*Mineralia Slovaca, 33 (2001), 473–486*

# Jurassic heavy mineral distribution provinces in the Western Carpathians

ROMAN AUBRECHT

Department of Geology and Paleontology, Faculty of Natural Sciences, Comenius University,
Mlynská dolina G, 842 15 Bratislava, Slovak Republic
Aubrecht@nic.fns.uniba.sk

*(Received August 6, 2001)*

**Abstract**

More than 100 samples from all important tectonic units of the Western Carpathians have been analysed for heavy minerals. The aim was the comparison of heavy mineral spectra with paleogeographic consequences. This paper provides the first report about the percentual proportions in the heavy minerals in the individual units and the conclusions resulting from them. Two main Jurassic heavy-mineral provinces were distinguished in the Western Carpathians: The first one: G-Z-R-T (garnet, zircon, rutile, tourmaline) is typical for most of the Pieniny Klippen Belt units and is probably related to Gresten Zone and autochthonous Jurassic cover of the Bohemian Massif margins. The second assemblage, T-Z-R (tourmaline, zircon and rutile), is typical for Central and Inner Western Carpathian units. This assemblage was impoverished due to resedimentation from older sediments and due to intrastratal dissolution. The assemblage is tourmaline-dominated; the major portion of tourmaline came most likely from low-grade metamorphics which are now not present in the crystalline basement (except Gemericum), whereas most of zircon and rutile came from older sediments. Borinka unit and Tatric units from Malé Karpaty Mts., which are dominated by tourmaline and apatite have similar heavy mineral spectra to Nordrahmenzone of the Eastern Alps which has similar proposed paleogeographic position as does Borinka unit. The only difference is in provenance of part of tourmaline. Among the Pieniny Klippen Belt units, Drietoma and Haligovce units have clear affinity to Central Western Carpathians. On the basis of some index heavy minerals it is likely that source of Nedzov nappe clastics (containing considerable amount of staurolite) was Tatric-Veporic type of crystalline complexes. Various bluish amphiboles and some bluish varieties of tourmaline in Silicic Jurassic came most likely from Gemericum. An overall lack of chromium spinels indicates that no larger obduction of ophiolites occurred in the Western Carpathian units during Jurassic.

**Key words:** Western Carpathians, Jurassic, heavy minerals, paleogeography

## Introduction

The aim of investigation of detrital admixture, namely the heavy minerals of Western Carpathian Jurassic, is to contribute to overview on Western Carpathian paleogeography and plate movement in the time of pre-rift to syn-rift period of the Vahic (Penninic) Ocean on the north and simultaneous convergence to collision period of the Meliata ocean on the south of the future Western Carpathian domain. Heavy mineral study is a tool of paleogeographic research that complements facial and paleobiogeographic research. In some aspects, its results may be even more valuable than those of the latter methods. On the other hand, there are also problems which reduce its power. In the Western Carpathians there is a problem of reduction of variability of heavy mineral assemblages due to intrastratal dissolution. Correlation of such assemblages is, therefore, very difficult and requires application of variation analysis (Morton, 1985). The results of heavy mineral study provide information on provenance of some index minerals, as well as similarities or differences between the individual samples, sampling sites and paleogeographic units.

The aim of this paper is to provide a relatively brief overview of the percentual proportions of heavy mineral assemblages in the Western Carpathian Jurassic and to distinguish the main provinces of their distribution. Variation analysis, e. g. microprobe data of garnet, tourmaline and amphibole, crystal typology of zircon etc., together with statistic analysis is beyond the scope of this paper as they would nearly double its length. Some of the results of variation analysis have been published earlier (see the following chapter); for still unpublished variation analysis and preliminary statistics the reader is referred to the author's habilitation thesis (Aubrecht, 1999).

More than 100 samples have been analysed from all important tectonic units of the Western Carpathians: Pienidic units, Manín, Drietoma, Klape and Kostelec units of the Pieniny Klippen Belt, Tatric, Fatric and Hronic units of the Central Western Carpathians, Silicic and Meliatic units of the Inner Western Carpathians. However, more than one third of the samples was negative.

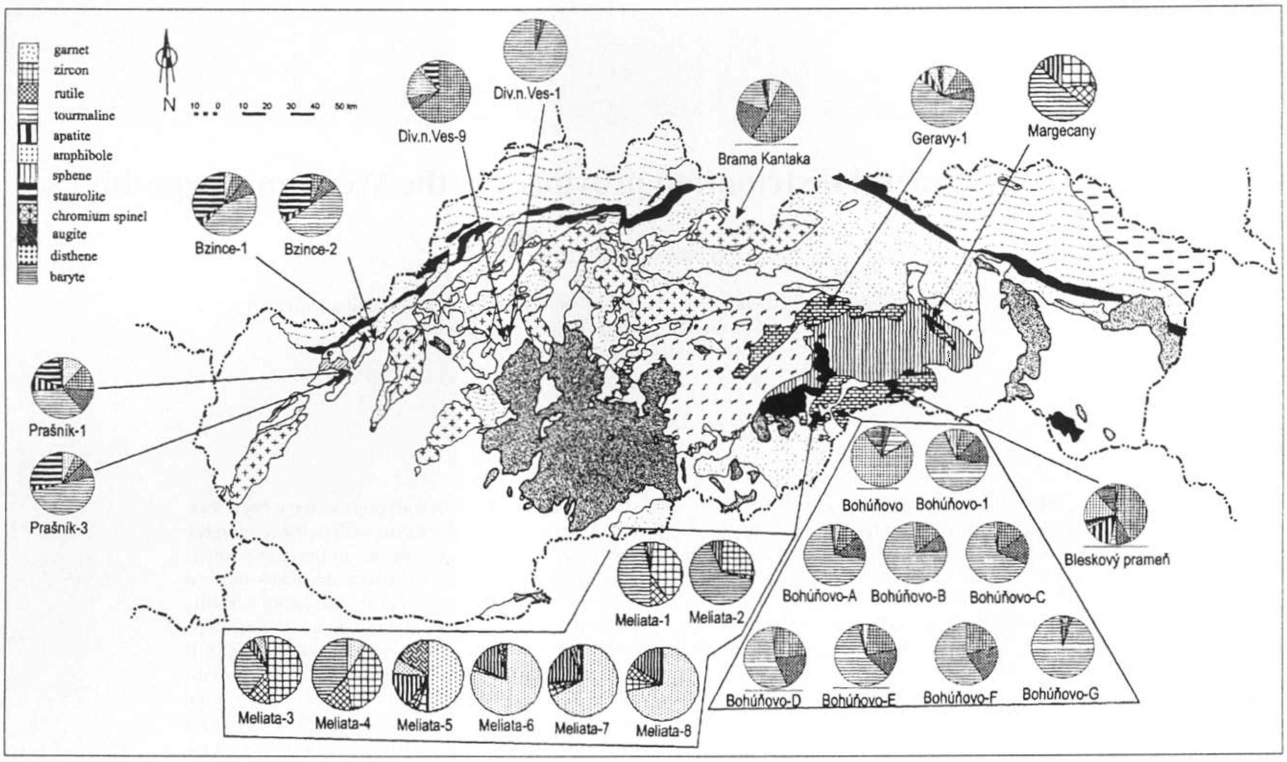


**Fig. 1.** Location of the sampled sites of the Inner Western Carpathians, transitional units related to them and diagrams of their heavy mineral proportions.

Those were the samples mainly from Hronicum and Silicicum. The reason was a general lack of siliciclastic admixture in the mentioned units, resulting from their different position in Jurassic paleogeography, if compared to Tatric and Fatric units, or units of the Pieniny Klippen Belt. The investigations are still in progress and the results presented here are considered still as preliminary. New, complementary data, together with variation analysis of various minerals and statistics will be published later.

## Previous heavy mineral studies of the Western Carpathian Jurassic sediments

Heavy minerals of Jurassic sediments of the Pieniny Klippen Belt were earlier treated by Łoziński (1956, 1957, 1959, 1966) and Halajová (1981). Łoziński (l. c.) dealt above all with heavy minerals from the Aalenian flysch (Szlachtowa Formation); Halajová (l. c.) in her MSc. Thesis dealt with heavy minerals from selected sites of Middle Jurassic crinoidal limestones of Czorsztyn unit and from some occurrences of Liassic sediments of Manín, Klape and Kostelec units of the Pieniny Klippen Belt. Aubrecht (1993) published new results from the Middle Jurassic crinoidal limestones of Czorsztyn unit and later (Aubrecht, 1994) also from the Liassic sediments of Borinka unit and Tatric units of the Malé Karpaty Mts. Provenance analysis of detrital tourmaline from the Malé Karpaty Mts. was analysed by Aubrecht and Krištín (1995). Provenance interpretation of detrital garnet from the Pieniny Klippen Belt units was published by Aubrecht and Méres (2000). The results presented in this paper are part of the data presented in author's unpublished theses (Aubrecht, 1994a, 1999).

## Methods of research

After field sampling of Jurassic sediments containing siliciclastic admixture they were treated by laboratory methods depending on their lithology. Sandy limestones were dissolved in diluted acetic acid. Sandstones and sandy shales were crushed, then pulverized. Subsequently, the fraction between 0.08 and 0.71 mm was separated by sieving. Smaller grains were washed out as they difficult to be determined by optical methods. The remaining fraction underwent separation in heavy liquids (bromoform, density cca 2.8). The fraction 0.08–0.25 mm was studied in transmitting light, the whole fraction was examined also by binocular lense. Percentual ratios of the heavy mineral assemblages were determined by ribbon point counting. The opaque minerals in all samples were invariably strongly dominated by limonite and pyrite, that are insignificant from the point of view of clastic provenance. Therefore, the results presented in this paper are exclusively from translucent or semiopaque (e. g. chromium spinels) heavy minerals. To remove the inessential limonite, some samples had to be boiled in hydrochloric acid. In such cases, apatite grains were omitted because their number was largely decreased by dissolution which would influence the resulting heavy mineral ratio. Selected minerals underwent variation analysis, either geochemical or typomorphic. Its results will be published later.

