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# Methane-seep brachiopod fauna within turbidites of the Sinaia Formation, Eastern Carpathian Mountains, Romania

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ABSTRACT

This study elucidates the paleoecology and paleobiogeography of the Early Cretaceous brachiopod *Peregrinella* known in museum collections from a few localities in Romania, supplemented with new material from a rediscovered locality first mentioned in the 1870s. Most *Peregrinella* fossils are enclosed in mass waste deposits, but at two sites authigenic limestones with assemblages of brachiopods preserved in life position have been recognized. Paleontological, petrographic, stable isotopic, and organic geochemical investigations of these brachiopod-bearing limestones from the Upper Sinaia Formation, Eastern Carpathian Mountains, Romania, confirm *Peregrinella* as having lived at methane seeps in a siliciclastic-dominated flysch basin. The seeps developed on the slope of the External Dacides Basin. The new collections of *Peregrinella* indicate that shells derived from contemporaneous intrabasin methane seeps and were transported downslope by turbidity currents. Previous paleoecological models that consider *Peregrinella* to be solely derived from transport downslope from shelf environments are questionable especially as *Peregrinella* has never been recovered from typical shelf faunas; in the instance documented here from the External Dacides Basin methane-seep faunas with *Peregrinella* are likely to be the origin of such allochthonous faunas. The Sinaia Formation was deposited in a deep-water marine basin, derived from an intracontinental rift that developed during Late Jurassic-Early Cretaceous extension. The fractured and faulted basin margin provided the backdrop for the development of the methane seepage and the associated fauna. Foraminifera from background sediments in the sequence with turbidites confirm a late Hauterivian to early Barremian age for *Peregrinella* within the Sinaia Formation. This is significant because it indicates that *Peregrinella* ranged through into the Barremian, whereas it has typically been considered to range only as high as the Hauterivian.



## 1. Introduction

The Early Cretaceous brachiopod genus *Peregrinella* is one of the largest-sized Mesozoic brachiopods, reaching maximum dimensions of 10 cm or greater. The brachiopod has attracted much attention not only for this large size but also for its enigmatic occurrence *en masse* in "*Peregrinella*" beds (e.g., Biernat, 1957; Ager, 1965, 1968; Thieuloy, 1972; Campbell and Bottjer, 1995a; Sandy, 1995; Kiel and Peckmann, 2008) and also for its disjunct distribution and unusual paleoecology and paleobiogeography. *Peregrinella* is never found with other brachiopod genera and is absent from contemporaneous brachiopod shelf faunas that can typically be expected to include a few brachiopod species, including both terebratulids and rhynchonellids (Middlemiss, 1979, 1984). *Peregrinella* is found as monospecies or monogeneric brachiopod accumulations that can be part of more diverse invertebrate assemblages that may include associated molluscs (Stanton, 1895; Biernat, 1957; Campbell et al., 1993; Kiel and Peckmann, 2008) that belong to chemosynthesis-based lineages. The disjunct distribution of *Peregrinella* (France, Italy, Poland, Tibet, California, Alaska, Crimea (Ukraine); e.g., Ager, 1967; Owen, 1973; pre-1995 occurrences summarized in Table 1 by Campbell and Bottjer, 1995a; Sandy and Blodgett, 1996; Posenato and Morsilli, 1999; Kiel and Peckmann, 2008), and its isolation from other brachiopods, have led to the development of intriguing paleoecological models, such as *Peregrinella* living restricted to rocky shorelines and subsequently washed downslope into basins—with the original rocky shoreline never preserved (Ager, 1965); however, no brachiopods are known to have had such a paleoecology (Art Boucot, personal communication, 2011). A shallowing, uplifting basin floor within the deeper water Vocontian Basin was proposed to explain the occurrence of *Peregrinella* in southern France (Thieuloy, 1972).

