuralian Zone (Pre-Uuralian Foredeep), limestone beds with rare layers of marl, containing *D. noduliferus*, overlie dolomitized limestones with Serpukhovian foraminifers.
2. In the West Uralian facies Zone (Lakly, Yakhino, Bolshaya Luka, Sim, Askyn, Zigan, and Verkhnebikkuzino sections) (Fig. 2), the boundary deposits are represented by shallow-water coral–brachiopod facies, with infrequent conodonts. The upper portion of the Serpukhovian is characterized by the *Striatifera* coquina (Staroutkinskian regional substage), which in thin beds contains the foraminifers *Globivalvulina bulloides, Monotaxinoides transitorius, Neoarchaediscus incertus* (Kulagina et al. 1992, 2001, 2002). The Staroutkinskian beds are unconformably overlain by shallow-water, commonly oolitic, limestones with foraminifers of the *Pl. bogdanovkensis* Zone, and isolated conodonts *Rhachistognathus minutus* and *Declinognathodus inaequalis*. Erosion at the Mississippian–Pennsylvanian boundary is indicated by the cut-off brachiopod shells and the absence of the lowermost Bashkirian *Pl. varvariensis* Zone.
3. In the Central Uralian Zone, in the Sakmara-Ik Region (Muradymovo, Kugarchi, and Bolshaya Karsakla), the boundary beds are composed of the Bukharcha Formation. The sections of this zone are the most stratigraphically significant, as they are composed of deep-water slope facies with foraminifers, ostracods, ammonoids, and conodonts. The most complete palaeontological characterization has been obtained from the Muradymovo section (Kulagina et al. 2014). In this section, *Declinognathodus inaequalis* is found in association with ammonoids *Proshumardites delepinei* and foraminifers of the *Monotaxinoides transitorius* Zone. In the Kiya-Shandy Region, Sholak-Sai section, the boundary beds are composed of thin limestone beds (about 10 m), whereas the Yuldybaevian Substage is composed of thin-bedded, micritic limestones with ammonoids, small brachiopods, trilobites, and crinoids. One conodont specimen similar to *Declinognathodus bernesgae* (Sanz-Lopez and Blanca-Ferrera 2013) is found with Serpukhovian ammonoids of the *Fayettevillea–Delepinoceras* Genozone. The Bashkirian beds unconformably overlie the Serpukhovian deposits and consist of thin-bedded ammonoid-bearing

Series	Stage	Russian platform	West-Uralian subregion	East-Uralian subregion	Biozones in the South Urals			
					Ammonoids	Conodonts		Foraminifers
Lower Pennsylvanian	Bashkirian (part)	Krasnopo-lyanian	Syuranian Kamenno-gorian	Syuranian Kamenno-gorian	Reticuloceras-Bashkortoceras	Idiognatho-ides sinuatus		Semistaffella variabilis
		Voznesen-skian	Bogdanov-kian	Bogdanov-kian	Homoceras-Hudsonoceras Hud. proteus			S. minuscilaria
					H. coro-natum R. cor-pulentus Beds	D.noduli-ferus	Late	Pl. bogdanov-kensis
							Early	Pl. varvariensis
Upper Mississippian	Serpukhovian (part)	Zapaltyubian	Staroutkinskian/ Yuldybaevian	Chernyshevkian	Fayettevillea - Delepinoceras D. bressoni	Gn. bollandensis (part)		M. transitorius
		Protvian	Protvian	Khudolazian (part)	P. uralicus			E. paraprotvae (part)

Fig. 1 Regional subdivisions of the Mid-Carboniferous boundary deposits of Eastern Europe and biozones of the South Urals

Fig. 2 Locations of the studied sections: *1* Lakly, *2* Bolshaya Luka, *3* Yakhino, *4* Sim, *5* Askyn, *6* Zigan, *7* Verkhnebikkuzino, *9* Muradymovo, *10* Bolshaya Karsakla, *11* Kugarchi, *12* Sholak-Sai, *13* Bolshoi Kizil, *14* Khudolaz, *15* Verkhnyaya Kardailovka, *16* Uvelka

limestones with thin layers of clayey mudstones (thickness 0.5 m). These beds contain ammonoids of the lower part of the *Homoceras–Hudsonoceras* Zone (Ruzhencev and Bogoslovskaya 1978) and conodonts of the *Idiognathoides sinuatus* Zone, but the *D. noduliferus* Zone is missing.

4. In the East Uralian Subregion (Magnitogorsk Zone), the boundary beds are composed of shelf carbonates. The predominant facies are algal and foraminiferal–brachiopod (Bolshoi Kizil and Khudolaz) (Kulagina et al. 2009; Stepanova and Kucheva 2006). In the Bolzhoi Kizil Section, *D. noduliferus* enters together with *Pl. varvariensis.* The relatively deep cephalopod limestones have a limited distribution (Verkhnyaya Kardailovka) (Nikolaeva et al. 2009), in which conodonts ancestral to *D. noduliferus* first appear in limestones of the upper part of the *Fayettevillea–Delepinoceras* Genozone.

5. In the East Uralian Zone (Uvelka Section), the boundary beds are represented by shallow-shelf carbonates, although here they are more strongly recrystallized (Kulagina et al. 2001).

Conclusions

In the South Urals, the upper Serpukhovian includes the following zones: the ammonoid *Fayettevillea–Delepinoceras*, conodont *Gnathodus bollandensis* (part), and foraminiferal *Eostaffellina paraprotvae* and *Monotaxinoides transitorius* zones. The lower Bashkirian Syuranian Substage contains the *Homoceras–Hudsonoceras* and *Reticuloceras–Bashkortoceras* ammonoid zones, *D. noduliferus* (with two subzones—Early and Late) and the *Idiognathoides sinuatus* conodont zones, and ?*Monotaxinoides transitorius* (uppermost part), *Plectostaffella varvariensis*, *Pl. bogdanovkensis*, *Semistaffella minuscilaria*, and *S. variabilis* foraminiferal zones.

Based on ammonoids, the Mississippian–Pennsylvanian boundary in the South Urals is recognized by the appearance of a new morphotype of ribbed homoceratids. In practice, this boundary is demarcated by the first appearance of the genus *Isohomoceras* and the species *Ramosites corpulentus*, which is observed in the most informative section of Muradymovo above the entry of *D. noduliferus*. The *Homoceras–Hudsonoceras* Genozone is subdivided into two zones: *Homoceras coronatum* and *Hudsonoceras proteus*. The *Homoceras coronatum* Zone contains beds with *Ramosites corpulentus* in its lower part. The base of the *Pl. varvariensis* zone is drawn by the appearance of the index species against the background of an impoverished assemblage. In the Muradymovo section, the first appearance of *Pl. varvariensis* is recorded above the entry of *D. noduliferus*. However, *Pl. varvariensis* in sections of other regions is reported from different levels within the upper Serpukhovian. The most significant changes in the foraminiferal assemblage are observed in the *Pl. bogdanovkensis* Zone, which correlates with the Late *D. noduliferus* conodont Zone. This zone shows the disappearance of the Viséan foraminiferal species and appearance of various *Plectostaffella* and *Millerella* species.

The succession of the foraminiferal and conodont assemblages established in the South Urals can also be traced in the sections of the Middle Urals (Kucheva et al. 2002; Ponomareva et al. 2002; Ponomareva 2004) and Peri-Caspian

(Zaitseva and Klenina 2008). Rich fossil contents allow broad correlations with the type Mississippian section in North America (Brenckle et al. 1997), the Donets Basin (Nemyrovska et al. 2011; Vachard and Maslo 1996), Japan (Mizuno and Ueno 1997), and Spain (Sanz-Lopez and Blanca-Ferrera 2013).