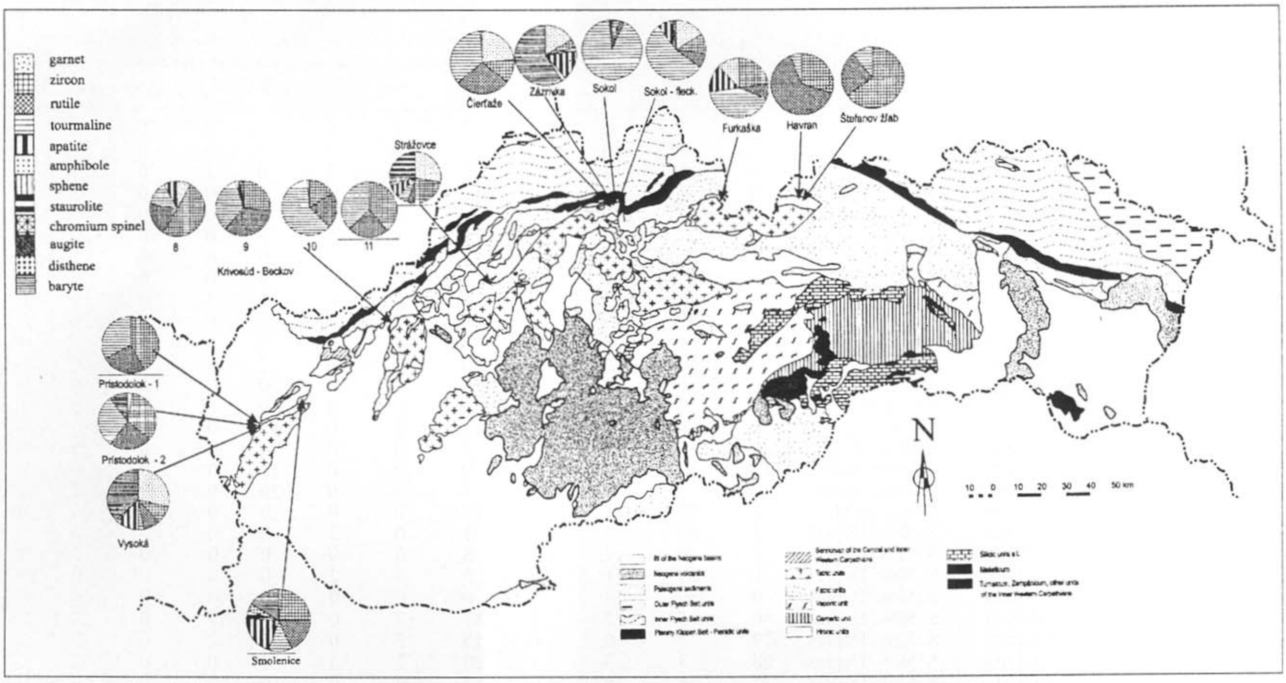


Fig. 2. Location of the sampled sites of Fatricum and diagrams of their heavy mineral proportions.

## Percentages of heavy minerals in the units of the Central and Inner Western Carpathians

### Meliaticum

The data on heavy minerals from Meliata unit were published by Mock et al. (1999). Ten positive samples were analysed from the Meliatic siliciclastic rocks of Middle to Upper Jurassic age (Liassic rocks of Meliaticum have not been found with certainity yet). The samples (sandy to silty greenish siliceous shales to sandstones) came from the Meliata area but also from the large quarry near Margecany and from the Florianikogel, the first Meliatic locality discovered in Austria (Mandl and Ondrejičková, 1992).

The data of the translucent heavy mineral grains are grouped by their composition into two different groups. The first group includes the sandstone and quartzite samples of uncertain stratigraphic position within the Meliatic unit. The uncertainty was caused by the complex geological structure resulting from subduction and collision tectonics that generally makes it difficult to distinguish between normal beds and olistoliths of tectonicly involved blocks. This group is characterized by the presence of the assemblage of tourmaline, zircon and rutile, which is the most resistant group of heavy minerals. It indicates that either its source were some older siliciclastic rocks, or it originated after deposition by an intrastratal dissolution of less stable minerals. Such assemblage is typical for the Jurassic sediments all around the Central and Inner Western Carpathians. The second group is represented by the siltstone samples, coming from the greenish noncalcareous claystones and by the sandstone sample from Florianikogel locality. This group contains mainly garnet and abundant apatite, barite (likely authigenic), sparse chromium-spinel grains are also present.

### Silicicum s. l.

From Silicicum s. l. more than 20 Liassic samples were taken but only 12 were positive. The rest was free of siliciclastic admixture coarser than fine silt, i. e. they were not suitable for optical determination. The positive samples came mostly from Bohúňovo (Rhetian and Liassic of Silica nappe); one positive sample came from Bleskový prameň locality (Toarcian-Aalenian of Silica nappe) and one from Geravy Plateau (Liassic of Stratená nappe). Lithologically they represented marly sandy to silty limestones. Samples from Bleskový prameň, Miglinc valley (both Silica nappe) and from Tesná skala syncline (Muráň nappe) were so far negative. The high number of negative samples reflects an overall lack of siliciclastic admixture in Silicic and Hronic (see following chapters) units. These units are much poorer in siliciclastic admixture than for example Tatric or Fatric units. It is probably related to different geotectonic position of these units. The northern, Tatric and Fatric units were influenced by rifting of the Ligurian-Penninic-Vahic ocean, the southern (Meliatic and Silicic) units were located near the convergence zone of closing Meliata ocean, or they occurred in relatively neutral zone between these oceans (Hronicum).

The Bohúňovo samples show that the predominant assemblage is the most stable one, dominated by tourmaline, zircon and rutile. It is again a poor assemblage, resulting either from intrastratal dissolution or multiple resedimentation of the detrital material. The new results show that the heavy mineral assemblages are very similar to those from the Central Western Carpathians, mainly

Tab. 1
Percentual proportions of translucent detrital heavy minerals of Liassic sediments from the Central and Inner Western Carpathians

| Locality | Unit | Mountains | Gr | Zr | Ru | Tu | Ap | Am | Ti | St | Sp | Aug | Dis | B. A. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bohúňovo | Silicic | Slov. Karst | 0 | 1 | 5 | 12 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 80 |
| Bohúňovo-1 | Silicic | Slov. Karst | 2 | 9 | 16 | 65 | 1 | 0 | 6 | 0 | 0 | 0 | 0 | 0 |
| Bohúňovo-A | Silicic | Slov. Karst | 3 | 11 | 13 | 70 | 2 | 0 | 1 | 0 | 1 | 0 | 0 | 0 |
| Bohúňovo-B | Silicic | Slov. Karst | 0 | 16 | 9 | 75 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| Bohúňovo-C | Silicic | Slov. Karst | 1 | 14 | 16 | 65 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| Bohúňovo-D | Silicic | Slov. Karst | 0 | 23 | 20 | 55 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| Bohúňovo-E | Silicic | Slov. Karst | 2 | 20 | 15 | 59 | 1 | 1 | 2 | 0 | 0 | 0 | 0 | 0 |
| Bohúňovo-F | Silicic | Slov. Karst | 0 | 21 | 19 | 59 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bohúňovo-G | Silicic | Slov. Karst | 0 | 3 | 2 | 94 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Bleskový prameň | Silicic | Slov. Karst | 1 | 47 | 9 | 3 | 16 | 2 | 1 | 0 | 0 | 3 | 0 | 19 |
| Geravy 1 | Silicic s. l. | Muráň plat. | 9 | 12 | 7 | 58 | 6 | 5 | 0 | 0 | 3 | 0 | 0 | 1 |
| Diviacka n. Ves.-9 | Hronic | Stráž. vrchy | 0 | 60 | 6 | 9 | 15 | 0 | 0 | 2 | 9 | 0 | 0 | 0 |
| Diviacka n. Ves-1 | Hronic | Stráž. vrchy | 0 | 3 | 2 | 95 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Brama Kantaka | Hronic | Západné Tatry | 7 | 52 | 21 | 17 | 2 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| Bzince p. Javorinou-1 | Hronic | Čachtic. Karp. | 1 | 6 | 8 | 50 | 4 | 0 | 0 | 31 | 0 | 0 | 0 | 0 |
| Bzince p. Javorinou-2 | Hronic | Čachtic. Karp. | 4 | 7 | 8 | 43 | 3 | 0 | 0 | 34 | 0 | 0 | 0 | 0 |
| Prašník-1 | Hronic ? | Čachtic. Karp. | 12 | 14 | 13 | 35 | 9 | 0 | 0 | 17 | 0 | 0 | 0 | 0 |
| Prašník-3 | Hronic ? | Čachtic. Karp. | 7 | 5 | 9 | 49 | 3 | 0 | 0 | 26 | 0 | 0 | 0 | 0 |
| Margecany | Meliata | Slov. Ore Mts. | 1 | 23 | 11 | 53 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Meliata 1 | Meliata | S. Slov. Depres. | 2 | 39 | 9 | 47 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| Meliata 2 | Meliata | S. Slov. Depres. | 1 | 26 | 2 | 65 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Meliata 3 | Meliata | S. Slov. Depres. | 0 | 49 | 11 | 28 | 5 | 5 | 2 | 0 | 0 | 0 | 0 | 0 |
| Meliata 4 | Meliata | S. Slov. Depres. | 9 | 39 | 14 | 38 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Meliata 5 | Meliata | S. Slov. Depres. | 50 | 5 | 2 | 2 | 17 | 7 | 0 | 0 | 17 | 0 | 0 | 0 |
| Meliata 6 | Meliata | S. Slov. Depres. | 79 | 2 | 0 | 0 | 15 | 2 | 0 | 0 | 2 | 0 | 0 | 0 |
| Meliata 7 | Meliata | S. Slov. Depres. | 68 | 3 | 3 | 1 | 20 | 2 | 3 | 0 | 0 | 0 | 2 | 0 |
| Meliata 8 | Meliata | S. Slov. Depres. | 72 | 6 | 6 | 0 | 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Florianikogel | Meliata | E. Alps | 35 | 13 | 6 | 7 | 36 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| Havran | Fatric | Belanské Tatry | 0 | 31 | 64 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Štefanov žľab | Fatric | Belanské Tatry | 0 | 66 | 24 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Furkaška | Fatric | Vysoké Tatry | 0 | 23 | 8 | 42 | 15 | 12 | 0 | 0 | 0 | 0 | 0 | 0 |
| Strážovce | Fatric | Strážov. vrchy | 37 | 30 | 6 | 9 | 10 | 2 | 5 | 0 | 0 | 0 | 0 | 0 |
| Vysoká | Fatric | Malé Karpaty | 46 | 15 | 13 | 4 | 20 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| Smolenice | Fatric | Malé Karpaty | 2 | 28 | 21 | 15 | 26 | 0 | 0 | 4 | 0 | 0 | 4 | 0 |
| Prístodolok-1 | Fatric | Malé Karpaty | 3 | 36 | 26 | 34 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Prístodolok-2 | Fatric | Malé Karpaty | 0 | 43 | 25 | 33 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Čerťaže | Fatric | Malá Fatra | 13 | 14 | 32 | 40 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sokol-fleckenmerg. | Fatric | Malá Fatra | 17 | 12 | 8 | 55 | 7 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Sokol | Fatric | Malá Fatra | 0 | 4 | 3 | 91 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Zázrivka | Fatric | Malá Fatra | 39 | 13 | 0 | 4 | 39 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| Krivosúd-Beckov-8 | Fatric | Považ. Inovec | 8 | 51 | 19 | 14 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Krivosúd-Beckov-9 | Fatric | Považ. Inovec | 0 | 26 | 35 | 34 | 2 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| Krivosúd-Beckov-10 | Fatric | Považ. Inovec | 0 | 18 | 20 | 60 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Krivosúd-Beckov-11 | Fatric | Považ. Inovec | 0 | 39 | 24 | 37 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Brložnica | Tatric | Veľká Fatra | 9 | 27 | 24 | 37 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| Veľký Šiprúň | Tatric | Veľká Fatra | 12 | 25 | 10 | 49 | 3 | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| Belanská dolina | Tatric | Veľká Fatra | 3 | 31 | 10 | 49 | 4 | 0 | 3 | 0 | 0 | 0 | 0 | 0 |
| Malý Šiprúň | Tatric | Veľká Fatra | 12 | 22 | 19 | 43 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| Kominy Tylkowe | Tatric | Vysoké Tatry | 0 | 28 | 11 | 56 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Osobitá | Tatric | ZápadnéTatry | 0 | 45 | 15 | 34 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Kunerad | Tatric | Malá Fatra | 0 | 47 | 28 | 25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WNW of Dúbravina | Tatric | Malá Fatra | 0 | 50 | 32 | 18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| W of Dúbravina | Tatric | Malá Fatra | 0 | 40 | 40 | 19 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Bralo | Tatric | Malá Fatra | 6 | 11 | 0 | 37 | 37 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Žibrica | Tatric | Tribeč | 0 | 41 | 25 | 17 | 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Žibrica-2 | Tatric | Tribeč | 0 | 30 | 20 | 33 | 2 | 11 | 0 | 0 | 5 | 0 | 0 | 0 |
| Ladice | Tatric | Tribeč | 1 | 24 | 20 | 53 | 3 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| Donovaly | Tatric | Nízke Tatry | 3 | 42 | 16 | 24 | 13 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| Donovaly 1 | Tatric | Nízke Tatry | 4 | 35 | 39 | 16 | 3 | 0 | 2 | 0 | 2 | 0 | 0 | 0 |
| Humienec-olist. | Tatric | Považ. Inovec | 0 | 27 | 9 | 21 | 42 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| Hranty-olist. | Tatric | Považ. Inovec | 1 | 49 | 11 | 27 | 11 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| Nová Lehota | Tatric | Považ. Inovec | 4 | 29 | 16 | 23 | 29 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Ostrý vrch | Tatric | Malé Karpaty | 3 | 23 | 14 | 12 | 48 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| S of Zabité | Tatric | Malé Karpaty | 2 | 31 | 14 | 26 | 28 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Hrubé Vápenné | Tatric | Malé Karpaty | 0 | 45 | 19 | 26 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Kadlubek | Tatric | Malé Karpaty | 0 | 4 | 8 | 44 | 44 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Zrkadlisko | Tatric | Malé Karpaty | 12 | 10 | 7 | 2 | 67 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| Medené Hámre | Borinka U. | Malé Karpaty | 0 | 18 | 9 | 46 | 26 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Somár | Borinka U. | Malé Karpaty | 1 | 37 | 5 | 28 | 28 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Pajštún | Borinka U. | Malé Karpaty | 4 | 41 | 5 | 20 | 29 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Borehole MKZ 233m | Borinka U. | Malé Karpaty | 3 | 12 | 3 | 39 | 44 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Borehole MKZ 197m | Borinka U. | Malé Karpaty | 2 | 7 | 2 | 28 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Marianka | Borinka U. | Malé Karpaty | 0 | 36 | 10 | 31 | 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Explanations: Gr – garnet, Zr – zircon, Ru – rutile, Tu – tourmaline, Ap – apatite, Am – amphibole, Ti – sphene, St – staurolite, Sp – chromium spinels, Aug – augite, Dis – kyanite, B. A. – bluish amphibole

