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# SEDIMENTARY PETROLOGY OF THE LOWER TRIASSIC QUARTZITES FROM THE VYSOKÉ TATRY AND MALÉ KARPATY ENVELOPE UNIT

(Figs. 1—38)

Abstract. Results of sedimentary-petrologic investigations of Lower Triassic quartzites are reported from the Malé Karpaty and Vysoké Tatry Envelope Units with the aim to solve problems of the way and environment of sedimentation. So far it is not possible to define the genesis of quartzites on the basis of grain-size analyses and modal analyses. It is evident, however, that quartzites arose in the beach environment where material was supplied from the source area situated on N from the West Carpathians, supposedly by long rivers. In this way mineralogically mature sediment was formed, which is simultaneously texturally immature owing to the supply of fine-grained material from the river. Lower Triassic quartzites were deposited in the shallow water beach environment, which was under strong influence of rivers, entering the sea in those places.

Резюме: Основная проблема — изучение среды возникновения кварцитов нижнего триаса в Западных Карпатах — была решена методами седиментологии. Изучаемые кварциты возникли в прибежных условиях, куда материал был принесен с источника сноса лежащего севернее от Карпатской дуги длинной или длинными реками. Таким образом возник минералогически зрелый и структурно незрелый седимент, потому что прибрежная средз была под сильным влиянием рек впадающих в этих местах в море.

## *Introduction*

The detailed investigation of West Carpathian quartzites has not been performed yet, they were examined only by mapping works. Therefore it was necessary to obtain the data about their mineral and chemical compisition, structural and textural properties and then to solve the way and the environment of their origin and to locate and characterize the source area. Mineral composition and oriented flow structures are helpful in the indication of the source area. The sedimentary environment of quartzites and the way of material transportation were studied by common sedimentological methods, on the basis of modal and grain-size analyses of sedimentary rocks. It is possible to attain some conclusions about sedimentary environment and transport mechanism comparing the obtained data with the results of recent clastic sediments.

The presented paper brings new data about quartzites from the Malé Karpaty Envelope Unit and from the western part of the Vysoké Tatry Envelope Unit (Osobitá and Tichá dolina regions). Samples were taken along the sections from the lower part in the upper part of the outcrops and are ordered in that way in tables.

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Despite of their wide regional extent quartzites were not studied in details in the West Carpathians. The exception are quartzites from the Vysoké Tatry Envelope Unit

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in Poland (S. Dżułyński, R. Gradziński 1960, P. Roniewicz 1965, 1966) and in our country (K. Borza 1958). Quartzites were studied only as a stratigraphic member of individual series or units in other regions, their mineral composition and heavy minerals were not exemined profoundly, chemical composition is known only at two localities (for the purpose of evaluating the raw material for production of silica, J. Jarkovský 1954). Similar stage of investigation of Lower Triassic quartzites is in the Alps (J. Debelmas 1960) and according to personal communication of L. Contescu also in Rumania.

According to the results existing till now the basal Lower Triassic is formed by quartzites and quartzose sandstones of white, grey, yellow, pinkish red and green colour. At the basis they often contain intercalations of conglomerates mainly with quartz pebbles. In the upper part of the complex pelitic intercalations and layers appear. The layers of arcose and lithic sandstones often occur. Quartzites are sometimes epimetamorphosed. Mineral composition is following: quartz, plagioclase (kaolinized and sericitized), orthoclase, muscovite, biotite, amphibole, zircon, rutile, tourmaline, garnet, apatite. As rock fragments there occur quartzites, chert and micaceous schists.

## *Definition, Mineral Composition*

Quartzites belong to the sandstone group with high content of clastic quartz, which are completely and firmly cemented with secondary quartz or silica. Clastic fraction must contain at least 90 % of quartz or chert (F. J. Pettijohn 1957). In the adapted Pettijohn's classification (J. Petránek 1963), which is used in our country, the content of stable components may decline under 90 %, whereby the portion of clayey components must not exceed 20 % and the portion of unstable components (feldspar, rock fragments) 10 %.

Quartz is a chief component. Grains are seldom angular, mostly they are rounded to a different degree. Original roundness is very often misrepresented by secondary quartz overgrowths in crystallographic continuity on the clastic quartz grains.

The important factor for determination of the provenance of clastic sediments and especially quartzites is the differentiation of the types of clastic quartz grains. According to the aggregation of quartz crystals we can deduce the origin of quartz grains. The main work in this was done by H. Blatt (1959) and H. Blatt and J. M. Christie (1960). Z. Kukal (1966) has used the results of the quartz grain types study for determination of the provenance of clastic sediments from the Příbram-Jince Cambrian. As the best criterion is considered the way of quartz crystal aggregation in the grains, as well as the determination of inclusions. According to these principles the following types of quartz grains are described:

1. Monocrystalline quartz without any possibility to distinguish the provenance. It occurs seldom and usually is already moderately undulatory.

2. Bipyramidal quartz, often with inclusions and coatings of aphanitic matrix. It is derived from acidic effusive rocks or their tuffs. This type has not been found in the studied quartzites perhaps because during the transportation of material which must have been at a quite long distance in order to reach high mineralogical maturity, and during the diagenesis, the original morphology of grains was wiped out.

3. Coarse polycrystalline quartz with parallelly arranged or wedge-like crystals. It contains often inclusions of sulphides or worm-like chlorite. It is vein quartz. Z. Kukal (1966) designed this type as „comb quartz". The content of this type in the Vysoké Tatry quartzites is 16,1 % – 0,7 %, in the Malé Karpaty quartzites 10,5 % – 1,7 % (fig. 1, 2).

Fig. 1. „Comb-like" vein quartz. Malé Karpaty, Červený Kameň. Crossed nicols, 43 ×. Foto T. M a s t i h u b a.

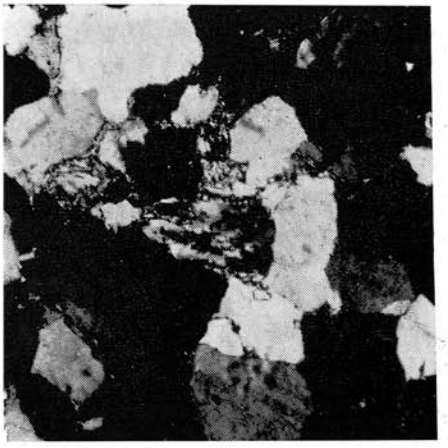

Fig. 2. „Comb-like" vein quartz. In the upper left corner we can see oriented overgrowth of quartz on the originally well rounded grain. Vysoké Tatry, Tichá dolina, X nicols, 43 ×. Foto T. M a s t i h u b a.

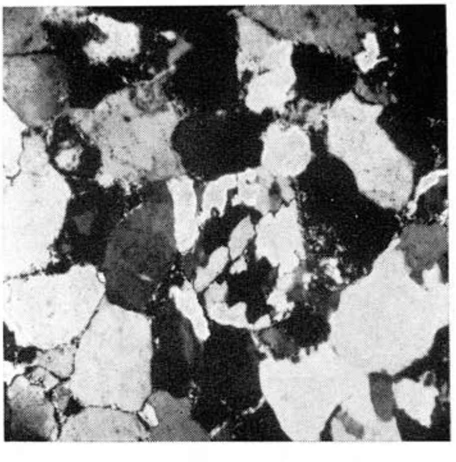

Fig. 3. Polycrystalline quartz. Vysoké Tatry, Tichá dolina, X nicols, 43 ×. Foto T. M a s t i h u b a.

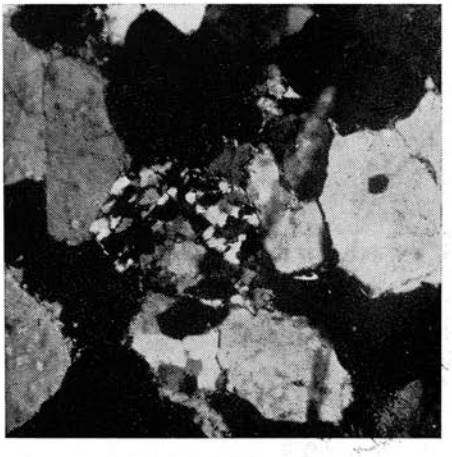

Fig. 4. Polycrystalline fine-grained quartz. Vysoké Tatry, Tichá dolina, X nicols, 43 ×. Foto T. M a s t i h u b a.

4. Irregular polycrystalline quartz, grains of which are formed partly by smaller aggregates with aggregate polarisation, partly by larger undulatory crystals.

5. Polycrystalline quartz, formed by non-oriented mosaic.

The grains of 4. and 5. types (fig. 3, 4, 5) can be derived from different sources, they come often from kata-metamorphosed rocks. Their content ranges between 22,7 %

and 3,0 % in the Vysoké Tatry quartzites, and between 18,1 % and 4,1 % in the Malé Karpaty quartzites.

6. Polycrystalline quartz, formed by parallelly oriented mosaic. It often contains parallel scales of chlorite or sericite. Parallelly elongated large quartz crystals of tooth-like delimitation are sometimes found in the fine-grained mosaic. Those types of quartz grains are derived presumably from the epi- and meso-metamorphosed rocks. Their content is 4,4 % to traces in Vysoké Tatry quartzites and 7,3 % to traces in the Malé Karpaty quartzites (fig. 6, 7).

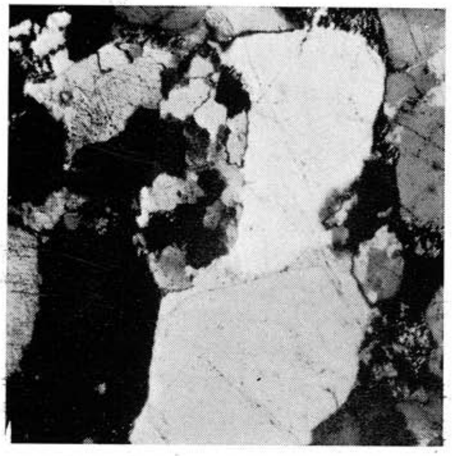

Fig. 5. Polycrystalline quartz and monocrystalline grains with oriented overgrowths. Malé Karpaty, Devín, X nicols, 43 ×. Foto T. Mastihuba.

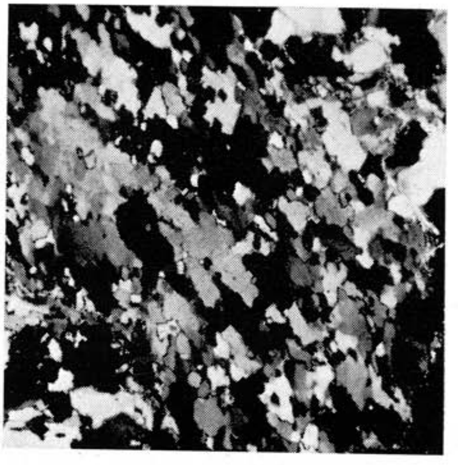

Fig. 6. Oriented mosaic quartz. Malé Karpaty, Šišoretné, X nicols, 43 ×. Foto T. Mastihuba.

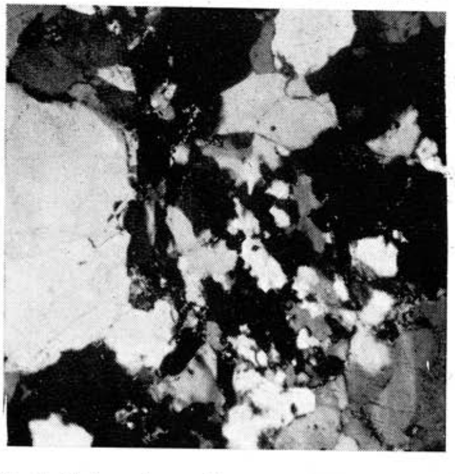

Fig. 7. Oriented mosaic quartz. Vysoké Tatry, Okulík, X nicols, 43 ×. Foto T. Mastihuba.

Fig. 8. Undulatory quartz of cataclastic origin. Vysoké Tatry, Tichá dolina, X nicols, 43 ×. Foto T. Mastihuba.

