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Fossil karst in the Jurassic of the Kościuszko Mound in Kraków (southern Poland): discussion

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Wójcik et al. (2015) wrote that pre-Quaternary fillings of the karst cavities in the Jurassic limestones beneath the Kościuszko Mound are Upper Cretaceous and Middle Miocene marine sediments. However many already published facts neglected by the Authors as well as critical analysis of their paper makes their conclusions highly dubious.

Although the drillings studied by Wójcik et al. (2015) aimed, i.a., to recognize the geological structure before designation of a tunnel on "Zwierzyniecka Route", the authors neglected three boreholes drilled along the preliminary course of the tunnel, i.e., 550 metres eastward from the Kościuszko Mound. Drillings T1, T2 and T3 (completed in 1975 by the HYDROGEO Co.) were marked in the map published by Felisiak et al. (2005: fig.1) cited by Wójcik et al. (2015). A part of the original map from Felisiak et al. (2005) is presented as Figure 1, only the names of the boreholes were supplemented. Stratigraphic symbols of sediments underlying the Quaternary strata were left unchanged, even if some have become outdated. The Miocene marls and the oyster limestones, included previously into the Karpatian, are recently interpreted as sediments of the first phase of Badenian transgression (Pilarz and Olejniczak, 2013).

The green clays known from the T3 borehole, belong to the deposits of the middle level of pre-mid-Miocene (Oligocene–Early Miocene?) karst (Felisiak, 1992), filling sub-Miocene karst valleys. Such a best-recognized palaeovalley was found in underground workings of the Matylda Zn-Pb ore mine in Chrzanów (Panek and Szuwarzyński, 1976), which enabled its unique 3D reconstruction. The 3 kilometres long valley had incised down to nearly 70 m into the Triassic carbonate formation at the western margin of the Kraków Upland. The valley was filled with the residuum left after karstification of the Jurassic limestones, and by the Miocene oyster limestones (as in the T3 borehole; Felisiak, 1992: fig. 3). The horizontal karst conduits at the bottom level of the valley are connected with the sediment-filled sinkholes located in the upper, gentle slopes of the valley. In Kraków, the sediments of the middle level of pre-mid-Miocene (Oligocene–Early Miocene?) karst are located at the elevation of 180–230 metres a.s.l., similarly to those identified by Wójcik et al. (2015) as fillings of pre-Quaternary, horizontal caves. These facts demonstrate that data from the T1 to T3 boreholes must be taken into account if anyone attempts to explain the origin of karst features in the nearby G1 to G4 boreholes.

All samples of greenish-grey clay with calcareous debris (below named briefly "the greenish-grey clay") are marked Cr_m – Maastrichtian in figure 3, though the only one quoted as Maastrichtian in the text originates from the 2G borehole (depth 63.9 m). In that sample, the authors identified four taxa of genus rank and two species of foraminifers (table 1), from which the only one suitable for age determination seems to be *Abathomphalus mayaorensis* (Bolli). However, this is a Tethyan species, which has not been identified in Poland out of the Carpathians (Dubicka and Peryt, 2012). Furthermore, photographic documentation of this microfossil is more than insufficient because it lacks the most characteristic, ventral side and the side view (Wójcik et al., 2015: fig. 5B). Undoubtedly, Campanian is the age of fauna identified in a sample collected from the 1G borehole at 18.8 m depth, also marked as Maastrichtian in figure 3, but left uncommented on in the text. The fauna assemblage includes the foraminifer *Globorotalites michelinianus* (table 1), which points out to a stratigraphic interval not younger than the Middle Campanian (Inoceramus tenuilineatus Zone; Peryt and Dubicka, 2015). Moreover, this foraminifer was derived from sediment located higher in elevation than above-mentioned *Abathomphalus mayaorensis* (Bolli) and closest to the erosional top surface of the Jurassic formation. It suggests deposition of Maastrichtian clay deeply in the limestone massif through karst conduits filled yet with Campanian sediment. The authors wrote (p. 68) that the Maastrichtian greenish-grey clay does not contain sand in spite of the younger karst sediments described in the literature (Gradziński, 1962; Felisiak, 1992). However, the absence of sand admixture in the greenish-grey clay is very unusual because sand fraction is a typical component of true Maastrichtian marine rocks (Jurkowska, 2016).

