GEOLOGICA CARPATHICA, 47, 4, BRATISLAVA, AUGUST 1996
227–238

SERPENTINITIC SANDSTONES FROM THE ŠAMBRON-KAMENICA ZONE IN EASTERN SLOVAKIA: EVIDENCE OF DEPOSITION IN A TERTIARY COLLISIONAL BELT

JÁN SOTÁK and JURAJ BEBEJ

Geological Institute, Slovak Academy of Sciences, Bratislava; Branch: Severná 5, 974 01 Banská Bystrica, Slovak Republic

(Manuscript received December 13, 1994; accepted in revised form October 5, 1995)

Abstract: The specific type of sediments, which arise in subduction complexes are serpentinitic sandstones. Their material originates from disintegrated ophiolite series. The first occurrences of serpentinitic sandstones in the Western Carpathians have been recorded from the Peri-Klippen area in Eastern Slovakia (Šambron-Kamenica Zone). They occur within the Upper Oligocene flysch formations. The sequence is notable for its thin-rhythmic character and the constant thickness of the sandstone–claystone intervals ("zebra"- type flysch). The proportions $Q_{25}F_8L_{67}$ express the average modal composition of the sandstones. The high content of detrital serpentinites and glassy clasts (Lv = 62 %) causes a prevalence of unstable lithic components. The interstitial material of sandstones corresponds mainly to pseudomatrix (originating from the breakdown of lithic grains), recrystallized during diagenesis into orthomatrix and/or epimatrix. In diagrams for determining the provenance of arenites, the projection points of serpentinitic sandstones are concentrated in the field of magmatic-arc related sandstones (Dickinson et al. 1983) or oceanic-arc related sandstones (Valloni 1985). The preservation of fragile clasts of serpentinite points to deposition from a diluted turbidite suspension. In dense flows with a high dispersive pressure caused by grain collisions the serpentinites should be almost destroyed. Accumulation of these clasts could also occur as a result of hydrodynamic separation, with the lighter grains of serpentinite reaching a higher level of the currents, which carries them to deeper parts of the basin.
The occurrence of serpentinitic sandstones in the Šambron-Kamenica flysch deposits indicates a suture zone of the Tertiary collision occurring on the contact of the Central Carpathian Paleogene and the Klippen Belt. The flysch formations of the Šambron-Kamenica Zone are sediments of perisutural basins, which, to the north were connected with trench-type flysch deposits in the Magura Unit.

Key words: Eastern Slovakia, Šambron-Kamenica Zone, serpentinitic sandstones, sedimentology, petrofacies, provenance, source area, geodynamic significance.

Introduction

Terrigenous sediments containing a high portion of serpentinite clasts are known as serpentinitic sandstones (Okada 1964), or detrital serpentinites (Lockwood 1971). They occur mainly in synorogenic formations, which are represented by flysch deposits (Zimmerle 1968). The serpentinite detritus in the flysch sandstones originates from rocks of disintegrated ophiolite series (Lockwood 1971; Arai & Okada 1991). Serpentinitic sandstones were described from Hokkaido Island (Okada 1964), subduction complexes of the Eastern Pacific (Dickinson 1982), Ligurian complexes of the Southern Appenines (Critelli 1991, 1993), the Franciscan complexes in California (Dickinson et al. 1982), and Columbia (Zimmerle 1968), accretionary terranes of the Himalayas (Critelli et al. 1990), and elsewhere. The abundance of the serpentinite grains has also been recorded in sandstones, the material of which was recycled from ancient suture zones (e.g. in the Gosau Formation of the Northern Calcareous Alps — Dietrich & Franz 1976; Wagreich 1993; the Siwalik Formation in the Himalayas — Critelli & Ingersoll 1994, and others).

Data about the distribution of serpentinitic sandstones show that they are related to continental margin settings, especially to zones of lithospheric subduction. Their identification is therefore important for the understanding of the geotectonic development of orogens, especially in cases where a suture zones ceased during the collision. Occurrences of serpentinite and spinel detritus have also received attention in studies of the Alpine flysch zones (Winkler 1988; Wildi 1985; Winkler & Slaczka 1992; Pober & Faupl 1988; etc.). In the flysch regions of the Western Carpathians, occurrences of serpentinitic sandstones were not recorded up to now. The occurrences of serpentinitic sandstones described in this work, have been found in the East-Slovak territory of the Peri-Klippen area (Šambron-Kamenica Zone). They occur on the contact of the Central Carpathian Paleogene with the Klippen Belt, which is considered to be a suture zone after the Tertiary collision.

The flysch deposits of the Šambron-Kamenica Zone

The Šambron-Kamenica Zone is situated on the northern margin of the Levočské vrchy Mts. and Šarišská vrchovina Highland, where the Central Carpathian Paleogene joins with the Klippen Belt. The Šambron-Kamenica Zone is formed by flysch deposits, which are not entirely identical with the formations of the Central Carpathian Paleogene (Fig. 1). This is documented by certain differences in the sequence develop-

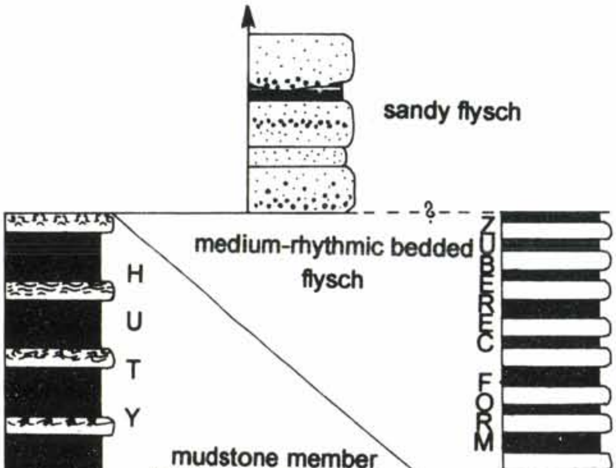


Fig. 1. Lithostratigraphic column of the Paleogene formations of the Šambron-Kamenica Zone.

ment of the flysch formations, and especially their thickness (in the Lipany 3 and Lipany 4 boreholes, up to 3000 m, Rudinec 1992). The variegated claystones, conglomerates and nummulite limestones from some boreholes in the area of Lipany, are regarded as the basal sediments of the Paleogene formations of the Šambron-Kamenica Zone (Leško et al. 1983; Gross & Ďurkovič 1991). The lower division of the Šambron-Kamenica Zone is formed by subflysch claystone sediments and by thin-rhythmic flysch deposits of the Šambron Beds (Chmelík 1959). Numerous bodies of conglomerates, pebble mudstones, slump breccias and olistolites, also occur within the Šambron Beds. Locally, Menilite-type shales are also interbedded in them (Chmelík 1958, 1959); Nemčok et al. 1990). It is possible to correlate the Šambron Beds, either with the lower part of the Huty Formation (Andrusov & Samuel et al. 1983), or with the Šaflar Beds of the Špišská Magura Mts. (Chmelík 1958).

The Šambron Beds are overlain by a formation with a prevalence of claystones ("Claystone Beds" according to Chmelík 1959). This formation is characterized by sandstone beds with distinct current ripple lamination and convolute bedding ("Convolute Flysch" according to Marschalko 1961). The lithofacial development of this formation, resembles the upper part of the Huty Formation, or the Zakopane Beds of the Podhale Flysch. Higher up, the claystone beds pass into the medium rhythmic flysch deposits, with an equal claystone-sandstone ratio ("Claystone-Sandstone" Beds according to Chmelík 1959). They represent normal flysch lithotypes, similar to the Zuberec Formation, or the lower part of the Chocholov Beds. The facies is characterized by presence of medium-bedded sandstones with BOUMA intervals and with distinct hieroglyphs. The top sediments of the Šambron-Kamenica Zone are locally developed as a non-turbiditic formation of sandstones and doloarenites. They occur in massive, homogeneous and amalgamated beds and recall the sediments of the Biely Potok Formation, or the Ostrysz Beds of the Podhale Paleogene. Stratigraphically the sediments of the Šambron-Kamenica Zone have been attributed to the Bartonian and the Priabonian (Nemčok et al. 1977, 1990; etc.). New stratigraphic information also point to the presence of Oligocene sediments in the Šambron-Kamenica Zone (A. Nagymarosy, unpublished).