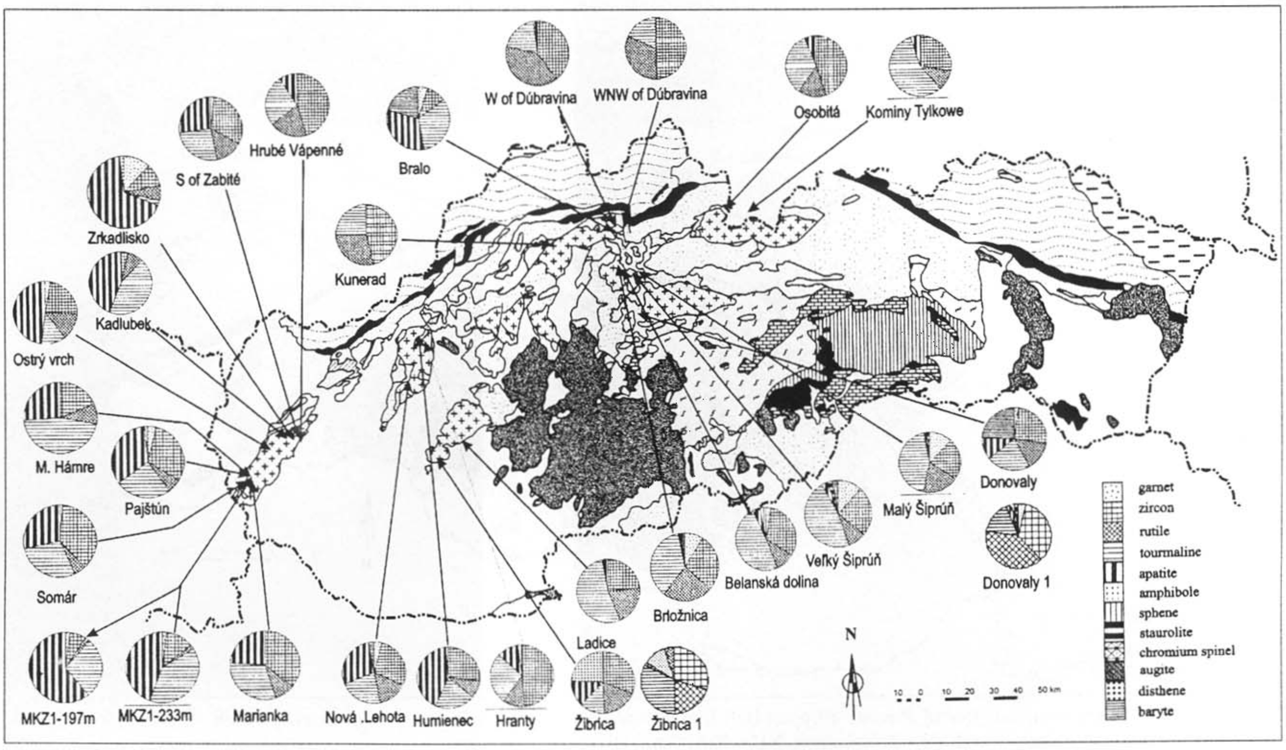


**Fig. 3.** Location of the sampled sites of Tatricum and diagrams of their heavy mineral proportions.

from Tatric units (Aubrecht, 1994). Predominance of tourmaline in most samples can be explained by the Gemeric source but the same is noteworthy in Tatricum (Aubrecht and Krištín, 1995, see separate chapter) as the Tatric and Veporic crystalline complexes lack considerable amounts of tourmaline. In some samples, bluish amphiboles were found at Bohúňovo and single grains were found also at Geravy locality. Their composition corresponds to Al-Fe-Mg-hornblende (N+K<0.5) to Al-edenite (Na+K≥0.5) with structural formula $NaCaFeMg_3AlSi_7AlO_{22}(OH)_2$ (Aubrecht, 1999). Similar bluish amphibole was described from some paleobasalt occurrences in Rakovec Group of Gemericum (Hovorka et al., 1988) and from amphibolite near Rudňany (Faryad, 1995, p. 11).

## Nedzov nappe

Nedzov nappe represents a transitional unit between Silicic and Hronic units (Mello in Salaj et al., 1987). Altogether, 8 samples (4 positive samples) were taken from Liassic crinoidal limestones from the vicinity of Bzince pod Javorinou and Prašník villages in Čachtické Karpaty Mts. The samples are characterized by special heavy mineral assemblages. Along with dominant stable tourmaline also much less stable staurolite and eventualy garnet (mostly almandinic – Aubrecht and Méres, 2000) are abundant. This assemblage is conspicuous by its dominance of staurolite over the garnet, since the Western Carpathian crystalline complexes (possible source areas) are strongly dominated by garnet which is also more resistant to intrastratal solution than staurolite. This infers to atypical composition of source rocks. They were most probably medium-grade metamorphics, i. e. their source area was not Gemericum but rather some sort of crystalline complexes closer to Tatricum or Veporicum. Predominance of tourmaline, together with presence of relatively unstable staurolite and garnet show that primary enrichment in tourmaline was through resedimentation from older rocks and not through intrastratal dissolution in sediment.

## Hronic units (Choč nappe)

Liassic of the Choč nappe (Hronicum) is mostly represented by crinoidal limestones, from which 12 samples were taken from the following sites: Brama Kantaka (Polish part of Tatra Mts., 1 positive sample), Rohatá skala (Strážovské vrchy Mts., no positive sample), Diviacka Nová Ves (2 positive samples).

The heavy mineral assemblages are variable. In one sample (DNV-1), turmaline occurs almost exclusively, with lesser amounts of zircon and rutile. In other samples there is predominance of zircon, with lesser amount of rutile, tourmaline and apatite, eventually garnet. Rare chromium spinels were found also. The first sample, dominated by tourmaline, is close to other samples from Central and Inner Western Carpathians whereas the two remaining ones are also depleted but they are dominated by zircon and contain also some unstable minerals.

## Fatric units

From the Krížna nappe and its equivalents, coming from the Fatric sedimentary area,16 positive samples were analysed. They were represented by sandy shales to

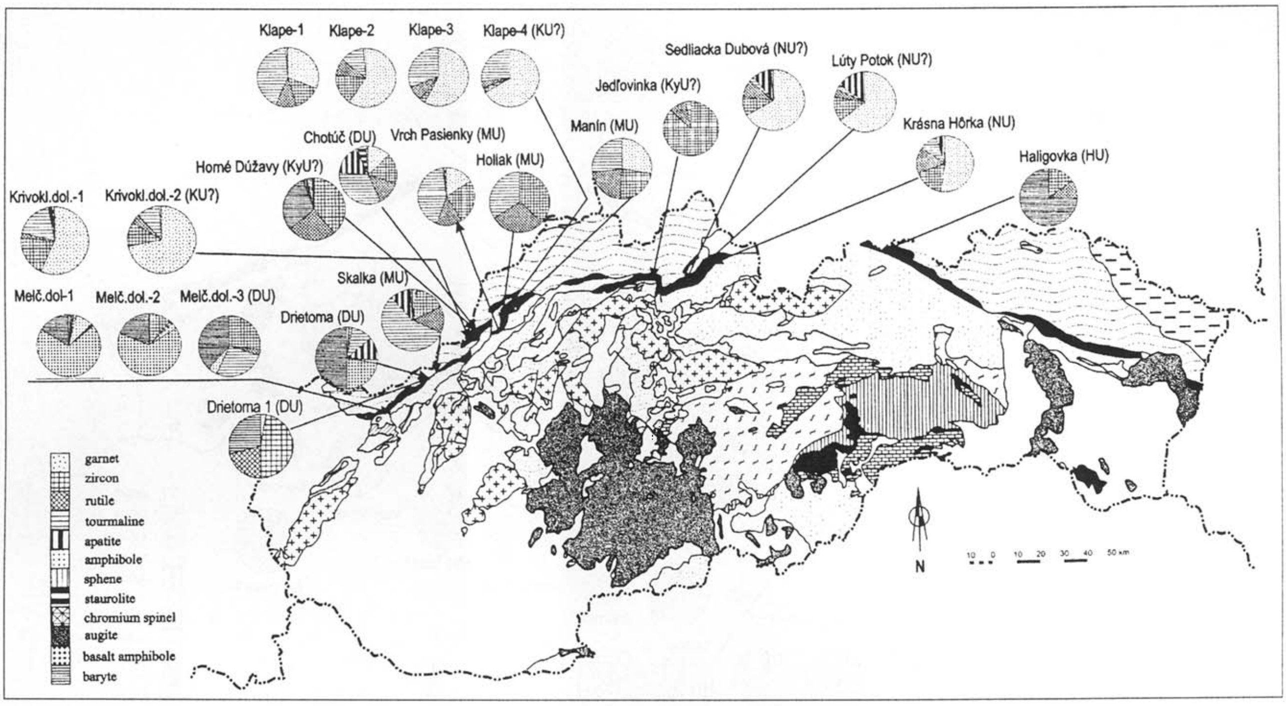


**Fig. 4.** Location of the sampled sites of Pieniny Klippen Belt Liassic and diagrams of their heavy mineral proportions. DU = Drietoma unit, MU = Manín unit, KU = Klape unit, KyU = Kysuca unit, NU = Nižná unit, HU = Haligovce unit.

sandstones of Kopienec Formation and Pisana Quartzite (Hettangian-Sinemurian, Zliechov and Havran developments) and sandy crinoidal limestones (Pliensbachian of Vysoká development, Malé Karpaty Mts.). The samples (mostly crinoidal limestones) taken from Veľký Bok unit (Low Tatra Mts.), which is considered to be the rear, near-suture unit coming from Fatric domain, were entirely sterile, free of siliciclastic admixture.