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Stratigraphic and Palaeogeographical Distribution of the Ordovician Eocrinoid *Ascocystites* Barrande 1887 (Echinodermata, Blastozoa)

Yamouna Makhlouf, Bertrand Lefebvre, Elise Nardin, Ahmed Nedjari, Serge Régnault and Mohamed Ferhi

Abstract All available data on the stratigraphic range, palaeobiogeographical distribution, and systematics of the blastozoan genus *Ascocystites* (Echinodermata) are reviewed and discussed. Its stratigraphic extent appears to be limited to the Darriwilian–Sandbian interval. Its palaeogeographical distribution is restricted to high-latitude peri-Gondwanan regions of the Mediterranean Province (Algeria, Bohemia, France, Morocco, and Portugal). *Ascocystites* is reported herein for the first time in the Darriwilian (Middle Ordovician) of the Central Anti-Atlas, Morocco. The species *A. micraster* Barrande 1887 and *A. barrandei* Jaekel 1918 are both reinterpreted as junior synonyms of *A. drabowensis* Barrande 1887.

Keywords: Blastozoa · Echinodermata · Eocrinoidea · Gondwana · Ordovician · Palaeogeography

Ascocystites Barrande 1887 is a genus of stemmed blastozoans, locally abundant in shallow settings of high-latitude peri-Gondwanan regions (Algeria, Czech Republic, France, Morocco, and Portugal). Its stratigraphic range is restricted to the Darriwilian–Sandbian interval.

Y. Makhlouf (✉) · A. Nedjari · M. Ferhi
Faculté des Sciences de la Terre, Université des Sciences et de la Technologie Houari Boumediene, de Géographie et de l'Aménagement du Territoire, Alger, Algeria
e-mail: yamouna.makhlouf@gmail.com

B. Lefebvre
UMR CNRS 5276 Laboratoire de Géologie de Lyon, Terre, Planètes, Environnement (LGLTPE), Géode, campus de la Doua, Université Lyon 1, 2 rue Dubois, 69622 Villeurbanne cedex, France

E. Nardin
UMR CNRS 5563 Géosciences Environnement Toulouse (GET), Observatoire Midi-Pyrénées (OMP), 14 avenue Edouard Belin, 31400 Toulouse, France

S. Régnault
Muséum d'Histoire Naturelle, 12 rue Voltaire, 44000 Nantes, France

1045

The morphology of *Ascocystites* was thoroughly described by Ubaghs (1967), and complemented by both Sprinkle (1973; morphology and growth of the ambulacral system) and Régnault (1990, 2007; identification of the anal opening). The morphology consists of: (1) numerous (20–30) delicate feeding appendages (brachioles); (2) an elongate theca with a flat oral surface; and (3) a holomeric stem made of heteromorphic columnals. The aboral part of the theca is hexagonal in cross-section; it consists of six longitudinal columns of strongly ridged skeletal elements separating six vertical areas of irregularly arranged polygonal plates. The anal pyramid is located on the lateral walls of the theca. No respiratory structures are present (e.g., sutural pores, diplopores, and rhombs). The oral surface bears the central mouth and the hydropore, as well as five ambulacral rays showing the typical 2-1-2 pattern.

Although originally assigned to the "cystoids" (i.e., non-crinoid pelmatozoans) by Barrande (1887), *Ascocystites* was later identified variously as a member of the holothurian stem-group (Haeckel 1896), a camerate crinoid (Bather 1900), and a member of the crinoid subclass Eocrinoidea (Jaekel 1918). Following Barrande (1887), Chauvel (1941) reaffirmed the blastozoan affinities of *Ascocystites*, and suggested a possible placement within rhombiferan cystoids. Ubaghs (1967) erected the family Ascocystitidae within the class Eocrinoidea (eocrinoids were elevated to class-level by Regnell (1945) and assigned to the subphylum Blastozoa by Sprinkle (1973)). All subsequent contributions suggest various phylogenetic positions for *Ascocystites* within blastozoan echinoderms, and affinities with diverse "eocrinoid" and/or glyptocystitid genera: *Eustypocystis*, *Nolichuckia*, and *Pareocrinus* (Sprinkle 1973), *Cambrocrinus*, *Eocystites*, and *Macrocystella* (Broadhead 1982), *Pareocrinus* and *Rhopalocystis* (Paul 1988), and *Ampheristo-cystis*, *Cryptocrinites*, and *Lysocystites* (Nardin 2007).

The genus *Ascocystites* was erected by Barrande (1887) based on abundant material collected in the Prague Basin between 1843 and 1883. All specimens were originally sampled in sandstone levels of Barrande's "bande d2" in the localities of Drabow (Mont Ded, near Beroun), Wesela (Vesela farm near Beroun), and Chrustenitz (Chrustenice). The revision of Barrande's stratigraphy by Chlupac (1999) indicates that assemblages collected in these three localities can be assigned to the Letna Formation (upper Sandbian). However, a more extensive stratigraphic range including the underlying Liben Formation (lower Sandbian) was suggested for *Ascocystites* (Havlicek and Vanek 1966; Prokop and Petr 1999). Two species were described by Barrande (1887): *A. drabowensis* (type species) and *A. micraster*. However, *A. micraster* was defined based on a single, fragmentary portion of theca collected in the same locality (Drabow) and from the same levels as *A. drabowensis*. The morphology of *A. micraster* does not exhibit any difference with co-occurring specimens of *A. drabowensis* (see Barrande 1887, pl. 26 Figs. 3 and 4). Consequently, *A. micraster* is here synonymised with *A. drabowensis*. A third species of *Ascocystites* (*A. barrandei*) was described by Jaekel (1918, Fig. 9) based on material collected also from the same locality (Drabow) and same stratigraphic level as *A. drabowensis*. After Jaekel (1918, p. 16), the two main differences between the two species concern their thecal size

(*A. barrandei* being larger than *A. drabowensis*), and the number of side branches observed along each ambulacral ray on the oral surface (4–5 in *A. drabowensis*, 6 in *A. barrandei*). However, the detailed description of the growing pattern of the ambulacral system in *Ascocystites* shows that new side branches are regularly added along each ambulacral ray during ontogenesis (Sprinkle 1973). Consequently, the differences pointed out by Jaekel (1918) appear to be simply correlated with different growth stages (larger specimens have more ambulacral side branches than do small ones); *A. barrandei* is thus synonymised herein with *A. drabowensis*. As pointed out by Ubaghs (1967), the putative distal holdfast of *A. barrandei* noted by Jaekel (1918, Fig. 9D, E) more likely corresponds to a conularid shell covered by epizoans.

The Middle Ordovician sandstones of the Moitiers d'Allonne Formation (*D. murchisoni* Biozone, Darriwilian) in Cotentin peninsula (Normandy, France) have yielded abundant remains of small-sized specimens of *Ascocystites* (Chauvel 1941; Régnault 1990). This material was assigned to a distinct species (*A. cuneiformis*, Chauvel 1941), because of the smooth aspect of thecal walls in most observed specimens. A stronger thecal ornamentation (with radiating ridges) appears only in the largest specimens of *A. cuneiformis* (see Régnault 1990, pl. 1 Figs. 13 and 14), whereas it is present even within the smallest observed specimens of *A. drabowensis* (see Barrande 1887, pl. 32 Figs. 1–10).

Three incomplete specimens of *Ascocystites* were found in a same concretion collected at the base of the Middle Ordovician Brejo Fundeiro Formation (*D. (D.) artus* Biozone, Darriwilian) of the Dornes region, central Portugal (Young and Donovan 1993). Their extremely poor preservation prevents any identification at species level.

Abundant specimens of exquisitely preserved specimens of *Ascocystites* were described recently in sandstones of the Upper Ordovician Izzeguirène Formation (lower Sandbian) in the eastern Anti-Atlas, Morocco (Regnault 2007; Lefebvre et al. 2008). This material was left in open nomenclature (*Ascocystites* sp.). A new occurrence of *Ascocystites* is reported herein from the Middle Ordovician Ouine-Inirne Formation (upper Darriwilian) of central Anti-Atlas.

