Turbidite Deposit Systems of the Central-Carpathian Paleogene Basin

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Regional background

Central-Carpathian Paleogene Basin (CKP Basin) occurs in the northern part of the Central Western Carpathians. Generally, it is an elongated, about 200 km long and 60 km wide basin extending from Žilina in the Central Slovakia to Humenné in the eastern Slovakia (Fig. 1). The northernmost part of the basin occurs in Poland where it is named the Podhale Basin. To the west and south it is bounded by Mesozoic and Paleozoic units, which also prevailingly underlie the sedimentary fill of the basin. From the Outer Flysch Zone the basin is separated by the Klippen Belt. In the east it passes into the East-Slovakian Neogene Basin (Fig. 1). Opening of the basin resulted from oblique convergence of the North European Platform and Carpathians and isostatic load of the Carpathian nappes. The sedimentation commenced in the area of contemporary Klippen Belt and gradually shifted southward. Structural plan of the basin given by tectonics, tectonic history of source areas, climate and history of eustatic sea level belong to the most important factors determining evolution of sedimentary systems in the basin. Interplay of all these factors contributed to the shifting of basin depocenters and polyphase development of the basin fill reflected by individual sedimentary sequences.

Sediments

Age of the basin sedimentary fill, based mainly on benthic foraminifera and nanoplankton, ranges from the Middle Eocene to the Eggerian (Fig. 2). However, deposition in various subaerial sedimentary environments probably commenced already in the Paleocene as suggested by thick package of sediments underlying Middle Eocene marine strata. These sediments are barren of fossils and rare polen are stratigraphically not significant. Maximum thickness of sediments is up to 4000 m. The sediments

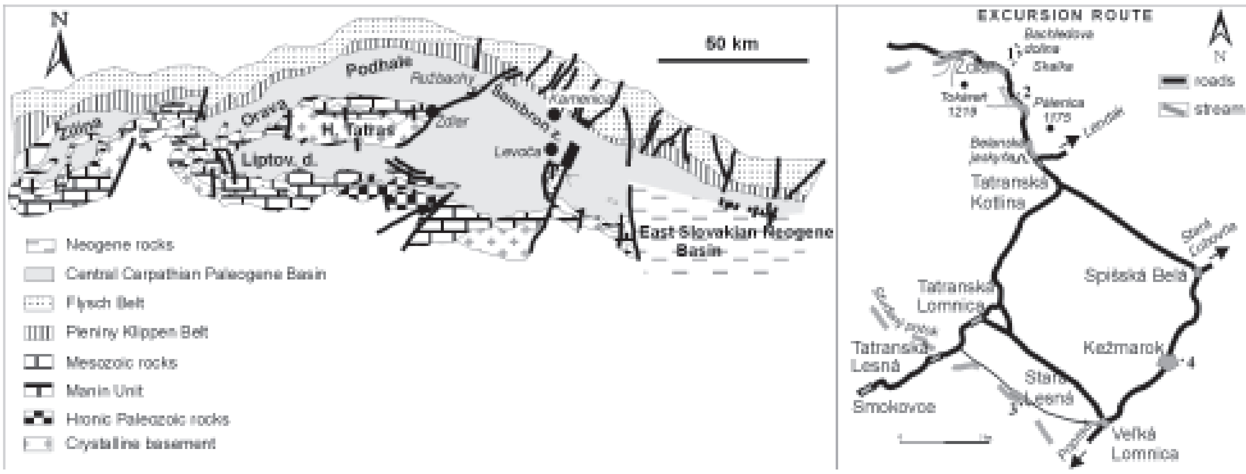


Fig. 1. Scheme of the Central-Carpathian Paleogene Basin and excursion route.

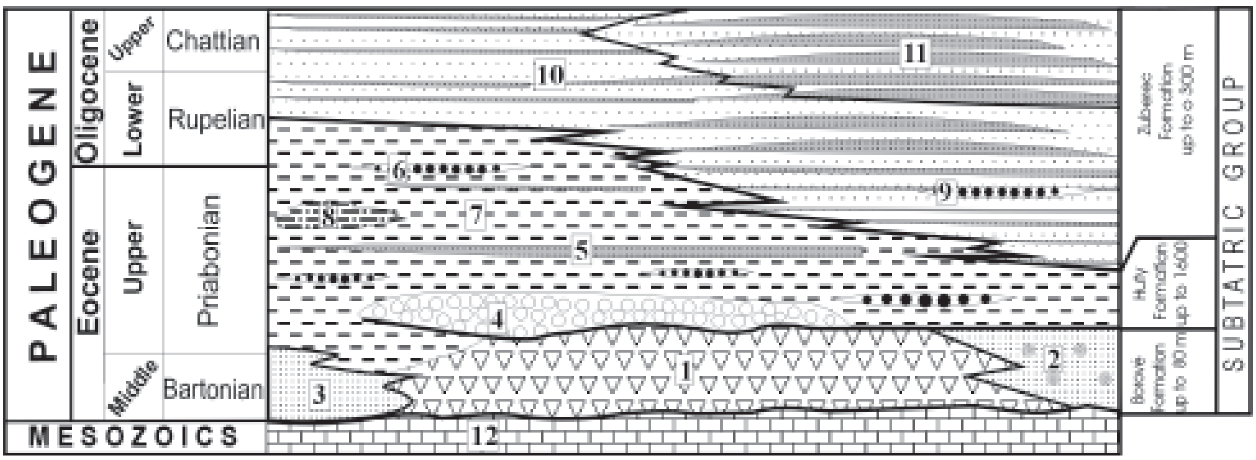


Fig. 2. Lithostratigraphy of the Paleogene deposits in the excursion area.

