GEOLOGICA CARPATHICA, 44, 1, BRATISLAVA, FEBRUARY 1993
35 - 42

TURBIDITES AS FILLINGS OF CAVITIES IN TRIASSIC LIMESTONES OF THE SILICA NAPPE (WESTERN CARPATHIANS, PLEŠIVEC KARST PLATEAU)

RÓBERT MARSCHALKO[1] and JÁN MELLO[2]

[1] Geological Institute, Slovak Academy of Sciences, Dúbravská cesta 9, 842 26 Bratislava
[2] Dionýz Štúr Institute of Geology, Mlynská dolina 1, 817 04 Bratislava, Slovak Republic

(Manuscript received December 3, 1991; accepted in revised form March 25, 1992)

Abstract: The filling of cavities in Wetterstein limestones of the Plešivec Karst Plateau consists of a banded series of light-coloured graded siltstones and black mudstones of turbidite type. According to plant pollen and spores, the sediments are of Santonian - Campanian age. Sharp bases of beds, graded parallel as well as climbing current-ripple lamination, indicate gradual vanishing of current which deposited these rock. No breaking has been found in the one sets of laminae, which leads to the assumption that they were deposited within a few hours. Thin bedded sequences are accompanied by buried limestone blocks (over 1 ton) fallen from above and representing delapsed structures. The opinion has been presented that suspension gravity currents inflow into empty karst spaces suddenly below groundwater level, where circulation did not exist and a favourable anoxic environment could occur. The sedimentary fill deformed later into synclinal form does not display even the early stage of diagenesis. In view of possible redeposited of pollen and spores, the age of sedimentary fillings as well as its subsequent deformation is uncertain.

Key words: turbidites of karst cavities, syndiaganesis stage of compaction, Upper Cretaceous.

Introduction

Sedimentary filling of cavities in Wetterstein limestones of the Silica Nappe has been found in quarries of the Plešivec Karst Plateau in the South Slovak Karst region, and it had been studied earlier (Mello & Snopková 1973) from the viewpoint of age dating (Upper Santonian - Campanian). Since, except for spores and pollen grains, no other fauna necessary for paleoecological conclusions could be found, we applied other methods of study for the determination of the process of formation of the sedimentary filling. A considerable part of the fillings destructed with progressing exploitation and it is at the present not accessible for study. In the presented contribution, the largest filling is documented in the Gombasek quarry NE of Plešivec.

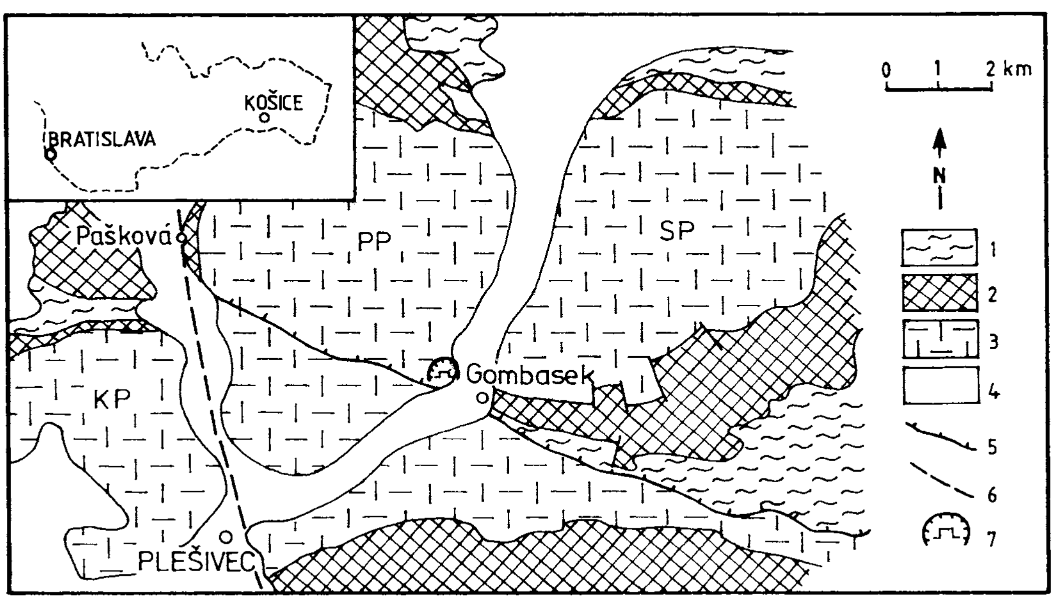

Fig. 1. Geological setting of the studied territory.
1 - 3 Silica Nappe: 1 - Lower Triassic sequence, 2 - Anisian sequence, 3 - Wetterstein limestones (Ladinian - Cordevolian), 4 - Quarternary sediments, 5 - high angle reverse fault, 6 - fault, KP - Koniar Karst Plateau, PP - Plešivec Karst Plateau, SP - Silica Karst Plateau, 7 - Gombasek quarry.