The results indicate that there are several heavy mineral assemblages in the Fatric units, likely coming from different sources. Different assemblages can be found also by point sampling but also within the sampled profiles (Malá Fatra Mts., Malé Karpaty Mts.). There are two mean assemblages. The first one is characterized by garnet-apatite-zircon, locally with significant amount of authigenic barite (not counted). The second assemblage is represented by the stable zircon-rutile-tourmaline±apatite assemblage. The ratios between the individual minerals are variable. Occurrence of both assemblages in some profiles indicates that the second assemblage most probably did not originate from the first one by intrastratal dissolution. For instance, garnet present in the first assemblage is strongly corroded but never lacks completely. More probable is a hypothesis of mixing of two different sources (e. g. Tatric and Veporic) in the Fatric Basin.

## Tatric and Penninic (?) units

Tatricum and the units assigned to belong to Penninic margin (e. g. Borinka and Belice units), as the northernmost units of the Central Western Carpathians, are the key areas for reconstruction of the relationship between the Central and Outer Western Carpathian units. The Liassic sediments of Tatricum contain considerable amounts of siliciclastic admixture. Heavy minerals of these units, coming from Malé Karpaty Mts. were treated for the first time by Aubrecht (1994). These data were later complemented by yet unpublished samples from Malá Fatra Mts., Veľká Fatra Mts., Tribeč Mts., Low Tatra Mts., High Tatra Mts. and Považský Inovec Mts. The final number of samples was 27. Almost all the assemblages are dominated by ultrastable trinity of tourmaline, zircon and rutile. There are some striking facts: the lack of garnet and dominance of tourmaline which is very rare in the Central Western Carpathian crystalline complexes. There were also some anomalies, e. g. in the samples from Malé Karpaty and Považský Inovec Mts. and in some other mountains, apatite is significant or even dominant over the mentioned ultrastable trinity. Relatively increased portion of garnet (max. 12 %) and some other unstable minerals in Veľká Fatra Mts. is also anomalous. Apart from these anomalies it is clear that all the samples represent relatively uniform heavy mineral assemblage of the ultrastable trinity (T-Z-R), which dominates the whole Central and Inner Western Carpathians. It originated probably by intrastratal solution during diagenesis to anchimetamorphism which removed all unstable minerals. Similar, significantly impoverished heavy mineral assemblage was mentioned by Häusler (1988) in Lower Jurassic of the units from the Penninic/Lower Austroalpine boundary in the Eastern Alps. Unlike in Tatricum, the assemblages are dominated by zircon.

In the Borinka unit, which is considered to be a marginal unit at the Penninic/Tatric boundary (Plašienka et al., 1991), in the heavy mineral assemblages (Aubrecht, 1994),

Tab. 2
Percentual proportions of translucent detrital heavy minerals of Liassic sediments from the Pieniny Klippen Belt

| Locality | Unit | Gr | Zr | Ru | Tu | Ap | Am | Ti | St | Sp | Aug | Dis | B.A. | Kae |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jedľovinka | Kysuca ? | 0 | 38 | 38 | 20 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Horné Dúžavy | Kysuca ? | 0 | 39 | 25 | 30 | 2 | 3 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| Krásna Hôrka | Nižná | 52 | 17 | 15 | 10 | 4 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| Lúty potok | Nižná ? | 64 | 13 | 4 | 3 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sedliacka Dubová | Nižná ? | 67 | 10 | 9 | 3 | 10 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Chotúč | Drietoma | 13 | 17 | 13 | 33 | 17 | 0 | 2 | 5 | 2 | 0 | 0 | 0 | 0 |
| Melčická dolina-1 | Drietoma | 1 | 1 | 1 | 2 | 0 | 11 | 0 | 0 | 0 | 1 | 0 | 1 | 82 |
| Melčická dolina-2 | Drietoma | 0 | 15 | 0 | 1 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 81 |
| Melčická dolina-3 | Drietoma | 0 | 43 | 4 | 43 | 0 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Drietoma | Drietoma | 2 | 5 | 0 | 22 | 25 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 43 |
| Drietoma-1 | Drietoma | 3 | 47 | 21 | 29 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Skalka | Manín | 2 | 16 | 14 | 56 | 11 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| Holiak | Manín | 0 | 29 | 24 | 27 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 19 |
| Vrch Pasienky | Manín | 16 | 24 | 14 | 41 | 1 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| Manín Gorge | Manín | 28 | 23 | 22 | 27 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Krivoklátska dolina-1 | Klape ? | 57 | 19 | 3 | 18 | 2 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| Krivoklátska dolina-2 | Klape ? | 72 | 12 | 4 | 11 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Klape-1 | Klape | 31 | 14 | 11 | 42 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Klape-2 | Klape | 59 | 17 | 9 | 13 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Klape-3 | Klape | 57 | 3 | 8 | 30 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| Klape-4 | Klape | 66 | 3 | 4 | 26 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Haligovka | Haligovce | 1 | 15 | 10 | 74 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

For explanations see Tab. 1

apatite is dominant over the tourmaline, zircon and rutile. This is a common feature with so called Nordrahmenzone (Peer and Zimmer, 1980), a transitional zone between Penninic and Lower Austrolapine units in the northern rim of the Tauern Window. These two units have similar sedimentary facies and common heavy mineral ratios. The only difference is in composition of tourmaline. In the Borinka unit, the tourmalines came exclusively from the metasediments (Aubrecht and Krištín, 1995) whereas in the Nordrahmenzone there is a significant portion of tourmalines coming from Li-poor granitoids (unpublished data – Aubrecht, 1999). The samples from the transitional Borinka Unit are practically the same as those from the Tatric units of the Malé Karpaty Mts. (Aubrecht, 1994).

## Percentages of heavy minerals in the units of the Pieniny Klippen Belt

### Kostolec unit

Liassic crinoidal limestones from Kostolec Klippe are very poor in siliciclastic admixture. Only in the lowermost part of the klippe there were recently some samples found with sandy admixture. These samples are now undergoing extracting procedures. The overall lack of siliciclastic admixture in the klippe supports an older oppinion of Andrusov (1938) that Kostolec Klippe comes from the Choč nappe Jurassic.

### Drietoma unit

Drietoma, as an independent unit was distinguished by Rakús (1977). It was formerly considered as one of the developments of Manín unit in the SE sector of the Pieniny Klippen Belt (Began, 1969). Mahel' (1978) named it as Bošáca unit. By its development, namely by its Upper Triassic and Lower Jurassic members, this unit is obviously similar to the Fatric units. Already Began (l. c.) and earlier by Gross (1959) and Scheibner (1967) considered its occurrences between Moravské Lieskové and Zemianske Lieskové as slices of the Krížna nappe overlying the Manín unit (although Mahel', 1978 also considered Manín unit as coming from the Fatric domain). Began (l. c.) called it as Dúbrava development of the Krížna nappe, differing from the Manín unit namely in Liassic sediments.

From Drietoma unit, 7 samples were analysed. At some of them, their ranking to the Drietoma unit was only supposed (Krivoklát valley samples – see Jurkovičová, 1980).

Percentual ratios of heavy minerals from Drietoma and Melčická dolina valley is dominated by brown basalt amphibole (kaersutite) which indicates basaltic source rocks. No other samples from the Western Carpathians contain this mineral in considerable amounts. Its presence is surprising mainly because the amphiboles belong to the most unstable heavy minerals. They are easily removed by weathering, transport and intrastratal dissolution during diagenesis. As the latter process is time-dependent, presence of kaersutite in Liassic sediments is surprising. Only one sample from Melčická dolina (sample No. 3) was free of this amphibole. This was, however, taken from different parts than the previous ones. This site was assigned to belong to Manín unit by Began (1969). Chotúč locality, usually also considered as a part of Drietoma unit, has different heavy mineral composition with relatively equal contents of garnet, zircon, rutile, tourmaline and apatite, with lesser amounts of some other minerals (including some chromium spinel grains).

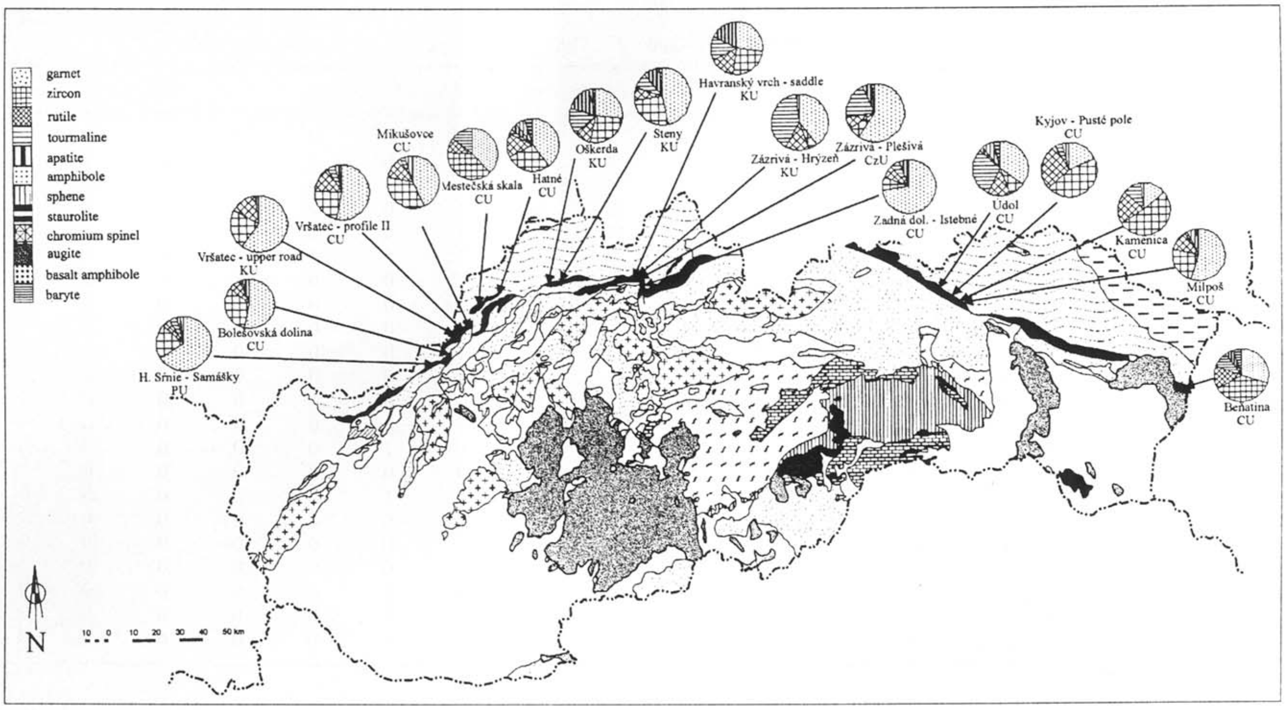


**Fig. 5.** Location of the sampled sites of Middle Jurassic sediments of the Pieniny Klippen Belt and diagrams of their heavy mineral proportions. CU = Czorsztyn unit, PU = Pruské unit, KU = Kysuca unit.