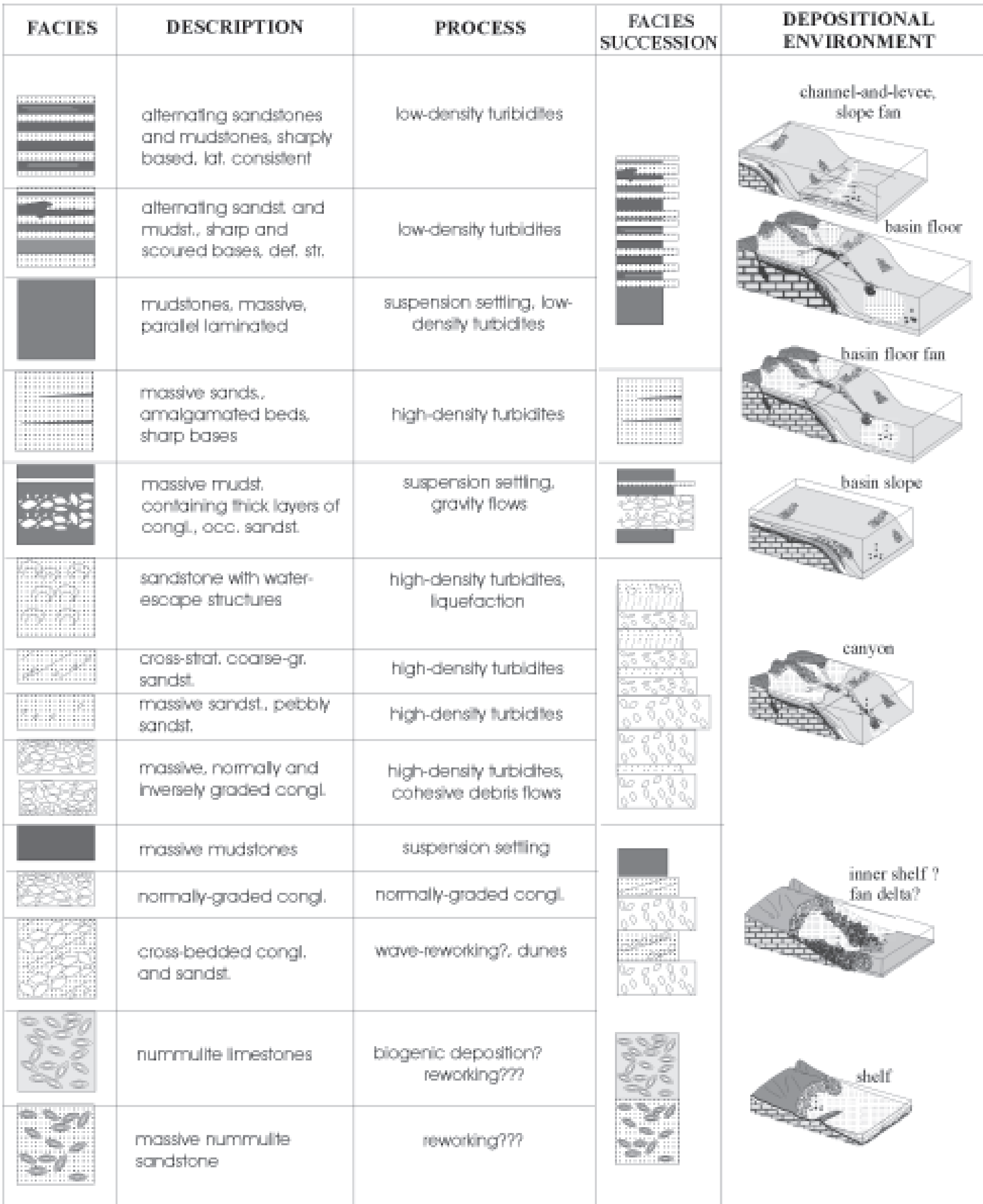


Fig. 3. Description of facies which will be shown during the excursion.

have been divided into several formations reflecting their lithology. In the Slovakia divisions published by Marschalko for the eastern part of the CKP Basin (e.g., Marschalko 1965) and Gross et al. (1984) have widely been used. In the Polish part of the basin (Podhale Basin) units defined by Golab (1952) have been used.

Gross et al. (1984) divided four formations and one member. Borové Formation is the lowermost one and represents transgressive, shallow-marine deposits. The overlying Huty Formation mostly consist of claystones with minor sandstones. The Zuberec Formation is composed of alternating sandstone and claystone beds. The whole succession is capped by Biely Potok

Formation mostly composed of massive, thick-bedded sandstone and minor conglomerates. The authors also divided Pucov Member representing coarse-grained sediments entering basin laterally.

Golab (1952) divided Numulitic Eocene (Slovak Borové Fm.), Zakopane Member (Huty Formation), Chocholow Member (Zuberec Formation) and Ostrysz Member (Biely Potok). Formation. Slovak Sambron Member have been correlated to the Polish Szaflary Member.

Recently some new lithostratigraphic units were introduced in the eastern part of the CCP Basin: Hornád and Chrastné Members of Borové Formation (Filo and Siráňová 1996, 1998) and Kežmarok Member of Zuberec Formation (Gross 1999).

