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Trace geochemistry of the Early to Late Cretaceous deposits of the Grajcarek thrust-sheets – a palaeoenviromental approach (Małe Pieniny Mts., Pieniny Klippen Belt, Poland): reply

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Gedl (2012) question the validity of our correlation of the geochemical boundary between the Albian/Cenomanian and Turonian deposits from the Grajcarek thrust-sheets of the Pieniny Klippen Belt (PKB), with that between similar deposits from the Polish Outer Carpathians. This boundary determines the appearance of the Turonian red shales, known as the Cretaceous Oceanic Red Beds (CORB). They occur in all successions of the Outer Carpathians and Grajcarek thrust-sheets of the PKB. In carbonate successions of the PKB, the red marls of the Jaworki Formation are the equivalent of the CORB.

In the Outer Carpathians, red shales (CORB-type) are underlain by Cenomanian deposits, represented by manganiferous black shales, radiolarian green shales and, locally, by radiolarites of the Barnasiówka and Dołhe formations (Bąk *et al*., 2001; Kotlarczyk, 1979). Below the CORB there are spongiolites and the Gaize beds, the flysch deposits of the Lhoty Fm. as well as dark bituminous shales of the Veřovice and Spas Formations lain (Albian–Aptian). In the Grajcarek thrust-sheets of the PKB, the red shales of the Malinowa Formation (Turonian) are underlain by manganiferous black shales, green radiolarian shales and, locally, by radiolarites and spotted limestones of the Cenomanian Key Horizon (CKH). The CKH is underlain by up to 10 m of light grey, massive, marly shales with intercalations of sideritic limestone and pyrite concretions of the Opaleniec Formation (Albian–Cenomanian). There are also dark grey, marly shales with a few thin intercalations of micaceous sandstones from the uppermost part of the Szlachtowa Formation (Aptian–Albian).

The age of the Szlachtowa and Opaleniec formations, either Jurassic or Cretaceous, is the subject of a long-lasting (over 50 years) controversy. Debate was rekindled following a publication by Oszczypko *et al*. (2004), which provided new geological and palaeontological evidence suggesting a Cretaceous age for the above-mentioned formations in the same PKB sections in Poland and Slovakia. Subsequently, several publications appeared in response to our arguments, not least from supporters of a Jurassic age for these formations (e.g., Birkenmajer and Gedl, 2004; Birkenmajer *et al*., 2008). A culmination of these disputes is found in the discussions included in *Przegląd Geologiczny* (Gedl, 2008*a*–*c*; Oszczypko *et al*., 2008*a*, *b*). A further publication in support of a Jurassic age has now been forwarded by Gedl (2012).

Previous discussions have shown that both parties have, to a large extent, exhausted their arguments and their views remain unchanged. In such circumstances, fresh, compelling evidence from an integration of geological, palaeontological, sedimentological and geochemical data are required to enable further progress in this field of research. Our aim here was to trace the changes in the geochemical profile of the Szlachtowa, Opaleniec and Malinowa formations (see Wójcik-Tabol and

Oszczypko, 2010, 2012). The results of this research were used for comparison with similar deposits of the more external nappes of the Polish Outer Carpathians.

GEOCHEMISTRY

A group of major and trace elements was studied in the Grajcarek thrust-sheets. Due to the lithological similarity between these sequences and others from the Tethys Ocean, geochemical indicators (V/V+Ni and U/Th ratios; concentrations of Mo, Cu, Zn, Ni, Co and relative to the contents of S and organic matter) were applied to determine a correlation between them. In sum, the Szlachtowa and Opaleniec formations appeared similar to the Verovice and Lhoty formations from the Outer Carpathians and to the Kapuśnica Fm. from the PKB. These are considered as a record of an Early Cretaceous event of wide-spread oxygen deficiency (OAE 1). The Cenomanian Radiolarian Shales resemble the Barnasiówka Fm. and Magierowa Mbr that represent the CKH in the Outer Carpathians and PKB. Therefore, an interpretation of these as the Cenomanian-Turonian anoxic deposits that resulted from OAE 2 is reasonable. The transition of organic-rich deposits to red marls, the facies of the CORB, reflects a global change in deposition involving a rise in oxygen content, a drop in organic productivity, climate cooling and so on (Wójcik-Tabol and Oszczypko, 2010).

The main aim of Wójcik-Tabol and Oszczypko (2012) is to demomnstrate the chemical pattern through this sedimentary succession. The absolute contents of major and most trace elements are not reliable for age estimation. The expectation that the amounts of redox-sensitive elements (e.g., V, Ni, Cr as proposed by Gedl, 2012) remain independent, following syn- and post-depositional processes. Therefore Wójcik-Tabol and Oszczypko (2012) showed trends, e.g., the enrichment/depletion of particular elements and inter-elemental relations represented by Pearson correlation coefficients (r). In this way, the Hulina Fm. appears similar to other Cenomanian Radiolarian Shales due to the exhaustion of LILE (Large Ion Lithophile Trace Elements) and HFSE (High Field Strength Elements), relative to the underlying deposits and regardless of the variation in absolute contents of elements in samples from various exposures. Therefore, the suggestion that the interpretation of the Hulina Fm. geochemistry is discrepant does not hold and can not be confirmed.

