STUDIA GEOMORPHOLOGICA CARPATHO-BALCANICA
VOL. XXIX KRAKÓW 1995 PL ISSN 0081-6434

ANNA PAZDUR AND MIECZYSŁAW F. PAZDUR (GLIWICE),
HELENA HERCMAN (POZNAŃ), PAVOL MITTER (LIPTOVSKÝ MIKULAŠ)

DEVELOPMENT OF SELECTED CAVES OF THE SLOVAK KARST DURING LATE QUATERNARY[1]

INTRODUCTION

In 1986, during a several days field work in the Slovak Karst, the authors have collected a suite of speleothem samples from four caves for radiometric age determinations. The aim of this introductory study was to gather preliminary data for evaluation of main periods of speleothem formation in the area which may be used as guidelines for future systematic studies. This paper presents short description of the study area and samples used for dating. The results obtained with the radiocarbon and TL / ESR methods of dating are compared with the available global paleoclimatic records and used for reconstruction of selected elements of the study area during the last 300 ka.

GEOLOGY

The massif of Slovak Karst situated in the Bodwa river basin south of Slovak Rudawy is one of the largest karst regions in Europe. The area of limestone rocks occurring at surface exceeds 600 km^2 and the number of known caves exceeds 500 (Kunsky 1956). In the southern part of the area the outcrops of Mesosoic base units are dominating. Mesosoic rocks are in some places overlain with flysh sedimentary rocks of Paleogene age. In the southern part of the area there is a continuous transition from Miocene marine sediments to lower Pliocene sediments.

Characteristic relief of the region is determined by flattopped lengthy limestone ridges called planinas. At their surface occur numerous karstic forms with large karstic cones of diameter up to 200 m and depth reaching up to 50 m. At slopes

[1] Sudden death of Pavol Mitter interrupted the study of speleothem formation in the Slovak Karst and limited the number of speleothem samples available for dating. All other imperfections of the present paper should be attributed to the coauthors.

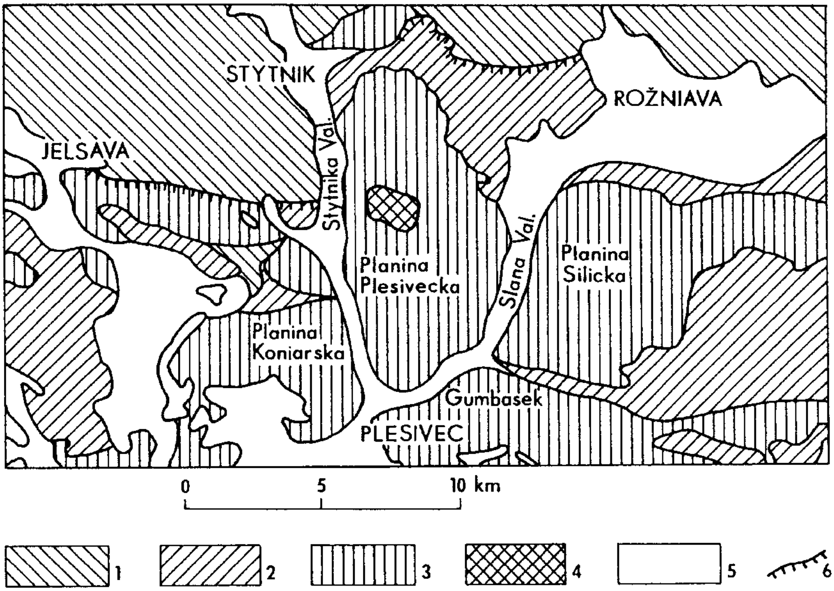

Fig. 1. Simplified geological map of the Slovak Karst (acc. to Wójcik 1968). Explanations: 1 — Paleozoic, 2 — Lower Triassic shales and sandstones, 3 — Middle Triassic limestones and sandstones, 4 — Upper Triassic shales, 5 — Neogene and Quaternary conglomerates, gravels and sands, 6 — rift boundaries

Rys. 1. Uproszczona mapa geologiczna Słowackiego Krasu (wg Wójcik, 1968). Objaśnienia: 1 — paleozoik, 2 — łupki i piaskowce dolnego triasu, 3 — wapienie i piaskowce środkowego triasu, 4 — łupki górnego triasu, 5 — zlepieńce, żwiry i piaski czwartorzędowe, 6 — granice nasunięć

of planinas occur vertical shafts of depth exceeding 100 m. Along major fault lines are developed uvalas and small poljas (Wójcik 1968).

This study was confined to four caves located on Plesivecka Planina and Silicka Planina in the central part of the Slovak Karst (Fig. 1). The caves Diviaca, Salanka and Zakrutova are located on the Plesivecka Planina, the entrance to the fourth cave, Krasnohorska, is situated at the northern slope of Silicka Planina. Flat top of the Plesivecka Planina is elevated by ca 500 m above the valley floors of Snitnicki Potok and Slana rivers. Its surface is slightly inclined to the south, northwestern slopes form escarpments of c. 400 m height. Sampling places are shown in Fig. 2.