The flysch sediments of the Šambron-Kamenica Zone are strongly deformed. Their tectonic structure is mainly characterized by folds (chevron, inclined and recumbent types), less by kink-bends, intrastratal duplexes, reverse faults and strike-slip faults. The character of the deformation points to complete detachment of the flysch sequence from the substratum, in the position of the fold-and-thrust belt, followed by later backthrusting and dextral transpression. Thus the Šambron-Kamenica Zone is structurally individualized with respect to flat-lying formations of the Central Carpathian Paleogene in the Levočské vrchy Mts. The assignment of the Šambron-Kamenica Zone is therefore not clear. The majority of authors regard it as part of the Central Carpathian Paleogene, raised in the elevation structure on the southern margin of the Klippen Belt (Nemčok 1978; Nemčok et al. 1990; Marschalko 1975). There are also views that the Šambron-Kamenica Zone is not an integral part of the Central Carpathian Paleogene, but a pendant of the Krichevo Unit (Grecula et al. 1980; Leško & Varga 1980; etc.).

Localization of serpentinitic sandstone occurrences

The type occurrence of serpentinitic sandstones is situated 100 m west of the village of Kamenica nad Torysou, in an outcrop at the right erosional bank of Lipiansky Potok Creek (Figs. 2, 3). Further occurrences of serpentinitic sandstones are found in the wash-cut of Lipiansky Potok Creek at Slané Mláky between Kamenica nad Torysou and Pusté Pole. An increased portion of serpentinite detritus was also recorded in sandstones cropping out in the valley of Putnovský Potok Creek, SE of Pusté Pole and near the village of Hanigovce.

Serpentinite-bearing flysch deposits at Kamenica Creek locality are folded into recumbent to moderately plunging folds inclined toward the NNW. In the hinge parts, there are folds cut by overthrust faults, which declined at angles of 15-60° to the SSE.

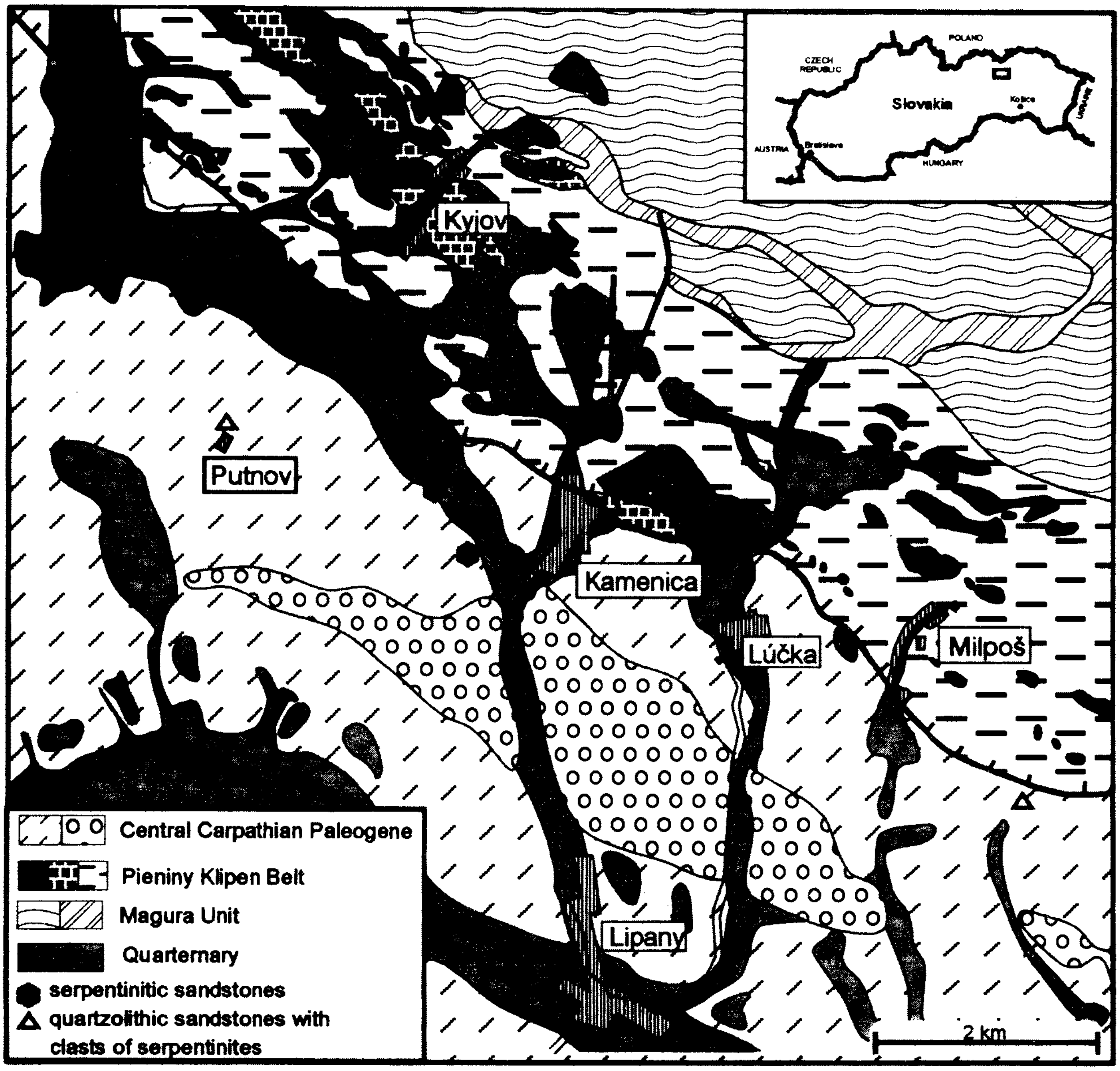


Fig. 2. Geological sketch map of the area near of Kamenica nad Torysou (Nemčok et al. 1990, simplified) depicting the localities of serpentinitic sandstones.

Sedimentology of serpentinitic sandstone deposits

The serpentinitic sandstones occur in the thinly bedded flysch sequences, where they alternate with claystone and siltstone intervals (Fig. 4). The sandstones have a greenish-grey to greenish colour, and occur in beds with an average thickness of 5.96 cm. The granulometric composition of the sandstones in percentages of modal classes is as follows (12 thin-sections): 0.03–0.06 mm = 0 %; 0.06–0.125 mm = 16.2 %; 0.125–0.25 mm = 41.2 %; 0.25–0.5 = 27.9 %; 0.5–1 mm = 14.7 %; 1–2 mm = 0 %. Laminated bedding or unclearly developed diffuse lamination is observable in the sandstone beds. Occasionally, claystone rip-up clasts are arranged in lamination. The sandstone beds are divided by intervals of weakly calcareous claystones and clayey siltstones. The presence of chlorite and mixed-layer chlorite/smectite in the claystones was proved by X-ray diffraction analysis. The av-

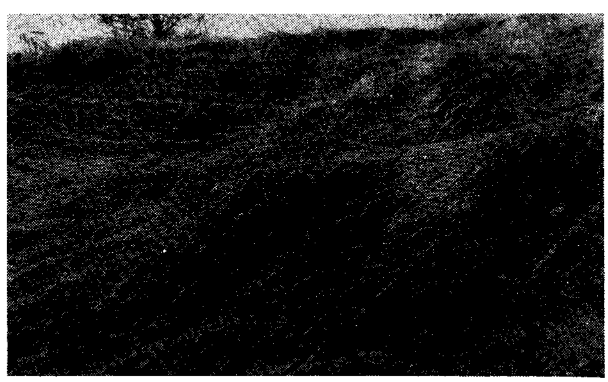


Fig. 3. General view at the outcrop of serpentinitic sandstones in the creek near Kamenica nad Torysou. The thin-rhythmic flysch formation is folded into recumbent up to moderately plunging megafolds (scale in the right lower corner: 1 m).

