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LOWER TRIASSIC QUARTZITES OF THE WESTERN CARPATHIANS: TRANSPORT DIRECTIONS, SOURCE OF CLASTICS

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Abstract: The possibility of localizing the source area for the Lower Triassic (Scythian) quartzites and sandstones (Lúžna Fm.) was checked. Cross-bedding measurements show the transport from the Carpathian foreland, from the NW and N (the same as in the Eastern Alps). The source area could be in the eastern part of the Bohemian Massif (now subducted under the Carpathians), or in the Armorican Massif, if the supposed large left-lateral shift of the Central Western Carpathians took place. The sedimentary environment can be characterized as fluvial braidplain of ephemeral sandy-pebbly streams with intervals of eolian transport. Rare intercalations of psephitic clasts contain only the most resistent rocks: vein quartz, quartz porphyries (rhyolites) with their pyroclastics, rare intermediary volcanites, postvolcanic products as jaspers and hematitic quartzites, graphitic metaquartzites, radiolarian lydites, silicified wood of *Dadoxylon* sp., limnosilicites with pollen grains and a single silicite with ostracods. Various tourmalinitic rocks are the most promissing for the identification of the provenance area.

Key words: Western Carpathians, Lower Triassic, paleogeography, braided rivers, pebble analysis, tourmalinites.

Introduction

Our study was focused thoroughly on both the Malé Karpaty and Považský Inovec Mts.; supplementary analyses were carried out from six other mountain ranges.

The previous authors considered the Scythian quartzites (Liptovská Lúžna Fm., Fejdiová 1980), prevailingly as marine littoral sediment. In the Austrian Alpine literature, these quartzites used to be designated as the Permo-Scythian Semmering Quartzite. In the Tatric Superunit of the Western Carpathians, they occur in a new sedimentary cycle without direct connection to more polymictic Permian sediments with synchronous acid volcanism. Scythian conglomerate intercalations lack granitic pebbles; a continuous passage into "Campilian" strata can be observed. The quartzites are conventionally assigned to the "Seis" (probably Griesbachian) without paleontological or radiometric evidence. Mišík & Jablonský (1978) interpreted them as continental sediments of ephemeral braided streams on a piedmont plain.

Paleogeographical problems

Transport directions (Fig. 1, details in further text) of quartzites attest that the source area was placed at the outer side of the West-Carpathian arc (transport from NW and N). There are two comparative models for the concrete source area.

The first paleogeographical model (Michalík 1994) supposed a left-lateral shift of several hundreds of kilometers of the Tatric Superunit with the whole Central-Carpathian Block against Paleo-Europe including Outer Carpathian units. In this case the material of the Scythian quartzites of the Tatric Superunit should have been derived from the Armorican Massif and its prolongation now hidden under the platform cover of the Paris Basin (l.c., Fig. 1). He estimated the volume of Scythian clastics deposited in the Alpine-Carpathian area at 75,000–100,000 km^3 and calculated that the source area of these clastics must attain not less than 750,000 km^2. According to the second alternative more or less "autochthonous" or assuming a smaller left-lateral shift, the eastern part of Bohemian Massif should have been the source of clastics.

Due to the maturity of psephitic clastics containing only several of most resistent rocks, the identification of the source area is extremely difficult. A complete inventory of identified rocks will be given in the further text. Only some specific types could be indicative. Tourmalinitic rocks are the most promissing. The comparison of identified clasts with rocks of the supposed source areas is also handicapped by the erosion of considerable pre-Triassic complexes, by their large covering under the younger platform strata and by the subduction of the eastermost part of the Bohemian Massif under the Carpathian Belt.

Lithoclasts in the Scythian quartzites

The evaluation of clasts was done from 120 thin sections. The localization of the identified rock types is given on Fig. 1.

Clasts from the Scythian quartzites were already partly studied in the Vysoké Tatry Mts. by Turnau-Morawska (1955), Borza (1955), Roniewicz (1966); in the Vepor Mts. by Losert (1963), in the Nízke Tatry Mts. by Koutek (1931) and Fejdiová (1985), in the Malá Fatra Mts. by Ďurovič

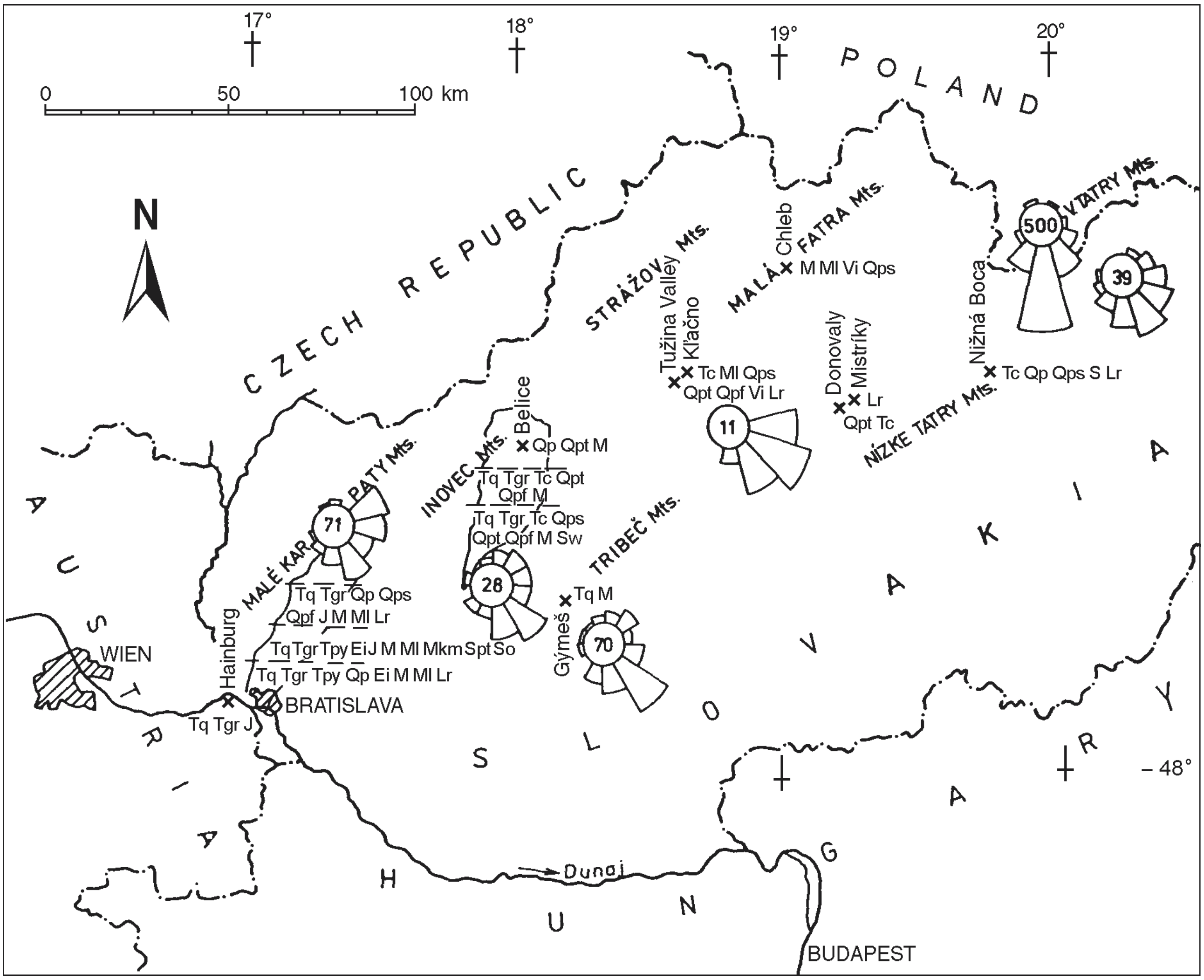


Fig. 1. Transport directions derived from the cross-bedding in the Scythian quartzites of the West-Carpathian area (number in the centre of current rose represents sum of measurements) and the composition of psephitic clasts in their intercalations: **Tgr** — tourmalinite, **Tvq** — tourmalinized vein quartz, **Tqt** — tourmalinized quartzite, **Tpy** — tourmalinized pyroclastic rock, **Tch** — tourmalinized chlorite schist, **M** — graphitic metaquartzite, **Ml** — graphitic laminated metaquartzite, **Mhm** — hematitic metaquartzite of Dill-Lahn type, **Ch** — chlorite schist, **Qt** — quartzite, **Qp** — quartz porphyry (paleorhyolite), **Qps** — spherulitic quartz porphyry, **Qpf** — felsite clast of devitrified volcanite without phenocryst, **Vi** — volcanic rock probably of intermediary composition, **J** — jasper-rosy silicite connected with postvolcanic activity, **L** — lydite-black silicite, **Lr** — lydite with remains of radiolarians, **S** — grey silicite very fine-grained, **Spl** — silicite with fragments of plant tissue, **Sw** — silicified wood, **So** — silicite with ostracods.

