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TRAVERTINE MOUND AND CAVE IN A VILLAGE OF LASKI, SILESIAN-CRACOW UPLAND

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Abstract: The paper deals with Holocene travertine mound occurring near Olkusz, southern Poland. The mound developed within a spring zone maintained by ascending groundwater, which drained the Muschelkalk carbonates. The travertines formed by intense calcification of the moss vegetation colonizing the spring area. The obtained radiocarbon ages indicate that the mound developed in early and middle Holocene times. Outwashing of the underlying sandy deposits resulted in a breaking of the travertine mound and involved development of a small cave within the mound.

Key words: travertine mound, moss travertine, palaeohydrology, radiocarbon dating, Holocene

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INTRODUCTION

In early ninetieth of the 20^{th} century a small cave has been found in a village of Laski near Olkusz, during the cave inventory works doing on the Silesian-Cracow Upland (Tyc, 1996; Tyc & Polonius, 1998). The cave occurs within highly porous Quaternary travertines. Because of the iron mineralisation the travertine was for a long time misinterpreted as the ore-bearing Triassic dolomite, that in fact occur in the region. The travertine differs from the other travertine deposits known from the southern Poland (Szulc 1983, 1984; Pazdur *et al.*, 1988a) with its hydrogeological setting and geometry. The presented study deals with the origin and age of the travertine and with genesis of the cave developed within the travertine mound.

GEOLOGICAL AND HYDROGEOLOGICAL SETTING

The travertine mound occurs in the NW outskirts of the village of Laski (Fig. 1) and reaches some 25 m in length and up to 3 m in height (Figs 2, 3). The travertine is underlain by 10 m thick middle Pleistocene fluvioglacial sand cover (Szczypek & Wach, 1989). The sands are also overlapping the travertine at the eastern and southern margins of the mound (Fig. 3). The Quaternary deposits are underbedded by the complex of Triassic rocks. The complex consists of Buntsandstein sandstones, Roet–Muschelkalk carbonates, and finally, the Keuper claystones (Fig. 4, 5; Śliwiński, 1964). Total thickness of the Triassic deposits does not exceed 200 m.

Such a cake-like geology of the basement rocks controls the hydrogeological properties of the discussed region. The porous-fissured-cavernous aquifer of Triassic carbonates is confined by overlying impermeable Keuper claystones. Unconfined porous aquifer developed within the cover of Quaternary sands. The both aquifers are divided by Keuper claystones (Motyka, 1988). The hydrogeological properties have resulted in the artesian condition and the groundwater orifices reached up to 7 m above the surface level (Figs 5, 6). Very intensive drainage followed the nearby lead-zink mine exploitation during the last 40 years, has depressed the ground water level below the artesian conditions.

The basement rocks are cut by complex system of faults

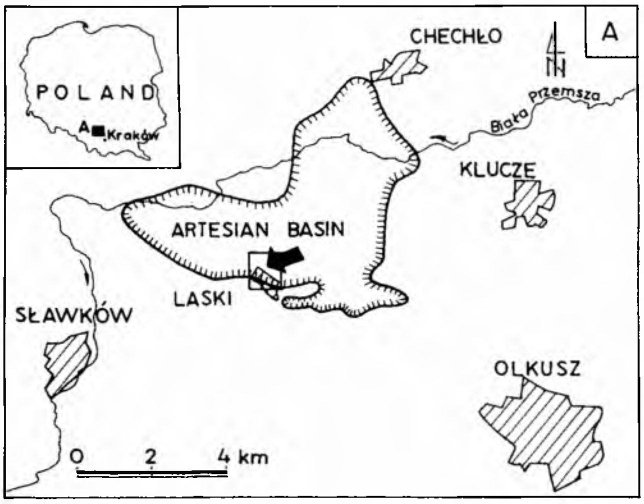

Fig. 1. Location map of the travertine dome (arrow), extent of artesian basin is indicated, rectangle shows area of Fig. 4

Fig. 2. View of the travertine dome from the south; note the exploitation pits

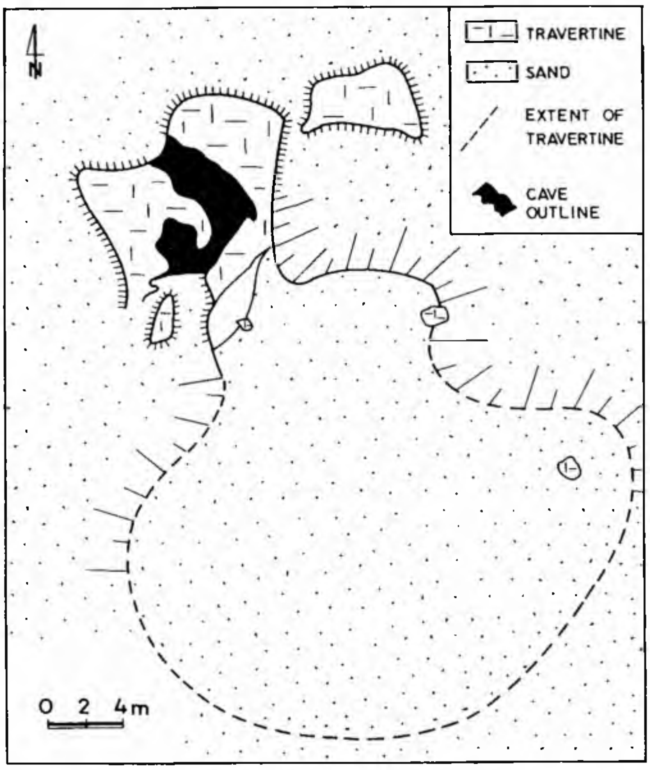

Fig. 3. Scheme map of the travertine dome, lateral extent of travertine carbonates under sands is indicated