As the Drietoma unit is thought to belong to the Fatric sedimentary domain (present Krížna nappe and its developments), the variability revealed in the heavy mineral assemblages is consistent with increased variability in the Fatric units. An overall lack of garnet also points to the Central Western Carpathian provenance of this unit.

The samples from the Krivoklát valley are dominated by garnet, with lesser amounts of zircon and tourmaline, which is typical for Pienidic units or for Klape hill locality (see separate chapter). Their lithological character is also different from the Drietoma unit. It indicates that attribution of the Krivoklát valley occurrences to Drietoma unit (Jurkovičová, 1980) was erroneous.

### Manín and Haligovce unit

Four samples were analysed from the Manín unit and one from the Haligovce unit. The results show relatively irregular distrbution of garnet, zircon, rutile and tourmaline. Other minerals are mostly missing due to intrastratal dissolution. The absence of apatite in the samples can be influenced by treating the samples by hydrochloric acid. The increased portion of tourmaline and in some cases the lack of garnet reminds the Central Western Carpathian samples. On the contrary, microprobe analyses of garnets displayed an exotic granulitic source of most of them which is typical for Pienidic units (Aubrecht and Méres, 2000). Haligovka locality (Haligovce unit – – commonly presented as close to Manín unit) displays the assemblage typical for Central Western Carpathian units, i. e. it is dominated by tourmaline, with lesser amounts of zircon and rutile.

### Klape unit (Klape hill locality)

Four samples were analysed from Klape hill locality from various part of the klippe. The results show dominance of garnet and tourmaline over zircon and rutile. Similarly as in Manín unit, some garnet grains also show their provenance from exotic granulitic source rocks (Aubrecht and Méres, 2000). On the other hand, the predominance of tourmaline over zircon and rutile is usually typical for the Central Western Carpathians units. The results obtained by us are largely different from those obtained by Halajová (1981). Our revision of her samples revealed her erroneous methods of counting the heavy mineral grains. Therefore, the reliability of some results from the Middle Jurassic crinoidal limestones adopted from this work by Aubrecht (1993) is also doubtful.

### Pienidic units

From various Pienidic units, 5 Lower Jurassic samples, complemented by 18 Middle Jurassic samples (some of them published by Aubrecht, 1993), have been analysed. All samples, except those from Jedľovinka and Horné Dúžavy localities, contain garnet-dominated assemblages, with lesser amounts of zircon, tourmaline and rutile. Other minerals are subordinate. This composition documents relative uniform source rocks for the Pienidic sedimentary area and is consistent with the data of Łoziński (1956) obtained from Aalenian flysch. Again, the pyrope-almandine types prevailed among the garnets which testifies their exotic origin coming from granulitic rocks (Aubrecht and Krištín, 2000). At Jedľovinka and Horné

Tab. 3
Percentual proportions of translucent detrital heavy minerals of Middle Jurassic sediments from the Pieniny Klippen Belt

| Locality | Unit | Gr | Zr | Ru | Tu | Ap | Am | Ti | St |
|---|---|---|---|---|---|---|---|---|---|
| Mestečská skala | Czorsztyn | 36 | 36 | 9 | 14 | 0 | 0 | 0 | |
| Beňatina | Czorsztyn | 30 | 36 | 14 | 9 | 5 | 0 | 0 | 5 |
| Bolešovská dolina | Czorsztyn | 53 | 32 | 8 | 1 | 5 | 0 | 0 | |
| Vršatec-profile II | Czorsztyn | 53 | 22 | 15 | 5 | 3 | 0 | 1 | 0 |
| Údol | Czorsztyn | 35 | 9 | 13 | 29 | 2 | 0 | 7 | 4 |
| Hatné | Czorsztyn | 39 | 28 | 14 | 3 | 4 | 0 | 6 | 5 |
| Mikušovce | Czorsztyn | 43 | 35 | 14 | 3 | 0 | 0 | 5 | 0 |
| Kamenica | Czorsztyn | 14 | 52 | 20 | 11 | 0 | 0 | 2 | 0 |
| Milpoš | Czorsztyn | 54 | 23 | 12 | 2 | 0 | 0 | 6 | 1 |
| Kyjov-Pusté Pole | Czorsztyn | 18 | 44 | 28 | 4 | 0 | 0 | 4 | 0 |
| Zadná dolina-Istebné | Czorsztyn | 73 | 8 | 7 | 6 | 6 | 0 | 0 | 0 |
| Havranský vrch-saddle | Czorsztyn ? | 27 | 25 | 15 | 15 | 17 | 0 | 0 | 0 |
| Horné Sŕnie-Samášky | Pruské | 64 | 20 | 5 | 4 | 2 | 0 | 2 | 0 |
| Zázrivá-Plešivá | Czertezik | 59 | 7 | 6 | 20 | 5 | 0 | 0 | 2 |
| Vršatec-upper road | Kysuca | 60 | 23 | 15 | 0 | 2 | 0 | 0 | 0 |
| Steny | Kysuca | 47 | 26 | 7 | 9 | 9 | 0 | 0 | 2 |
| Oškerda | Kysuca | 26 | 27 | 10 | 16 | 16 | 0 | 2 | 2 |
| Zázrivá-Hrýzeň | Kysuca | 40 | 5 | 13 | 40 | 2 | 0 | 0 | 0 |

For explanations see Tab. 1

Dúžavy localities, a relatively well-matured assemblage has been found, consisting almost exclusively of zircon, tourmaline and rutile. The modal composition of the sediment itself also points to high maturity of the rocks, in which the unstable heavy minerals were removed by intrastratal dissolution. The quartzites from Jedľovinka were frequently compared with those from Krásna Hôrka locality (Andrusov, 1931) but they are apparently different. They are strongly arcosic, i. e. much less matured than the Jedľovinka quarzites which is reflected also in heavy mineral composition.

## Discussion

The new investigations brought interesting new data, interpretation of which is, like commonly in geology, unambiguous. The new data, besides resolving of problems, brought also many new questions. In the following discussion, some of the most important problems will be treated.

*1. Why are the samples from the Central and Inner Western Carpathians dominated by the most stable trinity tourmaline, zircon and rutile?*

The preliminary results revealed that the Jurassic sediments from the units situated recently south of the Pieniny Klippen Belt are characterized by impoverished heavy mineral assemblages, mostly with the most stable tourmaline, zircon and rutile. On the other hand, the crystalline basement is highly dominated by garnet, whereas the mentioned ultrastable trinity is subordinate. The impovershment might be caused by two reasons, either by multiple resedimentation of the clastics or by intrastratal dissolution in the sediment. In Tatric units, the intrastratal dissolution might play the principal role. The Tatric units are largely affected by tectonic and anchimetamorphic processes (Plašienka et al., 1993). Tatricum has also the highest ZTR index from all the examined units (Aubrecht, 1994a). It represents the ratio of the ultrastable trinity zircon-tourmaline-rutile to the other minerals (Hubert, 1962). This index reflects an overall maturity of the sediment and also indicates a possible redeposition from older sediments. The higher the index is, the more matured is the sedimentary material. However, our results show that impoverishment of the heavy mineral assemblages is also displayed in tectonically higher, less tectonometamorphically affected units, such as Hronicum and Silicicum. These units do not seem to be more affected than the Pieniny Klippen Belt units and have similar composition but the difference between the ZTR indexes of these zones are large. Intrastratal dissolution is influenced by burial depth (Morton, 1987) as well as by organic acids present in the sediment (Hansley, 1987). In the case of Hronic and Silicic units, the most likely explanation is the impoverishment by the resedimentation probably from Permian to Triassic sediments.

Assemblages poor in garnet and rich in the most stable minerals such as chromium spinels, zircon, tourmaline and rutile are ubiquitous all through the Western Carpathian Cretaceous; in Paleogene there is a sudden onset of the garnet-dominated assemblages (Mišík et al., 1980; Salaj and Priechodská, 1987; Wagreich and Marschalko, 1995). As the intrastratal dissolution is time-dependent process, if the impoverished assemblages were exclusively the result of intrastratal dissolution a gradual increase of unstable minerals amount would be observed towards the younger formations. Instead, the sudden onset rather indicates different source rocks. The most probable version is that in the Central and Inner Western Carpathians the impoverishment of heavy mineral assemblages was due to combination of multiple recycling of the material and of intrastratal dissolution (mainly Penninic, Tatric and eventually Fatric units).

*2. Why are the Jurassic sediments of the Central and Inner Western Carpathian units dominated by tourmaline which is rare in Tatric-Veporic crystalline complexes?*

Most of the works concerning accessoric minerals in the Tatric-Veporic crystalline rocks revealed relatively low amounts of tourmaline. Only Hvožďara (1980) and Ženiš and Hvožďara (1985), on the basis of heavy mineral prospection in Veporicum, mentioned increased portion of tourmaline but without quantitative specification.