Gross et al. (1984) stressed the superposition of individual units with the oldest Borové and youngest Biely Potok Formations. However, recently this supeposition was questioned (e.g. Soták and Starek 1999; Janočko and Jacko 1999) and attention was drawn to sediment transition within facies tracts.

The excursion localities occur in the Spišská Magura region and Poprad Depression, which form the NE part of the CCP Basin. Different tectono-sedimentary history and postsedimentary evolution resulted in high geologic diversity in this part of the basin. Generally, the sedimentary fill in this region consists of Borové, Huty and Zuberec Formations. However, in order of better understanding of sedimentary evolution in this part of the basin, it is more appropriate to divide individual lithofacial units in these formations and to define sedimentary successions and architectural elements (Fig. 3).

The lowermost part of the sedimentary succession consists of coarse-grained deposits of Borové Formation. Based on large foraminifera, the age of the deposits is Middle to Late Eocene (P14–P15). The sediments may be divided into three lithological units: breccias and conglomerates, nummulitic sandstones and limestones and sandstones with high content of molluscs. Massive and crude cross bedding, sharp and erosive bases and amalgamated beds are typical for all these facies. Although the composition of the most of clasts is closely related to the Mesozoic basement, occurrence of small percentage of quartz and crystalline rocks suggests far-travelled deposits. The deposits are thought to be deposited in fan deltas, deltas and shallow-marine environments.

Borové Formation is overlain by deposits of Huty Formation with high stratigraphic span from the Late Eocene up to the Late Oligocene. In the excursion area we can only observe superimposition of the deposits of Huty Formation above the deposits of Borové Formation, however, occurrence of redeposited clasts containing Late Eocene nummulites strongly suggests lateral transition from the coarse-grained, shallow-marine sediments (Borové Fm.) into the sediments of Huty Formation. We divide sediments of Huty Formation into several lithologic units which are from the base upward as follows:

- mudstones with occasional intercalations of sandstones and conglomerates. The dark mudstones are massive and parallel-laminated, sandstone and conglomerate beds are mostly sharply based. The unit probably originated on the outer shelf and basin slope.
- Tokáreň conglomerates – conglomerates and sandstones deeply incised into underlying mudstones, Borové Formation and Mesozoic basement. The overall trend of deposits is fining and thinning upward. The Tokáreň conglomerates represent submarine canyon fill deposits.
- mudstones with abundant layers of conglomerates and sandstones. The mudstones are dark, massive and parallel laminated, conglomerates and sandstones are massive, normally and inversely-graded and sharply-based. The unit represents basin slope depositional environment.
- massive, thick-bedded sandstones. The sandstone forms up to 1 m thick, often amalgamated beds with composite thickness about 7 m. We believe that it comprises basin floor fan.
- mudstones with occasional conglomerate and sandstone beds. The mudstone is dark, massive, parallel and ripple cross laminated. The depositional environment of these deposits is still ambiguous – it may represent slope deposits or distal part of slope fan deposits.

The uppermost part of the sediment succession in the excursion area consists of Zuberec Formation. Deposits of the formation are composed of alternating sandstone and mudstone beds. They are divided into three units which are interpreted as a part of basin slope fan:

- alternating sandstone and mudstone beds. The ca. 10 cm thick beds are sharply-based and laterally consistent. Sandstone is fine to medium-grained, massive, parallel- and ripple cross laminated. The unit represents overbank deposits of a turbidite system.
- alternating sandstone and mudstone beds. Typical are synsedimentary folds and small, upward-thinning cycles suggesting levee deposits.
- alternating sandstone and mudstone beds with striking upward-thickenning cycles. The sanstones comprise up to 60 cm thick beds. This unit is interpreted as a part of channel system within the basin slope fan.

Tectonics

Tectonic history of the Paleogene deposits was conspicuously determined by the most striking structure in the region of the Spišská Magura represented by the Subtatric – Ružbachy fault system (SRFS). The system, having NE-SW strike and steep dip toward SE, cuts the eastern extension of the Tatras and continues toward SE. It governed polyphase kinematic evolution of the Spišská Magura region, which based on structural analysis, may be divided into four deformation stages (Jacko in Janočko et al. 2000; Jacko and Janočko 2001).

The oldest deformation stage is related to the NNW-SSE compression in the area of the SRFS resulting in NE-SW thrust structures dipping southward. The compression determined uplift of the area N of the SRFS and subsequent erosion of the uppermost part of the basin fill. The extension component $\sigma3$ had E-W direction. The timing of the deformation, based on the fission track analyses (e.g., Kráľ 1977), is Middle to Late Miocene. The uplift of the Tatras Mts. during the Neogene (about 2700 m) and Quaternary (about 400 m; Nemčok et al. 1993) strongly suggests recent activity of the structure. The Miocene uplift of the Paleogene deposits also determined exposure of the oldestmost Paleogene sediments on the S-SE margin of the region and general gentle dip of the Paleogene deposits northward.

