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Posidonia becheri Bronn, 1828 from the Tournaisian of SE Turkey: A palaeobiogeographic enigma

Posidonia becheri Bronn, 1828, du Tournaisien du Sud-Est de la Turquie

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ABSTRACT

The posidoniform bivalve species *Posidonia becheri* Bronn, 1828, has been identified for the first time in the Lower Carboniferous (Tournaisian) sandy limestone-dark grey shale deposits of Hakkari Province, south-eastern Turkey. Palaeogeographically, this area was located at the northern tip of the Gondwanan Arabian Palaeozoic platform at the southern Palaeotethyan margin during the Carboniferous. The closest localities to this new occurrence are the Lower Carboniferous of northern England, Germany (Kulm Basin), Poland (Walbrzych Basin), Northwest Belgium, Spain (Cantabrian Mountains), Portugal, and Northwest Turkey (Zonguldak Basin). All these locations are considered parts of the Avalonian or Perigondwanan terranes, and were located NW of the Palaeotethys. Hence, our new finding from the SE Palaeotethyan margin, together with the data from Morocco, indicates that this posidoniid bivalve had probably been transported by oceanic currents in its larval stage to lower palaeolatitudes (about 50° S) within the Palaeotethyan Ocean during the Early Carboniferous, or alternatively, the northern Arabian platform margin was located in lower latitudes than previously suggested.

Mots clés :
Bivalvia
Posidonia becheri
Carbonifère précoce
SE Turquie
Nord Gondwana

RÉSUMÉ

L'espèce bivalve posidoniforme *Posidonia becheri* Bronn, 1828 a été déterminée pour la première fois dans les dépôts de calcaire sableux et d'argilite gris foncé du Carbonifère inférieur (Tournaisien) de la Province d'Hakkari, Sud-Est de la Turquie. Du point de vue paléogéographique, cette zone était localisée à l'extrémité nord de la plate-forme arabique paléozoïque du Gondwana, à la marge sud de la Paléotéthys, au cours du Carbonifère. Les localités les plus proches de cette occurrence sont le Carbonifère inférieur du Nord de l'Angleterre, l'Allemagne (Bassin du Culm), la Pologne (Bassin de Walbrzych), le Nord-Ouest de la Belgique, l'Espagne (Monts cantabriques), le Portugal et le Nord-Ouest de la Turquie (Bassin de Zonguldak). Toutes ces localisations sont considérées comme des parties des formations avaloniennes ou périgondwaniennes et se trouvent dans le Nord-Ouest de la Paléotéthys. En conséquence, notre découverte à la marge sud-est de la Paléotéthys, ainsi que les données en provenance du Maroc indiquent que ce bivalve posidonoïde a probablement été transporté dans son état larvaire par des courants océaniques jusqu'à des paléolatitudes plus basses (aux environs de 50° S) dans l'Océan paléotéthysien au cours du

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Carbonifère précoce ou, à titre d'alternatives, que la marge nord de la plate-forme arabique était alors localisée sous des latitudes plus basses que celles suggérées jusqu'alors.

1. Introduction

Studies of Carboniferous bivalves in NW Anatolia were conducted in the late 1970s (Dil and Konyalı, 1978), but no such fossils have yet been described from SE Turkey. The most recent record of Late Visean-Early Namurian bivalves is from the Zonguldak Basin in NW Turkey (Fig. 1) (Okan and Hoşgör, 2007), where a few myalinids (*Septimyalina sublamellosa*, *Septimyalina lamellosa* and *Septimyalina minor*) and a single posidoniid species (*Posidonia becheri*) were reported (Okan and Hoşgör, 2007).

Posidoniid bivalves are common fossils in shallow marine deposits, especially in shales and sandstones from the Early Carboniferous onwards. The Tournaisian-Early Namurian (Kulm Facies) bivalve *Posidonia* has been a subject of investigation due to its stratigraphic and systematic importance (Amler, 2004). The present paper reports a new record of a posidoniform bivalve from the Carboniferous sediments of SE Anatolia of the Zap River Section, Hakkari Province (Fig. 1). The faunal succession is within the Border Fold Zone (Ketin, 1966) of SE Turkey that represents the northern edge of the Arabian Plate during the Palaeozoic. The outcrops in this area are still poorly known palaeontologically, because accessibility is difficult. Hence, this work is a preliminary study of the Lower Carboniferous in the Hakkari province.