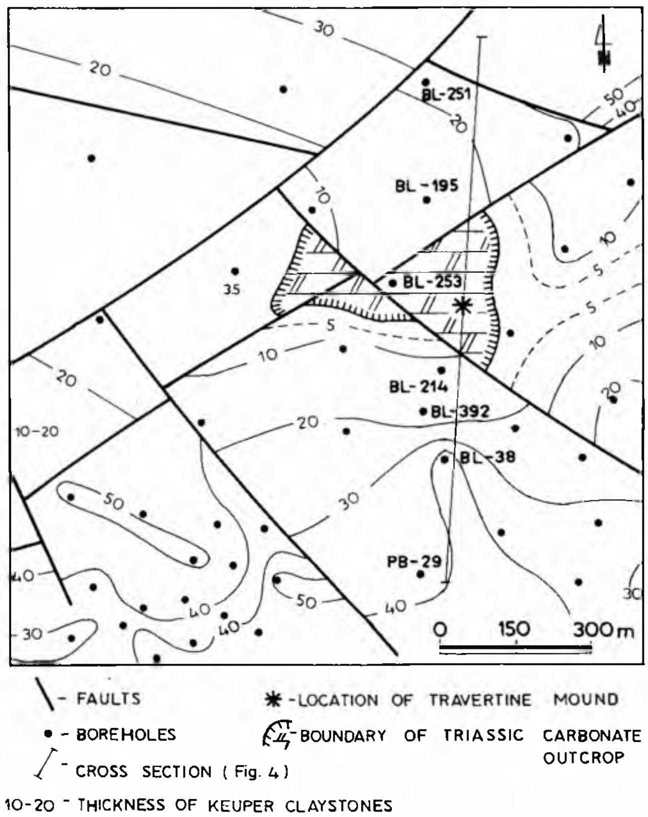

Fig. 4. Isopach map of the Keuper claystones (in meters)

reaching up to 25 m of displacement and resulting in small horst-graben network. One of the horsts, occurring directly beneath the travertine mound, has been erosionally devoid of the impermeable Keuper cover (Figs 4, 5). In this way this structures became a local hydrogeological window and conduit for the surfacing groundwater. The spring is told to exist yet in sixties 20th century. Afterward, owing to the mentioned industrial drainage, the groundwater level sank several tens meters down and nowadays the meteoric water percolates through the Quaternary sands into the Triassic conduits.

TRAVERTINE MOUND

The mound is constructed by porous but hard travertine (Fig. 7). The basic part of the travertine is made by light coloured highly porous sediments but some reddish lenses displaying more compact texture are quite common. Detailed study by means of light and scanning electron microscopy enabled to decipher some carbonate microfacies types building the travertine body.

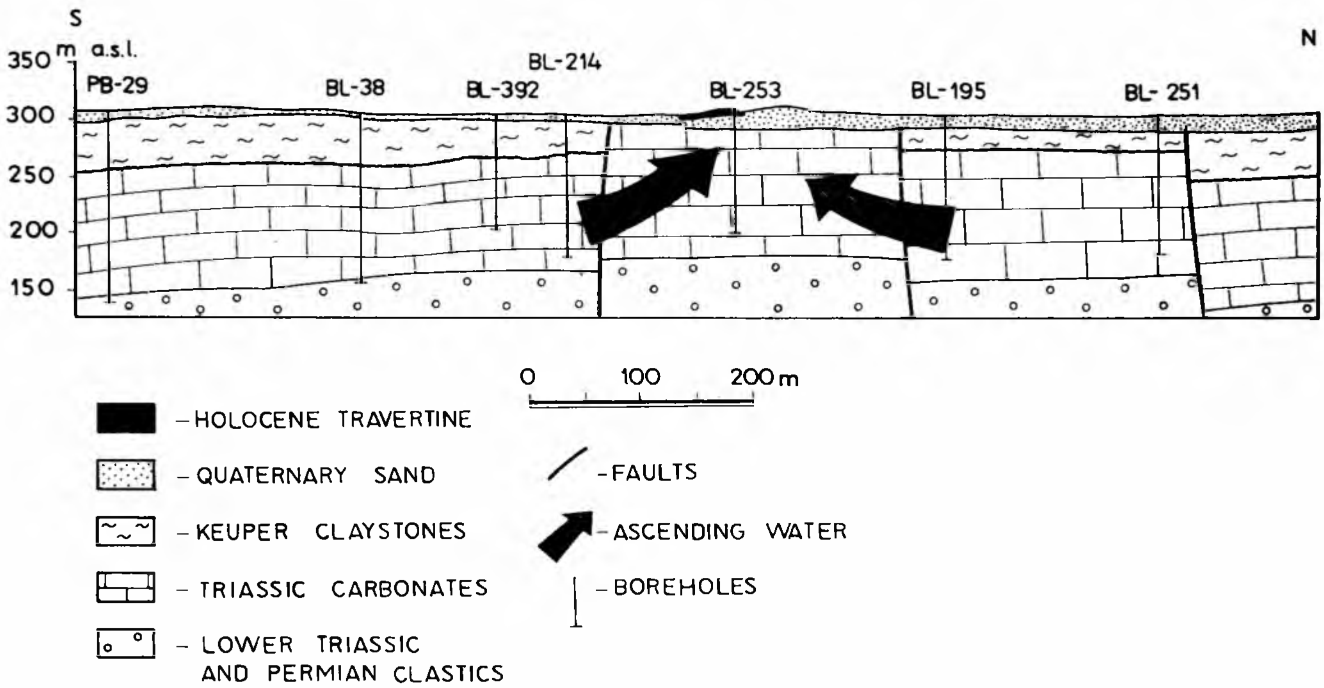

Fig. 5. Geological cross section of the study area

Fig. 6. Outflow of the artesian groundwater surfacing in the neighbouring area; photograph taken by Ryszard Gradziński in 1953