The second deformation stage is related to the E-W compression resulting into NE-SW dextral strike slips along the SRFS. They initiated almost perpendicular “releasing” NW-SE structures and may be well observed mainly in the SE marginal zone where they often segment SRFS. N of the SRFS the compression had $\sigma1$ ENE-WSW direction and the extension stress component $\sigma3$ was of NNW-SSE direction. In this stress field conjugate pairs of ENE-WSW dextral strike slips and WNW-ESE sinistral strike slips having characteristics of Riedl shears R and R’ originated. Increase of deformation resulted in NNW-ESE dextral strike slip in the main shear zone between the Tokáreň and Skalka elevation points. To the activity along these conjugate strike slips is also related formation of mezoscopic shear folds with fold axis dipping southward. Origin of these NW-SE and NNW-ESE structures in the whole region of the Spišská Magura is probably related to the transpression movements in the Tatras area (Hrušecký et al. 1995). The analyses in the Spišská Magura region showed that these dislocations are often related to the local uplift. Structurally they are manifested by bed flexures and striation on dislocations in carbonates and conglomerates. Commonly they are accompanying by subparalel system of subvertical joints having carbonate fill. Travertines at these structures indicate the Quaternary activity of the system continuing from the Neogene when the system was probably established.

The third deformation stage was only found in the Paleogene deposits N of the SRFS. It is related to the NNE-SSW σ1 compression component and WNW-EWE σ3 component resulting into WNW-ESE overthrust structures dipping toward NNE and ENE-WSW extension structures. Flexures, duplex and fold structures with E and ENE fold axes direction having about 10° dip originated along these overthrust structures. The folds may be characterized as "fault propagation folds". The described overthrust structures probably have local character and they are related to the formation of the NNW-SSE dextral shear zone between the Tokáreň and Skalka elevation points described in the 2nd stage. Intensive kinematic activity along the shear zone induced local overthrusts consistent with the dextral movement in the area. The σ1 compression and σ3 extension stress of this deformation stage only partly rotated of the main compression and extension stress field found in the 2nd main deformation stage of the central part of the studied region. We assume almost synchronous developoment of the system with the assumed activity on the NNW-SSE shear zone.

The youngest deformation stage is related to the NW-SE extension. This stage of the SRFS is accompanied by origin of NE-SW normal faults dipping SE and WSW-ENE normal faults dipping NNW. To this stage formation of NE dipping folds is related. The described system belongs to the youngest dislocation structures strikingly segmenting lithologically different sediments of the CKP Basin of the Spišská Magura region and transversal NW-SE faults.