SAMPLE DESCRIPTIONS

DIVIACA CAVE

Main part of cave was discovered and explored in 1964 (Erdös 1984). Its entrance is in the western part of Plesivecka Planina near the Gombasecki

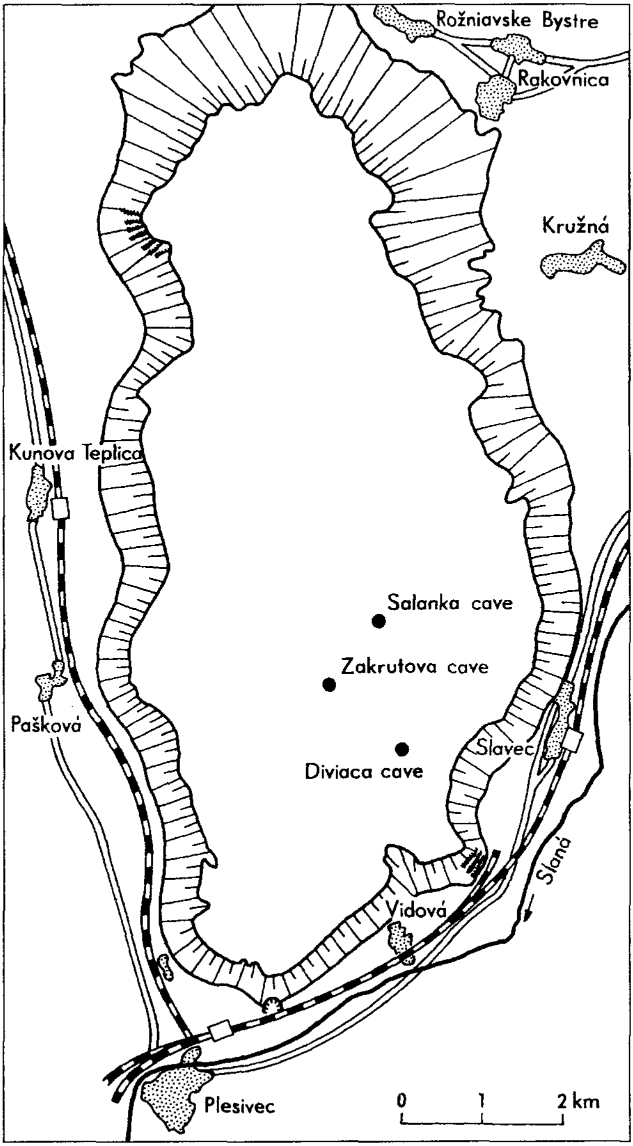

Fig. 2. Location of studied caves within the Plesivecka Planina (acc. to Erdös 1984)

Rys. 2. Lokalizacja badanych jaskiń na obszarze Plesiveckiej Planiny (wg Erdös 1984)

kiln. Cave is developed in form of vertical shafts of total depth c. 127 m, connecting several chambers. This is the deepest cave within the area of Plesivecka Planina (Erdös 1984). Sample D1 used for dating is made of coarse-grained, white, transparent calcite, deposited as flowstone on wall of vertical shaft at depth c. 24 m below actual cave entrance.

SALANKA CAVE

Salanka Cave, located in the central part of Plesivecka Planina is developed in form of vertical shafts of maximum depth c. 38 m connecting several chambers. A flowstone consisting of three well distinguished layers, separated with distinct erosion surfaces, formed on wall of side niche of a chamber, was collected. Three samples were chosen for dating according to distinct changes of sedimentological properties of the flowstone:
S1 — coarse-grained, white, transparent calcite from lowermost layer,
S2 — medium-grained reddish-brown calcite from middle layer,
S3 — fine-grained white calcite from outermost layer.

ZAKRUTOVA CAVE

This cave, located near Salanka Cave in the central part of Plesivecka Planina, has actually a form of small shaft, partly filled with rubble. Flowstone cover occurring on wall of a chamber, consisting of nine well distinguished layers, separated with distinct surfaces marking breaks of calcite deposition, was collected for this study. Three samples of reddish-brown, medium-grained calcite were separated for dating:
Z1 — from base layer,
Z4 — from fourth (middle) layer,
Z9 — from top layer.

KRASNOHORSKA CAVE

The cave was discovered in 1964 (Kucera *et al.* 1981). Entrance to the cave is situated in northern slope of Silicka Planina (cf. Fig. 1), near large karstic spring Buzgo. The cave is developed in form of long and narrow horizontal corridors of total length exceeding 1500 m. A goaf consisting of limestone rock with blocks of flowstone of older generation occurs in the middle part of the cave. Thin layer of silt covering the goaf is partly overlain by younger flowstone. In the final chamber of the cave occurs large stalagmite of c. 32 m height, which is regarded the largest stalagmite in European caves. The top of the stalagmite is broken and rests near its base on floor of the chamber. For the purpose of this study three samples were collected from the goaf:
K1 — fragment of a flowstone cover built of coarse- and medium-grained calcite formed on the goaf in central part of the cave. Sample used for dating was taken from middle layer of white, transparent, coarse-grained calcite.
K2 — small stalagmite, c. 8 cm height, built of medium-grained calcite, growing of flowstone covering the goaf.
K3 — piece of stalactite, c. 4 cm in diameter, incorporated in flowstone covering the goaf.
Two other samples used for dating (K2SB and K2SA) were fragments of the broken topmost part of the large stalagmite. Sample K2SB was taken from thin outermost

layer, separated from the older layer with an erosion surface (Fig. 3). Sample K2SA of white, medium-grained calcite, was taken immediately below the erosion surface.