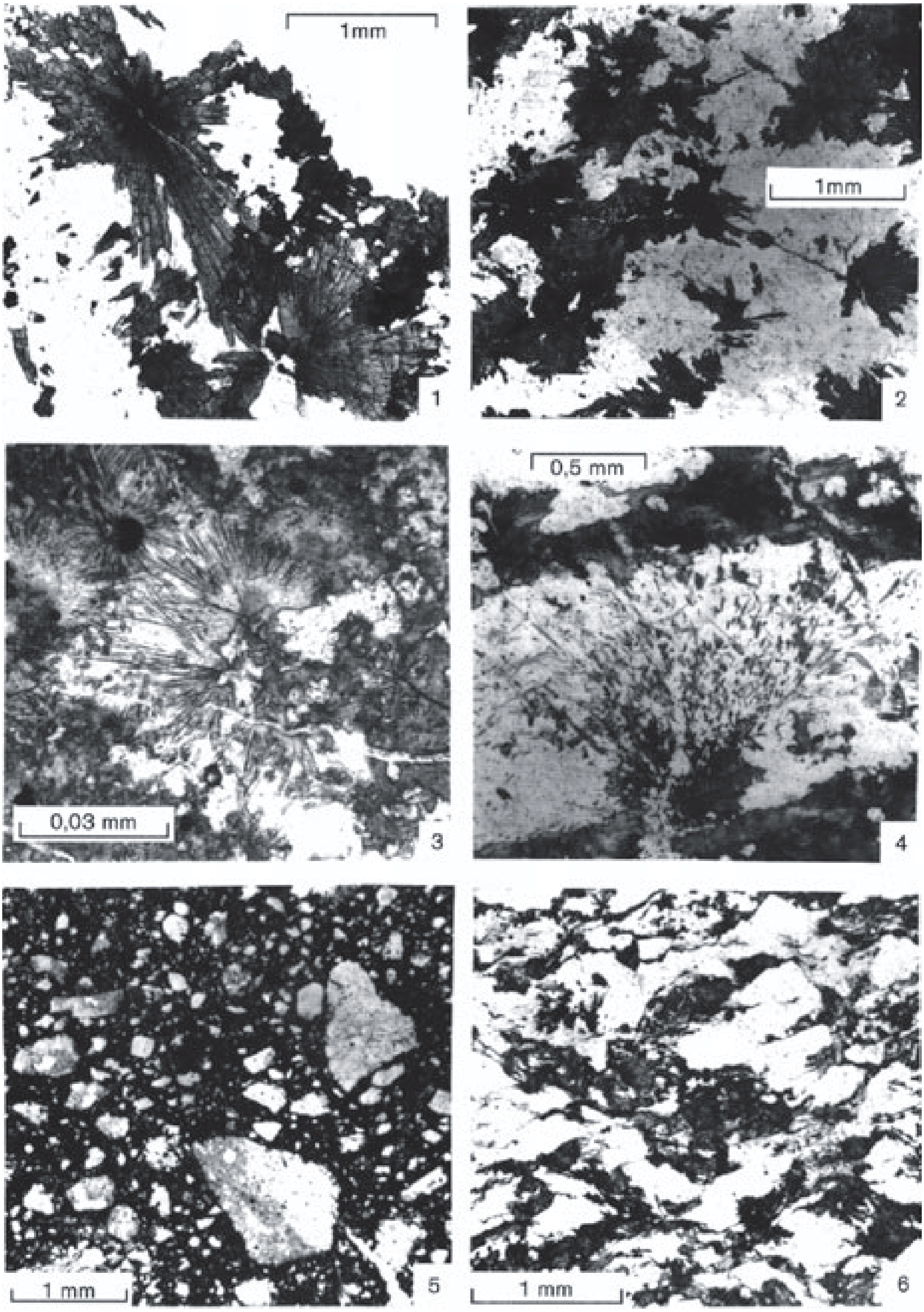
(1973 but his material was mixed with Permian conglomerates), in the Malé Karpaty Mts. by Mišík & Jablonský (1978) and in the Považský Inovec Mts. by Mišík & Jablonský (1999), now completed here.

Tourmalinitic rocks

In the Malé Karpaty Mts. (including the Hainburg Hills), Tribeč Mts. and partly in the Považský Inovec Mts., clasts of quartz-tourmaline rock with tourmaline spherolites up to 2 mm in diameter occur (Pl. I: Figs. 1–3). Tourmaline is frequently zonal (Pl. II: Fig. 1) with blue colour mostly on the periphery of green or brown crystals. Their columns are commonly broken and healed by quartz (Pl. II: Fig. 1). Sometimes the whole rock is penetrated by veinlets with tiny tourmaline aggregate of the second generation (Pl. II: Fig. 4). Quartz grains display undulatory extinction, pressure lamellae and cataclastic disintegration. Clasts of tourmaline quartzites are rare (Pl. II: Fig. 5). They have a mosaic of

Plate I: Clasts of tourmaline rocks in the Lower Triassic quartzites. Fig. 1. Tourmaline spherulites in quartz aggregate. Dúbravka-1, slopes of Devínska Kobyla near Bratislava, Malé Karpaty Mts. **Fig. 2.** Blue tourmalines in quartz-tourmaline rock. Former Stockerau kiln-4 near Bratislava, Malé Karpaty Mts. **Fig. 3.** Quartz-tourmaline rock. Hradište-6, Považský Inovec Mts. **Fig. 4.** Quartz-tourmaline rock. Sonnwendstein, Weinstrasse Eastern Alps, Austria. **Fig. 5.** Quartz-tourmaline with very fine-grained felt-like "cryptic" tourmaline aggregates. Dúbravka-4, Malé Karpaty Mts. **Fig. 6.** Quartz-biotite-tourmaline rock with elongated, pointed clasts of quartz. Tri Jazdce-2 near Pezinok, Malé Karpaty Mts.

PLATE I



quartz grains about 1 mm. The tourmaline spherolites are situated independently in the quartz mosaic.

Several clasts of tourmalinized pyroclastic rock were identified. In one case a fragment of red acid volcanite with fluidal structure was enclosed. Feldspar phenocrysts were silicified. In another case a magmatic corroded quartz phenocryst was found.

In all the other mountain ranges (Fig. 1) only clasts of "cryptic tourmalinite" were found. They represent an initial stage of tourmaline formation represented by extremely tiny acicular aggregates in almost undifferentiated groundmass with floating angular quartz fragments (Pl. I: Figs. 5, 6). Acicular tourmalines penetrate in their marginal parts. Their second generation in veinlets are more visible (Pl. II: Fig. 4). The "cryptic" tourmalinites contain rare fragments of felsites and jasper. Such aggregates are colloidal and/or gel related.

One single clast of a totally aberrant sericitic-tourmaline rock with brown columnar tourmaline in haphazard position was found in Donovaly, Nízke Tatry Mts. (Pl. II: Fig. 3).

The content of boron in three analyzed clasts was 0.7 %, 1.2 % and 1.2 %, that is approximately up to 40 % of tourmaline in the rock (Mišík & Jablonský 1978). In the preliminary geochemical study of tourmaline by Uher (1999, Fig. 1, Table 1) several types were found: schorl to foitit, dravite to magnesian uvite. Besides quartz rarely fine-grained muscovite, biotite, chlorite and also feldspars were present. Among the accessory minerals zircon, monazite (Ce), xenotime (Y), hematite, rutile, titanite, anatas (Pl. II: Fig. 2) and epidote were found.