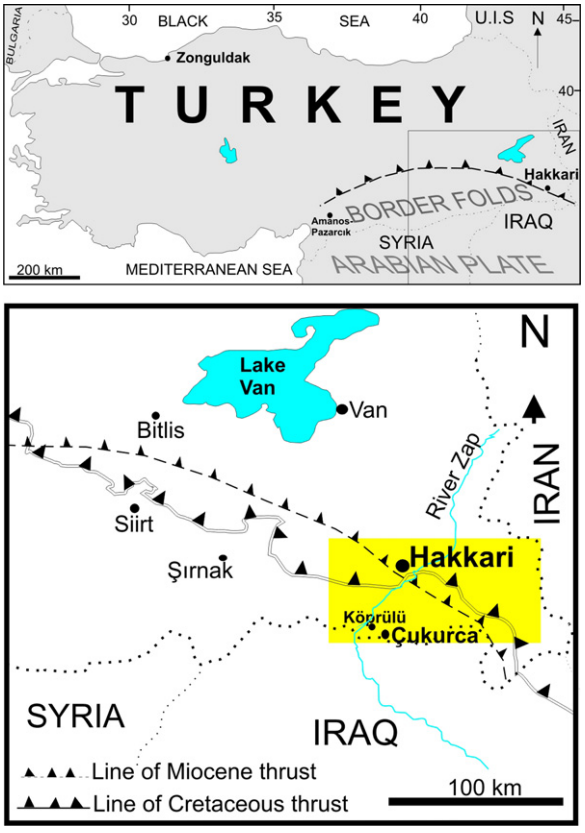

Fig. 1. Sketch map of southeastern Turkey showing main localities mentioned in the text.
Fig. 1. Carte schématique du Sud-Est de la Turquie montrant les principales localités mentionnées dans le texte.

The aim of this article is to present the first occurrence from the Lower Carboniferous rocks of this region and correlate the data with the well-established biostratigraphy of Europe. *P. becheri*, the only bivalve species in this formation, occurs with cephalopod remains in dark shales. Apart from the authors' samples described in this paper, some new material was recently found by private collectors and donated to the Palaeontology Collection of the University of Ankara, Turkey and included in this study.

2. Geological framework and stratigraphy

The study area is located in south-eastern Anatolia, along the northern margin of the Arabian plate of Gondwana. The limited geological work on this area was conducted during the field-mapping projects of the Turkish Petroleum Company (Günay, 1990; Perinçek, 1980; Perinçek et al., 1991). The marine and non-marine Palaeozoic strata in this area mainly consist of sandstones, dark grey shales and limestones. Well-developed Upper Devonian-Early Carboniferous successions outcrop in the Çukurca anticline and Amanos-Pazarcık areas. In the core and flanks of the Çukurca anticline (Fig. 2), the Zap Group with Famennian-Tournaisian sandstone-dolomite alternation, dark grey shale and limestone were reported in earlier studies (Cater and Tunbridge, 1992; Perinçek et al., 1991). The Zap Group comprises the Upper Devonian (Famennian) Yığınlı and the Upper Devonian-Lower Carboniferous Köprülü formations.

The Yığınlı Formation is represented by red clastics with some dolomites at the top; it unconformably overlies the Cambro-Ordovician rock-units (Dean et al., 1981). It is conformably overlain by the Köprülü Formation with variable marine sediments, changing from restricted to deeper muddy shale environment and finally to restricted shelf conditions in the upper part of the succession (Cater and Tunbridge, 1992; Higgs et al., 2002; Janvier et al., 1984; Tunbridge, 1988). The formation is unconformably overlain by the Permian Harbol Limestone (Higgs et al., 2002).

3. Köprülü formation

The studied samples come from a dark grey shale horizon in the Köprülü Formation from the Zap Valley, near Hakkari. The Köprülü Formation was measured and investigated along the Zap 1 and Zap 2 (Fig. 2) sections during three field trips. The measured sections of the Köprülü Formation are located on the north-east of Köprülü village, 8 km north-west of Çukurca. Based on the field observa-