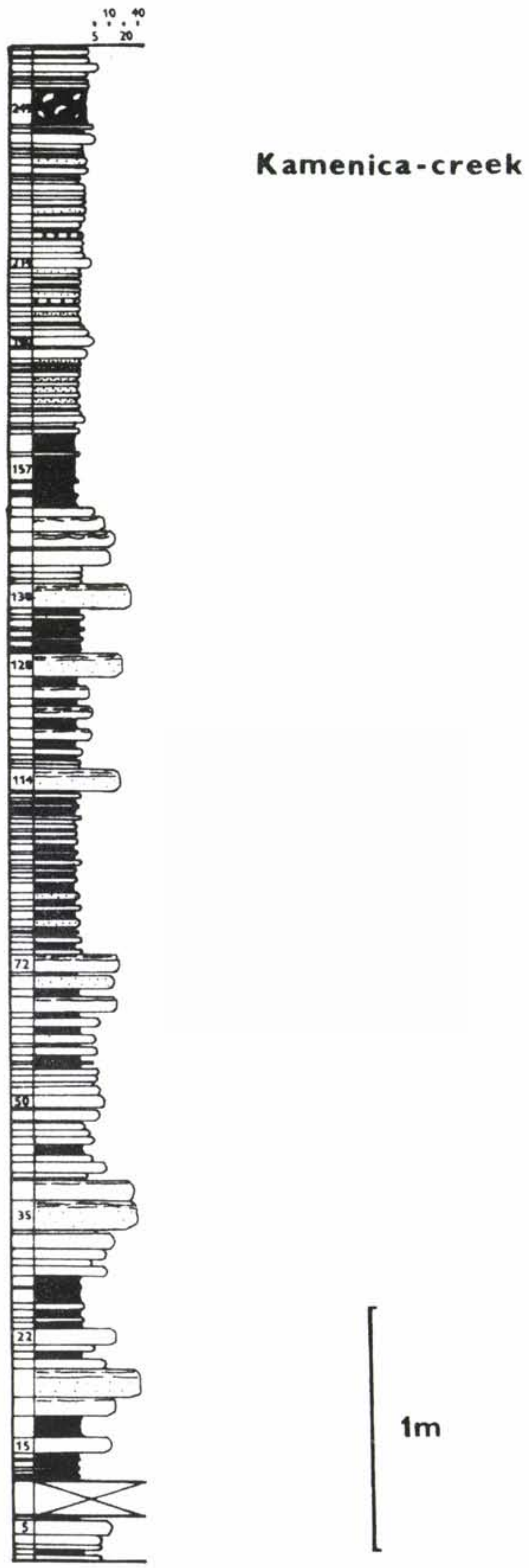


Fig. 4. Detailed profile in the formation of serpentinitic sandstones at Kamenica Creek locality.

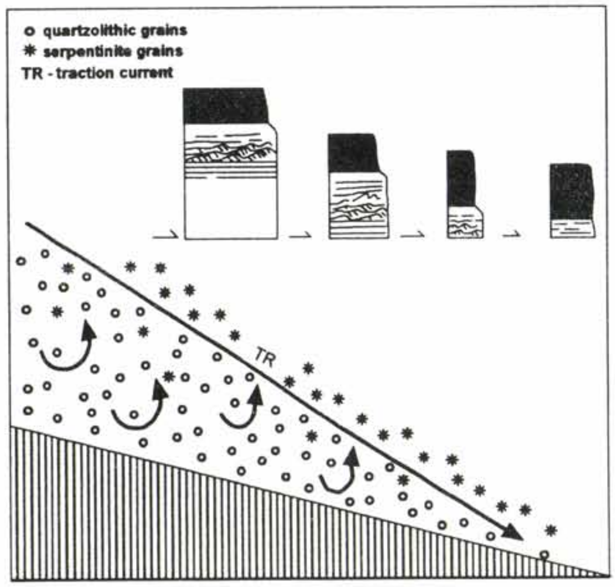


Fig. 5. Suggested mechanism of the hydrodynamic flow separation responsible for the deposition of serpentinitic sandstones.

erage thickness of the claystone/siltstone intervals is 4.78 cm. The ratio S : C = 1.1. Thin layers of dolomites with a white patina are also present in the flysch formation. Claystone layers with "drowned pebbles" of calcareous sandstone, which also contain fragments of serpentinites and spinel detritus, also appear sporadically in the formation. The sandstone pebbles come from washed material of the same formation.

The sandstones have flat lower bedding surfaces without current traces and wash-outs. The absence of basal erosion, as well as the lack of lower BOUMA intervals testifies to the fact that the sandstones did not originate under conditions of the upper flow regime. Only traction textures of lamination corresponding to higher intervals of the BOUMA sequence are developed in the sandstones. The sequences are marked by a constant thickness of the sandstone-claystone/siltstone intervals repeated in non-cyclic trends (Fig. 4). They resemble the "zebra" type flysch (Nelson & Nilsen 1984), which is characteristic for the basin plain environment with lower flow regime. The sandstone layers are arranged only in T_d-T_e BOUMA divisions without basal intervals and erosional traces. Such an arrangement is characteristic of the distal flysch facies, and points to deposition from the diluted suspension in a zone where turbidity currents become inactive.

Deposition from diluted flows can also explain the preservation of serpentinite clasts in the flysch sandstones. In the dense flows the fragile serpentinite clasts would have been destroyed due to high dispersion pressure caused by grain collisions. Thus, the accumulation of these clasts could be a result of hydrodynamic separation, by which the lighter grains of serpentinites reach higher levels within the flow (traction current), which carries them to deeper parts of the basin (Fig. 5). Flow separation of minerals resulted from their different specific weight, which is significantly lower for serpentinite, than for quartz, feldspar and most rock fragments (2.51–2.56 — Zimmerle 1968). Flow separation may also be the reason, why the basin-ward facies of the Šambron-Kamenica Zone are richer in serpentinite detritus than the normal flysch facies, in which the heavier and more resistant chromian spinel is concentrated. The sedimentation in a lower flow regime was only occasionally influenced by stronger currents, causing erosion of the bottom (claystone intraclasts, washed pebbles).

The age of serpentinitic sandstone deposits

The age of the serpentinitic sandstone deposits has been determined by the study of the calcareous nanoplankton (A. Nagymarosy, Budapest). The nanoplankton associations are composed of the species *Cyclicargolithus abisectus* (Müller), *Reticulofenestra lockeri* Müller and *Zygrhablithus bijugatus* (Deflandre), which date the Upper Oligocene age of the formation (NP 24-25 nanoplanktone zone).

Petrofacial composition of serpentinitic sandstones

The sandstones display a variable mineralogical-petrographic composition. They contain lithic, quartzose and feldspathic grain constituents.

Lithic grains (L): include mainly serpentinite rock fragments, which are attributed to ophiolitic lithics (Critelli & Ingersoll 1994, p. 817). Serpentinite grains are colourless to olive green, and it is possible to observe the typical mesh and loop textures in them (Pl. I: Figs. 1-3, 5-6; Pl. II: Figs. 1-4). Among serpentinite fragments the coarse-flaky lizardites (Pl. I: Fig. 4) and fibrous chrysotiles are also present (Pl. II: Fig. 8). In the categorization of lithic grains, detrital serpentinites are included among the components of the volcanic-metavolcanic grain type category **Lv** (Valloni 1985). Thus serpentinites, like volcanites and glass shards are among the very unstable elements, which regularly occur together in the detritic associations of sandstones (Critelli 1991, 1993; Zimmerle 1968; etc.). The sandstones have also a significant portion of glassy fragments and rocks with a vitritic up to vitrophyric structure. On the margins of glassy fragments, hydratation rims formed by clayey minerals are usually developed (Pl. I: Fig. 8). Thus, the volcanic source of the glassy clasts seems to be more probable than their origin from opaline-replaced ultramafic rocks or cherts. A similar origin can also be proposed for the small particles included in the sandstone matrix (Pl. II: Fig. 7). They display peculiar twinning structures, which resemble more those occurring in opal-CT lepispheres. Therefore, the particles are regarded as lepispheres formed by intergrowths of leaf and blade-like crystals of opal-CT modifications of quartz, with various degrees of coalescence. The origin of lepispheres may be immediately connected with the dissolutional processes of SiO_2, during diagenetic transformation of glass through the stage of devitrification, to the stage of smectites formation (Hesse 1989). Such a type of spherulitic opal-CT crystals originated from dissolution and devitrificacion of volcanic glass has also been shown by Christidis et al. (1995). The lithic grains of sedimentary category (**Ls**) consist of sparry carbonates up to crystalloclastic calcites. Fragments of phyllitic rocks (**Lm**) and mica microlites (monomineral phyllosilicates — **M**) also participate in lithic grain associations.

Quartzose grains (Q): occur as monocrystalline and polycrystalline types. Monocrystalline grains (**Qm**), with weak features of undulatory extinction have a significant predominance. Some quartzose grains are rimous, and have hair-line fissures filled with cross-fibre aggregates of chrysotile. Polycrystalline grains (**Lq**) consist of subcrystals of quartz and phyllosilicates. They are formed by dynamically recrystallized aggregates of blade-like quartz and grains with suture intercrystalline surfaces.

Feldspathic grains (F): form accessory components of the sandstones. The K-feldspars (**Kf**) are usually clouded due to sericitization passing mainly along the cleavable fissures. They often contain mineral inclusions. The grains of plagioclase (**Pf**) display a zonal character, and a lower intensity of sericitization.