The problem of detrital tourmaline has been already treated by Aubrecht (1994) and Aubrecht and Krištín (1995). The chemical composition of tourmalines from various units of the Western Carpathians indicates that most of the detrital tourmaline came from metasediments, probably phyllites (Aubrecht and Krištín, 1995; Aubrecht, 1999). Regression statistical analysis shows that in the ultrastable trinity tourmaline, zircon and rutile there is a good correlation between the zircon and rutile but their correlation with tourmaline is low (Aubrecht, 1999). Therefore, the tourmaline source had to be different. Zircon, rutile and little amount of tourmaline was most probably resedimented from older sediments, whereas most of the tourmaline came from the above mentioned metasediments. These had to be already removed by erosion as the average content of tourmaline in presently outcropped crystalline rocks is low (except Gemericum). This interpretation, however, meets some difficulties. There are two alternatives. The first supposed that the erosion has to take place still before Triassic (before deposition of Lower Triassic quartzites – Lúžna Formation). In this case, all the tourmalines in Liassic would be resedimented from Triassic sediments. Another possibillity is that the erosion of metasediments took place during Liassic. This would require removal of the underlying Triassic sediments to reach the crystalline basement. However, there were found almost no instances of direct overlying of the crystalline basement by Liassic sediments in the Western Carpathians, except perhaps Somár Breccias in the Malé Karpaty Mts. (Borinka Unit). This fact contradicts to relatively large onset of siliciclastic sedimentation in Liassic (mainly in Tatricum). It is hard to presume that all the material is result of resedimentation. Moreover, there were crystalline clasts identified in the detritic admixture. A hypothetic crystalline terrane formed by low-grade metamorphics situated north of Tatricum serves as the most likely solution. This might be also a source of exotic tourmalinic clastics in Lower Triassic quartzites (Mišík and Jablonský, 1978). Its location is deduced from the transport indicators measured in the quartites, as well as diminishing of clastic admixture in Liassic sediments from north to south. A considerable portion of tourmaline in Silicic units might also come from Gemericum where it is ubiquitous.

*3. Where did the bluish detrital amphiboles found at some Silicic sites come from?*

The bluish amphiboles occurred only in three samples from Bohúňovo and in one sample from Bleskový prameň; a single grain have been found also at Geravy locality. The samples with bluish amphiboles were rare and were not present in whole profiles a contamination source was suspected at first. However, because of our attempt to keep the extracting process as clear as possible, the high ratio of bluish amphiboles in some samples (up to 80 %) makes the contamination source unlikely. The bluish amphibole grain from Geravy locality, which was extracted two years after Bohúňovo and Bleskový prameň localities testifies this theory. Even later, three new grains of bluish amphibole have beeen found at Bohúňovo. However, these have different appearance with violetish pleochroism very similar to that of glaucophane. Microprobe analyses showed that these grains contain almost no sodium which was suprised. Sum of their oxides never reached more than 93 %. Optical properties of this mineral, together with proportion of measurable elements allows us to presume that it represents a rare Li-amphibole holmquistite (Li cannot be measured by microprobe). An overall rarity of detrital amphiboles in older sediments is caused by their instability in sediments. The grains are preserved mainly in conditions where they are protected against intrastratal dissolution. Most of authors agree with theory that sediments protected from access of water and other fluids, e. g. concretions or beds isolated by impermeable rocks, use to preserve much more diverse heavy mineral spectra (Hubert, 1971 and the literature cited therein). Our positive samples containing amphiboles were invariably found in the rocks surrounded with claystones and marlstones or they were clayey themselves, i. e. protected from fluid access.

The question of origin of the bluish amphiboles after oral communication was discussed by Kozur and Mock (1995, 1996). Without analytical results they evaluated the bluish amphiboles as a product of a HP/LT metamorphism due to subduction of "northern" branch of the Meliata ocean.

Despite of lack of higher number of analyses it can be stated that the mentioned amphiboles do not probably represent a direct result of HP/LT metamorphism but rather retrogressive stage of metamorphism which followed the HP/LT stage (Dr. Peter Ivan – oral discussion). By their character (Al-Fe-Mg-hornblende to Al-edenite) they are closer to bluish amphiboles from Rakovec unit of Gemericum (Hovorka et al., 1988) than to glaucophanes of the Bôrka nappe (Meliaticum s. l.).

There were also some bluish varieties of tourmaline found in Bohúňovo samples. They are similar to some tourmalines from Gemeric granites (Faryad and Jakabská, 1996). The supposed holmquistite might also belong to products of metasomatic alteration in the surroundings of these granitic bodies where it was formed by metabasic rocks (holmquistite originates via Li-metasomatic alteration of normal amphiboles). If these presumptions were supported by further facts, the Silicic-Gemeric paleogeographic relationship would be proved. If the mentioned minerals were related to Gemeric granitoids it would be an indirect prove of their pre-Late Triassic age (Poller et al., 2000).

*4. What is the provenance of detrital staurolite in Nedzov nappe?*

The heavy mineral assemblages from the Nedzov nappe are inexpected. On one hand there is dominant the very stable tourmaline, on the other hand, relatively unstable staurolite is abundant too. Other minerals such as zircon, rutile, apatite and garnet are much sparser. Staurolite and garnet might come from Tatric-Veporic type of crystalline complexes, but again, the high amount of tourmaline would be problematic. Moreover, there had to be dominance of staurolite over the granet. Garnet is more resistant to intrastratal dissolution than staurolite but in the Nedzov nappe samples the staurolite is dominant. The rocks dominated by staurolite are rare in the Western Carpathians and staurolite nowhere occurs in considerable amounts to provide the proportions we have obtained. For instance, in staurolite zone of metapelitic rocks in the Malé Karpaty Mts. staurolite reaches up to 49 %, whereas garnet just up to 42 % (Broska and Janák, 1985). According to Hubert (1971) staurolite is more resistant to intrastratal dissolution. This would shift this ratio in favour of staurolite as the garnet would disappear more quickly. This process most probably increased the proportion of staurolite also in our samples, provided that the source rock had similar composition as those of Broska and Janák (1985).

*5. What is the relationship between the Pieniny Klippen Belt units and Central Western Carpathian units deduced from heavy mineral analysis?*

Our results display obvious difference between two heavy mineral assemblages: Pieniny Klippen Belt units and the units south of it. They can be considered as two principal heavy-mineral distribution provinces. The units of Pieniny Klippen Belt have affinity to stable North European margin. Important information came from the work of Faupl (1975) from Gresten Klippen Belt of the eastern Alps and from the works of Štelcl et al. (1972) and Štelcl et al. (1977) from the boreholes that penetrated the autochthonous Mesozoic cover of the Bohemian Massif beneath the Carpathian Foredeep and the Flysch Belt. The Gresten Klippen Belt domain was part of the Nort-European platform later incorporated into the Alpine zone. Faupl (l. c.) provided data from 19 samples of detrital heavy minerals from Gresten Liassic. Most of the samples were dominated by garnet, only minor amount of samples consisted of the stable assemblage zircon, rutile, tourmaline and apatite. These results are consistent with those obtained from the Pienidic units. Jurassic detritic sediments also occur in the platform cover of Bohemian Massif beneath the Tertiary filling of the Carpathian Foredeep and overthrust Flysch Belt. Summarizing lithostratigraphic description of these units was introduced by Adámek (1986). The data were carried out on the basis of numerous deep boreholes and geophysical profiles. These Jurassic sediments are named Diváky Formation but their age determination is limited. The lower part of the formation is called Gresten Beds (Adámek, l. c.) which expresses their relationship with similar facies in the Gresten Zone. Detailed data on heavy mineral were obtained from several boreholes: Nikolčice-1, 2 (Štelcl et al., 1972), Nikolčice-4, 6, Mušov-1, Vranovice-1, Mikulov-1 and Kobylí-1 (Štelcl et al., 1977). Again, the predominating assemblage is garnet, zircon, rutile, tourmaline and apatite, which is consistent both with the Gresten Zone and Pieninic units. Except of some samples from Krížna nappe, no other investigated unit from Central or Inner Western Carpathians is garnet-dominated. Therefore, these sedimentation realms were most probably separated from each other still in Liassic, i. e. they have to had different positions when being parts of the Triassic North-European shelf. Garnet analyses showed also different sources (see Aubrecht and Méres, 2000 and discussion therein). Manín and Klape samples differ from those of Pienidic units by their amount of tourmaline, which is increased, i. e. closer to Central and Inner West Carpathian units. A possibillity, though improbable, still exists that removal of unstable minerals might lead to similar ratios in the mentioned assemblages. From the Pieniny Klippen Belt units, only Drietoma and Haligovce units are completely free of garnet which indicate their ranking among the Central Western Carpathian units.

## Conclusions

1. Jurassic (namely Liassic) sediments of the Western Carpathians display reduction of heavy mineral spectra if compared with the source rocks. This reduction is remarkable namely in the Central and Inner Western Carpathians, whereas in the Pieniny Klippen Belt units it is not so expressive. The reasons of impoverishment of heavy mineral spectra are not only in intrastratal dissolution as thought before but also in resedimentation of the minerals from older sedimentary rocks.

2. The ultrastable trinity: tourmaline, zircon and rutile that prevails the Central and Inner Western Carpathians is tourmaline-dominated. The regression analysis shows common source of zircon and rutile; major portion of tourmaline most likely came from low-grade metamorphics which are now not present in the crystalline basement (except Gemericum).

3. The lack of any considerable admixture of chromium spinels (ophiolitic source rocks) is noteworthy from the paleotectonic point of view. Chromium spinels belong to ultrastable heavy minerals and their presence would be also detectable in impoverished samples. There are minor amounts of Cr-spinelids in the Meliata unit which was in the phase of convergence and closure. In more northern units that were under influence of Penninic rifting and spreading, only continental crust-derived heavy minerals are present. The experience with Cretaceous chromium spinels (Mišík et al., 1980) shows that they are present in the time of obduction large ophiolite bodies which was most probably not the case in Jurassic.

4. Two main Jurassic heavy-mineral provinces may be distinguished in the Western Carpathians: G-Z-R-T (garnet, zircon, rutile, tourmaline) and T-Z-R (tourmaline, zircon and rutile). The first one is typical for Pieniny Klippen Belt units and has obvious affinity to Gresten Zone and autochtonous Jurassic cover of the Bohemian Massif margins. The second assemblage, impoverished due to resedimentation from older sediments and due to intrastratal dissolution, is typical for Central and Inner Western Carpathian units.

5. On the basis of some index heavy minerals it is likely that source of Nedzov nappe clastics was Tatric--Veporic type of crystalline complexes (source of stauro-

lite). Various bluish amphiboles and some bluish varieties of tourmaline in Silicic Jurassic came most likely from Gemericum.

*Acknowledgement.* This paper is a contribution to the project *Tectogenesis of the West Carpathian Sedimentary Basins* of Ministry of Environment of Slovak Republic, managed by the Geological Survey of Slovak Republic. Additional financial support was provided by grants No. 1/6169/99 and 1/7370/20 of VEGA agency. The author would like to express thanks to Prof. RNDr. Michal Kováč, DrSc. for his full support of the author's activities.

## References

Adámek, J., 1986: Geological data of Mesozoic structures in the section SOUTH, of the southeastern slopes of the Bohemian Massif. *Zem. Plyn Nafta (Hodonín), 31, 4, 453–481* (in Czech).

Andrusov, D., 1931: Geological investigations of the inner Klippen Belt in the Western Carpathians. Parts I. (Introduction) and II. (Stratigraphy – Triassic and Liassic). *Rozpr. St. geol. Úst. Čs. Republ. (Praha), 6, 167* (in Czech and French).

Andrusov, D., 1938: Geological investigations of the inner Klippen Belt in the Western Carpathians. Part III. (Tectonics). *Rozpr. St. geol. Úst. Čs. Republ. (Praha), 9, 135* (in Czech and French).