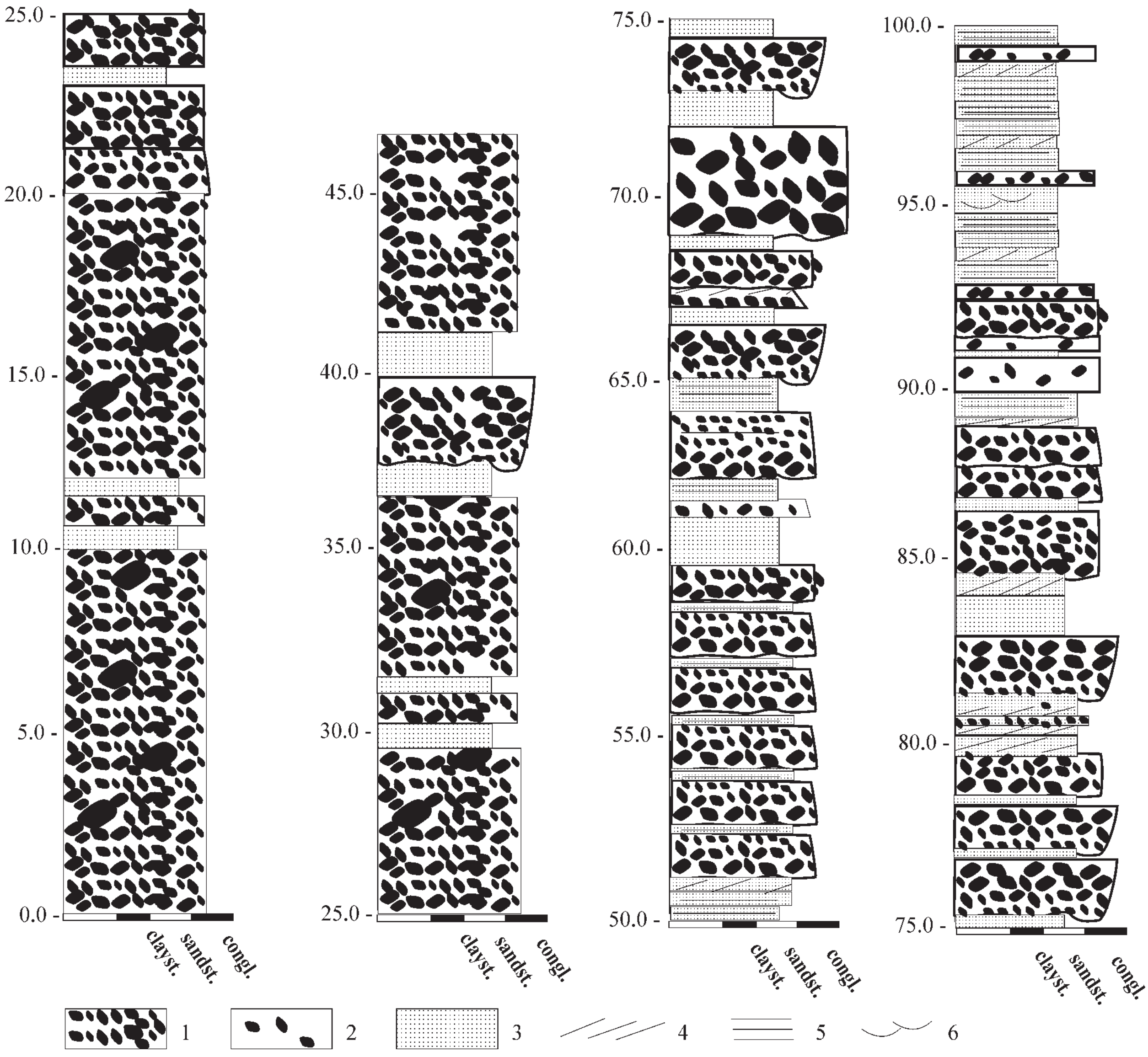


Fig. 4. Sedimentological log of canyon fill deposits east of Ždiar, stop 1.

Stop I
Tokáreň Conglomerates; Skalka Elevation Point, East of Ždiar

Tokáreň conglomerates are part of the Huty Formation. They fill a canyon incised into the underlying mudstones of Huty Formation, coarse-grained deposits of Borové Formation and Mesozoic basement. The maximum incision is about 60 m. The deposits consist of conglomerates and alternating sanstones. The conglomerates are mostly clast-supported, massive, normally and inversely graded. Occasionally they also are crudely cross bedded. The composition of angular and rounded clasts varies. Some beds are composed of exclusively carbonate clasts, however, beds composed of carbonate, shale, quartz and crystalline clasts may be also found. Typical is occurrence of sandstone, mudstone and numullitic limestone clasts suggesting their redeposition from the underlying Paleogene deposits (Fig. 4). The clasts contain *Nummulites cf. brongniarti* D'ARCH. et HAIME and *Nummulites puschi* D'ARCHIAC suggesting the upper part of the Middle Eocene (P 14 zone). The clast diameter varies from a few centimeters to one meter.

The beds are thick up to 2 m. In the lower part of the succession they are often amalgamated and form several meters thick layers. The whole succession has an overall upward-fining and upward-thinning trend. The internal organization of conglomerates also improves upward. The beds are commonly sharply and erosively based. Rarely flute cast may be found suggesting palaeoflow direction eastward. The conglomerate beds are separated by sandstones. The sandstones are parallel and cross laminated, occasionally normally graded (F4, 5, 6 facies of Mutti 1992). They often show water-escape structures. The thickness of sandstone beds is up to 80 m.

Tokáreň conglomerates represent fill of a canyon which is a part of a turbidite system in the basin. Strong incision was caused by fall of relative sea level. The petrographical composition of clasts suggests multiple source areas of the deposits. Prevailingly massive conglomerates in the lower part of the succession probably originated by debris flows (e.g. Nemec and Steel 1984). The better internal organization of beds in the upper part of the succession point to transformation of the debris flows into high-density turbidity flows. The described characteristic of the deposits suggests the back-filling of the basin during the rise of relative sea level.

Stop II
Sandstones of Huty Formation; Quarry in Bachledova Valley

The sandstones cropping out in the quarry in the Bachledova valley are part of the Huty Formation. They are sandwiched by mudstones of the formation and form striking "marker" bed extending from Ždiar up to the Lendak. Massive sandstones near Veľký Lipník village (NE of the stop locality) may also be a part of the described system.

The sandstone, characterized as sublitic arenite, is mostly medium grained, massive and parallel laminated. It comprises up to 1 m thick beds which are often amalgamated. The amalgamated beds comprise in the lower part of the outcrop up to 6 m thick layer. The sandstones passes into overlying mudstones gradually by several thinnner sandstone beds alternating with mudstones (Fig. 5). The base of beds is sharp and scoured with occasional scour marks. Common is occurrence of organic matter, plant stems and thin layers of coal. Rip-up clasts, composed of older Paleogene mudstones, suggest erosive ability of the flow.

The observed sandstones are interpreted as part of basin floor

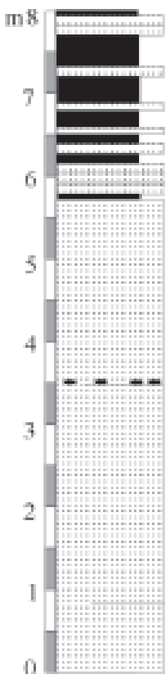


Fig. 5. Sedimentological log of massive sandstones in the Bachledova dolina, stop 2.

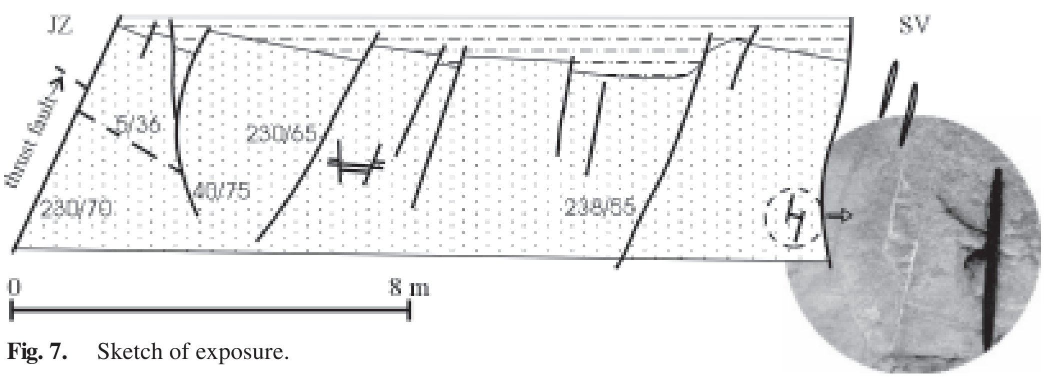


Fig. 7. Sketch of exposure.

fan. We relate origin of this element to a significant lowering of relative sea level.

