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First report of myalinid bivalves in the Lower Carboniferous of the Hakkari Basin, SE Turkey: paleoecologic and paleogeographic implications

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Abstract: Knowledge of the Late Paleozoic sedimentary history of the northern Gondwana shelf is advanced by new data from the Şort Dere section (Hakkari Basin). Early Carboniferous myalinid bivalves from the Middle East are reported here for the first time. The pre-Permian basement of the Hakkari Basin consists of a Lower Carboniferous sedimentary sequence including the Köprülü and Belek formations. The Köprülü Formation has yielded rich assemblages of vertebrates and invertebrates. Hitherto myalinid bivalves were unknown from this formation; this paper reports the discovery of small and poorly calcified myaliniform shells from two thin beds in the middle part of the Köprülü Formation of the Şort Dere section in the Zap Valley. The morphological characteristics of the specimens, especially the umbonal region with the numerous rounded wrinkles, suggest that it probably belongs to an undescribed species of *Selenimyalina* Newell, 1942. Based on this record, the state of the art of warm-water myalinid taxa in the Paleotethyan Realm is shortly discussed with a focus on the pteriomorph bivalve faunas within a global scenario for both paleobiogeography and patterns of Gondwana-Laurussia faunal exchange. The new occurrence is one of the most important pteriomorph bivalve records ever made in Southeast Turkey, helping to assist paleogeographic reconstructions of the Paleotethyan paleocontinents.

Key words: Lower Mississippian, Köprülü Formation, Kulm Facies, Gondwana shelf, Paleotethys, *Selenimyalina*

1. Introduction

Invertebrates have been abundantly used to reconstruct ancient paleoenvironments from Carboniferous strata of Paleotethyan shelves, encompassing marine shelf through to nonmarine, coal-bearing strata (e.g., Melville, 1947; Semertzidis, 1976; Amler, 2004; Huwe, 2006; Denayer and Hoşgör, 2014; Denayer, 2015). With the beginning of geological and stratigraphical research in Western Europe in the early 19th century, the Carboniferous Limestone represents the shallow-water platform facies and was first identified in the British Isles and southern Belgium. The Kulm is the equivalent of the deeper water, basinal facies of the German Rhenohercynian Basin. Both names are still widely in use and especially the Kulm has been exported outside its regional and stratigraphical context (Aretz, 2016). Knowledge of the European Mississippian bivalves increased during the last decades (e.g., Amler, 1987; 1995; 1999; 2004; Rathmann and Amler, 1992; Amler and Winkler Prins, 1999; Amler and Schöllmann, 2012) because some of the material collected since the early 19th century has been revised. Additional data on the Carboniferous bivalves from North America, Mexico, Patagonia, western Argentina, Brazil, China, Morocco and Libya were provided by, e.g., Huvelin (1961), Hoare et al. (1989), Renjie and Daoping (1993), Quiroz-Barroso and Perrilliat (1998), Mergl et al. (2001), González (1994, 2010), González and Waterhouse (2004, 2012), Pagani (2006) and Anelli et al. (2006).

Thick and almost complete Carboniferous sequences are represented at different locations of distinctive geological settings in Turkey (e.g., Hoşgör et al., 2014; Atakul-Özdemir et al., 2017). Carboniferous marine deposits with macrofossils including posidoniid and myalinid bivalves are known in two areas: the Kokaksu Valley (Zonguldak Coal Basin, NW Turkey) (Okan and Hoşgör, 2007), and the less extensive Zap Valley (Hakkari, SE Turkey) (Hoşgör et al., 2012; Hoşgör and Okan, 2012) (Figure 1a). In the Zonguldak Basin, a few myalinids (*Septimyalina sublamellosa, S. lamellosa* and *S. minor*) and a single posidoniid species (*Posidonia becheri*) were reported from the upper Viséan-lower Namurian (Okan and Hoşgör, 2007). In the Zap Valley, posidoniid bivalves are rare in the Tournaisian-Viséan sediments (Hoşgör et al., 2012).