Aubrecht, R., 1993: Clastic admixture in Dogger crinoidal limestones of Czorsztyn unit. *Geol. Carpath., 44, 2, 105–111.*

Aubrecht, R., 1994: Heavy mineral analyses from "Tatric" units of the Malé Karpaty Mts. (Slovakia) and their consequence for the Mesozoic paleogeography and tectonics. *Mitt. Österr. Geol. Gesell., 86, 121–132.*

Aubrecht, R., 1994a: Sedimentology, and facial relationship of the Jurassic sediments of the Pienidic units of the Pieniny Klippen Belt a their relationship to the Central West Carpathian units based on the study of heavy minerals. Unpublished PhD. Thesis. *Faculty of Natural Sciences, Comenius University, Bratislava, 119 (in Slovak).*

Aubrecht, R., 1999: Heavy minerals of detrital admixture in the Lower Jurassic sediments of the Western Carpathians and their paleogeographic and paleotectonic importance (preliminary results). Unpublished habilitation thesis. *Faculty of Natural Sciences, Comenius University, Bratislava, 97 (in Slovak).*

Aubrecht, R. & Krištín, J., 1995: Provenance of detrital tourmaline in the Lower Jurassic of the Malé Karpaty Mts. *Mineralia Slov., 27, 1, 37–44.*

Aubrecht, R. & Méres, Š., 2000: Exotic detrital almandine-pyrope garnets in the Jurassic sediments of the Pieniny Klippen Belt and Tatric Zone: where did they come from? *Mineralia Slov., 32, 1, 17–28.*

Began, A., 1969: Geological structure of the Pieniny Klippen Belt in the central Váh Valley. *Zbor. geol. Vied, Západ. Karpaty, 11, 55–103* (in Slovak).

Broska, I. & Janák, M., 1985: Akcesorické minerály metapelitov a ich vzťah k metamorfóze v oblasti Záhorskej Bystrice (Malé Karpaty). *In: Zbor. Akcesorické minerály. Bratislava, GÚDŠ, 101–106.*

Faryad, S. W., 1995: Estimation of P-T metamorphic conditions of Spiš-Gemer Ore Mountains rock complexes. *Mineralia Slov., 27, 1, 9–19* (in Slovak, with English summary).

Faupl, P., 1975: Kristallinvorkommen und terrigene Sedimentgesteine in der Grestener Klippenzone (Lias-Neokom) von Ober und Niederösterreich. Ein Beitrage zur Herkunft und Genese. *Jb. Geol. B.–A. (Wien), 118, 1–74.*

Gross, P., 1959: Contribution to biostratigraphy and lithology of the Pieniny Klippen Belt in the central Váh Valley. Unpublished MSc. Thesis, *Dept. of Geol. and Paleont., Comenius Univ.*

Halajová, L., 1981: Terrigenous admixture in Jurassic limestones of the Pieniny Klippen Belt and structure of Babiná Klippe near Krivoklát-Bohunice. Unpublished MSc. Thesis, *Dept. of Geol. and Paleont., Faculty of Natural Sciences, Comenius Univ., Bratislava, 1–73* (in Slovak).

Hansley, P., 1987: Petrologic and experimental evidence for the etching of garnets by organic acids in the Upper Jurassic Morisson Formation, Northwestern New Mexico. *J. sed. Petrology (Tulsa), 57, 4, 666–681.*

Häusler, H., 1988: Unterostalpine Jurabreccien in Österreich. Versuch einer sedimentologischen und paläogeographischen Analyse nachtriadischer Breccienserien im unterostalpinen Rahmen des Tauernfensters (Salzburg-Tirol). *Jb. Geol. Bundesanst. (Wien), 131, 21–125.*

Hovorka, D., Ivan, P., Spišiak, J. & Jilemnická, L., 1988: Petrology and geochemistry of metabasalts from Rakovec (Paleozoic of Gemeric unit, Inner Western Carpathians). *Geol. Zbor. Geol. carpath., 39, 395–425.*

Hubert, J. F., 1962: A zircon-tourmaline maturity index and the interdependence of the composition of heavy mineral assemblages with the gross composition and texture of sandstones. *J. sed. Petrology (Tulsa), 32, 3, 440–450.*

Hubert, J. F., 1971: Analysis of heavy-mineral assemblages. *In: Carver, R. E. (Ed.): Procedures in sedimentary petrology. Wiley-Interscience Publ., 453–478.*

Hvožďara, P., 1980: Prospection minerals of Tatric-Veporic crystalline complexes. *Acta geol. geogr. Univ. Comen., Geol., 35, 5–43* (in Slovak).

Jurkovičová, H., 1980: Stratigraphy, lithology and microfacies of Jurassic of the Pieniny Klippen Belt in Krivoklát area. Unpublished MSc. Thesis. *Dept. of Geol. and Paleont., Faculty of Natural Sciences, Comenius Univ., Bratislava, 1–78* (in Slovak).

Kozur, H. & Mock, R., 1995: First evidence of Jurassic in the Folkmár Suture Zone of the Meliaticum in Slovakia and its tectonic implications. *Mineralia Slov., 27, 5, 301–307.*

Kozur, H. & Mock, R., 1996: New paleogeographic and tectonic interpretations in the Slovakian Carpathians and their implications for correlations with the Eastern Alps. Part I: Central Western Carpathians. *Mineralia Slov., 28, 3, 151–174.*

Łoziński, J., 1956: Mineraly ciężkie piaskowców aalenu fliszowiego w pieninskim pasie skalkowym. *Acta geol. pol. (Warszawa), 6, 17–23.*

Łoziński, J., 1957: Porównanie zespolów mineralów ciężkich fliszu podhalanskiego, aalenu fliszowego w pasie skalkowym i egzotyków jurajskich z Bachowic. *Rocz. Pol. Tow. geol. (Kraków), 26, 2, 157–164.*

Łoziński, J., 1959: Mineraly ciężkie piaskowców dolnej i srodkowej kredy w pieninskim pasie skałkowym. *Rocz. Pol. Tow. geol. (Kraków), 29, 1, 119–125.*

Łoziński, J., 1966: Mineraly okruchowe w piaskowcach fliszowych pieninskiego pasa skalkowego i obszarów sasiadujących. *Prace geol. (Pol. Akad. Nauk), 37, 1–57.*

Maheľ, M., 1978: Manín unit – a partial nappe of the Krížna nappe group of nappes. *Mineralia Slov., 10, 4, 289–309* (in Slovak).

Mandl, G. W. & Ondrejičková, A., 1992: Uber eine triadische Tiefwasser Fazies (Radiolarite, Tonschiefer) in den Nördlichen Kalkalpen – ein Vorbericht. *Jb. Geol. B.–A. (Wien), 134, 2, 309–318.*

Mišík, M., Jablonský, J., Fejdi, P. & Sýkora, M., 1980: Chromian and ferrian spinels from Cretaceous sediments of the West Carpathians. *Mineralia Slov., 12, 3, 209–228.*

Mock, R., Sýkora, M., Aubrecht, R., Ožvoldová, L., Kronome, B., Reichwalder, P. & Jablonský, J., 1998: Petrology and stratigraphy of the Meliaticum near the Meliata and Jaklovce Villages, Slovakia. *Slovak Geol. Magazine (Bratislava), 4, 4, 223–260.*

Morton, A. C., 1985: Heavy minerals in provenance studies. *In: Zuffa, G. G. (Ed.): Provenance of arenites, 249–277.*

Morton, A. C., 1987: Influences of provenance and diagenesis on detrital garnet suites in the paleocene Forties Sandstone, Central North Sea. *J. sed. Petrology (Tulsa), 57, 6, 1027–1032.*

Peer, H. & Zimmer, W., 1980: Geologie der Nordrahmenzone der Hohen Tauern (Gasteiner Ache bis Saukarkopf-Großarltal). *Jb. Geol. Bundesanst. (Wien), 123, 2, 411–466.*

Plašienka, D., Korikovsky, S. P. & Hacura, A., 1993: Anchizonal Alpine metamorphism of Tatric cover sediments in the Malé Karpaty Mts. (Western Carpathians). *Geol. Carpath., 44, 6, 365–371.*

Plašienka, D., Michalík, J., Kováč, M., Gross, P. & Putiš, M., 1991: Paleotectonic evolution of the Malé Karpaty Mts. – an overview. *Geol. Carpath., 42, 4, 195–208.*

Poller, U., Broska, I., Finger, F., Uher, P. & Janák, M., 2000: Permian

age of Gemeric granites constrained by single zircon and EMPA monazite dating. *Mineralia Slov., 32, 3, 189–190.*
Rakús, M., 1977: Contributions to Jurassic and Cretaceous lithostratigraphy and paleogeography of the Manín unit in the central Váh valley. *Geol. Práce, Spr., 68, 21–38* (in Slovak).
Salaj, J. et al., 1987: Explanations to geological map of Myjava Upland, Brezovské and Čachtické Karpaty Mts. (1 : 50 000). *Publ. GÚDŠ, Bratislava, 181* (in Slovak).
Salaj, J. & Priechodská, Z., 1987: Comparison of the Gosau type of Senonian and Paleogene between the Myjavská pahorkatina Highlands and the Northern Calcareous Alps. *Mineralia Slov., 19, 6, 499–521* (in Slovak with English abstract).
Scheibner, E., 1967: Carpathian Klippen Belt. *In: Buday, T. et al. (Eds.): Regional geology of ČSSR, part II – Western Carpathians (Praha), 7–105* (in Czech).
Štelcl, J., Schmidt, J., Svoboda, L. & Novotný, M., 1972: Notes to the petrography of autochtonous Paleozoic, Mesozoic and Paleogene in the basement of the Carpathian Foredeep and Flysch Belt in southern Moravia. *Folia Univ. Purkyn. brun., Geol. (Brno), 13, 23, 2, 3–106* (in Czech).
Štelcl, J., Svoboda, L., Schmidt, J. & Zádrapa, K., 1977: Notes to the petrography of autochtonous Paleozoic and Mesozoic in the platform basement of the Carpathian Foredeep and Flysch Belt (sections "SOUTH" and "CENTRE"). *Folia Univ. Purkyn. brun., Geol. (Brno), 18, 29, 14, 5–120* (in Czech).
Wagreich, M. & Marschalko, R., 1995: Late Cretaceous to Early Tertiary palaeogeography of the Western Carpathians (Slovakia) and the Eastern Alps (Austria): implications for heavy mineral data. *Geol. Rdsch., 84, 187–199.*
Ženiš, P. & Hvožďara, P., 1985: Tourmaline – important prospection mineral of the Veporic crystalline complexes. *In: Zbor. Akcesorické minerály. Bratislava, GÚDŠ, 107–114* (in Slovak).