However, the clay mineral composition in the Szlachtowa and Opaleniec formations is not unusual as regards Carpathian strata, though it is not true that clay mineral assemblages remain invariant in turbiditic deposits (e.g,. Gucwa and Ślączka, 1984; Dziubińska, 2010). In illitisation, kaolinite is relatively resistant and its transformation into illite triggers a negative feedback. More common in fine-grained deposits is the illitisation of smectite, that increases as diagenesis progresses. Note, Wójcik-Tabol and Oszczypko (2012, p. 177) wrote about compositional, and not thermal maturity!

The supposed controversy over the anoxity of the Szlachtowa and Opaleniec formations, may easily be explained by their comparison to other deposits in which anoxia is generally accepted. Indeed, the Veřovice Formation, about 200 m thick, is considered as an example of an anoxic deposit. However, thin intervals of light coloured, bioturbated strata occur locally in this and indicate brief dysaerobic events. This suggestion was supported by ichnofossils and dinoflagellate cyst data (Cieszkowski *et al*., 2001), organic geochemistry (Golonka *et al*., 2008), and stable carbon isotopes of organic matter (Smaržová and Skupien, 2010).

The doubts voiced by Gedl (1012) are therefore surprising because he in fact discusses the Veřovice Fm. Moreover, sediments with ichnofabrics occur frequently in Carpathian successions, though, one should add that they are not called Fleckenmergel facies. Wójcik-Tabol and Oszczypko (2012) wrote about the pyrite concretions in the spotted marls of the Opaleniec Fm. The pyrite framboids arise at the redox boundary (Wilkin *et al*., 1996), which separates the H_2S-bearing water from oxic water and usually occurs below the sediment-water interface. Therefore, our statement concerning anoxia represented within the Szlachtowa and Opaleniec formations remains valid.

THE LATEST GEOLOGICAL RESULTS

Geological progress has also been made in the Małe Pieniny Mts. in Poland and in the adjacent area to the east of Lubovnanska Verchovina in Eastern Slovakia (Oszczypko *et al*., 2010; Plašienka and Mikuš, 2010). These studies have showed that within the PKB, and beneath the Pieniny and Sub-Pieniny *s.l.* nappes, deposits of the Grajcarekth rust-sheets as well as the so-called "Autochthonous Magura Paleogene" are exposed in tectonic windows. In the eastern sector of the Slovak PKB, as a counterpart to the Grajcarek thrust-sheets, the Faklovka and Sariš units have been distinguished. From these studies, one can interpret that the presence of the Szlachtowa Formation at the base of the Czorsztyn, Niedzica, Czertezik and Branisko successions may well be of tectonic origin as opposed to the stratigraphic interpretation previously made (Birkenmajer, 1977; Gedl, 2012).

New and important evidence of a Cretaceous age for the Szlachtowa and Opaleniec formations has paved the way for integrated geological and palaeontological research, as already conducted around of Litmanowa and Jarabina in the PKB of Eastern Slovakia (Plašienka *et al*., 2012; Plašienka, 2012). This research is a direct extension of that carried out within the Małe Pieniny Mts. in Poland and was carried out a few miles SE of the Polish-Slovakian border. This area has already been investigated by the boreholes Jar 1 and Jar 2 – hence, the Sub-Pieniny Nappe, which is 20–40 m thick and represented by the Czorsztyn and Niedzica-Czertezik successions, is flatly overthrust onto the Sariš (Grajcarek) Unit (Plašienka *et al*., 2012). In the Jar 1 borehole (see Plašienka *et al*., 2012, figs. 2, 4, 8), 200 m deep, the Sariš (Grajcarek) Unit is represented by 3 moderately dipping thrust sheets. The upper thrust sheet, which is approximately 50 m thick, is represented by the Jarmuta and Malinowa (upper Turonian–Coniacian) formations as well as by "black flysch" – shales and micaceous sandstones (?Szlachtowa Fm.). The middle thrust-sheet, *ca*. 40 m thick, is composed of the Malinowa Fm. (Cenomanian–lower Turonian) with "black flysch"-black shales and micaceous sandstone of upper Albian age (?Szlachtowa Fm.). The lowermost thrust-sheet is composed of the Malinowa Formation (Turonian–Santonian) and underlain by upper Albian–lower Cenomanian dark grey shales (probably the Opaleniec Fm.).

The results of this new geological research in the PKB of Eastern Slovakia (Plašienka *et al*., 2012; Plašienka, 2012) supports our earlier (Oszczypko *et al*., 2004, 2010; Wójcik-Tabol and Oszczypko, 2010, 2012) and present opinions on the Cretaceous age of the Opaleniec and Szlachtowa formations in the Polish and Eastern Slovakian sector of the PKB.

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