Other known occurrences of tourmalinitic rocks in Western Carpathians should be mentioned. Tourmalinitic rocks were described from the Cretaceous Upohlav Conglomerate by Šimová (1985, p. 42–43). Birkenmajer & Wieser (1990, p. 22) mentioned pebbles of tourmalinized ignimbrites from the Upper Cretaceous conglomerates of the Pieniny Klippen Belt. Soták (1990) found a single pebble of tourmalinized pyroclastic rock in Sedlec from the Paleogene Ždánice-Hustopeče Formation, Soták et al. (1996, p. 108) mentioned them from the Eocene Šambron Conglomerate. Turnau-Morawska (1953) found one pebble within Keuper conglomerates (Upper Triassic) of the High Tatra Mts. Radwański (1959, p. 359) identified a clast of tourmaline-quartz rock in Liassic sediments of the High Tatra Mts. Vozárová-Minarovičová (1966) found pebbles of tourmalinites in Permian conglomerates of the Veporic Superunit. Miko & Hovorka (1978) described tourmalinitic intercalations in crystalline complex of the Nízke Tatry Mts; Ženiš & Hvožďara (1985) found comparable synmetamorphic layers of quartz with tourmaline also in Veporic crystalline complex.

As our clastic material was undoubtelly transported from the NW and N, it cannot be in a connection with previously mentioned localities in the Veporic Superunit. Occurrence of tourmalinitic rock in Scythian quartzite of the Eastern Alps (Vetters 1970) indicates the existence of common Alpine-Carpathian sedimentary sources at that time.

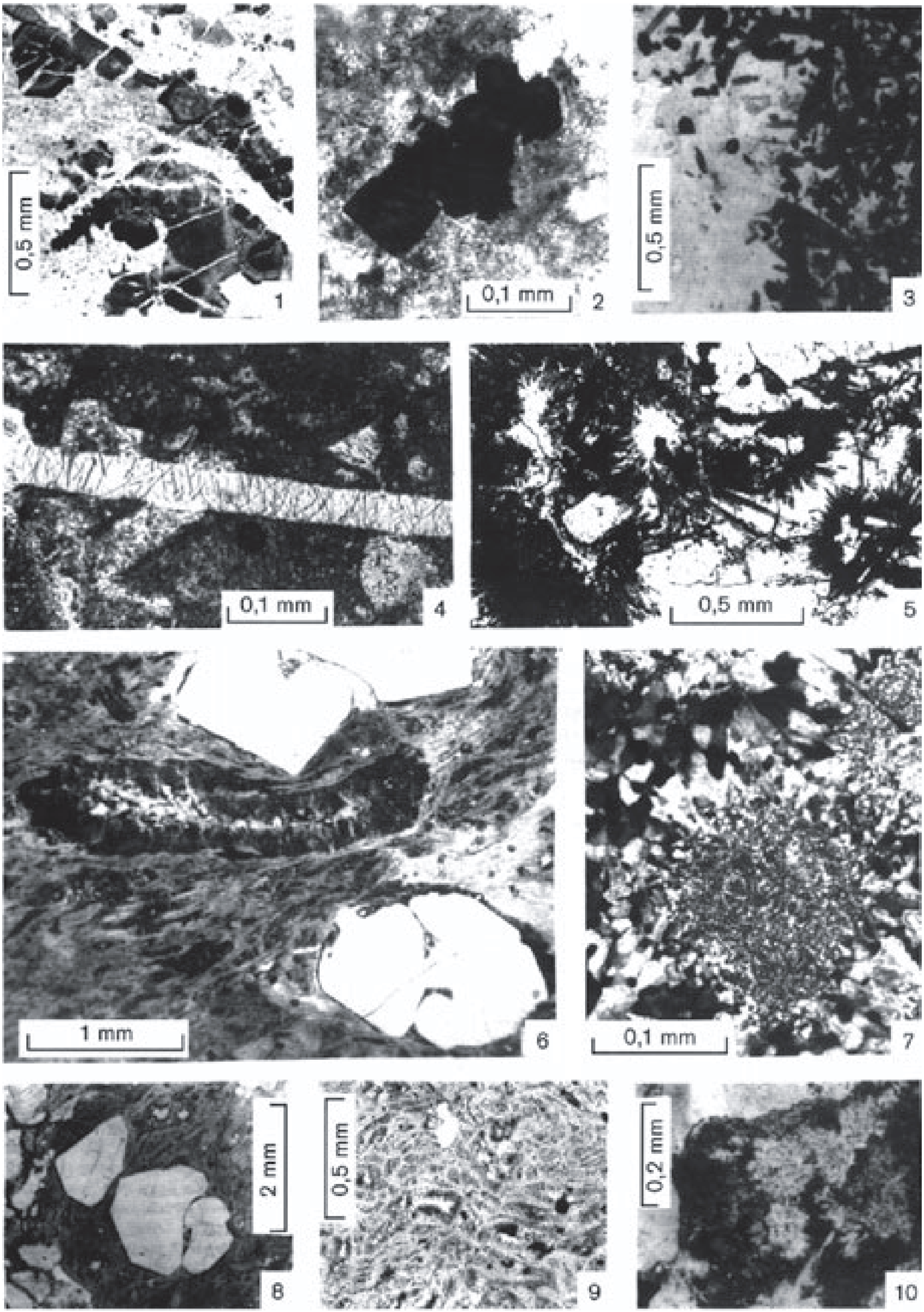
If we suppose Czech Massif as a potential source, the data about tourmalinite occurrences in "Variegated" Group of Moldanubian Unit as well as in other crystalline complexes of the Czech Massif (Kebrt et al. 1984) are important for us. There tourmalinites accompany small lenticular bodies of amphibolites, leptynites in paragneisses and micaschists. They are frequently joined with a stratiform mineralization. It is noteworthy that they were also known earlier from pebbles than from outcrops: from Ordovician conglomerates of the Krkonoše Mts. (Chaloupský 1963) and Paleozoic conglomerates of the Branná Group (Bukovanská & Mísař 1959). In the southern Moldanubian Unit, two types occur: tourmaline up to 2 mm in granoblastic quartz with metamorphic structure and very tiny tourmaline grains (0.00X mm) in brecciated quartzites with arsenopyrite. No tourmaline spherulites were mentioned in contrast to their abundance in our material from the Scythian quartzites.

Allen (1967) described clasts of tourmalinitic rocks from the Hastings Beds of Permo-Triassic New Red Sandstone from the second potencial source — the Armorican Massif. They are clasts of veinrocks and tectonized tourmalinitic quartzites. No tourmaline spherulites were mentioned either. The author supposed their transport from the SW. Jiang et al. (1999) described pebbles of tourmalinitic rocks from the Devonian Old Red Sandstone of SW Ireland originating from quartz-tourmaline veins, "banded tourmalinites" and tourmalinitic pegmatites.