The sandstones examined consist of mostly unstable detrital components and fine grained clayey interstitial matrix. Such compositional and structural parameters are characteristic for sandstones of the greywacke category (according to Dickinson 1970, immature sandy rocks with grey to dark grey colour, variable mineralogical-petrographic composition, and with the clayey interstitial matrix firmly cementing an angular detritic framework). According to Dott's classification (1964), serpentinitic sandstones belong to the category of wackes, that is sandstones containing more than 10 % of matrix. However the fact that sandstones of the appropriate petrographic composition, and a lower degree of compaction are placed in the wacke area, while those with a higher degree of compaction are placed in the arenite area, is a deficiency of this approach to classification (Williams et al. 1969). In the composition diagram of Füchtbauer (1959), these sandstones also fall into the greywacke area (Fig. 6). Sandstones with such a high content of detrital serpentinites are designated serpentinitic greywackes, in accordance with Zimmerle (1968). The typical features of greywackes also include strong interpenetration of detritic rock fragments, and their intensive secondary alteration, obscuring the relationship between the detritic grains and the matrix. The result of this is a diffuse boundary between the matrix and the majority unstable detritic grains (mostly serpentinites). Therefore it is difficult to determine the modal composition of serpentinitic sandstones (compare Zimmerle 1968). Planimetric analyses of the studied sandstones are summarized in Tab. 1. The proportions $\mathbf{Q}_{25}\mathbf{F}_8\mathbf{L}_{67}$ express their average modal composition. Lithic grains have the greatest quantity in the sandstones (e.g. sample No. 256 — $\mathbf{Q}_{10}\mathbf{F}_{10}\mathbf{L}_{80}$). The dominance of this grain category is caused by the high contents of detrital serpentinites and clasts of a vitritic nature ($X: \mathbf{Lq}_{22}\mathbf{Lv}_{62}\mathbf{Ls}_{16}$), which, according to Critelli (1993), are characteristic of sandstones of volcanolithic composition. With decline in the content of serpentinite and increasing silicoclastic material, the composition of sandstones approaches the composition of quartzolithic petrofacies (e.g. sample No. 264 — $\mathbf{Q}_{48}\mathbf{F}_{11}\mathbf{L}_{41}$).

The sandstone groundmass has the character of a grey to green-grey microcrystalline matrix formed by crushed material of serpentinites and the minerals of the chlorite/smectite to chlorite group (recorded by XRD analysis). The matrix is significantly influenced by diagenetic recrystallization (orthomatrix according to Dickinson 1970). The evidence of recrystalization can be seen in zonal structure of the cement, which it is observable mainly in back-scattered electrons — Pl. II: Figs. 5-6). The zonal cement is formed by radially overgrowing minerals, the fibrous habitus of which resemble the "c" type of phyllosilicate cements described by Dickinson (1970). According to habit and analogy with the serpentinite sandstones described by Dietrich & Franz (1976), the main component of the zonal cement should be secondary chrysotile. Such a composition is probable, since some quartz grains cracked during

Table 1: Modal composition of serpentinitic sandstones in percentages of grain categories (see text for explanation of symbols). Loc. Kamenica Creek.

Sample	Number	Q	F	L	Lq	Lv	Ls
253	366	19	3	78	19	73	8
254	512	19	9	72	14	63	23
255	438	33	13	55	29	41	30
256	351	10	10	80	9	79	12
257	329	19	8	74	13	74	13
259	333	25	6	69	19	65	16
260	300	32	11	57	46	24	27
262	340	48	11	41	46	36	18
264	356	20	6	74	15	73	12
265	395	22	8	69	17	74	9
266	361	22	3	75	16	73	11
Mean	4081	25	8	67	22	62	16

compaction are also mineralized with chrysotile fissures with the cross-fiber structure. The remaining cavities between grains are cemented by fan-shaped aggregates of chlorite/smectite (Pl. II: Fig. 7). The crystallization of these aggregates into the free spaces of the pore network, is responsible for the epimatrix (according to Dickinson 1970). The replacement of large detritic grains with matrix minerals is also observed locally. On the basis of the above mentioned criteria, it is possible to classify the interstitial material of the sandstones as pseudomatrix, originating from the breakdown of lithic grains, and orthomatrix to epimatrix arising from diagenetic recrystallization.

Subhedral, non-zonal grains of chromium spinel are a typical component of the sandstones studied. The spinel detritus is inhomogeneously distributed, and the presence of spinel grains was not recorded in clasts of serpentinites, in even one case. The spectrum of accessory minerals in thin sections also includes grains of rutile, ilmenite and Fe-oxides.

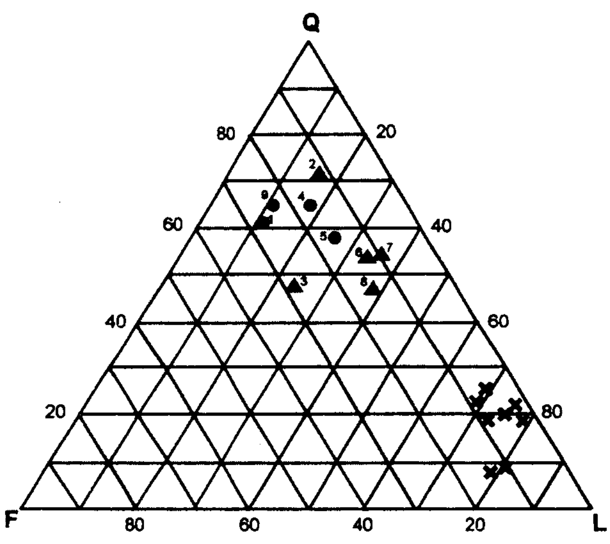
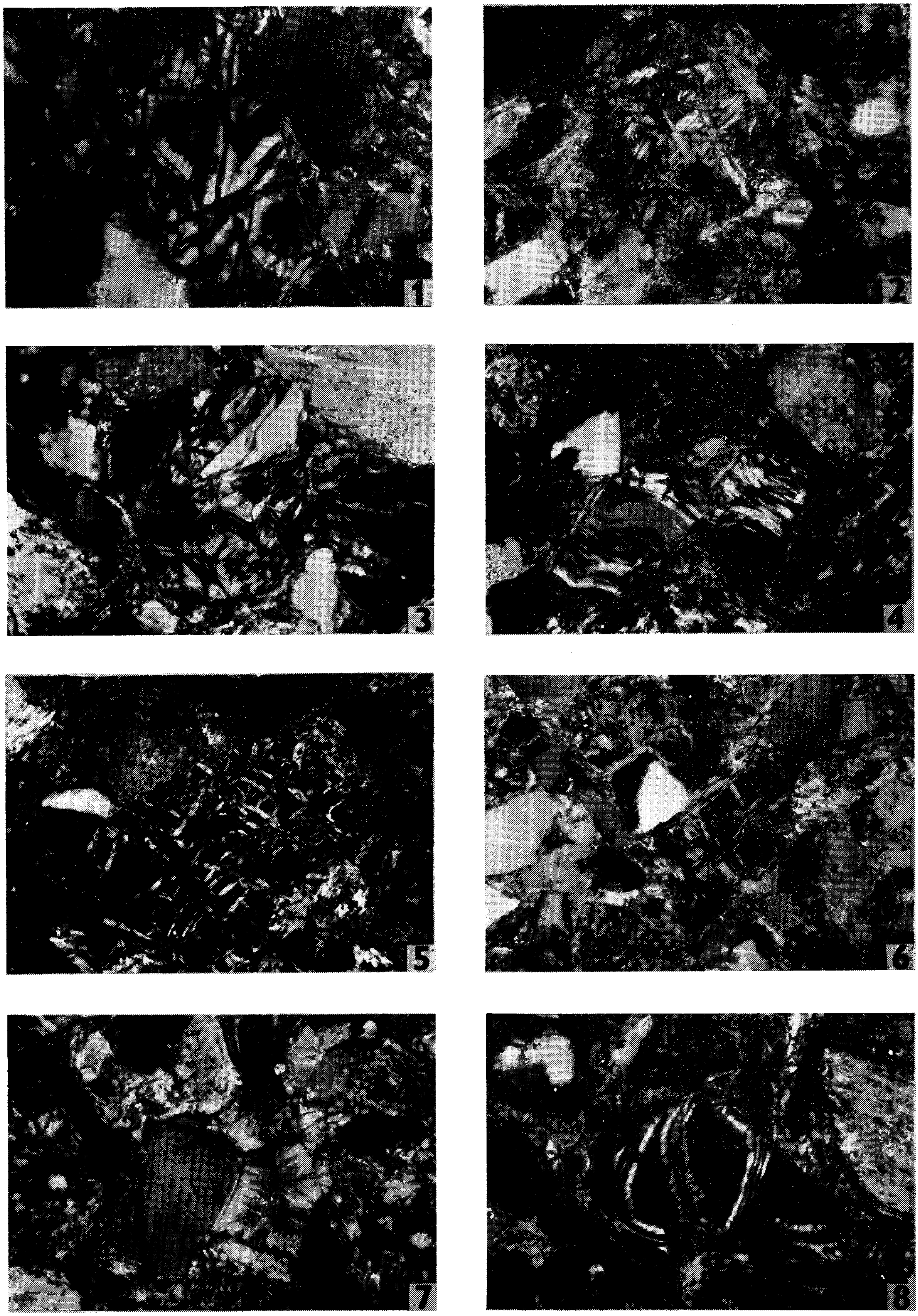