7. Polycrystalline quartz with many cryptocrystalline aggregates, mainly on the borders of quartz crystals.

8. Undulatory quartz with many pressure foldings.

Grains of types 7 and 8 (fig. 8, 9) are of cataclastic origin. Their content is the highest among all the types of quartz grains, in the Vysoké Tatry quartzites it is 84,7 % — 57,1 %, in the Malé Karpaty quartzites 86, % — 60,7 %.

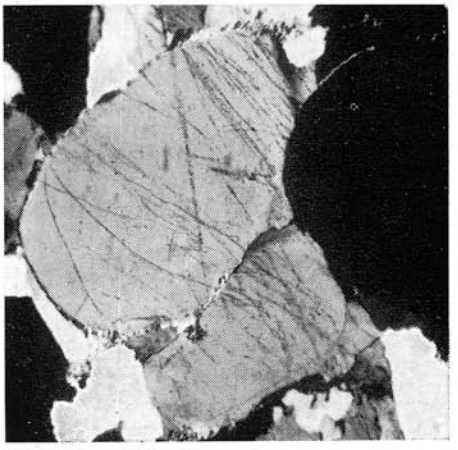

Fig. 9. Quartz with the influence of cataclastic deformation and with the matrix coatings. Malé Karpaty, Devín, X nicols, 43 ×. Foto T. Mastihuba.

9. Microperthitic intergrowths of quartz with feldspar, derived from pegmatites and other last differentiates of acidic magma. The occurence of this type is sporadic.

The high content of cataclastic quartz can be explained by initial, mild metamorphism of quartzites complex, due to which the grains originally of another provenance acquired the character of cataclastic grains.

Besides the clastic quartz grains also clastic chert occurs in a small amount.

Feldspars are mostly represented by more stable K-feldspar (orthoclasse, less microcline). Grains are poorly up to moderately rounded, sometimes a little sericitized. Also microperthitic intergrowths with quartz can be found, although rather seldom. The feldspar content ranges from 16,8 % to 0,9 % in the Vysoké Tatry quartzites, and from 4,1 % to 0,9 % in the Malé Karpaty quartzites. According to Petránek's classification feldspar and unstable rock fragment content must not exceed 10 %. It means that some samples can be considered as arcosic varieties (see tab. 1).

Next component are rock fragments, mostly fragments of effusive an phyllitic rocks. Their content is 9,4 % to traces in the Vysoké Tatry quartzites, and 2,7 % to traces in the Malé Karpaty quartzites.

As accessory minerals there occur heavy minerals, micas and Fe-minerals. Tourmaline is the most abundant heavy mineral. Generally it forms small grains about 0,05 mm large, we can find sometimes grains up to 0,1 mm large. According to P. D. Krynine (1946) the size of tourmaline crystals in sediments depends on the size of crystals in the source area. The shape is usually prismatic, crystals are moderately rounded, the sections perpendicular to c axis were sometimes found, which were usually zonal. The colour is pale-green up to dark-green. Tourmaline occurs as small transparent or turquoise grains of authigene origin as well.

Table 1

| Min. / Loc. | quartz types: cataclast | quartz types: mosaic oriented | quartz types: polycrist | quartz types: vein | feldspars | fragments rock | quartz | matrix | cement | grains |
|---|---|---|---|---|---|---|---|---|---|---|
| **Vysoké Tatry** | | | | | | | | | | |
| Mačie diery 3 | 84,3 | 1,7 | 5,7 | 2,4 | 1,6 | 0,9 | 94,1 | 1,7 | 1,7 | 96,6 |
| Mačie diery 4 | 80,4 | 2,5 | 3,4 | 1,8 | 3,4 | 3,3 | 88,1 | 4,3 | 0,9 | 94,8 |
| Mačie diery 5 | 70,8 | 0,4 | 10,1 | 3,1 | 1,0 | 1,2 | 84,4 | 1,9 | 11,5 | 86,6 |
| Mačie diery 6 | 69,6 | 0,6 | 11,4 | 5,4 | 7,2 | 1,9 | 87,0 | 2,8 | 1,1 | 96,1 |
| Mačie diery 7 | 61,0 | 0,6 | 16,1 | 1,4 | 12,4 | 1,3 | 79,1 | 5,7 | 1,6 | 92,8 |
| Mačie diery 8 | 72,7 | 0,9 | 6,9 | 4,8 | 7,9 | 1,2 | 85,3 | 4,7 | 1,4 | 94,4 |
| Okulík 9 | 68,7 | 2,6 | 11,8 | 3,0 | 4,0 | 1,9 | 86,1 | 5,8 | 1,2 | 92,0 |
| Okulík 10 | 75,0 | 2,5 | 3,0 | 1,0 | 5,9 | 2,1 | 81,5 | 9,4 | 1,1 | 89,5 |
| Okulík 11 | 72,1 | 1,0 | 7,9 | 9,8 | 3,0 | 1,2 | 90,8 | 4,5 | 0,6 | 95,0 |
| Okulík 12 | 72,7 | 0,2 | 8,1 | 3,5 | 1,6 | 2,6 | 84,5 | 10,4 | 1,1 | 88,7 |
| Okulík 13 | 73,7 | 0,9 | 3,7 | 1,0 | 6,4 | 5,0 | 79,3 | 7,7 | 1,6 | 90,7 |
| Okulík 14 | 64,0 | 4,2 | 7,5 | 3,3 | 4,9 | 3,4 | 79,0 | 3,7 | 9,0 | 87,3 |
| Roh 38 | 65,2 | — | 4,5 | 1,0 | 16,8 | 3,4 | 70,7 | 8,1 | 1,1 | 90,9 |
| Roh 37 | 66,1 | — | 5,1 | 1,0 | 15,1 | 0,7 | 72,2 | 9,6 | 2,4 | 88,0 |
| Roh 36 | 72,2 | + | 7,3 | 3,8 | 11,1 | 0,8 | 83,3 | 3,9 | 0,5 | 95,2 |
| Roh 35 | 73,8 | + | 6,5 | 2,2 | 2,6 | 0,8 | 82,5 | 4,6 | 9,5 | 85,9 |
| Roh 34 | 62,0 | + | 9,0 | 4,3 | 5,7 | 0,9 | 75,3 | 8,1 | 10,1 | 81,9 |
| Roh 33 | 58,4 | 1,3 | 10,6 | 4,8 | 0,6 | + | 75,1 | 0,3 | 24,0 | 75,7 |
| Roh 32 | 78,0 | + | 6,6 | 2,6 | 6,4 | + | 87,2 | 3,5 | 2,9 | 93,6 |
| Končisté 41 | 81,6 | 0,6 | 10,0 | 3,7 | — | 1,2 | 95,9 | 1,3 | 1,6 | 97,1 |
| Končisté 42 | 71,2 | 0,6 | 5,9 | 1,9 | 4,6 | 2,9 | 79,6 | 12,4 | 0,5 | 78,1 |
| Končisté 43 | 76,0 | + | 10,0 | 1,9 | 3,4 | 4,8 | 87,9 | 1,6 | 1,1 | 96,1 |
| Končisté 44 | 78,6 | — | 7,9 | 0,7 | 4,9 | 0,6 | 87,2 | 2,6 | 4,7 | 92,7 |
| Končisté 45 | 78,6 | 2,0 | 7,7 | 1,3 | 1,8 | 1,9 | 89,6 | 4,5 | 2,2 | 93,3 |
| Končisté 46 | 75,0 | + | 10,5 | 2,5 | 5,8 | 0,8 | 88,0 | 2,0 | 3,4 | 94,6 |
| Tomanovské sedlo 1 | 80,5 | 0,3 | 6,9 | 2,4 | 6,8 | 0,2 | 90,1 | 1,7 | 1,2 | 97,1 |
| Tomanovské sedlo 2 | 69,7 | 2,8 | 6,2 | 2,5 | 0,3 | 0,9 | 81,2 | 3,6 | 14,0 | 82,4 |
| Tomanovské sedlo 3 | 72,8 | + | 3,9 | 2,3 | 2,7 | 2,4 | 79,0 | 13,9 | 2,0 | 84,1 |
| Tomanovské sedlo 4 | 68,8 | 0,2 | 8,1 | 5,0 | 6,8 | 0,8 | 82,1 | 7,9 | 2,4 | 89,7 |
| Liptovská Tomanová 1. 5 | 76,1 | + | 5,2 | 2,1 | 4,2 | 2,0 | 83,4 | 3,4 | 2,0 | 89,6 |
| Liptovská Tomanová 1. 6 | 76,1 | 1,0 | 8,0 | 4,9 | 1,3 | 0,7 | 90,0 | 6,1 | 1,9 | 92,0 |
| Liptovská Tomanová 1. 7 | 58,5 | + | 20,3 | 3,7 | 2,4 | 2,3 | 82,5 | 12,1 | 0,7 | 87,2 |
| Liptovská Tomanová 1. 8 | 79,6 | 1,1 | 4,6 | 1,7 | 3,2 | 1,3 | 78,0 | 3,2 | 5,4 | 91,5 |
| Liptovská Tomanová 1. 9 | 68,9 | 1,5 | 16,5 | 2,3 | 4,5 | + | 89,2 | 3,4 | 2,9 | 93,7 |
| Liptovská Tomanová 2.14 | 74,9 | 1,3 | 9,4 | 4,1 | 1,1 | 1,8 | 89,7 | 5,5 | 2,0 | 92,6 |
| Liptovská Tomanová 2,13 | 80,1 | 0,6 | 6,9 | 1,7 | 3,1 | 1,4 | 89,3 | 0,5 | 1,0 | 93,8 |
| Liptovská Tomanová 2.12 | 60,3 | 0,7 | 12,0 | 4,4 | 2,8 | 9,4 | 77,4 | 2,6 | 7,8 | 89,6 |

