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# Exceptionally favourable life conditions for macrobenthos during the Late Cenomanian OAE-2 event: Ichnological record from the Bonarelli Level in the Grajcarek Unit, Polish Carpathians

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ABSTRACT

Pelagic and hemipelagic sediments of the Bonarelli Level (uppermost Cenomanian) in the Sztolnia section (Grajcarek Unit, Polish Carpathians) contain trace fossils of the *Zoophycos* ichnofacies, including (in descending order of abundance): *Chondrites* (smaller and larger forms), *Planolites*, *Thalassinoides*, *Palaeophycus*, *Taenidium*, *Teichichnus*, and *Zoophycos*. They occur in thick bioturbated layers, which are interbedded with rare, thin layers of unbioturbated black shales. The black shale layers mark the Bonarelli Level and are interpreted as a record of anoxia or dysoxia. Coeval sections in the Western Tethys contain similar trace fossils but they are less abundant and these sections are characterized by thicker unbioturbated black shale layers and thinner bioturbated layers. This confirms the exceptionally favourable life conditions in sediments of the Sztolnia section, which do not record strong global anoxia during the OAE-2 event. Such favourable conditions were probably caused by effective oxygenation of pore waters and deep burial of organic matter, which are a consequence of high rates of accumulation and the palaeogeographical location of the section on a flank of a submarine high, under strong circulation.


## 1. Introduction

Cretaceous oceanic anoxic events are worldwide phenomena, usually characterized by the presence of black-shale facies, and by significant ecological and evolutionary biotic changes (e.g., Schlanger and Jenkyns, 1976; Arthur et al., 1990). An especially significant event at the Cenomanian–Turonian boundary interval is responsible for faunal extinctions and turnovers inasmuch of a series of significant environmental perturbations, including increased volcanic activity, changes of circulation, climate and productivity (Schlanger and Jenkyns, 1976; Jenkyns, 1980; Arthur et al., 1990; Tsikos et al., 2004; Mort et al., 2007 and references therein). It is classified as a second-order, stepwise marine mass extinction event affecting different groups of organisms (Harries and Kauffman, 1990; Kauffman and Erwin, 1995; Kauffman and Hart, 1996; Harries and Little, 1999; Wan et al., 2003). These biotic changes are related mostly to the Oceanic Anoxic Event 2 (OAE-2), which is recorded in the highest Cenomanian as a package of dark anoxic shale horizons named the Bonarelli Level.

The Bonarelli Level is not uniform, and the number, thickness and lateral range of anoxic horizons varying as shown by high-resolution ichnological analyses in the western Tethys realm, in the Silesian Unit of the Polish Carpathians (Uchman et al., 2008), Betic Cordillera in Spain (Rodríguez-Tovar et al., 2009a,b) and the Gubbio area in the Apennines of Italy (Monaco et al., 2012). In all these cases, a dozen anoxic, mostly black shale horizons are intercalated with lighter, bioturbated, dysoxic or oxic horizons within the Bonarelli Level, which is 1–2.5 m thick. The anoxic horizons dominate in these sections.

In this paper an exceptional section of the Bonarelli Level, Sztolnia section of the Grajcarek Unit, Polish Carpathians (Fig. 1), is presented and discussed, including the incidence of particular topographic and palaeoceanographic conditions. Its anoxic horizons are thin, less numerous, occupying only a small percentage of the section (Fig. 2), and the intercalated intervals display higher trace fossil diversity (Figs. 3 and 4) than in other sections. Such development of the Bonarelli Level points to an exceptional seafloor environment. Its presentation contributes to the general picture of the OAE-2 event, demonstrating that conditions during OAEs are not persistently and globally anoxic or euxinic, and that there is local geographic and temporal variation in environmental changes.