Finally, Makhlouf et al. (2010) reported the presence of several exquisitely preserved specimens of *Ascocystites* in Ordovician sandstone deposits of the Ougarta Range, western Algeria. The precise stratigraphic position of this material is yet unknown, but the associated fauna suggests that the deposit is uppermost Darriwilian–Sandbian.

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Dynamics of Upper Sinemurian Macrobenthic Groups (Bivalves and Brachiopods) Preserved in Organic-Rich Facies of the Lusitanian Basin (Western Iberia)

Ricardo Paredes, María J. Comas-Rengifo and Luís V. Duarte

Abstract Bivalves and brachiopods are the most abundant macrobenthos of the upper Sinemurian marine assemblages preserved in the Lusitanian Basin (Portugal). The wide variety of life habits of the bivalves and the taxonomic diversity of both groups indicate that these elements should be taken into account for marine assemblages analysis. Although the basin contains many upper Sinemurian outcrops, those in the S. Pedro de Moel and Peniche areas are exceptionally fossil rich. The palaeontological content of the basin's Água de Madeiros Formation is well preserved and has provided taxonomic and quantitative data regarding the abundance of bivalves and brachiopods. This lithostratigraphic unit shows two distinct sequences of biofacies: (1) shallow-water and soft-bottomed assemblages; and (2) hemipelagic assemblages associated with organic-rich facies. The transition between them corresponds to faunal turnover in the basin, recorded in the Raricostatum Subchronozone. The transition is particularly clear in the S. Pedro de Moel area, but does not seem to be synchronous with that observed in the Peniche area.

Keywords Macrobenthic assemblages · Bivalves · Brachiopods · Organic facies · Upper Sinemurian · Lusitanian Basin

R. Paredes (✉) · M. J. Comas-Rengifo
Departamento de Paleontología, Facultad de Ciencias Geológicas, Universidad Complutense de Madrid, C/José Antonio Novais, 28040 Madrid, Spain
e-mail: ricardo.paredes@ucm.es

R. Paredes · L. V. Duarte
IMAR-CMA, Faculdade de Ciências e Tecnologia, Universidade de Coimbra, Largo Marquês de Pombal, 3000-272 Coimbra, Portugal

L. V. Duarte
Departamento de Ciências da Terra, Faculdade de Ciências e Tecnologia, Universidade de Coimbra, Largo Marquês de Pombal, 3000-272 Coimbra, Portugal

Introduction

The upper Sinemurian in the Lusitanian Basin (Portugal) is represented by the Água de Madeiros Formation in its western sector (Duarte and Soares 2002). Macrobenthos (bivalves and brachiopods) are the most abundant faunal elements, found mainly in the Polvoeira Member (Duarte et al. 2010, 2012). The wide variety of life habits of the bivalves and the taxonomic diversity of both bivalves and brachiopods indicate that these elements should be taken into account for marine faunas analysis. The stratigraphic distribution of bivalve and brachiopod taxa has been presented at a high-resolution scale (see Paredes et al. 2013a, b). In addition, a new proposal for the chronostratigraphy for this time interval in the basin has recently been presented (Comas-Rengifo et al. 2013).

Results and Discussion

The lower part of the Oxynotum Subchronozone in the S. Pedro de Moel area (Fig. 1) is dominated by the association *Merophricus*? *ribeiroi–Zeilleria quiaiosensis.* Above this, a faunal replacement is observed, and the association *Pleuromya–Pholadomya* becomes dominant together with zeilleriid brachiopods. Throughout the Oxynotum Subchronozone, a great diversity and abundance of bivalves (23 families, 29 genera, and 43 species; n = 1858) and brachiopods (9 families, 14 genera, and 21 species; n = 751) is observed. The bivalves are dominated by the association *Liostrea hisingeri–Gryphaea mccullochi–Pseudopecten equivalvis*, which coexists with brachiopods; the brachiopods are represented mainly by the *Tetrarhynchia dunrobinensis–Lobothyris sinemuriensis–Cuersithyris gijonensis* association.

In the S. Pedro de Moel area, the aforementioned faunal replacement is observed in the Raricostatum Chronozone, concomitant with an increase in organic matter, and clearly related to a transgressive event (Duarte et al. 2010). In the Raricostatum Subchronozone, endobenthic forms disappear and there is a significant reduction in the diversity of both bivalves (9 families, 13 genera, and 13 species; n = 147) and brachiopods (4 families, 5 genera, and 8 species; n = 114). The assemblages represented are dominated by thin-shelled epifaunal bivalves of the *Pseudomytiloides* aff. *dubius–Oxytoma inequivalvis* association. The *Piarorhynchia rostellata–Tetrarhynchia ranina* brachiopod association is also represented, although in different layers. In the Macdonnelli Subchronozone, a low diversity of brachiopod forms is observed, dominated by the association *Piarorhynchia rostellata–Squamirhynchia squamiplex*. The brachiopods in S. Pedro de Moel are apparently absent in the lower part of the Aplanatum Subchronozone. The bivalve content is limited to sporadic occurrences of low-diversity *P.* aff. *dubius–O. inequivalvis* associations and a few examples of *Plagiostoma punctata* Sowerby and *Steinmannia* aff. *bronni* (Voltz in Zieten). *Mesomiltha* sp. is observed
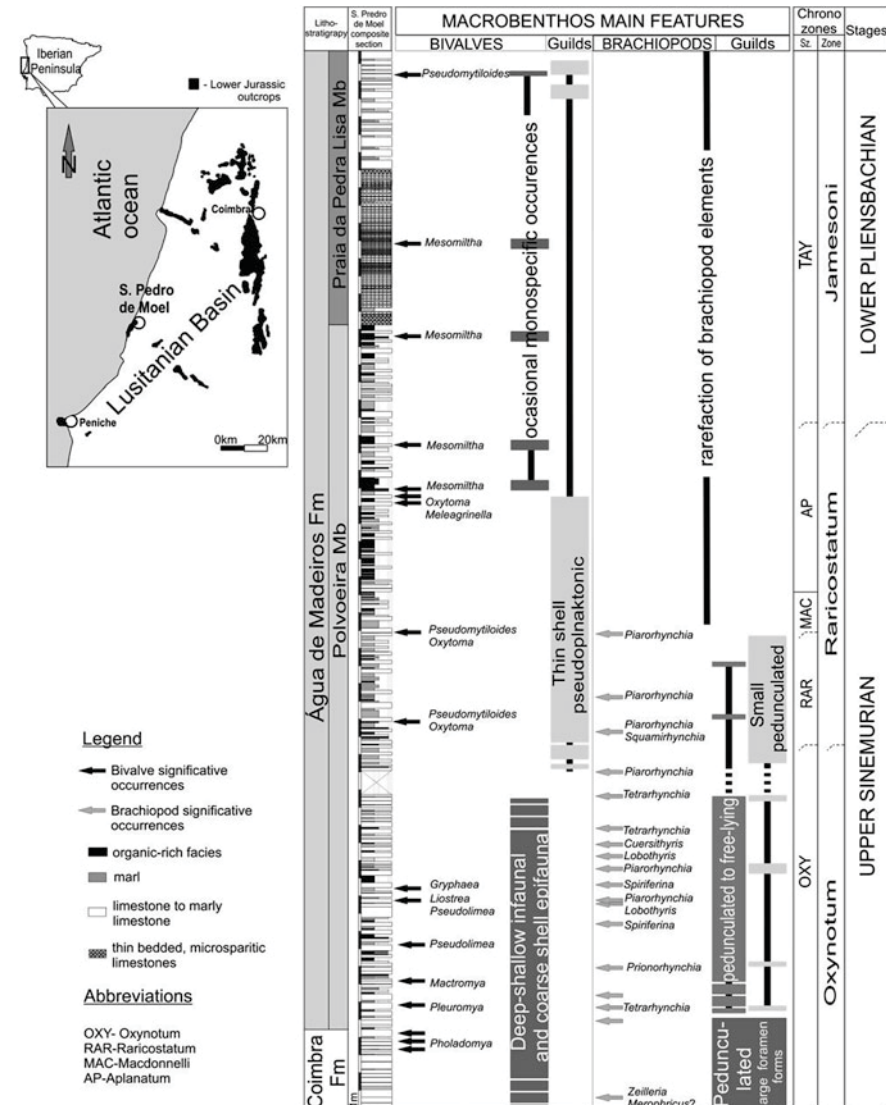
Fig. 1 Main features of macrobenthos (bivalves and brachiopods) in the upper Sinemurian for S. Pedro de Moel composite section (Lusitanian Basin). The detailed log is after Duarte et al. (2010, 2012). Bivalve data are from Paredes et al. (2013a), and brachiopod data are after Paredes et al. (2013b). Chronostratigraphy is from Comas-Rengifo et al. (2013)