Acid volcanic rocks

Rosy rhyolite (paleorhyolite, quartz porphyry) in clasts larger than 2 cm are rare. They contain quartz phenocrysts with magmatic corrosion (Pl. II: Figs. 6, 8), sometimes also sericitized feldspars phenocrysts; matrix is devitrified. Fluidal structure is common (Pl. II: Figs. 6, 8, 9). Macroscopic spherulite structure was found only once (Pl. II: Fig. 7). The rock is red and white, the spherulites contain micrograined centres bordered with radial palisade quartz. Small felsitic fragments (under 3 mm) with relics of spherulitic structure are common (Pl. II: Fig. 10). The same types were present as clasts in Liassic crinoidal limestones of the Pieniny Klippen

Plate II: Clasts of tourmaline rocks and paleorhyolites in the Lower Triassic quartzites. Fig. 1. Zonal tourmalines in quartz-tourmaline rock cracked and healed by younger quartz. Tri Jazdce-6 by Pezinok, Malé Karpaty Mts. **Fig 2.** Anatas aggregate in felt-like tourmalinite. Pred Kostolným vrchom-6, Považský Inovec Mts. **Fig. 3.** Sericite-tourmaline rock with haphazard distribution of brown columnar tourmaline — an aberrant type. Donovaly — Hiadel Valley, Nízke Tatry Mts. **Fig. 4.** Veinlet of quartz with tourmaline needles in "cryptic" tourmalinite. Kľačno-Fačkov Saddle, Strážovské vrchy Mts. **Fig. 5.** Tourmalinized quartzite. Block in Quarternary sediments, 2 km SW from Jablonové, Malé Karpaty Mts. **Fig. 6.** Rhyolite with fluidal structure and corroded quartz phenocrysts. Devín Castle. **Fig. 7.** Remnants of spherolite texture in silicified rhyolite; fine-grained quartz fills the spherulite centers. Zlatý vrch-10, Považský Inovec Mts. **Fig. 8.** Fluidal structure in rhyolite (quartz porphyry). Devín-3, Malé Karpaty Mts. **Fig. 9.** Fluidal structure in acid volcanite. Zrkadlisko-9, near Dolany, Malé Karpaty Mts. **Fig. 10.** Felsite with remnants of spherulitic structure. Kľačno-Fačkovské sedlo-2, crossed polars.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Belt (Mišík & Aubrecht 1994, Pl. I: Figs. 5, 6). Quartz-muscovitic xenoliths were found twice in them. A peculiar rock — darkgrey brecciated rhyolite (autobrecciation in the lava flow — Pl. III: Fig. 1) also contains terrigenous admixture of quartz aggregates with undulatory extinction. Crystallo-lithoclastic tuffites are very rare. As the isolated phenocrysts of the beta-quartz type are almost missing among the grains in the Scythian quartzites, the vitroclastic tuffites should have been the principal type. The acid volcanites described are most probably of Permian age. One case of a probably porphyroid with phantoms of phenocrysts visible due to the absence of pigment and with schistosity accompanied by sericite aggregates could be, eventually, derived from Lower Paleozoic (Ordovician?) strata.

Intermediate and basic volcanic rocks

Small fragments of volcanic rock with acicular feldspars (Pl. III: Fig. 2) and another one with feldspar microlites (Pl. III: Fig. 3) were exceptionally found. They might belong, to the trachytic varieties.

Red silicites — postvolcanic products

Hematitic jaspers — with metacolloidal annular structure and syneretic cracks (Pl. III: Fig. 4), — with clasts of tiny ooids possessing pigmented centres and enclosed in a clear quartz aggregate (Pl. III: Fig. 5), — with skeletal hematite (Pl. III: Fig. 6), — with idiomorphic quartz crystals within a hematitic aggregate (Pl. III: Fig. 7), — with phantoms of hematitic spherulites are interpreted as postvolcanic products of the acid Permian volcanism. A silcrete nature of some samples is not excluded (e.g. rosy brecciated silicite from the Chleb locality, Malá Fatra Mts.). We have illustrated a comparable clast of red jasper from Liassic crinoidal limestones of the Pieniny Klippen Belt (Mišík & Aubrecht 1994, Pl. II: Figs. 1, 2).

Hematitic metaquartzite containing laminae of coarse-grained cataclastic quartz alternated with fine-grained quartz laminae enriched in hematite (tiny leaflets — Pl. III: Fig. 9) is comparable to ferrolitic quartzites of the Lahn-Dill type. The rock contained 25.01 % of Fe_2O_3. Another ferrolitic quartzite displays metamorphic folding. Early Paleozoic ages for both are not excluded.

Dark silicites with organic remains

Silicified wood of Coniferae displays perfectly preserved cellular tissue (Pl. IV: Fig. 1). This black fragment of the araucarite *Dadoxylon* sp. (according to the determination of V. Sitár) with the diameter of 7 cm is one of the largest clasts. In the thin section the tissue is brown coloured. It was silicified by permeation. A coarse-grained quartz mosaic independent of the cellular structure can be seen in the polarized light (Pl. IV: Fig. 2). Its Stephanian–Permian age is guaranteed.

Ostracode silicite (Pl. IV: Fig. 3) of black colour is formed by microquartz ("chalcedony") mosaic. It contains a lot of silicified ostracods with both valves. The former voids between them are filled by coarse-grained quartz. A fragment of plant tissue, phantoms of probable coprolites and a ghost of carbonate rhombohedron are present. Ostracode silicite might represent former chert nodules in limestones (Silurian-Devonian?) or a hydrothermally silicified sediment.

Radiolarian lydites are formed by microquartz and especially by fine-grained quartz mosaic elongated along the plane of metamorphic foliation, sometimes with laminae of metamorphic differentiation. The rock is pigmented by graphite. Voids after the former radiolarians are also deformed according to the foliation (Pl. IV: Fig. 4); they differ by the absence of pigment. Small pyrite crystals occur rarely. Five pebbles of this type were found in the Malé Karpaty Mts., Nízke Tatry Mts. and Strážovské vrchy Mts. They are probably of Early Paleozoic age.

Black and grey limnosilicites formed by microquartz ("chalcedony") contain badly preserved fragments of plant tissue and rare spore grains (Pl. IV: Fig. 5). In one case a brecciated structure was present with tiny kaolinite crystals and dissolved rhombohedra between the fragments. Only three samples occurred. We considered them to be limnosilicites most probably of Permian age.

Black lydites without organic remains possess similar features as those with radiolarians. The periphery of lydite clasts was frequently altered in microstylolites; exceptionally a rectangular microstylolite was found inside the rock (Mišík & Jablonský 1978, Pl. I: Fig. 2; Pl. IX: Fig. 3).

Graphitic metaquartzites

They are among the most frequent and largest (up to 8 cm) psephitic clasts in Scythian quartzites (31 thin sections from all mountain ranges). They almost always possess a distinct metamorphic lamination and therefore platy form of clasts. Rod-like sections of graphite crystals (Pl. IV: Fig. 6; similar rock was illustrated by Roniewicz 1966, Pl. VII: Fig. 1) are roughly concentrated in laminae (Pl. IV: Fig. 9). Tiny hexagonal crystals also occur (Pl. IV: Fig. 8). Fine undulation formed by isoclinal folds is exceptional. Micas occur in vari-