The Hakkari area constitutes the regional unit of southeastern Turkey that belongs to the northern part

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of the Arabian Plate (Figure 1a). During the early stages of the studies in the 2010s, the main objective was the determination the age of the mixed carbonate-siliciclastic strata sandwiched between Permian and Precambrian rocks (Hoşgör et al., 2014). The age of these, mostly paleontological barren, sedimentary rocks has been variably defined from Precambrian to Permian. Hitherto, only Late Devonian-Mississippian microfloras, ostracods and fish remains were previously reported from the Hakkari province (Janvier et al., 1984; Alişan, 1990; Higgs et al., 2002). Recently, abundant but poorly diversified rugose corals (small nondissepimented and dissepimented solitary corals), a juvenile eucladid crinoid and a single posidoniid species (*Posidonia becheri*) were described from the Zap Valley in the Hakkari area (Hoşgör et al., 2012; Denayer and Hoşgör, 2014; Ausich and Göncüoğlu, 2020).

This discovery provides additional information and extends the known paleogeographical distribution of myalinid bivalves in the Gondwana-Laurussia regions. The paper aims to analyze the Early Carboniferous myalinid bivalve record from the Hakkari Basin (Figure 1a), southeastern Turkey and to correlate it with the central and eastern European Kulm realms.

2. Geological and stratigraphical setting

The distribution of the Paleozoic deposits in southeastern Turkey indicates that the Mardin High extended in a northwest-southeast direction (Figure 1a). This high separated two basins in the platform: the Diyarbakır Basin in the east and the Akçakale Basin in the west. The Hakkari Basin was separated from the Diyarbakır Basin by another high formed in the Siirt area and active from the Devonian to the end of the Permian (Bozdoğan et al., 1987; Bozdoğan and Erten, 1990). In southern Hakkari, the late Devonian to early Carboniferous strata of the upper Yığınlı, Köprülü and Belek formations (Figure 1b) represent a several hundred kilometres wide mixed carbonate-siliciclastic ramp along a passive continental margin (Janvier et al., 1984; Perinçek, 1990; Hoşgör et al., 2014). During the early Carboniferous, the ramp evolved into a platform. Mixed fluvial-marine depositional environments are suggested for the lower part of the Yığınlı Formation (Givetian?). Shallow-marine conditions prevailed during the deposition of the Upper Yığınlı and Köprülü formations as indicated from the dominant shale lithology with common brachiopods and corals (Gourvennec and Hoşgör, 2012; Denayer and Hoşgör, 2014). Concomitantly, the carbonate content increases, the type of the bedding changes from plain to wavy, the colors of the sediments in general get lighter and shallow-water faunas become more frequent.

The Şort Dere section (Figure 1c) was described by Hoşgör et al. (2012) and Denayer and Hoşgör (2014). At the base of the sequence, mudstones are followed by a layer, only 10 to 30 cm thick, of bioturbated argillaceous limestone with solitary rugose corals. This interval, characterized by the occurrence of *Amplexizaphrentis zapense* Denayer and Hoşgör (2014), is overlain by a 28 cm thin myalinid horizon (first myalinid bed thickness: 10 cm, second myalinid bed thickness: 18 cm). The myalind shell beds are thin lensoid patches that were recorded about 8 m above the base of the Köprülü Formation (Figure 1c). Most of the shell beds in the Hakkari area are monospecifically dominated by *Selenimyalina* sp. indet. They have varying size and outline, most are preserved disarticulated with two valves closed and the commissure parallel to the bedding plane. The Şort Dere section (Figure 1c, GPS 37 17'05.08"N 4332'25.78"E) is situated on the southern limb of the Çukurca Anticline, cropping out along the northern flank of the valley and exposes the Yığınlı and Köprülü formations. Palynomorphs from the myalinid horizon indicate a late Tournaisian age (*pretiosus-clavata*-PC Miosopore zone; Higgs et al., 2002). This age is compatible with the data for foraminifers, posidoniform bivalves and rugose corals, which gave a late Tournaisian or early Viséan age (Perincek et al., 1991; Hoşgör et al., 2012; Denayer and Hoşgör, 2014).