Table 1

| Min. / Loc. | quartz types | | | | feldspars | fragments rock | quartz | matrix | cement | grains |
|---|---|---|---|---|---|---|---|---|---|---|
| | cataclast | mosaic oriented | polycrist | vein | | | | | | |
| Liptovská Tomanová 2.11 | 73,4 | 0,9 | 11,9 | 1,5 | 2,9 | 2,2 | 87,7 | 5,9 | 4,6 | 92,8 |
| Liptovská Tomanová 2.10 | 78,1 | 2,3 | 7,7 | 1,7 | 2,2 | 0,4 | 89,8 | 3,2 | 1,7 | 92,4 |
| Červený úplaz 240 b | 57,3 | 1,3 | 22,7 | 9,4 | — | 0,9 | 90,7 | 11,0 | 5,2 | 91,6 |
| Červený úplaz 230 b | 60,7 | 0,7 | 15,0 | 6,6 | — | 1,9 | 83,0 | 0,8 | 4,6 | 84,9 |
| Červený úplaz 220 b | 61,6 | 0,6 | 16,1 | 6,6 | — | 1,3 | 84,9 | 2,4 | 13,0 | 86,2 |
| Červený úplaz 210 b | 63,4 | 1,5 | 13,9 | 10,5 | — | 1,2 | 89,3 | 2,7 | 7,1 | 90,5 |
| Tichá 15o b | 67,6 | 4,4 | 14,2 | 8,1 | — | 1,1 | 94,3 | 6,2 | 1,9 | 95,4 |
| Tichá 16o a | 76,3 | 0,8 | 5,6 | 7,1 | — | 1,1 | 88,4 | 9,3 | 2,9 | 90,9 |
| Tichá 17o b | 68,2 | 0,3 | 7,1 | 12,8 | — | 1,2 | 89,8 | 6,8 | 1,1 | 89,6 |
| Tichá 18o b | 57,1 | 1,7 | 14,1 | 16,1 | — | 3,4 | 89,6 | 11,6 | 1,0 | 93,0 |
| Tichá 19o b | 68,2 | + | 10,3 | 7,0 | — | 1,0 | 85,5 | 2,6 | 1,9 | 86,5 |
| Tichá 20o b | 70,7 | 2,9 | 6,8 | 5,7 | — | 6,2 | 86,1 | 6,2 | 1,5 | 92,3 |
| Malé Karpaty | | | | | | | | | | |
| Devín 10o | 78,8 | + | 8,2 | 7,0 | — | 0,9 | 94,0 | 2,4 | 2,7 | 94,9 |
| Devín 11o | 80,1 | 0,4 | 7,7 | 7,3 | — | 1,1 | 96,2 | + | 2,7 | 97,3 |
| Devín 12 | 82,3 | 0,8 | 7,1 | 2,8 | — | 1,0 | 93,0 | 1,4 | 4,6 | 94,0 |
| Devín 13 | 78,7 | + | 9,5 | 1,9 | — | 1,4 | 90,1 | 4,9 | 2,4 | 92,7 |
| Medvedie skaly 1 | 77,5 | + | 6,2 | 4,5 | — | 1,1 | 88,2 | 2,4 | 8,3 | 89,3 |
| Medvedie skaly 2 | 77,4 | 1,6 | 8,7 | 7,0 | — | 0,9 | 94,7 | 2,9 | 1,5 | 95,6 |
| Medvedie skaly 3 | 69,1 | 2,7 | 18,1 | 6,0 | — | 0,7 | 95,9 | 1,9 | 1,5 | 96,6 |
| Medvedie skaly 4 | 86,7 | 1,9 | 5,3 | 4,5 | — | 0,7 | 97,7 | 1,1 | 0,5 | 98,4 |
| Medvedie skaly 5 | 80,0 | + | 6,7 | 2,6 | — | 0,6 | 89,3 | 9,2 | 0,9 | 89,9 |
| Medvedie skaly 6 | 79,6 | 1,8 | 9,7 | 6,7 | — | 1,1 | 97,8 | 0,9 | 0,3 | 98,9 |
| Medvedie skaly 7 | 84,3 | — | 6,7 | 3,5 | — | 1,9 | 94,5 | 3,0 | 0,6 | 96,4 |
| Červený Kameň 3o/65 | 70,9 | 3,4 | 5,4 | 9,1 | 2,3 | 0,2 | 88,8 | 7,8 | 0,9 | 91,3 |
| Červený Kameň 4o/65 | 73,9 | — | 4,1 | 5,1 | 0,9 | — | 83,1 | 19,8 | 0,2 | 84,0 |
| Červený Kameň 5/65 | 84,5 | + | 6,1 | 4,9 | 4,1 | 0,2 | 95,5 | 2,2 | 1,8 | 99,8 |
| Červený Kameň 6/65 | 60,7 | 2,8 | 11,8 | 10,5 | 2,4 | 0,3 | 85,8 | 11,8 | 1,1 | 88,5 |
| Šišoretné 42o | 83,6 | + | 6,8 | 2,4 | 3,1 | 0,3 | 92,8 | 2,1 | 0,2 | 96,2 |
| Šišoretné 43o | 66,7 | 0,4 | 12,9 | 2,6 | 1,8 | + | 82,6 | 9,6 | 1,1 | 84,4 |
| Šišoretné 45o | 61,0 | 7,3 | 13,1 | 8,9 | — | 2,6 | 90,3 | 5,0 | 2,1 | 92,2 |
| Šišoretné 46o | 78,0 | 0,5 | 14,4 | 1,9 | — | 2,7 | 94,8 | 1,5 | 1,0 | 97,5 |
| Šišoretné 47o | 72,5 | 0,9 | 19,2 | 1,7 | — | 0,6 | 94,3 | 1,3 | 3,8 | 94,9 |

Z i r c o n occurs as small, about 0,05 mm large, mostly well rounded grains. Idiomorphic grains can be found very seldom. Sometimes it is zonal.

L e u k o x e n e occurs very often. They are most common heavy minerals together with tourmaline. Leukoxene is usually golden-yellow up to opaque, having aggregate polarisation and forming relatively large grains about 0,1 mm. Totally transparent variety occurs very seldom.

Rare minerals are r u t i l e and a p a t i t e in the investigated quartzites.

P y r i t e together with h e m a t i t e are of common occurrence, particularly in the red and pink quartzites, hematite forms only cotings on the quartz grains. Pyrite forms small, usually idiomorphic cryštals, often in clusters or even in laminae.

B i o t i t e is more common then m u s c o v i t e. It forms pleochroic scales, sometimes bent, seldom baueritized.

M a t r i x content is ranging from 13,9 % to 0,3 % in the Vysoké Tatry quartzites, from 19,8 % to traces in the Malé Karpaty quartzites. Relatively high matrix content is generally unusual in the quartzites and indicates lower textural maturity of the examined quartzites. However, according to Petránek's classification matrix content does not exceed the upper limit of 20 %.

C e m e n t is quartzose, porous, its content is 24,0 % in the silicified varieties to 0,5 % in the Vysoké Tatry quartzites, 0,3 % to 0,2 % in the Malé Karpaty quartzites.

The diagrams have been drawn demonstrating the representation of three textural components of quartzites — grains, matrix and cement (fig. 10, 11). In these diagrams we can see relatively high textural maturity, although in generally quartzites have much less proportion of matrix than the examined quartzites.

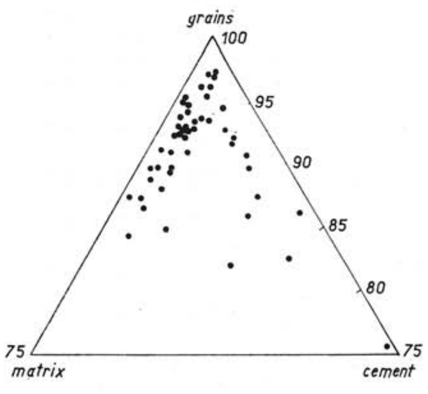


Fig. 10.

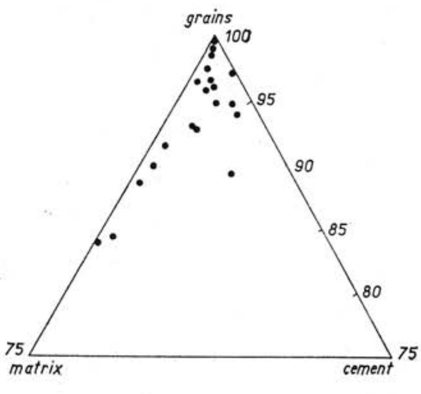


Fig. 11.

The results of modal analyses are presented in tab. 1. There are individual types of quartz grains combined into four groups according to their provenance due to the restricted possibilities to count them by point counter. Correlation coefficients were computed and the diagrams were constructed and also the dependences of modal composition upon mean M and sorting coefficent $\sigma\, \varphi$ were found out. Compulations were carried out at the Institute of Technical Cybernetics of the Slovak Academy of Sciences on the computer GIER. Only diagrams for the Vysoké Tatry quartzites are presented in this paper because the small amount of values (20) for the Malé Karpaty quartzites is not sufficient and therefore correlations are different from the relationships valid for the Vysoké Tatry quartzites. In tab. 2 are summarized the values of correlation coefficients also for the Malé Karpaty quartzites.

With increasing values of mean or decreasing values of the content of cataclastic quartz increases. The dependence is fairly significant, correlation coefficient $r_{ij} = -0{,}22$ (fig. 12). With increasing mean content of oriented mosaic grains decreases,

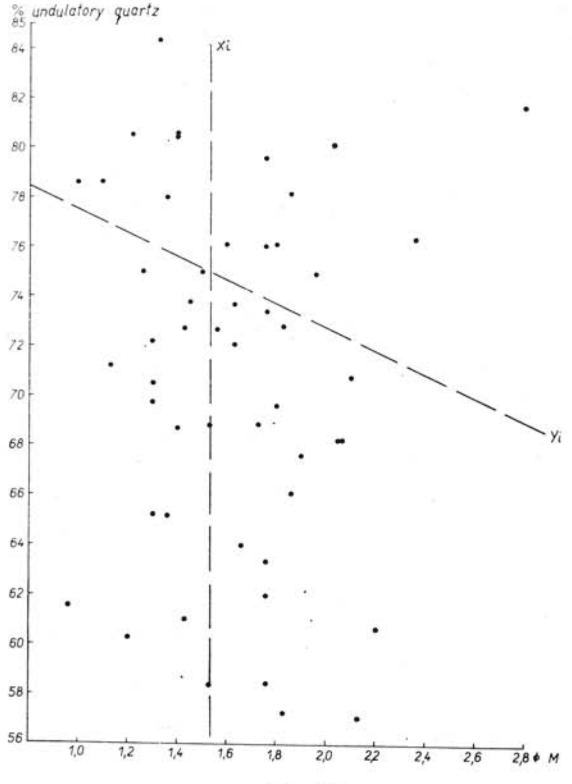


Fig. 12.

$r_{ij} = 0{,}13$ (fig. 13). Correlation dependence of polycrystalline quartz upon the mean is less significant, values are spread over the diagram (fig. 14), $r_{ij} = 0{,}08$. Between mean and the content of vein quartz indirect dependence exists there, with decreasing values of mean the content of vein quartz decreases, $r_{ij} = 0{,}46$, correlation is significant (fig. 15). The dependence of feldspar content upon the mean is direct, with increasing

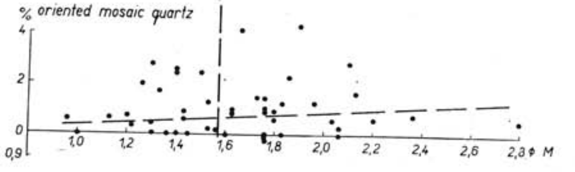


Fig. 13.

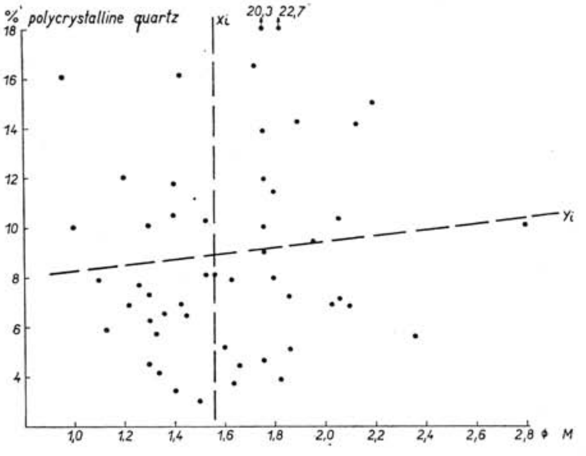


Fig. 14.

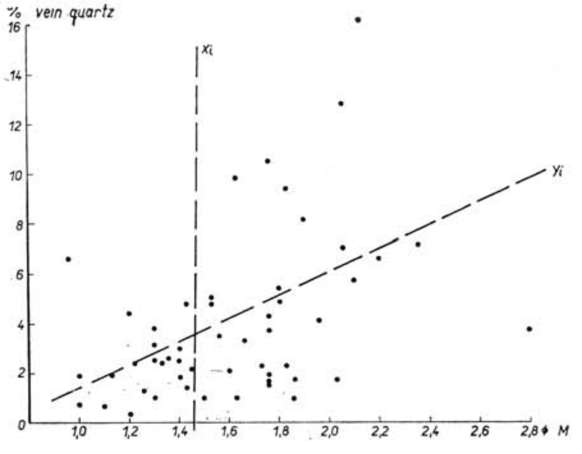


Fig. 15.

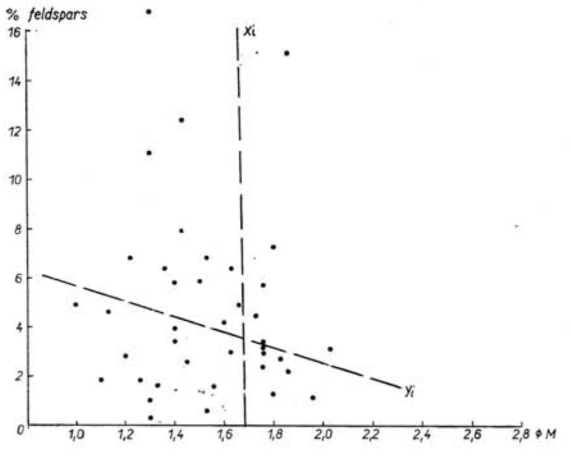


Fig. 16.