Shape and size of cavities

The cavity was found during excavation of Level V in light-coloured massive Wetterstein limestones (Carnian) (Figs. 1, 2, 3). It was restricted by two irregular walls with an strike NNE - SSW and dip of 80 - 85° to E. In the lower part it ended by a U-shape, the upper dome has not been preserved. The maximum width of the cavity reached 35 - 45 m in E - W cross-section, for and its height reached about 40 - 45 m. Its lenght could be followed for a distance of 50 - 60 m. The walls were irregular, and undulating, with protrusions. They were covered by a ferricrust, the bottom was karsted.

Sedimentary filling

The mudstone-sandstone filling surrounded by limestones was very characteristic a heterogeneity undesirable for economic reasons. The structure of the filling was synclinal, the beds were bent towards the axis on the contact with walls (Figs. 2 - 5), they had constant direction towards the sides and they did not wedge out. The study of the sequence showed vertical changes. The karsted floor was covered by yellow to brown duricrust and yellow to red mudstones, in greater depressions 10 - 100 cm thick, which gradually passed into greenish-grey, dark grey to black colour. The basic filling was concluded by deep-black mudstones alternating with light-coloured to light-grey beds and laminae of sandstones, and fine laminae of siltstones. The alternation of light-coloured beds and laminae with black mudstones formed a parallel bedded sequence and indicated abrupt changes in the deposition.

Mudstones and sandstones displayed within the whole thickness minimal compaction and very slight diagenetic lithification. When the cavity was opened at the contact with water and air, mudstones started to expand and during drying they rapidly decreased in volume, they cracked irregularly and disaggregated (Fig. 6). The lamination resulted neither in tabular jointing, nor fissility.

Sedimentary structures and their arrangement in beds

The differences of grain size in sandstones and siltstones caused colour changes in beds, which has also been confirmed in cases where grains could not be observed with the naked eye. More coarse-grained sand layers were lighter than fine-grained ones. According to the mean grain size, the layers belonged to fine-grained sands (0.05 - 0.25 mm) and they contained 50 to 70 % of quartz and 25 - 45 % of carbonate non-rounded grains (Figs. 7, 8). Thin silt beds and laminae also contained more quartz grains. The sandstone beds were sharp-based on the contact with the underlying mudstones, but displayed a hardly visible decrease of grain-size towards the overlying mudstones.

The upper contact of these beds was unclear and their thickness could not be determined accurately (Fig. 6). This grading distribution formed not quite 20 % of the whole set of 29 beds studied. The average thickness of well-defined graded beds reached 7 cm and in one exceptional case 40 cm.

A separate category were fine, light-coloured parallel laminae with a thickness of several mm to cm, with irregular frequency of occurrence in mudstones (Figs. 3, 6). They were composed of grains with silt as well as sand size, with graded lower contact (Fig. 7), without clear preferential orientation of grains. They occurred also in separate series unconnected with graded beds and formed continuous sets with current-ripple lamination (Fig. 6). In vertical sections a considerable part of current-ripple