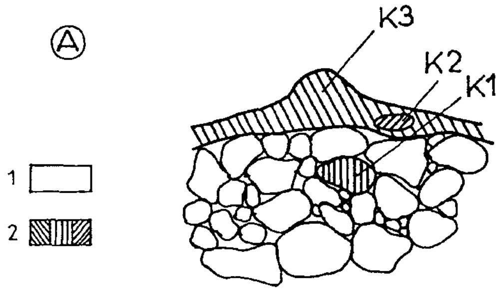

Fig. 3. Location of dated speleothem samples within the goaf in the central part of Krasnohorska Cave. 1 — blocks of limestones, 2 — speleothems

Rys. 3. Lokalizacja datowanych próbek nacieków w obrębie zawaliska w centralnej części Jaskini Krasnohorskiej. 1 — bloki wapienia, 2 — nacieki

LABORATORY METHODS

Samples used for radiocarbon dating were converted to carbon dioxide by treating them with 8% hydrochloric acid. Age determinations were performed with proportional counters of different volume, filled with pure carbon dioxide (cf. Pazdur and Pazdur 1986). The reservoir effect was taken into account by assuming initial radiocarbon activity of speleothem equal to 85% of the activity of contemporary biosphere (Geyh 1972, Srdoc *et al.* 1983).

Samples of speleothems separated for TL and / or ESR dating were crushed and sieved to obtain grains of size 100–150 μm. Equivalent dose ED accumulated by calcite grains was determined by the additive method. The dependence of the TL / ESR signal upon the strictly determined additive doses of gamma radiation from ^{60}Co source was extrapolated to evaluate the ED value. ESR measurements were performed with the SEX 2543 spectrometer manufactured by Radiopan, Poznań. The line $g = 2.0005 \pm 0.0003$ was used to evaluate the effective dose ED from ESR spectra. TL measurements were made with apparatus designed by A. Bluszcz (1986) using 5 mg calcite samples. The value of ED was evaluated from the height of the TL glow peak occurring at 280°C.

The annual dose necessary for evaluation of TL / ESR age may be represented as a sum of two components. The external component (D_{ext}) caused by natural radiation field in the cave, associated with radioactivity of bedrock and cave sediments, radon present in the air, etc., was determined by in situ measurements performed during the field work using the portable gamma-scintillation spectrometer. The internal component (D_{int}), caused by radioisotopes incorporated in the dated sample, was determined in the laboratory with the multichannel gamma-spectrometer with NaJ(Tl) crystal. Concentrations of ^{238}U and ^{232}Th were calculated from measured activities of ^{214}Bi and ^{208}Tl isotopes assuming secular equilibrium in the uranium and thorium series. Final value of the annual dose was evaluated as a sum of external dose measured in situ and internal annual dose calculated from known U, Th and K concentrations assuming the efficiency of alpha radiation equal to 0.5. The values of different components of the annual dose are listed in Table 1. All analysed samples of speleothems showed very low uranium content, in some samples it was below the detection limit of the counting system. Because of this some components of the annual dose were determined in form of limiting values.

The assumption of secular equilibrium in the uranium series is obviously not valid. Final values of TL / ESR ages were calculated taking into account the disequilibrium in the U / Th series according to the method described by Goslar and Hercman (1988).

Table 1

Components of annual dose of radiation (in Gy/ka)
Składowe rocznej dawki promieniowania (w Gy/ka)

		Lab. No	D_{ext}	D_{int}	
				D_{ume}	D_{Th+K}
Z9	ESR	GdESR–31	0.10 ± 0.01	0.22 ± 0.03	0.20 ± 0.03
Z4	ESR	GdESR–32	0.40 ± 0.04	≤ 0.60	0.08 ± 0.02
Z4	TL	GdTL–345	0.40 ± 0.04	≤ 0.60	0.08 ± 0.02
Z1	ESR	GdESR–33	0.55 ± 0.06	0.13 ± 0.04	0.36 ± 0.03
Z1	TL	GdTL–346	0.55 ± 0.06	0.13 ± 0.04	0.36 ± 0.03
D	ESR	GdESR–42	0.13 ± 0.01	0.09 ± 0.04	0.05 ± 0.02
S1	ESR	GdESR–40	0.40 ± 0.04	≤ 0.06	≤ 0.05
S2	ESR	GdESR–41	0.40 ± 0.04	≤ 0.15	0.08 ± 0.03
K1	ESR	GdESR–46	0.50 ± 0.01	0.18 ± 0.04	0.23 ± 0.03

Explanations: D_{ext} — external dose rate of gamma radiation (Gy/ka) measured in situ; D_{int} — internal dose rate, with contributions given by U-series (D_{ume}) and by thorium and potassium

Objaśnienia: D_{ext} — moc dawki zewnętrznej promieniowania gamma (Gy/ka) mierzona in situ: D_{int} — moc dawki wewnętrznej, z wyróżnieniem składowej pochodzącej od izotopów szeregu uranowego (D_{ume}) oraz składowych pochodzących od izotopów toru i potasu

Table 2

Results of age determination of speleothem samples
Wyniki oznaczeń wielu próbek nacieków

Cave	Sample	Method	Lab. No.	Age ka BP
Krasnohorska	K1	ESR	GdESR–46	280 (+40, –55)
	K2	C14	Gd–5162	13.14 ± 1.50
	K3	C14	Gd–5144	35.50 ± 1.70
	KZSA	C14	Gd–2675	12.90 ± 1.30
	KZSB	C14	Gd–5145	36.6 (+5, –3)
Diviaca	D1	C14	Gd–5770	> 45
	D1	ESR	GdESR–42	130 ± 60
Salanka	S1	ESR	GdESR–40	210 ÷ 330
	S2	ESR	GdESR–41	170 ÷ 260
	S3	C14	Gd–3293	4.36 ± 0.06
Zakrutowa	Z1	TL	GdTL–346	350 ± 70
	Z1	ESR	GdESR–33	360 ± 95
	Z4	TL	GdTL–345	175 ÷ 200
	Z4	ESR	GdESR–32	145 ÷ 170
	Z9	ESR	GdESR–31	70 ± 20

RESULTS AND DISCUSSION

The results are presented in Table 2, which includes six radiocarbon dates and nine TL / ESR dates obtained on seven samples. It may be noted that replicate age determinations by the TL and ESR methods on samples Z1 and Z4 from the Zakrutova Cave have yielded consistent results. Radiocarbon age obtained on sample D1 from Diviaca Cave, reported as > 45 ka BP, is also consistent with the corresponding result obtained by ESR method (130 ± 60 ka BP).

