Relationship between Moldanubicum, the Kutná Hora Crystalline Unit and Bohemicum (Central Bohemia, Czech Republic): A result of the polyphase Variscan nappe tectonics

Vztahy mezi moldanubikem, kutnohorským krystalinikem a bohemikem (Střední Čechy, Česká Republika): výsledek variské polyfázové příkrovové tektoniky

(51 text-figs, 16 tabs)

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The Moldanubian Zone, forming a highly metamorphosed root of the Variscan orogenic belt in Central Europe, is surrounded by several different lithotectonic units within the Bohemian Massif. These units mostly show lower metamorphic grade and different P-T histories. The relationships of these units to the Moldanubicum s. s. have been explained in different ways, but especially the relationships with the Bohemicum and the lowermost part of the Kutná Hora Crystalline Unit (KHCU) remained unclear.

Boundaries between the above mentioned units are exposed in the Sázava River valley area, 50 km ESE of Prague, which allows to study lithological, structural and metamorphic interrelationships of these units in detail.

The following lithotectonic units of different lithologies and P-T paths can be distinguished from the bottom to the top of the structural succession: Moldanubian Variegated Group (MVG), Micaschist Zone (MSZ), Kouřim orthogneiss nappe (both usually assigned to KHCU), Gföhl Unit (GU) and strongly sheared granitoids of CBP with preserved relics of metasedimentary and metavolcanic rocks of the Bohemicum. All units (except for the Kouřim Nappe) are dominated by psammitic to pelitic lithologies. Amphibolites and marbles are interlayered in MVG and MSZ, anatexites with relics of HP-HT rocks such as peridotites, eclogites and granulites are typical of GU.

Studies of the protolith of amphibolites and host metasediments in all the above mentioned units were carried out to reveal possible primary pre-collisional relationships and geotectonic settings of these units. While metasediments and metabasalts of MSZ and MVG share some common features, rocks of GU and Bohemicum differ significantly and originated in separate basins and tectonic settings.

Paragneisses of MSZ and MVG show evolved REE patterns as well as enrichment in K_2O, P_2O_5, Rb, Ba, Th and depletion in CaO, Na_2O nad Sr compared to the average upper continental crust composition. They were probably derived from the more evolved crustal segments in comparison to Late Proterozoic greywackes of the Bohemicum.

Migmatites of GU are mostly geochemically more evolved than paragneisses of the first group, but show larger variety in composition due to their complex tectonometamorphic history and primary variability of their source rocks. The former usually have higher contents of K_2O, P_2O_5, La, Ce, Cr, Ni and lower contents of CaO and N_2O.

Unlike the above mentioned groups, the metasediments of Bohemicum display contrasting geochemical signature. They are enriched in Na_2O, CaO, and Sr, and depleted in K_2O and Rb; different ratios of K_2O/Na_2O, Al_2O_3/Na_2O and SiO_2/Na_2O are also typical. The chemistry of metagreywackes was influenced by influx of less evolved material, probably derived from an island arc setting.

Banded plagioclase-bearing amphibolites of MSZ and MVG fall mostly in the field of tholeiitic basalts with a variable degree of crustal contamination. The more evolved types with steeper REE patterns, stongly enriched in K, Rb, Ba, Th, U, La and Ce and with a very slight Nb and Ta depletion, correspond to tholeiitic within-plate basalts.

Metabasites of GU show higher petrographic variability. The most primitive MORB-like signatures appear in coarse-grained pyroxene-bearing gabbroamphibolites. Banded amphibolites have usually higher contents of lithophile elements and steeper REE patterns. Coarse-grained metamonzogabbros and metamonzodiorites show features typical of more evolved Al-rich calc-alkaline rocks.

Metabasites of the Bohemicum from the Stříbrná Skalice area differ from both the above mentioned units in both major element contents (high SiO_2, Al_2O_3, Na_2O and K_2O) and REE chemistry. They probably originated in a convergent setting.

The present geological configuration of the nappe sequence is a result of polyphase westerly-orientated shearing of deep crustal slices with incorporated mantle material. This process started on a major shear interface located between GU and extremely ductile Kouřim orthogneisses. Sm-Nd garnet cooling ages of mantle peridotites and eclogites (Beard et al. 1991, Bruckner et al. 1991) suggest that exhumation of deep crustal and mantle rocks occurred between 370 and 340 Ma. When deep crustal nappes reached middle crustal levels (in the amphibolite facies field), strain partitioned into structurally lower unit (Micaschist Zone) and the whole nappe sequence was thrust over the paraautochthonous MVG. During this thrusting event, rocks of GU followed a retrograde P-T path in the kyanite stability field. Rocks of GU cooled down below the closing temperature of the Ar-Ar system on micas at ca. 340 Ma (Maluski, pers. comm), while rocks of MSZ and MVG underwent prograde metamorphism, partly comparable in both units. Peak metamorphic conditions reached sillimanite field in both units. Clockwise part of the P-T path can be interpreted by underthusting during emplacement of higher nappes.

The partly syntectonic emplacement of the Central Bohemian Pluton (350–330 Ma) postdates the main thrusting event at the Moldanubian–KHCU boundary. During this separate phase, rocks of CBP and associated roof pendants were thrust in a dextral transpressive ramp regime over the above mentioned stack of deep crustal nappes.

Subsequent decompression probably associated with a slight increase in temperature represents tectonic uplift in later phases penecontemporaneous with the emplacement of the Central Moldanubian Pluton (328–305 Ma). The greenschist facies retrogression and mylonitization in the Rataje Zone is associated with the strike-slip deformation operating at the interface between MSZ and MVG.

Key words: Bohemian Massif, Moldanubicum, Bohemicum, Kutná Hora Crystalline Unit, Gföhl Unit, metabasite, gneiss, metamorphic and structural evolution, Variscan nappe tectonics

1. Objective of the study, area studied, methods

This paper presents principal results of a study in the area of contact of three regional geological units: NW margin of the Moldanubian Region, S part of KHCU and the so far poorly known NW part of CBP, which lies at direct contact with the two above given units. The objective of this study was to apply multidisciplinary approach to the definition and delimitation of individual units, and to the explanation of their mutual lithological relationships, metamorphic and structural histories.

The framework of geotectonic evolution of this segment of Central European Variscides was elaborated on the basis of geochemistry of magmatic rocks in this area and, to a lesser degree, on the basis of lithology and geochemistry of metasediments including the results of comparative study of metamorphic histories of the studied units. In addition, the study of metamorphic mineral assemblages of metasediments and metabasites supplemented by thermobarometric data from suitable mineral pairs of metasediments/metabasites and the corresponding microstructures allowed to evaluate the kinematic and P-T histories of the units during the Variscan collision.

Field studies concentrated especially on the key area, where the three units (i. e., Moldanubicum, CBP and KHCU) meet. They focussed particularly on the incised valley of the Sázava River and its tributaries between Stříbrná Skalice and Český Šternberk, where a new geological survey was done. Continuation of the contact zone between Moldanubicum and KHCU to the east was studied along transverse, mostly N-S sections following deeper stream incisions. This method was applied on the contact between Moldanubicum and KHCU as far as to the SW limits of Čáslav.

Mineral chemical compositions for the purpose of comparative study and thermobarometric calculations were studied using CAMEBAX microanalyser (operator J. Hovorka) at the Faculty of Science, Charles University, Prague.

Mineral analyses were performed with the use of CAMEBAX microanalyser (operator J. Hovorka) at the following parameters: accelerating voltage 15 kV, current 22 μA, t = 10 s. Mineral recalculations were largely made using Mincalc program (Melín et al. 1992), amphibole recalculations using AMPHTAB program (Rock 1987). Some other recalculations employed original procedures in Quatro for Windows.

Bulk analyses of some samples, trace element analyses and REE determinations using INAA were performed by Gematrix Černošice (analysts Štrůblová – bulk analyses and trace elements, Hanzlík – REE using INAA). The remaining analyses of REE and a selected set of trace elements were done by J. Bendl, Analytika Praha, on ICP-MS. More detailed information about the material analysed is provided in the explanations of tables, which show results of chemical analyses of rock groups from all studied units.

2. Position of internal zones of the Bohemian Massif in the Central European Variscides

The Bohemian Massif (BM) represents the easternmost part of the Variscan orogenic belt (fig. 1): Its complex structure results from processes linked with the commencing Cambro-Ordovician breakup of peri-Gondwanan microcontinents (Matte 1986, Ziegler 1986, Franke 1989a, b, Neugebauer 1989, a. o.), closure of ocean basins and subsequent progressive amalgamation of microcontinents during the Gondwana – Laurussia (Baltica) collision in the Devonian to Lower Carboniferous. Variscan convergence, culminated by the destructions of oceanic regions between the individual terranes and subsequent continental collisions of different segments, resulted in the formation of the Variscan orogenic belt (Dallmeyer et al. 1995).

The Variscides, and the Bohemian Massif itself, therefore represent a collage of terranes of different pre-collisional and collisional histories, united during the Variscan Orogeny. The individual terranes can be traced almost along the whole course of the orogen in the external segments of the Variscan mountain belt (Rhenohercynian Zone and partly Saxothuringian Zone in the original sense of Kossmat 1927, Stille 1951). In the internal zones (particularly the Moldanubian Zone), however, correlation between separate isolated relicts of the Variscan Orogen in Europe is much more difficult. As suggested by radiometric data (Van Breemen et al. 1982, Kröner et al. 1988, Gebauer and Friedl 1993, Wendt et al. 1993, 1994, Frýda et al. 1995), by the presence of eclogites and mantle rocks in different units of the Moldanubian Zone of the Bohemian Massif, and by other observations, the orogen has a complicated internal structure comprising separate autonomous units (see Fiala et al. *in* Dallmeyer et al. 1995, Fiala and Patočka 1994, Vrána 1995, Urban and Synek *in* Dallmeyer et al. 1995, and others). Similar problems also relate to the correlation of e. g. micaschist zones (mostly following the outer limits of Moldanubicum s. s.), and the position and internal structure of the Svratka and Kutná Hora crystalline complexes.

A large number of unsolved problems persists despite of the plentiful new information obtained from palaeomagnetic, palaeofacies and palaeobiogeographic reconstructions, or deep reflection profiles (see e. g. Franke 1989, Oncken 1988, Vollbrecht et al. 1989, Vrána 1992, Vrána and Tomek 1994, Edel and Weber 1995). The most topical problems in the Bohemian Massif and the Moldanubian Region particularly relate to:

a) the number and interrelationships of sutures indicated by massifs of basic and ultrabasic rocks with bodies of high-pressure rocks formed at subduction of oceanic lithosphere, and the corresponding CA (calc-alkaline) volcanic belts (see Matte 1986, Matte et al. 1990, Franke 1989, Neugebauer 1989) at the boundary between the Teplá-Barrandian and Saxothuringian terrane, Moldanubicum and the Teplá-Barrandian terrane, and along the Moldanubicum/Moravo-Silesian boundary (Fritz

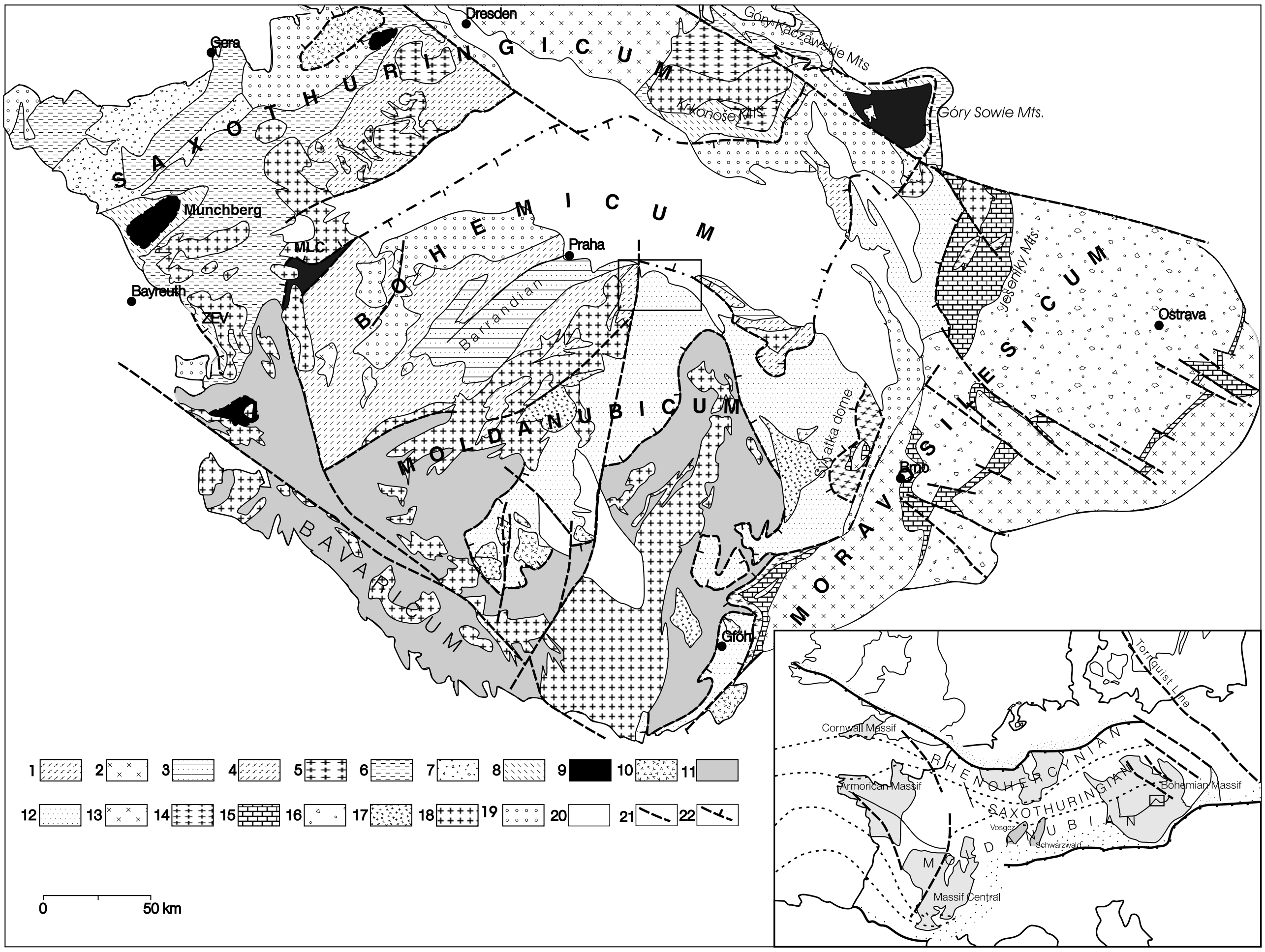


Fig. 1. Tectonic sketch map of the Bohemian Massif showing the main terranes (modified after Matte et al. 1989). Bohemicum (Teplá-Barrandian Unit): 1. Late Proterozoic volcano-sedimentary sequences; 2. Pre-Variscan (Cadomian granitoids); 3. Early Palaeozoic metasediments and volcanics (Cambrian to Devonian). Saxothuringicum: 4. Late Proterozoic metasediments; 5. Cadomian metagranitoids (orthogneisses); 6. Early Palaeozoic metasediments (Cambrian to Devonian); 7. Early Carboniferous diastrophic sediments. Allochthonous units (in Saxothuringicum and Moldanubicum): 8. lower part of allochthonous units consisting of weakly metamorphosed metasediments, basic volcanics and ultrabasic rocks; 9. high grade rocks (gneisses, metagabbros, eclogites); 10. granulite massifs including eclogites and HP mantle peridotites; Moldanubicum: 11. high grade gneisses probably Late Proterozoic up to Early Palaeozic age (Ostrong and Drosendorf Groups); 12. allochthonous complexes of the Gföhl Unit with relics of HP rocks; Moravosilesicum (including Brunovistulicum): 13. Cadomian basement of Brunovistulicum (Cadomian granitoids and their metamorphic mantle); 14. Cadomian orthogneisses of the Moravosilesian Units; 15. Early to Late Palaeozoic volcano-sedimentary sequences of the Moravosilesicum (icluding basement units); 16. Visean to Namurian diastrophic sediments (Culm facies) in the upper part with transition to weakly deformed sediments of the Variscan foredeep. Variscan granitoids: 17. melanocratic granites and syenites (durbachites); 18. tonalites to granites; 19. Late Carboniferous to Permian clastic sediments and volcanics (epi-Variscan platform sediments); 20. post-Permian cover; 21. major fault zones; 22. thrust, nappe boundaries.

1990, Neubauer 1991, Fritz et al. 1994, 1995, in print, Steyer and Finger 1994),

b) protolith ages for the individual “terranes” or lithotectonic units of the Moldanubicum (Monotonous Group = Ostrong Unit, Variegated Group = Drosendorf Group and GU), or the Královský hvozd Unit, Kaplice Unit and the Bavaricum,

c) correlation of the occurrences of ultrabasic and lower-crustal rocks in units at the periphery of the Moldanubian Region: KHCU, Svratka Anticline, Letovice Crystalline Complex, with rocks of allochthonous GU of Moldanubicum s. s. (Synek and Oliveriová 1993, Schulmann et al. 1991, Fritz et al. in print, Steyer and Finger 1994, Mísař 1994, Montag and Höck 1994, Medaris et al. 1994, 1995),

d) the age and geotectonic position of ultrabasic rocks within the Moldanubicum, e. g., near the boundary between the Monotonous Group and Světlík orthogneiss and Variegated Group (Světlík eclogite belt, Vrána 1994, 1995),

e) the senses of transportation and mechanisms of exhumation of lower-crustal nappes with incorporated mantle rocks in the whole Moldanubian Zone including the units at its periphery (see discussions in Tollmann 1982, Matte 1986, Matte et al. 1990, Schulmann et al. 1991, Neubauer et al. in print),

f) the geotectonic position of the Teplá-Barrandian Region and its relation to the Moldanubian Region and the Kutná Hora-Svratka Region.

As the study area lies at the contact of the Moldanubian Region with the Kutná Hora-Svratka Region (Mísař et al. 1983) and the Teplá-Barrandian Region (Bohemicum *sensu* Malkovský 1979), the attention will be paid particularly on the study of these units.

Reconstruction of their interrelationships is based mainly on:

1. comparison of the protolith chemical compositions and metamorphic histories of pelitic-psammitic rocks of the Micaschist Zone – MSZ (Koutek 1933, Oliveriová 1993) and the underlying gneisses of the Šternberk-Čáslav Variegated Group of the Moldanubicum (Losert 1967) and migmatite relicts newly correlated with GU,

2. comparison of chemical composition and metamorphism of metavolcanic rocks of the above mentioned units and their palaeotectonic interpretation,

3. comparison of granitoids emplaced into the rocks of MSZ and the Moldanubicum in the area immediately adjacent to the NE part of the Central Bohemian Pluton (CBP) with CBP rocks; this allows to determine the ages of tectonic processes in the adjacent Moldanubicum and KHCU relative to those of dated emplacements of some CBP members.

Formulation of a consistent idea on palaeotectonic relationships within the present configuration of Moldanubian units necessitates a comparison of material, structural and metamorphic aspects of the individual segments and a comparison of their protolith ages. This is why rocks from other occurrences of GU and rocks of the different variegated groups were correlated on the basis of the available published data.

3. Summary of the present knowledge of individual units exposed in the study area

Several lithotectonic units can be distinguished in the study area near the NW margin of Moldanubicum *s. s.* at its contact with the Kutná Hora-Svratka Region, Bohemicum (Teplá-Barrandian Unit) from the base to the top in structural position – fig. 2:

1. **Moldanubicum** of the Šternberk-Čáslav Variegated Group (slightly different from the original definition of Losert 1967),

2. **Kutná Hora Crystalline Unit (KHCU)** represented by the Micaschist Zone – MSZ (Koutek 1933, Synek and Oliveriová 1993) and Kouřim orthogneiss (nappe) in the study area,

3. a relict of the **Gföhl Unit** (similarity of the so-called Čeřenice orthogneiss was reported as early as in

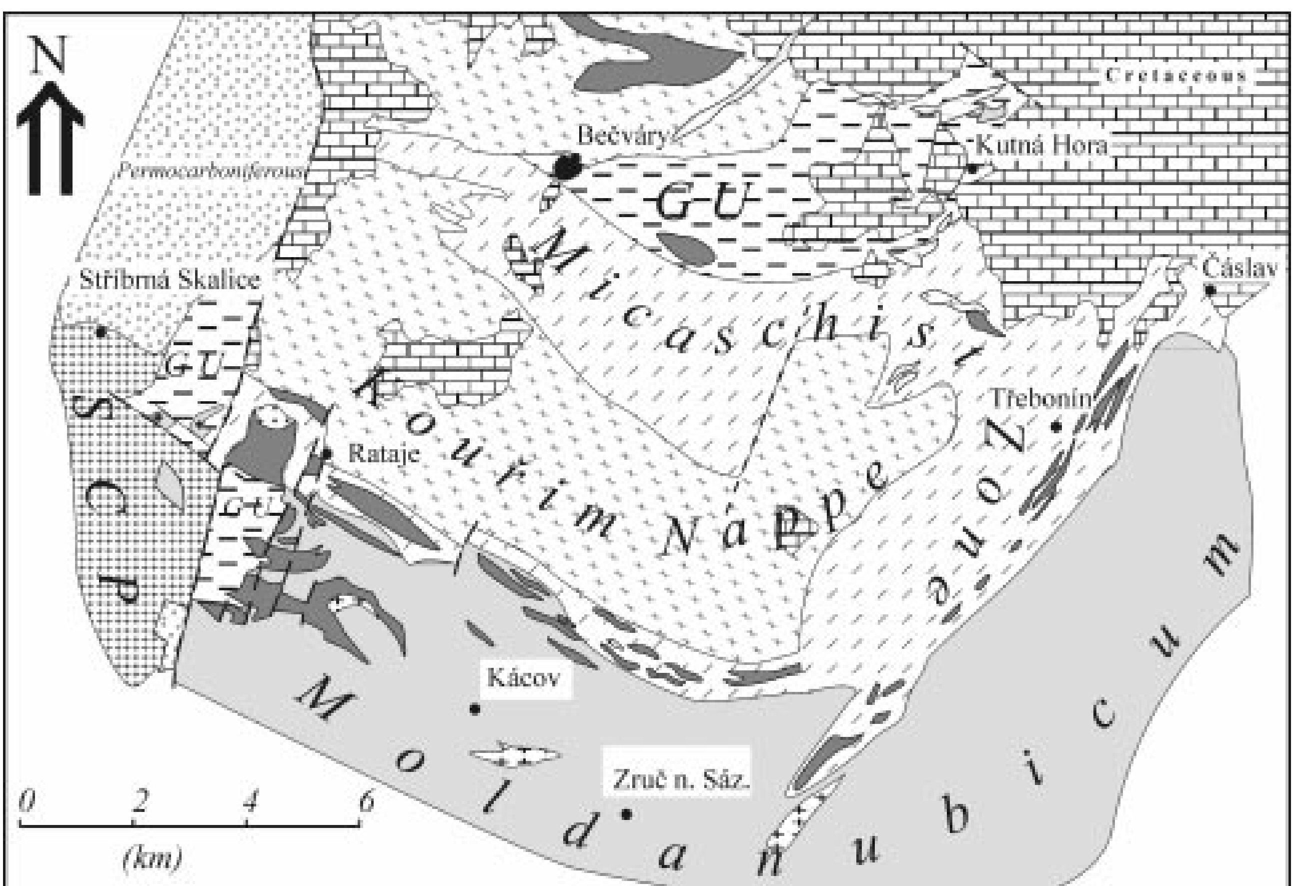


Fig. 2. Schematic tectonic map of the of the southestern part of KHCU at the contact with Moldanubicum and Bohemicum showing main units and their relationships. Explanations: 1. serpentized peridotite; 2. amphibolite; 3. orthogneiss; 4. paragneiss; 5. migmatite, pearl gneiss; 6. retrogressed paragneiss, "micaschist"; 7. granodiorite, tonalite; 8. sandstone, shale, conglomerate; 9. sandstone, mudstone, marlite.