The fascination with *Peregrinella* has appeared warranted as its story has become even more intriguing. *Peregrinella* is now considered an associate of chemosynthesis-based communities (e.g.,

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Campbell et al., 1993; Campbell and Bottjer, 1995a; Kiel and Peckmann, 2008). Macsotay (1980) and Lemoine et al. (1982) had first suggested hydrothermalism to explain the occurrence of *Peregrinella* in outcrops in the south of France. Once petrographic and isotope work was combined with paleontological studies (for a Californian occurrence, Campbell et al., 1993, 2002), it became clear that the brachiopod was associated with hydrocarbon seeps during life. In a review of the occurrence of *Peregrinella,* Campbell and Bottjer (1995a) identified 17 localities globally. Of these (including new occurrences) only 2 have been confirmed as having a methane-seep origin: (1) California (Campbell et al., 1993; Campbell and Bottjer, 1995a; Birgel et al., 2006) and (2) Crimea (Kiel and Peckmann, 2008; Peckmann et al., 2009). This study marks the third confirmed association of *Peregrinella* with chemosynthesis-based seep environments. Presumably work will continue on trying to ascertain the paleoecology of other *Peregrinella* occurrences in an attempt to determine if *Peregrinella* is, in fact, restricted to these environments. Other representatives of the rhynchonellid superfamily Dimerelloidea, to which *Peregrinella* belongs, have also been shown to be associated with chemosynthesis-based environments (Sandy and Campbell, 1994; Peckmann et al., 2001, 2007, 2011; Gischler et al., 2003). Of these, *Dzieduszyckia* from the Devonian is known from hydrocarbon-seep carbonates but also from sedimentary strata apparently unaffected by seepage (Peckmann et al., 2007). Therefore *Dzieduszyckia* is considered to be a brachiopod that is more plastic in its ecological tolerances (Peckmann et al., 2007). Such an association has not been confirmed for *Peregrinella,* and based on current knowledge, it seems unlikely given the absence of *Peregrinella* from shelf brachiopod faunas.

Here we describe different modes of occurrence of *Peregrinella* from the Upper Sinaia Formation, Eastern Carpathian Mountains, Romania, studying the paleontological, taphonomical, sedimentological, petrographic, stable isotopic, and organic geochemical characteristics of brachiopod-bearing rocks. Our study reveals that the paleoecology of this brachiopod can only be constrained based on fossil associations preserved in authigenic rocks that formed in the brachiopods' habitat. An attempt to reconstruct brachiopod paleoecology from accumulations of transported shells is hampered by the apparent lack of diagnostic features that help to identify the paleoenvironmental conditions of the original habitat. Criteria have yet to be identified from brachiopod shells that would allow such an assignation.

## 2. *Peregrinella* records in Romania

In Romania *Peregrinella* is known from turbidites and blocks of limestone from the Neocomian flysch deposits of the Upper Sinaia Formation, well exposed in outcrops in the southern part of the Eastern Carpathians (Fig. 1). The first mention of *Peregrinella* in the Eastern Carpathians was by Herbich (1878, p. 248) who recorded *Rhynchonella peregrinella* d'Orbigny from sandstone deposits that outcrop in the Vărghiş Valley. Subsequently *Peregrinella* was mentioned by Toula (1911), Macovei (1927), Macovei and Atanasiu (1933), Băncilă (1958), Zberea (1962), Filipescu and Grigorescu (1966), Patrulius (1969), Pauliuc (1968), Gräf (1975), Földvary (1988), Solcanu (1991, 2007), as well as Săndulescu and Dimitrescu (2004). All of these authors refer to a total of four localities: (1) Zizin Valley; (2) Vărghiş in the Sărman Valley; (3) Belin Valley (Perşani–Baraolt area) and; (4) Cădăreşti in the Ciughieş Valley (Fig. 1). These localities with *Peregrinella* are in the southern half of the Eastern Carpathians (in the Perşani, Baraolt, Bodoc, and Ciuc mountains). All previous authors mention *Peregrinella* from coarse sandstones and/or from isolated blocks of limestone found as loose samples in valleys where the Sinaia Formation is exposed. However, none of these works mentions the exact location of the limestones within the flysch succession. We were unsuccessful in our recent efforts to relocate these limestones. The limestone samples with *Peregrinella* that we studied in the present paper are samples held in the paleontological collections of the University of Bucharest (samples from Zizin, Perşani–Baraolt area, and Cădăreşti) and the Geological Institute of Romania (samples from Belin). During field work in 2009 and 2010 we rediscovered the turbidite outcrop with *Peregrinella* from Vărghiş (Herbich, 1878; Băncilă, 1958 first mentioned the occurrence of *Peregrinella* from the area but not a specific outcrop). Two additional samples (one *Peregrinella* specimen in carbonate and one sandstone sample with external molds of *Peregrinella* from Cădăreşti, Ciughieş Valley) were donated to the University of Bucharest collections in 2010 by Mihai Solcanu. We present here the first integrated study on the occurrences of *Peregrinella* in Romania concerning macro- and micropaleontology, taphonomy, microfacies, sedimentology, isotope geochemistry, and biomarkers.