The accuracy of TL / ESR ages listed in Tabl 2 is not high enough to draw detailed conclusions concerning the age of single definite geologic events. However, the results obtained in this study may be reasonably compared with long-term pattern of climatic changes during the Quaternary, and may be also helpful in establishing the absolute time scale for reconstruction of some important geological processes in the study area during the last 300 ka BP.

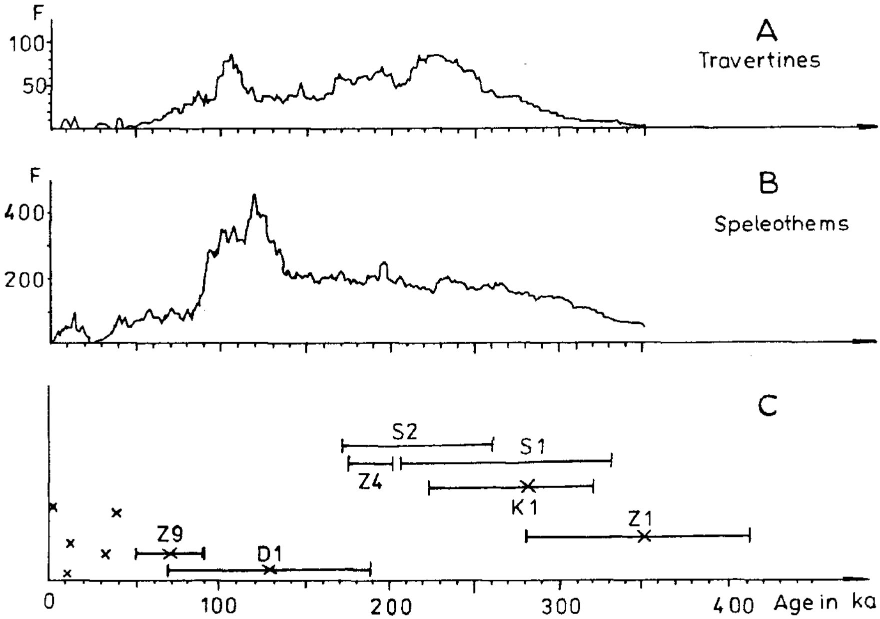

Fig. 4. Comparison of speleothem dates with frequency histograms of travertines and speleothems from N hemisphere compiled by Hennig *et al.* (1983)

Rys. 4. Porównanie wyników datowań nacieków z histogramami częstości dat trawertynów i nacieków z obszaru półkuli północnej, zestawionymi przez Henniga i in. (1983)

In recent years significant paleoclimatic data have been obtained from statistical analysis of temporal changes of speleothem growth frequency (Hennig *et al.* 1983, Kashiwaya *et al.* 1991, Baker *et al.* 1993), as well as from studies of single speleothems (Lauritzen *et al.* 1990) or vein calcite (Winograd *et al.* 1988, 1992). Because the most recent study of speleothem frequency distribution of Baker *et al.* (1993) is limited to the period of the last 150 ka and is based on results from the NW Europe, our data from the Slovak Karst are compared with global frequency histograms obtained by Hennig *et al.* (1983). The comparison, shown in Fig. 4, indicates that the dates obtained on speleothems from selected caves of the Slovak Karst coincide with main periods of speleothem growth, but does not allow for more detailed conclusions.

The above mentioned frequency distributions of speleothem ages correlate fairly well with oxygen isotope records available from deep-sea cores (Pisias *et al.* 1984) and orbital theories of climatic changes during Quaternary (Martinson *et al.* 1987, Imbrie *et al.* 1984). General conclusions drawn by Kashiwaya *et al.* (1991) and Baker *et al.* (1993) may be therefore used as justification for correlation of relatively low-accuracy chronological data obtained on speleothems from the Slovak Karst with stacked oxygen-isotope curve of Imbrie *et al.* (1984), reflecting global climatic changes during the last 800 ka.