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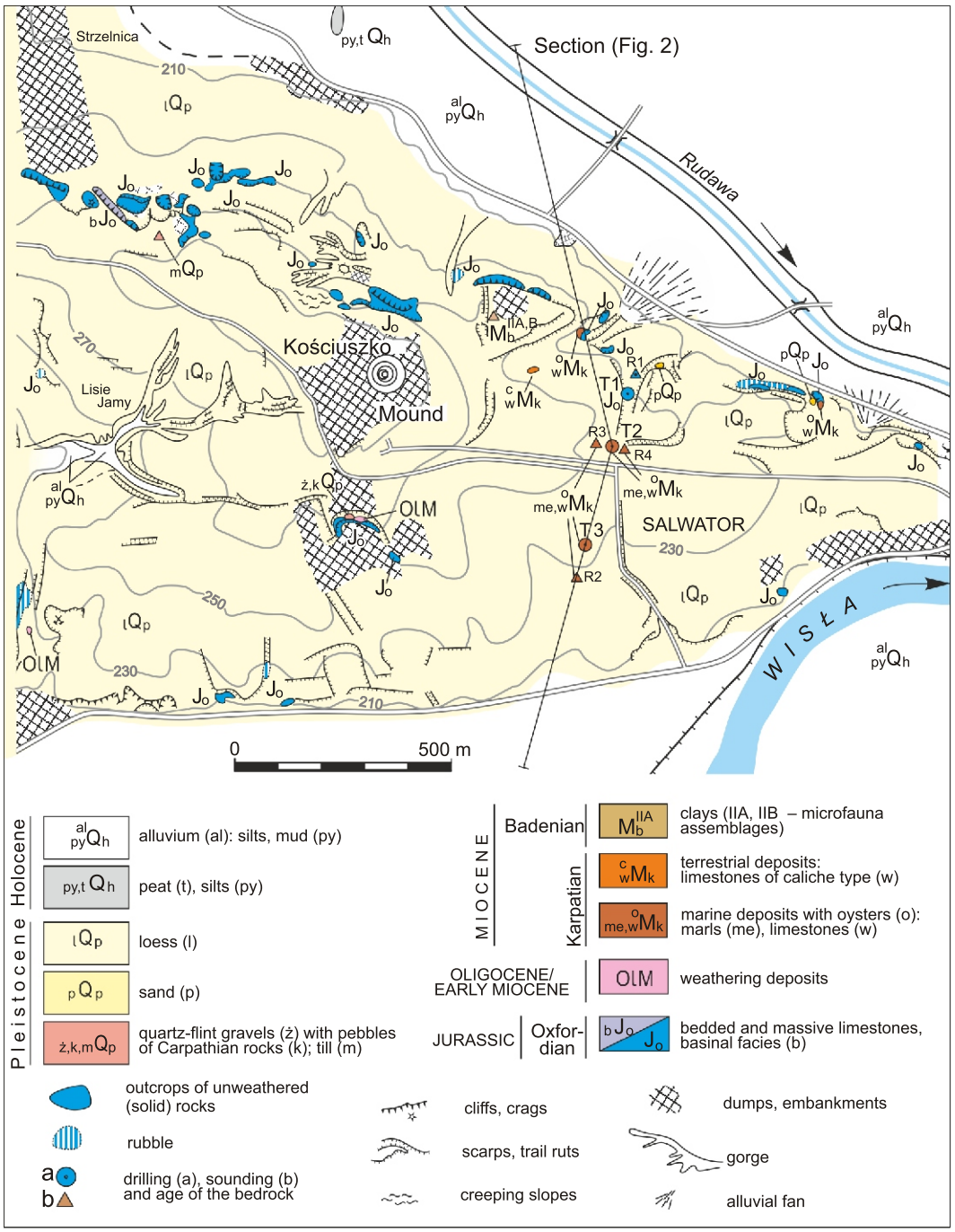

Fig. 1. Geological map of the St. Bronisława Hill after Felisiak et al. (2005; modified)

The cross-section (Wójcik et al., 2015: fig. 4) was drawn in a manner that supports the pre-Badenian age of faults; thus, the bottom surface of the Miocene formation is drawn totally flat under the Rudawa River valley, where no observations could be made, and is cut through by the faults. Moreover, the faults cut also the Quaternary strata in terraces of the Vistula and Rudawa rivers on both sides of the Lasek Wolski Hill. Such position of the faults is in conflict with, i.a., numerous outcrops of Miocene littoral structures and oyster limestones (Felisiak et al., 2005: fig. 1). Their presence proves that the recent foothills of the Las Wolski Hill represent mostly the uncovered rocky coastline from before 11 Ma. This problem has already been discussed by Dżułyński (1953) and by Radwański (1968: 415) who illustrated his concept with a meaningful photograph (Plate II) of the Vistula River bed seen in the south-east corner of the study area. However one sector of the cross-section drawn by Wójcik et al. (2015: fig. 4) differs significantly, just in the area of landslide in Spadzista Street, where the authors gained more field observations. Between Królowa Jadwiga Street and the 1G borehole in figure 4, Miocene clays – clearly younger than the fault – are deposited onto the strongly incised top surface of faulted Jurassic limestones.