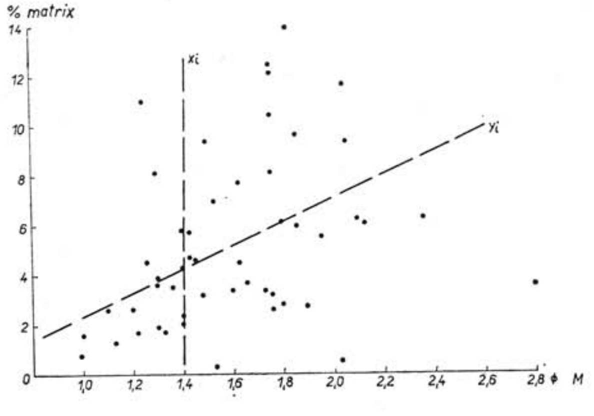


Fig. 17.

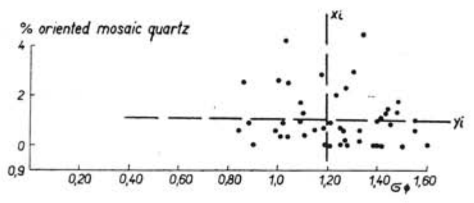


Fig. 19. ▶

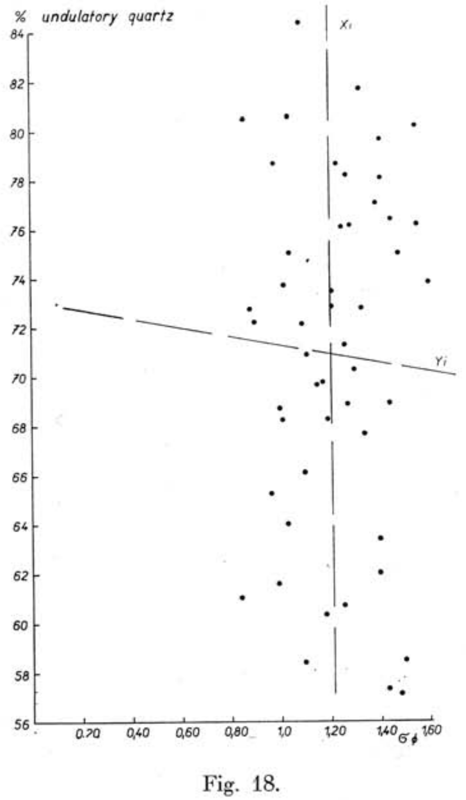


Fig. 18.

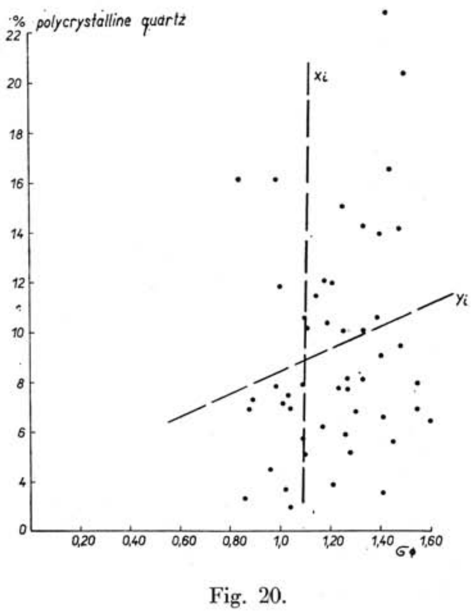


Fig. 20.

M feldspar content increases (fig. 16). Correlation is significant, $r_{ij} = -0{,}27$. Between the matrix content and mean indirect dependence exists (fig. 17), with increasing mean the matrix content decreases. Correlation is significant, $r_{ij} = 0{,}45$.

The content of cataclastic quartz does not depend upon the degree of sorting or only very little, in the case of poorer sorting (values of $\sigma\varphi$ increase), the content of cataclastic quartz lowers, $r_{ij} = 0{,}06$ (fig. 18). Depedence of oriented mosaic content upon the degree of sorting, $r_{ij} = 0{,}07$ (fig. 19). With decreasing sorting the content of polycrystalline quartz increases. Dependence is significant, $r_{ij} = 0{,}21$ (fig. 20). The

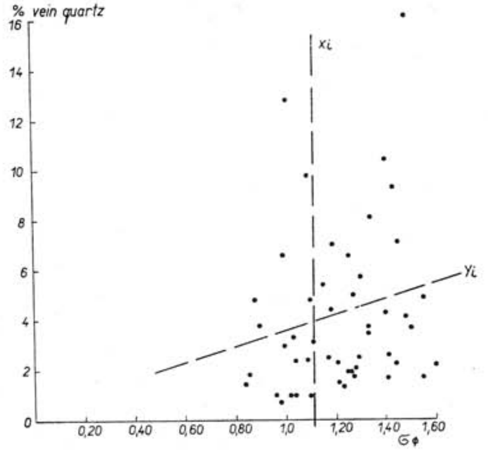


Fig. 21.

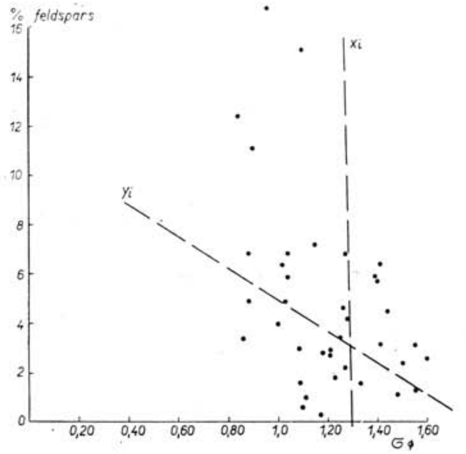


Fig. 22.

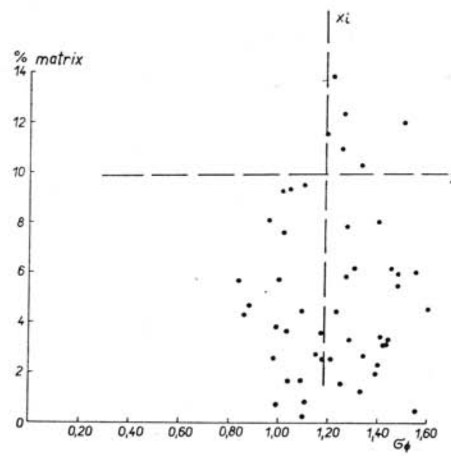


Fig. 23.

content of vein quartz increases with lowering sorting degree, correlation is significant, $r_{ij} = 0{,}23$ (fig. 21). As the sorting degree is getting worse, feldspar content decreases, correlation is significant, $r_{ij} = -0{,}31$ (fig. 22). Dependence of matrix content upon sorting coefficient is slight, nearly none. It means that matrix content is independent upon the degree of sorting, $r_{ij} = 0{,}07$ (fig. 23).

Table 2

| | cataclast | oriented mosaic | polycrist | vein | feldspars | matrix |
|---|---|---|---|---|---|---|
| | | | Vysoké Tatry | | | |
| M | −0,22 | 0,13 | 0,08 | 0,46 | −0,27 | 0,45 |
| σφ | −0,06 | −0,02 | 0,21 | 0,23 | −0,39 | 0,27 |
| | | | Malé Karpaty | | | |
| M | −0,17 | 0,06 | −0,24 | −0,02 | 0,51 | 0,30 |
| σφ | −0,57 | 0,34 | 0,12 | 0,19 | 0,54 | 0,22 |

*Grain-size analyses*

Statistical textural parameters are very sensitive indicators of sedimentary environment, because they express differences in transport and sedimentation of clastic particles. On the basis of the values of those parameters and their mutual relationships the main types of sedimentary environments can be distinguished. Despite of the existing obstacles in the application of results from the study of recent sediments on the ancient sands and sandstones, certain progress has been reached (F. P. Shepard and R. Young 1961, A. J. Moss 1962, J. Chappel 1967, G. M. Friedman 1967). When we consider many factors, acting in the geological environments, the grain-size distribution study of clastic sediments is of great help in the interpretation of sedimentary environments. The fundamental work in this field was done by R. L. Folk (1966). R. L. Folk and W. C. Ward (1957), G. M. Friedman (1958, 1961, 1962, 1967) and D. L. Inman (1952).

Grain-size analyses were made from thin-sections in the common way (W. C. Krumbein and F. J. Pettijohn 1938). 500 grains had been measured in the each thin-section. Cumulative frequency curves were plotted in the log probability chart (fig. 24—26). For the computation of textural statistic parameters the formulae

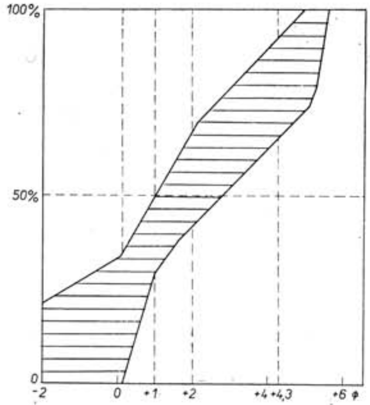


Fig. 24.

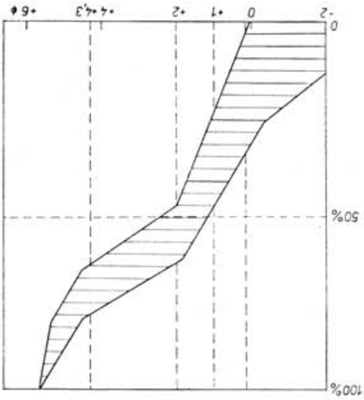

Fig. 25.

of G. M. Friedman (1967) were used. Computed values have not been corrected for random sections yet, it will be the subject of further investigations. Values of textural parameters are in table 3.

Mean M expresses the average grain-size of the sediment, how it was influenced by the source of clastic material and sedimentary environment. The Vysoké Tatry quartzites are medium to fine-grained, average value is 1,64 $\varphi$ and extreme values are 0,96 $\varphi$—2,8 $\varphi$. The Malé Karpaty quartzites are fine to coarse-grained, average value is 1,3 $\varphi$, extreme values are 0,66 $\varphi$—1,96 $\varphi$.

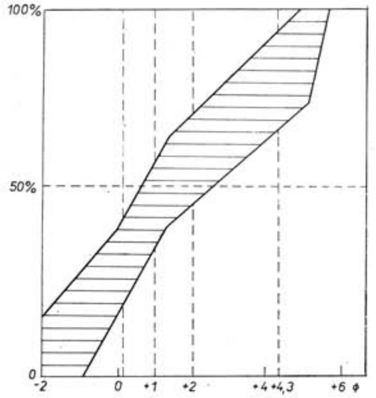


Fig. 26.

Sorting coefficient $\sigma\varphi$ ranges between 0,84 $\varphi$ and 1,22 $\varphi$, average value is 1,22 $\varphi$ in the Vysoké Tatry quartzites, it means they are moderately to poorly sorted (according to sorting scale, R. L. Folk and W. C. Ward 1957, G. M. Friedman 1962), average value falls into the group of poorly sorted clastics. The Malé Karpaty quartzites are moderately up to poorly sorted, average values is 1,13 $\varphi$ and extreme values are 0,83 $\varphi$ and 1,62 $\varphi$.

Skewness or coefficient of asymmetry, $Sk_I$ is a measure of symmetry of distribution curve and characterizes the distribution especially in its tails, depending on the content of fine- or coarse-grained fraction. According to that $Sk_I$ can achieve positive or negative values. The Vysoké Tatry quartzites have positive values between + 0,11 $\varphi$ and + 0,68 $\varphi$, average value is + 0,31 $\varphi$. The Malé Karpaty quartzites have extreme values — 0,04 $\varphi$ and + 0,46 $\varphi$ Coefficient of asymmetry $\varphi$, average value is + 0,21 is very sensitive parameter for the identification of sedimentary environment.

Kurtosis or peakedness $K_G$ expressed the relation of central part and tails in the distribution. The Vysoké Tatry quartzites have values 0,78 $\varphi$—2,04 $\varphi$, average value is 1,36 $\varphi$ and 1,82 $\varphi$. The Malé Karpaty quartzites have extreme values 0,84 $\varphi$ average value is 1,34 $\varphi$. Values of $K_G$ point at the leptokurtic distribution (R. L. Folk 1966), i. e. distribution which contains coarse- and fine-grained fractions together.