in life position in a few levels of organic-rich, marly limestone facies of the upper part of the Aplanatum Subchronozone. These organisms probably lived in oxygen-poor conditions, chemosymbiotically associated with sulphur-reducing bacteria, similar to modern-day lucinids.

Only the Aplanatum–Taylori Subchronozone interval (Comas-Rengifo et al. 2013) can be examined in the Peniche outcrops. However, the outcrops contain some of the macrobenthic taxa represented in the Oxynotum Chronozone in the S. Pedro de Moel area.

Concluding Remarks

Throughout the upper Sinemurian series of the Água de Madeiros Formation, two distinct sequences of biofacies can be interpreted: (1) shallow-water, soft-bottomed assemblages; and (2) hemipelagic assemblages associated with organic-rich facies. The transition between them corresponds to faunal turnover in the basin, recorded in the Raricostatum Subchronozone. The transition is particularly clear in the S. Pedro de Moel area, but does not seem to be synchronous with that observed in the Peniche area.

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Part XX
Theme C: Applied Stratigraphy

Microfossils in Stratigraphy

cnw@bgs.ac.uk

Improving the Palaeoecological Understanding of the Lisboa–Sintra Region Cenomanian Units: The S. João Das Lampas Section

M. Cristina Cabral, Ana C. Azerêdo and Elba A. Boavida

Abstract The S. João das Lampas section, in the Sintra region (Lusitanian Basin, Portugal), exhibits a highly fossiliferous marl–limestone Cenomanian succession and belongs to the Caneças Formation. In this work, we present data from ongoing studies on ostracods and microfacies to address palaeoecological issues within the regional framework. The fossil assemblage comprises ostracods (very abundant and represented mainly by brackish and marine littoral species), benthic foraminifers, dasycladalean and bryopsidalean algae, bivalves, gastropods, serpulids, and echinoderms. The succession consists predominantly of oyster-rich marls and marly limestones, interbedded with skeletal/microfossil-rich carbonate and marly layers and skeletal storm beds or lenses. Overall, the data point to a low- to moderate-energy marginal-marine setting with frequent variations in salinity.

Keywords Ostracods · Foraminifers · Dasycladales · S. João das Lampas · Cretaceous · Portugal

Introduction

The S. João das Lampas section is exposed along the road between the localities of S. João das Lampas and Assafora in the Sintra region (north of Lisbon, Lusitanian Basin, Portugal; Fig. 1). This section exhibits a marl–limestone succession belonging to the Caneças Formation (Rey et al. 2006). The section (12 m, 22 levels) is assigned to the Cenomanian (e.g., Berthou 1984), but no descriptions of

M. Cristina Cabral (✉) · A. C. Azerêdo · E. A. Boavida
Faculdade de Ciências, Departamento e Centro de Geologia, Universidade de Lisboa,
Campo Grande, C6, 4° piso, 1749-016 Lisbon, Portugal
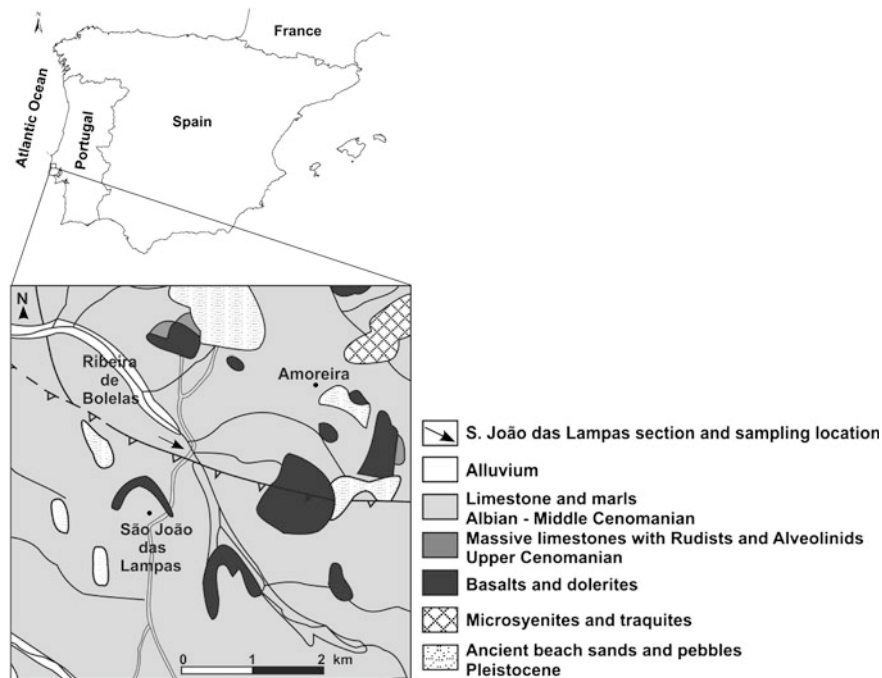e-mail: mccabral@fc.ul.pt

Fig. 1 Location map of the studied section (lat 38°52′49.54″N, long 9°23′46.41″W)

it have been published. In this work, we couple data from ongoing studies on ostracods (25 marl samples) and microfacies (25 limestone samples) to address palaeoecological issues within the regional framework.