Koutek 1933), lying in the direct tectonic hangingwall of the Variegated Group of the Moldanubicum with the exception of the separate segment of pearl gneisses in the Sázava River cut S of Malovidy, where paragneisses of the Variegated Group overlie rocks of Gföhl provenance due to re-folding or possibly local tectonic-slice setting,

4. **Central Bohemian Pluton – CBP** (Holub 1991, Holub et al. 1995) represented by strongly ductile-deformed quartz diorites, metagabbros, leucocratic granitoids and several types of heterogeneously ductile-deformed biotite granitoids of Benešov type.

3.1. Moldanubicum

Moldanubian Zone of the Bohemian Massif poses an extensive polymetamorphic segment of the Variscides, which incorporates supracrustal, lower-crustal and mantle elements of different ages and P-T histories. Their present arrangement results from intensive Variscan compressional horizontal tectonism (Tollmann 1982, Matte 1986, Franke 1989, Urban and Synek in Dallmeyer 1995) and subsequent reworking under tensional regime (e. g., Zulauf 1994a, b, Fritz et al. in print, Schulmann et al. 1991). The original relationships between the units may be masked by movements in a large-scale ductile strike-slip regime (e. g., Rajlich et al. 1988). The former lithostratigraphic approach to Moldanubicum subdivision (Vejnar 1962, 1965, 1968, Jenček and Vajner 1968, Chaloupský 1978, 1989, Zoubek 1988, Zoubek et al. 1988) therefore does not correspond to the present information on protolith age and metamorphic and tectonic histories of the individual units.

Definition of the Moldanubicum and its relations to the neighbouring units

This extensive unit is surrounded (mostly tectonic contacts) by the following units (fig. 1): Saxothuringicum in the NW (Vollbrecht et al. 1989), Bohemicum in the N and the Cadomian basement of the Moravosilesicum in the SE. In the south and southwest, Moldanubicum plunges beneath younger, Mesozoic or Tertiary, platform cover. In the north, two separate units are distinguished at the boundary between Moldanubicum s. s. and Bohemicum: Kutná Hora and Svratka crystalline complexes. These complexes share many common features with the Moldanubicum (e. g., the presence of lower-crustal and mantle rocks) and were therefore included in the Moldanubian Zone by some authors (Zoubek 1988), although some of their parts show a somewhat lower degree of metamorphism. The boundaries between the Moldanubicum and the neighbouring units are generally considered tectonic (see review in Franke 1989, Fiala and Wendt in Dallmeyer et al. 1995) but were also explained as zones of facies and metamorphic transitions by some authors (e. g., Suk 1973, Vejnar 1962, 1965, Losert 1967, Frank et al. 1990, Frank 1994).

Several separate units ("terranes", lithotectonic units bounded by significant tectonic discontinuities) can be distinguished in the Moldanubicum on the basis of lithologies, P-T histories and protolith ages. These include (from the base to the top in structural position):

a) **Ostrong terrane** (Fuchs and Matura 1976), corresponding to the former **Monotonous Group** and additionally including the Kaplice Unit (Vrána 1979, 1992). It is composed of a thick succession of mostly LP-HT (low-pressure, high-temperature) biotite and biotite-cordierite gneisses, often migmatitized (~650–700 °C, 3–4 kb), with occasional bodies of quartzites, amphibolites, ultrabasic rocks and associated eclogites. An older MP/LT-MT (medium-pressure, moderate temperature values) stage is known from residual associations mostly enclosed in garnets (Blümel and Schreyer 1976, Babůrek 1995, O'Brien 1994). A more complicated polymetamorphic history was described by Vrána (1979, 1992) from the Kaplice Unit. The age of metasediments of the Monotonous Group is not known. Middle Proterozoic age of the protolith of gneisses was suggested by Máška and Zoubek (1960) and Chaloupský (1978). The youngest determined age of detrital zircons from the Monotonous Group gneisses of 727 ± 106 Ma (Kröner et al. 1988) is considered by the authors as evidence of the maximum, i. e. Upper Proterozoic, age of sedimentation for the Monotonous Group pelites. High ages of the different populations of detrital zircons indicate that the source of material was a very old, Lower to Middle Proterozoic, crust. The frequency of the determined zircon ages indicates that the sediments were probably derived from the crust building the present Gondwana sediments (Kröner et al. 1988, Wendt et al. 1993, 1994). The Ostrong Unit is not present in the study area.

b) Drosendorf terrane (= Variegated Group in older concept)

Despite some impropriety and inconsistency in its application (see Tollmann 1982, Franke 1989, Mísař 1994), the term Drosendorf Group (terrane) is used to denote the Variegated Group and its Precambrian basement, represented by the Dobra orthogneiss (1 380 Ma, Wendt et al. 1993) and its equivalents, which were probably transgressed by the Variegated Group (Fuchs and Matura 1976). The Dobra orthogneiss and Variegated Group rocks are thrust over the underlying Ostrong Unit.

The Variegated Group is composed of biotite-sillimanite paragneisses with frequent garnet, which include – unlike the preceding series – very common intercalations of quartzites, carbonates, erlanes, graphite gneisses and amphibolites. The petrographical variety of the intercalations and a different character of pelitic material indicates a different environment for sediment deposition, probably a rather stable shelf of a passive continental margin. The age of deposition of the Variegated Groups rocks is a matter of dispute. Low Sr isotope ratios in the Variegated Group carbonates (Frank et al. 1990,

1994) are interpreted by the above authors as evidence of the Upper Proterozoic age (800–900 Ma) of the Variegated Group carbonates. In their concept, these carbonates together with the carbonates of the Moravicum represent shelf deposits of the Brunovistulicum, involved in Variscan convergence. This interpretation is contradicted by finds of microfossils of Silurian age (Andrusov and Čorná 1976, Pacltová 1980, 1986). The Paleozoic age of at least a part of the Variegated Group is indirectly evidenced also by the presence of detrital zircons derived from Cadomian granitoids in sediments of the Variegated Group and by the Paleozoic ages of zircon crystallization in leptites – volcanic rocks considered to be synchronous with sedimentation.

Metamorphic mineral assemblages of gneisses of the Variegated Group from the period of peak metamorphism correspond to temperatures of 700–800 ˚C and pressures of 7–9 kb (Petrakakis 1986). This period was followed by isothermal decompression at ~5 kb and subsequent cooling at 600–450 ˚C (Carswell 1991).

The minimum age of the metamorphism is defined by the Lower Viséan age of conglomerates containing pebbles of Moldanubian rocks (Štelcl 1969) and also by the emplacement ages of the Weinsberg granite and Rastenberg granite (346 and 349 Ma, Rb-Sr, Frank et al. 1990; 338 Ma, U-Pb, Klötzli and Parrish 1994), by K-Ar age of amphibole cooling from the Variegated Group amphibolites (338–320 Ma, Fritz et al. in print). Data from different types of intrusive rocks obtained using different methods show a relatively wide dispersion; the data partly overlap with the age of granulite metamorphism. This evidences a very rapid exhumation of lower-crustal rocks intruded by granitoids.

Rocks of the Variegated Group in the study area are generally represented by biotite-sillimanite paragneisses with frequent amphibolite bodies and less frequent carbonates, quartzites (N of Zruč nad Sázavou) and calc-silicate gneisses and graphite gneisses (confluence of the Blanice and Sázava Rivers). They extend from Rataje and Český Šternberk to Čáslav, along the southern periphery of MSZ. The association of gneisses with metabasites and occasional carbonates is a common feature of rocks of MSZ and the underlying MVG. The two units were therefore united by Losert (1967) into a single lithostratigraphic unit called the SCVG. Losert considered this group to be Upper Proterozoic in age and believed this was an argument for a direct connection between KHCU and Moldanubicum, and for non-existence of the earlier suggested unconformity (Máška and Zoubek 1960, Beneš 1962, 1964).

c) Gföhl Unit

Allochthonous GU is the stucturally uppermost unit of the Moldanubicum. It mostly rests upon the underlying MVG or locally Monotonous Group in the form of tectonically confined klippen. Its equivalents, however, lie at high structural positions also in the adjacent units: KHCU (Synek and Oliveriová 1993, and possibly Svratka Anticline – Schulmann et al. 1991). GU is generally formed by leucocratic migmatitic gneisses and migmatites passing into rocks of orthogneiss appearance, and banded amphibolites. The unit also comprises tectonically emplaced granulite bodies accompanied by mantle-derived ultrabasic rocks. The unit is interpreted as mélange of various segments of the crust and mantle, prolapsed from the oceanic suture after the closure of the presumed ocean during Variscan continental collision. Relicts of the ocean crust are preserved in the form of ophiolite sequences of the **Raabs Unit** – Raabs-Meisling Unit (Steyer and Finger 1994, Fritz 1994), correlated with the Letovice Ophiolite Complex. Amphibolite bodies of the Variegated Group and of GU are correlated by some authors such as Montag and Höck (1994) and referred to as the **Rehberg Amphibolite**. As no important differences exist between the metamorphism of the underlying Variegated Group and that of GU, the boundary between the two units cannot be unambiguously defined. Nevertheless, Paleozoic protolith ages of Gföhl gneisses (Arnold and Scharbert 1973, Scharbert 1987, Frank et al. 1990, Frank 1994), some amphibolites and granulites (van Breemen 1982, Aftalion et al. 1989, Carswell 1991, Wendt et al. 1994), ultrabasic rocks (Carswell and Jamtveit 1990), as well as the presence of HP (high-pressure) mantle-derived rocks convincingly document the allochthonous character of the two units. The complex history of the Moldanubicum is, however, evidenced by the newly obtained Sm-Nd data from South Bohemian granulites, which indicate Proterozoic, 722 Ma (Frýda et al. 1995) event in the history of granulites and subsequent Variscan HP-HT (high-pressure, high-temperature) event dated to ca. 390–370 Ma (Frýda et al. 1995); similarly by U-Pb data from zircons (Wendt et al. 1994) – 373 Ma.

3.2. Kutná Hora Crystalline Unit

The Kutná Hora Crystalline Unit (KHCU) lies in tectonic hangingwall of the Moldanubicum *s. s.*, i. e. of its SCVG, around which it bends in the Čáslav sigmoidal flexure. The complex is covered by Cretaceous platform sediments in the north, and bounded by the Železné hory Fault in the NE. This structure was reactivated as a reverse fault during Alpine Orogeny and separates Cretaceous sediments in the footwall block from the crystalline complex, Proterozoic and Paleozoic units of the Železné hory Mts. in the hangigwall block. In the west, KHCU borders across the Kouřim Fault with migmatites, pearl gneisses and strongly ductile-deformed orthogneisses of GU, which is transgressed by clastic sediments of the Permo-Carboniferous Český Brod Basin further north.

Taking into account the studies of Koutek (1933, 1940), Kodym (1954) later defined KHCU as an independent unit on the basis of somewhat lower degree of metamorphism manifested by the presence of two-mica gneisses and micaschists with kyanite, staurolite and garnet, and the presence of red Kouřim orthogneisses often paralleled with analogous rocks of the Saxothuringian Region. On the other hand, features shared by the Moldanubicum include the presence of numerous bodies of ultrabasic rocks, eclogites and leptites (Kratochvíl 1947, Fiala 1965, Fiala et al. 1982, Pouba et al. 1987, Medaris et al. 1994). The multitude of parallel as well as divergent elements in KHCU on one hand and Moldanubicum on the other was reflected by the different interpretations of their mutual relation (structural unconformity of Beneš 1962, 1964 vs. lithological transition of Losert 1967, Staník 1976).

A completely new idea on the structure, tectonometamorphic history and relations to the ambient units was presented by Synek and Oliveriová (1993). This study explains, to a certain degree, the existence of similar and contrasting features between KHCU and the Moldanubicum by defining three separate lithotectonic units within KHCU, separated by subhorizontal tectonic structures of nappe character produced during the Variscan Orogeny (Beard et al. 1992, Oliveriová, Synek and Maluski 1995). These thrust planes separate crustal segments, which differ in their lithology, metamorphic history and probably also in their age.

These segments include (from bottom to top):

a) **Micaschist Zone (MSZ)**, overlying the Moldanubicum and exposed in a tectonic half-window from the footwall of the Kouřim and Gföhl nappes in the central part of KHCU. This unit was considered a product of retrogression of Moldanubian rocks at the important tectonic boundary between the two units (Koutek 1933). Its polymetamorphic character was evidenced by Synek and Oliveriová (1993) and Oliveriová (1993). Older metamorphic stages documented by inclusions in garnets indicate an event corresponding to greenschist facies and epidote-amphibolite facies conditions, followed by a typical Barrovian association with kyanite, staurolite and garnet and by association biotite-sillimanite, linked with decompression and accompanied by minor temperature increase. The last event recorded in these rocks is a retrogression under greenschist facies conditions, manifested by the growth of muscovite and chlorite at the expense of older mineral parageneses.

b) **Kouřim Nappe** represented by a compositionally homogeneous body of the Kouřim orthogneiss, probably pre-Variscan in age, which corresponds to a strongly and relatively homogeneously deformed K-rich calc-alkaline metagranitoid (Klečka and Oliveriová 1992) with relatively insignificant relicts of strongly migmatitized mantle-derived rocks. During the Variscan collisional event, the granitic rock (together with its envelope) was intensively recrystallized into a homogeneously deformed orthogneiss, locally having the character of pencil gneiss. Final stages of deformation linked with the growth of newly formed biotite were dated at 320 Ma using Ar-Ar method (Matte et al. 1990).

c) **Gföhl Nappe**, occupying the highest structural position, is a rock association comparable to GU exposed in the Moldanubicum *s. s.* in the ages of HP-HT metamorphism of eclogites (Brueckner et al. 1991) and cooling of peridotites (ca. 370 Ma, Sm-Nd, Beard et al. 1991). The ascent of the nappe into the middle crust is associated with retrogression taking place under amphibolite facies conditions. This retrogression has been dated to 340 Ma by Beard et al. (1991). The Gföhl Nappe in KHCU can be subdivided into three separate lamellae on the basis of rock associations and variations in metamorphic development (Synek and Oliveriová 1993): Malín Formation (Losert 1967), Plaňany Formation and Běstvina Formation.

3.3. Bohemicum (Teplá-Barrandian Unit)

Bohemicum – Malkovský 1979 (Central Bohemian Region – Mísař et al. 1983, Central Bohemicum – Návrh 1994, Teplá-Barrandian Unit), is a crustal block characterized by a positive gravity anomaly, where unconformably folded and un-metamorphosed Cambrian to Middle Devonian sedimentary and volcanic rocks overlie a Cadomian fundament subjected to weak anchimetamorphism or low-grade metamorphism of Panafrican age. In its northern, northeastern and eastern parts, folded Proterozoic and Paleozoic units are covered by Permo-Carboniferous sediments of Variscan inner molasse and locally by younger, largely Upper Cretaceous platform sediments. Large Variscan plutonic bodies were emplaced along the SE margin of the Bohemicum: the Central Bohemian Pluton (Holub et al. 1995) and the Železné hory Pluton. The emplacement ages vary in the range of 355–331 Ma (van Breemen et al. 1982, Holub et al. 1996, Dörr et al. 1996, Zulauf 1995).

The Cadomian fundament, especially at its contacts with the higher-grade metamorphosed complexes of Saxothuringicum and Moldanubicum, was strongly reactivated during the Variscan Orogeny, locally reaching the amphibolite facies conditions. Formation of Lower Paleozoic basins, emplacement of Cambro-Ordovician magmatites (Dörr et al. 1992) and rift-related and intraplate volcanics of Ordovician-Devonian ages indicate extension of the Cadomian basement during the Early Paleozoic.

The onset of Variscan compressional tectonics is sedimentologically indicated as early as in the Middle Devonian (onset of siliciclastic sedimentation). The older Barrovian-type MP-MT metamorphic event at 370–360 Ma (Beard et al. 1991, Dallmeyer and Urban 1994) in the Teplá Upland is correlated with crustal thickening during the collision of Saxothuringian and Teplá-Barrandian microplates (see Franke 1989, Zulauf 1994). Late Variscan (330–320 Ma) LP-HT reactivation of the Teplá-Barrandian Region and the underlying Moldanubicum is associated with the post-orogenic extension in some areas such as the West Bohemian Shear Zone (Zulauf 1994). The emplacement of most significant masses of CBP was immediately preceded by movements on the Central Bohemian Shear Zone (338–332 Ma, Košler et al.

1993, 1995, Košler 1995), although the ages of formation of steeply-dipping cleavage planes may be even somewhat higher as indicated by new radiometric datings of some plutonic rocks (Holub et al. 1996). The deformation of minerals produced by contact metamorphism in the region of CBP (Kachlík 1992) however implies that tectonic processes, which gave rise to uniformly striking NNE-SSW structures in the Islet Zone, were of polyphase character. Timing of the youngest deformations coincides with the emplacement of CBP.

Paleotectonic position of the Bohemicum within the zoned structure of Central European Variscides is still a matter of discussion. The Bohemicum is interpreted either as an upper structural floor of the Moldanubian Region (Franke 1989) or as a member of the Saxothuringian Region, or possibly a separate microcontinent bounded by sutures on both sides (Matte 1986). Other authors emphasize large-scale strike-slips, which controlled movements of blocks in final stages of the Variscan Orogeny – Rajlich et al. (1988), Matte et al. (1991).

As it has been demonstrated by Pitra et al. (1994) and Pitra and Girauld (1996), the Hlinsko Zone was not formed by backward thrusting of the Bohemicum (?) over Moldanubicum, but represents a shear zone dominated by normal faults, along which the Svratka Crystalline Complex was exhumed and now occupies the position of a metamorphic core complex relative to the Hlinsko Zone. A detailed assessment of a possible nappe discontinuity at the boundary between KHCU and the Podhořany and Oheb Crystalline Complexes, Proterozoic and Paleozoic of the Železné hory Mts., would confirm or reject the idea that at least the marginal part of the Bohemicum is incorporated in the Variscan nappe structure and that rocks of GU indicate the existence of a suture between crustal blocks of different provenance. Such an assessment is, however, missing.

In analogy with the Železné hory Region, the contact between Bohemicum with Moldanubicum *s. s.* is obscured by the presence of the Central Bohemian Shear Zone (Rajlich et al. 1988) and younger emplacement of the Central Bohemian Pluton. The Upper Proterozoic and Lower Paleozoic rocks preserved in the envelope of the Central Bohemian Pluton can be correlated with the Bohemicum (Chlupáč 1986, 1992, Kachlík 1992a, b) and, in some parts of the succession, with the Paleozoic rocks of the Železné hory Mts. in their close lithofacies characteristics (Chlupáč 1986). Chlupáč (1992) pointed out the marked lithofacies similarities between the Paleozoic of the Islet Zone and some parts of the Sušice-Votice Variegated Series of the Moldanubicum. The position and age of bodies of ultrabasic rocks in the Mirovice Islet have not been sufficiently evaluated yet (Pouba et al. 1994). Intrusive relationships between Mirotice and Staré Sedlo orthogneisses and their envelope formed by the rocks of both Moldanubian and Bohemicum regions suggest that the above mentioned units were juxtaposed at the time of orthogneiss emplacement at 373 ± 5 Ma (Košler 1995) and hence got to their position in pre-Devonian times already as two different crustal segments. Their present position was modified by movements along the Central Bohemian Shear Zone before the emplacement of the pluton (370–340 Ma, Košler 1995, cf. Holub et al. 1996). Forcible emplacement of CBP in a dextral shear zone explains its present position in the hangingwall of the Moldanubicum, shown by geological maps on the SE margin of CBP (cf. Kettner 1930). As indicated by the closing of K-Ar isotope system in biotites of mylonitized pearl gneisses and Kouřim orthogneisses at the contact between CBP and the Moldanubicum, the last active movements associated with final emplacement of nappes at the boundary between the Moldanubicum and CBP and KHCU occurred as late as at 336–325 Ma (Oliveriová et al. 1995).

4. Geological and petrographic characteristics of units at the contact between Moldanubicum, the Kutná Hora Crystalline Unit and the Central Bohemian Pluton

4.1. (Šternberk-Čáslav) Variegated Group of the Moldanubicum

Rocks of the SCVG of the Moldanubicum occur at low to moderate dip angles along the whole contact with KHCU or the Micaschist Zone in its tectonic footwall (see figs 3, 4). In the S and SW vicinity of Drahňovice and Šternov SW of Český Šternberk, they also occur in the footwall of migmatites with boudins of ultrabasic rocks, penetrated by bodies of orthogneisses and pegmatites. Rock association can be correlated with rocks of GU according to many common features (cf. Koutek 1933). In some parts of the tectonically complicated area SE of Malovidy, where large folds with NW-SE-trending axes are closed, pearl gneisses were also found in the footwall of paragneisses of the Variegated Group (see fig. 3). As in other areas within the Moldanubicum, discriminating between the Variegated Series and GU is problematic particularly in cases, where the boundary between the two units is complicated by the presence of numerous bodies of metabasic rocks. Amphibolites with limestone intercalations were usually placed in the Variegated Group. Coarse gabbroamphibolites with pyroxenite boudins S of Poříčko, garnet amphibolites S of the Vrabov Castle ruin and strongly deformed gabbroamphibolites overlying the interval of alkaline pearl gneisses near Vraník were classified with GU as they alternate with gneisses of Gföhl provenance and include rock types characteristic of GU, such as serpentinites and pyroxenites. It can be ruled out that the large amphibolite body in the Stříbrná Stream valley near Český Šternberk splits into a number of small apophyses alternating with orthogneisses. It merely represents a more strongly retrogressed equivalent of the above described rocks and belongs to GU rock association.