## 3. Geological setting and stratigraphy

The stratigraphy of the Sinaia Formation in the Eastern Carpathians has been studied by numerous authors, among them, Popovici-Haţeg (1898), Protescu (1936), Oncescu (1965), and Patrulius (1969). Numerous refinements of the general geological context and stratigraphy of the Sinaia Formation have subsequently been made. However, in this paper we restrict our discussion to the authors that studied the stratigraphy of the Sinaia Formation where *Peregrinella* occurs. The flysch deposits of the Sinaia Formation belong to the sedimentary cover of the Ceahlău Nappe, External Dacides of the Carpathian Orogen (Fig. 1), corresponding to an external rift (extensional basin). The External Dacides consists of narrow north–south oriented nappes that developed from a Jurassic-Cretaceous paleo-rift within the European continental margin (Săndulescu, 1994). This rifting was associated with Tethyan Ocean spreading and reached its maximum extension in the Middle-Late Jurassic. In the Eastern Carpathians, the Black Flysch, Baraolt and Ceahlău nappes are floored by intraplate basalts, resulting from this extension. The basalts are overlain by flysch formations. In the Ceahlău Nappe, flysch is represented by the Sinaia Formation. In the Middle Cretaceous, compressional tectonics resulted in a thick pile of nappes, the Median Dacides (Săndulescu, 1994), which in turn were covered by obducted slabs of Tethyan oceanic crust (the Transylvanides). Both the Median Dacides and the Transylvanides were overthrusted onto the Sinaia flysch of the External Dacides (Kräutner and Bindea, 2002). End-Cretaceous compression is evident in the External Dacides (Săndulescu, 1994).

The Sinaia Formation is up to 2500 m thick (Patrulius, 1969) and consists mainly of flysch represented by carbonate-rich siliciclastic and marly sediments, divided into three members based on the petrography of the units (Figs. 2, 3). The *Peregrinella* levels are located within the Upper Sinaia Member that is 400–500 m thick (Fig. 3) and represented by shales alternating with sandstones, marls, limestone, sandy-limestone, and silty-limestone. The succession reveals intercalations of conglomerates, breccias, and coarse gravelly sandstone toward its upper part.

Macro- and microfossils are not very common in the Sinaia Formation, therefore the stratigraphic age of the Sinaia Formation has been the subject of much debate. Patrulius (1969) made a very detailed inventory of all the paleontological arguments, concluding the range of the Sinaia Formation is Berriasian to Late Hauterivian, with the Upper Sinaia Member restricted to the Upper Hauterivian (Murgeanu et al., 1959; Patrulius, 1969). However, Avram and Matei (1964), Avram (1970), and Gräf (1975) described stratigraphically important taxa from the Upper Sinaia Member: *Lamellaptychus angulocostatus* (Peters), *Neolissoceras grasianum* d'Orbigny, *Barremites subdifficilis* (d'Orbigny), *Euphylloceras tethys* d'Orbigny, and *Lythoceras* sp. These fossils indicate a Late Hauterivian to Early Barremian age.

The section we studied with *Peregrinella* is located in the Sărman Valley, a tributary to the Vărghiş Valley, near the village of Vărghiş. We rediscovered the outcrop that Băncilă (1958) briefly mentioned in his monographic work concerning the geology of the Eastern Carpathians. The flysch deposits of the Upper Sinaia Member outcrop