3. Material and methods

Hundreds of specimens of *Selenimyalina* sp. indet. have been carefully collected from two thin myalinid beds (Figure 1c) in the middle part of the Köprülü Formation of the Şort Dere section in the Zap Valley. All specimens figured here are stored in the Cumhuriyet University Natural History and Science Museum in Sivas, Turkey (collection numbers "CUTABH101" to "CUTABH105"). All linear measurements are given in millimeters. The traditional morphological analyses here are based on type species of *Myalina meliniformis* Meek and Worthein, 1866, for Myalinidae Frech, 1891 and generally used characters to define them in several monographs (Rathmann and Amler, 1992; Carter et al., 2012).

4. Myalinid bivalve occurrence

The Myalinidae are a highly diverse group of marine and nonmarine bivalves represented in a variety of habitats from Carboniferous to the Middle Triassic (McRoberts and Newell, 2005). Currently, the following genera are considered to be marine Myalinidae: *Myalina* (Devonian, Carboniferous-Early Triassic, Middle Triassic), *Septimyalina* (Carboniferous-Late Permian), *Orthomyalina* (Late Carboniferous-Early Permian), *Myalinella* (Late Carboniferous-Early Triassic), *Arctomyalina* (Late Carboniferous), *Elversella* (Middle Permian), *Pseudomyalina* (Early Permian), *Selenimyalina* (Late Carboniferous-early Permian), *Novaculopermia*