A considerable innovation of the existing geological maps (figs 3, 4) is the shift of MSZ/Moldanubicum boun-

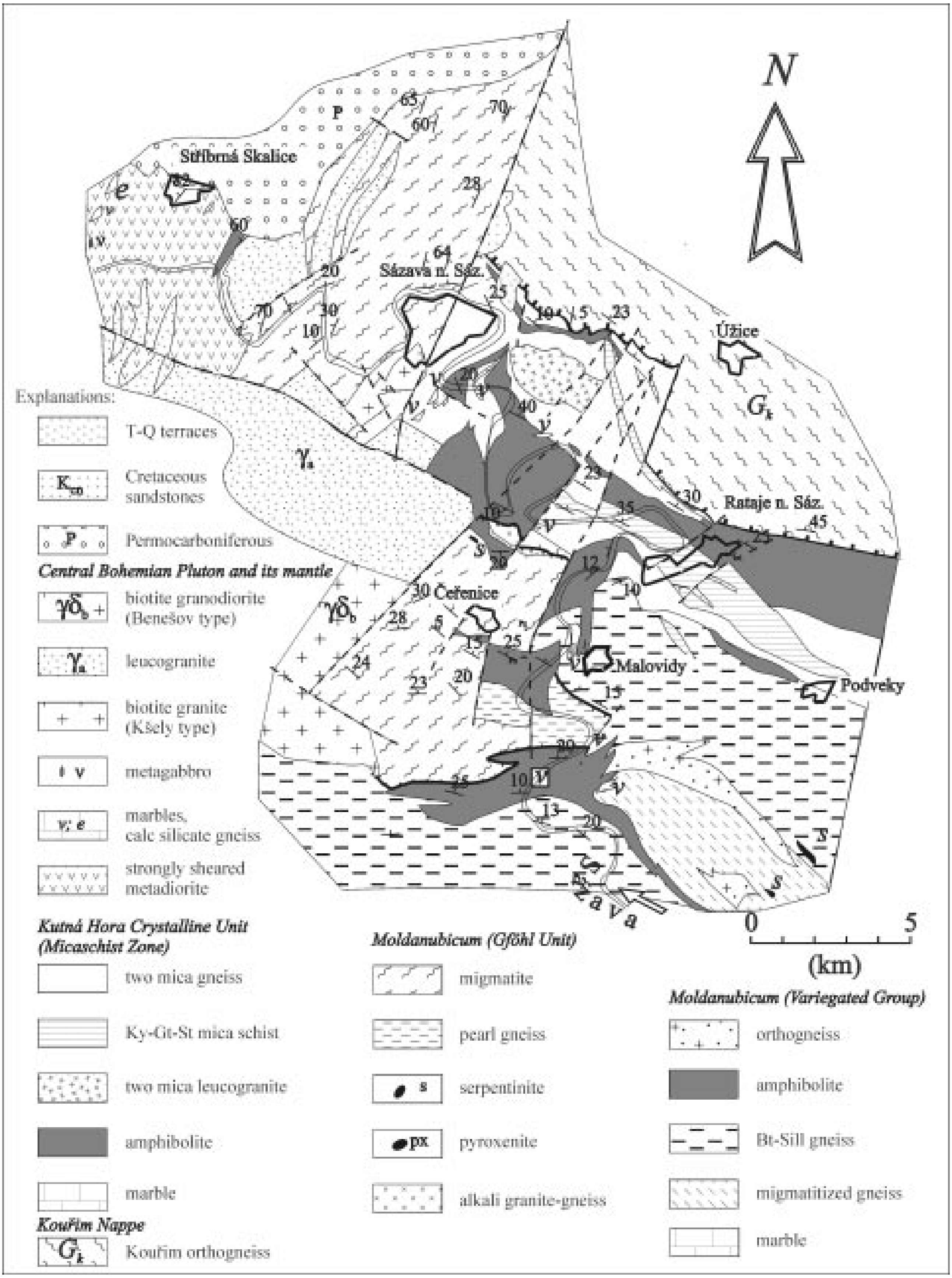


Fig. 3. Detailed geological map of the area at the contact of KHCU, Moldanubicum and Bohemicum near Sázava nad Sázavou (Kachlík 1996).

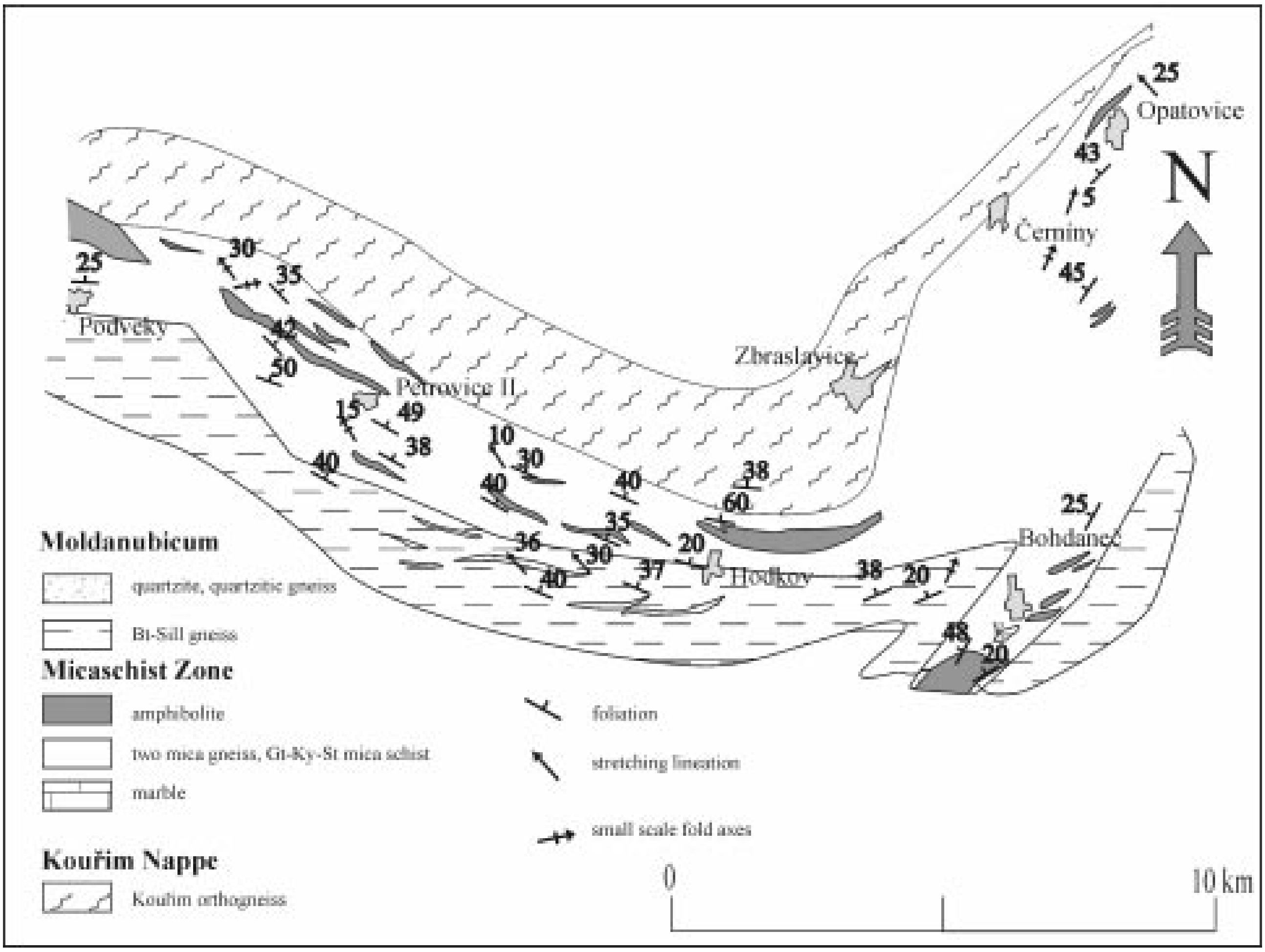


Fig. 4. Geological map of the southern and eastern part of MSZ and underlying Moldanubicum (eastern part partly after Štěpánek (1992).

dary in Bohdaneč area. This shift was, independently of the present authors, equally interpreted by Štěpánek (1992) in the new map 1:25,000. A sudden change in foliation plane orientations in the Moldanubicum, Micaschist Zone and the overlying Kouřim orthogneisses is linked with the presence of a prominent NNE-SSW-striking shear zone with left-lateral strike-slip movement. Besides NNE-SSW-trending lineations, the shear zone is associated also with folds with subhorizontal axes and often subhorizontal axial planes; folds in this zone can be observed in outcrops between Bohdaneč and the Vrchlice Stream valley W of Kutná Hora (see Koutek 1967). One of the folds of this type is also responsible for the southeasterly protrusion of the Bohdaneč spur of MSZ into the Moldanubicum (cf. structural map of Holubec 1977). The relation of MSZ rocks to orthogneisses and skarns in a belt NE of Vlastějovice was not studied. Other arguments for the inclusion of the Bohdaneč spur within MSZ are presented in the chapter on rock geochemistry.

The reinterpretation of the body of leucocratic two-mica orthogneisses at the Jeřáb Hill NE of Mrchojedy nad Sázavou poses a slight modification relative to the map 1:200,000, sheet Tábor (Kodym jr. 1963). These orthogneisses can be by no means correlated with the Kouřim orthogneisses. Microscopic study of these rocks has shown that, unlike the Kouřim orthogneisses, these rocks did not undergo an intensive deformation resulting in an almost complete recrystallization of feldspars. None of the previous interpretations, such as a tectonic klippe (Koutek 1933) or a tectonic window (Figar 1988), is acceptable. These rocks probably represent leucocratic granites emplaced in rocks of MSZ and subsequently mylonitized.

The principal rock type of the Variegated Series are biotite-sillimanite schistose paragneisses in a typical rhythmic development, which can be best observed along a several kilometres long, continuous outcrop in the incised valley of the Klejnárka Stream between Chedrbí and Březí. Metabasites are the most common intercalated rocks and occasionally form large bodies, especially near Ledečko and Český Šternberk. Light grey to mostly white medium-grained marbles occur much less frequently, forming layers several metres thick either within the metabasite bodies (Český Šternberk – SE of the castle, SE of Samopše) or, more frequently, at the transition between metabasites and gneisses (Nový Dvůr near Český Šternberk, Stříbrná N of Český Šternberk). Individual occurrences in biotite paragneisses are very rare. Intercalations of muscovite quartzitic gneisses passing into quartzites are more frequent in the area N and NE of Zruč n. Sázavou. Calc-silicate rocks are very rare.

In the area SE of Český Šternberk, the original paragneisses are strongly migmatitized in a zone traceable as far as to Kácov (see, e. g., Oliveriová 1987, Štěpánek 1992), and occasionally pass into rather massive, weakly foliated leucocratic two-mica aplitic anatectic granites. These granites are well exposed in railway cut, such as between Český Šternberk and Soběšín. Planes of the original foliation in the granites are accentuated merely by biotite accumulations. In Otryby area, for example, these rocks are associated with amphibolite bodies with boudins of amphibolized ultrabasic rocks and bodies of serpentinized ultrabasic rocks. This was probably the reason why some authors (e. g., Fiala and Patočka 1994) considered this rock belt a continuation of rocks from Čeřenice area and placed it in GU. If this was the case, however, the tectonic position of the Gföhl Nappe within the Moldanubicum would be much more complicated: rocks of the Variegated Series occur below as well as above the rocks of the whole studied part of the belt, and should be therefore interpreted as a separate slice of the Gföhl terrane incorporated in the Variegated Series. The concept of the above authors would imply structural position of GU between the older Monotonous Group and younger Variegated Group. Hence, this belt more probably represents more strongly migmatitized and partly melted portions of the Variegated Series. The position of ultrabasic rocks spatialy associated with these rocks is unclear and was not subjected to a closer study.

Discordant dykes of aplitic to pegmatitic leucocratic tourmaline orthogneisses with muscovite and rare biotite are very abundant in the northern environs of Český Šternberk near Stříbrná. For example, they diagonally intersect metamorphic foliation of feldspar-rich biotite paragneisses. Finer types, however, form concordant bodies alternating with metasediments or amphibolites.

Biotite-sillimanite gneisses of the Moldanubicum gradually pass upwards into two-mica gneisses of MSZ, which do not differ much from the former in terms of lithology and metamorphic grade with the exception of late retrograde products, i. e. muscovite and chlorite growth at the expense of an older, higher-temperature mineral association (see Chapter 6). The indistinct character of the boundary results from the upwards increasing gradient of deformation culminating at the boundary between MSZ and the Kouřim Nappe. MSZ shows a somewhat greater proportions of plagioclase-rich gneisses, frequently thick-bedded, planar-foliated muscovite-biotite gneisses, locally approaching strongly mylonitized granitoids or fine-grained, feldspar-rich volcanosedimentary rocks in their character (series of outcrops along road Sázava nad Sázavou – Talmberk).

Biotite paragneisses, biotite-sillimanite paragneisses and feldspar-rich greywacke gneisses

Biotite and biotite-sillimanite paragneisses (fig. 5) are the principal and a really most extensive rock type of the Variegated Series. The fundamental mineral association of these rocks comprises quartz, rusty brown Ti-rich biotite and plagioclase (oligoclase, andesine), tab. 6. The proportion of fibrous or long-columnar to acicular sillimanite in the rock is highly variable and sillimanite is absent from some types of gneisses, especially plagioclase-rich gneisses. In the Český Šternberk area, sillimanite fibres aggregate to form minute sillimanite nodules. Subsidiary and accessory minerals are represented by K-feldspar (forming rounded porphyroclasts in portions richer in feldspar) and garnet of almandine-pyrop composition (see tab. 3, figs 26, 27), which forms xenomorphic, strongly corroded and fractured grains probably not in equilibrium with biotite. Newly formed fine, scaly biotite and light green chlorite grew at the expense of garnet. Garnet grains contain numerous inclusions, generally formed by euhedral plagioclase, muscovite and opaque minerals. The highest contents of garnet in paragneisses were recorded in the Sázava River valley N of Český Šternberk. Here, the paragneisses are intercalated with amphibolite-rich metatuffites and tuffs with garnet and locally pass into thicker amphibolite layers.

Amphibole-biotite paragneisses occur very rarely in some types of paragneisses, especially near bodies of limestone and metabasites. These paragneisses are petrographically very close to similar types of gneisses from MSZ. Products of the subsequent retrograde stage are mostly represented by muscovite intergrown with biotite, formed at the expense of biotite and sillimanite, and chlorite originating from biotite and garnet. These minerals are commonly present even in paragneisses at considerable distances from the boundary with MSZ. Prominent retrogression was registered in paragneisses underlying GU (e. g., in a highway cut SE of Šternov, in Stříbrná area N of Český Šternberk, S of Český Šternberk), which proves that the final stage of transportation of the slice of rocks of Gföhl provenance on top of rocks of the Variegated Group continued up to greenschist facies conditions. Typical accessory minerals in the paragneisses are apatite, locally forming spherical aggregates, ilmenite and brown-green tourmaline.

Sillimanite-biotite gneisses predominate among all gneiss types while feldspar-rich "greywacke gneisses" are subordinate in the area. The former type contains 5–10 % of plagioclase or possibly K-feldspar, whereas the latter type is composed of up to 30 % feldspar. Feldspar-rich, usually blue-grey gneisses form rather massive, thick-bedded, parallel-foliated bodies resistant to folding. Strongly retrogressed, chlorite-rich amphibole-biotite gneisses are very rare. With the increasing quartz content, gneisses from the area S of Zruč nad Sázavou pass into layers of quartzitic gneisses and small bodies of light muscovite quartzites).

Banding in gneisses reflects alternation of quartz-feldspar felsic bands and thin biotite-rich bands. The original sedimentary banding of the rock is underlined by preferred growth of biotite, and less distinctly by preferred arrangement and flattening of quartz and plagioclase grains. The dominant fabric type is S-fabric, passing into

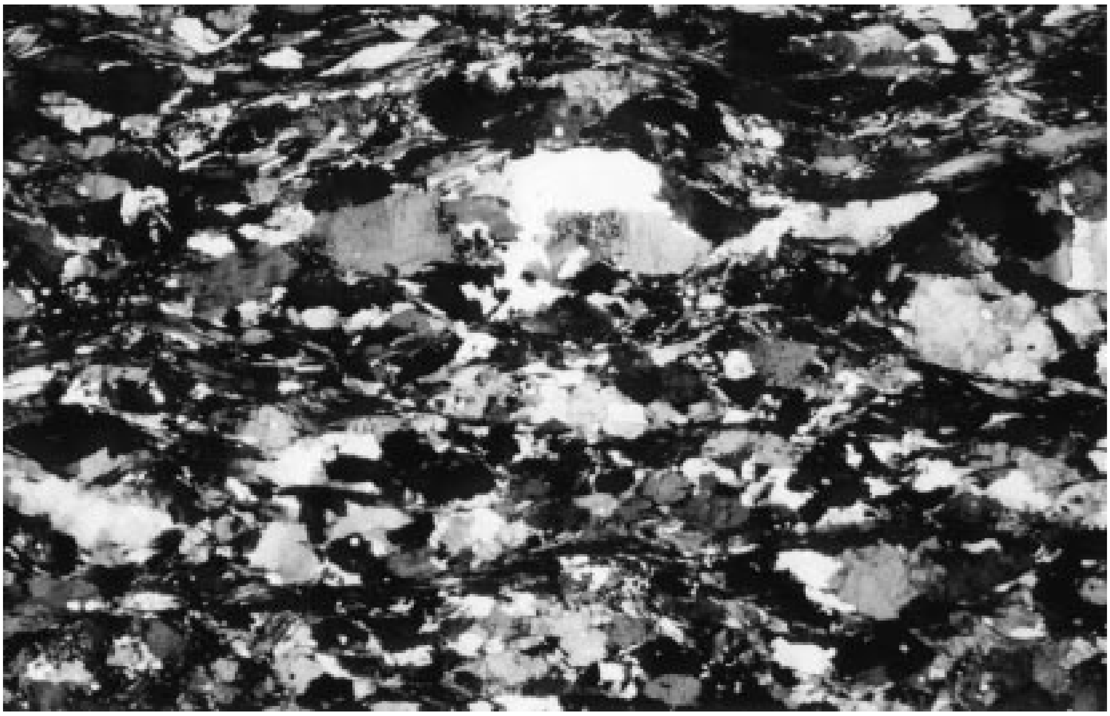


Fig. 5. Biotite, feldspar-rich, partly chloritized paragneiss of the Šternberk-Čáslav Variegated Group, close to its tectonic contact with overlying GU slice. Motorway cut near Šternov; polarized light, magn. 10x.

LS-fabric in the proximity of tectonic boundaries. Flattening is best visible on disc-like aggregates of quartz grains weathering out from disintegrated paragneisses. In only some cases, however, sharply bounded monomineral bands originated, being continuous within a thin section.

The size of xenomorphic quartz grains varies between 0.1 and 0.6 mm. Plagioclases and, if present, K-feldspars are somewhat larger. This is caused by a stronger dynamic, largely rotational recrystallization of quartz grains. Porphyroclastic structures can be observed in paragneisses richer in feldspar, with more strongly recrystallized quartz matrix surrounding harder feldspar porphyroclasts. Minerals growing in dominant foliation are sometimes deformed due to younger refolding. Then, relatively dense crenulation originates with newly formed biotite flakes growing in its axial planes. Formation of these structures is linked with the genesis of transverse folds (e. g., Beneš 1962, Holubec 1977) refolding the older NW-SE-trending structures.

Information on the chemistry of minerals of the individual units is presented in the chapter on metamorphism.

Crystalline limestones and calc-silicate gneisses

Crystalline limestones and erlanes represent relatively rare intercalation rocks of the SCVG of the Moldanubicum. The intercalations in paragneisses or amphibolites are only tens of centimetres to several metres thick. They are mostly associated with transitions between the two above given lithotypes. Limestones are generally light, sugar-white and thickly bedded, less frequently whitish-grey to bluish-grey, with more distinct foliation. In their composition, they mostly correspond to calcitic marbles with low content of dolomite component. They are very pure, with minimum silicate admixture. Some bodies can be, however, characterized as calcareous dolomites. Banded erlanes are present in the northern wall of an abandoned quarry near Nové Dvory and in an abandoned quarry near Koblasko. Their macro- and microscopic characteristics make them very similar to limestones of the overlying MSZ. There is no reliable evidence for the age of the limestones; Paleozoic age of limestones from Světlá nad Sázavou, SE of the study area, was advocated by Gunia (1985) on the basis of finds of disputable microfossils.

The occurrences of limestones and limestone deposits were described in more detail by Hoffmann and Trdlička (1967).

Amphibolites

Amphibolites generally form lenticular, stratiform bodies, several metres to several tens of metres thick, in biotite paragneisses or migmatitic gneisses and in rocks of orthogneiss appearance (an amphibolite belt stretching from Český Šternberk to Soběšín). Only in the area S and SE of Otryby, amphibolites enclose boudins of ultrabasic rocks metamorphosed into tremolite-actinolite schists. Amphibolites are occasionally associated with serpentinite bodies (see map in Oliveriová 1987, a. o.), traceable in a belt stretching further east as far as to Bernartice. Interrelationships of these ultrabasic rocks and their association with leucocratic, fine-grained orthogneiss rocks are unclear and should be subjected to further studies.

Amphibolites are characterized by tabular jointing, composite foliation with frequent relics of tight to isocli-

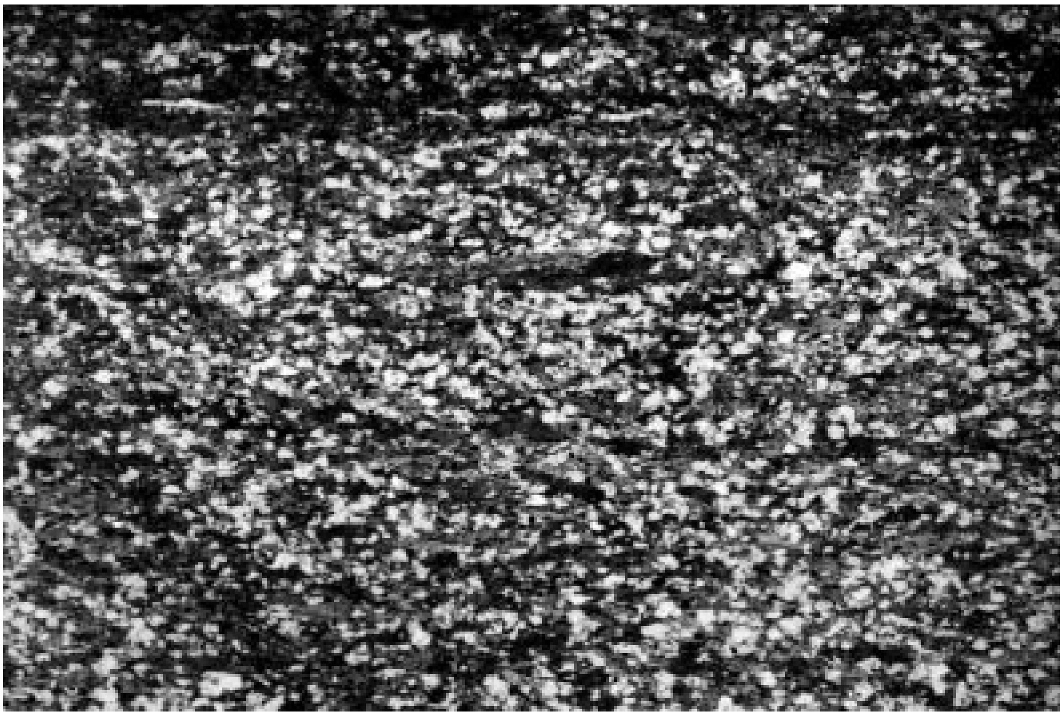


Fig. 6. Fine-grained amphibolite of the Šternberk-Čáslav Variegated Group with quartz admixture, S margin of Český Šternberk; magn. 12x.

nal folds. Axial planes of these folds are oriented subparallel to the dominant metamorphic foliation planes. Lineation subparallel to fold axes trends NW-SE (particularly in bodies close to MSZ). Amphibolite bodies are most frequent in the Český Šternberk area, where they directly underlie migmatites of the presumed GU and rocks of MSZ. This makes the classification of the bodies to the individual units highly problematic as petrographic, mineralogical and geochemical differences are very small (see Chapter 7). Most of the amphibolite bodies concentrate in MSZ and their number in Moldanubian rocks not subjected to retrogression decreases to the east.