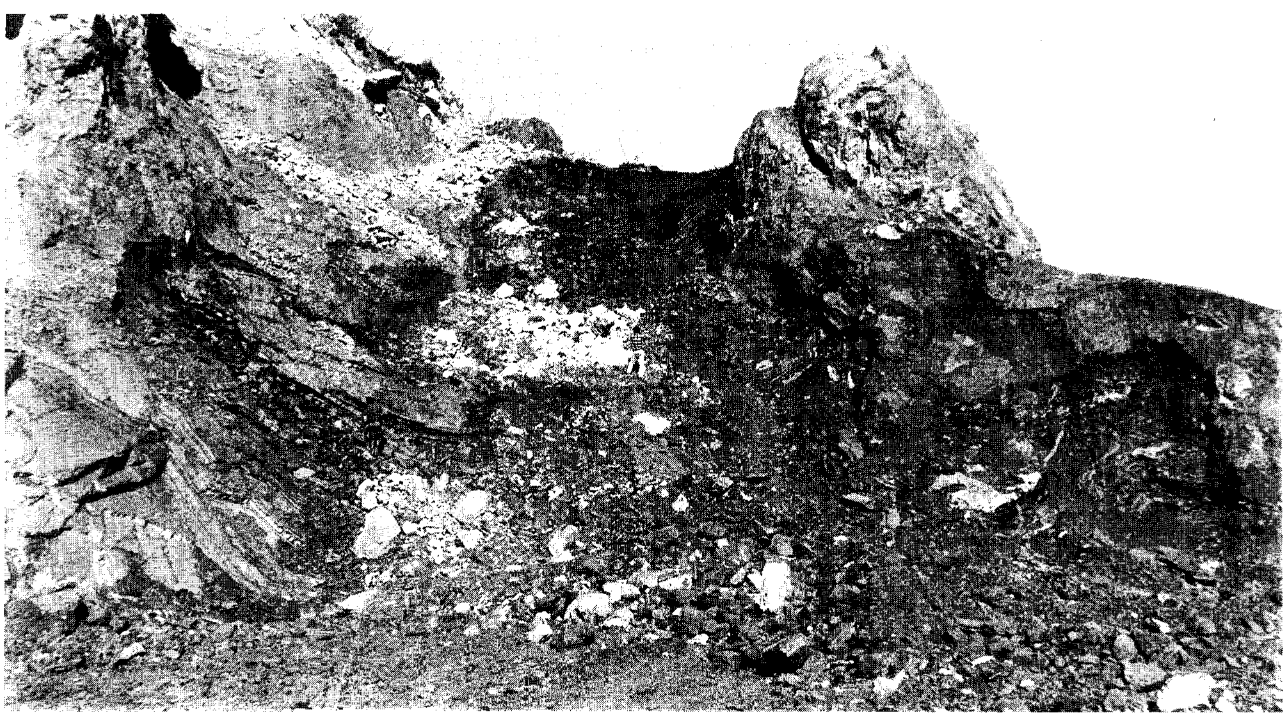

Fig. 2. Sedimentary filling in Wetterstein limestone of the Gombasek quarry (Level V). There are irregular protrusions and hollows in the left wall, covered by ferricrust. Synclinal structure is evident. The contact of beds with walls is secondarily affected by tectonics. The figure shows the preserved upper part of cavity filling. Two standing geologists have been included for a comparison of the size. Photo by R. Marschalko.

lamination reached a thickness of up to 2.5 cm. An analysis has shown that the laminae formed as a result of the migration of asymetric ripples in a unidirectional current in such a way, that the fine-grained sand eroded from the stoss side deposited laminae only on the lee side of ripples. Climbing of the sets above each other under a low angle (7 - 12°) indicates relatively higher current velocities (Jopling & Walker 1968). Complete forms of climbing ripples, with preserved stoss as well as lee side, with plant debris and mud drapes in the ripple troughs can be ascribed to low density turbidity currents with progressive decrease of velocity, inflows into stillwater bodies. If current ripple laminae were superposed by fine planar lamination, we can conclude that the ripple drift was not further washed (Figs. 3, 6) and the current capacity decreased.

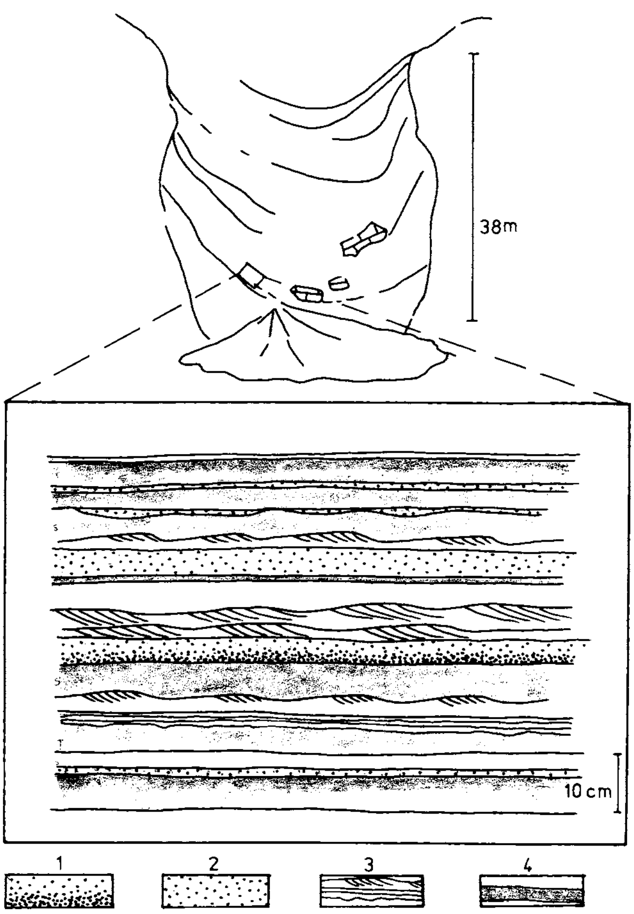

Fig. 3. Sedimentary filling of the Gombasek quarry. The filling is predominantly of banded mudstone. The direction of beds is constant. Beds of fine-grained sandstones and siltstone laminae on the base have sharp boundaries, on the upper side they are fading out. The beds are structureless as well as laminated (detail) formed as a result of abrupt change of flow conditions and their progressive vanishing. Sets of laminae, light- and dark coloured, have planar-parallel as well as current-ripple bedding. In the succession there are collapsed limestone blocks. *Explanations:* in detail: 1 - graded bedded sandstones, 2 - massive sandstones, 3 - thin bedded current-ripple lamination, 4 - dark mudstones.