The Studied Succession

General Aspects

The studied succession is dominated by highly fossiliferous marls and limestones, with a variable occurrence of ferruginous clay and fine-sand-grade, detrital, quartz-rich levels. The fossil assemblage comprises ostracods, benthic foraminifers, dasycladalean and bryopsidalean algae, bivalves (particularly oysters), gastropods, serpulids, and remains of echinoderms. The main overall features of this succession may be summarized as follows (Fig. 2): thick beds of oyster-rich marls and marly limestones, interbedded with thinner-bedded, skeletal/microfossil-rich carbonate and marly layers, often with undulated bedding surfaces and compactional features; highly skeletal, unevenly bounded storm beds or lenses; very abundant ostracods, including very common ostracodites; abundant bivalve–gastropod–ostracod or
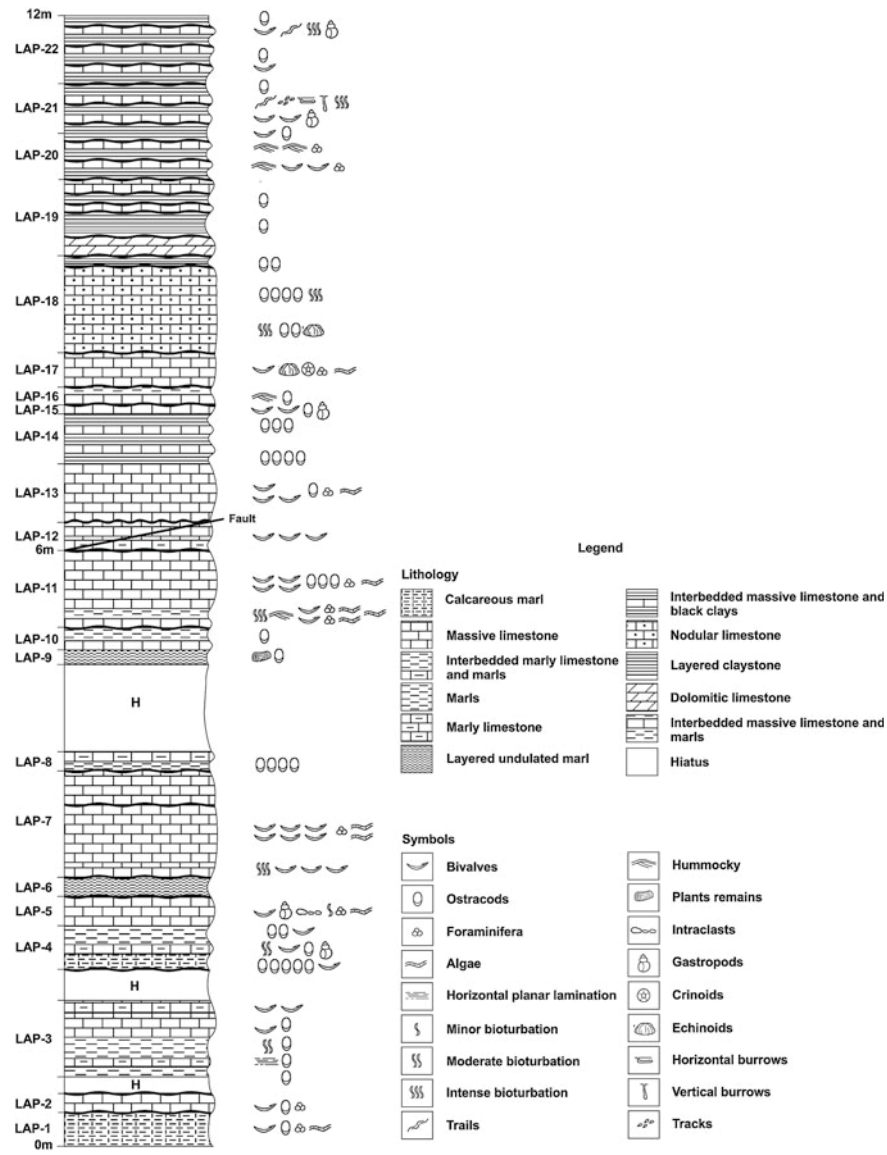
Fig. 2 Schematic lithostratigraphic column of the studied S. João das Lampas (LAP) succession

bivalve–serpulid coquinas; common dasycladales; the presence of (but neither abundant nor diversified) benthic foraminifers; and clear, high-frequency contrasts in palaeobiodiversity.

Microfossils

Regarding the ostracod assemblages, the brackish *Fossocytheridea merlensis* (Babinot and Colin 1976) is dominant in the ostracodite layers, but there are also (amongst others) *Perissocytheridea*? *estribeirensis* Andreu, 1981 (brackish), *Cythereis* cf. *condemiensis* Breman, 1976, *Cythereis ouillierensis* Babinot, 1971, *Cytherella* cf. *postangulata* Babinot, 1980, *Dolocytheridea iberica* Andreu, 1981, *Paracaudites* (*Dumontina*) aff. *grekoffi* (Babinot 1971), *P.* (*D.*) *juliensis* (Andreu 1981), *Platycythereis covoensis* Andreu, 1981, and *Trachyleberidea* aff. *arta* (Damotte 1971). Most of these species are typical marine littoral to sublittoral and are known from other western European countries, particularly France (e.g., Babinot et al. 1985), in levels of the same or similar age. Only very rare freshwater ostracods (*Darwinula* sp.) are found, in one level.

Among the algae, *Heteroporella lepina* (Praturlon 1967), Granier et al. 1995, *Neomeris cretacea* (Steinmann 1899), *Salpingoporella* spp., *Terquemella* sp., and *Boueina* sp. are the most common.

The foraminifer assemblages include *Pseudocyclammina rugosa* (d'Orbigny 1850), *Buccicrenata hedbergi* (Maync 1953), *Cuneolina* sp., *Daxia cenomana* Cuvillier and Szakall, 1949, miliolids, rare orbitolinids, and rare hyaline-walled forms.

Discussion and Conclusions

The levels with abundant *F. merlensis* are common in other locations in the region and also in Cenomanian units such as at Lousa, some 15 km to the east of S. João das Lampas (Cabral et al. 2008), and serve as a regional lithostratigraphic guide. At Lousa, other ostracods have been found, most of them belonging to the same genera/species identified at S. João das Lampas, but the assemblages at Lousa are more diversified, including a typical oligohaline one. *Heteroporella lepina* has been previously recorded in nearby sections, namely at Lousa (Cabral et al. 2008) and at Cacém, 25 km to the southeast of S. João das Lampas (Granier et al. 1995); the other algal species identified at S. João das Lampas have also been found at Lousa. With regard to the foraminifers, the S. João das Lampas succession yielded a much less diversified assemblage, with no record yet of the species that allowed beds at Lousa to be assigned to the middle Cenomanian to basal upper Cenomanian (Cabral et al. 2008).

The biofacies in the limestones (differing in both composition and diversity) and the diversity and abundance of ostracod assemblages in the marls attest to frequent palaeoecological variations, likely in salinity. Overall, the environment was shallow, of low to moderate energy, and marginal marine, with four main stages being recognized in the palaeoecological trends through the section:

(1) The lowermost interval suggests a shallow but relatively open lagoonal setting of near-normal marine salinity. This interval contains a moderate diversity of ostracods, with an absence of *F. merlensis*, and a presence of *Cytherella* cf. *postangulata*, *Cythereis* cf. *condemiensis*, and *Planileberis* spp. It also contains diverse algae and foraminifers, and diverse macrofossils.

(2) The overlying interval reflects more restricted, brackish lagoonal conditions, with almost-oligospecific ostracod assemblages represented by *F. merlensis* and gastropod–oyster–serpulid levels, intercalated by intervals indicating more open conditions (with higher diversity, as above, namely containing abundant dasycladaleans).

(3) Above this, a new more marine-influenced interval is indicated by the presence of more diversified ostracod assemblages (although still very rich in *F. merlensis*) or by assemblages poor in *F. merlensis*, coupled with a higher biodiversity recorded in the limestones again.

(4) Finally, the deposits record another stage of brackish depositional setting, punctuated by a more normal salinity episode, and very rich in marine ostracod genera such as *Cytherella* and *Paracaudites*. The dominant low- to moderate-energy hydrodynamic conditions were regularly subjected to stronger currents depositing tempestites. No clear evidence of subaerial exposure is found, suggesting that a shallow water body remained present even during local regressive coastal shifts.

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Miocene Dinoflagellate Cyst Assemblages: Preliminary Correlation Between the Lower Tagus and Algarve Basins (Portugal)

Lígia Castro, Marisa Borges, Zélia Pereira, Paulo Fernandes and João Pais

Abstract Biostratigraphic studies of several sections and a borehole (Belverde) of the Lower Tagus Basin, based on Miocene dinoflagellate cyst assemblages, have allowed a detailed stratigraphic investigation to be conducted. Assemblages are very diverse and abundant and can be used as important biostratigraphic guides. Recently, a palynostratigraphic study based on dinoflagellate cysts was conducted in two offshore wells, Ruivo-1 and Corvina, located in the Algarve Basin (southern Portugal). The recovered dinoflagellate assemblages are less abundant and diverse than those obtained in the Lower Tagus Basin. New inferences are made regarding the correlation between the dinoflagellate cysts known from the Lower Tagus Basin with the assemblages recently recovered from the Algarve Basin. Species of selected dinoflagellate cyst assemblages recovered are similar in both basins. Continuing progress with these new palynological studies and biostratigraphic data will help to refine knowledge of and correlations between Portuguese Miocene deposits.