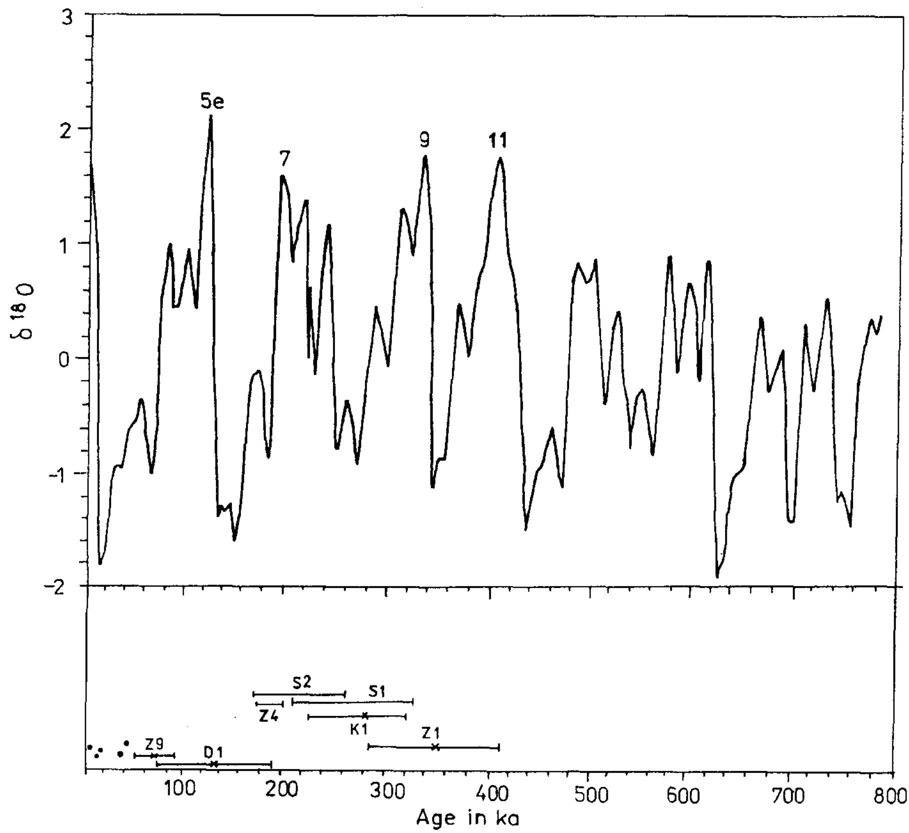

Fig. 5. Comparison of speleothem dates with the stacked oxygen isotope curve of Imbrie *et al.* (1984)

Rys. 5. Zestawienie wyników datowań nacieków z krzywą izotopową tlenu wg Imbrie i in. (1984)

Comparison of speleothem ages obtained with TL / ESR and radiocarbon methods with orbitally-tuned oxygen-isotope curve of Imbrie *et al.* (1984) is presented in Fig. 5. The oldest layer of flowstone from Zakrutova Cave (sample Z1) may be correlated with Stage 11, middle layer (sample Z4) with Stage 7 (final phase of Stage 7) and the youngest layer (sample Z9) with either Stage 5a or Stage 3. It may be also assumed that layers 2 and 3 (which were not dated) have been deposited during Stages 9 and 7, respectively, and layers 5–8 were formed during Stage 5 (Eemian Interglacial). Similarly, the formation of the two oldest layers of flowstone in Salanka Cave may be correlated with Stages 9 and 7, while the youngest layer (represented by sample S3) was formed obviously during younger Holocene.

Figure 6 presents comparison of radiometric dates obtained on speleothems from the Slovak Karst with periods of speleothem growth in the Polish Tatra Mts, determined by Hercman (1991) and regional chronostatigraphic sub-