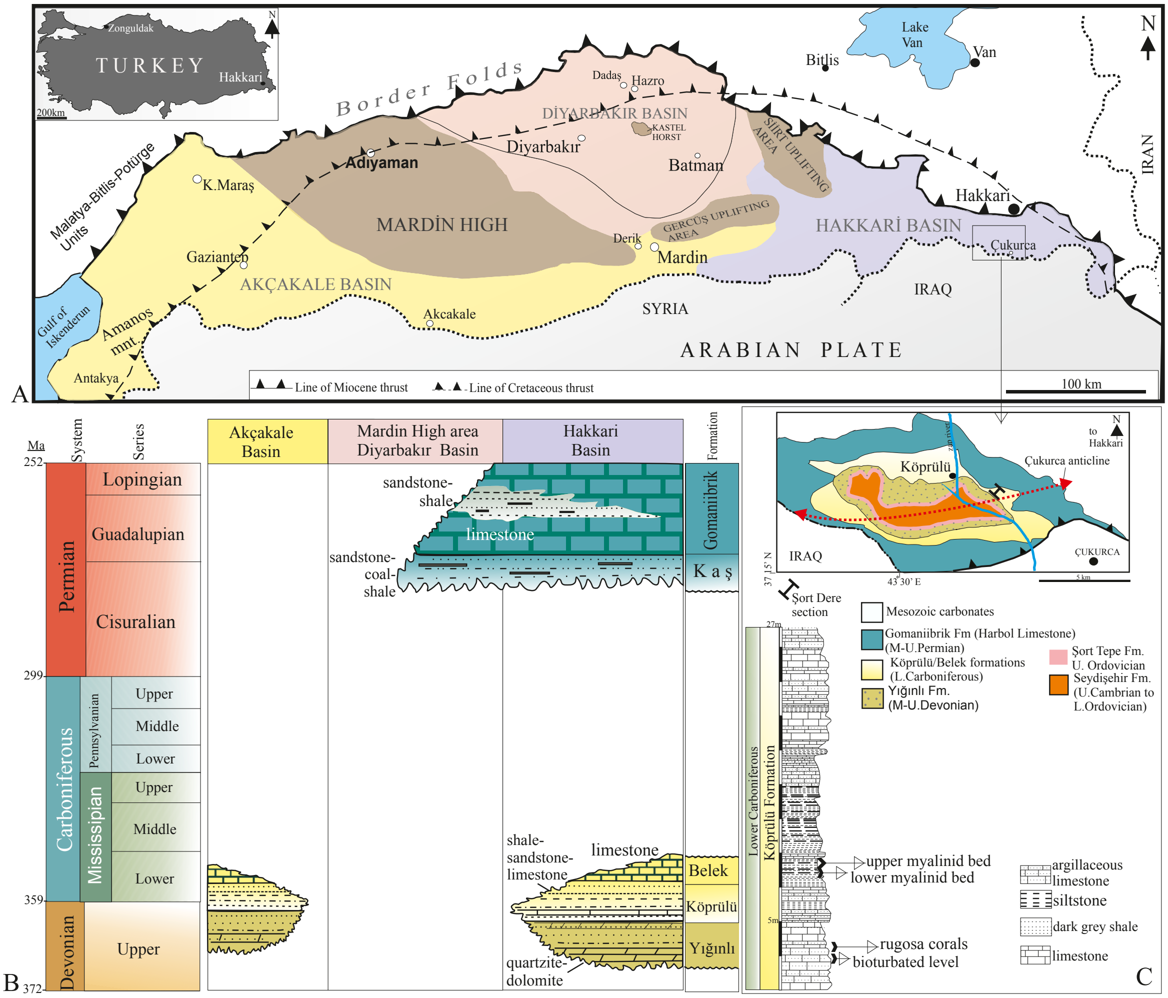

Figure 1. a) Paleozoic sedimentary basins of SE Turkey (Bozdoğan and Erten, 1990; Perinçek et.al., 1991), b) Late Paleozoic lithostratigraphic correlation chart of Akçakale, Diyarbakır and Hakkari basins (Perinçek et.al., 1991), c) Geological map of the northwestern Çukurca area showing the position of the studied section (Gourvennec and Hoşgör, 2012; Denayer and Hoşgör, 2014) and stratigraphic column of the Şort Dere section showing the myalina beds occurring at the middle part of the Köprülü Formation.

(Early Permian), *Promyalina* (Early Triassic) and, less certainly, *Liebea* (Late Permian) and *Aviculomyalina* (Middle Triassic) (McRoberts and Newell, 2005; Okan and Hoşgör, 2007; Neves et. al., 2014). The taxonomic determination was conducted by literature-based comparison with myaliniform bivalves (e.g., *Myalina*, *Orthomyalina*, *Myalinella*, *Selenimyalina*, *Septimyalina*, and *Arctomyalina*) of similar morphology from Carboniferous occurrences (e.g., Rathmann and Amler, 1992; McRoberts and Newell, 2005; Anelli et al., 2006; Okan and Hoşgör, 2007).

Most of the European Carboniferous myalinids have been assigned to *Myalina*, *Septimyalina* and *Selenimyalina*. Rathmann and Amler (1992) emphasized the hinge line shape as distinguishing features of *Selenimyalina*, *Myalina*, and *Septimyalina*. *Selenimyalina* has a convex internal and external edge; *Myalina* has a straight internal and convex external edge; and *Septimyalina* has straight edges (Anelli et al., 2006). Whereas typical marine myalinids of the Late Paleozoic are relatively large with robust shells and thick hinge plates (Newell, 1942; Bailey, 2011), the Hakkari myalinids are always small and poorly calcified with shells that are little more than periostracum (Figure 2a). They were so thin and flexible that, owing to sedimentary compaction, the umbonal region (the thickest part of the shell) is marked by numerous rounded wrinkles, resembling a rumpled napkin.

4.1. Systematic paleontology

The classification of the myalinid bivalves used herein follows Carter et al. (2011).