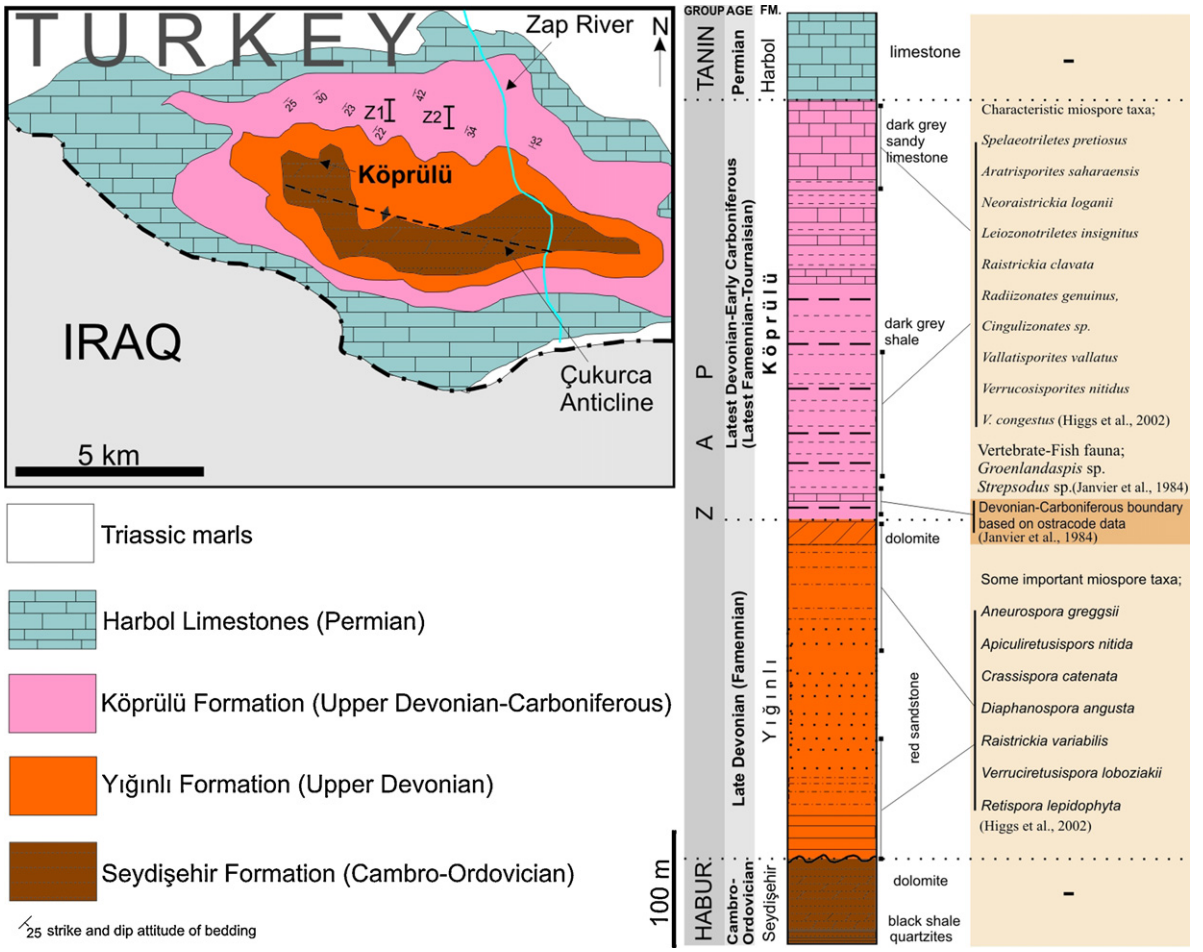

Fig. 2. Geological map of the Zap Valley with the location of the measured section and generalized columnar section of the Cambrian-Permian rock-units of the study area (Higgs et al., 2002; Janvier et al., 1984).
Fig. 2. Carte géologique de la vallée du Zap avec la localisation de la coupe et la colonne généralisée des unités rocheuses Cambrien-Permien de la zone étudiée (Higgs et al., 2002 ; Janvier et al., 1984).

tions of the studied succession, the Köprülü Formation can be subdivided into three informal members (Fig. 3).

The thickness of the lower member is 5 m and 7 m at Zap 1 and Zap 2 sections, respectively. The basal parts of the lower member at Zap 1 and Zap 2 represent transgressive carbonates throughout the area and consist of hard, dark grey to light pink limestones and sandy limestones.

The middle member's thickness decreases southward, from 7 m at Zap 1 to 5 m at Zap 2. The succession in the middle member is represented by an alternation of thinly-laminated dark grey calcareous shales and siltstones. The upper part of this middle member is characterized by carbonate concretions embedded in sandy limestone. The fossils, including bivalves and cephalopod remains (Fig. 4C), are well preserved in this member. *P. becheri* has been observed in dark grey shale horizons. The characteristic miospore taxa in these horizons include *Spelaeotriletes pretiosus, Aratrisporites saharaensis, Neoraistrickia loganii, Leiozonotriletes insignitus, Raistrickia clavata, Radiizonates genuinus, Cingulizonates* sp., *Vallatisporites vallatus, Verrucosisporites nitidus, V. congestus* (Higgs et al., 2002). The *Spelaeotriletes pretiosus-Aratrisporites saharaensis* assemblage is tentatively correlated with the Middle-Late Tournaisian *Spelaeotriletes pretiosus-Raistrickia clavata* (PC) miospore biozone of western Europe (Higgs et al., 2002).