By their mineral content, the amphibolites can be mostly characterized as fine-grained **amphibolites** (fig. 6) with prominent LS fabrics, locally passing into markedly prolate fabrics. Petrographic study allowed to distinguish two types of amphibolites: 1) dominating fine-grained, schistose amphibolites, and 2) rather massive, weakly foliated and coarser-grained amphibolites with residual isotropic textures. Type 2 is probably derived from gabbros and was recorded only in the belt between Český Šternberk and Soběšín. Similar types showing well-preserved isotropic gabbroic textures and associated with pyroxenites occur at the base of GU S of Ledečko, near the weekend houses of Vraník (with overlying serpentinites) and in the area of Poříčko, where they contain also minute bodies and boudins of pyroxenites (cf. Koutek 1933). These amphibolites were therefore classified as part of GU.

Schistose amphibolites are composed of variable amount of yellow-green, less commonly blue-green to colourless amphibole (mostly Mg-amphibole, less frequently tschermakitic and pargasitic amphibole – see fig. 32a, b), the content of which ranges between 40 and 65 %, and of plagioclase (oligoclase to andesine, for details see table 9 in Chapter 6). Accessory minerals include ilmenite and titanite, often arranged in chain-like aggregates. More acid types of amphibolites from the Český Šternberk area also contain an admixture of quartz. Products of amphibole retrogression are generally represented by anomalous, bluish purple chlorites, and by biotite and carbonate formed at the expense of the original amphiboles and calcic plagioclase.

Matrix of schistose amphibolites is formed by amphibole and plagioclase. Amphibole grains are mostly short columnar or irregularly bounded, elongated parallel to lineation, and arranged into fine mosaic (0.01 to 0.X mm in diameter). Plagioclases often form lenticular aggregates of recrystallized grains. Plagioclase and amphibole grains mostly compose well-equilibrated fabrics with intergrowths of the two mineral phases along regular grain boundaries. Deformational separation of these mineral phases may even occur in case of a more intensive deformation, giving rise to discontinuously banded amphibolites.

Coarser-grained **gabbroamphibolites** (fig. 7) with relicts of isotropic and porphyritic textures usually contain a higher proportion of plagioclase. Amphibole composition is more varied due to better preservation of products of the individual phases of retrogression. Amphiboles are richer in Ca and Fe. Fe-tschermakitic amphiboles are more frequent (see Chapter 6). Actinolitic amphibole and actinolite are common. Some amphiboles were formed by uralitization of pyroxenes, however, no relics were found. Poikiloblastic intergrowths of amphibole with plagioclase are more common.

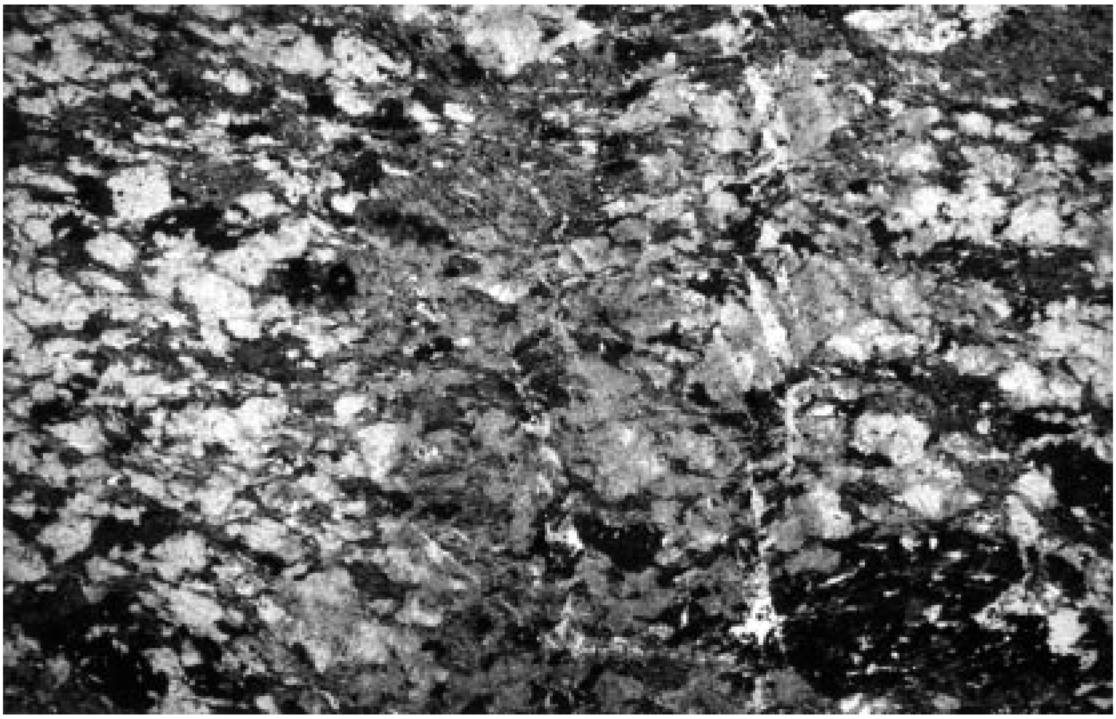


Fig. 7. Coarse--grained, titanite--rich gabbro-amphibolite, Šternberk-Čáslav Variegated Group, SE of Český Šternberk; magn. 11x.

Tourmaline orthogneisses

Leucocratic tourmaline orthogneisses are most frequent in the area N and NE of Český Šternberk. Smaller dykes of two-mica tourmaline orthogneisses are common on the left bank of the Sázava River N of the elevation of Vrabov (point-bar bank of a meander near Stříbrná N of Český Šternberk). The orthogneisses unconformably penetrate paragneisses and amphibolites of the Variegated Group and locally pass into pegmatitoids in some portions. A larger body of orthogneisses can be traced from the NE environs of Český Šternberk (Nový Dvůr) in the direction to Číhané Hill near Otryby; here, it bends towards SE – to the Sázava River.

A different type of fine-grained leucocratic gneissis exposed in the outcrop series on the right bank of the Sázava River between Český Šternberk and Soběšín and extends to Kácov according to field mapping (Oliveriová 1987). Muscovite and biotite are very rare, being preserved only in flasers indicating the original foliation planes. Transitions to rocks of paragneiss appearance, along with the presence of relics of para-material, suggest that these gneisses probably represent anatectic granitoids, produced by melting of host paragneisses.

4.2. Micaschist Zone

Rocks of the Micaschist Zone (MSZ) immediately overlie rocks of MVG (figs 3, 4). They can be traced from the SE environs of Sázava nad Sázavou along the whole norhern margin of Moldanubicum to the NW environs of Chotěboř, where they disappear in the tectonically strongly reduced zone following structures parallel to the Železné hory Fault. Kouřim orthogneisses, pinkish in colour and characteristic for KHCU, overlie the rocks of MSZ. In places, they are imbricated with MSZ paragneisses (e. g., in a roadside section between Malešov and Roztěž). Based on similar lithologies including the same variegated intercalations (limestones, erlanes, metabasites), rocks of MSZ were placed together with the underlying Moldanubian paragneisses into a single lithostratigraphic unit by Losert (1967): Šternberk-Čáslav Variegated Group. According to Losert, this unit evidences the same age and genesis as rocks of the Moldanubicum and the southern part of KHCU. MSZ rocks were believed to represent products of retrogression of the Moldanubian paragneisses by Koutek (1933). Protolith character and tectonic position of MSZ are still being discussed, much like those of its Moravian analogue (see Chapter 7 – geochemistry of paragneisses and amphibolites of the Moldanubicum and MSZ).

The essential rock type of MSZ are schistose, banded to laminated, grey to greyish brown, mostly parallel-foliated two-mica paragneisses, locally passing into blue-grey, mylonitized feldspar-rich fine-grained gneisses. Due to the high content of feldspar, these gneisses may have the appearance of mylonitized granitoids. This rock type is present especially in the immediate footwall of the tectonic contact with the Kouřim orthogneisses or rocks of GU SE of Sázava nad Sázavou. The eastern part of MSZ, the area from Hodkov to Malešov and Kutná Hora where MSZ bends, and the area SE of Čáslav are dominated by fine- to medium-grained gneisses (so-called "dense gneisses") with variable muscovite content and a small proportion of garnet. Occurrences of muscovite-biotite gneisses with amphibole (colourless, light green) are rare. As in the Moldanubicum, such occurrences were recorded at several places near metabasite or carbonate intercalations.

A typical rock of MSZ, which gave the zone its name, are two-mica porphyroblastic rocks of micaschist appearance with kyanite, staurolite, garnet and occasional sillimanite. These rocks form two continuous belts, which can be traced between Ledečko and Podveky (see fig. 3). Further south, such rocks were found in smaller tectonic slices S of Rataje. They pass into common two-mica paragneisses or feldspar-rich paragneisses (near a tunnel at Rataje, a section in a railway cut at Rataje). In the outcrop series along the Sázava River near the railway station at Rataje, these rocks contain small amphibolite bodies and bodies of fine-grained, felsic feldspar-rich gneisses. The number of amphibolite bodies gradually increases towards south. The last small relics of rocks of "micaschist habitus" were found in an outcrop series in the outer bank of a meander near Sázava nad Sázavou as a tectonically reduced continuation of the northern of the two above mentioned belts.

Protolith of these rocks can be characterized of as Al-rich pelites, as evidenced also by chemical analyses (Chapter 7). This composition pelites enabled the growth of Al-rich minerals indicating a the polymetamorphic character of MSZ. Farther east, these horizons were recorded at two more localities only: in a roadcut near St. Wenceslaus Chapel at Hodkov (with no indications of muscovitization and chloritization) and in an outcrop near the reservoir dam at Opatovice N of Červené Janovice. A find of analogous rocks near Solopysky in the central part of KHCU allowed Oliveriová (1993) and Synek and Oliveriová (1993) to place also rocks exposed in a tectonic half-window from the footwall of the Kouřim gneisses to MSZ.

Much like in the Moldanubicum, intercalations are mostly represented by schistose amphibolites and to a much lesser extent by crystalline limestones (figs 3, 4), comparable to the Moldanubian marbles in their texture and chemistry. The largest body of metabasites is exposed in a lower-order anticlinorial structure between Ledečko and Samopše. These metabasites display a highly primitive, tholeiitic chemistry and directly underlie rocks of GU. Stratiform bodies in paragneisses are abundant E of Ledečko and Rataje. Numerous bodies, several metres to several tens of metres thick, are present between Podveky and the bend of MSZ towards north. With the exception of the larger occurrence of amphibolites SW of Bohdaneč, newly classified with MSZ, all larger bodies concentrate in the NE part of the study area.

Two-mica paragneisses

Two-mica muscovite-biotite paragneisses (fig. 8) are the most common rocks of MSZ. These rocks are grey to bluish grey, fine-grained (average grain size 0.0X to 0.X mm), banded to laminated, usually with tabular jointing. Foliation planes are well-developed, defined by alternating lenticular bands of quartz and micas. These bands are sharply bounded, giving rise to specific mineralogical domains. Quartz grains recrystallized into lenses to continuous bands are strongly deformed. Individual grains with undulatory extinction in bands show irregular, poorly equilibrated contacts. Similar mica bands with intimately intergrown muscovite and biotite (with occasional relics of fibrous sillimanite) are often strongly folded and locally even crenulated. These phenomena result from subsequent deformations post-dating the formation of dominant metamorphic foliation, and are often linked with retrograde processes.

Two-mica gneisses are composed of quartz, rusty brown (partly or completely chloritized) biotite, muscovite and plagioclase (mostly oligoclase) the content of which ranges between 10–30 %. K-feldspar is also present as a subsidiary mineral in rocks with higher proportion of feldspar (30–40 %), particularly in feldspar-rich gneisses. Similar to Moldanubian paragneisses, two-mica gneisses of MSZ contain corroded, fractured grains of almandine-pyrope garnet, chloritized and biotitized along fractures (see Chapter 6), enclosing products of older metamorphic stages (muscovite, ilmenite, feldspar, chlorites, less frequently epidote). Some samples contain a higher proportion of acicular or fibrous sillimanite intergrown with biotite but largely muscovitized.

It has been newly found that sillimanite is not restricted to the SE tip of KHCU as shown in the map by Losert (1967), but occurs also in samples from Rataje, Petrovice and other samples. This suggests that metamorphic conditions of sillimanite zone were reached in the whole MSZ. Kyanite was also rarely recorded.

Typical accessory minerals are tourmaline (brown-green, often zoned, sometimes forming larger porphyroblasts), ilmenite and apatite. Light green chlorites, as products of mineral retrogression during peak metamorphic stage, form acicular to sheaf-like aggregates of low, brown-black interference colours. They originated at the expense of garnet and biotite. Chlorite flakes commonly occur in plagioclases, as well. Another common accessory mineral is sericite produced by feldspar decomposition. Larger sericite flakes are present especially in strongly deformed domains.

A variety of these types of gneisses are **biotite gneisses** containing colourless residual **pargasitic amphibole** often with chlorite and biotite overgrowths. These rocks are rich in feldspar and poor in muscovite, which may be even absent. Apatite contents are usually elevated, accessory epidote is also present. Biotite gneisses represent sediments enriched in Ca and Fe, Mg minerals, probably with a volcanogenic component as evidenced by their common occurrence with volcanic rocks also associated with carbonate occurrences.

Coarse lepidoblastic two-mica garnet-kyanite "micaschists"

Rocks of micaschist habitus, which gave name to MSZ, do not belong to the most common rock types (fig. 3) but due to their favourable overall chemical composition – pose an important material for the reconstruction

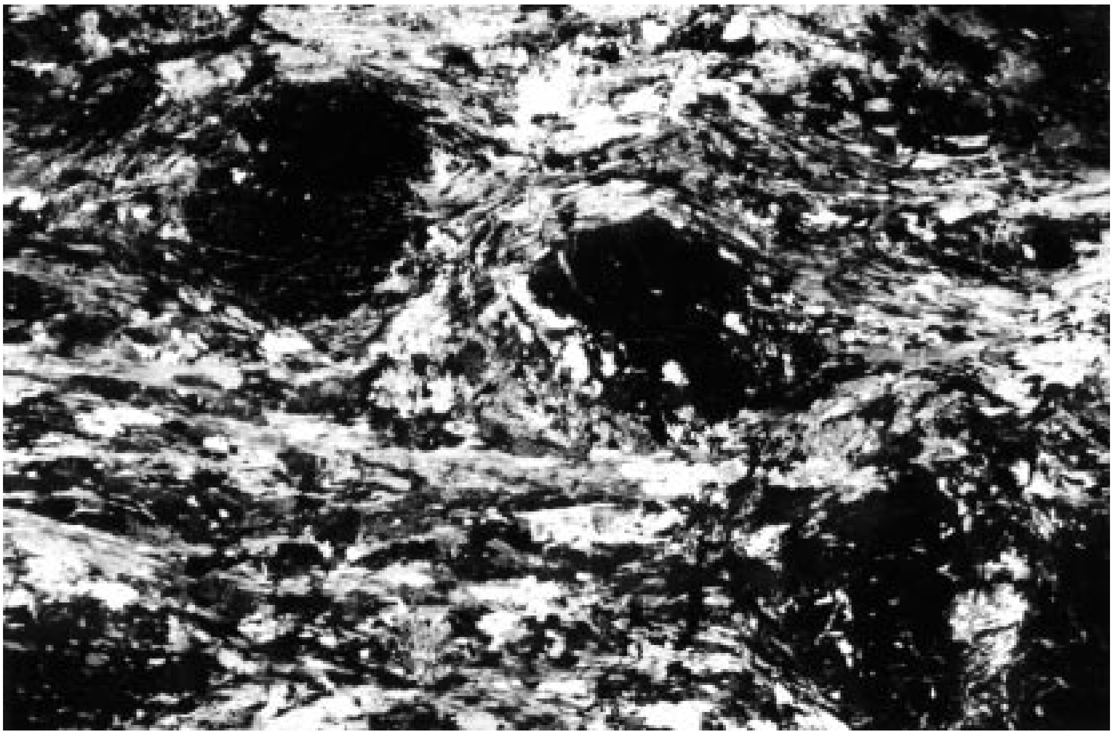


Fig. 8. Slightly retrogressed two-mica garnet-kyanite-bearing paragneiss of MSZ, Nový Dvůr, N of Rataje nad Sázavou; polarized light, magn. 11x.

of the polymetamorphic history of the Zone. They may represent former micaschists prograde-metamorphosed under epidote-amphibolite-facies to lower amphibolite facies (Oliveriová 1993), which, however, reached their metamorphic peak in the sillimanite zone. Only then were they retrogressed and deformed under greenschist-facies conditions. Therefore, their metamorphic mineral associations are disequilibrated and the minerals they contain relics of older metamorphic phases or products of superimposed retrograde-metamorphic reactions.

These rocks are light brown-grey, densely foliated, with light coatings of muscovite on foliation planes and large porphyroblasts of garnet occasionally reaching 1 cm (commonly 2–3 mm) in size. They show prominent banding, especially under the microscope. Quartz-feldspar bands are sharply separated from bands formed by both

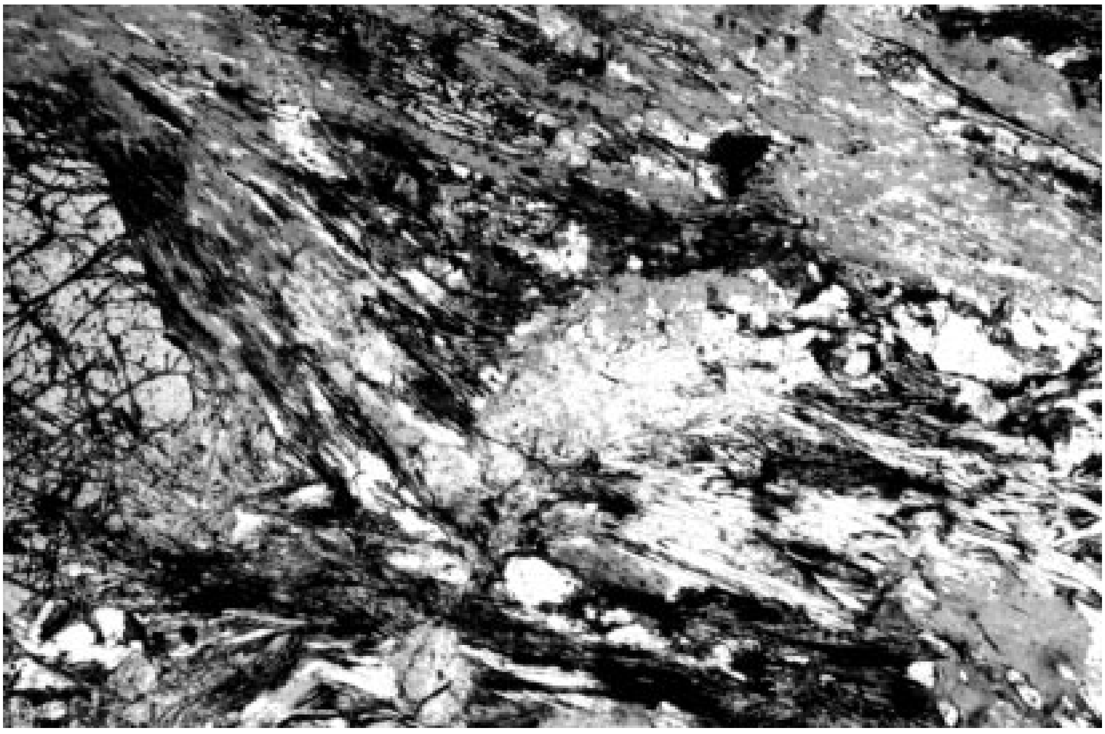


Fig. 9. Retrogressed two-mica garnet-kyanite-bearing paragneiss of MSZ. Al-rich horizon in MSZ. Locality: Rataje railway bridge. Note large tabular crystal of kyanite parly replaced by muscovite in the upper left part of the picture; magn. 15x.

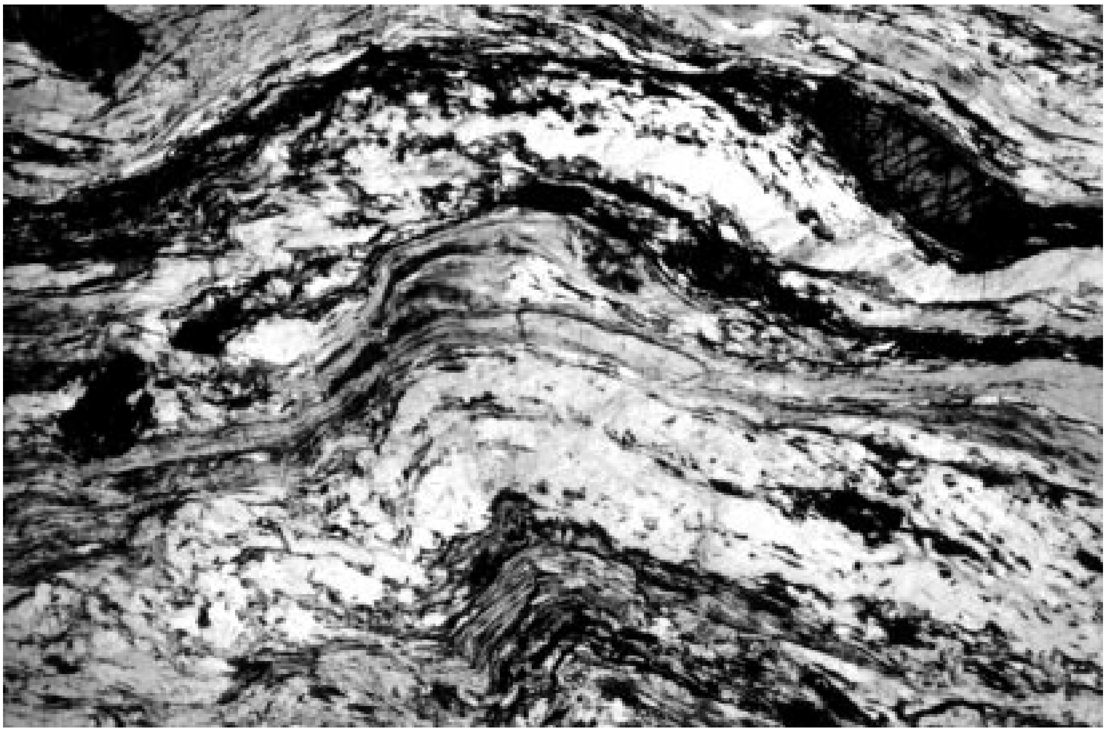


Fig. 10. Strongly retrogressed two-mica garnet-bearing paragneiss “micaschist” of MSZ, Talmberk W of Sázava n. Sázavou. Note the strongly flattened garnet grains; kyanite is mostly completely replaced by muscovite and chlorite aggregates, magn. 13x.

micas, often intergrown, with occasionally preserved long-columnar to acicular sillimanite, thickly tabular kyanite (fig. 9) and garnet. Pressure shadows of garnet host coarse recrystallized aggregates of plagioclase intergrown with flakes of brown-rusty biotite. Plagioclase (oligoclase, andesine – see tab. 6) is also commonly dispersed throughout quartz matrix, clouded, frequently strongly sericitized and chloritized.