The outcrop is a nice example of time succession and extension tectonics which is manifested both in the main and secondary fractures (Figs. 6, 7). It is possible to observe several tectonic structures forming postsedimentary structure of the region.

The oldest structures are represented by ENE-WSW normal faults dipping 85° SSE. They are result of WNW-ESE extension. The movement orientation is recorded by calcite striae.

The younger, striking structure segmenting ENE-WSW normal faults, which is parallel to bedding planes, is represented by south-vergent, WNW-ESE overthrust plane resulted from NNE-SSW compression. The overthrust is well recorded by striae on planes. The origin of these deformations is described in the introductory part.

The youngest structures at the locality are related to the NE-SW extension. The extension resulted into NW-SE normal faults dipping 35–75° SW which segment older structures. The only exception is antithethic listric fault dipping SW. Besides the fault structures with calcite striae it is possible to observe parallel open strain fractures either without or with calcite fill. Also note nice example of hooked beds on these fault planes.

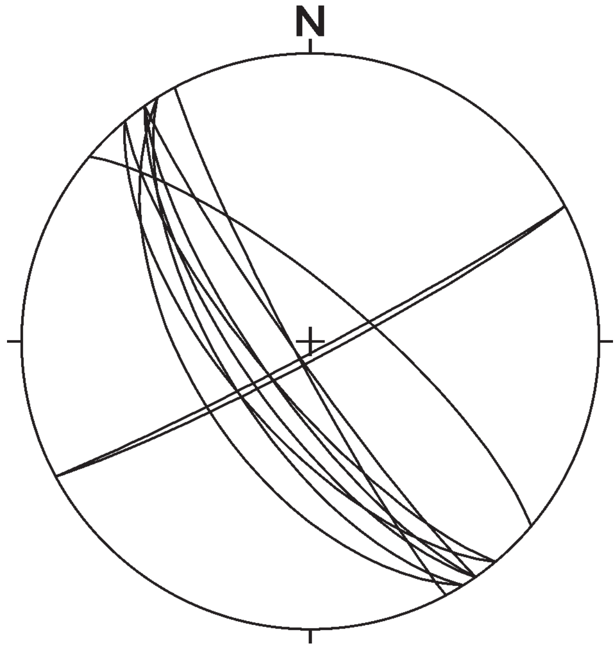
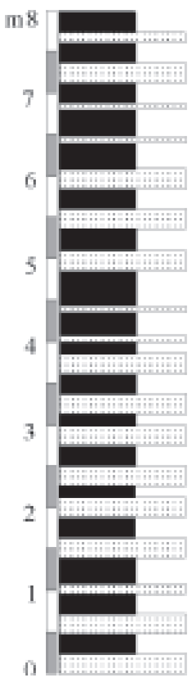


Fig. 6. Orientation of extension faults in the Bachledova dolina.

Stop III
Deposits of Zuberec Formation; Bank of Biela Voda Creek, Stará Lesná



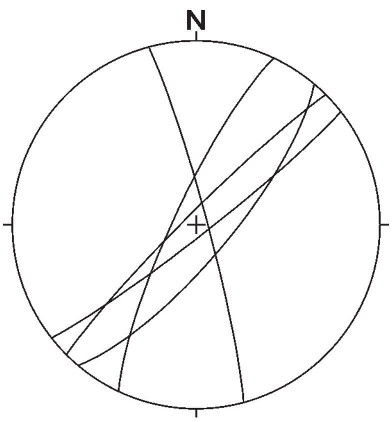


Fig. 9. Orientation of extensional faults in the Stará Lesná.

Fig. 8. Sedimentological log of deposits at stop 3 – Stará Lesná.

The outcrop on the left side of the Biela Voda creek in the village Stará Lesná shows typical deposits of Zuberec Formation. They consitsts of alternating sandstone and mudstone arranged in sharp-based, laterally consistent and 5–20 cm thick beds (Fig. 8). The mudstone is dark, massive and parallel laminated. Occasionally, ripple-cross lamination may be found. In the mudstones it is possible to observe early diagenetic features – concretions. The mudstones are sometimes deformed showing synsedimentary deformation structures related to loading and creep on the inclined topography. The fine- and medium-grained sandstones are massive, parallel and ripple cross laminated. Although the sandstone beds are laterally consistent, it is possible to observe variation in bed thickness along the outcrop. Occasionally flute casts may be found on bedding planes.

Based on the nanoplankton analyses, the age of the deposits is Early Oligocene. The sedimentary feature of deposits and relationship to surrounding geology suggests their origin in the interdistributary area of a turbidite system. We relate this area to the slope fan.

Synsedimentary structures at the outcrop are represented by sedimentary folds having E-W axis directions (Fig. 9). The sediments are deformed by two systems of penetrative faults – – NE-SW and NNW-SSE striking faults. The amplitude of movement on these open structures is almost negligible, however, on the NE-SW fault planes it is possible to observe small downthrows. The origin of these deformations is related to the last extension stage of the Subtatric-Ružbachy fault system. The younger NNE-SSW fault systems are related to the youngestmost Quaternary tectonics which has the same direction.