The following basic signs characterize the physical conditions of sediment formation:

1 - the alternation of sand and silt layers with dark mudstones displays sharp changes in sedimentation and fluctuation of currents with different velocities. The duration of these changes cannot be estimated yet;

2 - the graded bedding and subsequent planar and current-ripple lamination are the products of a change from turbulent to traction phase in turbidity currents with gradually decreasing velocity. Therefore these beds are called turbidites;

3 - the predominance of only fine-grained sands and silts in the beds (grain population I according to Lowe 1982) confirms that grains were sustained and carried in suspension by low-density turbidity currents. With increasing turbulence the capacity of suspended load increased until the slope caused a reduction of turbulence. The capacity of the current decreased, the load fall towards the bottom and thus formed the described structure.

The absence of graded interval in the majority of our cases can be most probably explained by deposition in the previous phase nearer to sources. Transitions from fine-laminated planar intervals to structurally pure mudstones require deposition from low-density non-cohesive turbidity currents.

From the low thickness of the turbidites it appears that the volume and capacity of flows were limited by the quantity of clastic source material supplied. Paleocurrent measurements obtained from current-ripple lamination showed consistent regional direction to S and SE. We assume in this direction a decrease of the paleoslope, as well as a continuation of sedimentary deposit.

Mudstones

Mudstones form about three fifths of the volume of the filling. Since mudstones were predominantly laminated, and differentialy coloured sand beds and gradational laminae gradually pass into structurally pure mudstone (Fig. 6), we assume that they contain a considerable quantity of fine silt grains. Where the laminae are not very marked, they form thin, almost imperceptible, vanishing ripples or pseudonodules. Silt and mud turbidites must have played a role in their formation (Stow 1982). Certain part of the mudstones must be "allochthonous" and deposited by slow sedimentation from suspensions.

Black and dark-grey colour is an important criterion of the environment and it is connected with the occurrence of C_{org}. Pyrite concretions on the boundary between sands and mudstones also indicate the presence of organic substance and an anoxic sulphidic environment (Berner 1981). There are several reasons for the assumption that at high sedimentation rates of turbidites, non-oxidated organic substance were accumulated, since it is a case of sudden sedimentary events. It is surprising that the mudstones, and especially the fine planar and current-ripple lamination, were not bioturbated. This confirms the opinion of sedimentation in an anoxic environment with limited circulation and water stagnation, which became a factor determining the evolution of any life.

The mineral composition as well as the shape of mudstone bodies did not provide reliable data for the reconstruction of the sedimentary environment. Black mudstones were associated with quartz siltstones, which is partly consistent with the opinions that black mudstones contain weathered and more mature material. We found no traces of evaporites, which would indicate