Inclusions of chlorite, Ca-mica – margarite, epidote, ilmenite, clinozoisite, quartz, staurolite and tourmaline in garnets, first described by Oliveriová (1993), are products of the oldest metamorphic event. The study of additional samples from new localities (N of the mill of Chuchelník, Hodkov, Rataje-tunnel) revealed traces of other inclusions. Inclusions of hypidiomorphic to idiomorphic plagioclase are abundant, often containing vermicular exsolutions of quartz. Garnets were found to enclose also kyanite (in one case) and biotite (common).

Garnet II, staurolite, kyanite, muscovite and biotite II are products of metamorphic phase M2. Metamorphic peak was reached by crossing sillimanite isograde and by the formation of the association muscovite-biotite-sillimanite and garnet III, which is well equilibrated. Early metamorphic stages are not preserved in cores of smaller garnet grains. Chlorite and muscovite, which gave the rock its present micaschist habitus, were formed in the youngest retrograde phase at the expense of sillimanite, kyanite and garnet. Fine sericite and chlorites were growing at the expense of plagioclases. The succession of crystallization vs. deformation relationships is also documented by mutual relations of the individual minerals to the respective structural elements. Large, poikiloblastic kyanite, enclosing numerous quartz grains and fine feldspar grains, is older than the dominant foliation planes with muscovite, biotite and sillimanite. It frequently shows typical folding (kink bands). Biotite, muscovite and sometimes even kyanite grew behind locally strongly corroded and often flattened garnet grains. Sillimanite is sometimes formed directly from kyanite although it is mostly enclosed by biotite. Accessory minerals in the micaschists are tourmaline, ilmenite or rutile and epidote. Strongly retrogressed samples, such as those from the direct footwall of the Kouřim Nappe, contain only very small amount of kyanite, which in places, is completely pseudomorphosed by a mixture of muscovite and chlorite (fig. 10). Garnet grains are very rare, fractured and chloritized along fractures. Coarsely lepidoblastic muscovite concentrates into relatively broad bands.

An interesting occurrence of these rocks was recorded near Hodkov: a body in amphibolites, several tens of centimetres thick. Unlike samples from Rataje and Ledečko, sample R-58 contains no muscovite. Here, kyanite is directly transformed into sillimanite and biotite is replaced at the formation of sillimanite and melt. No signs of later retrograde processes are present. From this viewpoint, the rocks shares all attributes of Moldanubian gneisses. Features common for MSZ rocks include the presence inclusions of garnet, typical poikiloblastic kyanite, and the occasional presence of staurolite, often pre-dating foliation planes defined by biotite and sillimanite. This demonstrates the difficulty in determining the boundary between the two units as well as the very similar metamorphic history of MSZ and the Moldanubicum in stages M2 and M3 (*sensu* Synek and Oliveriová 1993, for details see Chapter 6).

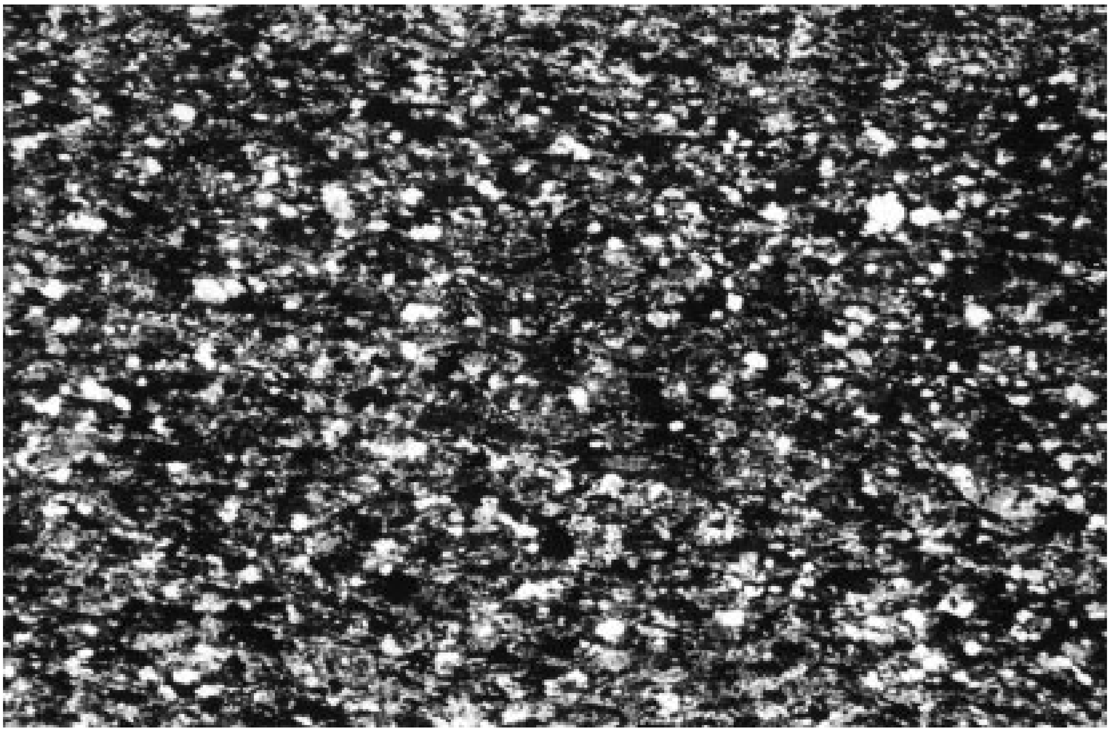


Fig. 11. Fine--grained well-foliated titanite--rich amphibolite of MSZ; road cut E of Sázava nad Sázavou; polarized light; magn. 20x.

Amphibolites

Fine- to medium-grained epidote amphibolites, mostly banded with prominent linear-planar fabrics, with occasional calc-silicate bands and minute dykes filled with minerals of Alpine type paragenesis, represent the most important intercalation rock of MSZ. Their distribution within the studied part of MSZ is irregular. The largest, mostly stratiform bodies are present in the area of Rataje and Ledečko. Smaller but abundant intercalations are developed in the tectonically reduced portion of MSZ between Podveky and Hranice. In agreement with field mapping of Štěpánek (1992), amphibolite bodies between Bohdaneč and Machovice were also placed within MSZ amphibolites on the basis of their chemistry, mineralogy and common features of the host paragneisses. These amphibolite bodies were grouped with the Moldanubicum in older maps (e. g., Kodym ed. 1963). The frequency of amphibolite bodies decreases further north again, where amphibolites are more abundant only in the area SW of Čáslav. Amphibolites of MSZ can be hardly macroscopically and microscopically distinguished from amphibolites of the Variegated Group of Moldanubicum and from strongly deformed and retrogressed amphibolites of GU west of Ledečko and SW of Rataje (fig. 3). Besides minor differences in chemistry (Chapter 7, amphibole composition – Chapter 6), amphibolites of MSZ are characterized by stronger retrogression, usually better developed deformational banding, coarser grain-size homogeneity of amphibole and plagioclase grains, higher proportion of retrograde products (chlorite, epidote) and higher titanite content.

Petrographically, mineralogically, structurally and geochemically, amphibolites present a relatively homogeneous group with very low number of varieties. The petrographically dominant type is banded, perfectly equilibrated fine-grained plagioclase amphibolite (average grain size of 0.2–0.4 mm) with epidote, titanite and clinozoisite (fig. 11). Fine, roughly equigranular plagioclase and amphibole grains form mosaic with mostly straight grain contacts. Relicts of originally larger recrystallized plagioclase and amphibole phenocrysts are visible in places, with the two minerals mutually intergrown. In areas of more intensive deformation, separation of plagioclase and amphibole bands occurs, minerals show a better expressed preferred arrangement with their longer axes parallel to x-axis of the strain ellipsoid. The proportion of amphibole and plagioclase varies between the individual samples: amphibole prevails in some samples while plagioclase in others. Strongly tight to isoclinal folds are preserved in some outcrops in banded amphibolites with calc-sillicate bands. These folds evidence transposition of metamorphic foliation, parallel to axial planes of residual folds. Similar fold types were also recorded in the Moldanubian amphibolites.

Relationships between amphibolites of MSZ and amphibolites of the Moldanubicum are discussed in Chapter 7.

Amphiboles are mostly light yellowish green, browngreen to bluish green (with relics of older textures in coarser-grained types). Mg-rich common amphiboles and varieties of pargasitic and tschermakitic amphiboles are present. An important feature of the amphiboles, which distinguishes them from those in the Variegated Group and GU amphibolites, is the elevated content of alkalies. In areas of stronger retrogression, amphiboles are locally substituted by epidote group minerals, chlorite and occasionally by epidote.

Plagioclase is clear or strongly clouded and sericitized in bands subjected to alterations, locally replaced by epidote group minerals, particularly clinozoisite. It generally correspond to oligoclase to andesine, with rare occurrences of labradorite.

Typical subsidiary to accessory minerals are titanite and epidote – xenomorphic or accumulated into fine-grained aggregates. Ore minerals are dominated by ilmenite. The above mentioned biotite, chlorite and some of the epidote group minerals, formed at the expense of plagioclases, represent products of retrogression. Fractures in amphiboles are often filled with carbonate, chlorites and minerals of Alpine type paragenesis (adularia, chlorites, epidote, prehnite, titanite, natrolite, laumontite and others – Hoffmann and Trdlička 1967).

Strongly deformed, laminated amphibolites with quartz were recorded occasionally (e. g., in the Klejnárka Stream valley N of Chedrbí). Further south, in the Medenický potok valley near Paběnice, they pass into biotite-amphibolite gneisses (metatuffites). Quartz in rather accessory proportions is also present in amphibolites between Talmberk and Sázava.

Another type of amphibolites, though not common, are medium-grained amphibolites with relics of original magmatic textures evidenced by recrystallized phenocrysts of plagioclase and Fe, Mg minerals, originally at least partly pyroxenes (porphyroblasts up to 5 mm in size, frequent twinning), which were completely replaced by amphibole. The largest body of these amphibolites lies in the area NW of Samopše in the Sázava River meander. These amphibolites are intensively folded and deformed and pass westward into parallel-foliated schistose amphibolites. In the central part of the outcrop, they are penetrated by a dyke of amphibole-biotite porphyrite several metres thick.

Limestones and calc-silicate gneisses

In an analogy with the Moldanubicum, limestones and calc-silicate gneisses are represented only by minute lenticular bodies, frequently only several metres thick. Larger occurrences near Sázava nad Sázavou are exceptional. Limestones form intercalations in two-mica gneisses and amphibolites. They locally pass into calc-silicate gneisses. Occasionally, they are enclosed as blocks in orthogneisses. A continuous limestone belt, traceable for several hundred metres, was newly found on the western slope of the elevation Jestřáb, E of Sázava nad Sázavou.

Limestones are mostly represented by very clean, sugar-white types, passing into greyish white, more distinctly laminated limestones. They are practically silicate-free and locally contain ore-mineral grains.

Calc-silicate gneisses form bands in metabasic rocks, usually only several centimetres thick. Two types are present: 1. calc-silicate gneisses composed of plagioclase (andesine), diopside, epidote and carbonate, produced by metamorphism of the original basalts, and 2. calc-silicate gneisses containing a higher proportion of quartz. The latter type has higher amphibole and epidote contents, while carbonate is present as an accessory only.

A yet different genetic type of calc-silicate gneisses often occurs in the form of several tens of centimetres thick boudins in two-mica paragneisses in the eastern part of the study area. These calc-silicate gneisses contain an association comprising pyroxene, garnet, plagioclase, amphibole, quartz and opaque minerals, which were produced by metamorphism of Ca-rich sediments (as suggested by the shapes of ?nodules).

Leucocratic orthogneiss

A small body of leucocratic muscovite-biotite orthogneiss builds the peak of elevation Jestřáb. Earlier it was interpreted as a tectonic klippe of the Kouřim orthogneisses (Koutek 1933), or as a tectonic window of these orthogneisses exposed from the footwall of MSZ rocks (Figar 1988). Petrographic composition different from that of the Kouřim orthogneisses together with metamorphic and deformational structures generated under completely different conditions (flow folding of feldspars in the Kouřim orthogneisses vs. cataclastic feldspar deformations at elevation Jestřáb), however, exclude any connection of this body with the Kouřim gneisses. It is a body emplaced in MSZ rocks and subsequently deformed and recrystallized, thereby acquiring its present orthogneiss appearance.

4.3. Kouřim Nappe

Muscovite-biotite orthogneisses of the Kouřim Nappe represent a relatively exotic element in the architecture of KHCU. They form a folded, tabular body overlying the rocks of the Micaschist Zone and underlying the lower-order sub-units of GU (figs 2, 3). The largest bodies of ultrabasic rocks and eclogites are situated near the base of GU, directly at contact with the Kouřim orthogneisses. These are spatially associated with genetically interesting bodies of skarns (Malešov – Koutek 1952, Malejovice – Koutek 1961, etc.). Intensive tectonic movements at the boundary of rheologically different units resulted in interslicing of rocks of the neighbouring units near their contact. The shape of the orthogneiss body was modified by younger ductile strike-slips, which caused a sudden flexure of the body, its termination in the eastern part of the study area (figs 2, 4 for details see Synek and Oliveriová 1993, a. o.) and the limitation of the body against MSZ in the interval between Podveky and Hodkov.

In some portions, Kouřim orthogneisses (fig. 12) are accompanied by host leucocratic migmatites, particularly along the body margin N of Rataje, where coarser porphyritic portions are substituted by fine-grained aplitic granites.

During the pre-Variscan tectono-deformational period, the original coarse-grained, porphyritic, K-rich calc-alkaline granites probably of pre-Variscan age (Klečka and Oliveriová 1992) and their host rocks were relatively homogeneously deformed and recrystallized into the form of the present orthogneisses. These are characterized by linear-planar fabrics and locally – in areas of intensive non-coaxial deformation – by linear fabrics. The age of the youngest deformations was determined with the use of Ar/Ar method from biotites from mylonitic foliation at 325 Ma (Matte et al. 1990). Nevertheless, the protrusion of orthogneisses from the middle plastic crust and their tectonic affinity with rocks of the Gföhl Nappe occurred already earlier as evidenced by Sm-Nd data obtained from garnet peridotites (Beard et al. 1991) and eclogites (Brueckner et al. 1991), which cluster around 340 Ma. Under middle crust conditions, extremely plastic quartz-feldspar rocks facilitated the ascent of mantle rocks into upper crustal levels.

As the study was focussed especially on the rocks of MSZ, relics of GU and the underlying Moldanubicum, only a very brief characteristic of the Kouřim orthogneisses is presented in this paper. The character of the gneisses varies depending on the magnitude of deformation. A whole range of orthogneiss types was recorded: porphyritic orthogneisses with isotropic-arranged feldspar porphyroclasts several centimetres long, more strongly recrystallized orthogneisses with prominent linear-planar fabrics with markedly decreasing number and size of porphyroclasts, and pencil orthogneisses, where feldspar and quartz grains are deformed into sharply separated, continuous bands.

Petrographically, the orthogneisses are composed of quartz, plagioclase, perthitic and myrmekitic K-feldspar (microcline), muscovite and biotite. Tourmaline and apatite are present in accessory amounts. An intensive deformation is visible at the mineral level, as well; most conspicuously, feldspar grains and quartz aggregates are strongly dynamically recrystallized and often form monomineral lenses or bands. Micas frequently display asymmetrical, fish-like character, and indicate typical kinematics with hangingwall-to-the-northwest movements.

A shift in the deformation from amphibolite facies conditions to greenschist facies conditions, which marks the final stage of nappe advance, is evidenced by the growth of fine sericite at the expense of feldspar and by chloritization along margins of biotite flakes.

4.4. Gföhl Unit

Two areas with exposures of rocks markedly contrasting with rocks of MSZ, CBP and the Variegated Group of Moldanubicum was newly extended to the Gföhl Unit (cf. Koutek 1933): pearl gneisses, migmatites with a significant proportion of leucosome penetrated by granitoids, leucocratic anatectic granites and pegmatites, which contain small bodies of serpentinites, pyroxene amphibolites, monzogabbros and high-alkaline pearl gneisses.

The main reasons for classification of these rocks with GU include:

a) analogous petrographic characteristics of rocks from the area of Sázava nad Sázavou (particularly pearl gneisses), microscopically comparable with the occurrences in western Moravia (comparative material provided by A. Dudek),

b) the association of migmatites, leucocratic rocks and rocks of orthogneiss habitus penetrating advanced migmatites with ultrabasic rocks typical for occurrences of GU,

c) their structural position in the hangingwall of both the Variegated Series and MSZ, typical for the classic areas of occurrence of Gföhl gneisses,

d) the substantial representation of K-feldspars, the presence of high-temperature, three-component feldspars typical for Gföhl provenance rocks, the extensive perthitization, mutual reactions between plagioclases and K-feldspars: all these features are absent from rocks of MSZ and also the Variegated Group of Moldanubicum. Another possible interpretation views these rocks as strongly ductile-deformed rocks of CBP (biotite granodiorites to syenites-durbachites, Koutek 1967, Kachlík 1992). This idea was, however, rejected after a detailed geochemical study of these rocks and their comparison with typical representants of granitoids of CBP. Geochemistry of pearl gneisses from the Křešický Stream correlates well with that of pearl gneisses from the Pyskočely meander and of rocks exposed farther to the N.

e) pearl gneisses are penetrated by small bodies of subsequently metamorphosed and deformed biotite-amphibolite monzodiorites and porphyrites east of Sázava nad Sázavou. With the exception of higher alkali content, CA chemistry of these rocks is close to that of the Sázava suite tonalites. Provided that the intrusions really have a common magma source with CA rocks of CBP, the emplacement succession would contradict the present knowledge about CBP (Holub et al. 1995),

f) rocks in the western part of the Pyskočely meander are strongly folded (close to tight folds with subhorizontal axial planes and axes parallel to NW-SE-trending lineation). Such intensive folding and the emergence of a completely new metamorphic fabric also contradicts the presumed position of durbachites in the granitoid emplacement succession of CBP (Holub et al. 1995).

The above mentioned rocks are exposed in two areas. The first one is a flat synclinal structure overlying both MSZ and Moldanubian rocks between Ledečko and SW environs of Šternov. With respect to the intensive tectonic reworking of rocks at the contact, the occurrence of GU in this area can be considered a tectonic klippe resting on the Variegated Series of Moldanubicum and MSZ, which arrived into its present position prior to the emplacement of CBP. Despite later tectonic modification along ruptures parallel to the Kouřim Fault or even

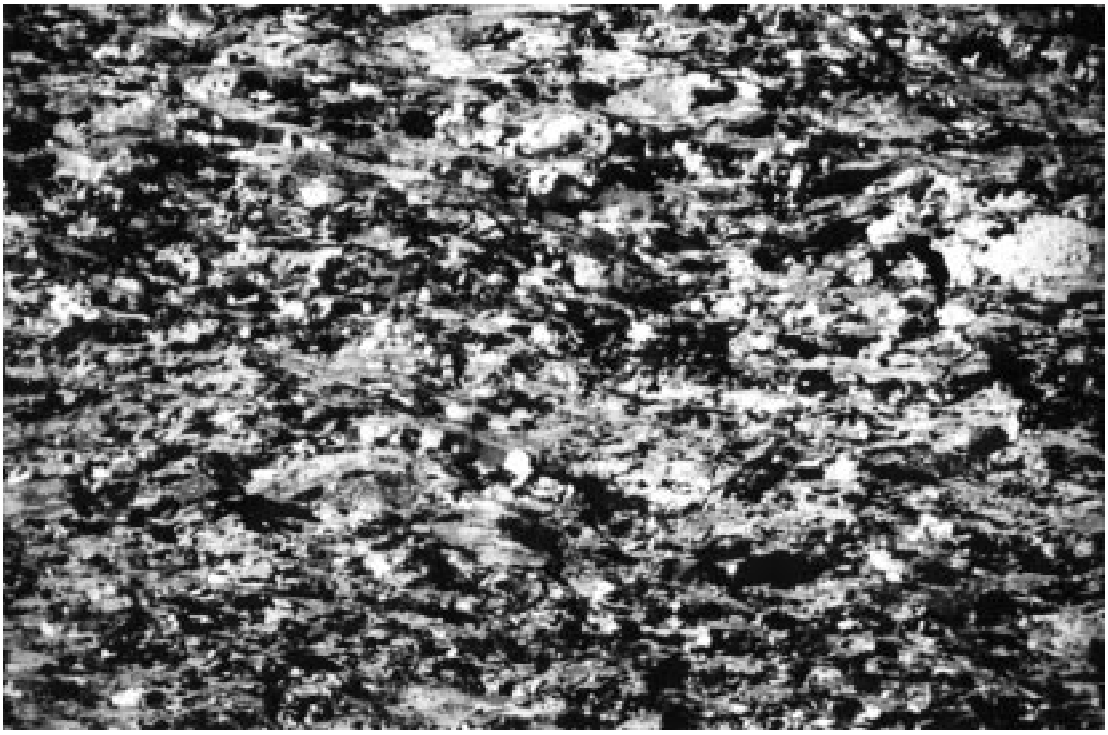


Fig. 12. Asymmetric extensional crenulation cleavage in the completely recrystallized Kouřim orthogneiss close to the contact with underlying rocks of MSZ, Čekanov E of Sázava nad Sázavou; polarized light; magn. 11x.

transverse to this fault (see figs 2, 3), CBP lies in the tectonic hangingwall of this unit (as observed in an outcrop series along the River W of Sázava nad Sázavou) – see Chapter 5.

The second area of the occurrence of rocks of GU lies W of the Kouřim Fault, between Sázava nad Sázavou and Drletín (figs 2, 3). In this segment, the rocks lie at contact with the Kouřim orthogneisses, rocks of MSZ across the Kouřim Fault in the east, and with strongly deformed dioritic rocks of CBP across a NW-dipping, subvertical shear zone in the west. Rocks of GU are penetrated by a small intrusion of the Kšely granite in the SW.

Rocks in this northwestern block are petrographically rather different in their character. They are markedly dominated by leuco- or melanocratic pearl gneisses passing into medium-grained rocks of orthogneiss appearance with feldspar porphyroclasts up to several centimetres long. These are penetrated by irregular bodies of leucogranites, mostly sills. They contain practically no intercalations of amphibolites or ultrabasic rocks (pertinence of coarse-grained gabbroamphibolites to metagabbros E of Sázava nad Sázavou to this group is problematic). The intrusive rocks are mostly of younger age, and were later subjected to weak deformation (so were porphyrite dykes recorded N of Černé Boudy and at other places). Pure paragneiss portions are less common; in the southern part, they occur N of Čeřenice. The differences probably reflect variations in primary lithologies, which are common also in other areas within GU (cf. Dudek et al. 1974), by the presumably complex tectonic-slice setting and the different erosional levels. For example, in the Čeřenice area, pearl gneisses are exposed especially in the deeply incised valley of the Křesetický potok Stream, while the area of Drahňovice is characterized by occurrences of stromatitic migmatites locally passing into portions dominated by para-material.