Fig. 6. QFL ternary diagram summarizing compositional data from the sandstones of the Šambron-Kamenica Zone and those from the the Levočské vrchy Mts. Localities : **1** — Kežmarok, **2** — Kamenica 38/D, **3** — Kamenica 38/A, **4** — Tichý Potok 1, **5** — Dravce, **6** — Krivany, **7** — Kamenica 38/C, **8** — Rožkovany, **9** — Tichý Potok 2, crosses - Kamenica - creek.

Provenance-classification of the serpentinitic sandstones

Using data about the composition of the sandstones in the various geotectonic environments it is possible to define the provenance of the serpentinitic sandstones. Provenance fields of various types of sandstone were interpreted in the **QFL** diagrams of Dickinson & Suczek (1979) and Dickinson et al. (1983), or the **LqLvLs** diagrams of Valloni (1985). In the case of these sandstones, the abundance of serpentinite grains shows a significantly increased proportion of unstable lithic components. Therefore in the diagram of Dickinson et al. (1983), the projection points of the serpentinitic sandstones are plotted in the field of sandstones derived from magmatic arc (Fig. 7.B — undissected arc), and in the diagram of Val-

Plate I: Figs. 1–6 Thin-section appearance of serpentinite clasts in the sandstones of the Šambron-Kamenica Zone. The clasts display mesh, loop and flaky textures (lizardite — 4, 6) and are surrounded by fine detrital lutum of serpentinites - pseudomatrix. Loc. Kamenica-creek, crossed nicols, magnif. 170× (1, 3), 86× (2, 4, 5, 6). **Fig. 7** Fan-shaped aggregates of chlorite/smectite filling pore spaces of serpentinitic sandstones. Loc. Kamenica-creek, crossed nicols, magnif. 170×. **Fig. 8** Glassy clast with hydratation rims of clayey minerals. Loc. Kamenica-creek, crossed nicols, magnif. 170×.


1
2
3
4
5
6
7
8

also recorded in other places of the Šambron-Kamenica Zone (Kamenica — railway cut: 65.4-89.0 %, Krivany: 97.2 %, Šambron: 74.7-100 %, Plavnica: 81.7-100 % etc.).

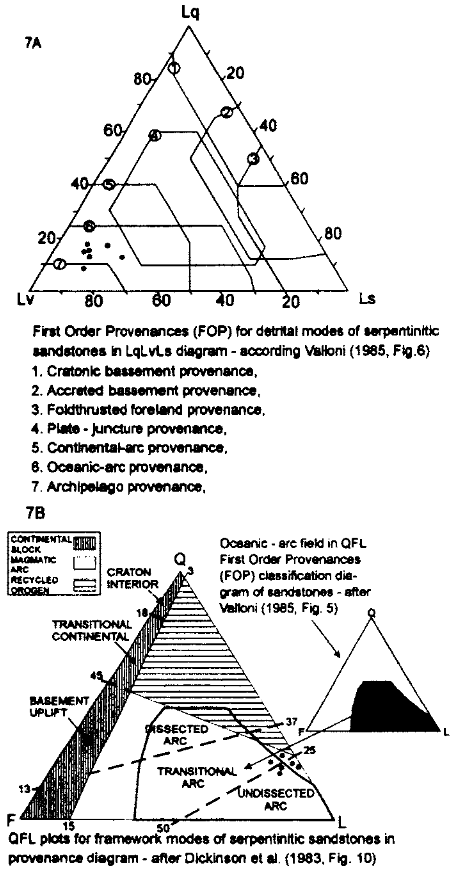


Fig. 7. Projection points of the serpentinitic sandstone data plotted in the provenance-classification diagrams of **QFL** (according to Dickinson et al. 1983) and **LqLvLs** (according to Valloni 1985).

Table 2: Abundance of heavy minerals in the serpentinitic sandstones at Kamenica Creek locality (in wt. %).

Spinel	30.6
Zircon	0.8
Turmaline	1.0
Rutile	1.7
Leucoxene	63.4
Apatite	2.5

loni (1985) they fall into the field of sandstones derived from oceanic arc (Fig. 7.A).

Heavy mineral assemblages from serpentinitic sandstones

The heavy minerals of serpentinitic sandstones at Kamenica Creek locality are characterized by prevalence of chromium spinel and leucoxene (see Tab. 2). Such composition of heavy mineral assemblages illustrates the presence of ultrabasic rocks in the source areas feeding the flysch deposits of the Šambron-Kamenica Zone. The minerals of supracrustal sources, such as garnets for example, fully absent in the associations here. High contents of chromium spinels and minerals of the Ti-group were

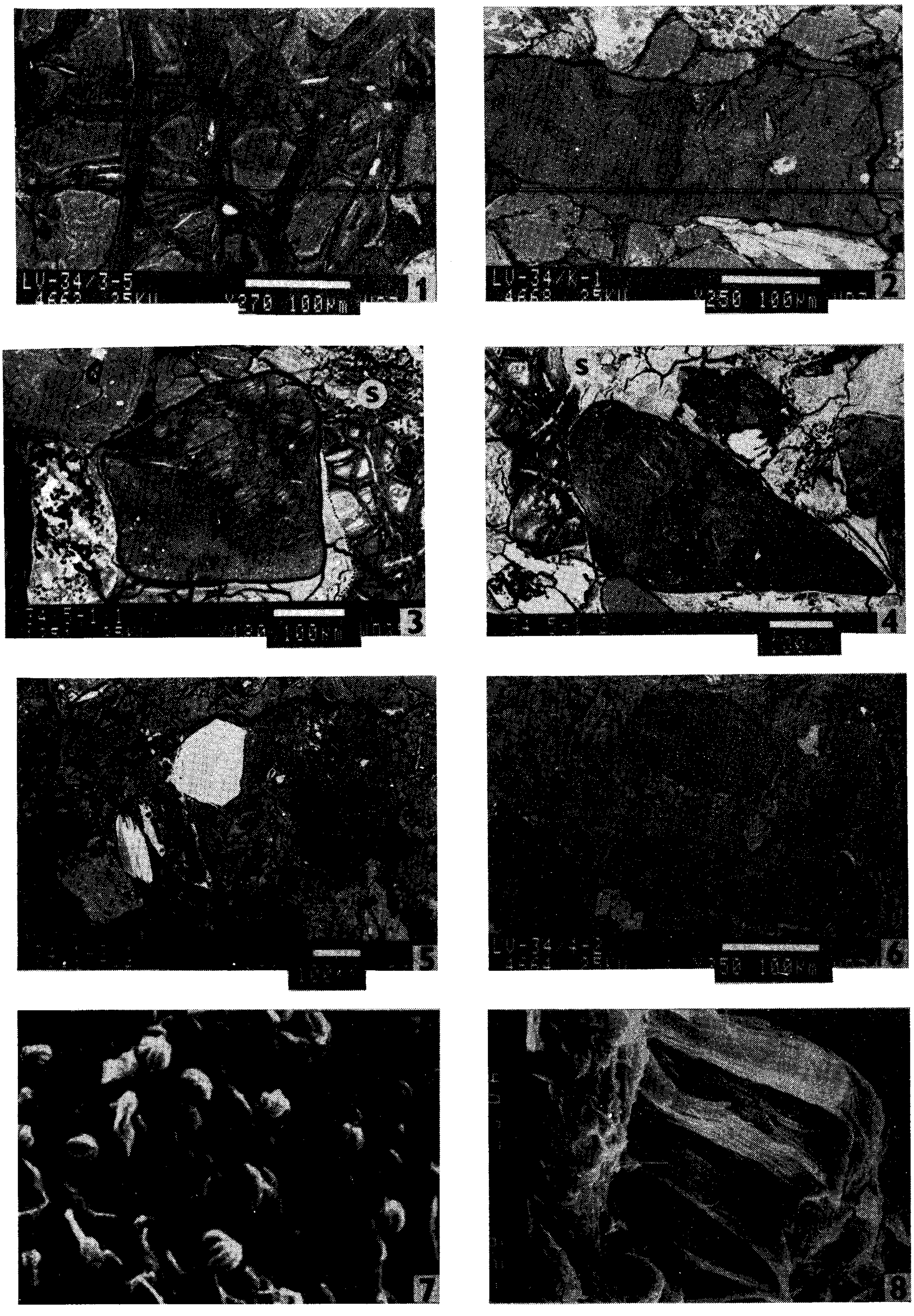
Occurrences of ultrabasic rocks and their residual detritus in the area of the North-Eastern Slovakia and Transcarpathian Ukraine