Infraclass Pteriomorphia Beurlen, 1944

Order Myalinida Paul, 1939

Superfamily Ambonychioidea Miller, 1877

Family Myalinidae Frech, 1891

Genus *Selenimyalina* Newell, 1942

Type species. *Myalina meliniformis* (Meek and Worthen, 1866, p. 343, pl. 27, Figure 3), from the Carboniferous deposits of the USA, by original designation of Newell (1942, p. 63).

***Selenimyalina* sp. indet.**

Figure 2a

Material: 96 poorly preserved specimens from the Şort Dere section were found in two thin beds, about 28 cm thick, in the siltstone/argillaceous limestone of the Köprülü Formation (Slab numbers: CUTABH101 to CUTABH105).

Measurements (in mm): (indicates an incomplete measurement or a crushed specimen), maximum height: 16 mm; maximum length: 17.4 mm; height to length ratio average: 0.98.

Description and comparison: Shell small to medium, moderately narrow; elongate, thin, prosocline, flattened umbones, distinct irregular commarginal overlapping growth lines, anterior region of shell strongly reduced, ventral margin straight; postero-dorsal margin slightly rounded. Growth lines are apparent across much of the shell (Figure 2a). Hinge characters and muscle scars not preserved. However, it seems to have some similarities in shape with *Selenimyalina mytiloides* (vKoenen, 1879), from the Lower Carboniferous Kulm succession in the vicinity of Aprath near Wuppertal (NW Germany) (Rathmann and Amler, 1992). These morphological characteristics of the specimens indicate that they probably belong to an undetermined species of *Selenimyalina* Newell, 1942.

5. Paleoecologic and paleogeographic approach

The Şort Dere section yields mainly two thin shell beds, mostly made up of disarticulated valves with a concordant orientation (Figure 2b). The lower myalinid bed is preserved in fissile, dark grey mudstone/wackestone. Lamination consists of thin, 5–10 mm thick, graded wackestone sheets alternating with 10–20 mm thick barren mudstone. The upper myalinid bed consists of dark grey and slightly bioturbated siltstone where shells occur throughout the whole bed thickness, although with differing abundances. The size of myalinid specimens increases upwards in the studied beds (Figure 2b). Length and width measurements of specimens were recorded from abundant individuals on particular bedding planes. The shell length ranges from a mean of 8 mm in the lower beds to about 14 mm in the upper beds. Composite argillaceous limestone mold of conjoined valves preserved convex-up and convex-down. The ratios of articulated and disarticulated valves, and the ratios of convex-up and convex-down oriented valves are shown in Figure 2b. Articulated valves are rare throughout the studied horizon and only occur at the top of bed. The upper myalinid bed is characterized by poor sorting, a high degree of covering and an increased shell size compared to the underlying bed. These taphonomic signatures suggest an amelioration of environmental conditions with increasing oxygenation in nearby habitats and, possibly, a shallowing of the water depth.

Members of the nonauriculated myalinid *Selenimyalina* are considered epifaunal suspension feeders (Stanley, 1972; Kranz, 1974). Whereas the adults most probably were epibyssate, their larvae passed through a planktotrophic stage. The myalinid forms have probably evolved many strategies of life habits from the Devonian to the Triassic (McRoberts and Newell, 2005) but generally, Paleozoic species were myaliniform edgewise recliner resting on the broad and byssus-bearing anterior surface (Figure 2b) (Okan and Hoşgör, 2007; Hoşgör and Okan, 2012). Hind (1893) reported myalinid bivalves attached to robust, perhaps terrestrial plant material from shales of Namurian age, and many examples of mid-Namurian *Naiadites* including young juveniles in abundance attached to plant material were documented by Huwe (2006). González (1994) suggested that *Posidoniella malimanensis* of the Lower Carboniferous of western Argentina was probably gregarious, forming small clusters attached to the bottom by a byssus. Okan and Hoşgör (2007) also reported posidoniids and myalinids from upper Lower Carboniferous strata of NW Turkey (Zonguldak Coal Basin) attached to driftwood or similar plant material.