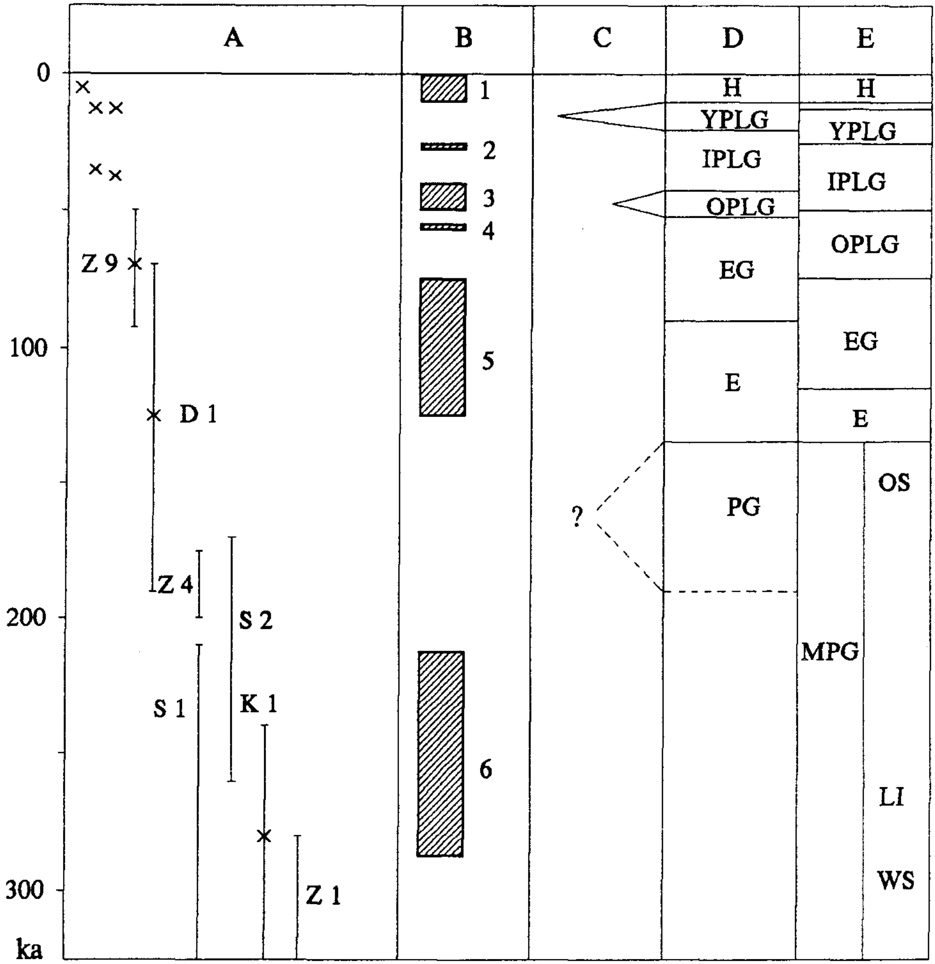

Fig. 6. Comparison of speleothem dates from the Slovak Karst (A) with selected regional paleoclimatic and chronostratigraphic data: B — periods of speleothem growth in the Polish Tatra Mts (after Hercman 1991), C — glaciations of the Tatra Mts (acc. to Halouzka, after Hercman 1991), D — chronostratigraphic subdivision of late Quaternary in the Tatra Mts (after Hercman 1991), E — chronostratigraphic subdivision of Quaternary in Carpathians (acc. to Starkel 1980, 1988). Abbreviations: H — Holocene, YPLG — Younger Pleniglacial, IPLG — Interpleniglacial, OPLG — Older Pleniglacial, EG — Early Glacial, E — Eemian Interglacial, PG — Penultimate Glaciation, MPG — Middle Polish Glaciation, OS — Odranian Stadial, LI — Lublinian Interstadial, WS — Wartanian Stadial

Rys. 6. Porównanie wyników datowań nacieków z obszaru Słowackiego Krasu (A) z wybranymi regionalnymi danymi paleoklimatycznymi i chronostratygraficznymi: B — okresy wzrostu nacieków w Tatrach Polskich (wg Hercman 1991), C — zlodowacenia Tatr (wg Holouzki, za Hercman 1991), D — podział chronostratygraficzny późnego czwartorzędu w Tatrach (wg Hercman 1991), E — podział chronostratygraficzny czwartorzędu w Karpatach (wg Starkel 1980, 1988). Objaśnienia skrótów: H — holocen, YPLG — młodszy pleniglacjał, IPLG — interpleniglacjał, OPLG — starszy pleniglacjał, EG — wczesny glacjał, E — interglacjał cemski, PG — zlodowacenie przedostatnie, MPG — zlodowacenie środkowopolskie, OS — stadiał Odry, LI — interstadiał lubelski, WS — stadiał Warty

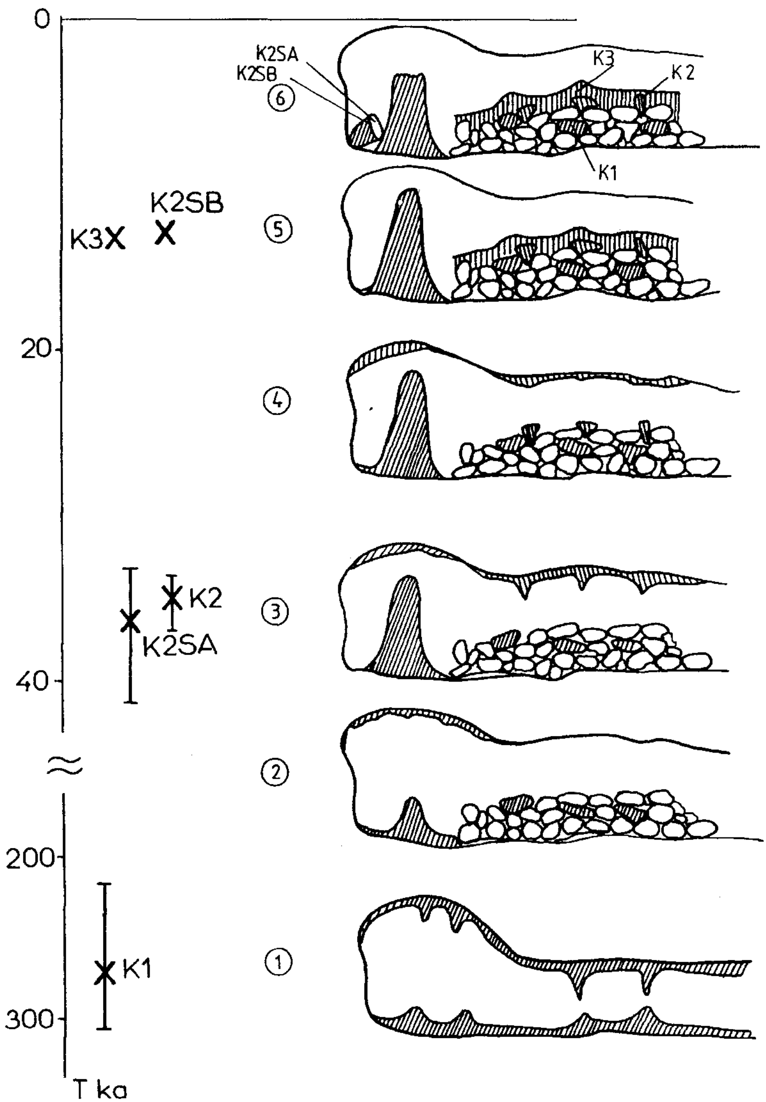

Fig. 7. Reconstruction of geological history of Krasnohorska Cave during the last 300 ka. 1 — formation of first generation of speleothem (ESR date c. 300 ka BP); 2 — first tectonic event, formation of goaf; 3 — growth of large stalagmite in the final chamber of cave, growth of flowstone cover in corridor in the central part of cave; 4 — second tectonic event, causing destruction of flowstone cover on roof of corridor; 5 — formation of flowstone cover on the goaf; 6 — last tectonic event, break of topmost part of large stalagmite