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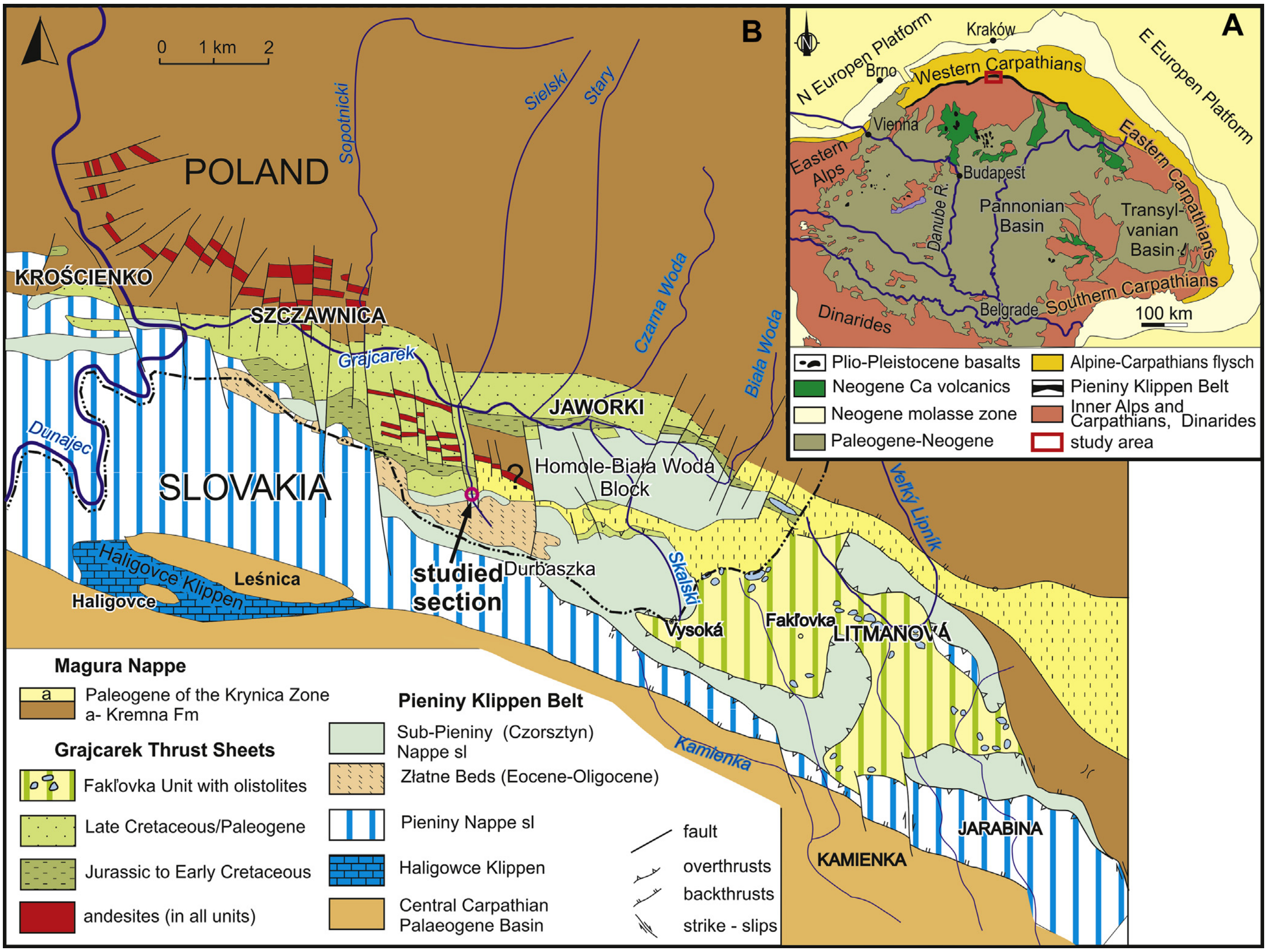


**Fig. 1.** A, Position of the studied area in the Alpine–Carpathian and Panonian realm. B, Geological sketch map of the Małe Pieniny Mts. and Ľubovnianska Vrchovina (based on Birkenmajer, 1979, supplemented and modified by Oszczypko et al., 2010, 2012).

## 2. Geological setting

In the Polish Carpathians, the Inner and Outer (Flysch) Carpathians are separated by the Pieniny Klippen Belt (PKB) suture zone (Fig. 1), whose succession consists of Jurassic to Upper Cretaceous pelagic and flysch deposits (Birkenmajer, 1986). In the Małe Pieniny mountain range, the PKB succession is separated from the Magura Nappe of the Outer Carpathians by a narrow, strongly deformed zone, distinguished as the Grajcarek Unit (Birkenmajer, 1977, 1986) or Grajcarek thrust sheets (Oszczypko et al., 2010, 2012). The Grajcarek thrust-sheet succession consists of Jurassic, Cretaceous and Palaeocene pelagic and flysch deposits belonging to the Magura succession (Birkenmajer, 1977, 1986). Dark shales of the so-called Black Flysch, belonging to the Szlachtowa and Opaleniec formations, are characteristic components of the Grajcarek thrust sheets. They have been dated alternatively to Lower and Middle Jurassic (Birkenmajer and Pazdro, 1968; Birkenmajer et al., 2008) or to "middle" Cretaceous (Sikora, 1962, 1971; Oszczypko et al., 2004, 2012), being a subject of long-lasting controversy. Nevertheless, at least part of these deposits occurs with sedimentological continuity below the Upper Cretaceous red and variegated shales of the Malinowa Shale Formation (Turonian–Campanian) and is distinguished as the "Cenomanian Key Horizon" (Sikora, 1962, 1971; see also Oszczypko et al., 2012), which corresponds to the Bonarelli Level.

The Sztolnia section (called also the "small waterfall section") starts with a 3–4 m thick succession of dark-grey marly shales with a few intercalations of micaceous sandstones belonging to the uppermost part of the Szlachtowa Formation (GPS co-ordinates: N49°24.082′; E20°31.537′). It is overlain by thin intercalations of grey, marly shales, sideritic limestones and grey greenish, non-calcareous shales with pyrite concretions that together represent the Opaleniec Formation. The "Cenomanian Key Horizon" starts with an 80 cm-thick interval of green and grey, non-calcareous manganiferous radiolarian shales, which are capped by lenses of light green radiolarites with remarkable pyritization (Fig. 4F), covered by a cherty limestone, which are together 15 cm thick (Fig. 2). Above, the proper Bonarelli Level begins at the base of the first black shale intercalation, which is 2.75 cm thick. The Bonarelli Level comprises 10–35 cm-thick layers of cherty, partly "spotty" limestones intercalated with black shales, grey marly shales and green non-calcareous shales at the top (Fig. 2). Twelve black shale intercalations are present; the thickest of which attains 15 cm. The topmost black shale layer marking the top of the Bonarelli Level is overlain by green and red non-calcareous shales of the Malinowa Shale Formation. The Malinowa Shale Formation is dominated by red mudstones, which become marly to the south. These sediments represent the Cretaceous oceanic red beds. Sediments of the studied interval resulted from pelagic and hemipelagic sedimentation, beyond the range of gravitational flows.