Paleoecological questions arose from the reconstruction of paleoenvironments of typical bivalve-bearing deposits like the Early Carboniferous successions of western and central Europe (e.g., *Posidonia* and *Actinopteria* beds; Amler, 2004; Nyhuis et al., 2014; Herbig et al., 2019) and the Early Jurassic shallow-water black shales of western Europe (*Eomiodon* horizon with byssally attached *Lithioperna* bivalves (Posenato et al., 2013). Myaliniform bivalves were acknowledged to be attached to floating or benthic objects in the water column like driftwood, vesicular algae, plants or cephalopod shells with byssal threads analogous to other thin-shelled bivalves from black shales (Figure 2b).

Correct biostratigraphic correlation between the European Kulm Basin and the shallow-water basins and correct placement of the Tournaisian-Viséan boundary is the prerequisite for the approach to the phenomenon of the supposed Viséan high global sea-level (Herbig, 2016). Therefore, biostratigraphic problems have to be addressed in the following. Early Carboniferous (Tournaisian-Viséan/Global Stage and Dinantian/ Regional Stage) zonation of the European Kulm Basin is

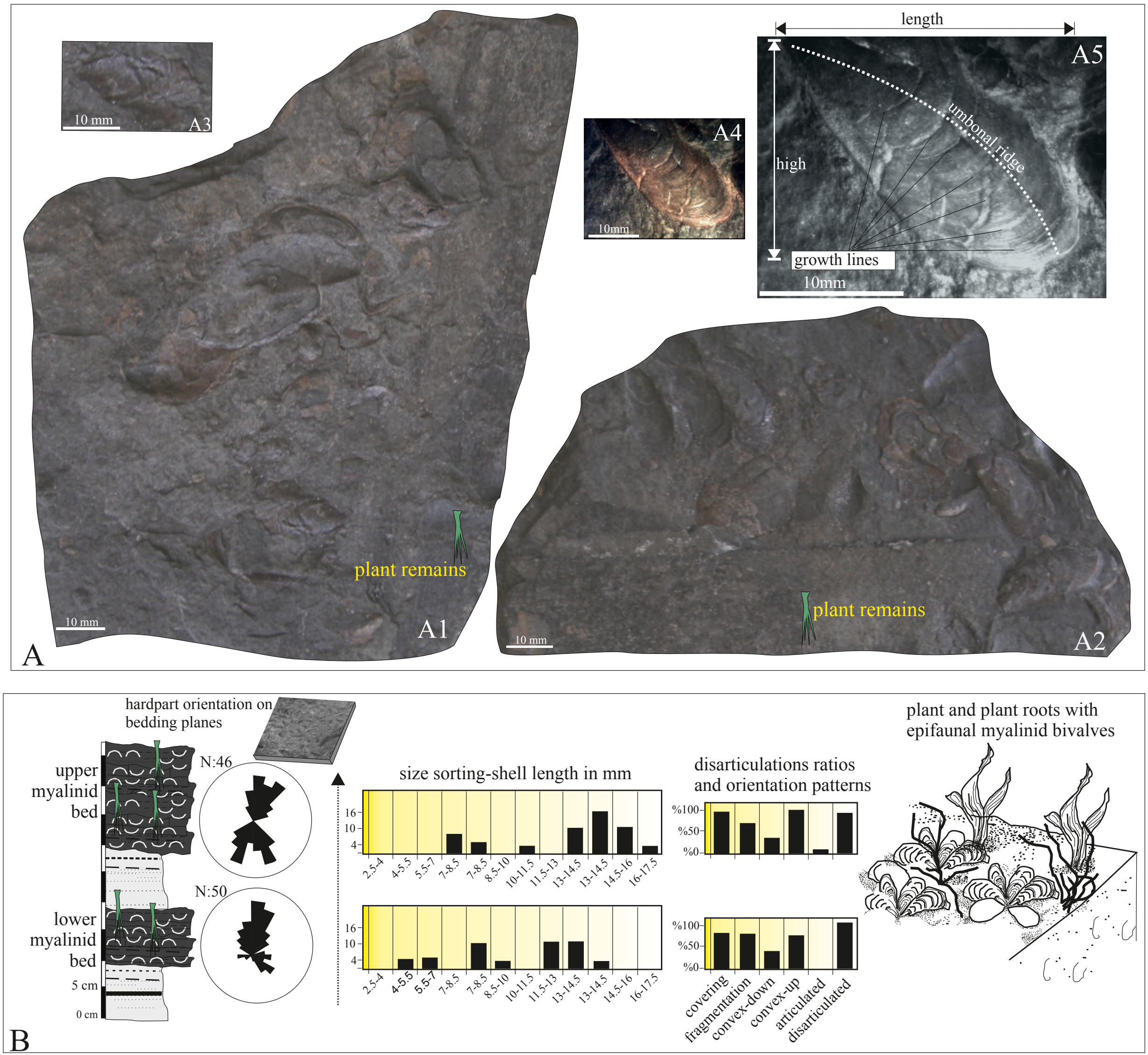

Figure 2. a) Monotaxic myalinid bivalve shell slabs, internal and external molds of fragmented valves with plant roots/wood fragments (CUTABH102-105), b) The studied bed intervals, size-frequency diagram and some taphonomic characters of the myalinid beds with paleoecological model (modified after Okan and Hoşgör, 2007).