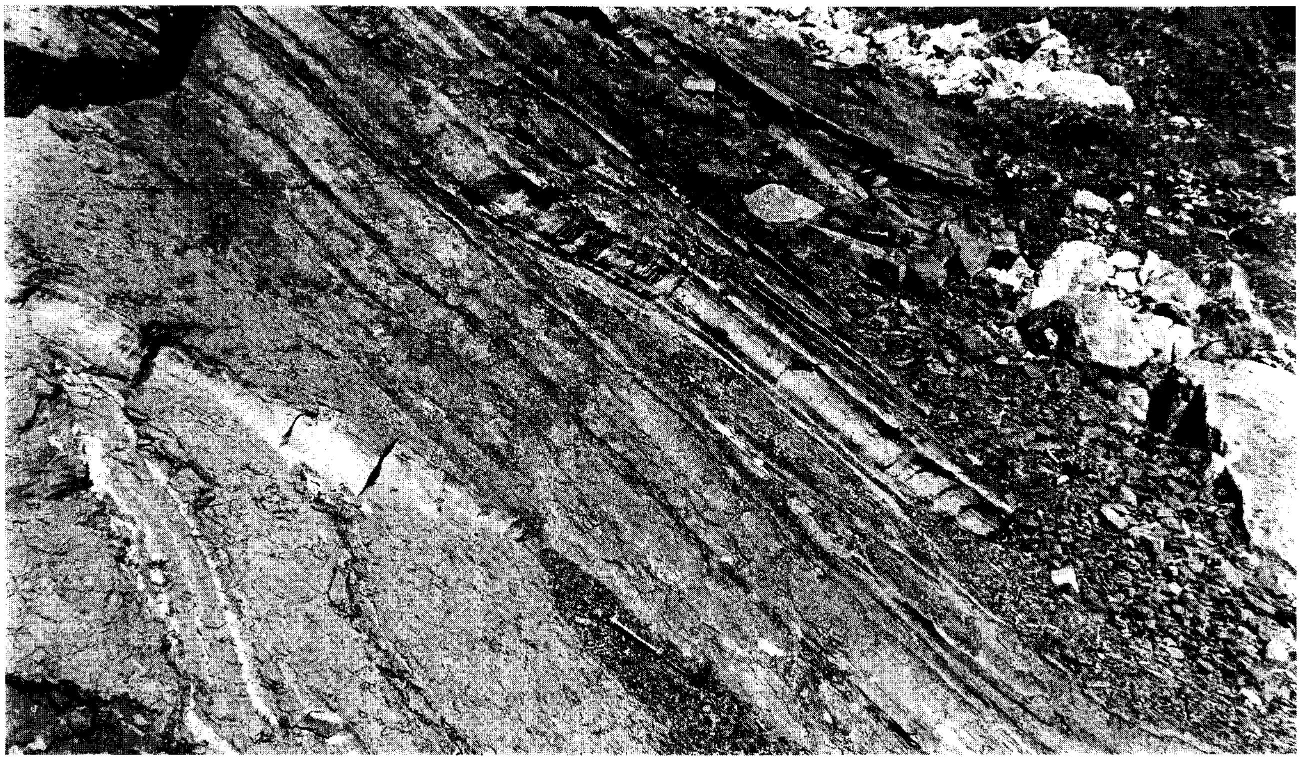

Fig. 4. Detail of the left limb of the syncline. Alternation of turbidites and laminae did not show cyclic changes of bed thickness. Two thickest graded beds in the sequence. Lateral persistence is a characteristic feature of the turbidites. Photo by R. Marschalko.

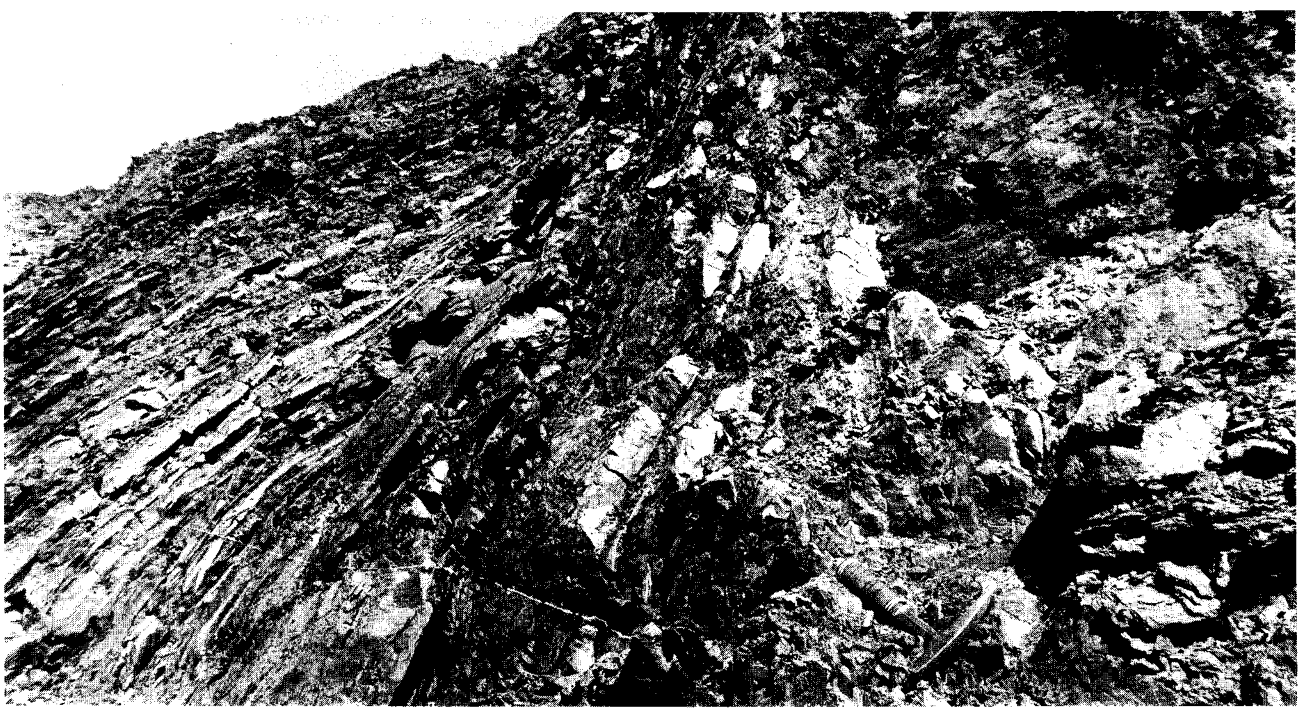

Fig. 5. Thin bedded parallel sequence of light- and dark coloured beds indicates rapid changes in the filling. The thickness of turbidites reached 3 - 7 cm. Tectonic contact of the filling with Wetterstein limestones can be seen in the right limb of the syncline. Photo by R. Marschalko.