In North-Eastern Slovakia, larger occurrences of ultrabasic rocks are present only in the basement of the Transcarpathian Depression. They were found in several boreholes (Zbudza-1, Senné-8, Senné-2, Pavlovce-1, Blatná Polianka-1), and more extensive bodies of them are assumed in the area of the Sečovce and Zbudza magnetic anomalies (Gnojek 1987; Gnojek et al. 1991). The ultrabasic bodies of the basement of the Transcarpathian Depression occur within the rock complexes of the Iňačovce-Krichevo Unit, which is formed by Penninic-like metasediments (Soták et al. 1993a,b; Biroň et al. 1993). The young metamorphic and deformational history of this unit is also documented by the overthrusting of the ultrabasic bodies onto Eocene metasedimentary formations (borehole Zbudza-1). The ultrabasic rocks of the Iňačovce-Krichevo Unit display different degrees of alteration from relatively fresh peridotites, through serpentinites with relicts of primary minerals, to chrysotile-lizardite serpentinites and chlorite-talc-tremolite-actinolite rocks.

Ultrabasic rocks are also present in pebbly material of the Merník Conglomerate, which occurs at the contact of the Neogene fill of the East Slovak Lowland and the Central Carpathian Paleogene extending in the zone of Kapušany-Vranov nad Topľou. A high portion of ultrabasic rock pebbles (chiefly lizardite-chrysotile serpentinites), and an equally significant content of spinel grains in the interstitial groundmass, is characteristic of the Merník Conglomerates. The source of the detritus of the Merník Conglomerates is considered to be probably the ultrabasic bodies from the basement of the East Slovak Basin (Soták et al. 1990, 1991).

Magnetic structures, probably connected with the occurrence of ultrabasic bodies, are also traceable on the eastern side of the Šarišská vrchovina Highland near Bzenov (Gnojek 1987). The source of the Bzenov anomaly is a magnetic body in the basement of the Central Carpathian Paleogene. Gnojek et al. (1991) suppose that this body is composed of serpentinites, similar to those which were penetrated not so far below the surface in the borehole V-1 on the southern side of Prešov (Slávik 1974). It is also possible to derive the origin of the ultrabasic body near Sedlice from basement rocks. This body is evidently an olistolite in the basal lithofacies of the Central Carpathian Paleogene. The basic rock types of the Sedlice body are harzburgites, lherzolites and dunites (Hovorka et al. 1985). The Sedlice ultramafites are distinguished

Plate II: Figs. 1-4 SEM images of serpentinite clasts in the sandstones of the Šambron-Kamenica Zone. Loc. Kamenica-creek. **Figs. 5-6** Zonal structure of sandstone matrix in back-scattered electrons. The zonal cement is probably formed by secondary chrysotile, which crustifies the granular framework of serpentinitic sandstones. **Fig. 7** Small particles in the matrix of the serpentinitic sandstones. They display structure of lepispheres, which reflect an interpenetrative growth of opal-CT modifications of quartz. Loc. Kamenica-creek, SEM, magnif. 10,000×. **Fig. 8** SEM image of fibrous chrysotile in detrital constituents of serpentinitic sandstones. Loc. Kamenica-creek, SEM.


LV-34/3-5
270 100µm
1
LV-34/K-1
250 100µm
2
S
100µm
3
S
4
5
LV-34/4-2
250 100µm
6
7
8

from the serpentinites of the Spišsko-gemerské rudohorie Mts. by the lower degree of serpentinization and the character of the structural deformation (Jaroš et al. 1981; Gnojek & Kubeš 1991). Marschalko (1962) expressed doubts about their Lower Triassic age, and gave the opinion that they are rather post-Oligocene rocks.

Unknown sources of ultrabasic rocks can be supposed in the Peri-Klippen zone. From this zone, detrital material of the serpentinitic sandstones was probably derived. The presence of a quantity of spinel detritus in the sandstones of the Šambron Beds also proves the existence of these sources. Tracing the occurrences of chromium spinel in these sandstones recorded a relatively significant predominance of samples containing this mineral. The same results also came from the study of fluvial heavy mineral concentrates (Križáni 1985), which recognized the Šambron-Kamenica Zone as a significant chromium spinel anomaly. High contents of chromium spinel are also found in heavy mineral concentrates from the Spišská Magura Mts., where the Šambron Beds are developed only in claystone facies (Križáni l.c.).

The Klippen Belt is well known for its content of exotic rocks, among which ophiolite associations are also present. The ultrabasic rock fragments and chromium spinels were found mainly in the Urgonian limestones from pebbles of the Cretaceous and Paleogene conglomerates (Mišík & Sýkora 1981; Mišík et al. 1980; Mišík 1976, 1990; etc.). Chromium spinels are also a significant heavy mineral component of sandstone facies of Upper Cretaceous sediments (Masaryk 1980) as well as of Paleogene ones (Starobová 1962). Apart from ultrabasic rocks, the Klippen Belt conglomerates also contain a large portion of other rocks of exotic provenance, such as volcanoplutonic associations (greizenized granites, granitic porphyries, diabase porphyrites, basalts, ignimbrites, rhyolites, andesites etc.), hyperbaric associations (glaucophanites, lawsonite rocks, eclogitoid rocks etc.), metamorphic associations (actinolithic schists and greenschists, glaucophanized greywackes, contact cherts, basalt jaspers, adinoles etc.) and many others (see Mišík & Sýkora 1981; Šimová 1982a,b; Šimová & Šamajová 1982; Šimová 1985; Marschalko 1986 and others). The material of the Klippen Belt conglomerates originates from a subduction zone with ophiolites, island volcanism and high pressure/low temperature metamorphism. The position of this zone is still controversial. In a widely accepted concept, the source of pebbly material is placed to the Peri-Klippen area and interpreted as a subduction-related exotic ridge (e.g. Marschalko 1986; Mišík & Sýkora 1981). The rocks wedging out in this ridge would have been scraped off the oceanic substratum of the Vahic Unit. According to another approach (Plašienka 1995), the exotic flysch deposits of the Klippen Belt belonging to the Klape Unit originated in the Veporic accretionary terrane and so they could have had a source in the southernmost units of the Western Carpathians (Plašienka 1995).

The occurrences of serpentinitic sandstones in the flysch deposit of the Šambron-Kamenica Zone are located at the contact with the Klippen Belt. Occurrences of ultrabasic rocks, in a similar position, have also been described from Transcarpathian Ukraine. There serpentinite melanges and ultrabasic protrusions are exposed mainly on deep seated faults (Lomize 1976; Ploshko et al. 1980), such as the Uhlanich fault, which is genetically related to the suture zone of the Transcarpathian (= Peri-Pieniny) deep fault (Ploshko et al., l.c.). The great quantity of serpentinites and chromium spinel grains, in the sandstones of the Podhale Paleogene, also originates from ultrabasic rocks dragged upwards on the contact between the Klippen Belt and the Transcarpathian Depression (Kruglov 1974). The chromites recorded in the heavy mineral concentrates from the river Terebla also evidently have the same origin (Lazarenko et al. 1963, fide Mišík & Sýkora 1981). A further zone, which comprises large serpentinite bodies in Transcarpathian Ukraine, is exposed on the northern margin of the Marmaroš Klippen Belt, where they are associated with diabases, gabbros and glaucophanitic rocks (Kruglov l.c., Dolenko & Danilovič 1976).