Keywords Dinoflagellate cysts · Lower Tagus Basin · Algarve Basin · Miocene · Portugal

L. Castro (✉) · J. Pais
CICEGe, Departamento de Ciências da Terra, Faculdade de Ciências e Tecnologia,
Universidade Nova de Lisboa, Campus Caparica, 2829-516 Caparica, Portugal
e-mail: lscastro@fct.unl.pt

M. Borges
PetroStrat Ltd., Tan-y-Graig, Parc Caer Seion, Conwy, Wales, LL32 8FA, UK

Z. Pereira
LNEG, Unidade de Geologia, Hidrogeologia e Geologia Costeira, Rua da Amieira,
4465-965 S. Mamede Infesta, Portugal

P. Fernandes
CIMA, Universidade Algarve, Campus de Gambelas, 8005-139 Faro, Portugal

Introduction

The distal sector of the Lower Tagus Basin (LTB) is located mostly in the Setúbal Peninsula, Portugal. In this sector, Miocene deposits are confined to an asymmetric syncline with an almost E–W axis located near Lagoa de Albufeira, and include deposits from the Lower Aquitanian to the Middle Tortonian. Sedimentological, palaeontological (foraminifera, ostracoda, vertebrates, plant fossil remains, and palynomorphs), and magnetostratigraphic studies have been developed, allowing a high-resolution stratigraphic framework to be established (Antunes et al. 1999; Pais et al. 2003; Sousa and Pais 2004; Castro 2006, 2008; Pais et al. 2012). Palynostratigraphic studies from several sections (Carcavelos, Foz da Fonte, Foz do Rego north and south, IPQ, Penedo north and south, Ribeira das Lages, and Trafaria) and a borehole (Belverde) from the LTB have enabled different Miocene dinoflagellate cyst assemblages to be recognised (Sousa and Pais 2004; Castro 2006, 2008).

The Algarve Basin corresponds to the southernmost geological province of mainland Portugal, and comprises more than 3000 m of essentially marine sediments accumulated during the Mesozoic and Cenozoic. The Cenozoic sediments are restricted to Miocene, Pliocene, and Quaternary units. These sediments are relatively well studied based on geological mapping, palaeontology, and geochemistry (Antunes et al. 1999; Pais et al. 2012). The Mesozoic and Cenozoic Algarve deposits extend offshore, where their geology is seismically recognized and where a few hydrocarbon exploration wells were drilled during the mid-1970s and early 1980s.

A preliminary attempt to recover Miocene dinoflagellate cysts from the Algarve onshore deposits was made during a study of several cliff sections (at the beaches of Vau, Rocha, Canavial, Albandeira, Quelfes, Cacela, Oura, and Santa Eulália). However, the samples recovered were almost barren. However, more recently, palynostratigraphic research has been undertaken in two selected offshore wells, Ruivo-1 and Corvina (Fernandes et al. 2010; Borges et al. 2011; Borges 2012). Although the lithologies are essentially marine carbonates, some samples were collected in clastic facies; this allowed a palynostratigraphic study to be conducted, which has provided new biostratigraphic data based on dinoflagellate cysts (Borges 2012; Fernandes et al. 2010, 2013). The Ruivo-1 well has a total depth of 2134 m, with sediments consisting mainly of sandstones and siltstones of Miocene age in the uppermost 659 m (based on calcareous nannofossils and foraminifera). The Corvina well cored a 2894-m-thick succession of Miocene to Upper Jurassic sediments (Oxfordian) of which the uppermost 1015 m were assigned to the Miocene–Oligocene interval (Chevron 1975; Challenger 1976).

Materials and Methods

All studied samples were prepared using standard palynological techniques. The Lower Tagus Basin samples were sieved with 15–125-μm mesh sieves. The residues were separated by density using $ZnCl_2$ solution. All samples and residues are curated in the collections of the CICEGe, Portugal. The Algarve Basin samples and residues studied were sieved with a 15-μm mesh sieve and the unused samples, residues, microscope slides, and figured specimens are curated in the collections of the LNEG (Portuguese Geological Survey), S. Mamede Infesta, Portugal.

Palynostratigraphy: Dinoflagellate Cyst Assemblages and Temporal Distribution

Lower Tagus Basin

A total of 111 samples were collected from the studied sections and in which 36,260 palynomorphs were identified. The number of samples studied and the abundance of dinoflagellate cysts occurrences allowed the first occurrences (FOs) and last occurrences (LOs) of key species to be identified, thereby ensuring a detailed stratigraphic analysis. Dinoflagellate cysts are common in the LTB and can be used as important biostratigraphic guides: (1) the LOs of the species *Lejeunecysta globosa*, *Spiniferites cruciformis*, *Achomosphaera ramulifera*, *Hystricosphaeropsis pontiana*, *Invertocysta lacrymosa*, and *Polysphaeridium zoharyi zoharyi* are common in the basal Tortonian; (2) species with restricted stratigraphic distribution include the following: *Exochosphaeridium insigne* (Middle Burdigalian); *Apteodinium spiridoides*, *Cribroperidinium giuseppei*, and *Barssi-dinium evangelineae* (Upper Burdigalian); *Distatodinium paradoxum* (Middle and Upper Burdigalian); *Selenopemphix brevispinosa conspícua* (Burdigalian–Langhian); *Lejeunecysta marieae* (middle Langhian); *Pentadinium laticinctum*, *Labyrintodinium truncatum modicum*, and *Cleistosphaeridium placacanthum* (Burdigalian–Serravallian); *Bitectatodinium tepikiense, Palaeocystodinium golzowense*, and *Habibacysta tectata* (Upper Burdigalian–Serravallian); *Spiniferites cruciformis, Hystrichosphaeropsis pontiana, Invertocysta lacrymosa, Achomosphaera grallaeformis, Selenopemphix dionaeacysta, and Labyrintodinium truncatum truncatum* (Upper Serravallian–Tortonian); and (3) Miocene assemblages are characterized by the presence of the following species: *Melitasphaeridium choanophorum, Tectatodinium pellitum, Selenopemphix brevis-pinosa brevispinosa, Batiacasphaera sphaerica*, and *Tuberculodinium vancampoae* assigned to the Middle Burdigalian to Tortonian; *Amiculosphaera umbraculum, Cordosphaeridium minimum, Hystrichosphaeropsis obscura*, and *Selenopemphix nephroides* assigned to the Upper Burdigalian to Tortonian; and *Polysphaeridium zoharyi zoharyi, Spiniferites mirabilis, Dapsilidium pseudocolligerum, Lejeunecysta lata, Lingulodinium machaerophorum,*

Cordosphaeridium cantharellus, Operculodinium centrocarpum, Spiniferites pseudofurcatus, Achomosphaera andalousiensis, Spiniferites membranaceus, and *Operculodinium israelianum* occurring through the entire Miocene Series (Castro 2006, 2008).

Algarve Basin

Five samples were studied from the Miocene succession of Ruivo-1 and Corvina wells. These samples yielded moderately well-preserved and relatively low-diversity dinoflagellate cysts. One sample (R1) was collected from the Miocene sediments of Ruivo-1. Dinoflagellate cysts recognised include *Cleistosphaeridium* spp., *Hystrichokolpoma rigaudiae, Hystrichokolpoma cinctum, Hystrichokolpoma* spp., *Hystrichosphaeropsis obscura*, and *Spiniferites* spp., an association consistent with a Miocene age. Four samples (Co1, Co2, Co3, and Co4) were studied from the Corvina well. The dinoflagellate cysts recorded include *Hystrichokolpoma rigaudiae, Hystrichosphaeropsis obscura, Hystrichosphaeropsis* spp., *Impagidinium patulum, Operculodinium* spp., and *Spiniferites* spp. This assemblage is of moderate diversity and confirms a Miocene age (Borges 2012; Fernandes et al. 2013).