The last three textural parameters, $So_s$, $\alpha_s$, $\alpha_M$ were introduced for the first time by G. M. Friedman (1967) for distinguishing recent beach and river sands. These parameters are highly sensitive for the content of fine and coarse fraction, because the 5th and 95th percentiles are applied for computing. Since we cannot achieve exact values of them from thin-section grain-size analysis, no conclusions based on these parameters can be drawn. Generally, however, it is known that the negative values of $\alpha_s$ and $\alpha_M$ achieve beach sands, sometimes negative values can be expected even

Table 3

| par / sample | | Md | φ 84 | φ 16 | φ 95 | φ 5 | φ 75 | φ 25 | φ M | σφ | $Sk_I$ | $K_G$ | $So_S$ | $\alpha_S$ | $\alpha_M$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Vysoké Tatry | | | | | | | | |
| Mačie diery | 3 | 1,2 | 2,2 | 0,6 | 4,0 | 0,2 | 1,7 | 0,8 | 1,33 | 1,09 | 0,36 | 1,73 | 1,9 | 1,8 | 0,7 |
| Mačie diery | 4 | 1,4 | 2,1 | 0,7 | 3,7 | 0,2 | 1,8 | 1,0 | 1,4 | 0,86 | 0,16 | 1,79 | 1,75 | 1,1 | 0,4 |
| Mačie diery | 5 | 1,2 | 2,4 | 0,3 | 3,7 | −0,2 | 1,9 | 0,6 | 1,3 | 1,11 | 0,21 | 1,2 | 1,95 | 1,1 | 0,5 |
| Mačie diery | 6 | 1,5 | 3,1 | 0,8 | 4,0 | 0,2 | 2,3 | 1,0 | 1,8 | 1,15 | 0,35 | 1,19 | 1,9 | 1,2 | 0,7 |
| Mačie diery | 7 | 1,4 | 2,2 | 0,7 | 3,5 | 0,4 | 1,8 | 0,9 | 1,43 | 0,84 | 0,21 | 1,4 | 1,55 | 1,1 | 0,4 |
| Mačie diery | 8 | 1,4 | 2,2 | 0,7 | 3,7 | 0,4 | 1,9 | 0,0 | 1,43 | 0,88 | 0,21 | 1,35 | 1,65 | 1,3 | 0,6 |
| Okulík | 9 | 1,4 | 2,2 | 0,6 | 3,8 | −0,2 | 1,8 | 1,0 | 1,4 | 1,0 | 0,43 | 2,04 | 2,0 | 0,6 | 0,1 |
| Okulík | 10 | 1,5 | 2,4 | 0,6 | 3,6 | −0,3 | 2,0 | 0,8 | 1,5 | 1,04 | 0,31 | 1,33 | 1,95 | 0,3 | −0,2 |
| Okulík | 11 | 1,5 | 2,7 | 0,7 | 4,0 | 0,1 | 2,1 | 1,0 | 1,63 | 1,09 | 0,24 | 1,44 | 1,85 | 1,1 | 0,6 |
| Okulík | 12 | 1,4 | 2,9 | 0,4 | 4,1 | 0,6 | 2,0 | 0,8 | 1,56 | 1,33 | 0,37 | 1,23 | 1,75 | 1,9 | 1,2 |
| Okulík | 13 | 1,4 | 2,7 | 0,8 | 4,0 | 0,4 | 2,0 | 0,8 | 1,63 | 1,02 | 0,41 | 1,86 | 1,8 | 1,6 | 1,4 |
| Okulík | 14 | 1,5 | 2,7 | 0,8 | 3,8 | 0,1 | 2,1 | 1,1 | 1,66 | 1,03 | 0,25 | 1,52 | 1,85 | 0,9 | 0,4 |
| Roh | 38 | 1,2 | 2,2 | 0,5 | 3,8 | 0,2 | 1,8 | 0,7 | 1,3 | 0,96 | 0,36 | 1,34 | 1,8 | 1,6 | 0,5 |
| Roh | 37 | 1,5 | 3,2 | 0,9 | 4,2 | 0,6 | 2,2 | 1,1 | 1,86 | 1,1 | 0,67 | 1,34 | | 1,8 | 1,3 |
| Roh | 36 | 1,2 | 2,1 | 0,6 | 3,8 | 0,3 | 1,6 | 0,8 | 1,3 | 0,9 | 0,34 | 1,8 | 1,75 | 1,7 | 0,6 |
| Roh | 35 | 1,4 | 2,2 | 0,8 | 3,7 | 0,4 | 1,8 | 1,0 | 1,45 | 1,6 | 0,24 | 1,73 | 1,65 | 1,3 | 0,6 |
| Roh | 34 | 1,5 | 3,4 | 0,4 | 4,2 | −0,2 | 2,3 | 0,8 | 1,76 | 1,4 | 0,25 | 1,65 | 2,2 | 1,0 | 0,5 |
| Roh | 33 | 1,4 | 2,6 | 0,6 | 4,0 | 0,2 | 2,0 | 0,9 | 1,53 | 1,1 | 0,28 | 1,41 | 1,9 | 1,4 | 0,7 |
| Roh | 32 | 1,2 | 2,7 | 0,2 | 3,9 | −0,7 | 1,9 | 0,5 | 1,36 | 1,41 | 0,18 | 1,35 | 2,3 | 0,8 | −0,3 |
| Končisté | 40 | 2,4 | 4,0 | 0,2 | 4,8 | 0,6 | 3,7 | 1,5 | 2,8 | 1,33 | 0,14 | 0,78 | 2,1 | 0,6 | 0,8 |
| Končisté | 41 | 1,0 | 2,2 | 0,2 | 3,7 | −0,5 | 1,8 | 0,3 | 1,13 | 1,26 | 0,24 | 0,87 | 2,1 | 1,2 | |
| Končisté | 42 | 1,4 | 3,3 | 0,6 | 4,2 | 0,3 | 2,2 | 0,8 | 1,76 | 1,25 | 0,55 | 1,14 | 1,95 | 1,7 | 1,0 |
| Končisté | 43 | 1,1 | 1,8 | 0,1 | 3,7 | −1,8 | 1,6 | 0,4 | 1,0 | 1,25 | −0,35 | 1,9 | 2,75 | −0,3 | −1,6 |
| Končisté | 44 | 1,0 | 2,0 | 0,3 | 3,8 | 0,1 | 1,6 | 0,5 | 1,1 | 0,28 | 0,58 | 1,37 | 1,85 | 1,9 | 1,3 |
| Končisté | 45 | 1,2 | 2,4 | 0,2 | 3,8 | −0,7 | 1,9 | 0,6 | 1,25 | 1,23 | 0,12 | 1,4 | 2,25 | 0,7 | −0,4 |
| Končisté | 46 | 1,1 | 2,9 | 0,2 | 4,1 | −0,6 | 2,0 | 0,5 | 1,4 | 1,39 | 0,3 | 1,28 | 2,35 | 1,3 | 0,9 |
| Tomanovské sedlo | 1 | 1,1 | 2,1 | 0,6 | 4,0 | 0,2 | 2,7 | 0,7 | 1,22 | 1,04 | 0,4 | 1,58 | 1,9 | 2,0 | 0,7 |
| Tomanovské sedlo | 2 | 1,5 | 2,3 | 0,3 | 4,0 | −0,4 | 1,9 | 0,5 | 1,3 | 1,17 | 0,11 | 1,29 | 2,2 | 1,8 | 0,1 |
| Tomanovské sedlo | 3 | 1,5 | 3,5 | 0,5 | 4,6 | 0,1 | 2,6 | 0,8 | 1,83 | 1,21 | 0,19 | 1,04 | 2,25 | 1,7 | 1,2 |
| Tomanovské sedlo | 4 | 1,3 | 3,0 | 0,3 | 4,1 | −0,4 | 2,0 | 0,6 | 1,53 | 1,27 | 0,14 | 1,21 | 2,25 | 1,9 | 0,2 |
| Liptovská Tomanová 1. | 5 | 1,4 | 3,0 | 0,4 | 4,1 | −0,1 | 2,0 | 0,6 | 1,6 | 1,28 | 0,30 | 1,13 | 2,1 | 1,4 | 0,5 |
| Liptovská Tomanová 1. | 6 | 1,6 | 3,5 | 0,3 | 4,9 | −1,0 | 2,7 | 1,0 | 1,8 | 1,55 | 0,15 | 1,21 | 2,25 | 1,8 | 0,4 |
| Liptovská Tomanová 1. | 7 | 1,6 | 3,4 | 0,3 | 4,5 | −0,3 | 2,5 | 0,9 | 1,76 | 1,5 | 0,18 | 1,26 | 2,4 | 1,6 | 0,7 |
| Liptovská Tomanová 1. | 8 | 1,4 | 3,4 | 0,5 | 4,7 | 0,2 | 2,7 | 0,8 | 1,76 | 1,41 | 0,41 | 0,95 | 2,25 | 1,7 | 1,4 |
| Liptovská Tomanová 1. | 9 | 1,4 | 3,4 | 0,4 | 4,5 | −0,1 | 2,4 | 0,6 | 1,73 | 1,44 | 0,34 | 1,06 | 2,3 | 1,8 | 0,9 |
| Liptovská Tomanová 2. | 14 | 1,6 | 3,6 | 0,7 | 4,9 | −0,2 | 2,7 | 1,0 | 1,96 | 1,48 | 0,33 | 1,22 | 2,55 | 1,5 | 1,2 |
| Liptovská Tomanová 2. | 13 | 1,6 | 3,7 | 0,8 | 5,0 | 0,5 | 3,0 | 1,1 | 2,03 | 1,55 | 0,47 | 0,98 | 2,25 | 2,3 | 2,0 |
| Liptovská Tomanová 2. | 12 | 1,0 | 2,4 | 0,2 | 4,0 | − 0,2 | 1,8 | 0,3 | 1,2 | 1,18 | 0,68 | 1,14 | 2,1 | 1,8 | 0,3 |
| Liptovská Tomanová 2. | 11 | 1,4 | 3,2 | 0,7 | 4,2 | 0,3 | 2,1 | 1,0 | 1,76 | 1,21 | 0,51 | 1,44 | 1,95 | 1,7 | 0,4 |
| Liptovská Tomanová 2. | 10 | 1,5 | 3,3 | 0,8 | 4,2 | −0,1 | 2,2 | 1,2 | 1,86 | 1,27 | 0,37 | 1,76 | 2,15 | 1,1 | 0,6 |