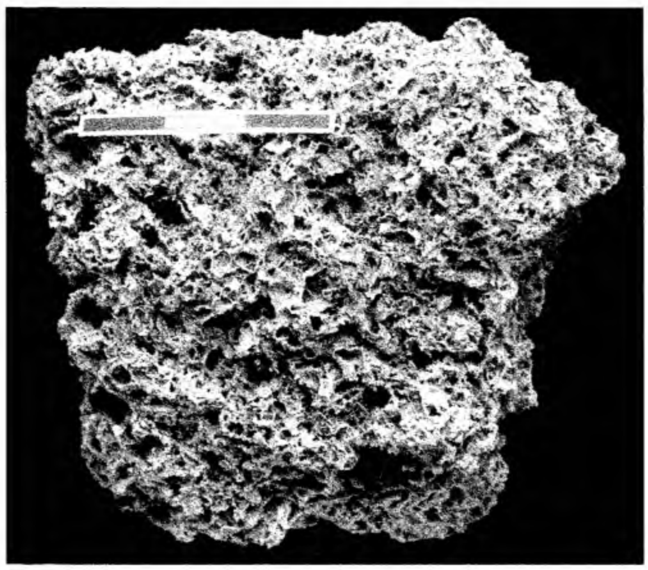

Fig. 7. Moss travertine with primary porosity, scale bar 3 cm

Moss travertine

The moss travertine forms the basic mass of the travertine buildup. The microfacies constructing the moss travertine are composed by micrite and sparitic calcite (Fig. 8). The micritic fabrics form 2–3 mm thin coating around the moss hypha (Figs 9, 10). Between micrite well preserved calicfied microbial (bacterial?) colonies are common (Fig. 11).

Habit of the sparitic crystals ranges from the isometric to columnar one (Figs 12, 13). The latter grows mostly within larger pores and form laminated crusts lining the pores. Similar crystals occur also in cave flowstones. Crystals size in the cement layers increases with the distance from the basic nucleation surface. This phenomenon reflects so called competition growth rule (Fig. 13; Bathurst, 1975 p. 422; González *et al.*, 1992). Most of the studied columnar crystals display rhombohedral tips but some sparitic layers, especially that from the cave flowstones covering the cave walls, display flat tips. Some other isometric sparite crystals occur in irregular patches within micritic matrix.

Beside the above discussed autochthonous carbonate deposits some clastic and/or intraclastic sediments are encompassed within the travertine mound. There are carbonate peloidal and intraclastic grains, claystone flakes and quartz grains derived from the nearby sandy deposits.

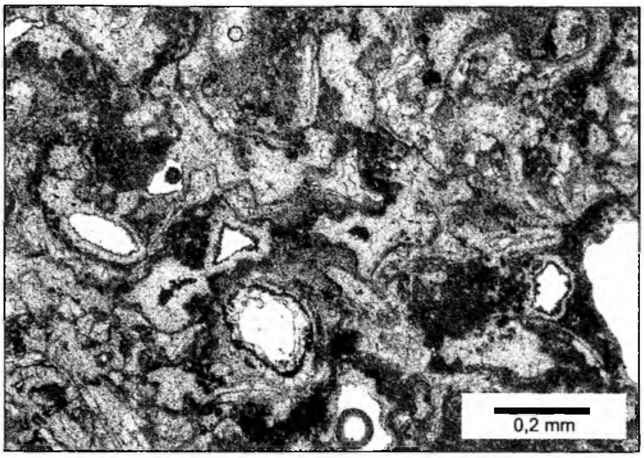

Fig. 8. Moss travertine, note the high proportion of sparitic cement, see text for further comments; thin section, II nicols

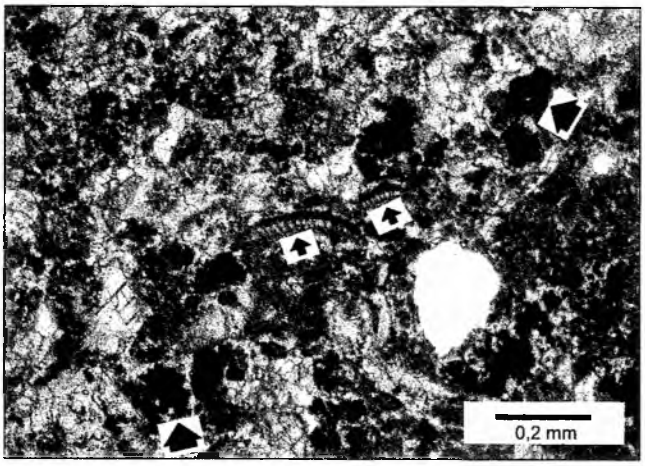

Fig. 9. Moss travertine with preserved remnant of moss fragments (small arrows) and ferrugineous agglomerates (big arrows); thin section, II nicols

