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Middle Pleistocene carbonate-cemented colluvium in southern Poland: Its depositional processes, diagenesis and regional palaeoenvironmental significance

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ABSTRACT

A colluvial origin is postulated for the enigmatic relic mantle of immature, carbonate-cemented rudites on the bedrock slope of Kraków Highland, preserved in the area of Kwaczała Gullies. The deposits comprise four sedimentary facies: (A) sporadic clast-supported openwork conglomerates; (B) predominant matrix-supported massive conglomerates, some with a coarse-tail normal grading; (C) subordinate sheets of parallel stratified and/or ripple cross-laminated fine-grained sandstones; and (D) local coarse-grained sandstones with gently inclined parallel stratification. The ^{230}Th–U dating of sparry calcite cements points to the penultimate Odranian/Warthanian interglacial. The debris was derived from local bedrock, inferred to have been frost-shattered in permafrost conditions during the Odranian glacial. Colluvial resedimentation was triggered by the rapid change in environment conditions brought by early deglaciation. Dense-snow/slush flows and slush-laden watery debris flows are thought to have transferred limestone debris from the upper to middle hillslope, where siliciclastic sand matrix was incorporated and solifluctional creep prevailed, accompanied by slope sheetwash processes. Carbonate cementation of the talus occurred in phreatic conditions during the penultimate Odranian/Warthanian interglacial (marine isotope stage 7), when soils formed and local springs supplied carbonate-saturated groundwater. The patchy preservation of cemented colluvium indicates its erosional relics. The Pleistocene colluvial mantle in the Kraków Highland was probably extensive, but was removed by subsequent erosion where non-cemented.

1. Introduction

Colluvial (talus) slope-waste sedimentary systems are associated with the foot zone of steep bedrock slopes or other topographic escarpments. These systems have a small aerial extent, but may be several tens of metres thick and are known to occur worldwide from the polar to equatorial regions. The preservation potential of colluvium may be low, but documented stratigraphic occurrences range from Quaternary to Precambrian (see review in Nemec and Kazancı, 1999).

The surficial aspects of modern colluvial systems have long been studied by physical geographers and geomorphologists, but the resulting sedimentary facies successions and their ancient counterparts have only recently attracted detailed sedimentological research (Blikra and Nemec, 1993a, 1993b, 1998; Nemec and Kazancı, 1999). Colluvial processes depend strongly on the geological nature and climatic conditions of the local slope, and may thus involve debris falls or rockfalls, high- to low-viscosity debris flows, channelized or unconfined water flow and possibly also aeolian sand deposition (Blikra and Nemec, 1998; Nemec and Kazancı, 1999; Ventra et al., 2013). The colluvial sedimentation is highly episodic, and hence is effectively "sampling" the slope climatic conditions and possibly recording their significant changes (Blikra and Nemec, 1998; Blikra and Selvik, 1998; Nemec and Kazancı, 1999; Aa et al., 2007; Decaulne et al., 2007; Sletten and Blikra, 2007; Stoffel et al., 2008; Matthews et al., 2009). Therefore, colluvial successions may serve as a valuable proxy record of terrestrial climate and climatic changes (Blikra and Nemec, 1998; Nemec and Kazancı, 1999; Sanders and Ostermann, 2011).

The vast majority of Quaternary colluvial deposits in the world is non-cemented, and thus is commonly subject to open-pit mining for road construction purposes in rocky terrains (e.g., Blikra and Nemec, 1998). Cases of calcrete- or tufa-cemented colluvium are indicators of specific local slope conditions (Kotański, 1958; Pentecost, 1993; Pentecost and Viles, 1994; García-Ruiz et al., 2001; Pentecost, 2005; Ostermann et al., 2007; Sanders et al., 2010a,b; Sanders and

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Ostermann, 2011). Such colluvia are often dominated by rockfall deposits and referred to as cemented rudites or slope breccias, with the carbonate precipitates considered to be calcareous tufa (meteogene travertine sensu Pentecost, 2005) and suitable for dating by the ^{14}C and U-series isotopic methods (García-Ruiz et al., 2001; Gradziński et al., 2001; Ostermann et al., 2006; Sanders et al., 2010b; Sanders and Ostermann, 2011).

A specific and controversial case of such a carbonate-cemented colluvium occurs in the south-western part of the Kraków Highland, south-central Poland. These deposits have been studied since the second half of the 19th century, and were initially recognized not as a young colluvium, but as a part of the Permian conglomerates occurring in the Kraków Highland (Tietze, 1884). Zaręczny (1894) was the first who suggested that they were Quaternary in age. Siedlecki (1952, 1969) postulated their age to be Pliocene or early Pleistocene and implied their origin as slope-waste deposits predating the Pleistocene loess in the area. Gradziński (1972, p. 119) suggested that these "Quaternary conglomerates" were a cemented mantle of weathered bedrock debris. Płonczyński and Łopusiński (1993) considered these deposits to be a slope-denudation residuum. However, neither the exact age nor depositional environment of these cemented rudites has thus far been determined.