The upper member consists mainly of limestones and dark grey shales. The limestones are grey to dark grey and massive. They contain variable amounts of sand size quartz grains to form sandy limestones that are locally replaced by dolomitic sequences (e.g. Fig. 3, Zap 2 section). This member thickness of 7 m at Zap 1 and 8 m at Zap 2 sections.

4. Systematic palaeontology

The systematic arrangement of higher taxa largely follows the scheme proposed by (Amler, 1999). The studied samples are from 081-1, 081-2, 082-3 and deposited in the Palaeontological Collection of Ankara University by archive Nr: AU 08.01, AU 08.02, AU 08.03.

Class: BIVALVIA Linné, 1758

Subclass: PTERIOMORPHIA Beurlen, 1944

Superorder: EUPTERIOMORPHIA Boss, 1892 (Anisomyaria Neumayr, 1883)

Order: PTERIOIDEA Newell, 1965

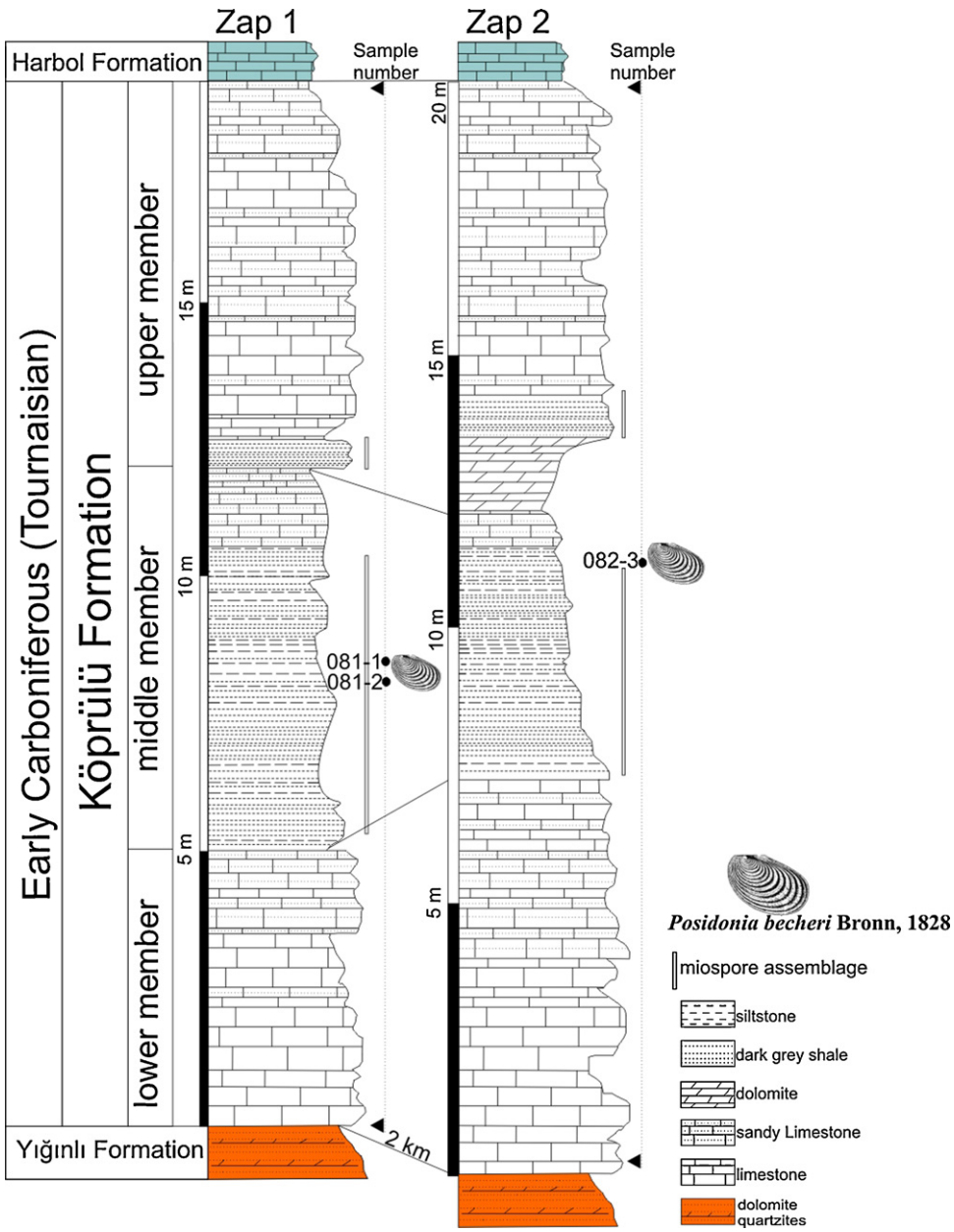

Fig. 3. Correlation of the Lower Carboniferous (Tournaisian) Köprülü Formation for the two sections studied, southeastern Turkey, Hakkari and miospore assemblage sequences for these sections (Higgs et al., 2002).
Fig. 3. Corrélation entre les deux coupes étudiées dans la formation Köprülü du Carbonifère inférieur (Tournaisien), Hakkari, Sud de la Turquie et séquences d'assemblages de miospores pour ces deux coupes (Higgs et al., 2002).

Suborder: PTERIINA Newell, 1965
Superfamily: PTERIOIDEA Gray (1820), 1847
Family: POSIDONIIDAE Frech, 1909
Genus ***Posidonia*** Bronn, 1828

Type Species. *Posidonia becheri* Bronn, 1828.
Posidonia becheri Bronn, 1828
Fig. 4A–C
1828 *Posidonia becheri* Bronn, p. 262, pl. 2.
1854 *Posidonia becheri* Bronn, Roemer, p. 91, pl. 13, fig. 21.
1876 *Posidonomya becheri* Bronn, Roemer, p. 38, fig. 2.
1879 *Posidonomya becheri* Bronn, Koenen, p. 334, pl. 6, fig. 8.
1901 *Posidonomya* cf. *becheri* Bronn, Hind, p. 27, pl. 6, fig. 11–15.
1922 *Posidonomya becheri* Bronn, Weigelt, p. 118, pl. 22–31, fig. 43.
1924 *Posidonia becheri* Bronn, Schmidt, p. 43, pl. 11, fig. 1–2.
1930 *Posidonomya becheri* Bronn, Patteisky, p. 216, pl. 17, fig. 1–2.