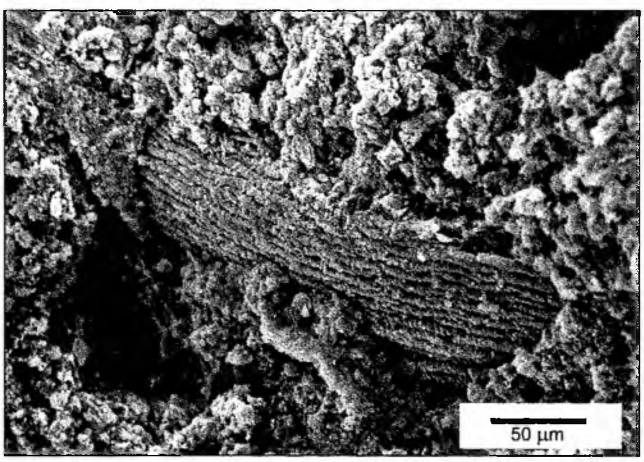

Fig. 10. Mold of moss stalk within calcite crystals; SEM image

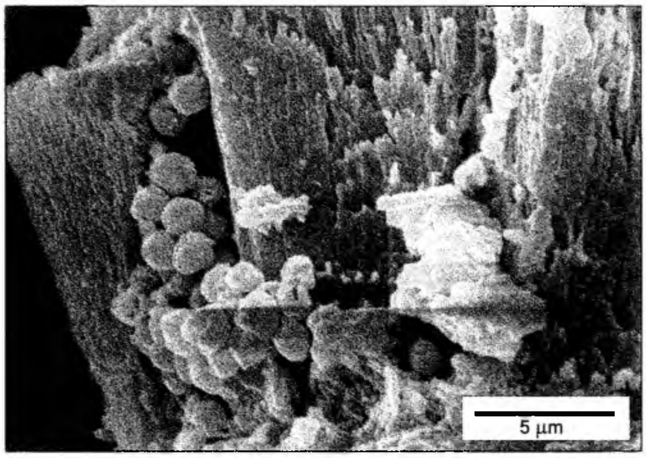

Fig. 11. Calcified microbial (bacterial?) cells dwelling moss colony; SEM image

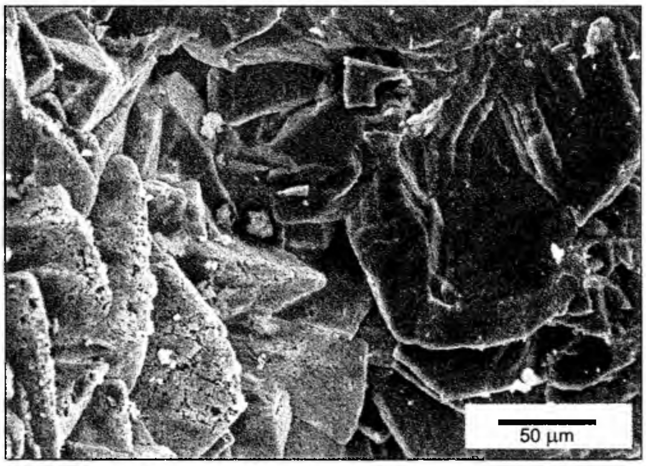

Fig. 12. Sparitic cement of moss travertine; SEM image

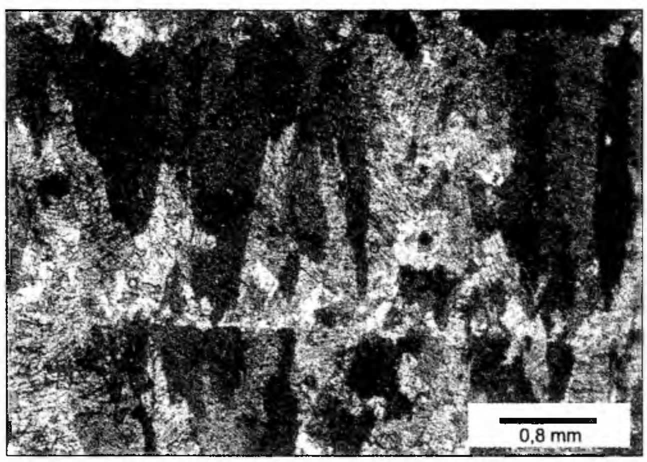

Fig. 13. Columnar calcite from the cave flowstone, note flat crystal terminations; thin section, X nicols

As noted above, some parts of travertine mound show red staining. The reddish colour comes from iron (hydro)oxides minerals, very common in the travertine mound. In the microscopic scale the amorphous (hydro)oxides display microglobular texture (Fig. 9). The iron (hydro)oxides comprise also Zn, Pb, Mn, Mg and Si – elements which are likely derived from the underlying ore-bearing Triassic rocks.

The moss travertine represents the primary mineral framework that originated by instant calcification of the hypha. The mosses may passively promotes calcification process since by the CO_2-uptake they drive pH of the ambient water >8 (Ikenbery, 1936; Szulc, 1983). Moreover, although the moss plants themselves do not actively participate in the calcite precipitation, they create a basement for colonization by epiphytic algae and bacteria, that can actively mediate in biocalcification processes. This process depends generally on $CaCO_3$ precipitation within the microbial polymeric mucus (Pedley, 1992). The biocalcification is essentially enhanced by algal and cyanobacterial photosynthetic processes driving pH of solution toward the alkaline range (Pentecost, 1991) and/or by intracellular mineralization of the microbes (Szulc & Smyk, 1994). The calcified microbe ghosts are discernable even in mature travertine deposits (Fig. 11). Owing to very fast calcification process, the moss organs are preserved within the mineral coating (Fig. 9, 10, Weijermars *et al.*, 1986). The globular fabrics of the iron components can be also interpreted as a product of bacterial activity (cf. Ghiorse & Ehrlich, 1992; Ehrlich, 1996). The ferric bacteria precipitated iron (hydro)oxides from the gel solution in the same way as can be observed recently within small streams draining the sands in the region.