# Distribučné provincie ťažkých minerálov v jurských sedimentoch Západných Karpát

Zisťovali sme percentuálne zastúpenie ťažkých minerálov vo vyše 100 vzorkách jurských sedimentov (najmä z liasu) zo všetkých dôležitých tektonických jednotiek Západných Karpát. Sedimenty liasu Západných Karpát sa vyznačujú značnou redukciou spektra ťažkých minerálov oproti zloženiu pôvodných zdrojových hornín. Táto redukcia je markantná hlavne v jednotkách centrálnych a vnútorných Západných Karpát. V bradlovom pásme je redukcia menšia, a to aj v jednotkách, ktoré sa v súčasnosti pokladajú za pôvodnú súčasť centrálnych Západných Karpát (klapská a manínska jednotka). Príčinou redukcie nie je iba intrastratálne rozpúšťanie, ako sa doteraz predpokladalo, ale aj resedimentácia minerálov zo starších sedimentov (niekoľkonásobná recyklácia materiálu s elimináciou nestabilnejších zložiek). V najstabilnejšej trojici minerálov v jednotkách centrálnych a vnútorných Západných Karpát často prevláda turmalín nad zirkónom a rutilom. Na základe regresnej a variačnej analýzy usudzujeme, že posledné dva minerály majú spoločný pôvod (kryštalinikum tatroveporického typu a staršie z neho derivované sedimenty), kým turmalín pochádza aj z iných zdrojov (metasedimentov nízkeho stupňa metamorfózy).

Z paleotektonického hľadiska je zaujímavé, že sa v liase, ktorý je v tetýdnej oblasti obdobím výrazného riftingu, takmer nijaký prínos detritu z ofiolitov nezaznamenal. Pritom chrómspinelidy by sa pre ich veľmi vysokú stabilitu a odolnosť voči transportu aj intrastratálnemu rozpúšťaniu mohli zachovať aj v tých najochudobnenejších asociáciách. Zo skúseností z kriedových sedimentov je však známe, že prínos ofiolitového detritu prebieha hlavne pri obdukcii oceánskej kôry v procese konvergencie a kolízie. Pri riftingu zrejme prebieha prínos ofiolitových klastík výhradne do oceánskych paniev, ktoré zvyčajne úplne pohltila subdukcia v neskorších štádiách.

V nasledujúcom súhrne je stručné porovnanie percentuálneho zloženia ťažkých minerálov v jednotkách Západných Karpát:

a. Silicikum s. l. Podobne ako v hroniku aj v siliciku s. l. vidno nedostatok siliciklastickej prímesi, čo pravdepodobne súvisí s iným geotektonickým postavením spomenutých jednotiek v liase. Kým severnejšie jednotky ovplyvnil rifting ligúrsko-penninicko-váhického oceána, južnejšie jednotky boli v oblasti vplyvu konvergencie uzatvárajúceho sa meliatskeho oceána (silicikum) alebo sa vyskytovali v pomerne neutrálnej zóne medzi nimi (hronikum). Jurské sedimenty silicika sú na siliciklastickú prímes všeobecne o čosi bohatšie, aj keď je často len v siltovej frakcii, ktorá sa študuje dosť ťažko.

Zo vzoriek vidno, že prevláda najstabilnejšia asociácia turmalín – zirkón – rutil s veľkou prevahou turmalínu. Tieto najnovšie výsledky ukazujú, že percentuálne zastúpenie ťažkých minerálov je podobné ako vo vzorkách z centrálnych Západných Karpát, hlavne z tatrika, ale na rozdiel od jednotiek centrálnych Západných Karpát sa vo vzorkách z Bohúňova vyskytujú aj modrasté amfiboly a modré odrody turmalínu. Predbežný výskum modrastých amfibolov ukázal, že ich nemožno priamo zaradiť medzi vysokotlaké minerály, ale zároveň sa nedá ani vylúčiť, že ide o produkty premeny glaukofánov v regresnej fáze metamorfózy. Keďže sa podobné minerály vyskytujú aj v gemeriku, zdroj klastickej prímesi možno hľadať v tejto oblasti.

b. Vzorky z nedzovského príkrovu (lokalita Prašník a Bzince pod Javorinou) sa vyznačujú zaujímavou asociáciou ťažkých minerálov. Popri prevahe stabilného turmalínu sa v nich vyskytuje aj málo stabilný staurolit a v Prašníku aj o niečo stabilnejší granát. Asociácie z Bziniec pod Javorinou sú zaujímavé aj neprítomnosťou (alebo veľmi malým množstvom) granátu, ktorý je inak v západokarpatskom kryštaliniku oveľa hojnejší. Svedčí to o osobitom zložení zdrojových hornín a poukazuje na možnosť sekundárneho obohatenia asociácie o staurolit, lebo ten je podľa literatúry voči intrastratálnemu rozpúšťaniu odolnejší. Staurolit a granát sa vyskytujú prevažne v metamorfitoch stredných stupňov metamorfózy, a preto je takmer isté, že ich zdrojovou oblasťou nebolo gemerikum, ale skôr kryštalinikum tatroveporického typu.

c. Chočský príkrov. Pozitívne boli len tri z odobraných vzoriek (lokalita pri Diviackej Novej Vsi a Brama Kantaka v poľských Západných Tatrách), čo je dôsledok veľmi malého množstva siliciklastickej prímesi zastúpenej v sedimentoch. Obsah ťažkých minerálov vo vzorkách je rozličný. V jednej vzorke je takmer iba turmalín s malým množstvom zirkónu a rutilu (opäť najstabilnejšia asociácia), v ostatných dvoch prevažuje zirkón s menším obsahom rutilu, turmalínu a apatitu, prípadne granátu. Našli sa aj ojedinelé zrná chrómspinelidov. Je to takisto ochudobnená asociácia, a tak na jej základe nemožno robiť ďalekosiahle závery aj preto, že zatiaľ ide o malé množstvo pozitívnych vzoriek.

d. Fatrické jednotky sa vyznačujú variabilnými výsledkami, čo prezrádza, že v sedimentačnom priestore tatrika je viac asociácií ťažkých minerálov, ktoré pravdepodobne pochádzajú z rozličných zdrojov a v panve sa zmiešali v rozličnom pomere.

Skupiny zodpovedajúce jednotlivým zdrojom nemožno vyčleniť ani podľa výsledkov zhlukovej analýzy, a to napriek faktu, že istá odlišnosť v dvoch skupinách vzoriek je viditeľná.

Prvú skupinu, zistenú vo vzorkách hlavne z vysokej jednotky Malých Karpát, na strážovskom profile v Strážovských vrchoch a v dvoch vzorkách z Malej Fatry, reprezentuje asociácia granát – apatit – zirkón, druhú tvorí najstabilnejšia asociácia zirkón – rutil ± apatit. Pomer medzi minerálmi v druhej skupine je variabilný, ale dá sa predpokladať, že ide o asociáciu zo zdroja podobného zdroju v tatriku.

Z výskytu obidvoch asociácií aj v jednom profile vyplýva, že druhá asociácia nemohla vzniknúť iba ochudobnením pod vplyvom intrastratálneho rozpúšťania. Na vzorkách obsahujúcich granát je viditeľná silná korózia, ale k úplnej strate granátu nevedie. Z týchto výsledkov rezultuje predbežný predpoklad, že každá asociácia predstavuje inú zdrojovú oblasť a že sa sedimenty na dne fatrickej panvy miešali.

e. Tatrické jednotky sa vyznačujú prevahou ultrastabilnej trojice zirkón – rutil – turmalín. Zarážajúci je nápadný nedostatok granátu a veľmi prekvapujúce aj to, že v trojici často dominuje turmalín. Vyskytli sa aj anomálie, napríklad vo všetkých tatrických jednotkách Malých Karpát a Považského Inovca, v ktorých dominuje aj apatit. Anomálny je aj relatívne vyšší obsah granátu (na rozdiel od iných pohorí) vo Veľkej Fatre (maximálne 12 %). Chemické zloženie granátov odhalilo aj výskyt pyropovo-almandinických granátov, ale neistého pôvodu. Zo známych výskytov podobných granátov do úvahy prichádza iba kryštalinikum moldanubika alebo Malej Fatry.

Borinská jednotka, pokladaná za prechod medzi tatrikom a penninikom, má takmer zo všetkých hľadísk blízko k *Nordrahmenzone,* odkrytej v severnej časti tektonického okna Vysokých Taúr, ale v *Nordrahmenzone* prevládajú turmalíny pochádzajúce z granitoidov, kým v borinskej jednotke sa vyskytujú takmer iba turmalíny z metasedimentov.

f. Kostolecká jednotka v liase neobsahuje takmer nijakú siliciklastickú prímes, čo je prvok spoločný s jednotkami hronika alebo silicika. Predpokladáme, že bradlo pri Kostolci môže byť odtrhnutým blokom, pôvodne pochádzajúcim z chočského príkrovu.

g. Drietomská jednotka sa vyznačuje asociáciou s prevládajúcim čadičovým amfibolom. Pre zdroj klastického materiálu bola charakteristická dominancia bazaltov alebo metabazitov a iba skromne boli zastúpené minerály z metasedimentov a prípadne aj granitoidov. Nedostatkom granátu, ako aj sedimentárnym vývojom je drietomská jednotka blízka jednotkám centrálnych Západných Karpát.

h. Manínska jednotka sa vyznačuje pomerne nerovnomerným zastúpením granátu, zirkónu, rutilu, turmalínu a apatitu. Táto nerovnomernosť naznačuje, že niektoré výskyty uvádzané v mapách ako manínska jednotka môžu v skutočnosti patriť do odlišných jednotiek. Vzorky s vyšším obsahom turmalínu a s občasným chýbaním granátu pripomínajú jednotky z centrálnych a vnútorných Západných Karpát. Z porovnania vychodí aj to, že vzorky z manínskej jednotky sú pre uvedené príčiny dosť odlišné aj od vzoriek z pienidných jednotiek. Mikrosondové analýzy odhalili prítomnosť pyropovo-almandinických granátov, ale to je spoločný prvok s väčšinou skúmaných jednotiek bradlového pásma aj s lokalitami tatrika vo Veľkej Fatre.

i. Klapská jednotka (bradlo Klape) sa vyznačuje prevahou granátu a turmalínu nad zirkónom a rutilom. Podobnosť s pienidnými jednotkami je opäť narušená zvýšeným obsahom turmalínu, ktorý je typický pre jednotky centrálnych a vnútorných Západných Karpát. Podobne ako pri predchádzajúcej jednotke sa aj tu našli pyropovo-almandinické granáty.

Na základe analýzy ťažkých minerálov do klapskej jednotky zaraďujeme aj lokality v Krivoklátskej doline, ktoré Jurkovičová (1980) v diplomovej práci zaradila do drietomskej jednotky.

j. Pienidné jednotky sú charakteristické prevahou granátu, zirkónu, rutilu a turmalínu (v uvedenom poradí). Takáto asociácia je typická pre liasovú aj dogerskú časť pienidných jednotiek, ba i pre južné okraje stabilnej Európy vrátane grestenského bradlového pásma a podsunutej časti Českého masívu pod čelnou predhlbňou a flyšovými Karpatmi. Tieto oblasti pravdepodobne tvorili jednu spoločnú provinciu distribúcie ťažkých minerálov. Analýza granátov z pienidných jednotiek, ako aj manínskej a klapskej jednotky naznačujú, že zdrojovú oblasť tvorili prevažne granulity alebo eklogity (vyšší obsah Mg). V súčasnosti je takou oblasťou moldanubikum Českého masívu, ale podobnosť v zložení granátov oslabujú rozdiely zistené pri analýze obliakového materiálu dogeru a liasu pienidných jednotiek. Niekoľko hornín tohto typu nie je v moldanubiku zastúpených. Riešenie tohto problému azda prinesie ďalší výskum.