Biotite and muscovite-biotite pearl gneisses

Biotite pearl gneisses, mostly melanocratic, and migmatites are the essential rock types in both areas of GU exposures. They are penetrated by several generations of leucogranite dykes and sills. Thicker bodies of leucogranite are rare (belts between Drletín and SW environs of Vlkančice). Between Bělokozly and SE environs of Čeřenice, the proportion of light leucogranites increases to the point that they completely obscure the boundary between migmatites and leucocratic granitoids.

The group of pearl gneisses and migmatites can be petrographically subdivided into several types, which, however, pass into one another. They include:

a) mostly biotite melanocratic pearl gneisses with muscovite and medium to large porphyroclasts of feldspars (several mm to several cm in size – fig. 13). This type dominates the northern part of the Pyskočely area and is best developed in the SE arm of the Pyskočely meander. Finer-grained variety of this type are pearl gneisses rich in apatite, zircon and probably also other radioactive minerals. These gneisses are exposed at the base of the unit SW of the railway station Ledečko. They are characterized by anomalous contents of alkalis, LREE and uranium and thorium,

b) finer-grained, mostly biotite pearl gneisses (fig. 14) with feldspar porphyroclasts max. 2–4 mm in size. They

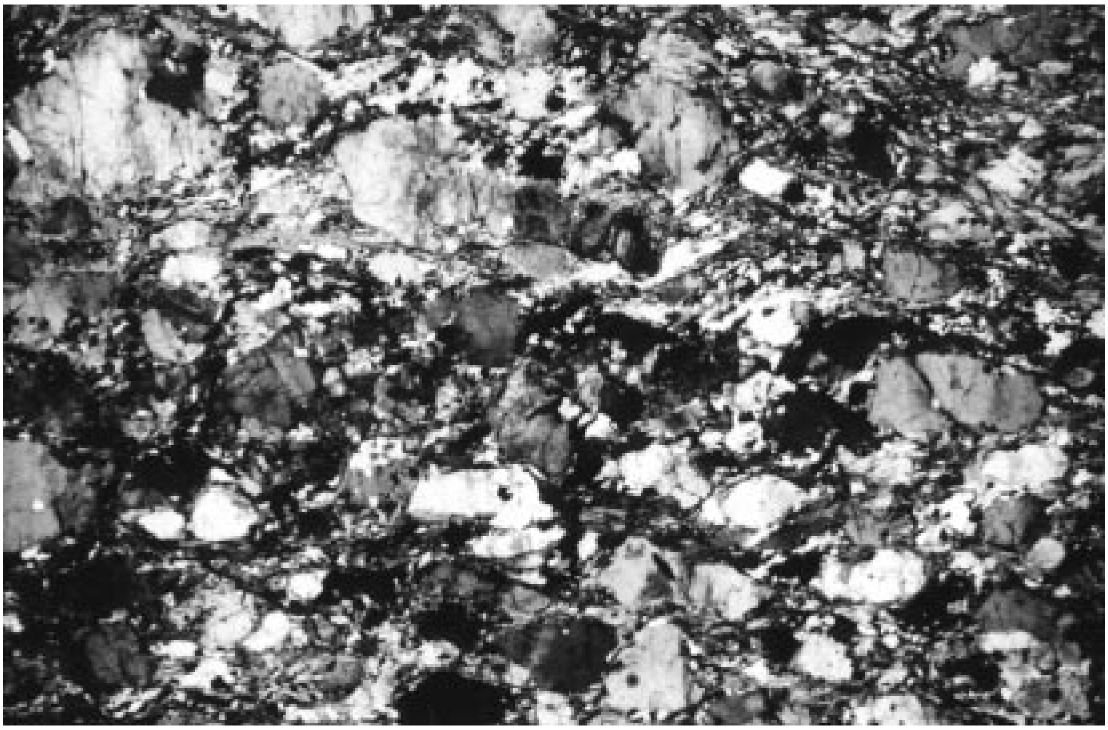


Fig. 13. Sheared coarse-grained two-mica migmatitic pearl gneiss, GU, Pyskočely meander NW of Sázava nad Sázavou; magn. 10x.

occur on the left bank of the Sázava River near Vrabov N of Český Šternberk and W of Sázava nad Sázavou. These rocks were subjected to very weak migmatitization and locally contain portions of paragneisses characterized by alternation of garnet-biotite laminae with intervals of amphibole-rich rocks. This group also comprises rather massive and coarse-grained gneisses with abundant foliation-parallel lenticular bodies of leucocratic metatect exposed in an outcrop series on the right bank of the Sázava River from Stříbrná in the direction to the railway station Malovidy. In portions of higher average grain size, they adopt the character of orthogneisses,

c) amphibole-biotite migmatites, which occur in the Křešický Stream valley SE of Čeřenice as a relatively rare type,

d) leucocratic, pinkish varieties of stromatitic migmatites with a prevailing orthocomponent, distributed in the area of Čeřenice and Drahňovice. Their occurrences have been marked in the map by Koutek (1933).

The primarily diffuse boundaries between the individual types were additionally obscured by different deformation and recrystallization, and by retrogression-related chloritization and muscovitization, which preclude cartographic visualization of the individual types.

A common feature of all the above described rocks is the following association: quartz, plagioclase (always prevailing over K-feldspar), K-feldspar (usually microcline and/or orthoclase), biotite with variable amount of muscovite. The accessory minerals most typically include brown-green tourmaline, often zoned, apatite an opaque mineral (rutile or ilmenite). The types with a higher proportion of paracomponent also contain sillimanite (Čeřenice area) and garnet. Besides garnet and muscovite, gneisses of the Malín Formation of GU below the dam on the Vrchlice Stream also contain kyanites. Some of them are enclosed in garnet, which represents a younger association together with sillimanite. Minerals partly generated as a result of retrograde processes include muscovite (replacing sillimanite, finer sericite is formed at the expense of feldspars), light green chlorite with anomalous blue-purple interference colours, epidote and partly biotite (biotitization, chloritization and epidotization of amphiboles).

Other features distinguishing rocks of GU from paragneisses of the Variegated Group are: substantial amounts of K-feldspar, mostly perthitic and also myrmekitized along contacts of deformed grains, and a generally coarser grain size of matrix, ranging between 0.8 and 1 mm on average.

Melanocratic biotite pearl gneisses

Biotite pearl gneisses are characterized by the prevalence of linear-planar fabrics; however, feldspar porphyroclasts are often randomly oriented in transverse xz-sections. Average grain size is a function of the intensity of deformation and recrystallization. These rocks are dominated by porphyroclastic textures. The hard fraction is formed by ellipsoidal, often asymmetrical feldspar grains, while K-feldspars are often larger and clear and only very slightly (along grain margins) recrystallized and myrmekitized. Finer plagioclase grains are usually present together with quartz in finer-grained (0.X mm) matrix, much more frequently recrystallized along margins or as a whole, and perfectly equilibrated. This indicates

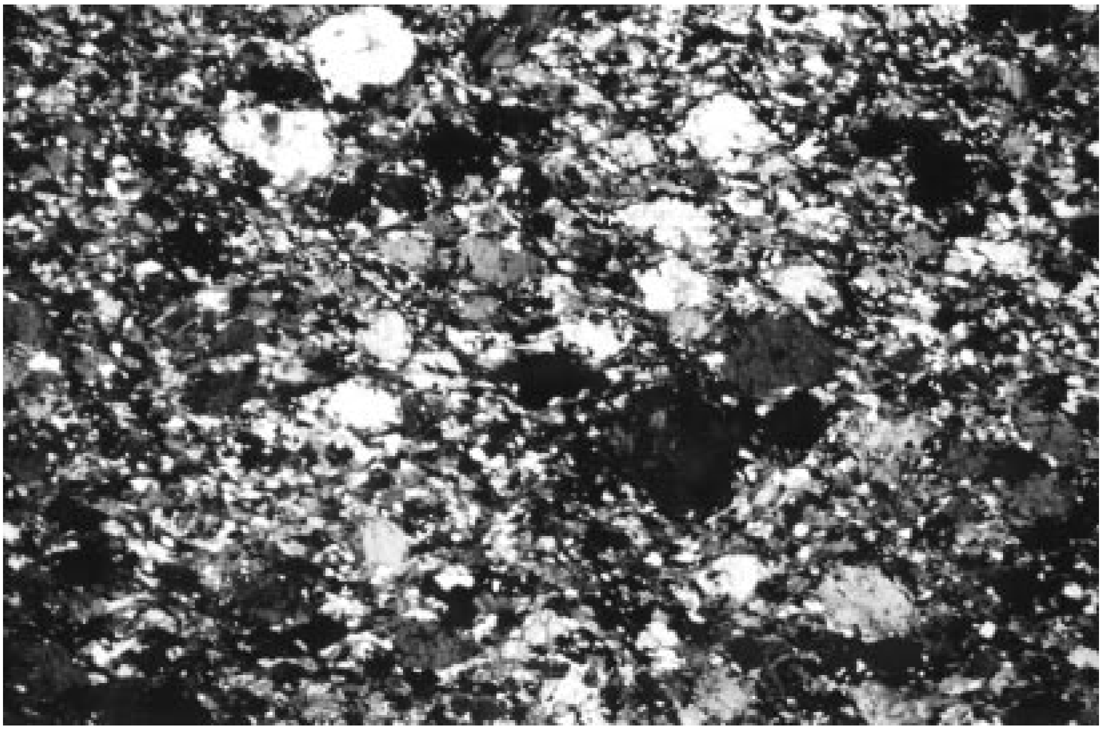


Fig. 14. Fine-grained two-mica pearl gneiss; GU. Sázava River cut N of Český Šternberk; polarized light; magn. 10x.

metamorphism under amphibolite facies conditions. Feldspar porphyroclasts are dispersed in quartz-feldspar matrix with muscovite and biotite, often showing flow patterns around the porphyroclasts. Non-coaxial S-C fabrics of orthogneisses are accentuated by bend fish-like flakes of chloritized biotite and muscovite, which are often intergrown. Quartz, originally forming larger monocrystalline grains, is mostly completely dynamically recrystallized and forms lenticular aggregates to bands. Grain geometries indicate the effect of moderate-temperature migrational recrystallization characterized by suture-like migration of grain boundaries. This deformational mechanism was followed by lower-temperature deformational mechanisms of rotational recrystallization, where grain recrystallization mostly concentrates to grain contacts (core and mantle structure). In this phase, plagioclase was subjected to cataclasis associated with filling of fractures with quartz, grass-green chlorite and muscovite.

Fine-grained, mostly biotite pearl gneisses

These gneisses occur in the neighbourhood of amphibolite bodies near Vrabov N of Český Šternberk. They differ from the above described pearl gneisses in finer-grained matrix and smaller and less abundant porphyroclasts, lower proportion of leucosome, and very weak migmatitization. Garnet is common and macroscopically visible. The gneisses alternate with thin layers of amphibole gneisses to amphibolites (with garnet). They probably represent the original parental rocks, whose migmatitization produced coarser-grained and more leucosome-rich types of migmatites and pearl gneisses.

Amphibole-biotite gneisses

Amphibole-biotite gneisses were recorded only in the neighbourhood of amphibolite bodies in the Křešický Stream valley SW of Poříčko. Unlike the types above, they contain relics of long-columnar green-blue amphibole passing into green-yellow amphibole near rims, which is replaced by biotite and chlorite. In their mineral composition and fabric, amphibole-biotite gneisses do not differ from the above discussed types.

Leucocratic varieties of pearl gneisses and migmatites

Leucocratic varieties are characterized by the prevalence of leucosome over melanosome. They are pinkish in colour. Mafic minerals are present in indistinct ribbons only, which indicate metamorphic foliation in the rock. This is less distinct and regular in its course than that in gneisses with a higher proportion of the original material. Neosome is dispersed throughout the rock in the form of continuous bands, several centimetres to tens of centimetres thick (stromatitic types), separated by bands richer in mafic minerals. Alternatively, neosome has the character of irregular lens-like penetrations in the whole volume of the rock (fig. 15). Mineral associations of these types of migmatites are identical with those of darker varieties; only amounts of the individual minerals are subject to variation.

Intercalation rocks

The complex of migmatites and paragneisses is intercalated with several types of rocks mostly represented – with

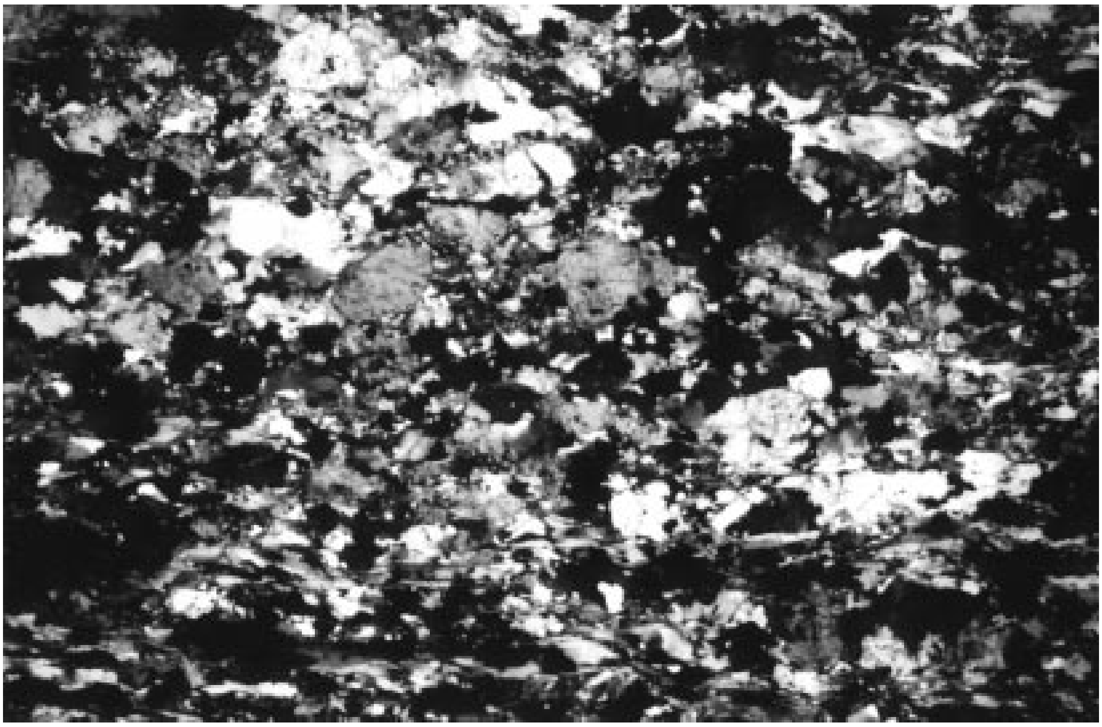


Fig. 15. Leucocratic muscovite-biotite migmatite; GU SW of Český Šternberk; polarized light, magn. 10x.

the exception of amphibolites (whose pertinence to GU may be problematic, see discussion in Chapter 7) – by small bodies metres to tens of metres thick. Occasional serpentinite bodies were detected S of Vraník, however, serpentinite boulders were also found at other places along the contact of coarse-grained amphibolites with migmatites NE of Vraník. Small bodies to boudins of pyroxenites found in a stream bed E of Čeřenice (fig. 3) were reported already by Koutek (1933) from gabbroamphibolite bodies SE of Poříčko. Amphibolites form thicker intervals (e. g., SE of Poříčko). Some amphibolite bodies at the contact of the migmatite complex and Variegated Group rocks can be placed in neither unit with certainty: bodies in the Šternov area, amphibolites S of Poříčko, etc. The most important rocks placed within GU are the coarse-grained gabbroamphibolites overlying alkali pearl gneisses S of Ledečko and the gabbroamphibolites from Poříčko area.

The occurrences of serpentinites and associated amphibolites and eclogites from the Malín Series in the broader vicinity of Kutná Hora were subjected to many detailed studies earlier: Kratochvíl (1947, 1952), Fiala (1965), Beard et al. (1991). Therefore, this paper does not provide their full characteristics but holds with the description of bodies from the areas of Ledečko, Vraník and Čeřenice.

Serpentinized peridotite

Serpentinized peridotite (fig. 16) forms a small body several tens of metres in size, overlying the pearl gneisses and metagabbros. Minor occurrences reported already by Koutek are dispersed SE of Čeřenice.

Although the rock displays signs of strong retrogression, its original texture is visible as secondary minerals generally form pseudomorphs after original grains. In addition, margins of olivine grains are rimmed with magnetite accumulations. The original rock was composed largely of olivine and orthopyroxene. Hence, it corresponds petrographically to harzburgite. The type of recrystallization and the present grain geometries indicate that olivine markedly prevailed over orthopyroxene. Olivine was largely replaced by serpentine, antigorite and chrysotile fibres of variable orientations. Pyroxenes (10–15 %), which formed rather scarce hypidiomorphic phenocrysts, are also recrystallized. Arrangement into polysynthetic lamellae and other types of recrystallization distinguish them from smaller, irregular and strongly fractured olivine grains.

Pyroxenites

The studied pyroxenites come from small boudins enclosed in migmatites from a cut of an intermittent stream flowing from Čečenice to Poříčko in the Sázava River valley.

These rocks are light green, fine-grained, massive, only indistinctly foliated, mostly composed of colourless, light greenish pyroxene corresponding to chromdiopside in its composition. They constitute mosaic-arranged, monomineral mass with weak preferred orientation. This mass incorporates randomly dispersed light green common Mg-amphiboles formed by recrystallization of primary amphiboles and, to a certain extent, probably also by pyroxene uralitization. In analogy with amphiboles, neither pyroxenes are of primary magmatic origin; they were produced by retrograde processes in the rock. In addition, magnetite is also present as a subsidiary component.

Fig. 16. Serpentinized peridotite, GU. Vraník village, SE of Ledečko. Note the relics of pyroxene (top right) in completely serpentinized matrix; polarized light; magn. 37x.

Metamonzodiorites and metamonzogabbros

Metamonzodiorites and metamonzogabbros passing into coarse-grained gabbroamphibolites under stronger recrystallization form larger bodies at the base of GU S of Ledečko. A separate larger body enclosed in migmatites is also exposed SE Poříčko. It contains bodies of pyroxenites reported already by Koutek (1933).

Metamonzogabbros and metamonzodiorites (fig. 17) are variably foliated, heterogeneously deformed rocks. They are mostly characterized by isotropic gabbroic texture, perfectly hypidiomorphic to idiomorphic mafic minerals and plagioclases in the matrix, which is much coarser than in common amphibolites (average grain size 1–2 mm). Amphibole phenocrysts (often exceeding 2 cm in size) frequently enclose smaller

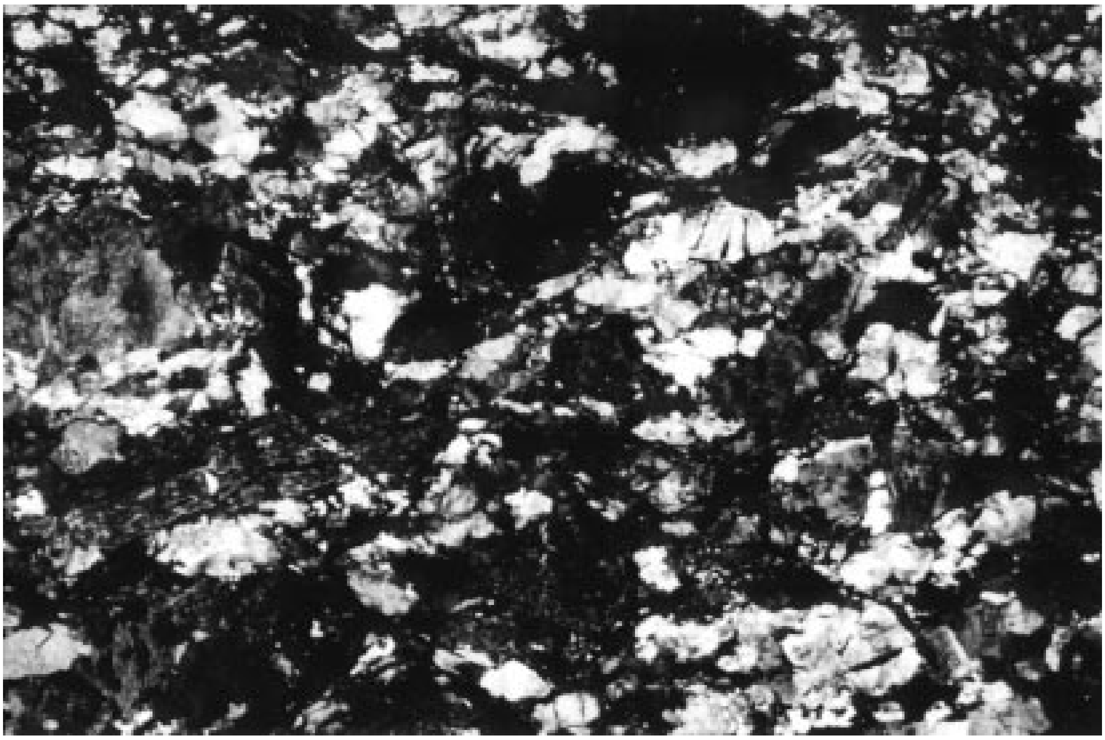


Fig. 17. Amphibole-biotite metaquartzmonzodiorite, GU E of Sázava nad Sázavou; polarized light, magn. 14x.

idiomorphic grains of plagioclase and occasional biotite.

The rocks are strongly retrogressed and subsequently altered. Primary magmatic minerals are only partly preserved. They include brown amphibole cores, mostly replaced by brown-green common amphibole and some of the non-recrystallized feldspars enclosed in mafic minerals. Feldspars in the matrix are strongly altered, sericitized and saussuritized as a result of late low-temperature alterations.

Metamonzogabbros and metamonzodiorites are formed mostly by brown-green common Mg-amphibole (see tab. 9), porphyritic plagioclase (An_{45} – andesine), the proportion of which may exceed that of amphibole in lighter varieties. Xenomorphic to hypidiomorphic, bluish grass-green chlorites with low grey-black interference colours are common and form pseudomorphoses after original Fe, Mg minerals. Chlorite grains are often rimmed by aggregates of xenomorphic titanite grains. Some more acid biotite-amphibole metadiorites contain accessory K-feldspar, perthitic at contacts with plagioclase. The most common accessory minerals are ilmenite and apatite, the hypidiomorphic, long-columnar grains of which are enclosed in amphibole and plagioclase grains.

4.5. Deformed granitic rocks of unknown provenance present in rocks of the Gföhl Unit, Variegated Group of Moldanubicum and the Rataje Micaschist Zone

Deformed, mylonitized and retrogressed granitic rocks form smaller, probably intrusive bodies, later tectonically modified. Despite some petrographic and geochemical features common with the tonalites of the Sázava type or leucocratic biotite and amphibole-biotite granodiorite variety of the Benešov type, they rather represent an integral part of GU (see discussion in Chapter 7). Although subjected to deformation and recrystallization, they show relatively well-preserved primary magmatic textures.