Intrinsic porous nature of the moss colonies involves its high porosity even after the primary micritic calcification. During the subsequent penetration of the spring hardwater throughout the micritic framework, the sparitic calcite is chemically precipitated within the remnant pores. The sparite constructs the cement fabrics, making the mat more and more massive and dense (Figs 8, 12; Szulc, 1983; Pentecost, 1987).

Competition growth rule of sparitic crystals confirms the similar origin of the discussed cement and the cave flowstone columnar microfacies (Gradziński *et al*, 1997). Rhombohedral tips of crystals indicate their unconstrained free growth within a thick water layer (Broughton, 1983; Kostecka, 1993). Sparitic layers from the flowstones covering the cave walls displaying flat tips evidence that the flowstone precipitated from a thin adhesive water film upon the cave wall. In contrary, isometric sparite crystals occur in irregular patches within micritic matrix and probably resulted from micrite recrystallisation (Bathurst, 1975; Love & Chafetz, 1987).

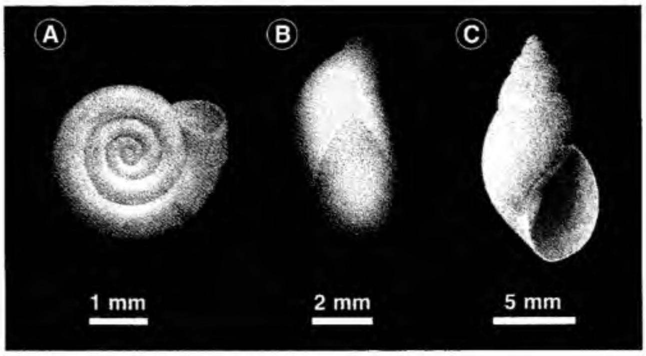

Fig. 14. Chosen snail found within the travertine: A. *Anisus spirorbis*, B. *Succinea putris*, C. *Lymnea truncatula*

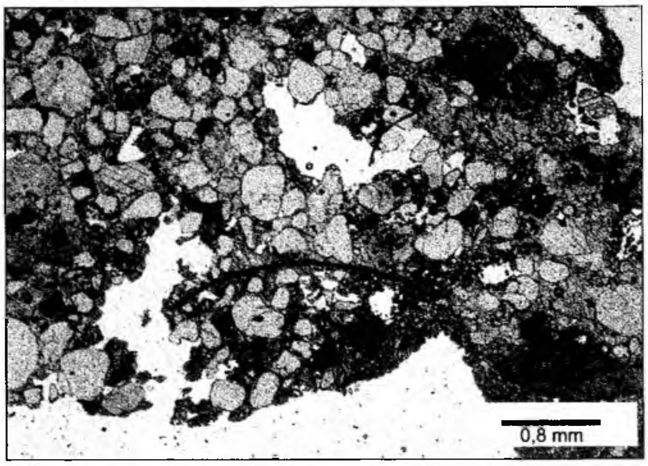

Fig. 15. Calcite-cemented basement sand, *Pisidium* shell visible in the middle of the photograph; thin section, II nicols

Associated faunal and floral fossils

Remains of malacofauna are rather few in the Laski travertine (Fig. 14). Three species of snails were determined by Andrzej Wiktor (see Gradziński *et al.*, 1999). They are: *Gyraulus laevis* (Alder), *Lymnaea peregra* (Müller) and *Succinea putris* (Linnaeus). Further, albeit scarce materials provided some other species: *Anisus spirorbis* (Linnaeus), *Discus rotundatus* (Müller), *Lymnaea truncatula* (Müller) and *Nesovitrea hammonis* (Ström). However, malacofauna examined is not sufficient to precise characterization for the environmental conditions of the travertine formation.

Among all the recognized species *S. putris*, *N. hammonis* and *D. rotundatus* are terrestrial snails. Recently they are widespread and very common species in Poland (Riedel, 1988), they are also known from numerous Quaternary localities. *S. putris* is hygrophilous species particularly characteristic of moist settings – damp meadows, marshes and shores of water basins. Being eurytopic species, *N. hammonis* occurs in a wide range of habitats: damp places both in woods and in open areas and dry grasslands. *D. rotundatus* is living in forest and bushes dwelling within detritus and under stones.

G. laevis, *A. spirorbis*, *L. peregra* and *L. truncatula* are freshwater species. Of them only *G. laevis* lives in lakes, ponds and oxbows whereas remaining species inhabit mainly small water reservoirs – ponds, ditches and marshes (Piechocki, 1979).

Malacofauna of Laski travertine contains only a little part of species known from other sites with calcareous sedimentation. Molluscan assemblages from tufas and travertines of the Cracow Upland consist usually of more than

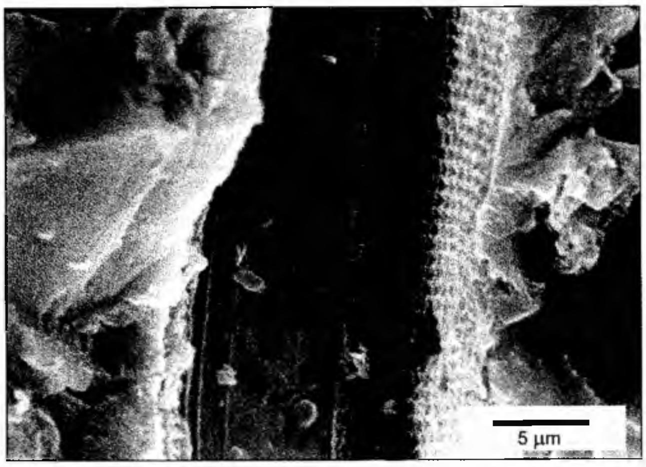

Fig. 16. Diatom frustule mold from moss travertine; SEM image

fifty species (Alexandrowicz, 1983, 1997).