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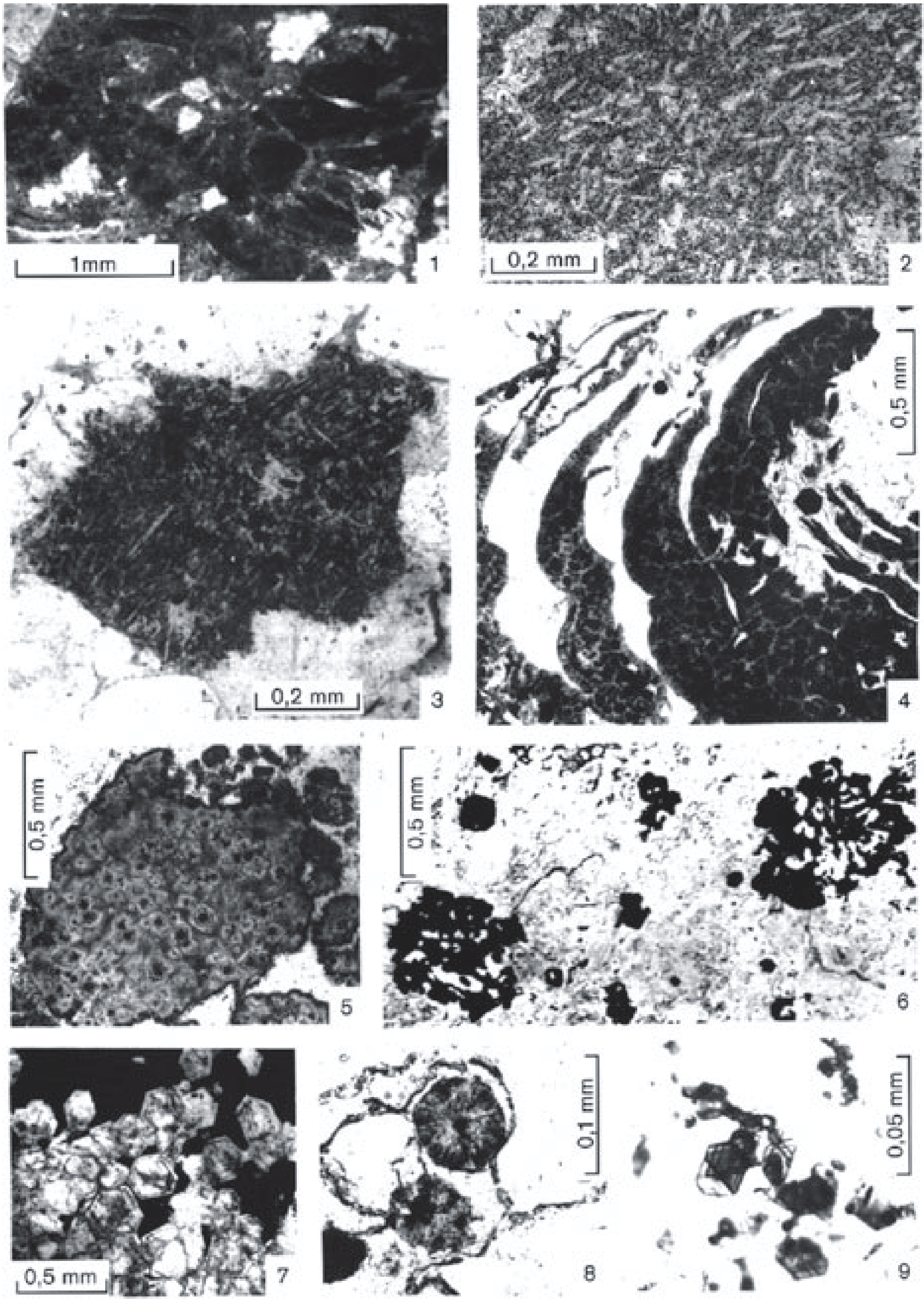
Plate III: Clasts of volcanic rocks and postvolcanic silicites in the Scythian quartzites. Fig. 1. Brecciated rhyolite. Hajabačka Valley near Donovaly, Nízke Tatry Mts. **Fig. 2.** Intermediary volcanite. Ladmovce, Zemplín Horst. **Fig. 3.** Small clast of basic volcanite. Zlatý vrch-10, Považský Inovec Mts. **Fig. 4.** Hematite jasper with annular metacolloidal structure affected by syneretic cracks. Zrkadlisko-2 near Dolany. Malé Karpaty Mts. **Fig. 5.** Fragment composed of ooids with hematite pigmented centres in brecciated hydrothermal silicite. ESE from Biela Skala near Sološnica, Malé Karpaty Mts. **Fig 6.** Red silicite with skeletal hematites. Zrkadlisko-7 near Dolany. Malé Karpaty Mts. **Fig. 7.** Red jasper with idiomorphic zoned quartz crystals; post-volcanic product of Permian acid volcanism. Hainburg Hills, Austria. **Fig. 8.** Phantoms of spherulites preserved due to the hematite pigment in red silicites (jasper). Zrkadlisko-2 near Dolany, Malé Karpaty Mts. **Fig. 9.** Tiny hematite crystals in the ferrolite (Fe-quartzite of Lahn-Dill type). Tri Jazdce-1 near Pezinok, Malé Karpaty Mts.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able quantities mostly concentrated in laminae enriched in muscovite, sericite, chlorite, rarely biotite partly chloritized. Quartz grains are cataclastic with undulatory extinction, sometimes with "chevron" pressure lamellae (Pl. IV: Fig. 10). Differentiation in coarse-grained and fine-grained laminae is frequent, graphite pigment is mostly bound to the latter. Accessory apatite, rare zircon and tourmaline are present, from the opaque minerals pyrite, magnetite and hematite are frequent. Two foliation planes crossed in an angle of 25° were noted in a thin section. One metaquartzite pebble with synsedimentary "neptunic" or clastic veinlet filled by quartzite matrix (Pl. IV: Fig. 9) is a testimony of pebble fragmentation under compactional pressure. This exceptional phenomenon contrasts with various cases of crushed pebbles with clastic veins found in deep-water conglomerates of Cretaceous and Paleogene age (e.g. Mišík, Sýkora, Mock & Jablonský 1991, p. 63, Pl. IX: Figs. 2, 3; Mišík, Sýkora & Jablonský 1991, Pl. XVII: Figs. 1, 2).

Vein quartz

Clasts of the milky white vein quartz are the most predominating psephitic component, composed of cataclastic quartz grains with denticulate and "mortar" structure boundaries. In thin sections some pyrite crystals and muscovite were present. The largest clasts on the localities were 8–10 cm, an exceptional clast attained 30 cm.

Comments on the composition of the quartzites

The granulometry of the Scythian quartzites was published by Fejdiová (1985), it will not be repeated here. The most frequent median diameter is about 0.5 mm. In more tectonized zones the quartz grains contain deformations, Böhm translation lamellae sometimes strongly contorted (Pl. V: Fig. 1). The outlines of grains are mostly angular, strongly affected by intrastratal solution. Chemical compaction can be estimated at 20 %. Matrix is rare, mostly represented only by coatings of neomorphic clayey (micaceous) minerals and Fe-hydroxides. Higher birefringence points to illite. In quartzites affected by tectonic pressures the flakes are either perpendicular to the grain surface or parallel to the foliation.

If the sediment was later affected by eolian transport, well rounded grains possess syntaxial quartz overgrowths (Pl. V: Fig. 3). In those localities also faceted clasts (ventifacts, "Dreikanter" Pl. V: Fig. 6) occur. Rounding of psephitic clasts is rare. Strongly angular clasts of vein quartz typical of braided rivers are most frequent (Pl. V: Fig. 2) which leads us to reject the formerly propagated idea about marine shoal sediment.