Table 3

| par / sample | | Md | φ 84 | φ 16 | φ 95 | φ 5 | φ 75 | φ 25 | φ M | σφ | $Sk_I$ | $K_G$ | $So_S$ | $\alpha_S$ | $\alpha_M$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Vysoké Tatry** | | | | | | | | | | | | | | | |
| Červený úplaz | 24o b | 1,6 | 3,5 | 0,4 | 4,6 | 0,2 | 3,0 | 0,8 | 1,83 | 1,43 | 0,29 | 0,83 | 2,2 | 1,6 | 1,3 |
| Červený úplaz | 23o b | 1,8 | 3,7 | 1,1 | 4,8 | 0,8 | 3,3 | 1,4 | 2,2 | 1,25 | 0,43 | 0,83 | 2,0 | 2,0 | 2,1 |
| Červený úplaz | 21o b | 0,9 | 1,8 | 0,2 | 3,4 | −0,5 | 1,5 | 0,3 | 0,96 | 0,99 | 0,20 | 1,34 | 1,95 | 1,1 | −1,6 |
| Červený úplaz | | 1,5 | 3,4 | 0,4 | 4,5 | 0,2 | 2,3 | 1,8 | 1,76 | 1,4 | 0,33 | 3,58 | 2,15 | 1,7 | 1,2 |
| Tichá | 15o b | 1,5 | 3,4 | 0,8 | 4,6 | 0,3 | 2,6 | 1,1 | 1,9 | 1,34 | 0,45 | 1,17 | 2,15 | 1,9 | 1,4 |
| Tichá | 16o a | 1,9 | 3,7 | 1,2 | 4,8 | 0,7 | 3,2 | 1,5 | 2,36 | 1,45 | 0,45 | 0,98 | 2,05 | 1,7 | 2,0 |
| Tichá | 17o b | 1,8 | 3,2 | 1,2 | 4,1 | 0,7 | 2,4 | 1,4 | 2,06 | 1,01 | 0,37 | 1,38 | 1,7 | 1,2 | 1,3 |
| Tichá | 18o b | 1,8 | 3,8 | 0,8 | 5,0 | 0,2 | 3,4 | 1,3 | 2,13 | 1,48 | 0,33 | 0,94 | 2,4 | 1,6 | 1,7 |
| Tichá | 19o b | 1,8 | 3,4 | 1,0 | 4,3 | 0,4 | 2,7 | 1,4 | 2,06 | 1,19 | 0,30 | 1,22 | 1,95 | 1,1 | 1,2 |
| Tichá | 20o b | 1,7 | 3,6 | 1,0 | 4,9 | 0,6 | 3,0 | 1,2 | 2,1 | 1,3 | 0,47 | 0,97 | 2,15 | 2,0 | 2,0 |
| **Malé Karpaty** | | | | | | | | | | | | | | | |
| Devín | 10o | 0,8 | 2,0 | 0,1 | 3,7 | −0,7 | 1,5 | 0,3 | 0,96 | 1,14 | 0,32 | 1,5 | 2,2 | 1,4 | 1,0 |
| Devín | 11o | 1,0 | 1,8 | 0,3 | 2,9 | −0,1 | 1,5 | 0,5 | 1,03 | 0,83 | 0,17 | 1,23 | 1,5 | 0,8 | 0,8 |
| Devín | 12 | 1,1 | 1,9 | 0,4 | 3,0 | 0,0 | 1,6 | 0,6 | 1,13 | 0,83 | 0,17 | 1,23 | 1,5 | 0,8 | −0,5 |
| Devín | 13 | 1,5 | 2,8 | 0,8 | 3,8 | 0,4 | 2,1 | 1,0 | 1,7 | 1,01 | 0,33 | 1,28 | 1,7 | 1,2 | 0,7 |
| Medvedie skaly | 1 | 0,9 | 1,8 | 0,2 | 2,8 | −0,3 | 1,6 | 0,4 | 0,96 | 0,87 | 0,18 | 1,05 | 1,55 | 1,7 | 0,0 |
| Medvedie skaly | 2 | 0,6 | 1,7 | 0,3 | 3,1 | −1,1 | 1,3 | 0,1 | 0,66 | 1,13 | 0,14 | 1,43 | 2,1 | 0,8 | −0,6 |
| Medvedie skaly | 3 | 0,8 | 1,9 | 0,0 | 3,5 | −1,7 | 1,5 | 0,8 | 0,9 | 1,1 | 0,22 | 1,32 | 2,1 | 1,2 | −0,7 |
| Medvedie skaly | 4 | 1,3 | 2,2 | 0,5 | 3,8 | 0,1 | 1,8 | 0,4 | 1,33 | 0,98 | 0,16 | 1,37 | 1,85 | 1,3 | 0,4 |
| Medvedie skaly | 5 | 1,4 | 2,3 | 0,4 | 3,8 | −1,1 | 1,9 | 0,8 | 1,36 | 1,22 | −0,04 | 1,82 | 2,45 | −0,1 | −0,8 |
| Medvedie skaly | 6 | 1,1 | 2,0 | 0,2 | 3,6 | 0,3 | 1,6 | 0,5 | 1,1 | 0,95 | 0,27 | 1,13 | 1,65 | 1,7 | 0,4 |
| Medvedie skaly | 7 | 1,2 | 1,9 | 0,5 | 3,5 | 0,1 | 1,6 | 0,5 | 1,2 | 0,86 | 0,17 | 1,74 | 1,7 | 1,2 | 0,1 |
| Červený Kameň | 3o/65 | 1,2 | 2,8 | 0,3 | 4,1 | −0,6 | 2,0 | 0,7 | 1,43 | 1,34 | 0,26 | 1,29 | 2,35 | 1,1 | 0,0 |
| Červený Kameň | 4o/65 | 1,7 | 3,4 | 0,8 | 4,1 | 0,2 | 2,4 | 1,2 | 1,96 | 1,2 | 0,27 | 1,33 | 1,85 | 0,9 | 0,8 |
| Červený Kameň | 5/65 | 1,4 | 2,2 | 0,5 | 3,8 | −0,2 | 1,8 | 0,7 | 1,36 | 1,03 | 0,07 | 1,5 | 2,0 | 0,8 | 0,1 |
| Červený Kameň | 6/65 | 1,6 | 3,3 | 0,5 | 4,3 | −0,5 | 2,5 | 0,9 | 1,8 | 1,42 | 0,17 | 1,23 | 2,4 | 0,6 | 0,3 |
| Šišoretné | 42o | 1,6 | 3,5 | 0,8 | 4,9 | 0,3 | 2,6 | 1,1 | 1,96 | 1,46 | 0,42 | 1,27 | 2,3 | 2,0 | 1,7 |
| Šišoretné | 43o | 1,9 | 4,1 | 0,8 | 5,1 | 0,2 | 3,4 | 1,2 | 1,26 | 1,62 | 0,32 | 0,84 | 2,45 | 1,5 | 1,8 |
| Šišoretné | 45o | 1,2 | 3,2 | 0,2 | 4,0 | −0,5 | 2,1 | 0,5 | 1,53 | 1,43 | 0,29 | 1,16 | 2,25 | 1,1 | 0,9 |
| Šišoretné | 46o | 1,1 | 2,0 | 0,3 | 3,9 | −0,3 | 1,7 | 0,6 | 1,13 | 1,05 | 0,2 | 1,6 | 2,1 | 1,4 | 0,1 |
| Šišoretné | 47o | 1,1 | 2,0 | 0,4 | 3,7 | −0,1 | 1,6 | 0,6 | 1,16 | 0,98 | 0,22 | 1,56 | 1,9 | 1,4 | 0,1 |

for river sands. As for completness in tab. 4 are reported extreme and average values of parameters $So_s$ $\alpha_s$ and $\alpha_M$.

The diagrams were plotted in order to illustrate the correlation relationship between the pairs of textural parameters and correlation coefficients were computed as well.

Table 4

| | Vysoké Tatry | | | Malé Karpaty | | |
|---|---|---|---|---|---|---|
| value of par. | min. | max. | average | min. | max. | average |
| $So_S$ | 1,55 | 2,55 | 2,05 | 1,5 | 2,45 | 1,99 |
| $\alpha_S$ | −0,6 | +2,3 | +1,42 | −0,1 | +2,0 | +1,14 |
| $\alpha_M$ | +0,3 | +2,1 | +0,73 | −0,8 | +1,8 | +0,33 |

Correlation coefficients greater than | 0,1 | are mentioned in tab. 5 (the Vysoké Tatry quartzites) and 6 (the Malé Karpaty quartzites). According to E. C. Dahlberg and J. C. Griffiths (1967) values of correlation coefficients $r_{ij}$>| 0,1 | point at the statistically significant relationship between pairs of parameters.

Only diagrams with more significant correlation relationships of parameters are presented in this paper. The dependence of sorting coefficient on mean is significant, with decreasing M sorting is getting poorer, $r_{ij}$ = 0,44 (fig. 27 a), the Vysoké Tatry quartzites. The same relationship is for the Malé Karpaty quartzites, $r_{ij}$ = 0,52 (fig. 27 b). The dependence of M upon $Sk_I$ is less significant, $r_{ij}$ = 0,23 (fig. 28 a), the Vysoké Tatry quartzites. We can observe some tendency of increasing $Sk_I$ values with decreasing M. This relationship is evident in recent sands, the presence of fine-grained fraction causes that distribution achieves positive values of $Sk_I$. The same relationship

Table 5

| | M | $\sigma\varphi$ | $Sk_I$ | $K_G$ | $So_S$ | $\alpha_S$ | $\alpha_M$ |
|---|---|---|---|---|---|---|---|
| M | 1 | 0,44 | 0,23 | −0,30 | 0,13 | 0,20 | 0,69 |
| $\sigma\varphi$ | | 1 | — | −0,21 | 0,68 | 0,21 | 0,27 |
| $Sk_I$ | | | 1 | −0,12 | −0,36 | 0,63 | 0,63 |
| $K_G$ | | | | 1 | −0,15 | −0,19 | −0,24 |
| $So_S$ | | | | | 1 | — | −0,13 |
| $\alpha_S$ | | | | | | 1 | 0,69 |
| $\alpha_M$ | | | | | | | 1 |

Table 6

| | M | $\sigma\varphi$ | $Sk_I$ | $K_G$ | $So_S$ | $\alpha_S$ | $\alpha_M$ |
|---|---|---|---|---|---|---|---|
| M | 1 | 0,52 | 0,33 | — | 0,27 | — | 0,47 |
| $\sigma\varphi$ | | 1 | 0,42 | −0,30 | 0,86 | — | 0,57 |
| $Sk_I$ | | | 1 | −0,52 | — | 0,75 | 0,74 |
| $K_G$ | | | | 1 | — | −0,42 | −0,42 |
| $So_S$ | | | | | 1 | −0,17 | 0,15 |
| $\alpha_S$ | | | | | | 1 | 0,54 |
| $\alpha_M$ | | | | | | | 1 |

is between M and $Sk_I$ in the Malé Karpaty quartzites (fig. 28 b), $r_{ij} = 0{,}33$. With increasing M values $K_G$ values in the Vysoké Tatry quartzites increase, $r_{ij} = 0{,}33$ (fig. 29). For the Malé Karpaty quartzites there is no relationship, probably because of small number of measurements. Relationship between M and $So_S$ is of little significance for the Vysoké Tatry quartzites (fig. 30 a), $r_{ij} = 0{,}13$. In the Malé Karpaty

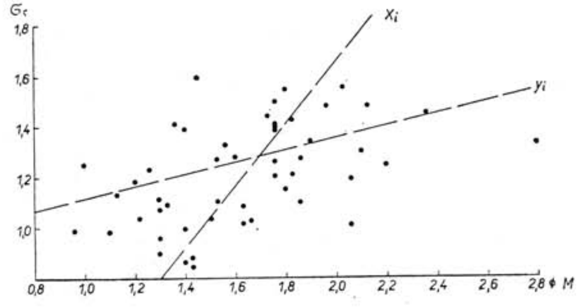


Fig. 27a.

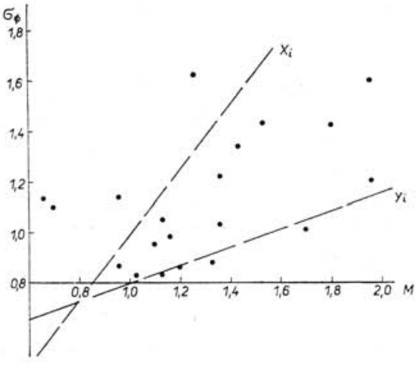


Fig. 27b. ▶

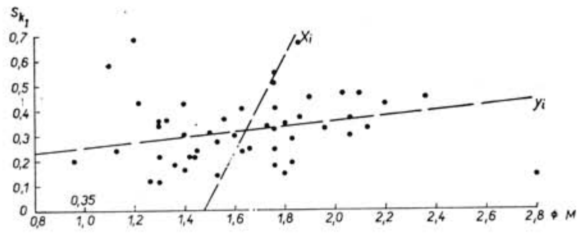


Fig. 28a.

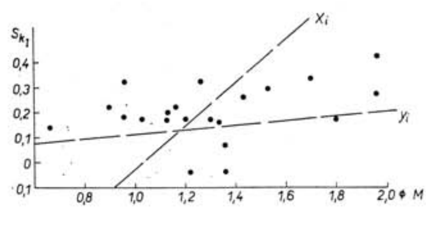


Fig. 28b. ▶

quartzites there exsist some closer relationship between M and $So_S$, $r_{ij} = 0{,}27$ (fig. 30 b). We can say that with decreasing M values $So_S$ values increase. Relationship between M and $\alpha_M$ is significant, in the Vysoké Tatry quartzites $r_{ij} = 0{,}69$ (fig. 31 a), in the Malé Karpaty quartzites $r_{ij} = 0{,}47$ (fig. 31 b). With decreasing M values of $\alpha_M$ increase, high values of M correspond with negative values of $\alpha_M$ Negative values are typical for beach sands, sometimes river sands have negative values as well.