Beside the above described snails the bivalvs (*Pisidium* sp.) and undetermined ostracods have been found (Fig. 15). The travertine carbonates comprise also diatom molds (Fig. 16). Carbonised wood fragments of pine stem and roots (determined by Leszek Trząski) are enclosed within carbonate sediments.

Radiocarbon dating

The travertine samples (of ca. 50 g) were purified, powdered and backed at 450°C. Measurements of radiocarbon activity was performed using liquid scintillation counter LKB 1211 PACK BETA in the Institute of Geological Sciences of the Academy of Sciences of Belarus in Minskh. The radiocarbon dates were being calculated according to recommendations by Stuiver and Polach (1977). Measurements of $\delta^{13}C$ were performed at the Mass Spectrometer SUMY of the Minskh laboratory. The standard measurement error is ± 0.2 ‰ and the stable isotope values are expressed as per mille deviations from the PDB standard. The results of ^{14}C age measurements are listed in Table 1.

The so called initial apparent age (T_{app}) of carbonate fraction has been obtained for the samples L6 and L7 were the co-occurring calcite and organic matter (pine charcoal) have been dated. The apparent age has been determined as the difference between the ^{14}C ages of the carbonate (T_c) and the organic fraction (T_{org}) (Pazdur *et al.*, 1988b):

$$T_{app} = T_c - T_{org}$$

The obtained value of apparent age is equal to 3150 yr. According to statements by Pazdur *et al.* (1988b) this value could be assumed as constant also for the other measured ages of the travertine samples. It means that the corrected ages of these samples are younger in fact of some 3150 yr as the obtained ^{14}C dates suggest.

Table 1

Results of radiocarbon age determinations and ^{13}C measurements

Sample	Type of deposit	Laboratory no	$\delta^{13}C$ [‰]	Age [yr BP]	T_{cca} [yr]
L 1	carbonate cement in sand underlain the travertines	IGSB-574	-6.9	8,690±300	5,540
L 2	flowstone on a cave wall	IGSB-575	-8.0	6,780±80	3,630
L 4	moss travertine, top of the mound	IGSB-576	-7.5	5,350±80	2,200
L 5	moss travertine	IGSB-577	-8.8	9,200±90	6,050
L 6	moss travertine, bottom of the mound	IGSB-655	-6.5	11,500±120	8,350
L 7	pine charcoal from sample L 6	IGSB-655a	–	8,350±240	–

ORIGIN OF THE TRAVERTINE MOUND

Geometry of the travertine mound, and the facies and biological indices evidence its crenic origin. As already mentioned the spring was maintained by artesian orifices displaying normal thermal conditions. ^{13}C values obtained from the travertines and ranging between -8.8 and -6.5‰ suggest the pedogenic source of the CO_2 within the groundwater under discussion (Table 1, see also Cerling, 1984; Baker *et al.*, 1997). The spring area was settled mostly by moss and bryophyta colonies and displayed internal variety between subaerial and shallow subaqual environments. This, in turn, resulted in a close co-occurring of the land and freshwater snails found within the mound body.

According to radiocarbon dating the travertine growth commenced in early Holocene and terminated by Subboreal time. Palaeomalacological and palynological data are of minor stratigraphical importance since they do not contain any index fossils (cf. e.g., Alexandrowicz, 1987; Latałowa & Nalepka, 1987). Nonetheless the occurrence of *Gyraulus laevis* snail, typical of the cold, early Holocene environments (Alexandrowicz, 1987) is in concordance with the radiometric chronostratigraphy.

Rapid calcification of the moss mat led to fast lateral and vertical growth of the travertine body as a result of competition between the moss vegetation and cementation processes (see Parihar & Pant, 1975; Weijermars *et al.*, 1986). A feedback nature of the competitive travertine growth resulted finally in an occluding of the spring zone and forced the surfacing waters to migrate. Such a mechanism of the travertine building has been commonly reported for the ascending springs (Pentecost & Viles, 1994; Pentecost, 1995) however most of the described cases concerns the thermal springs. Beside the most known example from Bagni di Tivoli (see e.g., Chafetz & Folk, 1984) the Slovakian travertines from Gánovce, Bešenova and Spišsky Hrad (Demovič *et al.*, 1972) are worthy to mention. In contrast to the above mentioned travertine sites the present one has been evidently formed from non-thermal waters.

The travertine mound of Laski originated in the same time as most of the other Holocene freshwater carbonates known from the Cracow Upland (cf. Pazdur *et al.*, 1988a). This, in turn, suggests climatic controls of its origin, despite of the ascending nature of the parent springs waters. Fur-

Fig. 17. Cave entrance, fissure developed in the roof is visible

thermore, one may assume that the decline of travertine formation was forced by climate cooling during Subboreal and Subatlantic times of the Holocene (cf. Pazdur *et al.*, 1988a). This cold phase is an European-wide phenomenon (Andrews *et al.*, 1994) however we presume the anthropogenic deforestation as another one important factor of the travertine vanishing (see also Goudie *et al.*, 1993). The deforested area underwent aeolian processes that could play a havoc with carbonate-depositing springs such as for example the Laski travertine springs.