Based on petrographic studies, these rocks are designated as biotite granodiorites to granodiorite gneisses with amphibole (outcrops under the stronghold ruin at Talmberk) and biotite to amphibole-biotite granodiorites (in the footwall of limestone deposit SE of Sázava nad Sázavou). Another type is represented by coarse-grained porphyritic biotite-amphibole monzodiorites penetrating pearl gneisses NE of Sázava nad Sázavou; their analogues were found in amphibolites in a Sázava River meander near the weekend-houses of Budín. They can be correlated with tonalites of the Sázava type and metamonzogabbros S of Ledečko in some petrographic and geochemical features. Nevertheless, metasyenodiorites differ from tonalites of the Sázava Suite in their considerably higher K_2O contents.

The third type is represented by alkaline leucocratic metagranitoids exposed in a railway cut W of Malovidy. They are comparable to pearl gneisses SW of Ledečko in their geochemistry and are also comparable with ultrapotassic rocks of CBP.

Deformed biotite metagranitoids are composed of quartz, plagioclase prevailing over microcline, and a smaller proportion (<< 10 %) of deep brown-green, almost completely chloritized biotite. They are characterized by porphyroclastic S-C fabrics of different intensities (fig. 18), very strong low-temperature deformation of quartz, and high instability of plagioclases recrystallized to sericite and chlorite due to the so-called reaction softening. Less deformed microcline forms larger porphyroclasts. At contacts with quartz, microcline is replaced by characteristic vermicular myrmekites. These rocks differ from plagioclase pearl gneisses, also present in MSZ and other areas, in their high proportion of microcline and textures. Minerals, especially feldspars, are intricately intergrown and enclose idiomorphic mica, apatite etc. K-feldspars are perthitic. Accessory muscovite is also present. Shear deformation of the rock affected particularly quartz and mica grains: micas are often fluidally arranged around feldspar porphyroclasts or form polycrystalline ribbons with strongly sutured recrystallized grains or markedly undulatory extinct subgrains. Chloritized biotites and chlorites also display prominent undulatory extinction. Quartz structures show a transition from higher-temperature to lower-temperature deformations under greenschist facies conditions. In their petrography and types of deformations, these rocks strongly resemble light biotite-rich portions of equally ductile-deformed granitoids of the Benešov type (e. g., exposures by the highway near Naháč service area).

Biotite and biotite-amphibole monzodiorites (fig. 17) contain plagioclase, strongly altered and sericitized (especially in cores). Some hypidiomorphic plagioclase still shows visible magmatic zoning, often with more basic muscovitized cores and very frequent twinning or other types of intergrowths. Some of them are, however, dynamically recrystallized. Recrystallized quartz fills spaces between plagioclase grains. Xenomorphic, partly recrystallized biotite is partly to completely chloritized in some samples. Amphibole was found in variable proportions, forms thickly columnar, zoned grains (dark brown cores, light yellow-green to bluish green rims). Some of these grains are fractured and recrystallized, intergrown in places with biotite. K-feldspar usually forms smaller xenomorphic grains in the matrix. Accessory epidote and titanite are present (particularly in a strongly metamorphosed sample from the footwall of a limestone quarry SE of Sázava). Amphiboles are often partly or completely replaced by chlorite.

Considerable amounts of quartz distinguish the monzodiorites from metamonzogabbros from the base of GU S of Ledečko: the latter rocks contain quartz in accessory amounts only or no quartz at all. The two rock types also differ in their geochemistry (see Chapter 7). Monzodiorites show some affinity to tonalites of the Sázava type but markedly differ from the latter in their higher potassium contents and higher degree of REE fractionation.

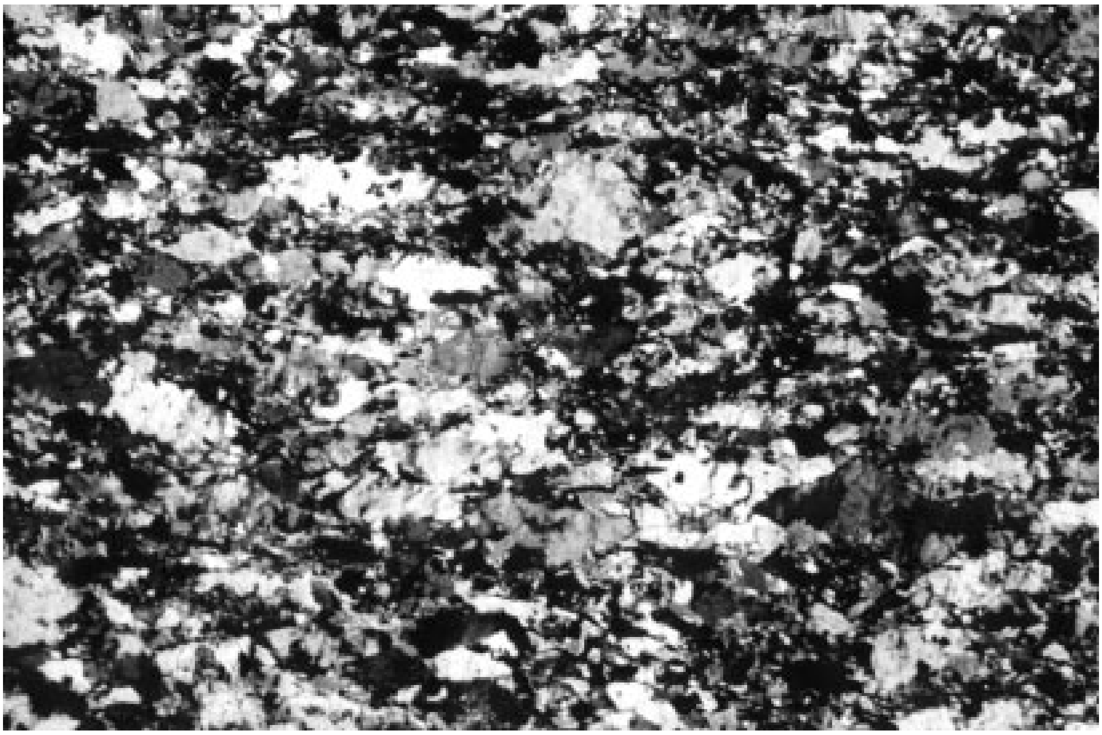


Fig. 18. Strongly deformed chloritized biotite granite gneisses with well-developed SC-fabric. Talmberk village E of Sázava nad Sázavou; polarized light, magn. 14x.

Alkali leucocratic granitoid forms a small lens-like body near the mouth of a stream flowing from Malovidy to the Sázava River. It is overlain by amphibolites and encloses a flat-lying block of crystalline limestone several metres thick.

The rock displays isotropic, porphyritic texture. Phenocrysts are represented by large grains of orthoclase. Indistinct and discontinuous foliation planes are accentuated by light green chlorites pseudomorphosing the original biotite. These are associated with ore accumulations of ilmenite and titanite, which forms 1–2 % of the rock. Feldspar prevails over quartz with fine recrystallized quartz grains filling interstices between larger and more regularly bounded feldspar grains. Rounded quartz grains isoften enclosed by plagioclase as well as K-feldspar. Plagioclase is strongly altered (clouded in deep brown), K-feldspars are mostly clear and perthitic at contacts with plagioclases. Accessory apatite is abundant, forming long, idiomorphic, columnar grains. The presence of these minerals results in high REE contents. These rocks are comparable to pearl gneisses from the base of the Gföhl Nappe S of Ledečko in the association of titanite and apatite with biotite, high alkali contents and overall chemical composition (see Chapter 7).

4.6. Central Bohemian Pluton (CBP)

In the area of contact with KHCU and Moldanubicum, CBP is represented by several types of granitic rocks, characterized by various deformation styles, associated dyke rocks and relicts of host rock of the granitic intrusions.

The only part of geological contact exposed in the surveyed area is between strongly deformed quartz metadiorites and pearl gneisses in the Sázava River valley NE of Sázava nad Sázavou, in the so-called Pyskočely meander. This outcrop clearly shows that pearl gneisses of GU dip at medium angles to the NW, beneath diorites of CBP. The two units are separated also by a certain structural unconformity defined by diverging of foliation planes and lineations – especially in dioritic rocks of CBP – to the orientation of a subvertical, NNE-SSW-striking shear zone, which modifies the contact of the two units as a younger phenomenon. Deformation was locally so intensive (outcrop series along the road near Marjánka, outcrop series at Stříbrná Skalice) that the original dioritic rocks were transformed into banded amphibolites. In such cases, it is very difficult to distinguish between host rocks and plutonic rocks metamorphosed and deformed under lower amphibolite facies conditions.

In the area of Sázava nad Sázavou, migmatites of GU are penetrated by cataclastic coarse-grained granite of the so-called Kšely type. This granite occurs in the form of giant olistoliths in rocks of the Český Brod Permian (Synek, pers. comm.). This granite, however, also shows signs of deformation and contains dominant NW-SE-trending lineation like all surrounding rocks. South of Sázava nad Sázavou, the contact is associated with outcrops of large bodies of light leucocratic granitoids penetrating the pearl gneisses far to the east in the form of smaller apophyses. These granitoids were described by Ulrych (1972) from the Pyskočely meander. They approach granite eutectic according to their composition and extend along the whole eastern contact between the Moldanubicum and CBP. Very close spatial association of these rocks with pearl gneisses suggests that they very probably originated as a product of partial anatexis of the gneisses.

The contact of two-mica schists of MSZ with Gföhl gneisses and leucocratic granitoids SE of Sázava nad Sázavou is modified by the tectonic zone of the Kouřim Fault and by transverse faults complicating the course of this zone. Gföhl gneisses in the southernmost part of the study area are exposed at contact with light biotite granites as well as dark biotite granites with amphibole included within the vaguely defined suite of the so-called Benešov type (in fact, this suite comprises several varieties of granitic rocks, not fully characterized).

Quartz diorites and diorites

Diorites and quartz diorites exposed in the area between Samechov and Stříbrná Skalice were described earlier by Krupička (1948) and by Babuška (1960), Palivcová (1966), Kučerová (1982) and Figar (1988). The opinions on their genesis and interrelationships were rather diverse. Some of the authors believed that these rocks represent heterogeneously foliated intrusives emplaced into the Proterozoic amphibolite host rock forming the so-called Chocerady Islet. Other authors considered them to be product of metasomatic replacement (*in situ* dioritization) of the original amphibolites of the Chocerady Islet. Xenoliths of fine-grained amphibolites, showing preferred orientation, are observed in coarser intervals of metadiorites in outcrops. An additional preferred orientation of xenoliths in subvertical cleavage, parallel to the shear zone strike, makes it sometimes very difficult to distinguish between heterogeneous deformation of diorites and assimilated blocks of host rock. A transformist explanation of diorite genesis can be, however, practically excluded, as documented by the presence of ellipsoidal, weakly deformed, several metres large bodies (pods) of diorites in outcrops. Bending of markedly developed foliation planes around these bodies evidences strain localization into anastomosing zones. Boundaries between the two rock types, if of metasomatic origin, should be diffuse. Dioritic rocks are accompanied by small bodies of medium-grained metagabbros, light aplitic granites to pegmatites and dyke porphyries and porphyrites.

The host rock is preserved in the form of small bodies of limestones and erlanes and biotite hornfelses.

Hence, all the available facts suggest that the rocks largely pertain to CBP and its envelope, the extent of which is smaller than indicated in older maps. Two types of the metabasite protolith were also evidenced by geochemical study (see Chapter 7).

Diorites are relatively highly variable in their petrography, mineralogy and textures. The most variable parameters are the proportions of amphibole and plagioclase, and the content of quartz, which is completely absent from some of the more basic types. In addition, diorites are intersected by numerous dykes compositionally close to diorites, which makes the lithology even more varied. Alternation of different structural and textural types is also controlled by the different intensities of shear deformation: rocks in the centre of the shear zone in the Marjánka area are characterized by prominent planar fabrics defined by the preferred orientation of columnar plagioclases and amphibole. Extreme deformations produce alternation of up to mm-thick monomineral layers of amphibole and plagioclase with streaks of epidote-group minerals and minute titanite crystals or accumulations of amorphous aggregates of titanite grains.

Diorites are largely composed of plagioclase and brown-green amphibole. Quartz, epidote and titanite are present as subsidiary minerals. Accessory minerals are represented especially by apatite and opaque minerals.

Light aplitic and locally even pegmatoid intrusions of leucocratic granites do not display such a high intensity of ductile deformation; however, they are subjected to a strong cataclasis in places.

Biotite granite to granodiorite (Kšely type)

This rock forms a NE-SW-elongated, transversely segmented body on the southern limit of Sázava nad Sázavou. It penetrates into Gföhl pearl gneisses and reaches to a close proximity of the two-mica gneisses of MSZ in the SE (they are separated by the Kouřim Fault covered by terrace accumulations of the Sázava River).

The Kšely granite is a coarse-grained granite with phenocrysts of K-feldspar and plagioclase up to 3 cm large and visible magmatic foliation dipping steeply towards SSE. Foliation planes are intersected by rather indistinct discrete shear zones with minimum displacement. Indications of S-C fabrics are only occasionally visible, dipping at an angle of ca. 45° towards SE. Foliation planes are accentuated by preferred orientation of biotite, which forms matrix together with recrystallized quartz aggregates.

The Kšely granite to granodiorite is composed of plagioclase, K-feldspar, quartz and biotite. Accessory amphibole is sometimes present. Muscovite, zircon and opaque pigmentation are common (ilmenite is enclosed in biotite, especially in flakes replaced by muscovite).

Leucocratic granites

Leucocratic granites (monzogranites, exceptionally granodiorites – Ulrych 1972) form different types of bodies (folded swelled sills, dykes and larger intrusive bodies) in rocks of CBP and adjacent units. It has not been demonstrated whether all occurrences are of the same type and were derived from the same protolith; this would require a separate study. Petrographic and mineralogical equivalence of leucogranites from pearl gneisses of the Pyskočely meander with similar rocks of CBP from Bělčice was documented by Ulrych (1972). Although frequently folded, these rocks do not clearly display such a high degree of deformation. Their deformation has rather the character of cataclastic deformation of rock components.

Quartz, plagioclase (An_{10-12}) and microcline are roughly equally represented in the rock. The only mafic minerals observed are accessory biotite, occasional garnet, micas and altered cordierite.

Biotite granodiorites

Biotite granodiorites conventionally grouped under the so-called Benešov type are only present in the SW part of the study area (see fig. 3). Two essential varieties were encountered:

a) light, fine-grained leucocratic granodiorite to granite with weak preferred orientation (fig. 19),

b) dark, strongly ductile-deformed biotite granodiorite with amphibole, exposed in the Křešický Stream valley E and NE of the highway bridge.

Steeply inclined foliation planes in the dark variety in the Křešický Stream valley are defined by the presence of a WNW-ESE-striking shear zone, which displaces the contact of GU migmatites relative to granitoids, and probably also modifies the termination of amphibolite bodies SW of Šternov.

A common phenomenon for all Benešov type granitoids is the strong cataclastic to ductile deformation resulting in an almost complete recrystallization of quartz in matrix: quartz can be locally described as having a fluidal structure. More rigid feldspar porphyroclasts were subjected to brittle deformation only. This implies that the deformation took place under greenschist facies conditions. This conclusion is also supported by very strong recrystallization of the original biotite to light yellow-green chlorite, which replaced most of the original biotite in leucocratic types. Plagioclase was also subjected to low-temperature metamorphism and alteration connected with the activity of the fluid phase.

Both types are composed of quartz, plagioclase, K-feldspar (mostly microcline) and biotite, sometimes completely pseudomorphosed by chlorite. Dark types sometimes contain accessory amphibole. Common accessories are zircon, apatite and opaque mineral (rutile, ilmenite), the needles of which are enclosed in chlorite produced from the original biotite.

5. Structural characteristics of geological units at the contact of Moldanubicum, the Kutná Hora Crystalline Unit and Bohemicum

Structural evolution of the Kutná Hora Crystalline Unit (KHCU) at the contact with Moldanubicum and CBP has already been discussed by Beneš (1964) and Holubec (1977). The most recent synthesis of the structural evolution of the area under consideration is given by Synek and Oliveriová (1993) who concentrated on microstructures and mesoscopic structural elements and their relationship with radiometric dating of some deformation-crystallization phases. Their study allowed to divide the Variscan deformation development into three phases which, however, are not recorded in all lithologies.

Structures of the oldest deformation phase D1 (370 Ma, Beard et al. 1991) can be occasionally traced in HP-HT rocks (granulites, peridotites) of GU, the Kouřim orthogneisses and migmatites, in rocks of the Micaschist Zone, and/or in Moldanubian rocks where they are missing or were completely overprinted by later deformations.

The most prominent deformation phase D2, which is characteristic of relatively homogeneous thrust deforma-

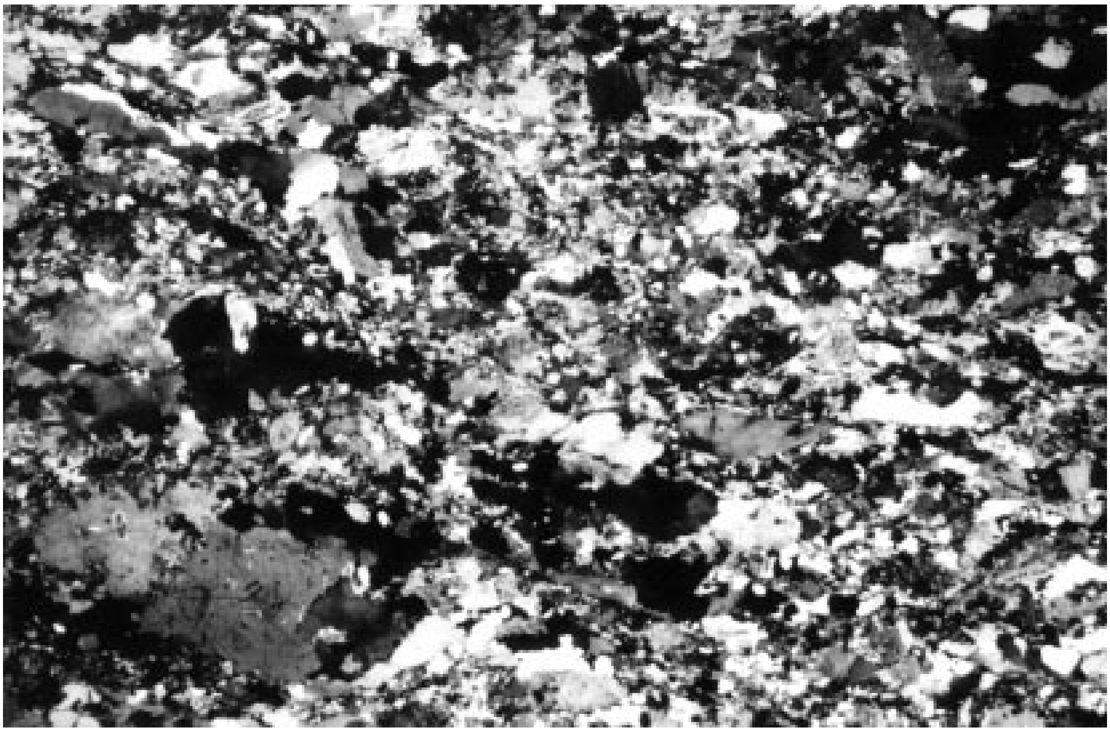


Fig. 19. Sheared leucocratic biotite granodiorite included in the so-called Benešov type; magn. 11x.

tion during which dominant planelinear foliation systems originated in all studied units. This D2 phase is imposed on the older D1 phase forming relics in appropriate lithologies. The D2 phase in granulites, peridotites and eclogites was accompanied by retrograde reactions indicated by coronas around HP-HT mineral phases. The age of this deformation phase, which occurred in amphibolite facies, was established by Beard et al. (1992) at 340 Ma. This deformation phase in rocks of GU is accompanied by extensive anatexis and migmatization.

During the D3 deformation phase, which occurred in rocks of MSZ in particular, a refolding of D2 foliation, took place. A subvertical cleavage formed in highly exposed zones. It is indicated by the growth of biotite and muscovite on newly formed planes. The origin of these structures is likely due to completion of nappe structures in late phases of thrusting of the Gföhl and Kouřim Nappes over the rocks of MSZ and Moldanubicum. These movements were controlled by motions in thrust zones which were of strike-slip fault character (cf. Synek, Oliveriová 1993).

5.1. Foliations

The foliation systems in individual lithologies and units show variable development and mostly composite character. The dominant foliation system resulted mostly from the D2 deformation whose structures could have been modified to various degree during the D3 deformation phase. The D2 structures in pelitic lithologies of MVG and MSZ are defined mostly by preferred orienation of mica flakes and/or by alternation of leucocratic and melanocratic layers in coarser types of augen gneiss. Conspicuous planar textures, defined by alternation of bands rich in amphibole and layers with abundant plagioclase, also occur in amphibolites of MSZ, in Moldanubian rocks and even in the overlying Kouřim orthogneiss in which layers rich in quartz and feldspar alternate with parts rich in micas. Marked ductile planar or planelinear structures were observed in granitoids of CBP along the contact with rocks of MSZ and the Gföhl Nappe. They occur in diorites in the area between Stříbrná Skalice and western vicinity of Sázava nad Sázavou and, to a lesser extent, in biotite granodiorites which are conventionally classed among the Benešov type granodiorites. These structures are believed to have originated in amphibolite to greenschist facies conditions particularly in MSZ, along the contact of GU with MVG and in deformed metabasites of CBP.

Foliations in Moldanubian gneisses

Foliations in Moldanubian gneisses are of a composite character. The major metamorphic foliation is defined particularly by orientation of phyllosilicates alteranting with layers richer in felsic minerals. Foliation systems preserved to various degrees and extent originated during three to four deformation phases. Relics of the oldest tectonometamorphic phase occur in the form of inclusions in garnet porphyroblasts.The structural record related to this metamorphic event has been almost completely destroyed. Inclusions of micas and ilmenite in garnets form no distinct foliation system.

Another relict foliation is defined by porphyroblasts of kyanite associated with staurolite and garnet. This foliation is mostly subparallel or sligthly diagonal to the younger foliation particularly regarding the large relict porphyroblasts of kyanite. The dominant foliation in Moldanubian and MSZ rocks is characterized by preferred orientation of biotite associated with garnet and sillimanite. It represents the thermal peak in both units reached during the decompression. The Ar/Ar dating of micas in paragneisses and amphibole in metabasites (330–345 Ma) showed that Moldanubian rocks, in contrast to the rocks of MSZ and the Kouřim Nappe, were not strongly affected by later processes. Discontinuous planes, mostly parallel with S3, originated during the latest phase. They are defined by preferred orientation of chlorite which formed at the expence of biotite during retrograde metamorphism in greenschist facies. This system of planes, however, can be observed only under microscope.

The direction of the major metamorphic foliation in Moldanubicum is relatively uniform, with the exception of an extensively folded area between the townships of Český Šternberk and Rataje, and the area SW of Bohdaneč. In the first case, the rock zones are deflected due to hundreds metres to kilometers large folds with axes trending NW-SE and inclinations to the NE (fig. 3). As for the southern segment of the Čáslav sigmoidal fold, the axes are deflected to the NE-SW and dip toward NW (fig. 4). Gently dipping foliations prevail in rocks below MSZ (see figs 3, 4, 20, 21). Intermediate inclinations are most abundant in the area between Hodkov and Petrovice where the contact between MSZ and Moldanubicum has a character of a strike-slip fault with some normal fault movement of the northern block. The intensity of deformation increases toward the roof to the contact with the Kouřim orthogneisses where abundant structures of asymmetric foliation boudinage can be observed (e. g., the Klejnárka River valey SE of Chedrbí).