Rys. 7. Rekonstrukcja historii geologicznej Jaskini Krasnohorskiej w czasie ostatnich 300 tysięcy lat. 1 — formowanie się pierwszej generacji nacieku (data ESR ok. 300 tysięcy lat); 2 — pierwsze zdarzenie tektoniczne, powstanie zawaliska; 3 — wzrost dużego nacieku w końcowej komorze jaskini, tworzenie polewy naciekowej w korytarzu części centralnej jaskini; 4 — drugie zdarzenie tektoniczne, zniszczenie polewy naciekowej w stropie korytarza; 5 — formowanie się polewy naciekowej na zawalisku; 6 — ostatnie zdarzenie tektoniczne, zniszczenie najwyższej części dużego stalagmitu divisions of Late Quaternary based on studies of cave deposits in the Tatra Mts (Hercman 1991) and geomorphologic, geologic and pollen studies in the Polish Carpathians and in the Subcarpathian Basins (Starkel 1980, 1988). It may be easily noted that the two youngest groups of dates coincide well with phases 1 and 2 distinguished in the Tatra Mts and the group of oldest dates in column A may be correlated with phase 6. Also the lack of speleothems dates correlates fairly well with regional coolings marked by glaciation periods of the Tatra Mts, shown in column C.

Results obtained on speleothems from Krasnohorska Cave may be used to reconstruct the history of the cave (Fig. 7). The oldest generation of speleothems was formed during Stage 9, c. 300 ka BP (Fig. 7.1). Much later serious tectonic events caused formation of the goaf in the central part of cave (Fig. 7.2). Second recorded phase of speleothem growth took place during the Interplenivistulian, at c. 35 ka BP (Fig. 7.3.). In the period of the last glacial maximum, probably between 20 and 15 ka BP, there was a break in speleothem deposition, marked by erosional surface at the topmost part of large stalagmite (cf Fig. 3). During that period some stalagmites formed previously (sample K2) on the roof of the cave were dropped down on the goaf (Fig. 7.4). The youngest generation of speleothems was formed at c. 13 ka BP, probably during warm interstadials of the Late Glacial, as is shown by two almost identical radiocarbon dates obtained on samples K2SB and K3 (Fig. 7.5). The last event visible in the speleothem record is second tectonic event which caused break of the topmost part of large stalagmite in the final part of cave (Fig. 7.6).

Age of the oldest speleothem in Krasnohorska Cave indicates that the cave has been dried not later than c. 300 ka BP. This indicates that the drainage system consisting of deep vertical shafts connected with approximately horizontal corridors, typical for the area of our study, has been formed earlier.

The youngest flowstone in the Zakrutova Cave were formed at c. 60 ka BP. As a result of erosion of the flat top of Plesivecka Planina these speleothems occur actually almost at the surface. The speleothem samples used for dating revealed typical features indicating for slow static deposition in the inner part of cave, and, in particular, they do not showed any features typical for speleothems formed near the cave entrance. This observation indicates for very high erosion rate of the surface of Plesivecka Planina during the last 50 ka.

This study was supported by grant PB 740/6/91 of the Committee for Scientific Research.

A. Pazdur and M. F. Pazdur, Department of Radioisotopes, Institute of Physics,
Silesian Technical University, Krzywoustego 2, PL-44-100 Gliwice, Poland
H. Hercman, Institute of Geology, Adam Mickiewicz University,
Maków Polnych 16, PL-61-606 Poznań, Poland
P. Mitter, Museum of the Slovak Karst,
031 01 Liptovský Mikuláš Slovak Republik

REFERENCES

Baker A., Smart P. L., Ford D. C., 1993. *Northwest European palaeoclimate as indicated by growth frequency variation of secondary calcite deposits*. Palaeogeogr. Palaeoclim. Palaeoecol., 100, 291–301.

Bluszcz A., 1986. *Stanowisko pomiarowe i metodyka pomiarów w Laboratorium TL w Gliwicach*. Zesz. Nauk. Pol. Śl., Seria Mat.-Fiz., 46, Geochronometria, 1, 147–158.

Erdös M., 1984. *Zoznam preskumanych jaskyn, priepasti a vyvieraciek Plesivskej Planiny v Slovenskom Krase*. Slovensky Kras, 22, 187–212.

Geyh M. A., 1972. *On the determination of the initial ^{14}C content in ground water*. Proc. 8th Intern. Conf. on Radiocarbon Dating, Wellington, New Zealand, vol. 1. D59–D69.

Goslar T., Hercman H., 1988. *TL and ESR dating of speleothems and radioactive disequilibrium in the uranium series*. Quaternary Sci. Rev., 7, 423–427.

Halouzka R., 1977. *Stratigraphical subdivision of sediments of the last glaciation in the Czechoslovak Carpathians and their correlation with contemporary Alpine and European glaciation*. IGCP Project 73 / 1 / 24 Report A, 83–91.

Hennig G. J., Grün R., Brunnacker K., 1983. *Speleothems, travertines, and palaeoclimates*, Quaternary Res., 20, 1–29.

Hercman H., 1991. *Rekonstrukcja elementów środowiska geologicznego Tatr Zachodnich na podstawie datowania izotopowego nacieków jaskiniowych*. Zesz. Nauk. Pol. Śl., Seria Mat.-Fiz., 66, Geochronometria, 8, 1–139.

Imbrie J., Hays J. D., Martinson D. G., McIntyre A., Mix A. C., Morley J. J., Pisias N. G., Prell W. L., Shackleton N. J., 1984. *The orbital theory of Pleistocene climate: support from a revised chronology of the marine* $d^{18}0$ record, [in:] *Milankovich and Climate*, Part I, Reidel Publ. Co., Boston, 269–305.