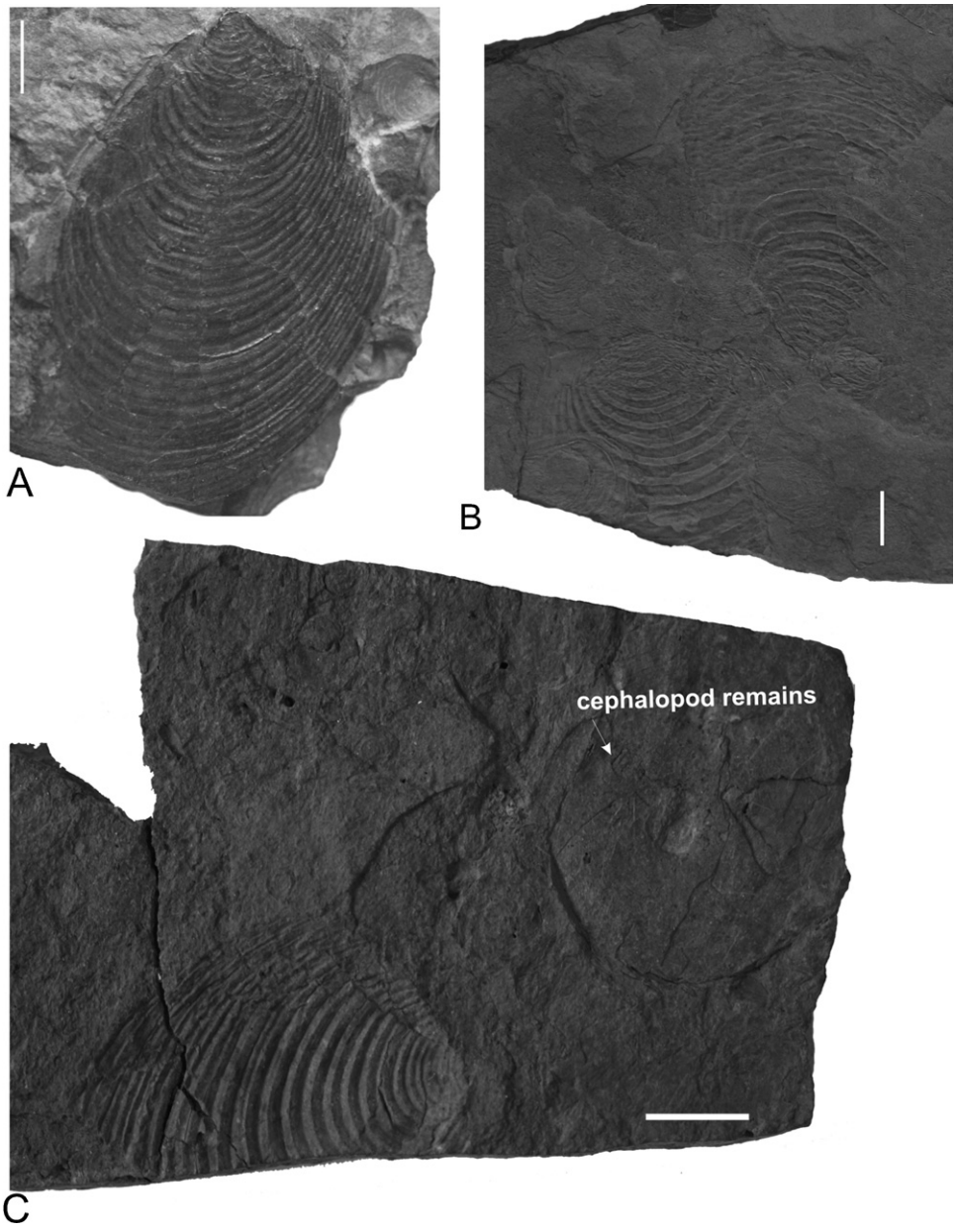

Fig. 4. *Posidonia becheri*, external views, from the Zap 1 and Zap 2 sections in the Hakkari Province (Köprülü Formation). (**A**) Locality: Zap 1, middle member HK 081-2 AU 08.02; (**B**) Locality: Zap 2, middle member HK 082-3 AU 08.03, (**C**) *P. becheri* and cephalopod remains, Locality: Zap 1, middle member HK 081-1 AU 08.01; (Scale bars 10 mm).

Fig. 4. *Posidonia becheri*, vues externes, en provenance des coupes Zap 1 et Zap 2 dans la province d'Hakkari (Formation Köprülü). (**A**) Localité : Zap 1, membre moyen HK081-2 AU 08.02 ; (**B**) Localité : Zap 2, membre moyen HK 082-3 AU 08.03 ; (**C**) *P. becheri* et restes de céphalopodes, Localité : Zap 1, membre moyen HK 081-1 AU 08.01 ; (barres d'échelle : 10 mm).

1938 *Posidonomya becheri* Bronn, Demanet, p. 111, pl. 10, fig. 1–4.

1941 *Posidonia becheri* Bronn, Paul, p. 175.

1958 *Posidonia becheri* Bronn, Zakowa, pl. 6, fig. 9.

1963 *Posidonia becheri* Bronn, Nicolaus, p. 190, pl. 13, fig. 4.

1999 *Posidonia* cf. *becheri* Bronn, Amler and Winkler Prins, p. 24, pl. 5, fig. 8–9.

2004 *Posidonia becheri* Bronn, Amler, p. 199, text-fig. 3–4.

2007 *Posidonia becheri* Bronn, Okan and Hoşgör, p. 231–232, pl. 1, fig. 9.

Figured specimens. AU 08.01; AU 08.02; AU 08.03.