Geotectonic interpretation of the source area

The course of the Tertiary collision in the Eastern Slovakia is associated with an extensional collapse of the overthickened Carpathian lithosphere, and the formation of the fore-arc basins of the Central Carpathian Paleogene. The northern margins of these basins, which were originally connected with the trench-like flysch deposits of the Magura Unit, were amputated and mark a zone of lithospheric subduction. The Paleogene flysch deposits of the Šambron-Kamenica Zone probably represent sediments from the perisutural basins, which were formed under the influence of active subduction. These flysch deposits partly covered the slopes of the Centrocarpathian plate, but they are also partly trench turbidites, enriched with ophiolitic lithics (serpentinites) and residual spinel detritus. The serpentinitic sandstone deposits originated by the local accumulation of detrital serpentinite in the most distal environments of the deep-sea fan system. The serpentinite and spinel detritus in the flysch sandstones of the Šambron-Kamenica Zone arrived probably from the slices of ultrabasic rocks dragged upwards along the collisional edge of the Centrocarpathian plate. By basal accretion under the Centrocarpathian plate, the ultrabasic rocks were also overthrusted onto the Paleogene formations of the Flysch Belt. Thus, in the underplate position, the bodies of ultrabasic rocks are overthrusted on Eocene metasedimentary formations as were observed in the East Slovak Basin basement (borehole Zbudza-1, Soták et al. 1993a,b).

Acknowledgements: This work was done with the support of Grant 575/93 (Slovak Academy of Sciences), as part of the project: "Flysch of Eastern Slovakia — the Levoča Mts."). The authors thank Dr. A. Biroň for evaluation of the XRD analyses, and help in carrying out field work. Dr. A. Nagymarosy also contributed to the work, by studying the calcareous nanoplankton, and Dr. P. Uher, CSc. by evaluating the associations of heavy minerals. We also express our thanks to Dr. T. Ďurkovič, CSc., Ing. R. Marschalko, DrSc., Prof. Dr. M. Mišík, DrSc. and Dr. D. Plašienka, CSc. for valuable consultations.

References

Andrusov D., Samuel O. et al., 1985: Stratigraphic dictionary of the Western Carpathians 2, L-Z. *GÚDŠ*, Bratislava, 15-359 (in Slovak).

Arai S. & Okada H., 1991: Petrology of serpentine sandstone as a key to tectonic development of serpentine belts. *Tectonophysics*, 195, 65-81.

Biroň A., Soták J., Spišiak J., Bebej J. & Magyar J., 1993: "Bündnerschiefer" metasediments of the Pozdišovce-Iňačovce unit: metamorphic petrology data. *Geol. Carpathica -Clays*, 2, 65-80.

Critelli S., 1991: Evoluzione delle mode detritiche delle succesioni arenitiche Terziarie Dell'Appennino meriodionale. *Mem. Soc. Geol. It.*, 47, 55-93.

Critelli S., 1993: Sandstone detrital modes in the Paleogene Liguride complexes, Accretionary wedge of the Southern Apennines (Italy). *J. Sed. Petrology*, 63, 3, 464-476.

Critelli S. & Ingersoll R.V., 1994: Sandstone petrology and provenance of the Siwalik Group (Northwest Pakistan and Western-Southeastern Nepal). *J. Sed. Research*, 64, 4, 815-823.

Critelli S., De Rosa R. & Platt J.P., 1990: Sandstone detrital modes in the Makran accretionary wedge, southwest Pakistan: implications for tectonic setting and long-distance turbidite transportation. *Sed. Geology* 68, 241-260.

Dickinson W.R., 1970: Interpreting detrital modes of graywackes and arkose. *J. Sed. Petrology*, 40, 2, 695-707.

Dickinson W.R., 1982: Composition of sandstones in circum-Pacific subduction complexes and forearc basins. *Am. Assoc. Petrol. Geol., Bull.*, 66, 121-137.

Dickinson W.R., Ingersoll R.V., Cowan D.S., Helmold K.P. & Suczek Ch.A., 1982: Provenance of Franciscan graywackes in coastal California. *Geol. Soc. Am. Bull.*, 93, 95-107.

Dickinson W.R., Beard L.S., Brakenridge G.R., Erjavec J.L., Ferguson R.C., Inman K.F., Knepp R.A., Lindberg F.A. & Ryberg P.T., 1983: Provenance of North American Phanerozoic sandstones in relation to tectonic setting. *Geol. Soc. Am. Bull.*, 94, 222-235.

Dickinson W. R. & Suczek, C. A., 1979: Plate tectonics and sandstone compositions. *Am. Assoc. Petrol. Geol., Bull.*, 63, 2164-2182.

Dietrich V.J. & Franz U., 1976: Ophiolith-Detritus in den santonen Gosau-Schichten (Nördliche Kalkalpen). *Geotekt. Forsch.*, 50, 85-109.

Dolenko G.N. & Danilovič L.G., 1976: New studies of geosynclines and their application to the Ukrainian Carpathians. *Geol. Zbor. Geol. Carpath.*, 27, 1, 1-9 (in Russian).

Dott H.J., 1964: Wacke Graywacke and matrix - what approach to immature sandstones classification? *J. Sed. Petrology*, 34, 625-632.

Füchtbauer H., 1959: Zur Nomenklatur der Sedimentgesteine. *Erdöl und Kohle*, 12, 605-613.

Gnojek I., 1987: Contribution to the interpretation of the magnetic field of East Slovakia Lowland. In: Grecula P., Együd K. & Varga I. (Eds): *Geological structure of the West Carpathians in relation to potential prediction of mineral resources.* Spišská Nová Ves, 331-341 (in Czech).

Gnojek I., Hovorka D. & Pospíšil L., 1991: Sources of magnetic anomalies in the pre-Tertiary basement of Eastern Slovakia (Czecho-Slovakia). *Geol. Carpathica*, 42, 3, 169-180.

Gnojek I. & Kubiš P., 1991: Magnetometric evidence to the Sedlice ultramafic body. *Miner. slovaca*, 23, 2, 161-164 (in Czech).

Grecula P., Kaličiak M., Tözser J. & Varga I., 1981: Geology of the borderland between the West and East Carpathians in the work of Ján Slávik: new data, correlations and problems. Regularities of raw material distribution. In: Grecula P. (Ed.): *Geological structure and raw materials in the border zone of the East and West Carpathians.* Košice, 17-31 (in Slovak).

Gross P. & Ďurkovič T., 1991: Discussion in the article: The two stage structure of the Inner Carpathian Paleogene on the south side of the Klippen Belt in East Slovakia. *Geol. Práce, Spr.*, 92, 163-164 (in Slovak).

Hesse R., 1989: Silica diagenesis: origin of inorganic and replacement cherts. *Earth-Science Reviews*, 26, 253-284.

Hovorka D., Iván P., Jaroš J., Kratochvíl M., Reichwalder P., Rojkovič I., Spišiak J. & Turanová L., 1985: Ultramafic rocks of the Western Carpathians, Czechoslovakia. *GÚDŠ*, Bratislava, 7-258.

Chmelík F., 1958: Concluding report on geological researches on the Central Carpathian Paleogene in the area of the Nízke and Vysoké Tatry Mts, Spišská Magura Mts. and Levoča Mts., in the years 1955-1957. *Manuscript*, Geofond Bratislava, 1-161 (in Slovak).

Chmelík F., 1959: Report on geological researches on the Central Carpathian Paleogene in Šariš between Šambron and Sabinov. *Zpr. geol. Výzk. v r. 1957*, Prague, 81-88 (in Czech).

Christidis G.E., Scott P.W. & Marcopoulos T., 1995: Origin of the bentonite deposits of Eastern Milos, Aegean, Greece: geological, mineralogical and geochemical evidence. *Clays and Clay Miner.*, 43, 1, 63-77.

Jaroš J., Kratochvíl M. & Zlocha J., 1981: Mesoscopic structural analysis of serpentinite bodies in the Spišsko-gemerské rudohorie Mts. (Eastern Slovakia). *Miner. slovaca*, 13, 6, 527-548 (in Slovak).

Križáni I., 1985: Analyses of heavy mineral concentrates in the East Slovak Region and the possibilities for their use. In: *Accessory minerals, Domaša. Faculty of Mining of SVŠT,* Košice, 127-165 (in Slovak).

Kruglov S.S., 1974: The Pieniny Klippen Zone; Soviet Carpathians. In: Maheľ M. (Ed.): *Tectonics of the Carpathian Balkan Regions. GÚDŠ*, Bratislava, 205-208.

Leško B. et al., 1983: Supporting borehole Lipany-1. *Region. Geol. Západ Karpát., GÚDŠ*, Bratislava, 5-77 (in Slovak).

Leško B. & Varga I., 1980: Alpine elements in the West Carpathian structure and their significance. *Miner. slovaca*, 12, 2, 97-130.