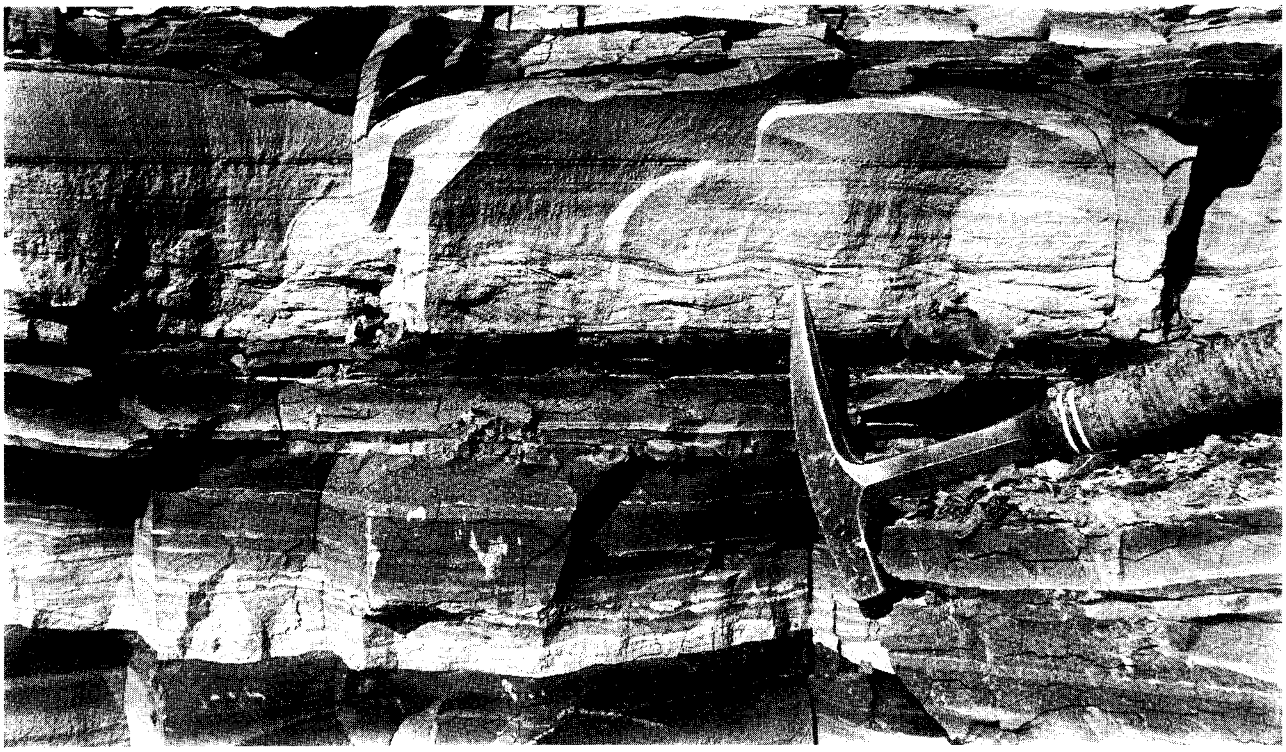

Fig. 6. Turbidite, separated sharply from the underlying mudstone begins with parallel lamination. Cross-bedding formed due to current-ripple migration, which was lying above each other under a low angle. Current-ripple lamination consisiting of fine sand and silt grains is on reflecting position of lee faces and stressed by a dark mud film. The ripple interval is covered by planar lamination and it fade out in mudstones. It is a succession of structures in which the grain gets gradually finer as a result of a disappearing flow.

the temperature of water bodies, neither were these traces of phosphates, glauconite, manganese crusts, or marine micro-plankton from the group *Dinnoflagelata*.

The concentration of some metals in mudstones (Tab. 1) - Ni, Zr and Co - can be related to high C_{org} contents, and low contents of Sr and B support the opinion of a non-marine sedimentation environment. We partly ascribe non-marine - continental - origin to red ferralitic soils occurring in dm thicknesses on the base of the cavity fillings. These variegated beds were formed by slow transport of solid products of weathering in by O_2 saturated water and their interreaction with free oxids and hydroxids in mudstone. With increasing sedimentation of mud turbidites the supply of C_{org} as well as reduction of trivalent Fe increased and the colour changed to green, grey and in an anoxic environment to black. We did not find any direct evidence of alluvial processes or mechanisms of other gravity flows, e.g. mudflow, unsorted debris flow deposits, residual channel lag deposits from karst valleys (Marschalko 1966), or upward fining alluvial cycle in the filling.

Another aspect that is difficult to understand - a dilemma - is the high age 72 - 83 Ma (Upper Santonian - Lower Campanian) of the mudstones and their very slight compaction (early stage of syndiagenesis according to Fairbridge 1967). Black mudstones did not undergo any internal metamorphosis, the packing of clasts is low (Fig. 7) and high static pressure of overlying sediments or increased temperature can be wholy excluded.