Kashiwaya K., Atkinson T. C., Smart P. L., 1991. *Periodic variations in Late Pleistocene speleothem abundance in Britain*. Quaternary Res., 35, 190–196.

Kucera B., Hromas J., Skrivanek F., 1981. *Jaskyne a propasti v Ceskoslovensku*, Praha.

Kunsky J., 1956. *Zjawiska krasowe*. PWN, Warszawa.

Lauritzen S. E., Lovlie R., Moe D., Ostbye E., 1990. *Paleoclimate deduced from a multidisciplinary study of a half-milion-year-old stalagmite from Rana, northern Norway*. Quaternary Res., 34, 306–316.

Martinson D. G., Pisias N. G., Hays J. D., Imbrie J., Moore T. C. Jr., Shackleton N. J., 1987. *Age dating and the orbital theory of Ice Ages: Development of a high-resolution 0 to 300 000-year chronostratigraphy*. Quaternary Res., 27, 1–29.

Pazdur A., Pazdur M. F., 1986. *Aparatura pomiarowa Laboratorium ^{14}C w Gliwicach. Doświadczenia konstrukcyjne i eksploatacyjne*. Zesz. Nauk. Pol. Śl., Seria Mat.-Fiz., 46, Geochronometria, 1, 55–70.

Pisias N. G., Martinson D. G., Moore T. C. Jr., Shackleton N. J., Prell W., Hays J., Boden G., 1984. *High resolution stratigraphic correlation of benthic oxygen records spanning the last 300 000 years*. Marine Geology, 56, 119–136.

Srdoc D., Horvatincic N., Obelic B., 1983. *Radiocarbon dating of tufa in paleoclimatic studies*. Radiocarbon, 25, 421–427.

Srdoc D., Sliepcevic A., Obelic B., Horvatincic N., 1977. *Rudjer Boskovic Institute radiocarbon measurements IV*. Radiocarbon, 19, 465–475.

Starkel L., 1980. *Stratigraphy and chronology of the Vistulian in the Polish Carpathians and in the Subcarpathian Basins*. Quaternary Stud. in Poland, 2, 121–135.

Starkel L., 1988. *Remarks on the Quaternary stratigraphy of the Polish Carpathians and their foreland*. Quatern. Stud. in Poland, 8, 49–59.

Stuiver M., Polach H. A., 1977. *Reporting of ^{14}C data*. Radiocarbon, 19, 355–363.

Winograd I. J., Szabo B. J., Coplen T. B., Riggs A. C., 1988. *A 250 000-year climatic record from Great Basin vein calcite: Implications for Milankovich theory*. Science, 242, 1275–1280.

Winograd I. J., Coplen T. B., Landwehr J. M., Riggs A. C., Ludwig K. R., Szabo B. J., Kolesar P. T., Revesz K. M., 1992. *Continuous 500 000-year climate record from vein calcite in Devils Hole, Nevada*. Science, 258, 255–260.

Wójcik J., 1968. *Rozwój geomorfologiczny wapiennych obszarów Tatr i innych masywów krasowych Karpat Zachodnich*. Prace Muzeum Ziemi, 13, 3–169.

STRESZCZENIE

A. Pazdur, M. F. Pazdur, H. Hercman, P. Mitter

ROZWÓJ WYBRANYCH JASKIŃ SŁOWACKIEGO KRASU W MŁODSZYM CZWARTORZĘDZIE

Rejon Słowackiego Krasu, położony w dorzeczu rzeki Bodwy na południe od Rudaw Słowackich należy do największych obszarów krasowych w Europie. Wychodnie skał wapiennych zajmują powierzchnię ponad 600 km^2 a liczba poznanych jaskiń przekracza 500. Wykonane zostały oznaczenia wieku metodami radiowęgla (C–14), termoluminescencji (TL) oraz elektronowego rezonansu spinowego (ESR) dwunastu próbek nacieków pobranych z wybranych jaskiń Słowackiego Krasu. Jaskinie Salanka, Zakrutova i Diviaca położone są na Plesivieckiej Planinie, zaś otwór wejściowy do Jaskini Krasnohorskiej znajduje się w północnym zboczu Planiny Silickiej. Wyniki datowań metodami C–14, TL i ESR badanych próbek nacieków z jaskiń Słowackiego Krasu pokrywają się w przybliżeniu z okresami wzrostu nacieków na półkuli północnej, wyznaczonymi na podstawie analizy statystycznej wyników datowań metodą uranowo-torową. Pomimo niewielkiej liczby datowanych próbek nacieków oraz stosunkowo dużych błędów dat uzyskanych metodami termoluminescencji i elektronowego rezonansu spinowego otrzymane wyniki pozwalają na sformułowanie wniosków dotyczących rozwoju systemów jaskiniowych Słowackiego Krasu w młodszym czwartorzędzie. Daty uzyskane na próbkach nacieków z Jaskini Zakrutovej (Z1), Jaskini Salanka (S1) i Jaskini Krasnohorskiej (K1), zbliżone do 300 ka, świadczą, że jaskinie te były w tym czasie osuszone, a zatem system odwadniania planin przez głębokie studnie, którymi wody docierają do w przybliżeniu poziomych kanałów, został ukształtowany wcześniej. Wynika stąd również wniosek, że już około 300 ka BP rejon Planiny Plesiveckiej i Planiny Silickiej, a być może i innych planin, był morfologicznie zbliżony do stanu obecnego.