These two contentious issues are addressed by the present study on the basis of field investigation and laboratory stable-isotope analyses. The study also sheds new light on the specific and rather unique diagenetic conditions of these deposits, which may explain why the pre-Vistulian colluvium in the highland region is so sparsely preserved.

2. Geological setting

The cemented rudites crop out in small south-trending ravines known as the Kwaczała Gullies (Wąwozy Kwaczalskie in Polish) in the south-western part of the Kraków Highland (Fig. 1). The steep-sided gullies lack perennial water courses, with a flow of water only due to heavy rains and spring snow thaw. They are up to 15 m deep, incised in bedrock slopes inclined at ca. 5–10° to the south. Bedrock consists

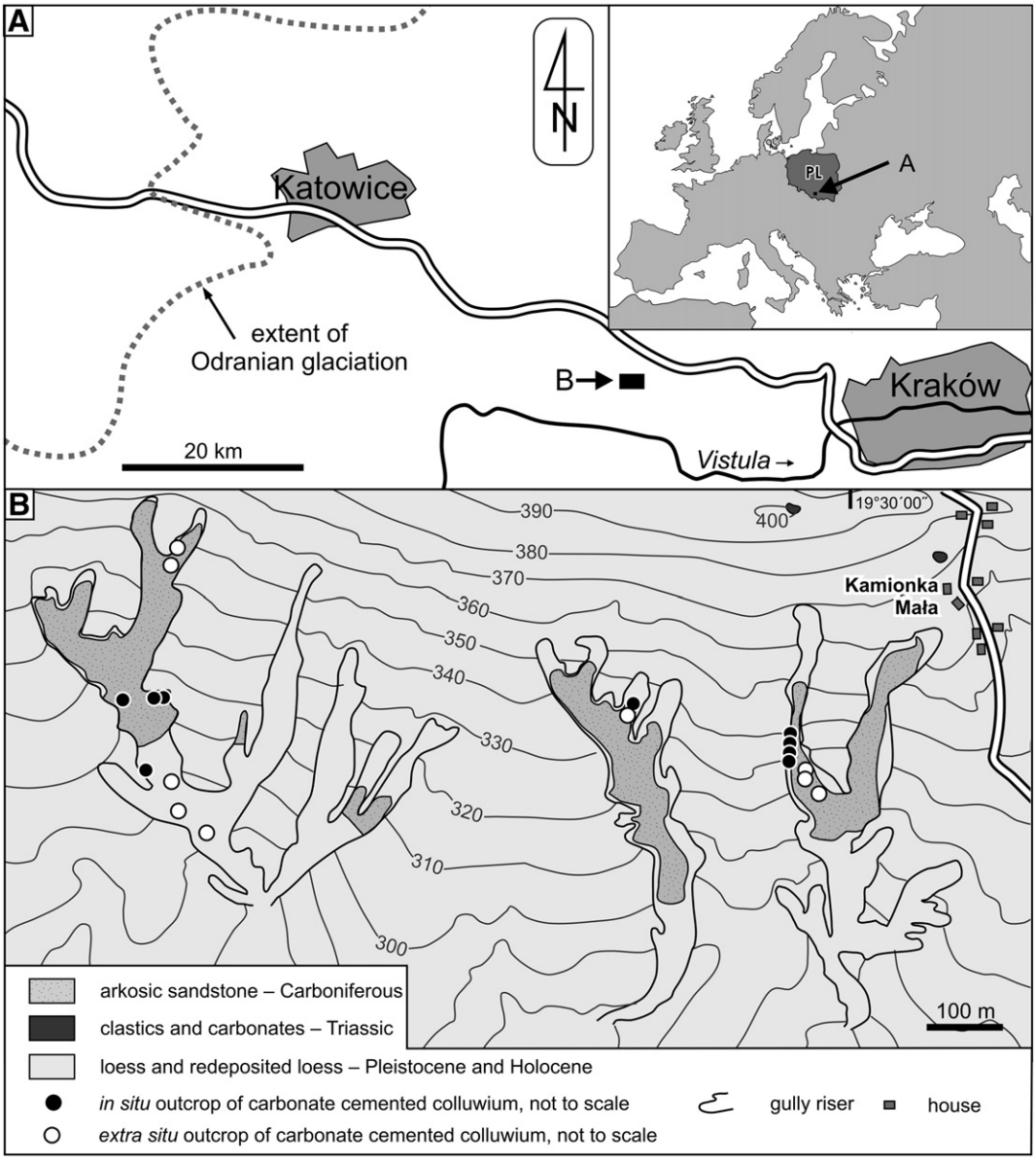

Fig. 1. (A) Location of the study area in southern Poland, showing also the local extent of Odranian ice-sheet margin. (B) Topographic map of the study area of Kwaczała Gullies, showing surface geology (after Żero, 1956 and Płonczyński and Łopusiński, 1988, modified) and the location of *in-situ* and *extra-situ* outcrops of the cemented colluvium.