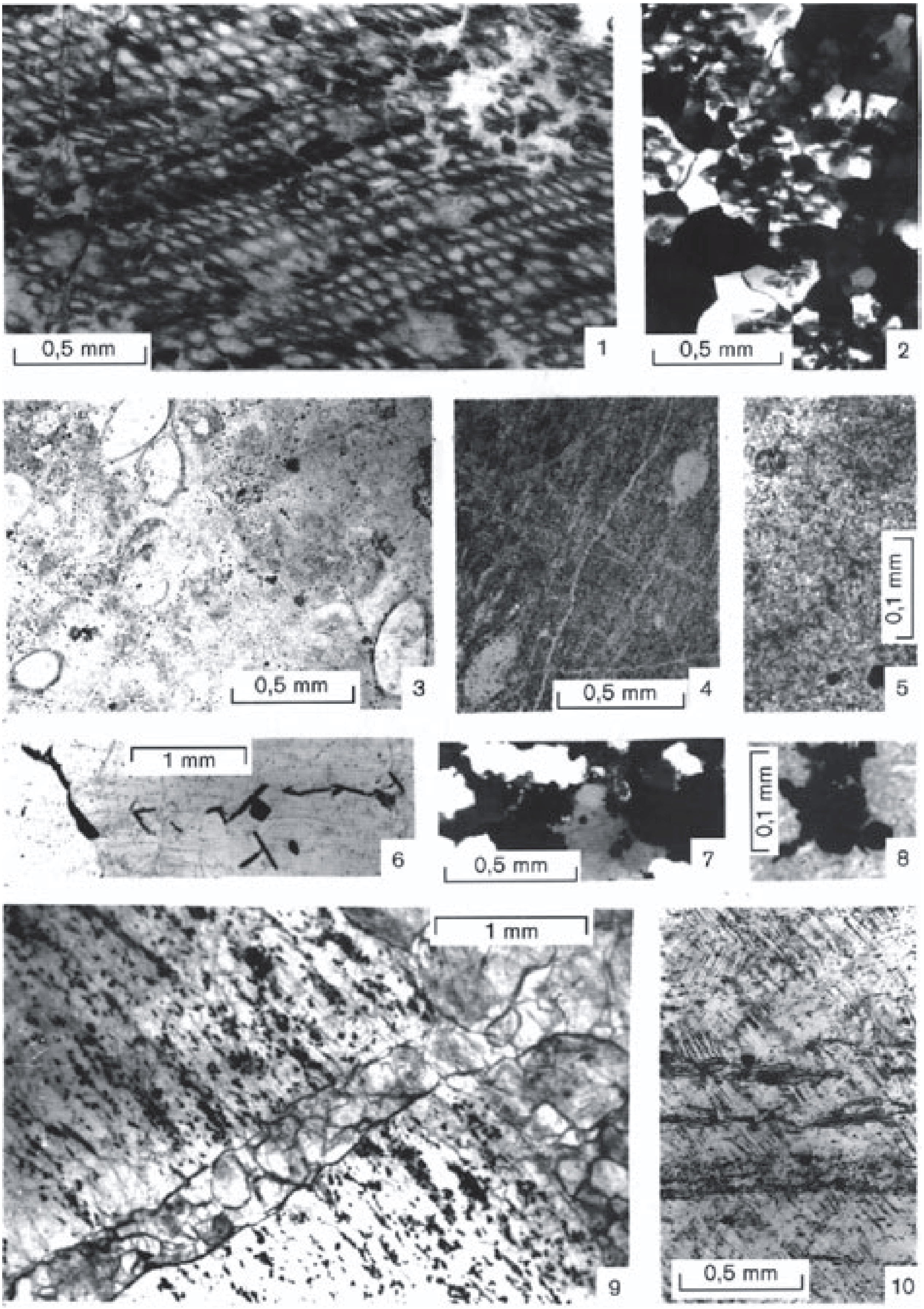
Feldspars are almost exclusively orthoclase and more rarely microcline; perthite and plagioclases are very rare. Their amount in subarcoses in the Považský Inovec Mts. is up to 10 % (Vozokany-2 — 9.95 %, Kostolný vrch-1 — 9.73 %, Šalgovce-3 — 6.35 %, Pred Kostolným vrchom-2 — 5.75 %, Zlatý vrch-3 — 3.72 %). According to our observations, feldspars in quartzites are almost missing in the Malé Karpaty Mts. The same was found by Fejdiová (1985, p. 119). Their content in six thin sections was 0.9 %–4.1 % and in another 13 samples they were totally absent. In the Malá Fatra Mts. she found their share between 4.5 % and 24.3 %, from the Nízke Tatry Mts. 2.8–17.3 %, from the High Tatra Mts. 0.3–27.4 %. Feldspars in the Považský Inovec Mts. are yellowish, cloudy due to kaolinization, those from the Strážovské vrchy Mts. (Tužinská Valley, Kľačno-Fačkov Saddle) are clear, containing some flakes of sericite, in the Nízke Tatry Mts. they are also clear.

Kalifeldspars are evidently more resistent to diagenetic solution. They frequently preserved their tabular habit, and partly penetrated in quartz grains. Even pointed overgrowths of Triassic age on older feldspars indented in quartz (Pl. V: Fig. 5). They were already reported by Fejdiová (1985). Diagenetic overgrowths on detrital microclines in the form of similar minute rhombs were described by Worden & Rushton (1992) from the Permo-Triassic continental clastics of Scotland.

Muscovite is very rare and degraded biotite even rarer, showing, that micas were eliminated by water currents or deflation before final deposition. Rare zircon, rounded tourmaline, rutile, titanite were present as accessory minerals in thin sections. Heavy mineral associations were analysed from the naturally disintegrated quartzites at two localities (Mišík & Jablonský 1978, p. 16): Červený Kameň (Malé Karpaty Mts.): tourmaline — 49 %, clouded grains (leucoxene, limonite etc.) — 37 %, zircon — 11 %, rutil — 2 %, titanite — 1 %. Donovaly (Nízke Tatry Mts.): barite — 71.3 %, clouded minerals — 15.1 %, zircon — 10.1 %, rutile — 2.0 %, tourmaline — 1.6 %. Barite (Pl. V: Fig. 7) is authigenic.

Voids after dissolved tiny pyrite cubes frequently occur in quartzites. They were sometimes filled by fine-grained quartz mosaic leaving small quadrate phantoms limited by Fe-oxides.

Plate IV: Clasts of black silicites with organic remains and graphitic metaquartzites in the Scythian quartzites. Fig. 1. Tissue of silicified wood, araucarite *Dadoxylon* sp. Zlatý vrch-9, Považský Inovec Mts. **Fig. 2.** The same in polarized light. Quartz mosaic is independent of the plant tissue. Crossed polars. **Fig. 3.** Ostracode silicite, ostracode valves replaced by microquartz. Block in Quaternary deposites, 2 km SW from Jablonové, Malé Karpaty Mts. **Fig. 4.** Deformed voids after dissolved radiolarians in radiolarian lydite. Dúbravka-10, Malé Karpaty Mts. **Fig. 5.** Spore grains preserved in probably limnosilicite. Ladmovce-1, Zemplín Horst. **Fig. 6.** Rod-like sections of graphite crystals and aggregates in metaquartzite. Kukla-2 near Dolany, Malé Karpaty Mts. **Fig. 7.** Graphitic metaquartzite without metamorphic lamination. Zlatý vrch-7, Považský Inovec Mts., crossed polars. **Fig. 8.** Cluster of graphite crystals in metaquartzite. Pliešiny-1, Považský Inovec Mts. **Fig. 9.** Synsedimentary crack in a clast of graphitic metaquartzite, filled by surrounding psammitic sediment of Scythian age. NNE from Kadlubek, Malé Karpaty Mts. **Fig. 10.** Chloritic metaquartzite penetrated by "chevron" pressure lamellae (inclusions trails in quartz oriented 45° to the foliation plane). Predné Šišoretné near Dolné Orešany, Malé Karpaty Mts.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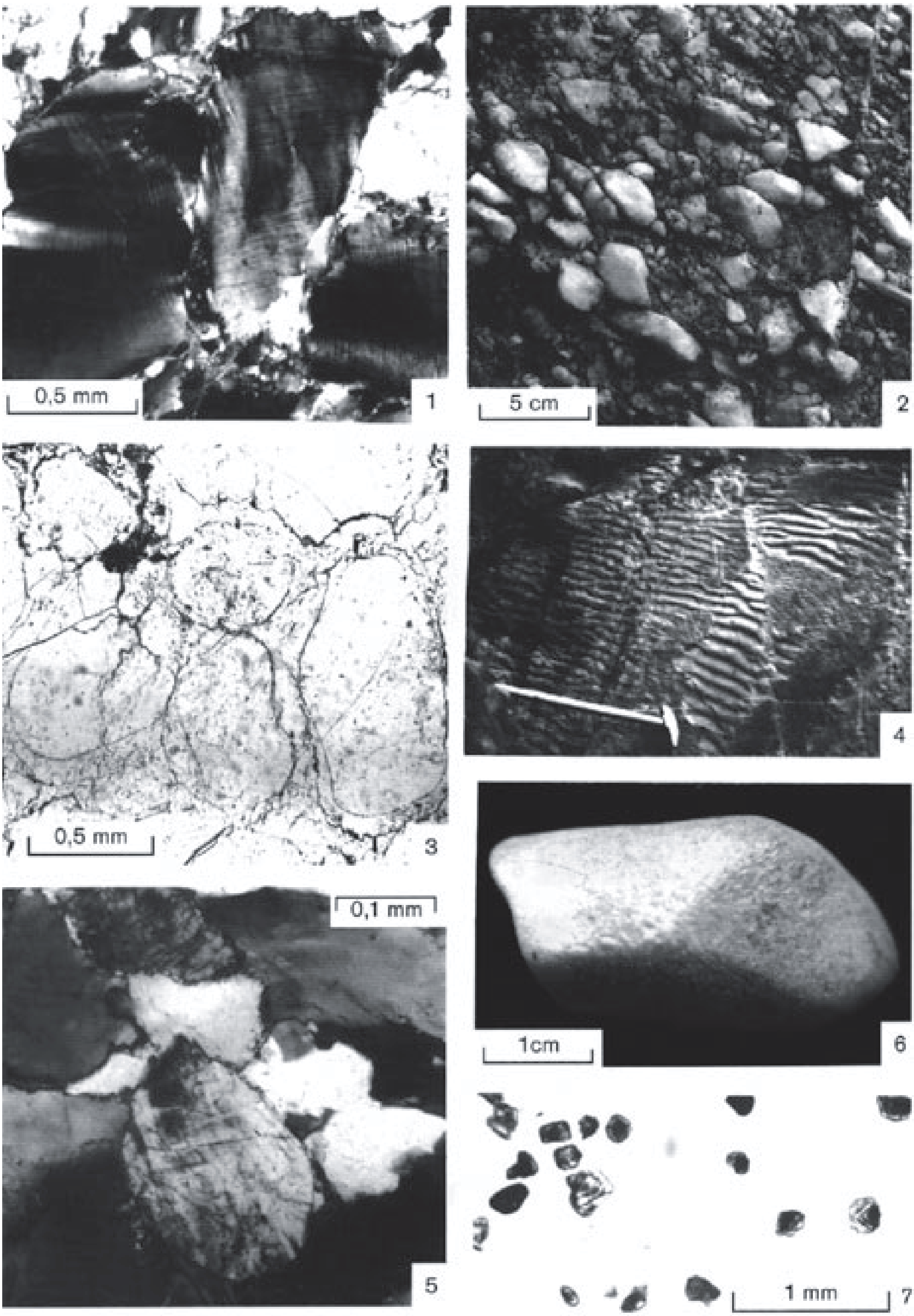
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Differences in the spatial distribution of some rock types