DEVELOPMENT OF THE CAVE

Roof and the side walls of the cave are constructed by moss travertine (Fig. 17). The bottom and some lowermost parts of the cave walls are formed by sands lithified by calcite cement (Fig. 15). The ^{14}C date of the cement is 5540 yr BP. One may presume that the sands were being cemented by the same ascending hardwater solutions as the main travertine buildup (cf. e.g., Cloud & Lojoie, 1980). The cave walls are covered by typical calcite flowstones up to 8 cm thick (cf. Fig. 12). Radiocarbon age obtained from the flowstone gives 3630 yr BP (Table 1).

As one may presume from crevice striking in the middle of the buildup, the cave originated when the NW part of the mound broken up as its sandy basement was outwashed by the surfacing spring water (Fig. 18). This break opened a new conduit for the spring waters. The concentrated and turbulent flow resulted in intensive outwashing of the underlying sands and led finally to development of the discussed cave. Origin of the cave could be dated as later as 5540 yr BP, that is after the sand cementation. On the other hand the 3630 yr. BP age obtained form the above discussed flowstones postdates its origin.

The Laski cave resembles the so called pseudokarst caves followed the joint network (known for instance from the Carpathian flysch rocks) and defined as "crevice caves" (cf. Vitek, 1983). However, as shown in this paper, its origin is quite different. The cave differs also from many other caves developed within the travertines, since the latter are mostly the growth-hollows originated by progradation of

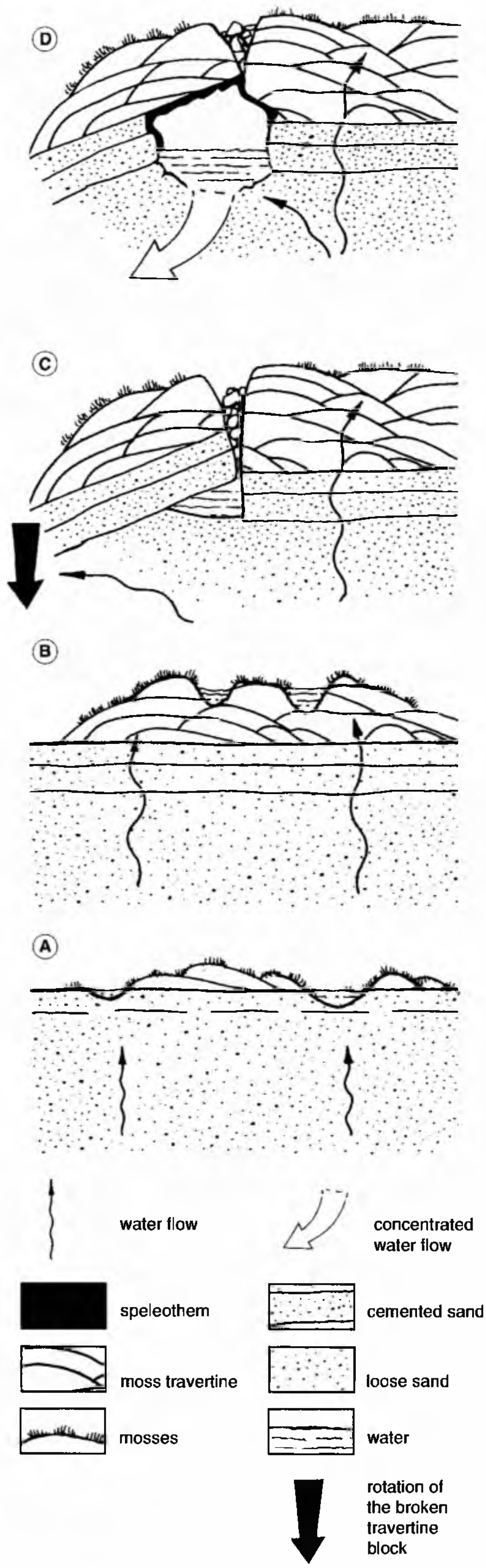

Fig. 18. Schematic reconstruction of the travertine dome and cave origins: **A–B** – cementation of the basement sand and aggradation of travertine body within the artesian spring zone, **C** – breaking and rotation of travertine blocks due to suffosion of the basement sand, and **D** – origin of the cave due to further outwashing of the underlying sands

the travertine dams as Höllgrotte in Switzerland (Bögli, 1980), Annabarlang in Lillafüred, Hungary (Jakucs, 1977) or nor more existing travertine cave from Racławka Valley in southern Poland (Ciętak, 1936).

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Streszczenie

KOPUŁA TRAWERTYNOWA I JASKINIA WE WSI LASKI, WYŻYNA ŚLĄSKO-KRAKOWSKA

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W początku lat dziewięćdziesiątych została znaleziona niewielka jaskinia położona we wsi Laski koło Olkusza (Tyc, 1996; Tyc & Polonius, 1998). Dzięki temu zwrócono uwagę na wychodnię skał węlanowych, w których jaskinia jest rozwinięta. Okazało się, że jest to niewielka kopuła trawertynowa, która zasadniczo różni się geometrią i sposobem powstania od innych znanych trawertynów z południowej Polski. Artykuł ten dotyczy rozwoju kopuły jak i genezy jaskini w niej rozwiniętej.