Lockwood J.P., 1971: Sedimentary and gravity slide emplacement of serpentinite. *Geol. Soc. Amer. Bull.*, 82, 919-936.

Lomize M.G., 1976: Questions about the Carpathian ophiolites. *Dokl. AN USSR*, 230, 6 (in Russian).

Marschalko R., 1961: Sedimentologic investigation of marginal lithofacies in flysch of Central Carpathians. *Geol. Práce, Zoš. 60, 197-230*

Marschalko R., 1962: Stratigraphic research on the flysch north of Čierna Hora Mts. *Geol. Práce*, Zoš. 63, 15-22 (in Slovak).

Marschalko R., 1975: Sedimentological research on the Paleogene conglomerates of the Klippen Belt, the neighbouring tectonic units, and the environment of their origin. *Náuka o Zemi, 9, sér. Geol., Slovak Academy of Sciences*, Bratislava, 1-147 (in Slovak).

Marschalko R., 1986: Evolution and geotectonic significance of the Klippen Belt Cretaceous Flysch in the Carpathian megastructure. *Veda*, Bratislava, 1-137 (in Slovak).

Masaryk P., 1980: Heavy minerals from the Albian-Cenomanian flysch formations of the Klippen Belt and Krížna nappe. *Manuscript*, Geofond Bratislava, č. 45816 (in Slovak).

Mišík M., 1976: The Klippen Belt and global tectonics. *Zborník referátov z vedeckej konferencie "Československá geológia a globálna tektonika", Smolenice, GÚDŠ*, Bratislava, 28-36 (in Slovak).

Mišík M., 1990: Urgonian facies in the West Carpathians. In: Biostratigraphic and sedimentological studies of Mesozoic of the Bohemian Massif and Western Carpathians. *Knihovnička ZPN*, 9a, 25-54.

Mišík M., Jablonský J., Fejdi P. & Sýkora M., 1980: Chromian and ferroan spinels from Cretaceous sediments of Western Carpathians. *Miner. slovaca*, 12, 3, 209-227.

Mišík M. & Sýkora M., 1981: Pieniny exotic ridge reconstructed from the pebbles of carbonate rocks in the Cretaceous conglomerates, Klippen Belt and Manín unit. *Západ. Karpaty, Sér. Geol.*, 7, 7-111 (in Slovak).

Nelson C.H. & Nilsen T.H., 1984: Modern and ancient deep-sea fan sedimentation. *SEPM short course No 14*, Society of Economic Paleontologists and Mineralogists, 1-404.

Nemčok J., 1978: Deformations of flysch sediments as a reflection of dynamics of the basement. *Záp. Karpaty, Sér. Geol.*, 3, 35-58 (in Slovak).

Nemčok J., Gašparíková V., Ďurkovič T., Váňová M. & Snopková P., 1977: Partial final report for the year 1977. Explanations of the geological map 1:25,000, V. Lipník sheet. *Manuscript, GÚDŠ*, Bratislava, 1-19 (in Slovak).

Nemčok J., Zakovič M., Gašparíková V., Ďurkovič T., Snopková P., Vrana K. & Hanzel V., 1990: Explanations to the geological map of the Pieniny, Ľubovnianská and Ondavská vrchovina Highlands and Čergov Mts., scale 1:50,000. *GÚDŠ*, Bratislava, 7-129 (in Slovak).

Nemčok J., Zakovič M., Gašparíková V., Ďurkovič T., Snopková P., Vrana K. & Hanzel V., 1990: Geological map of the Pieniny, Ľubovnianská and Ondavská vrchovina Highlands and Čergov Mts., scale 1:50,000. *GÚDŠ*, Bratislava.

Okada H., 1964: Serpentine sandstone from Hokkaido. *Mem. Fac. Sci. Kyushu Univ., Ser. D, Geology*, 15, 23-38.

Plašienka D., 1995: Mesozoic evolution of Tatric Units in the Malé Karpaty and Považský Inovec Mts.: Implications for the position of the klape and related units in Western Slovakia. *Geol.Carpathica*, 46, 101-112.

Ploshko V.V., Voloshin A.A., Troneva N.V. & Zaitseva V.N., 1980: Genetic types of ultramafites of the Soviet Carpathians. Proceedings of the XI Congress of Carpathian-Balkan Geological Association, Magmatism and metamorphism. *Naukova Dumka*, Kiev, 128-138 (in Russian).

Pober E. & Faupl P., 1988: The chemistry of detrital chromium spinels and its implications for the geodynamic evolution of the Eastern Alps. *Geol. Rdsch.*, 77, 641-670.

Rudinec R., 1992: Oil and gas accumulations near Lipany in Eastern Slovakia and their specialities and problems. *Miner. slovaca*, 24, 5-6, 357-366 (in Slovak).

Slávik J., 1974: Volcanism, tectonics and mineral resources of the Neogene of East Slovakia and the position of this area in Neo-Europe. *Manuscript*, Geofond, Bratislava 1- 341 (in Slovak).

Soták J., Križáni I. & Spišiak J., 1990: On position and material composition of the Merník conglomerates (the Central Carpathian Paleogene). *Acta Geol. Geogr. Univ. Comenianea, Geologica*, 45, 117-125.

Soták J., Križáni I. & Spišiak J., 1991: Position and sedimentology of Merník conglomerates. *Geol. Práce, Spr.*, 92, 53-69 (in Slovak).

Soták J., Rudinec R. & Spišiak J., 1993a: The Penninic "pull-apart" dome in the pre-Neogene basement of the Transcarpathian Depression (Eastern Slovakia). *Geol. Carpathica*, 44, 1, 11-16.

Soták J., Spišiak J. & Biroň A., 1993b: Position of the Pozdišovce-Iňačovce Unit within structural plan of the Western Carpathians. *Zemní plyn a nafta*, 38, 1, 3-8 (in Slovak).

Starobová M., 1962: Heavy minerals of the East Slovak Magura flysch and the inner Klippen Belt. *Geol. Práce, Zoš.* 63, 177-179 (in Czech).

Šímová M., 1982a: Glaucophanic rocks among pebbles of the Cretaceous conglomerates of the Pieniny zone of the Klippen Belt. In: Metamorphic processes in the Western Carpathians. *Konferencie - Sympózia - Semináre, GÚDŠ*, Bratislava, 81-96 (in Slovak).

Šímová M., 1982b: Eclogitoid rock in pebbles of Cretaceous conglomerates of Klippen Belt. *Geol. Práce, Spr.*, 77, 55-74 (in Slovak).

Šímová M., 1985: Magmatic rocks of the Cretaceous conglomerates in the western part of the Klippen Belt and Manín unit. *Západ. Karpaty, Sér. Min. Petrogr. Geoch. Metalogen.*, 10, 9-110 (in Slovak).

Šímová M. & Šamajová E., 1982: Lawsonite from rock pebbles in the Cretaceous conglomerate of the Pieniny Klippen Belt. *Miner. slovaca*, 14, 5, 431-441 (in Slovak).

Valloni R., 1985: Reading provenance from modern marine sands. In: Zuffa G.G. (Ed.): *Provenance of Arenites*. NATO, ASI (Dordrecht), Series No. 148, D. Reidel, 309-332.

Wagreich W., 1993: Serpentinitreiche Sandsteine als Anzeiger verschwundener Suturzonen am Beispiel der Oberkreide Nördlichen Kalkalpen (Gosau-Gruppe, Österreich). *Zbl. Geol. Paläont. (Stuttgart), Teil I*, 6, 663-673.

Wildi W., 1985: Heavy mineral distribution and dispersal pattern in penninic and ligurian flysch basins (Alps, northern Apennines). *Giorn. Geol. (Bologna), Ser. 3a*, 47, 1-2, 77-99.

Williams H., Turner F.J. & Gilbert Ch.M., 1969: Petrography — An introduction to the study of rocks in thin sections. *Vakils, Feffer and Simons private Ltd.*, Bombay, 3-403.

Winkler W., 1988: Mid- to Early Late Cretaceous flysch and melange formations in the western part of the Eastern Alps. Palaeotectonic implications. *Jb. Geol. B.- A. (Wien)* 131, 2, 341-389.

Winkler W. & Slaczka A., 1992: Sediment dispersal and provenance in the Silesian, Dukla and Magura flysch nappes (Outer Carpathians, Poland). *Geol. Rdsch.*, 81, 2, 371-382.

Zimmerle W., 1968: Serpentinitic graywackes from the North Coast basins, Colombia, and their geotectonic significance. *Neu. Jb. Mineral., Abh.*, 109, 156-182.