The composition of the clastic material of the Scythian quartzites seems to be very similar in all localities. However local differences may lead to identification of individual alluvial cones.

Tourmalinite rocks seem to be limited to the western part of Slovakia and disappear north- and eastwards. They were not found in the Malá Fatra Mts. (Ďurovič 1973 and our result from the locality Chleb), High Tatra Mts. (detailed description of Turnau-Morawska 1955 and Roniewicz 1966) and eastern Slovakia (our research in Zemplín Horst) until now. Coarse-grained tourmalinites are typical of the Malé Karpaty (including the Hainburg Hills) and Tribeč Mts. "Cryptic" tourmalinites occur in the Považský Inovec Mts., Strážovské vrchy Mts. and Nízke Tatry Mts.

Striking differences concern the feldspars in quartzites. They are almost totally absent in the Malé Karpaty Mts. (Fejdiová 1971; also Mišík & Jablonský 1978). In subarcoses of the Považský Inovec Mts. the feldspars possess a fine yellowish kaolinite staining. The feldspars in sporadic samples from the Strážovské vrchy Mts. and the Nízke Tatry Mts. are usually clear with tiny inclusions.

There is a hope that in spite of apparent homogenization of clasts several distributory provinces will be distinguished.

Transport directions derived from cross bedding

The transport of the material for Scythian quartzites was evaluated from cross bedding (Pl. VI: Figs. 1–6). The measurements of paleotransport directions were carried out in the Polish part of the High Tatra Mts. by Dzulyński & Gradzinski (1960), in the Slovak part by us, in the Tribeč Mts. by Hók (1989), in the Malé Karpaty Mts. by Mišík & Jablonský (1978), in the Považský Inovec Mts. by Mišík & Jablonský (1999) completed by new samples. The data coincide well with those from the Eastern Alps (Eisbacher 1963).

More than 80 % of all cross-beddings convicingly show a paleotransport from the N and NW, from the outer side of the Carpathian arc (Fig. 1). Broader dispersions at the remaining localities can be explained by meandering ephemeral streams, irregular morphology of the surface, later tectonic factors (e.g. rotation of several scales in the Malé Karpaty Mts.) and most probably by presence of eolian diagonal laminations.

Plate V: Scythian quartzites. Fig. 1. Torsion of pressure lamellae in quartz grains. Šalgovce-Holý vrch-3, Považský Inovec Mts., crossed polars. **Fig. 2.** Angular quartz clasts oriented along the "a" axis at the upper plane of the quartzite layer — lag sediment in the canal of a braided river. Zrkadlisko near Častá, Malé Karpaty Mts. **Fig. 3.** Syntaxial rims on well-rounded quartz grains with coatings attest the eolian origin for a part of the Scythian quartzites. Block in Quaternary sediments. Jablonové-7, Malé Karpaty Mts. **Fig. 4.** Asymmetrical ripples on the bedding surface of overturned quartzite bed. ENE from Biela Skala near Sološnica, Malé Karpaty Mts. Width of the hammer — 10.7 cm in all pictures. **Fig. 5.** Idiomorphic syntaxial feldspar overgrowth indentates in clastic quartz grain. Vozokany, Považský Inovec Mts. **Fig. 6.** Faceted clast (ventifact) attests eolian activity during the pauses of the stream transport. 500 m W of Hradište, Považský Inovec Mts. **Fig. 7.** Abundant barite grains in the heavy fraction separated from the naturally disintegrated Scythian quartzites. Donovaly, Nízke Tatry Mts.

Sedimentary environment

The sedimentary environment can be characterized as open fluvial braidplain of sandy-pebbly braided rivers a similar one as was interpreted by Mader (1985, Fig. 26) for the Buntsandstein time — the equivalent of our quartzites and sandstones.

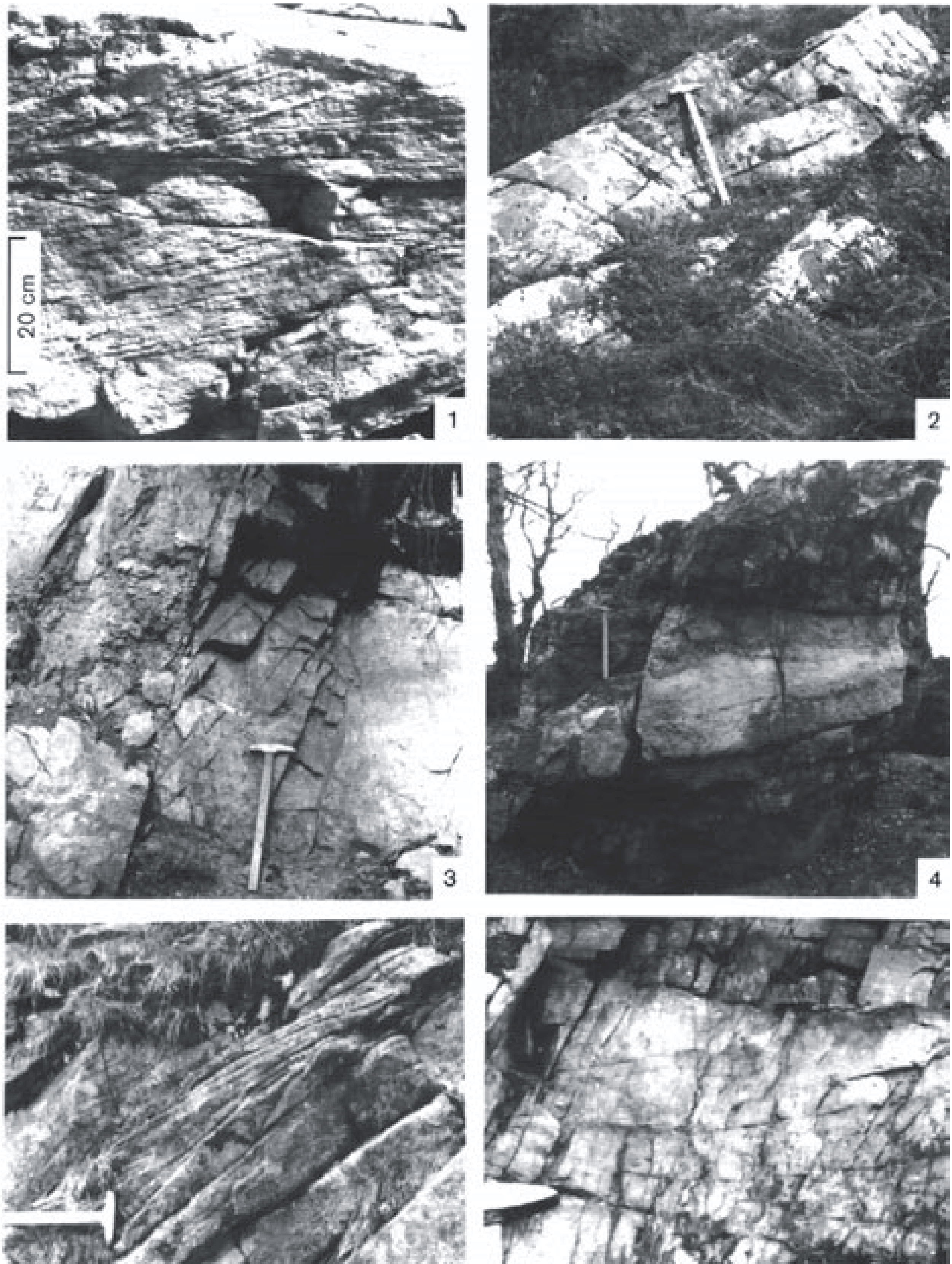
Diagonal beddings with distinct bedding-plane partings (Pl. VI: Figs. 2–6) are of fluvial origin. This interpretation is supported also by frequent poorer sorting in those beds, rare platy clasts in the foresets, single erosion channels and mainly by the erosion of the upper parts of diagonally laminated beds by the overlying bed. The alternation of diagonally laminated beds with those displaying parallel bedding reflects an inconstant intensity of flow. Pebbly-supported conglomerates of channel facies are totally missing, only matrix-supported conglomerate intercalations occur. We regard them as sediments liquefied during the flash floods transported by mass flows. Residual gravel sheet was formed as fluvial lags on the bottom of shallow stream courses.