Horizons and localities. Zap Valley, Köprülü Village, Turkey, Zap 1 (081-1; 081-2) and Zap 2 (082-3) sections middle member.

4.1. Description

The shell is medium to large (maximum height: 50 mm; maximum length: 58 mm), valves slightly subcircular in outline (height to length ratio average: 0.91), thin, equilateral and equivalved. Beak at the anterior margin; small, slightly pointed, articulated specimens often flat, nummular. The outer surface is characterized by obscure concentric striae lying among numerous coarsely prominent concentric lirae, regular to irregular. Ligament and interior morphology is not observed here.

4.2. Discussion

The superfamily Posidonioidea is limited to one family (Posidoniidae) that is worldwide in occurrence and has a stratigraphic range from Lower Carboniferous to Upper Jurassic. As currently constructed, three genera are included in the Posidoniidae: *Posidonia* (Late Palaeozoic), *Bositra* (Triassic and Jurassic), and *Lentilla* Conti and Monari, 1992 (Jurassic). *Posidonia* is regarded as the stem group of the superfamily Posidonioidea. Its duplivincular ligament system, bimineralic prismato-nacreous shell, and anisomyarian adductor musculature (Waller and Stanley, 2005; Webb, 2002) are all plesiomorphic characters, probably inherited from a pterineid ancestor such as the Early Carboniferous genus *Caneyella* (McRoberts, 2000; Waller and Stanley, 2005).