Stop IV
Kežmarok Member of Zuberec Formation; Kežmarok

The deposits at the outcrop represents stratotype locality of the Kežmarok Member defined by Gross (1999). They consists of repeating cycles composed of sandstones and mudstones. The cycles start with thick sandstone beds alternating with thin mudstone beds and they terminate by thick mudstone beds. The sandstone beds are sharply and erosive based, flute casts are quite common on bedding planes. Along the outcrop it is possible to observe slight erosion resembling compensation cycles or large-scale channel erosion. The sandstone is mostly medium-grained, massive, occasionally parallely laminated and ripple-cross stratified (Fig. 10). The sandstone beds sometimes contain rip-up clasts suggesting erosional ability of the flow. Also organic matter is largely preserved.

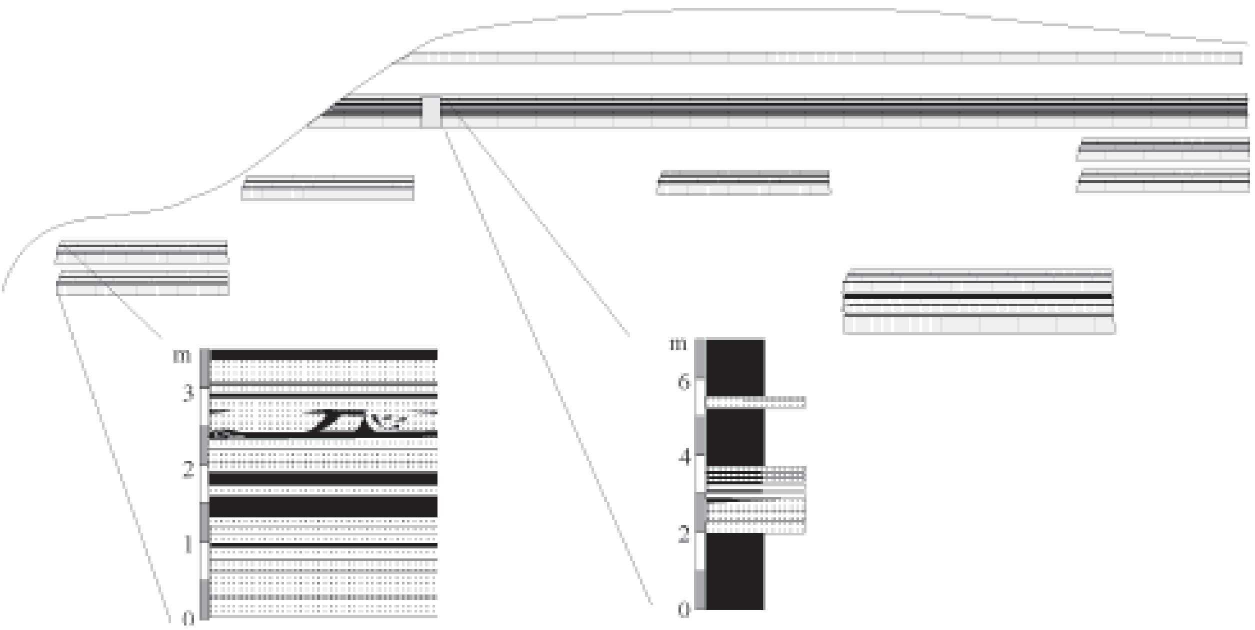


Fig. 10. Scheme and sedimentological log of deposits at stop 4 - Kežmarok.

The mudstones are massive and parallely laminated. They are not well observable at the outcrop because of their weathering. Between individual cycles of thick sandstone beds they form about 1–2 m thick separating intervals.

The deposits are interpreted as a part of channel element within the turbidite system. According to position of these deposits and relation to the surrounding geology we believe that the system represents a part of the slope fan.

At the outcrop it is possible to observe synsedimentary and postsedimentary structures. The synsedimentary deformations are represented by sedimentary folds copying the original slope during deposition. The dip of fold axes is consistent with palaeocurrent directions toward SW determined by flute casts.

The younger, post-sedimentary structures are mainly represented by extensional tectonics – NNW-SSE and ENE-SWS joints coated by calcite mineralization (Fig. 11). The segmentation by these joints is well observable in well-preserved sandstone beds. Origin of the structures is related to the Subtatric-Ružbachy fault system. Origin of older, NNW-SSE joints is probably related to the E-W extension during the first deformation stage when the Spišská Magura region was separated of the Levočské vrchy Mts. (see the introductory part). The younger, ENE-WSW joints probably resulted by NW-SE extension along the

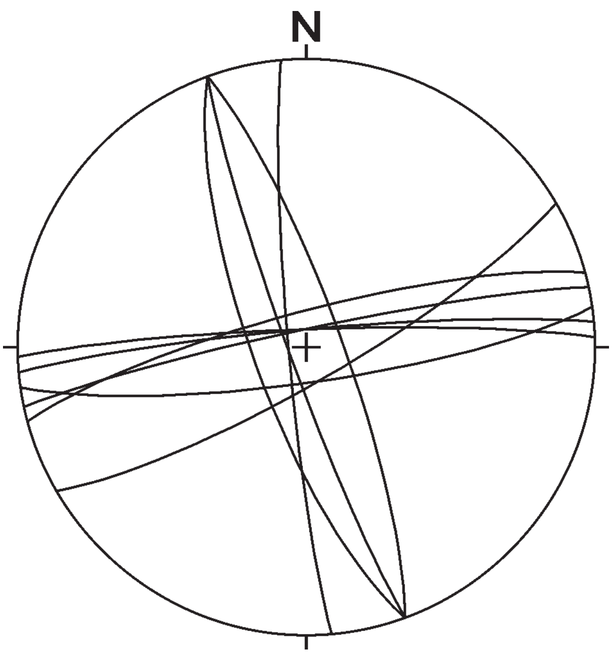


Fig. 11. Orientation of extension faults in the Kežmarok.