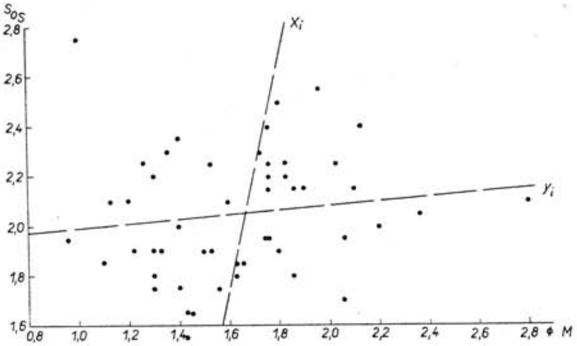


Fig. 29.

Grain-size analyses from thin-sections, the only possibility for solidified sands, show besides the subjective error of the observer also another error, which may essentially influence the values of statistic textural parameters and thereby also their interpretation. In grain-size analyses of thin-section fine fraction ≧ 0,02 mm is caught and computed. The remained fractions finer than 0,02 mm cause the innacuracy in the fine tails of distribution curves, which are very important for computing parameters $Sk_I$ and $K_G$; $So_S$, $\alpha_S$ and $\alpha_M$ as well). These parametres have the greatest genetic significance. For that reason correlation relationship have not existed yet between $Sk_I$ and $K_G$ taken from sieve- and thin-section (G. M. F r i e d m a n 1962, 1967). Also diagenetic processes, secondary overgrowths and supply of inteerstitial material affect first the fine tails of distribution. However, considering the restricted use of these parameters and

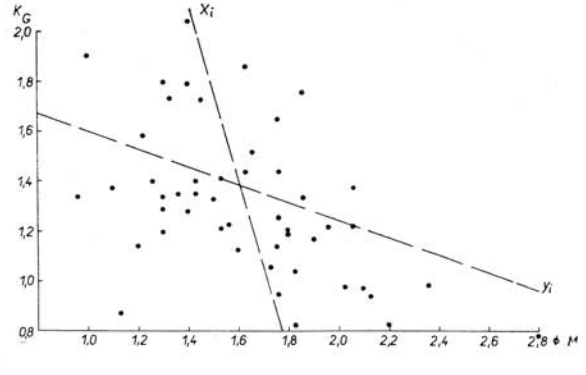


Fig. 30a.

combining with another results of geological investigations, the results from grain-size analyses yield the profit in endeavour to distinguish or to determine the sedimentary environment (J. C h a p p e l l 1967, A. J. M o s s 1962, 1963).

In the next study grain-size analyses results will be accomplished and improved by corrected parameters using the correction formulae by W. C. K r u m b e i n (1938) and B. S a h u (1965, 1967, 1968).

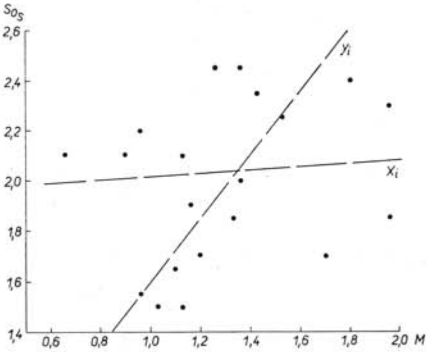


Fig. 30b.

*Conglomerate Layers in Quartzites*

Conglomerates do not appears as continuous horizon in the studied parts of the Vysoké Tatry Envelope Unit. They occur as coarse-grained beds not far from the basis of the series. Maximum pebble size is up to 10 cm, on an average they are 1—3 cm large. In most cases conglomerates have the character of pebble sandstone, or sandstone with scattered pebbles respectively (P. R o n i e w i c z 1966 — „pudding conglomerate"). Petrologic composition is as follows (M. T u r n a u - M o r a w s k a 1947, K. B o r z a 1956, P. R o n i e w i c z 1966): vein quartz, volcanic rocks (rhyolite, trachyte), lydites, graphitic schists, jasper, silicites with sponge spiculae.

Conglomerates of the Malé Karpaty Envelope Unit form more or less continuous

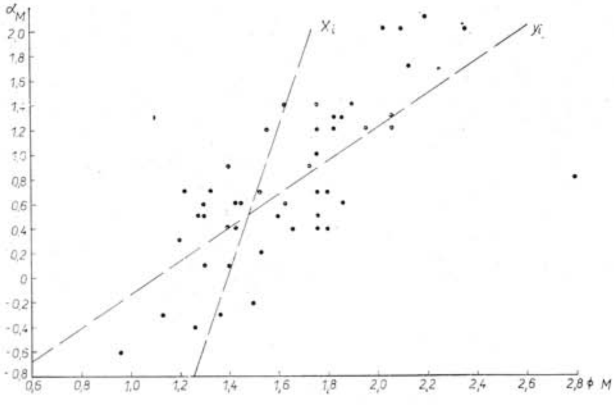


Fig. 31a.

horizon, situated not far from the basis or on the basis of quartzite beds. Pebbles are 2—4 cm large on an average, maximally 12 cm. According to personal communication of Dr. L. K a m e n i c k ý, pebbles collected in the Malé Karpaty quartzites are predominantly graphitic quartzites or metaquartzites from the low metamorphosed series, probably Carboniferous, sericitic-quartzose schists and to a great degree vein quartz.

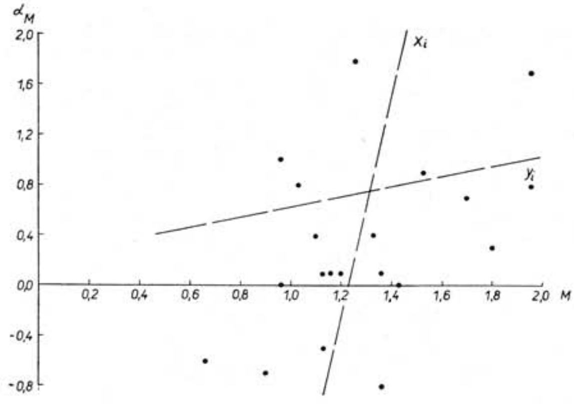


Fig. 31b.

*Structures*

Quartzites are usually bedded, sometimes it is difficult to distinguish the bedding. Within the bed quartzites are obviously laminated with laminae parallel to the bedding plane or with the cross-lamination, very seldom they are compact.

Fig. 32. Lower contact of conglomerate bed with quartzite bed. The bumps on the lower surface are pebbles coated with fine-grained quartzite „matrix". Malé Karpaty, Medvedie skaly. Foto O. F e j d i o v á.

Fig. 33. Cross-bedding. Malé Karpaty, Medvedie skaly. Foto O. F e j d i o v á.

Cross-bedding was observed partly in the outcrops, partly in the scree in great amount, so that we can say cross-bedding is a typical feature for these quartzites. As to other oriented flow structures, symmetrical ripple-marks were observed, P. R o n i e w i c z (1966) has described also desiccation structures, organic hieroglyphs, mechanoglyphs and groove casts. Also slump structures have been found in the studied areas (fig. 32—38).

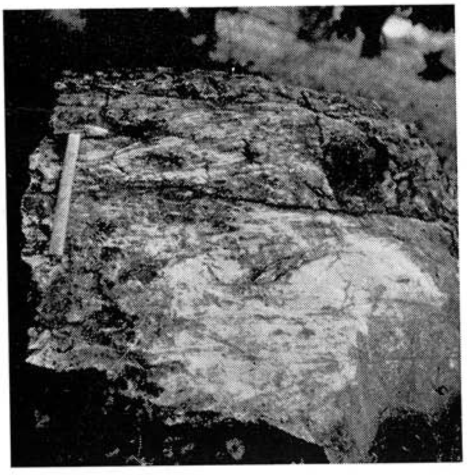

Fig. 34. Cross-bedding, the boulder in the scree, the voids of fallen out pebbles are visible. Malé Karpaty, Červený Kameň. Foto O. F e j d i o v á.

Fig. 35. Cross-bedding. Malé Karpaty, Traja jazdci. Foto O. F e j d i o v á.

Fig. 36. Cross-bedding, the section perpendicular to the c axis (ab plane), arch-like laminae are visible. Malé Karpaty, Medvedie skaly. Foto. O. F e j d i o v á.

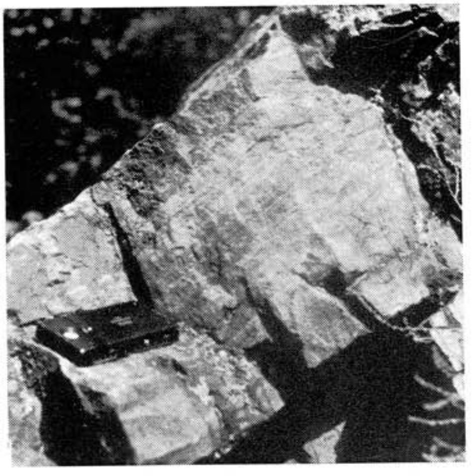

Fig. 37. Laminated quartzite. Malé Karpaty, Medvedie skaly. Foto O. F e j d i o v á.

The number of measurements of cross-bedding orientation is small owing to lack of outcrops, so that no conclusions can be drawn about the direction of currents. From the descriptive point of view cross-bedding is festoon, tangential, laminae are inclined under low angles to the bedding plane, angle of dip is 5°—45° in the Vysoké Tatry quartzites, 5°—20° in the Malé Karpaty quartzites. Thickness of cross-bedding is 10—40 cm in the Vysoké Tatry quartzites, 10—45 cm in the Malé Karpaty quartzites.

Cross-bedding of the studied quartzites indicates the origin in the unidirectional current sufficiently strong (P. E. Potter, F. J. Pettijohn 1963, R. Marschalko 1966, W. Niehoff 1958, P. Wurster 1958), which is proved by the presence of pebbles on the foresets at some localities.

Fig. 38. Slumps in the laminated quartzite. Malé Karpaty, Medvedie skaly. Foto O. Fejdiová.

### *Chemical Composition*

Chemical analyses were made from 9 samples of the Vysoké Tatry quartzites and 7 samples of the Malé Karpaty quartzites. $SiO_2$ content is 86,22 %—96,95 %. $Al_2O_3$ content is 0,78 %—5,80 %, $K_2O$ content is 0,24%—4,10 %, $Na_2O$ content is 0,04 %—0,33 %. Acrosic varieties have higher content of alkalies, $Al_2O_3$ and lower content of $SiO_2$ (e. g. see sample 34 Roh, Vysoké Tatry and sample 6 Červený Kameň, Malé Karpaty in tab. 7).

Results of chemical analyses are mentioned in tab. 7. Analyses were performed by ing. E. Walzel in the Chemical Laboratory of the Geological Institute of the Slovak Academy of Sciences.

### *Discussion of Results*

Results obtained from the grain-size analyses indicate the alternatives of Lower Triassic quartzites origin in river and beach environment as well, withouth any possibility to differentiate them exactly.