Although variable, the nummular shape, prosoponal relief and deep concentric striae of this species are distinctive. Specimens here show very thin remnants of the shell. Such fragile shells would have had little resistance to postdepositional compaction. Hinge, ligament and internal characters are lacking and poorly known elsewhere. *Posidonia corrugata* (Etheridge) (Nicolaus, 1963; p. 192, pl. 13, fig. 6), is a similar species described from the Visean of the Kulm Basin. The size, the distinct, slightly subcircular outline, deep concentric lirae and nature of the ornamentation are characteristic for this species. *P. becheri* most closely resembles *Posidonia kochi* (Koenen, 1879) (Amler, 2004; text-figures. 20–21), known from central Europe (Amler, 2004). *P. becheri* differs from *P. kochi* in that *P. becheri* is slightly subcircular.

5. Palaeogeographical implications

Posidoniform bivalves are important pseudoplanktonic forms throughout the Carboniferous period, and the faunal provinces defined for the Carboniferous have been used for palaeogeographic interpretations (Amler, 2009; Okan and Hoşgör, 2007). *P. becheri* from this group is a biostratigraphically important taxon in the Kulm Facies of the Lower Carboniferous (Mississippian) in the western and central European terranes. Our Hakkari specimens were assigned to the Middle-Late Tournaisian, based on miospores from the same horizons. The occurrence of this bivalve is used (Amler, 2004) to subdivide the Upper Devonian to Mississippian sequence into several zones.

The distribution of the Kulm Facies with its distinct litho- and biofacies is limited to West, central and eastern European terranes (Korn and Kaufmann, 2009). In these regions, ammonoids (goniatites) and posidoniid bivalves are the best index fossils that allowed the development of a very detailed stratigraphic scheme (Amler, 2004; Bronn, 1828; Demanet, 1938; Koenen, 1879; Korn and Horn, 1997; Nicolaus, 1963). Some Early Carboniferous bivalve taxa (e.g. *P. becheri, P. kochi, P. corrugata, P. trapezoedra, P. membranacea, Dunbarella mosensis, D. yatesae, D. carbonaria, Ptychopteria (Actinopteria) sulcata, P. (A.) lepida, Streblochondria praetenuis, Chaenocardiola haliotoidea, Euchondria losseni*) have also been used for palaeogeographic, palaeobiogeographic and palaeoclimatological purposes, mainly in Europe (Amler, 2004; Amler and Winkler Prins, 1999; Rathmann and Amler, 1992).

The distribution of *P. becheri* was restricted to the Early Carboniferous of South China (Renjie and Daoping, 1993), NW Belgium (Demanet, 1938), North England (Hind, 1901), Germany (Kulm Basin) (Amler, 2004; Koenen, 1879; Nicolaus, 1963; Paul, 1939, 1941; Roemer, 1854), Poland (Walbrzych Basin) (Nicolaus, 1963; Zakowa, 1958), Portugal (Roemer, 1876), Spain (Cantabrian Mountains) (Amler and Winkler Prins, 1999), and NW Turkey (Zonguldak Basin) (Okan and Hoşgör, 2007) and is regarded as a good indicator for tropical and sub-tropical climatic conditions (Fig. 5). All of these localities are considered Peri-Gondwanan and/or Avalonian terranes that were rifted off the NW Gondwanan margin and collided with Baltica by the closure of the Rheic Ocean (e.g. Göncüoğlu and Kozlu, 2000; Nance and Thomson, 1996; Sobhy and Ezaki, 2006). During the Late Devonian-Early Carboniferous, these terranes were located to the North of Palaeotethys (Fig. 6) and the northern shelf of the Palaeotethys covered vast areas in central Europe. The Istanbul-Zonguldak terrane assemblage (Göncüoğlu, 2001) including the Zonguldak Basin was attached to the central and SE European terrane assemblages (e.g. Saxo-Thuringian, Balkan etc.). The SE Anatolian terrane, on the other hand, was located southeast of the former and attached to Arabia (Bozdogan et al., 1996; Göncüoğlu, 1997; Göncüoğlu et al., 2007). Based on these data, together with a single finding from Morocco (Huvelin, 1961, 1977) our specimens from SE Turkey are the only occurrences from the northern platform of Gondwana at the southern Palaeotethyan margin, as shown in Fig. 6 (Sobhy and Ezaki, 2006; Torsvik and Cocks, 2004; Webb, 2002).

Considering the palaeogeographic reconstructions (Fig. 6), the locations of SE Anatolia and Morocco during the Middle-Late Tournaisian (Early Carboniferous) times were around 40–50° southern latitude. All the other localities with *P. becheri*, on the other hand, were located at latitudes lower than 20°, and mainly concentrated at the western margins of the Palaeotethys. This is also supported by the distribution of the Lower Carboniferous heterocorals (Sobhy and Ezaki, 2006). Based on this information, our new specimens of *P. becheri* in the Hakkari area, SE Turkey, should be regarded as the southernmost record of *P. becheri* in the circum-Palaeotethys region.