Comparison of the Dinoflagellate Cyst Assemblages

The dinoflagellate cysts known from the LTB are compared with the assemblages recently recovered from the Algarve Basin. The following selected assemblages occur in both basins: *Hystrichokolpoma rigaudiae, Cleistosphaeridium* spp., *Hystrichokolpoma* spp., and *Hystrichosphaeropsis obscura* occur in the LTB in the Burdigalian–Langhian; and *Operculodinium* spp. and *Impagidinium* spp. are represented in the LTB in the Burdigalian–Serravallian. Species of these selected dinoflagellate cyst assemblages are distinctive of Miocene age, and are similar in both basins. However, the dinoflagellate cyst distribution in the basins reflects high provincialism related to palaeoenvironment and biogeography.

Final Remarks

The palynostratigraphy of the LTB is characterized by particularly abundant Miocene dinoflagellate assemblages that can be used as important biostratigraphic guides. In the Algarve Basin, the dinoflagellate assemblages recovered are less abundant and diverse. This could be explained by the partially enclosed nature of the Algarve Basin during the Cenozoic. New inferences have been made regarding

the new biostratigraphic data and ongoing palynological studies, highlighting the importance of refining and correlating the time calibration of the Miocene in Portugal.

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Palynostratigraphic Data
for the Buntsandstein and Muschelkalk
Facies from the Iberian Ranges (Spain)

**José B. Diez, Alfredo Arche, Jean Broutin, Sylvie Bourquin,
Raul De la Horra, Javier Ferrer, Soledad García-Gil
and José López-Gómez**

Abstract This work presents results of a compilation of all published palynological data as well as other unpublished data, on the basis of which a unified palynological biozonation is proposed for the Buntsandstein and Muschelkalk facies from the Iberian Ranges (Spain).

Keywords Palynostratigraphy · Permian · Triassic · Iberian ranges

In the study area, covering the Iberian Range (Aragonese and Castilian branches) and the Balearic Islands (Fig. 1), Upper Permian to Lower–Middle Triassic formations show two main facies: siliciclastic redbeds attributed to the Buntsandstein and calcareous facies attributed to the Muschelkalk.

The main characteristics of the Permian to Middle Triassic formations of the Castilian Branch are now well established, and a wealth of data has been published since the 1970s by the Stratigraphy Group of the University Complutense of

J. B. Diez (✉) · S. García-Gil
Departamento Geociencias Marinas y Ordenacio'n del Territorio, Universidad de Vigo,
Campus Lagoas-Marcosende, 36200 Vigo, Spain
e-mail: jbdiez@uvigo.es

A. Arche · R. De la Horra · J. López-Gómez
Instituto de Geociencias (CSIC, UCM), Antonio Naváis, 2, 28040 Madrid, Spain

J. Broutin
UMR 5143 du CNRS, Paléobiodiversité, systématique, évolution des embryophytes/
Laboratoire de paléobotanique et paléoécologie, Université Pierre-et-Marie-Curie, MNHN,
bâtiment de géologie, CP48, 57, rue Cuvier, 75231 Paris, cedex 05, France

S. Bourquin
UMR 6118 du CNRS, Géosciences Rennes, Bat. 15 – Université de Rennes 1, Campus de
Beaulieu, 35042 Rennes Cedex, France

J. Ferrer
Dpt. de Ciencias de la Tierra (Paleontología), Universidad de Zaragoza, C/Pedro Cerbuna,
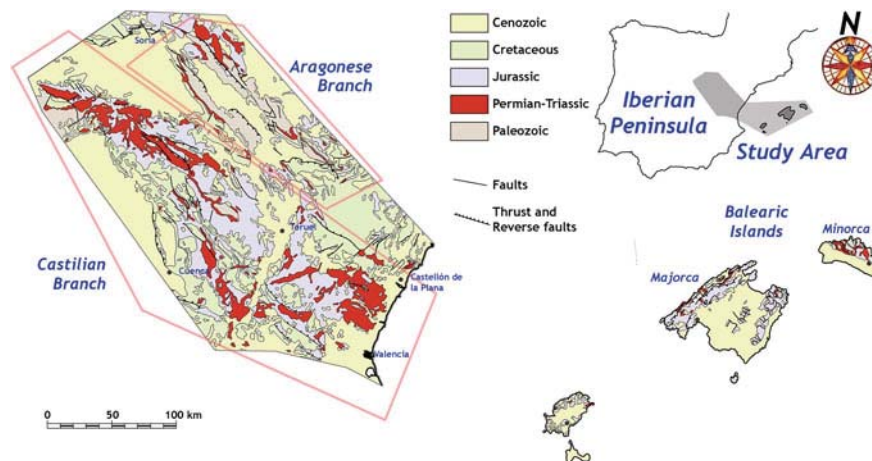12, 50009 Zaragoza, Spain

Fig. 1 Domains identified in the study area: the Aragonese (or Oriental) Branch, the Castilian (or Occidental) Branch, and the Balearic Islands

Madrid. That group has conducted many sedimentological and biostratigraphic investigations in this area (e.g., Arche et al. 2004; Arche and López-Gómez 2006) and has produced numerous associated studies including monographs, theses, and published articles. However, these studies proposed various diverse nomenclature systems.

For this time interval in the other two areas, some recent papers have been published for the Aragonese Branch (Diez 2000; Diez et al. 2007) and for the Balearic Islands (Linol et al. 2009; Bercovici et al. 2009) describing the sedimentological and stratigraphic contexts. However, a palynological assemblage for the study area for the Lower Triassic, similar to that presented in Diez et al. (2005, 2010), has not been reported.

The synthesis of the available palynological data examined herein provides a more accurate correlation of the lithostratigraphic formations (Fig. 2). This work could establish the necessary basis for terminological simplification as well as a better definition of sedimentary cycles for the Upper Permian–Middle Triassic deposits in the Iberian Ranges and Balearic Islands.

For the studied Permian formations, the current data do not allow a better biostratigraphic resolution to be achieved than the proposed Middle-Upper Permian ("Thuringian"). Conversely, Middle Triassic correlations are achieved with much more precision, to the definition of individual substages.
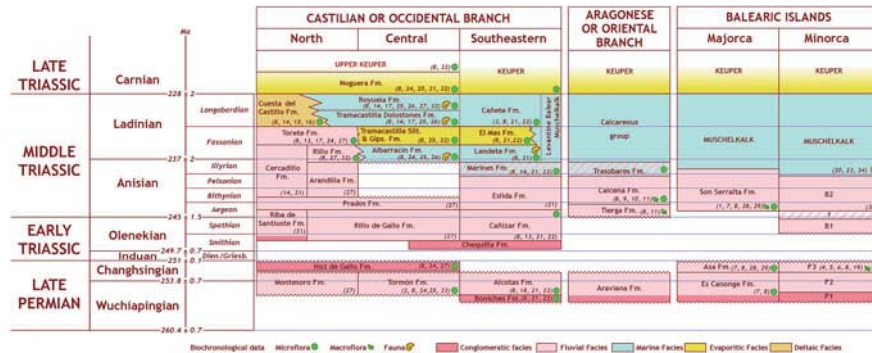
Fig. 2 Palynostratigraphic correlations: *(1)* Alvarez-Ramis et al. (1995), *(2)* Arche et al. (1983), *(3)* Arche et al. (1995), *(4)* Bercovici et al. (2009), *(5)* Bourrouilh (1973), *(6)* Broutin et al. (1992), *(7)* Calafat Colom (1988), *(8)* Diez (2000), *(9)* Diez et al. (1996), *(10)* Diez et al. (2005), (11) Diez et al. (2007), *(12)* Dinares et al. (2005), *(13)* Doubinger et al. (1990), *(14)* García-Gil (1984), *(15)* García-Gil (1990), *(16)* García-Gil and Diez (work in progress), *(17)* García-Royo et al. (1989), *(18)* De la Horra (2008), *(19)* Linol et al. (2009), *(20)* Llompart et al. (1987), *(21)* López-Gómez and Arche (1992), *(22)* López-Gómez and Arche (1994), *(23)* March (1991), *(24)* Pérez-Arlucea (1986), *(25)* Pérez-Arlucea and Sopeña (1985), *(26)* Pérez-Arlucea and Trifonova (1993), *(27)* Ramos (1979), *(28)* Ramos (1995), *(29)* Ramos and Doubinger (1989), *(30)* Rosell et al. (1987), *(31)* Sopeña (1979), *(32)* Sopeña et al. (1995), *(33)* Temiño (1982), *(34)* Vachard and Colin (1994). For an extensive bibliography, see Diez et al. (2005, 2010)