based on goniatites and bivalves (Amler, 2004; Korn et al., 2012; Herbig et al., 2019; Korn and Wang, 2019). The general distribution of myaliniform bivalves was restricted to the Carboniferous of NW Belgium (Demanet, 1938), Germany (Kulm Basin) (Roemer, 1854; von Koenen, 1879; Paul, 1941; Nicolaus, 1963; Rathmann and Amler, 1992; Amler, 2004), Poland (Walbrzych Basin) (Zakowa, 1958; Nicolaus, 1963), France (Babin and Delvolvé, 1989) and NW Turkey (Zonguldak Basin) (Okan and Hoşgör, 2007) and is regarded as a good indicator for tropical and subtropical climatic conditions (Figure 3). During the Late Devonian-Early Carboniferous, peri-Gondwanan terranes were located along the southern margin of Laurussia that formed the vast northern shelf of the Paleotethys (Figure 3). Somerville et al. (2013) reviewed several foraminiferal and rugose coral assemblages and provided a hypothesis that explained the paleobiogeographical provinces. They suggested that the rich equatorial fauna should have migrated southwards, crossing and colonizing the basins and platforms between Laurussia and Gondwana.

6. Concluding remarks

The different types of facies were documented in the NW Turkey (İstanbul-Zonguldak Zone) and the SE Turkey (Hakkari) areas, from carbonate grainstone to shale for the Tournaisian, but the Viséan is dominated by shallow-