Mudstone sediments of deep marine Cretaceous turbidite basins in the Western Carpathians with similar types of sedimentary structures display, in contrast to the above described ones, all stages of early as well as late diagenesis caused by physical changes like bioturbation, compaction, deformation of clay components and intraclasts, as well as by chemical alteration of sands, pressure solution of grains.

There are certain indications that the sediments were deposited in unclosed, passage-like subsurface cavities and not in an open basin. In black mudstones there were dispersed sunken large blocks of Wetterstein limestones (Figs. 9, 10). On the basis of the character of graded silt laminae, bending and copying of unevennesses of basal surface of the blocks in underlying beds as well as the depth of sinking and slight deformations and small post-sedimentary folds pushed to the sides, these objects can be classified as fallen from above and sedimentary structures as impact-related. The accompanying surrounding mudstones did not bear any signs of washout by flows and concurrent debris-flow deposits. The blocks reached dimensions of up to 195 x 120 x 90 cm, and weight of several tons. They did not fall from a great height and if they should have slipped from adjacent walls, they would have been sunken in the mudstone together with angular debris. The blocks were not brought in plant roots and if we exclude transportation by drift ice, the only explanation of their local provenance is roof break collapse. Only in one case sporadic ornamentation could have been found - traces of karstification - on the lower surface.

Table 1: Quantitative spectral analysis of trace elements (in ppm), black mudstones.

SampleNo.		Ba	B	Mn	Pb	Ga	Cu	Ti	V	Ni	Zr	Co	Y	Sc	Cr	Sr	L.o.i.
1		226	124	412	42	21	47	6350	130	96	275	26.6	34	17.5	116	68	14.17 %
2		174	129	420	48	23	65	6340	133	116	205	33.8	40	15.6	117	69	14.34 %
Spears Armin	freshw.	415	985		37		47		125	76	158	33	35		146	121	
	marine	415	507		155		140		288	125	101	35	36		153	184	

L.o.i. - Loss of ignition.

Discussion to the origin of the cavities and their filling

From sedimentological studies it follows that gravity turbidity currents inflows into an empty underground cave system which was a part of large-underground communication. There were not preserved any other filled cavities and hollows exhumated by exploitation on various levels. The most active agents in the moulding of underground hollows and cavities were erosion and corrosion of tectonic fault system or sets of joints coexisting in the surroundings of deep reverse faults (compare Mello 1977) (Fig. 1). According to their orientation, and shape, these cavities and hollows could from especially in the freatic and partly in the vadose zone and according to Bögli' s (1980) classification they were in the evolution stage of mature to old age, which has been confirmed by the destruction and accumulation process. From these viewpoints they appear to be the remains of an underground karst system, preserved by sinking rapidly deep below the water level to such depths where circulation of water did not exist. The sinking of the teritorry was rapid (collapse) and probably tectonically controlled.

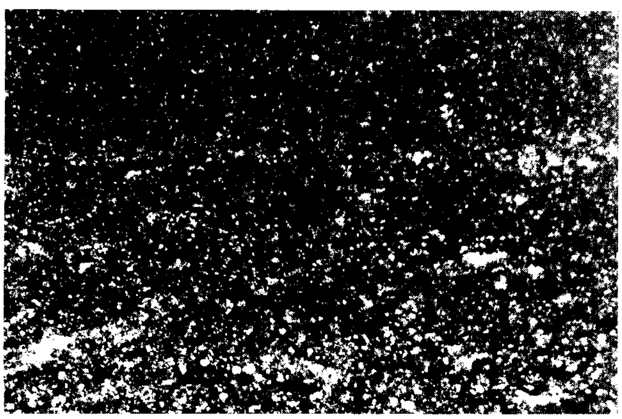

Fig. 7. Fine-grained sandstone with well-sorted angular grains. Section perpendicular to the base and parallel to the direction of transport. Magnif. 16 x.

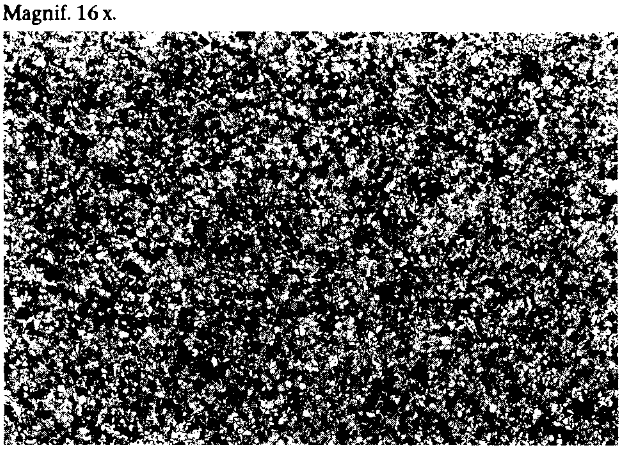

Fig. 8. Siltstone with upward-increasing quantity of matrix. A case of graded bending lamina. Magnif. 21 x.

