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Sedimentation of Holocene tufa influenced by the Neolithic man: An example from the Sąspowska Valley (southern Poland)

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A B S T R A C T

A complex of inactive tufas, the thickness of which reaches 3.5 m, was studied in the lowermost segment of the Sąspowska Valley in the Kraków Upland (Ojców National Park, Poland). Five fluvial tufa barrages were recognized. They are composed of moss tufa and stromatolitic tufa accompanied with oncoidal rudstone and detrital tufa. Interbarrage ponded areas were filled with detrital tufa, lutite, and subordinately oncoidal rudstone, limestone gravel and peat-like deposit. Radiocarbon dates suggest that the tufa formed during Subboreal, Boreal and Atlantic time. The main difference between the tufa in the Sąspowska Valley and contemporaneous tufas in other valleys of the Kraków Upland is the higher amount of non-carbonate fraction in the former. Other Lower and Middle Holocene tufas of the Kraków Upland are composed mainly or exclusively of carbonate fraction. The non-carbonate fraction in fluviatile tufas in the Sąspowska Valley resulted from erosion of loess cover in the upper part of the catchment. The erosion was related to local activity of Neolithic flint miners who cleared forest at a local scale, dug shafts in loess cover and exploited flints from underlying weathered residuum of Jurassic limestone. Consequently, they made copious amounts of loose material available for transport down the valley and subsequent trapping within the tufa depositional system.

1. Introduction

Tufa is a freshwater carbonate deposited chiefly in headwater streams (Ford and Pedley, 1996; Capezzuoli et al., 2014). This type of deposits is known also under the name of (meteogene) travertine (Pentecost, 2005 and literature quoted therein). Tufa originates in a wide range of freshwater environments from swamps with stagnant water, throughout calm-water pools, to fast flowing watercourses and vertical cascades. Hence, depending on environmental conditions different facies types originate (Pedley, 1990; Vázquez-Urbez et al., 2012; Arenas et al., 2014). Tufa faithfully records hydrological and climatic changes in its geochemical parameters (e.g., Andrews, 2006; Dabkowski et al., 2012). Therefore, there is a growing interest in studying mechanisms which govern its growth (e.g., Pedley et al., 2009; Gradziński, 2010; Vázquez-Urbez et al., 2010) and in deciphering the palaeoenvironmental context of ancient tufa sections (e.g., Andrews et al., 1994; Vázquez-Urbez et al., 2012).

Many authors have postulated a close link between a decline of tufa sedimentation and prehistoric man activity. Goudie et al. (1993) have listed and thoroughly discussed 26 hypotheses explaining the decline of tufa growth in Late Holocene time. The hypotheses assume several mechanisms which led to changes of water chemical composition and intensified surface runoff which in turn controlled chemical and physical degradation of tufa. The majority of the 26 hypotheses concerns the inhibitory role of human influence on tufa deposition mainly due to deforestation. Later on, such a role has been suggested for tufa degradation in many regions (see reviews by Capezzuoli et al., 2014; Dabkowski, 2014).

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For instance, Preece and Day (1994), Preece and Bridgland (1999) and Meyrick and Preece (2001) have blamed humans for erosion of tufa in the Late Holocene in England. Similarly, Pedley (2009) postulated human influence on cessation of tufa growth in the Mediterranean region, Luzón et al. (2011) in the Iberian Range (Spain), González-Amuchastegui and Serrano (2015) in the Upper Ebro Basin (Spain) and Gradziński et al. (2013) in the Slovak Karst (Slovakia). Carthew and Drysdale (2004) have reached similar conclusions studying tufa in New South Wales (Australia). Hence, it seems very probable that human activities negatively impacted tufa growth in many parts of the world.

Conversely, there is a limited number of examples illustrating such an influence of humans which did not cause tufa destruction but only affected tufa sedimentation. The most common and obvious examples concern precipitation of tufa in artificially created channels and pipes. Carbonates grow in channels constructed to distribute water in many regions of the world during a wide time span ranging from the Roman period to recent times (Pentecost, 2005, p. 106; Sürmelihindi et al., 2013a, 2013b). Tufa formed due to invasion of CO_2 in water artificially contaminated with slaked lime may serve as another example (e.g., Pentecost, 2005, p. 308).

This paper discusses a case of natural tufa depositing system which was substantially affected by the Neolithic man. The system is probably one of the oldest known examples of human influence on natural environment, which was recorded in freshwater calcareous deposits.

2. Study area

The tufa complex under examination is located in the Kraków Upland (southern Poland, Fig. 1A). Valleys oriented mainly meridionally are entrenched into resistant carbonate rocks of Devonian, Lower Carboniferous and, mainly, Jurassic age (Gradziński et al., 2008 and references quoted therein). Their uppermost segments are wide and have gentle slopes, whereas their middle and lower segments are narrow with limestone crags on the steep slopes. The valleys developed during the Neogene period and were deepened during the Pleistocene (Dżułyński et al., 1966). Holocene tufas were deposited in almost all the valleys (Szulc, 1984; Alexandrowicz, 2004, 2012). They are inactive now and underwent erosion in many places. The youngest tufa is of Late Holocene age, which was proved by radiocarbon dating (Pazdur et al., 1988). Thus, the tufas stopped growing in Late Holocene time. Subsequently, erosion of the tufas commenced and now they build distinctive accumulation terraces rising up to 9 m over the present riverbeds.