Comparing the characteristics obtained from the investigated quartzites with the characteristic features of beach and river sand (F. J. Pettijohn, P. E. Potter, R. Siever 1966) we attain the data saying about two possibilities of sedimentary environments. Studied quartzites do not contain carbonate fragments except for one

Table 7

| chem. / sample | | $SiO_2$ | $TiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | FeO | MnO | CaO | MgO | $K_2O$ | $Na_2O$ | $H_2O-$ | ign. loss | $P_2O_5$ | total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Vysoké Tatry | | | | | | | | | | | | | | | |
| Mačie diery | 5 | 94,75 | 0,04 | 1,99 | 0,23 | 1,56 | tr. | 0,11 | 0,06 | 1,04 | 0,12 | 0,11 | 0,12 | 0,03 | 100,16 |
| Okulík | 10 | 92,86 | 0,12 | 2,78 | 0,48 | 1,57 | tr. | 0,33 | 0,06 | 1,34 | 0,16 | 0,14 | 0,28 | 0,03 | 100,15 |
| Roh | 30 | 93,91 | 0,08 | 1,76 | 0,21 | 2,06 | tr. | 0,00 | 0,00 | 1,12 | 0,24 | 0,15 | 0,30 | 0,02 | 99,85 |
| Roh | 34 | 86,22 | 0,27 | 5,80 | 0,18 | 2,19 | tr. | 0,08 | 0,18 | 4,10 | 0,33 | 0,19 | 0,42 | 0,03 | 99,99 |
| Končisté | 46 | 91,60 | 0,36 | 2,78 | 0,34 | 1,26 | tr. | 0,28 | 0,20 | 1,85 | 0,25 | 0,15 | 0,75 | 0,01 | 99,83 |
| Tomanovské sedlo | 1 | 93,33 | 0,08 | 2,63 | 0,12 | 2,00 | tr. | 0,08 | 0,16 | 1,36 | 0,22 | 0,17 | 0,28 | 0,03 | 100,46 |
| Liptovská Tomanová | 1.8 | 93,39 | 0,19 | 2,26 | 0,23 | 2,00 | tr. | 0,37 | 0,02 | 1,16 | 0,23 | 0,16 | 0,24 | 0,03 | 100,28 |
| Liptovská Tomanová | 2.12 | 94,06 | 0,24 | 1,48 | 0,14 | 2,42 | 0,01 | 0,22 | 0,04 | 0,58 | 0,14 | 0,13 | 0,61 | 0,02 | 100,09 |
| Tichá | 16o | 92,23 | 0,25 | 3,02 | 0,36 | 2,20 | 0,01 | 0,14 | 0,20 | 0,94 | 0,17 | 0,17 | 0,19 | 0,03 | 99,91 |
| Malé Karpaty | | | | | | | | | | | | | | | |
| Devín | 11o | 96,95 | 0,03 | 0,78 | 0,25 | 1,71 | tr. | 0,28 | 0,00 | 0,24 | 0,04 | 0,09 | 0,00 | 0,04 | 100,41 |
| Devín | 13 | 93,95 | 0,11 | 1,87 | 0,00 | 2,56 | tr. | 0,22 | 0,24 | 0,74 | 0,22 | 0,13 | 0,12 | 0,02 | 100,18 |
| Medvedie skaly | 2o | 95,97 | 0,07 | 0,80 | 0,18 | 2,77 | tr. | 0,03 | 0,02 | 0,30 | 0,05 | 0,13 | 0,00 | 0,04 | 100,36 |
| Červený Kameň | 3o | 90,86 | 0,32 | 3,19 | 0,86 | 1,59 | tr. | 0,20 | 0,26 | 2,04 | 0,16 | 0,12 | 0,17 | 0,03 | 99,80 |
| Červený Kameň | 6 | 87,14 | 0,19 | 5,37 | 0,73 | 2,29 | tr. | 0,33 | 0,26 | 3,20 | 0,32 | 0,17 | 0,52 | 0,05 | 100,64 |
| Šišoretné | 43o | 89,84 | 0,16 | 3,83 | 0,08 | 2,41 | tr. | 0,06 | 0,22 | 2,25 | 0,25 | 0,19 | 0,22 | 0,01 | 99,52 |
| Šišoretné | 47o | 95,14 | 0,08 | 1,30 | 0,21 | 1,91 | tr. | 0,03 | 0,18 | 0,50 | 0,12 | 0,14 | 0,10 | 0,01 | 99,72 |

Table 8

| Against river origin | Against beach origin |
|---|---|
| $Sk_I$ sometimes negative | Sk mostly positive |
| Lower mineralogical maturity presence of less stabil minerals | Absence of fossiles |
| Relatively low content of fine-grained fraction | Poor sorting, matrix content up to 19,8 % |
| Values of $\alpha_S$ and $\alpha_M$ sometimes negative | Values of $\alpha_S$ and $\alpha_M$ mostly positive |
| Absence of carbonate fragments | |

sample from the Malé Karpaty (13, Devín), glauconite does not occur and feldspars are common minerals. Cement is detrital and chemical as well. In one case a claystone pebble has been found in the fine-grained quartzite (Osobitá, Vysoké Tatry). According to personal communication of dr. J. Veizer CSc the occurrence of such pebbles is common. Pebbles in the conglomerate layers are derived only from distant sources, considering their monotonous petrologic composition (mostly vein quartz). Fauna does not appear in the studied quartzites. Sorting is poor up to moderate, it is difficult to speak about roundness owing to the secondary overgrowths of quartz on quartz grains. Vertically quartzites are passing into claystones. Cross-bedding and asymmetric ripple-marks are present. Traces after action of living organisms have not been found.

Individual attributes, which speak against river origin on the one hand and against beach origin on the other hand are concentrated in tab. 8.

Presence of fine-grained fraction causes the greatest trouble in identification of the sedimentary environment. This fraction is almost always present in the river sands. Supply of fine particles from the upper part of the stream is continuous and they are transported parallelly with coarse particles. When supply of sediment exceeds the carrying power of water flow, fine particles settle. The water energy is never so low that the sedimentation of clayey and silty particles in beach environment is made possible. Sands on beaches are transported by the oscillatory movement of water (waving), which brings about sucking out of fine particles and they are settled afterward deeper in the sea (G. M. Friedman 1967). In the beach environment, when the amount of transported detrital material exceeds the energy of transport and also longshore currents take part in transportation, the sediment often contains fine-grained fraction as well. It is similar in another case, when rivers carry a great amount of fine-grained particles into near-shore environment (example from the SW coast of Louisiana, G. M. Friedman 1967), water energy is not able to carry fine particles into greater depths. Fine particles settle and beach sands therefore contain fine fraction. Thus statistical parameters of those sands fall into river sands. Such examples are common in the ancient beach sands (G. M. Friedman 1967), since sediments were settled during the period of progradation (the progress of shore line into the sea), when material supply exceeded energy of water flow as well as subsidence of basin.

Thus content of fine-grained fraction is conditioned by unidirectional water movement and by the great content of fine-grained particles able to settle. The presence of fine fraction changes the shape of cumulative frequency curve and values of statistical parameters as well (positive values $Sk_I$, $\alpha_S$, $\alpha_M$). These conditions and values characterize fluvial environment. Examples from recent sediments show, however, that they are not always of river origin. Besides that, the amount of fine-grained material is so great that it may exceed the water energy necessary for its dispersion, strong longshore currents help to distribute fine-grained material along the beach. That process results in origin of the beach sediment, which resembles river sediment. Such sediments can be found as very long stripes along the beach depending on the amount of fine-grained particle supply and on the current system, which distributes fine particles along the shore. A great influence of such a river on the beach sediments was found studying the modern river deltas. For example the Mississippi influences sediments at a distance of several 100 km from the mouth along the shore (F. P. Shepard 1964), Niger about 500 km (J. R. L. Allen 1964).

Most ancient sands and sandstones have positive values of $Sk_I$ (G. M. Friedman 1967), whereby they are evidently of marine origin. Recent beach sands have $Sk_I$ values about zero or negative ones. The difference can be caused by that way, that marine sedimentation was strongly prograding with high content of fine particles, which exceeded the water energy and subsidence of the basin, resulting in originating marine sands and sandstones respectively, with values of statistical parameters typical for river sands. Also diagenetic processes, which affected the fine particles first, influenced $Sk_I$ values that afterwards changed into positive ones. Secondary overgrowths, solution and supply of interstitial material modified the shape of distribution curve of sands. The very factor in modifying distribution curve during diagenesis is the supply of interstitial material.

The mode of transportation reflects the shape of cumulative curve. Material of beach sands is transported usually by means of saltation, while river sands are transported by sliding, saltation and in suspension as well. Cumulative curves of beach sands are usually straight, without any inflection points. Curves of river sands have three inflection points, which reflect three modes of transportation. River sands have characteristic change in slope of the curve near 3,0 $\varphi$ or in the interval 3,0 $\varphi$—4,0 $\varphi$. We cannot, however, sharply distinguish beach and river environment. Cumulative curves have tendency to be straight, marked changes of slope can be observed on samples from the eastern part of the Vysoké Tatry Envelope Unit only. Individual cumulative curves change their slope in the interval 2,0 $\varphi$—4,0 $\varphi$, especially between 2,0 $\varphi$ and 3,0 $\varphi$. However, not even this feature helps to distinguish the sedimentary environments because of above mentioned inaccuracies in the shape of cumulative curves from thin-section.

Another factor, complicating the differentiation of environments is high mineralogic maturity and simultaneous textural immaturity of quartzites. They have relatively monomineralic composition and association of maximally stable heavy minerals. They also contain some unstable components as feldspars, micas and matrix. Deltaic sediments of some, especially long and large recent rivers are of high mineralogic maturity, for example deltaic sediments of the Danube (N. Panin, St. Panin 1967) include sands predominantly composed of quartz grains, less represented are heavy minerals and shell fragments. Also sands from the Mississippi delta (F. P. Shepard 1964) are mineralogically mature. When material is transported in the river at a long distance, fine-grained and mineralogically mature quartz sands are formed. These differ from beach sands in textural immaturity since they contain a great amount of fine particles. Longshore currents disperse texturally immature and mineralogically mature river sands along the shore, where they settle. The presence of unstable minerals in the beach sands can also be caused by the supply of material from near-by sources in smaller and shorter rivers or during the floods. Coarse-grained fraction and conglomerate layers occur in river as well as beach sands.

## *Conclusions*

Quartzites are chiefly composed of quartz. The individual quartz grains enable to identify the kind of rocks which they come from. From the correlation relationships between the contents of quartz grains types and mean follows:

1. Most of cataclastic grains originally belonged to the other types of quartz grains as unimportant correlation may show. The cataclastic character has been acquired during the commencement of metamorphosis of quartzite.

2. Significant correlation relationship between the content of vein quartz, oriented mosaic, feldspars and matrix, and mean show that the coarser is the quartzite, the lower is the content of vein quartz, oriented mosaic and matrix, and the higher is feldspar content.

According to the mineral composition quartzites belong to sandstone quartzites in the sense of Kukal's (1957) classification. Only several samples (see tab. 1) are exceptions, since their feldspar content is higher then 10 %, which is admissible limit for quartzites. These quartzites can be considered as arcosic varieties.

According to the results of grain-size analyses quartzites are fine- up to medium-grained, moderately up to poorly sorted. Values of $Sk_I$, $\alpha_S$ and $\alpha_M$ are positive, sometimes negative as well. From the correlation relationship between individual parameters follows:

1. With finer-grained quartzite the sorting is poorer.

2. With finer-grained quartzite $Sk_I$ values are getting more positive.

It is not possible to define and characterize the source area yet, by help of results achieved till now. Quartzites are sediments with high mineralogic maturity, 90 % and more composed of quartz grains, which cannot characterize the source are. We can only roughly characterize it according to types of quartz grains. The association of heavy minerals (zircon — rutile — tourmaline) is stable, present in clastic sediments of any origin and age. These minerals can persist prolonged and repeated transport and therefore their source area can be quite different from the source area of other mineral components. Accesory biotite and muscovite can be of secondary origin, formed as a consequence of strong diagenesis and commencing metamorphosis of sediment (A. G. Kossovskaja, V. D. Šutov 1958).

Directional flow structures (cross-bedding, ripple-marks) can say very much about the situation of source area. Due to lacking outcrops and the insufficient number of measurement this possibility is not applicable. According to the conclusions of P. Roniewicz (1966) the direction of transport was from N towards S. He deduced from lack of erosive channels and from the predominance of symmetric ripple-marks that sedimentation has taken place in the shallow-water environment in stagnant water. According to the indirect proof he supposed shallow-marine origin of the Lower Triassic quartzites.

Detrital material was transported from the source area on the N of the Carpathian mountain arch by the long and large river or rivers into the near-shore environment. Prolonged transport results in the mineralogic maturity of sediment. Owing to the action of longshore currents, transporting material along the shore and simultaneous waving, the sediment was formed, which has high mineralogic maturity due to prolonged transport and washing on the beach, and low textural maturity (poor sorting) influenced by the river, chiefly supplying fine-grained material into relatively well sorted beach sediment. So far it is not possible to locate the river and its entry into the sea. May-be the study the Lower Triassic quartzites of the whole West Carpathian region will enable to solve this problem. This paper is only the first attempt in investigation of West Carpathian quartzites and therefore it may be incomplete in several aspects. Continuing work on this topic will bring further facts and improve many data.

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