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Integrated ichnology and ichthyology of the Oligocene Menilite Formation, Skole and Subsilesian nappes, Polish Carpathians: A proxy to oxygenation history

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ABSTRACT

The anoxic, mostly black or brown fine-grained sediments of the Menilite Formation (Oligocene–Early Miocene) in the Skole and Subsilesian nappes contain thin layers of bioturbated green or grey-green mudstones, some of which contain the trace fossils *Halimedides annulata*, *Multina* isp., *Palaeophycus* ?*tubularis*, ?*Planolites* isp., *Rhizocorallium* isp., *Trichichnus* isp. and *Zoophycos* isp. The *Trichichnus*–*Palaeophycus*–(*Multina*, *Halimedides*)–*Rhizocorallium* suite indicates an increase in oxygenation of sediments. The contribution of different ecological groups of fishes, including epipelagic, bathypelagic, benthopelagic, neritic and reef, and demersal taxa changes significantly through the Menilite Formation. The absence or reduction of bathypelagic fishes points to anoxia in the water column. The combination of ichnological and ichthyological data and incorporation of data on benthic foraminifers allowed a reconstruction of oxygenation changes in the sediment and water column during deposition of the Menilite Formation. Total anoxia at the sea floor and in the water column, attributed to a combination of thermo-stratification and extremely high organic productivity, occurred only during the period reflected by ichthyofaunal Zone IPM2 (middle part of the NP23 Zone). Anoxia restricted to the basin floor or upper slope, related in part to upwelling, occurred during sedimentation of the upper part of the Menilite Formation.

1. Introduction

The Oligocene–Early Miocene Menilite Formation (called also the Menilite Beds) is regarded as a good example of anoxic sediments (e.g., Paucă, 1936; Książkiewicz et al., 1965; Vető, 1987; Köster et al., 1989) deposited in large areas of partly isolated deep-sea basins in the Carpathian part of the Tethys after the Eocene–Oligocene boundary climatic changes (e.g., Soták, 2010 for review). Only a few, short mentions refer to trace fossils or bioturbation structures from the Menilite Formation (e.g., Vialov., 1961; Książkiewicz, 1977; Kotlarczyk, 1979; Haczewski, 1989; Bieńkowska-Wasiluk, 2010), but no conclusions from their occurrence have been drawn. New discoveries of trace fossils reported in this paper challenge the anoxic image of the Menilite Formation.

In the Skole and Subsilesian nappes, the Menilite Formation, which is up to 1000 m thick, is dominated by black or brown mudstone–siltstone but locally includes marlstone, sandstone, chert and limestone. Most of these fine-grained rocks display distinct primary lamination, and many contain well-preserved fishes of different ecological groups, including epipelagic, bathypelagic, benthopelagic, neritic and reef, and demersal taxa. The relative contribution of fishes from these groups changes significantly through the section (Kotlarczyk et al., 2006), reflecting changes in the water column oxygenation. Locally, at least in the Menilite Formation of the Skole and Subsilesian nappes (Fig. 1), thin, green mudstone layers occur. Commonly, they contain trace fossils and bioturbation structures that provide unequivocal evidence of *in situ* macrobenthic life. Contrary to previously held assumptions of permanent anoxia, the bioturbated horizons mark oxygenation events that had significant ecological impact on the distribution and preservation of fishes.

The combination of ichnological and ichthyological data in relation to sedimentary features provides a rare opportunity to reconstruct oxygenation changes on the sea floor as well as in the water column in the Skole and Subsilesian basins during sedimentation of the Oligocene part of the Menilite Formation. Such a reconstruction is the main aim of the paper.

2. Geological setting

2.1. The Menilite Formation

The Menilite Formation occurs in most of the main tectonic units of the Flysch Carpathians. It crops out in large areas of the Silesian and Skole nappes (Figs. 1, 2). Sediments of the Skole Nappe accumulated in the Skole Basin, which was a trough bordered by the European Platform

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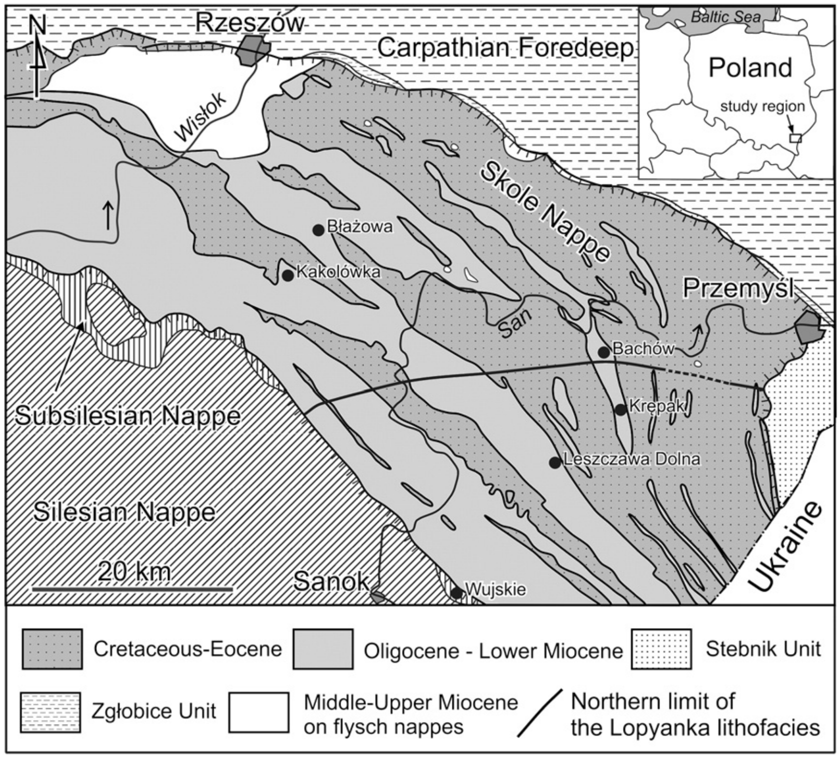