Kopuła występuje na obrzeżu wsi Laski (Fig. 1) i ma rozciągłość ok. 25 m i do 3 m wysokości (Fig. 2, 3). Kopuła jest podścielona plejstoceńskimi piaskami o miąższości ok. 10 m; piaski pokrywają również południową i wschodnią część kopuły. Osady czwartorzędowe są podścielone kompleksem utworów triasowych. W spągu tego kompleksu znajdują się piaskowce pstrego piaskowca, nad którymi zalegają węglanowe utwory retu i wapienia muszlowego. W stropie utworów triasowych znajdują się iły kajpru (Fig. 4, 5). Taka budowa geologiczna decyduje o istnieniu na omawianym obszarze warunków artezyjskich, gdzie warstwą napinającą są ilaste utwory kajpru (Fig. 5, 6). W bezpośrednim podłożu kopuły trawertynowej, na lokalnym zrębie, osady kajpru zostały zerodowane i piaski czwartorzędowe zalegają bezpośrednio na węglanowych utworach triasu (Fig. 6). W ten sposób powstało lokalne okno hydrogeologiczne, gdzie dochodziło do rozładowania ciśnień artezyjskich. Obecnie na skutek intensywnego drenażu górniczego nastąpiło obniżenie zwierciadła wód podziemnych o kilkadziesiąt metrów (Motyka, 1988).

Kopuła trawertynowa jest zbudowana z twardego lecz porowatego trawertynu lokalnie obfitującego w nagromadzenia związków żelaza. Obserwacje mikroskopowe (w mikroskopie petrograficznym i skaningowym mikroskopie elektronowym) wykazały, że główną masę kopuły trawertynowej stanowią trawertyny mchowe (Fig. 8–11). Powstają one wskutek wytrącania kalcytu wokół tkanek mszaków. Proces ten odbywał się zapewne przy udziale epifitycznych mikroorganizmów (Fig. 11; Szulc, 1983; Pedley, 1992). W dalszym etapie pierwotne próżnie, do jaskiniowych włącznie, są wypełniane wytrącanym fizykochemicznie kalcytowym cementem (Fig. 12, 13; por. Pentecost, 1987; Szulc, 1983). Część próżni jest wypełniona także klastycznymi osadami wewnętrznymi, o różnym składzie mineralnym (kwarc, skupienia minerałów ilastych i tlenków żelaza, peloidy węglanowe). W obrębie mchowych trawertynów znajdują się także aglomeraty tlenków żelaza, mające zapewne genezę mikrobialną (Fig. 9; por. Ghiorse & Ehrlich, 1992).

W obrębie trawertynów stwierdzono skorupy ślimaków: *Anisus spirorbis*, *Discus rotundatus*, *Gyraulus laevis*, *Lymnaea peregra*, *L. truncatula*, *Nesovitrea hammonis*, *Succinea putris*, muszle małży *Pisidium* sp., nieoznaczone skorupki małżoraczków i odlewy okrzemek (Fig. 14–16). Ponadto występują tam zwęglone drewna z pnia i korzeni sosny.

Wykonane zostały daty radiowęglowe zarówno węglanów budujących kopułę, węglanowych cementów spajających piaski ją podścielające, nacieków z jaskini, a także zwęglonych szczątków sosny (Tabela 1). Otrzymano wiek trawertynu "postarzony" o tzw. wiek pozorny (T_{app}), który został określony na podstawie zależności: $T_{app} = T_c - T_{org}$, (por. Pazdur *et al.*, 1988b).

Jak wynika z geometrii kopuły jak i ze wskaźników facjalnych i biologicznych kopuła tworzyła się w strefie źródłowej zasiedlonej przez higrofilne mszaki. Kalcyfikacja muraw mchowych doprowadziła do rozrostu kopuły na drodze lateralnej i wertykalnej "ucieczki" mchów ze strefy skalcyfikowanej. Powodowało to rozrastanie się kopuły jak i wymuszało migrację strefy źródła przez utrudnienie swobodnego wypływu przez jego "zacementowanie". Kopuła martwicowa z Lasek zasilana była wodą o normalnej temperaturze i zasobną w glebowy dwutlenek węgla, o czym świadczą m.in. proporcje izotopów trwałych węgla. Powstała ona w tym samym czasie co większość węglanowych martwic Wyżyny Krakowskiej (por. Pazdur *et al.*, 1988a). Świadczy to, że procesy wytrącania mchowych trawertynów były, pomimo ascenzyjnego pochodzenia wód, kontrolowane klimatycznie. Koniec depozycji węglanów należy wiązać zarówno z czynnikami klimatycznymi, jak i ingerencją człowieka (por. Goudie *et al.*, 1993).

Jaskinia rozwinięta w obrębie kopuły trawertynowej powstała już po uformowaniu się zasadniczej części ciała trawertynowego. Bezpośrednią przyczyną utworzenia próżni było grawitacyjne przesunięcie bloku trawertynowego stanowiącego jej północnozachodnią ścianę. Należy sądzić, że było to efektem sufozyjnego usuwania materiału piaszczystego budującego spąg kopuły trawertynowej. Powstała w ten sposób rozwierająca się stopniowo szczelina w kopule trawertynowej spowodowała koncentrację przepływu wód ascenzyjnych (Fig. 17, 18). Wody te zaczęły mechanicznie obniżać dno powstałej próżni poprzez selektywną erozję słabiej scementowanych piasków. Można sądzić, że procesy te miały miejsce przed lub w trakcie krystalizacji polew naciekowych (tj. ok. 3 630 lat BP), a po uprzedniej cementacji piasków podścielających kopułę (tj. ok. 5 540 lat BP).