Subtatric-Ružbachy fault system and its following downthrow of the southern margin. However, these system is not observable at the outcrop. Scarcely dextral strike slip may be observed which is evidently younger as calcite mineralizion. We assume that it is a remnant of dextral strike slip occurring along the Subtatric--Ružbachy fault system preceding the NW-SE extension.

References

FILO I. and SIRÁŇOVÁ Z., 1996. Tomášovské vrstvy – nová litostratigrafická jednotka podtatranskej skupiny. *Geol. Práce, Spr.*, 102: 41-50.

FILO I. and SIRÁŇOVÁ Z., 1999. Hornádske a chrastianske vrstvy – nové oblastné litostratigrafické jednotky podtatranskej skupiny. *Geol. Práce, Spr.*, 103: 35-51.

GROSS P., KÖHLER E. and SAMUEL O., 1984. A new lithostratigraphical division of the Inner- Carpathian Paleogene. *Geol. Práce, Spr.*, 81: 103-117.

GROSS P., BUČEK S., ĎURKOVIČ T., FILO I., MAGLAY J., HALOUZKA R., KAROLI S., NAGY A., SPIŠÁK Z., ŽEC B., BORZA V., LUKÁČIK E., JANOČKO J., JETEL J., KUBEŠ P., KOVÁČIK M., ŽÁKOVÁ E., MELLO J., POLÁK M., SIRÁŇOVÁ Z., SAMUEL O., SNOPKOVÁ P., RAKOVÁ J., ZLÍNSKA A., VOZÁROVÁ A. and ŽECOVÁ K., 1999. Explanation to geologic map of the Poprad Depression, Hornád Depression, Levoča Mts., Spišsko--šarišské medzihorie Mts. Geol. Surv. of SR, Bratislava, (in slovak, engl. resume).

GOLAB J., 1952. Tektonika Podhala. Geol. Buil. Inf. Pánst. geol., Warszawa, 1.

HRUŠECKÝ I., PLAŠIENKA D., KOVÁČ P. and MARKO F., 1995. Zhodnotenie perspektív vyhľadávania uhľovodíkov vo vybraných oblastiach Západných Karpát – Štruktúrno-tektonický výskum chočsko – podtatranského zlomového pásma. Manuscript, Geological Survey of Slovak Republic, 35.

JACKO S.Jr. and JANOČKO J., 2001. Kinematic evolution of the Central Carphatian Paleogene Basin in the Ždiar area, Slovakia. Slovak Geological Magazine, 4, in press.

JANOČKO J. and JACKO S., 1999. Marginal and deep sea deposits of Central Carpathian Paleogene Basin, Spišská Magura Region, Slovakia: Implication for basin history. *Slovak Geol. Mag.*, 4: 281-292.

JANOČKO J., GROSS P., JACKO Ml.S., POLÁK M., POTFAJ M., RAKÚS M., BUČEK S., JETEL J., KUBEŠ P., PETRO Ľ., BOOROVÁ D., FEJDIOVÁ O., HALASOVÁ E., HALOUZKA R., HAMRŠMÍD B., KAROLI S., KOHLER E., MILIČKA J., SIRÁŇOVÁ Z., ZLÍNSKA A., ŽEC B. and ŽECOVÁ K., 2001. Vysvetlivky ku geologickej mape Spišskej Magury v mierke 1:50,000, in press.

KRÁĽ J., 1977. Fission track ages of apatites from some granitoid rocks in West Carpathians. *Geol. Zbor. Geol. Carpath.*, 28 (2): 296-276.

MARSCHALKO R., 1965. Sedimentárne textúry a paleoprúdenie v okrajových flyšových litofáciách. *Geol. Práce, Zpr.*, 34: 75-102.

MUTTI E., 1992. Turbidite Sandstones. Spec. Publ. Agip., Milan.

NEMČOK J., BEZÁK V., JANÁK M., KAHAN Š., RYKA W., KOHÚT M., LEHOTSKÝ I., WIECZOREK J., ZELMAN J., MELLO J., HALOUZKA R., RACZKOWSKI W., REICHVALDER P., 1993. Vysvetlivky ku geologickej mape Tatier 1:50,000. GÚDŠ, Bratislava.

NEMEC W. and STEEL R. J., 1984. Alluvial and coastal conglomerates: their significant features and some comments on gravelly mass-flow deposits. In: KOSTER E.H. and STEEL R.J. (Editors), Sedimentology of gravels and conglomerates. *Mem. Canad. Soc. Petrol. Geol.*, 10: 1-31.

SOTÁK J. and STAREK D., 1999. Depositional stacking of the Central-Carpathian Paleogene Basin: sequences and cycles. *Geol. Carpath.*, 50: 69-72.