Fig. 1. Simplified geological map of the SE part of the Polish Flysch Carpathians showing the location of studied sections.

to the north and by the Subsilesian ridge and its slope (now the Subsilesian Nappe) to the south. The Menilite Beds (Couches à Menilite, Menilitenschichten), also called the Menilite Formation (e.g., Kotlarczyk and Leśniak, 1990), are dominated by variable fissile brown or black mudstones and dark grey siltstones. Parallel flat lamination is most common in highly fissile rocks. The sediments are mostly non-calcareous, rich in organic matter of marine and terrestrial origin, barren of macrobenthos, but rich in fossil fishes. The mudrocks are either allochtonous sediments deposited by turbiditic or bottom currents, or autochtonous (background) hemipelagic sediments. Allochtonous character of the former is proven by subtle graded bedding, sharp, locally erosive lower bedding surfaces, and occasionally sharp upper bedding surfaces. Also calcareous benthic foraminifers, found locally in the brown calcareous mudstones, are allochtonous; they belong exclusively to shelf or to shelf–upper bathyal taxa. They are not accompanied by exclusively bathyal taxa (Olszewska, 1984a,b, 1985). Autochtonous mudstones, deposited from suspension, are finely laminated and commonly contain well-preserved fishes and algae, untouched by scavengers (Jerzmańska and Kotlarczyk, 1976; Kotlarczyk et al., 2006; Bieńkowska-Wasiluk, 2010). These features point to anoxia on the sea floor. Subordinately, green mudrock layers of autochtonous or allochtonous origin occur (see chapter 2.2).

Mudrocks of the Menilite Formation contain white or beige, fine-grained, non-calcareous, non-micaceous quartz arenites. They occur as isolated ripples or thin beds. Thicker thick-bedded quartzarenite lithosomes, deposited as debrites or turbidites emanating from the northern margin of the basin (Kotlarczyk and Leśniak, 1990), are distinguished as the Boryslav, Kliva, Huwniki and Błażowa members (Fig. 2). Brown muddy sandstones, deposited as sand-mud gravitational flows are rare. Brown cherts of the Kotów Chert Member, light brown, bedded, hard turbiditic marls of the Dynów Marl Member, shales and sandstones of the Rudawka Tractionite Member and the Borek Nowy Member are widely distributed (Fig. 2; Kotlarczyk and Leśniak, 1990). Some of them, mainly the second to the last unit, contain thin sandstone layers deposited by traction currents (Unrug, 1980).

In the Skole and Subsilesian nappes, dark sediments of the higher part of the Menilite Formation grade laterally into grey and light grey, generally calcareous sediments (Lopyanka and Jutna members; Fig. 2), which display features of the overlying Krosno Formation. They derived from the southeast and spread from the axial part of the Skole Basin towards its margins (Kotlarczyk et al., 2006).

The Menilite Formation contains thin layers of coccolithic limestones (Fig. 2), including the Jasło Limestone, which are considered as chronohorizons (Jucha and Kotlarczyk, 1961; Koszarski and Żytko, 1961; Kotlarczyk, 1980) related to phytoplankton blooms (Nowak, 1965; Krhovský, 1981; Haczewski, 1989). Other chronohorizons of this type are distinguished as the Tylawa Limestone and the Wujskie Limestone (see Kotlarczyk et al., 2006).

The lower parts of the Menilite Formation are similar in the Skole and Subsilesian nappes, but sandstones are almost absent in the latter. The upper part of the formation in the Subsilesian Nappe is dominated by brown mudstones densely intercalated with green layers, without sandstones (Šitbořice Member; see Kotlarczyk et al., 2006).

2.2. Green layers in the Menilite Formation

Green layers are present in various levels of the Menilite Formation (Jucha and Kotlarczyk, 1961; Kotlarczyk, 1966; Kotlarczyk and Leśniak, 1990; Kotlarczyk et al., 2006). However, they are more common just below and above the Jasło Limestone and in the upper part of the formation. They are composed of light green, green, light grey, beige or beige green mudstones (hereafter referred as green layers). Most range from 1 to 40 mm thick, but some intervals may be as thick as a few metres locally (Vitryk et al., 1958; Vialov, 1961, p. 65). The lowest thick interval was distinguished as the Krępak Member (Kotlarczyk, 1985). Such thick packages of green layers are absent in the Subsilesian Nappe. The green layers are intercalated with layers of other lithologies (Fig. 3A). Commonly, they occur below layers showing distinctly coarser grains and sharp bases, including rippled sandstones. Some of the green layers contain very thin (0.5–2 mm thick) darker laminae with diffuse boundaries. Lower boundary of green layers are commonly slightly diffuse and grade into subjacent black, dark grey or brown mudstones. Green layers are more common and more calcareous in the