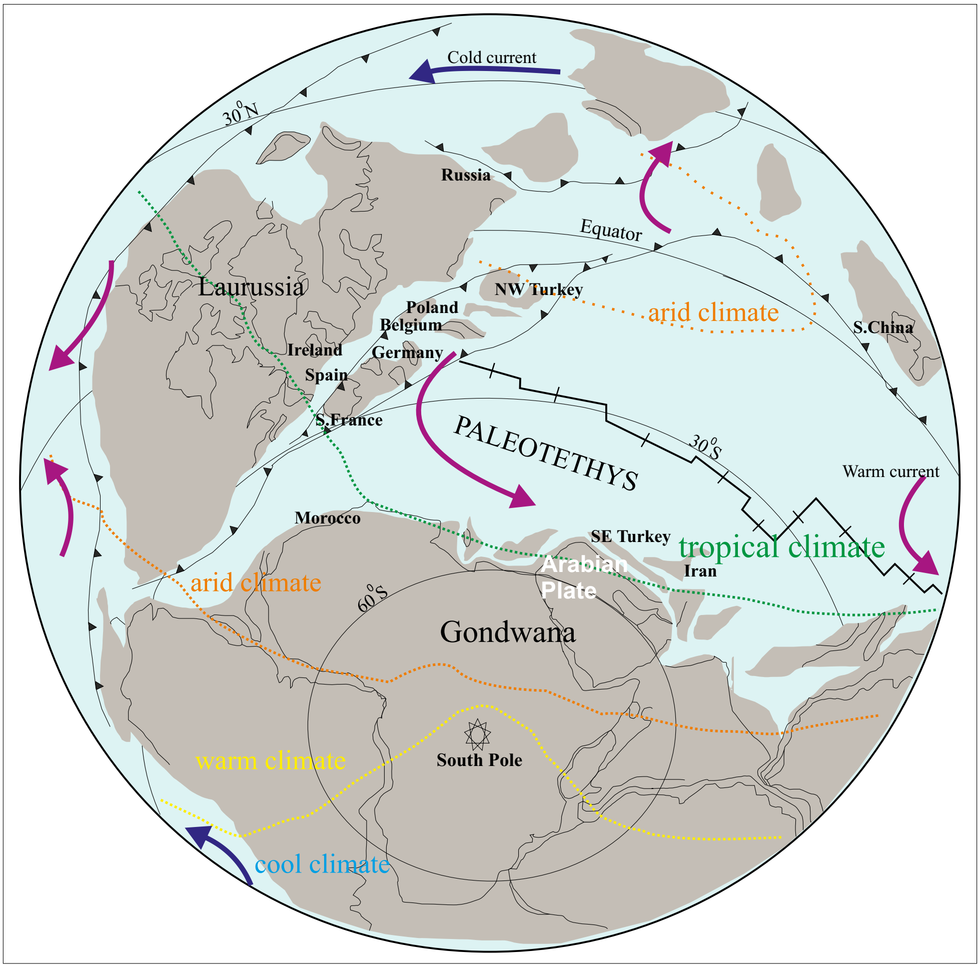

Figure 3. Early Carboniferous (c. 340 Ma) reconstruction of the Paleotethys Ocean and its margins (modified from Torsvik and Cocks, 2004; Hoşgör et al., 2012; Denayer and Hoşgör, 2014) with position of the discussed areas along the northern margin of Gondwana.

water mixed carbonate-siliciclastic facies witnessing a platform or ramp edging the margin of the northern Arabian plate (Denayer and Hoşgör, 2014; Denayer, 2015). The İstanbul-Zonguldak terrane assemblage including the Zonguldak Basin was attached to the central and SE European terrane assemblages (Hoşgör et al., 2012). The Hakkari fossil material – *Selenimyalina* sp. indet. – cannot help elucidation of the relationships of the known Carboniferous bivalves between the Laurussian and the Gondwanan province to paleogeographic units further east, because contemporaneous faunas of these regions are too poorly studied, although many communications of posidoniid and myalinid faunas seem to occur in between peri-Gondwana and/or Laurussia, and northern Gondwana (Figure 3).

Lower Carboniferous mixed carbonate-siliciclastic deposits of the Köprülü Formation in Southeastern Turkey provide an important record of the Late Paleozoic shallow marine fauna and flora along the northern margin of the Arabian plate, which contribute to elucidate important pieces of the Gondwana-Laurussia faunal exchange. As stated above, the Gondwana and Laurussia margins are characterized by early Carboniferous pteriomorph faunas dominated by *Posidonia becheri* and myalinid bivalves. The wide distribution is only partly explained by good marine communications linked to high relative sea level. The paleogeographic signatures of some of these myalinid species support the claim that they represent autochthonous to subautochthonous communities, and therefore record a meaningful dispersal pathways significance. As a consequence, the occurrence of the early Carboniferous Kulm-type bivalve fauna in the Arabian Platform represents another line of evidence in favour of strong faunistic affinity between Laurussia and the northern Gondwana margin.

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