The Sąspowska Valley (Dolina Sąspowska, in Polish) is an 8 km long tributary valley which joins the Prądnik Valley in the Ojców National Park (Fig. 1). The Sąspowska Valley is incised into a karst plateau composed of Upper Jurassic limestones (Gradziński et al., 2008). Numerous limestone crags are located on the valley slopes. The plateau and valley slopes are covered with Pleistocene loess. It was deposited under cold and dry conditions of the Last Glacial Maximum and was subjected to redeposition during the permafrost decay at the end of the Last Glacial Maximum (Pawelec, 2006). Weathered residuum of Jurassic limestones occurs in some places on the plateau; it is mantled by loess cover. It consits of red clay and flints which locally are very numerous. The now inactive tufa deposit occurs in the lowermost segment of the valley (Lewiński, 1913; Alexandrowicz, 1983; Szulc, 1984; Gradziński et al., 2008; Ślusarz, 2010). It builds an extensive, almost horizontal terrace stretching along the stream for 0.5 km up the mouth of the valley (Fig. 2A). Some outcrops of tufa are scattered in steep terrace risers, which are up to 5 m in height (Fig. 2B).

Archaeological data prove that man has inhabited the Sąspowska Valley and the surrounding Ojców Plateau since the Last Interglacial. During warm periods of the Late Pleistocene cave dwellers occupied this area periodically, which is testified by various archaeological findings in caves, predominantly flint tools (e.g., Cyrek and Madeyska, 2016). Neolithic humans used this area only incidentally (Lech, 2006; Rydzewski, 2016). The first most extensive man activity was connected with Neolithic flint-mining during the Atlantic phase (Lech, 1981). Farmers did not use the upland area then (e.g., Lech, 2006; Kadrow, 2006). They occupied the fertile areas located to the south and east of the Ojców Plateau. Up to the Roman times (i.e., to the Subatlantic phase), the Ojców Plateau and its caves were used sporadically for short-stays, chiefly during unrest and threat times (Latałowa and Nalepka, 1987; Dobrzańska, 2006). Later on, the plateau was inhabited gradually by farmers, who have densely settled this area only from the early Middle Ages (Poleski, 1995; Kołodziejski, 2016).

3. Methods

The tufa outcrop was cleaned from weathered material, described, measured bed-by-bed and sampled. The sampling was kept to an absolute minimum, because the area is strongly protected as a part of the Ojców National Park. Additionally, 38 boreholes up to 4.5 m deep, were drilled in the tufa terrace using an Eijkelkamp hand-auger set. Twenty thin sections of tufa were observed under a petrographic microscope. Observation of textures was extended under scanning electron microscope (SEM) JEOL 5410 coupled with a microprobe Voyager 3100 (Noran). Before observation some small samples of tufa were coated with carbon. Fifteen samples were analyzed under SEM.

Contents of calcium carbonate were measured with calcimeter (Eijkelkamp) in 42 samples, which is based on Scheibler's method. Contents of organic matter were determined in eight samples based on the Walkley-Black's chromic acid wet oxidation method. The mineral composition of four samples was analyzed by powder X-ray diffractometry (XRD), using a vertical XPert APD Philips goniometer (PW, 1830).

A peat sample was analyzed in Gliwice Radiocarbon Laboratory, Poland (cf. Pazdur et al., 2003). Acid-Alkali-Acid (AAA) sample pretreatment was used for removing of impurities. Radiocarbon dating was carried out using Liquid Scintillation Counting (LSC) method after CO_2 conversion to benzene. Radiocarbon concentration was measured using ICELS system (Tudyka et al., 2010). Radiocarbon dating of 10 carbonate samples was conducted in the Laboratory of Absolute Dating in Skała, Poland. Carbon dioxide, obtained by acid treatment has been converted to benzene. Radiocarbon concentration measurements have been done using the scintillation technique by the low-background liquid scintillation counter of new generation, HIDEX 300 SL (Krąpiec and Walanus, 2011). Obtained radiocarbon dates have been calibrated using the OxCal 4.1.7 program and IntCal13 calibration data (Bronk Ramsey, 2009; Reimer et al., 2013; respectively). Sequence model has been used for profile samples. Modelled age distributions have been used for the construction of the age-depth models. Age-depth model was constructed using the MOD-AGE software (Hercman and Pawlak, 2012). It takes into account full distribution of age as well as depth error estimation. Depth uncertainties for the model construction were assumed at the level $\pm$ 2 cm (assuming normal distribution).

Mollusc shells and their fragments were found in the six layers of the compact tufa of the outcrop P. They were encrusted by hard variety of tufa and it was not possible to extract them without