Diagonally laminated beds with bounding surfaces (Pl. VI: Fig. 1) and beds with a trough cross-lamination could be of eolian origin. Such types were rarely found in all the studied core mountains with the exception of the High Tatra Mts. Eolian activity is documented by ventifacts (Pl. V: Fig. 6) as well as by quartzites with well-rounded sand grains (Pl. V: Fig. 3). The eolian origin of some diagonal beddings was also postulated by Hók (1989) from the Tribeč Mts.

The lower parts of the quartzites contain thin sandy-conglomeratic intercalations with sparse clasts of the most resistent rocks. The largest diameter of clast in the majority of localities was 6–8 cm, the record diameter was 30 cm (clast of vein quartz, loc. Hrabníky, Považský Inovec Mts.). The clasts are predominantly angular, rarely well rounded and locally also faceted ventifacts were found accompanied by well rounded and sorted eolian sands transformed into quartzites.

The degree of roundness of quartz grains in quartzites cannot always be interpreted because the matrix is very rare to absent, and outlines of grains were influenced by pressure solution. They are well preserved only in eolian sands, where quartz grains possess typical syntaxial rims (Pl. V: Fig. 3). Due to the interstratal solution ("chemical compaction" up to 20 %) the share of eolian and fluvial material cannot be exactly interpreted from quartz grains in the thin sections. Feldspars are better for that purpose, because they are more resistent against pressure solution.

Heavy minerals were not studied systematically, but it may be stressed that in spite of frequent laminated stratification in quartzites no laminar concentrations of heavy minerals (microplacers) occur, which is further evidence against the older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opinion of their marine origin. Scythian quartzites overlie granitoids or phyllites. There is no relation between the composition of the clasts in the quartzites and these underlying rocks. The material was deposited on a peneplanized area.

Interpretation of source area

The source area was formed predominantly by granitoids and Permian strata. The primary source of the granitoids — uplifted granitoid basement, is shown by the presence of kalifeldspars sometimes with relicts of crystal habit. The absence of granitoid pebbles can indicate strong mechanical disintegration under an arid, desert climate.

We suppose that the greater part of the source area was covered by Permian strata represented by abundant clasts of acid volcanites. Pyroclastic rocks prevailed over lavas. Quartz porphyries were accompanied by postvolcanic rocks like jaspers. Intermediary volcanites are very rare, the basic ones are absent due to their instability. Their Stephanian — or Permian age is indicated by silicified Coniferae — araucarite *Dadoxylon* sp. fragments and by pollen grains of Coniferae.

The maturity of the psephitic clasts suggests that the majority of them originate from a secondary source; they were almost all redeposited from Permian conglomerates.

Abundant graphitic metaquartzites, quartz-tourmalinitic rocks and lydites with radiolarians evoke a supposition that metamorphosed complexes were also uncovered. But in such a case some less resistent rocks also had to be present with regard to the well-preserved feldspars. In the quartzites, quartz grains with acicular inclusions typical of more intensely metamorphosed complexes are almost totally lacking.

The Lower Paleozoic complexes supplying the Permian and Lower Triassic conglomerates were primary poor in carbonate rocks. No chert nodules from limestones were identified. A single ostracode silicite is probably a product of hydrothermal silicification.

The most frequent psephitic clasts, more than 95 %, belong to the white vein quartz, which was probably formed by lateral secretion within phyllites, but not even a small enclave of phyllite occurs in them. Neither vermicular chlorite nor metallic minerals were identified in the vein quartz.

Conclusions

Scythian quartzites were deposited by sandy braided rivers in an open plain. Rare psephitic clasts transported by fluidized sandy debris flows formed the channel lag on the bottom of shallow streams (Pl. V: Fig. 2). They contain the most resistent rocks (Fig.1, Pls. I–IV): vein quartz, tourmalinitic rocks, quartz porphyries (rhyolites), rare intermediate volcanites, postvolcanic products such as jaspers and hematitic quartzites, graphitic metaquartzites, lydites sometimes with phantoms of radiolarians, fragments of silicified wood *Dadoxylon* sp., limnosilicites with pollen grains and a single silicite with ostracodes. Intermittent eolian transport is documented by local rounding of psammitic grains with syntaxial rims (Pl. V: Fig. 3) and ventifacts (Pl. VI: Fig. 6).

The source area was formed predominantly by granitoids and their Permian cover. The primary source of granitoids from an uplifted basement is shown by currently present kalifeldspars with relicts of crystal habit. The total absence of granitoid pebbles is a sign of strong mechanical disintegration under an arid, desert climate. Eroded Permian strata are represented by abundant clasts of acid volcanites and postvolcanic silicites. The Stephanian–Permian age is indicated by silicified Coniferae and their pollen grains. Pebbles of resistent Lower Paleozoic rocks were probably redeposited from Permian conglomerates. Paleozoic complexes were primarily poor in carbonate rocks; no chert nodules from limestones were identified.

Cross-bedding measurements (Fig. 1; Pl. VI: Figs. 1–6) show that the material for the quartzites of the Central Western Carpathians was transported from the N, NW, from Bohemian Massif, or from the Armorican Massif, if the supposed large left-lateral shift (Michalík 1994) took place. There are not enough data to test these hypotheses. It can only be noted that the nearest relicts of Permian strata in the Boskovice and Blanik Furrows lack the volcanic rocks what would prove against the first hypothesis. Tourmalinites found in the southern part of the Moldanubian Unit and Svratka Dome (Kebrt et al. 1984) will later be compared in detail, but it may be stressed that no spherulitic aggregates were mentioned there in contrast to our material. Where the Armorican Massif is concerned, comparison with tourmalinitic rocks from Permian conglomerates in Britain (Allen 1976; Jiang et al. 1999) might be useful.

Perhaps more sophisticated methods (e.g. radiometric study of zircons) will make it possible to say more in future. A comparative study of Scythian quartzites from the Western Alps is badly needed.

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Plate VI: Cross stratifications in Scythian quartzites. Fig. 1. Megaripple cross-lamination. Kamenná brána near Pezinok, Malé Karpaty. **Fig. 2.** Planar angular cross-bedding. Devín Castle, Malé Karpaty Mts. Length of the hammer 50 cm. **Fig. 3.** Planar tangential cross-bedding in a bed about 60 cm thick. Kľačno-Fačkovské sedlo, Strážovské vrchy Mts. **Fig. 4.** Unusually large diagonal bedding. Červený Kameň, near Pálffy's tomb, Malé Karpaty Mts. **Fig. 5.** Low-angle tangential cross-bedding. Edge of the Jahňačí Peak, Vysoké Tatry Mts. **Fig. 6.** Planar tangential cross-bedding. 1.2 km ESE of Havran Saddle, Považský Inovec Mts.

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