The source of the filling sediments in not very well known. The material of quartzose siltstones does not come from the immediate surroundings. It could have been transported from lakes or a smaller basin which temporarily of for a longer period deposited the karst region and its tectonically dislocated depressions or valleys and filled them. At increased tectonic activity high- as well as low-density turbidity currents overflowed into underground spaces and flooded them with sediments. The sediment types indicated a humid climate in the region. As far as biofacial comparisons of the period on the boundary of Santonian and Campanian (83 Ma) are concerned, the sediments of fillings are compared (Mello & Snopková 1973) with coal series and mudstones of the Bakon Mts. In the Slovak Karst region, around the Ďobšiná ice cave, only relics of discordantly deposited molasse polymict conglomerates with intercalations of red shales with hematite substance have been preserved from this time (Santonian - Lower Campanian, Samuel 1977). They are sheet erosion products of lateritic soils from a non-karst substrate. Regardless of the conflicting opinions on the formation of red series ascribed by many authors only to arid climates, we would like to stress that except plant remnants - Cretaceous spores and pollen grains (73 - 83 Ma) - marine and other organisms have not been found in the sediments of the fillings. Because of very low diagenesis of the sediments, their high age is possibly only apparent in the view of permissible resedimentation of a wide range of plants remnants. The age of deformation of the sedimentary filling into synclinal forms remains still an unanswered question.

Conclusions

Turbidite sediments of karst cavities were banded fine-grained sandstones, siltstones and black mudstones.

The sharp boundaries of graded as well as structureless sandstones, siltstones with the underlying mudstones and transitions in to planar and current-ripple lamination and structurally pure mudstones require unidirectional, slowing turbidity currents inflow a stillwater body.

Large angular limestone blocks sunken into the mudstones are a result of roof break collapse and they unambiguosly indicate the existence of cave spaces.

The oldest possible age of the filling is according to pollen and spores Santonian - Campanian.

Compaction of mudstones did not reach even the early stage of syndiagenesis.

The synclinal structure indicates differential sedimentary subsidence and tectonic processes in the Tertiary.

Translated by K. Janáková

Fig. 9. Limestone block sunken into mudstone is bending a siltstone laminae. Microfolds formed as a result of squeezing of mud to the sides. Delapsed structure excludes the possibility of transport in slurry avalanches. Photo by R. Marschalko.

Fig. 10. A large block sunken into mudstone. A series of laminae in underlying beds is compressed by the weight of the block, but it is not broken or disturbed. No traces of erosion could be observed in the surrounding mudstones. The block was not stuck and it was not accompanied by slope debris. Its weight exceeds 1 ton. Photo by R. Marschalko.

References

Berner R. A., 1981: A new geochemical classification of sedimentary environments. *J. Sed. Petrology,* 51, 359 - 365.

Bögli A., 1980: Karst hydrogeology and physical speleology. *Springer Verl.,* Berlin, 284.

Fairbridge R. W., 1967: Phases of diagenesis and authigenesis. In : Larsen G. & Chilingar G. V. (Eds.): Diagenesis of sediments. *Elsevier,* Amsterdam, 19 - 89.

Jopling A. V. & Walker R. G., 1968: Morphology and origin of ripple-drift cross-lamination, with example from the Pleistocene of Massachusetts. *J. Sed. Petrology,* 38, 971 - 984.

Lowe D. R., 1982: Sediment gravity flows: II. Depositional models with special reference to the deposits of high-density turbidity currents. *J. Sed. Petrology,* 52, 279 - 297.

Marschalko R., 1966: Origin and depositional history of basal formation (Central Carpathian Paleogene). *Geol. Sbor.* (Bratislava), 17, 311 - 335.

Mello J., 1977: Triassic limestones lithofacial analysis and its application in tectonics (south part of the Plešivecká planina karst plateau). *Geol. Práce, Spr.* (Bratislava), 175 - 180 (in Slovak).

Mello J. & Snopková P., 1973: Upper Cretaceous filling in the cavities of Triassic limestones in the Gombasek quarry. *Geol. Práce, Spr.* (Bratislava), 61, 239 - 253 (in Slovak).

Samuel O., 1977: Find of foraminifers from variegated beds near Dobšinská ľadová jaskyňa (ice cave) and their stratigraphical interpretation. *Geol. Práce, Spr.* (Bratislava), 67, 93 - 103 (in Slovak).

Stow D. A. W., 1982: Toward an anatomy of fine-grained sediments. *Episodes,* 2, 3 - 4.

Spears D. A. & Armin M. A., 1981: Geochemistry and mineralogy of marine and non-marine Namurian black shales from the Tonsley Borehole, Derbyshire. *Sedimentology,* 28, 407 - 417.