Wójcik et al. (2015: 68) consider two potential processes of formation of karst conduits, earlier than Paleogene. The first, "classic" concept calls the subaerial conditions that occurred generally in the Early Cretaceous. The authors ignore the rule that the karst conduits, being in connection with the Earth surface (open upward), like other depressions of the terrain, must

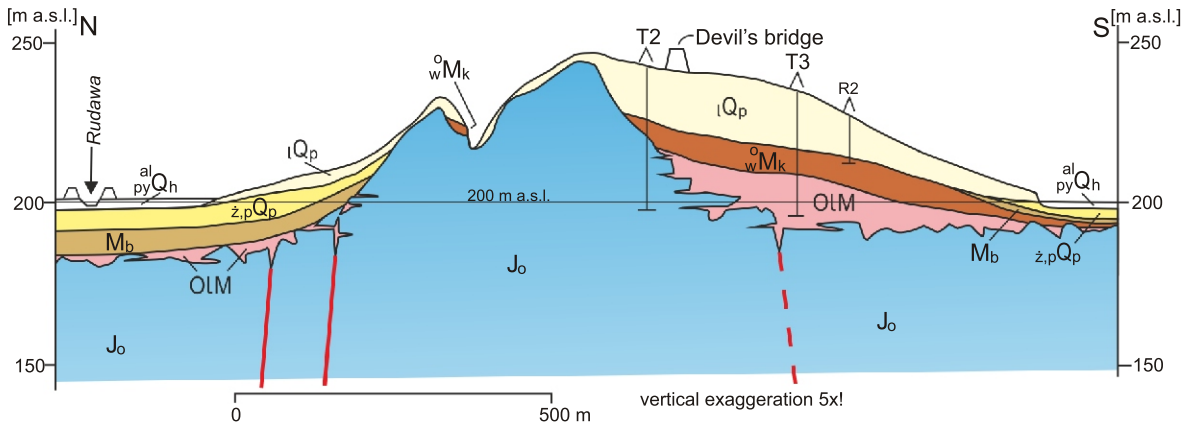

Fig. 2. Cross-section of the St. Bronisława Hill along the preliminary course of the tunnel of "Zwierzyniecka Route", 550 m east of the Kościuszko Mound

ż,pQp – Pleistocene alluvial deposits; ż – conglomerates, s – sands; other explanations as in Figure 1

have been filled with sediments at the latest at the beginning of the transgression. In the Kraków area, such conduits were filled with the well-known Cenomanian and latest Turonian?/Early Coniacian conglomerates (Kołodziej et al., 2010). The oldest Santonian and Campanian sediments have never filled the vertical fissures penetrating through the top of the Jurassic formation in a way observed in Cenomanian conglomerates (cf. Felisiak, 1995a; Kołodziej et al., 2010). Moreover, at the latest since the Campanian, the whole study area was successively covered by marly sediments of the recent thickness up to 50 m (Rutkowski, 1993: borehole no. 20). Despite these facts, Wójcik et al. (2015) claim that "Karst channel filling might have occurred during the Late Cretaceous submergence (Campanian–Maastrichtian)".

The second formation process of the karst conduits prior to the Paleogene could be the submarine karst developed in the mixing zone of fresh and saline waters along the coastline. However, the formation of karst conduits requires the hydraulic gradient, i.e., the rocky coast built of Jurassic limestone must have been at least several metres high whereas the authors need cliffs at least 100 m high, as revealed by their figure 3. The authors do not provide the age of this karst. Gradziński (1962: 480) concluded that "At the end of the Jurassic and during the Cretaceous the lack of larger elevation drops does not facilitate the development of large-scale karst circulation", and I consider this opinion still valid as it is consistent with the realities of Mesozoic stage of geological evolution of the Kraków area.

CONCLUSIONS

1. The greenish-grey clay with calcareous debris filling karst cavities recorded by Wójcik et al. (2015) is not Late Cretaceous marine sediment. There is no evidence that Maastrichtian sediments were deposited with an onlap/overlap unconformity directly upon a Jurassic bedrock, which was suggested by Wójcik et al. (2015).

2. The greenish-grey clay with calcareous debris does not correlate strictly with the green clays with flints known from the T3 borehole. Instead, this clay probably corresponds to somewhat younger, freshwater green and grey clays grading laterally into marls and caliche-type limestones belonging to the (former) Karpatian (Felisiak, 1995b). Common features of these sediments are: colour, absence of sand fraction, marly character (facilitating redeposition of microfauna) and Santonian-Campanian age of the source rocks.

3. Microfossils identified within grey calcareous silts indicate high variability of depositional environment, typical of oyster limestones (see Radwański, 1968). Grey calcareous silts originate probably from redeposition of fine-grained fraction of these deposits. The silts were deposited through subhorizontal conduits which were partly cleared of the clays during a short uplift of the study area between the first and the second phase of Badenian transgression. The infilling might have taken place during the rise of erosional base caused by the approaching second phase of the transgression.

4. The subhorizontal caves described by Wójcik et al. (2015) perfectly document the depth of the pre-Badenian palaeovalley of the Rudawa River. The valley is incised into the Jurassic limestones down to at least 100 m depth, i.e., 10 m deeper than Felisiak (1992) could document in the Zabierzów area. Again, the studies confirmed the principle of Gradziński (1962: 475) concerning the origin of caves in the Kraków Upland: "..the development of caves and the incision of valleys must have been roughly contemporaneous".

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