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New Sedimentological and Palynological Data for the Permian and Triassic of the Paris Basin, France

José B. Diez, Sylvie Bourquin, Laurent Beccaletto and Eric Lasseur

Abstract The aim of this study is to define the depositional environment of the Permian succession within the southwestern part of the Paris Basin, using core, well-log, and seismic data. A detailed palynological study allows the palynological evolution of the Middle–Upper Triassic succession in the Paris Basin to be precisely specified.

Keywords Palynostratigraphy · Sedimentology · Permian · Triassic · Paris Basin

In the Paris Basin, several isolated Permian basins identified only in the subsurface are described by Mégnien (1980), Mascle (1990), Perrodon and Zabeck (1990), and Autran et al. (1994). However, the lack of core data has not allowed a precise description of the depositional environment to be made, or dating of the subsurface Permian deposits to be performed. In the northern part of France (the Vosges Massif), only the uppermost Permian is present, dated from pollens and characterized by fluvial and shallow lake deposits (Durand et al. 1994). These deposits grade laterally to the east to the shallow-marine, evaporitic Zechstein facies of the Germanic Basin (Bourquin et al. 2011).

J. B. Diez (✉)
Departamento Geociencias Marinas y Ordenación del Territorio, Universidad de Vigo, Campus Lagoas-Marcosende, 36200 Vigo (Pontevedra), Spain
e-mail: jbdiez@uvigo.es

S. Bourquin
Géosciences Rennes, UMR CNRS 6118, Université de Rennes 1, Campus de Beaulieu, 35042 Rennes Cedex, France
e-mail: sylvie.bourquin@univ-rennes1.fr

L. Beccaletto · E. Lasseur
BRGM, Georesources Division, 3 av. Claude Guillemin, 45060 Orléans Cedex 2, France
e-mail: l.beccaletto@brgm.fr
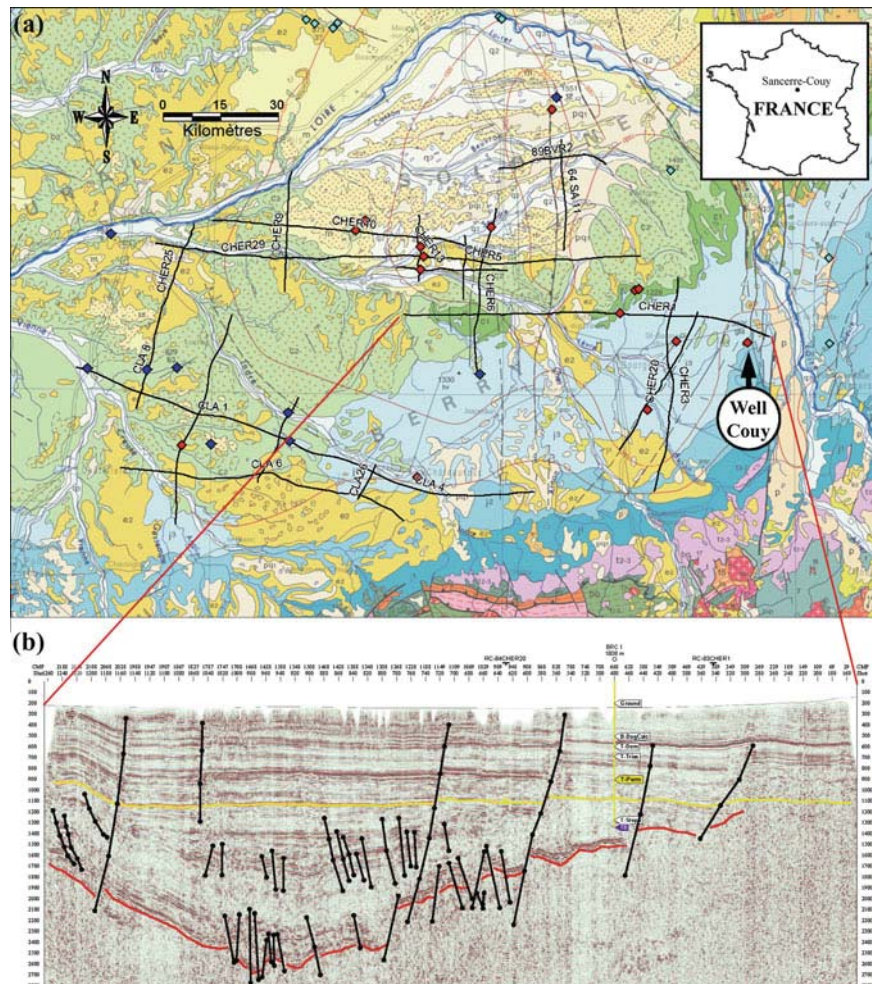
E. Lasseur
e-mail: e.lasseur@brgm.fr

Fig. 1 **a** Location of the Couy well; **b** Seismic profile 83CHER3 (Beccaletto et al. 2012)

A pre-Triassic unconformity is clearly observed on the southwestern edge of the Germanic Basin (i.e., the Paris Basin), which is associated with a progressive onlap of the Triassic succession onto the Palaeozoic basement (Bourquin et al. 2006). An angular unconformity separates Permian from Triassic deposits in the western part of the Germanic Basin.

During the Triassic, the Paris Basin formed the western extremity of the Germanic Basin. The Paris Basin only existed as an independent basin from the Late Triassic (middle Carnian) onwards (Bourquin and Guillocheau 1993, 1996). The Triassic evolution of the Paris Basin is well known from numerous studies based on sequence-stratigraphic correlations from well-log, core, and outcrop data

(e.g., Bourquin et al. 2002, 2006). However, the age of the succession, as determined from biostratigraphic data, is very poorly constrained, and age data are located mainly in the eastern part of the basin from outcrops.

Orszag-Sperber et al. (1992) conducted an early study based on core data from the Couy Well located in the southwest of the Paris Basin (Fig. 1a). We have made a recent study of this well by investigating core samples within Permian and Triassic successions, which has allowed us to specify the depositional environment of the Permian sequences and to better constrain the ages of the Triassic deposits. From this well, the aims of our study are: (1) to define the evolution in depositional environments as inferred from vertical changes in the succession of the Couy well, and to make correlations in the southwestern part of the Paris Basin using seismic and well-log data (Fig. 1b); and (2) to characterize in a precise way the palynological evolution of the Triassic succession in the Paris Basin based on the resampling and reanalysis of sequences attributed to the Permian, Triassic, and Lower Jurassic. A total of 54 palynological analyses were performed and 29 levels were identified; however, none is dated to the Permian. However, a large amount of new palynological data is described for the Ladinian, Carnian, and Rhaetian–Hettangian stages. These new data confirm the dating previously proposed (Courel et al. 1990; Adloff et al. 1992; Lorenz 1992) but at a higher level of precision.

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