There are two possible consequences of this new occurrence: either the life habit of this bivalve was not restricted to tropical and sub-tropical climatic conditions, but was more flexible than previously believed (Okan and Hoşgör, 2005, 2007), or the palaeogeographical setting of SE Turkey, together with North Arabia, was at still lower latitudes

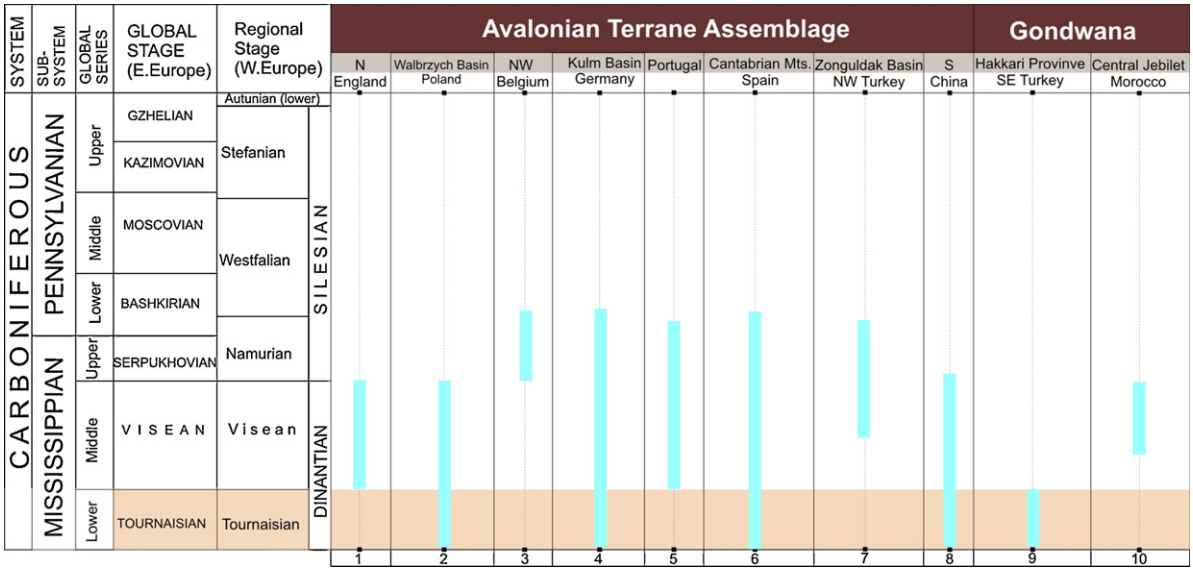

Fig. 5. Occurrences of *Posidonia becheri* Bronn, 1828 on the Palaeotethyan platforms during the Carboniferous. The primary data sources are: 1. Hind, 1901, 2. Nicolaus, 1963; Zakowa, 1958, 3. Demanet, 1938, 4. Amler, 2004; Koenen, 1879; Nicolaus, 1963; Paul, 1939, 1941; Roemer, 1854, 5. Roemer, 1876, 6. Amler and Winkler Prins, 1999, 7. Okan and Hoşgör, 2007, 8. Renjie and Daoping, 1993, 9. This study, 10. Huvelin, 1961, 1977.
Fig. 5. Occurrences de *Posidonia becheri*, Bronn, 1828 sur les plates-formes paléo-téthysiennes au cours du Carbonifère.

Fig. 6. Palaeogeographic reconstruction map of the Early Carboniferous and main Early Carboniferous basins of the Palaeotethys (Sobhy and Ezaki, 2006; Webb, 2002) and location of the SE Turkey (Hakkari Province).
Fig. 6. Carte de reconstitution paléogéographique du Carbonifère précoce et principaux bassins du Carbonifère précoce de la Paléotéthys (Sobhy et Ezaki, 2006 ; Webb, 2002) et localisation du Sud-Est de la Turquie (province d'Hakkari).

than suggested in several reconstructions (Sobhy and Ezaki, 2006; Webb, 2002). This second possibility necessitates a pseudoplanktonic mode of life of posidoniforms, which is the most widely encountered interpretation (Jefferies and Minton, 1965; Wignall and Simms, 1990). It further concerns the distribution of a palaeo-current system during the Tournaisian, on which there are almost no data from the NE African realm.

New findings of Kulm-type deposits with *P. becheri* in the northern Gondwanan realm coupled with detailed work on other palaeobiogeographically coeval reliable fossil groups may develop to have a more clear-cut answer to this problem.

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