Foliation in Moldanubian metabasites

Foliation in metabasites of the Šternberk-Čáslav Variegated Group is in conformity with the adjacent gneisses. The foliation is mostly well-developed and frequent which results in fair rock cleavage. Metamorphic foliation is defined by alternation of layers rich in plagioclase with those poor in plagioclase with respect to amphiboles or by marked planar orientation of porphyroblasts in homogenous rocks. Older fold structures, isoclinal or closed folds, are well-preserved in banded amphibolites. The axial planes of these fold structures are parallel with the dominant foliation, and the fold axes are inclined mostly to the NW but they may vary considerably.

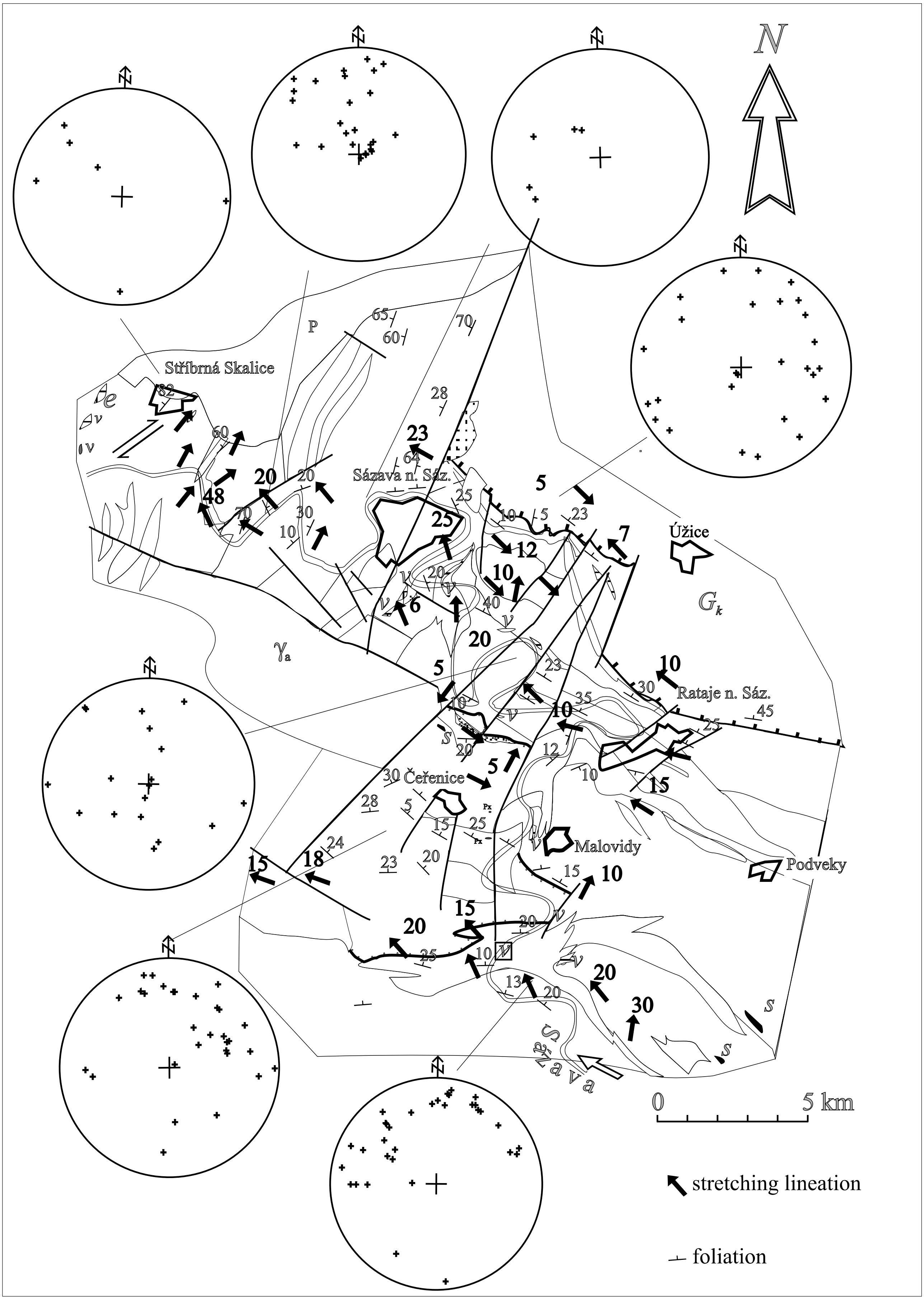


Fig. 20. Structural map of the neighbourhood of Sázava nad Sázavou. Points on equal area projections mark the dip direction of foliation planes in individual units.

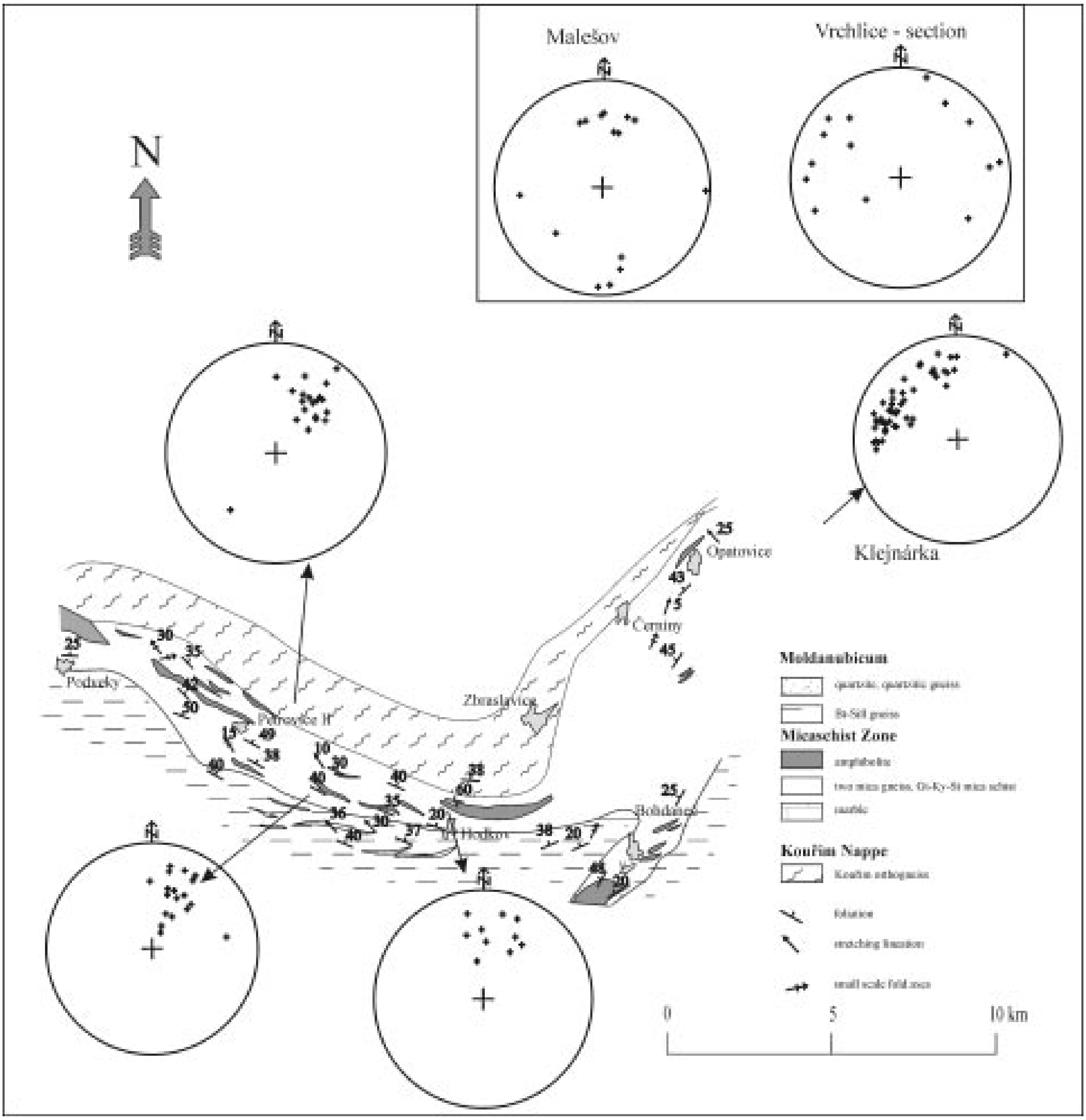


Fig. 21. Structural map of the E and NE part of MSZ and surrounding units. Points on equal projection mark the dip direction of foliation planes.

Foliation in rocks of the Micaschist Zone (MSZ)

Various types of two-mica paragneiss with a few horizons of micaschist, which were recently mapped in the area between the SE border of Sázava nad Sázavou and Podveky, represent the most abundant rocks in MSZ. The structural and metamorphic development of MSZ was close to that of MVG which is demonstrated by the sequence of metamorphic mineral assemblages in appropriate rock types of both units with the exception of the oldest assemblage with paragonite, muscovite and epidote (Oliveriová 1993), which is missing in garnet inclusions of Moldanubian rocks. A retrograde metamorphic mineral assemblage M3 is more abundant in rocks of MSZ (chapter 6). This mineral association is replaced by assemblages with sericite and chlorite which grow in the major foliation at the expense of garnet and biotite and/or feldspars. Retrograde processes, which played a more important role in the western part, caused sillimanite to have been preserved only in relics, and garnet and kyanite were often also resorbed or completely replaced by younger minerals in the form of pseudomorphs. Fibrous sillimanite is almost ubiquitous in paragneisses of the eastern part of the area.

Foliation in the entire MSZ, so far studied, is copying the contact with underlying Moldanubian rocks and with overlying rocks of the Kouřim Nappe. The foliation shows mostly gentle to intermediate inclinations. Steeper dips were observed close to ductile thrust zones having a strike-slip fault character (figs 20, 21). Complex course of foliations caused by folding of rock belts of MSZ was found to occur particularly in the area of Rataje and Ledečko (see figs 3, 20) where axes foldd trend approximately E-W. A more complex relationship occurs in the vicinity of Malešov where MSZ rokcs are imbricated with the Kouřim orthogneisses as well as with migmatites exposed in the Vrchlice River valley and the Malín gneisses. A sharp bend of foliations in the vicinity of Hodkov and Hranice at the SE margin of MSZ is thought to have been caused by a conspicuous shear zone of NNE-SSW strike which terminates a body of the Kouřim orthogneiss and can still be traced farther to the north. Rocks of MSZ in this area are intensely folded. The folds, mostly with fold axes parallel with the lineation, are dipping to the NNE at various angles.

Foliation in the Kouřim orthogneisses

Metamorphic mylonite foliation in the Kouřim orthogneisses was studied only marginally along the contact of the Kouřim Nappe with underlying rocks of MSZ. An indistinct foliation was observed in fine-grained leucocratic aplitic facies of the Kouřim orthogneiss at the nappe contact, which is likely due to low ductile contrast between matrix minerals and porphyroblasts planelinear textures in originally porphyric types of granitoids are very pronounced. Locally, pencil-like types of the Kouřim orthogneiss were found in a roadcut between Roztěž and Malešov. More detailed description of foliation was given by Synek and Oliveriová (1993). The foliation dip in the Kouřim orthogneisses along the contact is very low in the area between Nehyba and Talmberk but farther to the north it increases to 20 to 30° (fig. 20). Intermediate dips between 40 and 60° (fig. 20) prevail in the section between Podveky and the deflection of MSZ, and similarly in the section between Hranice and Opatovice. Foliations close to a small tectonic window W of Kutná Hora become again subhorizontal.

Foliation in rocks of the Gföhl Nappe

Planar structures in rocks of the Gföhl Nappe in the area of Sázava nad Sázavou (fig. 20) are influenced by proximity of a NNE-SSW trending shear zone of which the most deformed part is exposed in the neighbourhood of Stříbrná Skalice (cf. Figar 1988). Relatively flat foliations with shallow dip toward the north are farther to the NW more intensely folded and deflected to the NE-SW direction which is a characteristic and dominant feature for the entire area of CBP and the Islet Zone (fig. 20, Rajlich et al. 1988, Kachlík 1992). Here, the foliations of GU become almost subvertical and dipping mostly to the NW under strongly deformed rocks of the Central Bohemian Pluton. A different situation has been observed in the area of Čeřenice and Drahňovice where the rocks occur in an asymmetric synclinal structure with NW-SE trending axis described by Koutek (1933).

Foliation in rocks of the Central Bohemian Pluton

The entire area of the NE boundary of CBP, particularly that of the so-called Benešov type was considered, for its marked deformation, by some authors to be an older phase of the pluton (see for instance, discussion in Vrána and Cháb 1981). Fiala (1948) even suggested that pebbles in Proterozoic conglomerates of the Islet Zone might have come from the NE part of CBP. Rocks of this part of the pluton show a characteristic heterogenous subvertical cleavage of a NNE-SSW strike along which the originally magmatic structures were subjected to ductile deformation under subsolidus conditions. Some magmatites, however, show continuous transition from relatively steep magmatic foliation to deformation in solid state.

Transitions from flat planelinear structures to subvertical structures in the middle of a shear zone near Stříbrná Skalice are well exposed in the Sázava River valley between Sázava and Stříbrná Skalice. Along this section, there exists evidence that the older flat NW-SE trending structures (foliation as well as lineation) are reoriented to a NNE-SSW strike which becomes gradually the dominant structural element in the area. The deformation and recrystallization occurred in epidote amphibolite facies which is supported by a large amount of minerals of the epidote group, titanite and carbonates in preferred orientation, and unstable plagioclase which was replaced by sericite.

5.2. Linear elements

Linear elements observed in the study area are discussed together because they can be at least partly correlated in all units. As follows from figs 22, 23, where orientation of stretching lineations and mineral lineations, and to lesser extent also orientation of fold axes are plotted, the NW-SE locally to E-W trending lineations represent a dominant feature. These lineations, judging from observations of indicators of tectonic transport (i. e., asymmetric porphyroclasts, asymmetric boudinage, intrafoliation boudinage) show mostly movements of overlying rocks to the NW similar to those described by Synek and Oliveriová (1993) in the entire KHCU. These lineations were found in all units although in granitoids of the Central Bohemian Pluton rather scarce (e. g., local shear zone in melanocratic biotite granodiorite of the Benešov type). They limit further to the east the occurrence of GU (fig. 3). This lineation, which originated during the D2 deformation phase, was later modified and, in zones of more intense deformation, also folded, reactivated or partly rotated during the D3 deformation. A younger lineation manifested by muscovite and biotite was imprinted during D3. It can be seen mostly in younger shear zones. Its age was determined at 325 Ma using the K-Ar method (Matte et al. 1990).

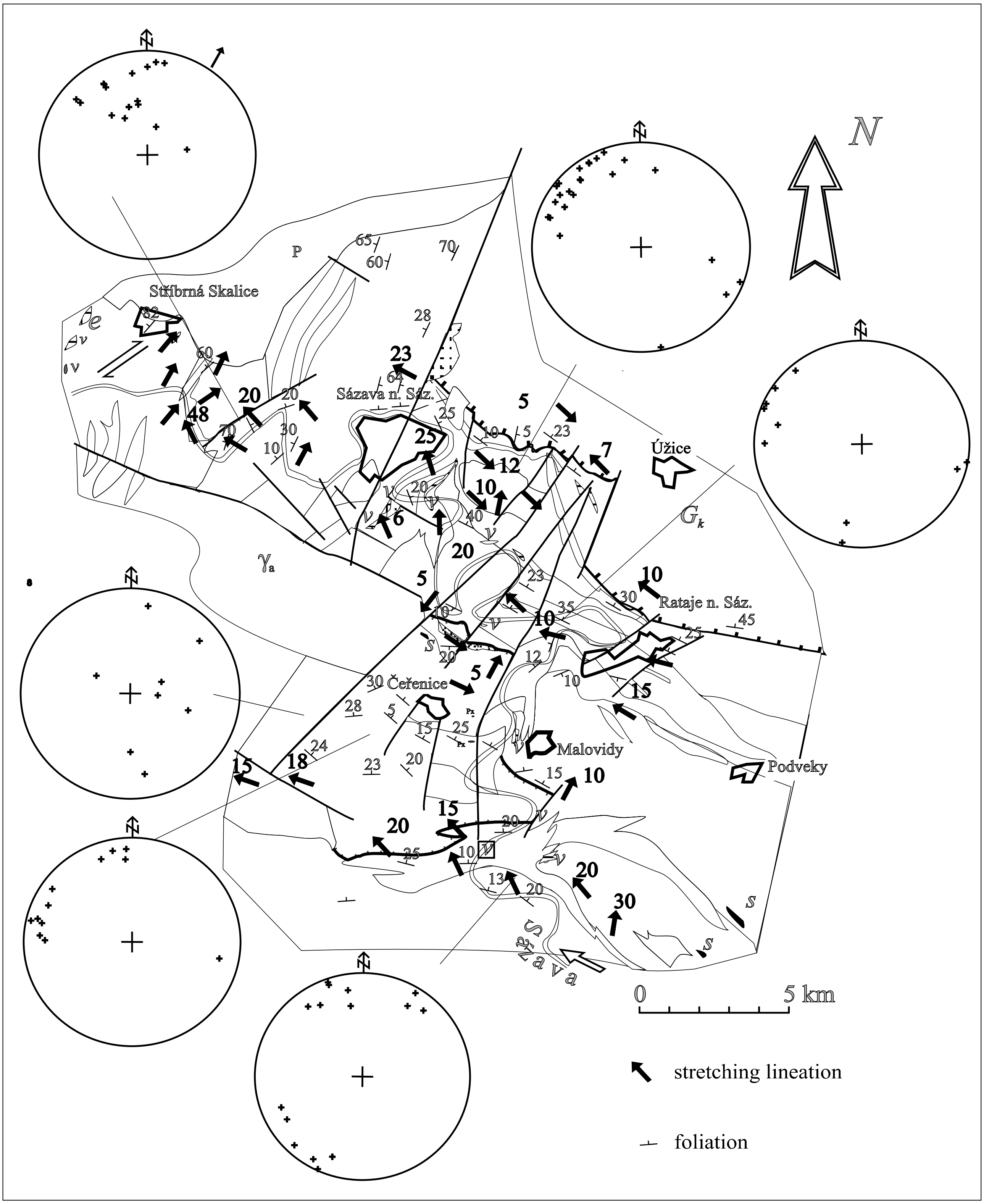


Fig. 22. Stretching lineation in individual units in the W part of MSZ and surrounding units. Points on equal area projection mark the dip direction of the stretching lineation.

Another conspicuous maximum of the N-S to NNE-SSW strike (fig. 22) is represented by mineral and stretching lineations in the area along the contact with CBP. They rotate the older NW-SE trending lineation (and also foliation) into a NE-SW direction. This lineation in the area of CBP is mostly subhorizontal and of penetrative character originated on planes of densely developed subvertical clevage, whereas in rocks of MSZ, Gföhl and Moldanubian Units it is mostly connected with local shear zones segmenting the dominant NW-SE trending structure. To the east, this lineation is rather sporadic with the exception of the area between Hranice and the Vrchlice River valley where a sharp deflection of MSZ takes place to the NNE-SSW strike, including termination of the Kouřim orthogneiss body. Here, the lineation is often subparallel with fold axes which gradually rotate in the direction of the shear zone. Abundant lineations of N-S strike were observed in MVG. They are deflected near the border with MSZ to the NW-SW direction. This change in strike is believed to have been caused by the movement of KHCU during the latest phases of development of the nappe structure which was compensated by movements on the sinistral horizontal shear zone limiting MSZ against Moldanubicum to the south (Synek, Oliveriová 1993). Therefore, the N-S trending lineations in Moldanubicum are mostly not equivalent to NNE-SSW running lineations in the area between Sázava nad Sázavou and Český Šternberk.

5.3. Fold structures

The studied area of KHCU and Moldanubicum represents a polyphase folded domain whose large structure consists of two fold systems. The older system of synmetamorphic folds with NW-SE trending axes, which originated during the D2 deformation phase, was modified by a large transversal synform (the Zruč syncline – Beneš 1964) which caused deflection of the Kutná Hora crystalline complex into the Čáslav (Kutná Hora) sigmoidal fold.

Mesoscopic fold elements studied particularly in the area between Sázava nad Sázavou and Český Český Šternberk exhibit similar features (fig. 20). The older closed to isoclinal mostly shear folds with NW-SE trending axes are subparallel with mineral lineation. These fold are refolded by transversal open to closed folds of N-S to NNE-SSW strike. In places of more intense deformation close to ductile shear zones with subvertical cleavage, there also occur closed to open folds with varying inclination of fold axes mostly to N to NNE or SSW (fig. 23). Folds of this type are very abundant also in the area between Malešov and Bohdaneč. These folds altered the M3 metamorphic foliation in MSZ and in Moldanubicum. Newly formed muscovite and occasionally even biotite grew on more compressed axial planes of these folds. The youngest folds, which cause change in inclination of the foliation particularly in the section between Sázava nad Sázavou and Talmberk, are represented by open folds which produced strongly varying inclination of foliations particularly in sections with very flat structure.

6. Metamorphism and deformation

Metamorphic evolution of the area under consideration was studied using conventional petrographic methods (i. e., definition of mineral assemblages and their succession, relationship between structural elements and metamorphic mineral assemblages) and supplemented by studies of mineral chemistry of selected mineral phases in gneisses and metabasites in order to correlate the metamorphic evolution in individual units and to establish P-T conditions under which single assemblages originated.

Mineral analyses were done on a Camebax electron microprobe at 15 kV, 22 μA current, t=10 s. X-ray data were converted to oxide weight per cent using mostly the computer program MINCALC (Melín et al. 1992); the AMPHTAB program (Rock 1987) was applied to calculate chemical composition of amphiboles. Some other calculations were also applied using Quatro for Windows.

6.1. Mineralogy of metasediments

The following minerals were analyzed as important metamorphic mineral indicators: biotites, muscovites, feldspars, garnets, chlorites, staurolites (recorded in two units only), titanites and some opaque minerals.

Biotite

Biotite is the most common metamorphic mineral in gneisses of MVG, MSZ and GU. It defines the major metamorphic foliations in all three units. Biotite mostly shows a good preferred orientation with the exceptions of some types of coarse-grained anatectic augen gneisses of GU. The mineral is a prominent constituent of two most conspicuous metamorphic associations M2 and M3 and relevant structures which mostly influenced the present habit of rocks. Biotite also commonly occurs as inclusions in large garnet porphyroblasts.

Biotite is a solid solution of Mg and Fe end members i. e., flogopite and annite. X_{Fe} of biotite varies between 0.4–0.65 with a maximum around 0.5–0.6 (fig. 24). Selected analyses of biotite from all three units are given in table 1. Chemical composition of biotite in all units reflects the grade of metamorphism and whole rock chemistry. High contents of Ti and Al in biotites of studied units correspond to the chemistry of biotites confined to HT metamorphic facies (sillimanite zone) with well-defined prograde metamorphic zoning (Guidotti 1984).

From the viewpoint of chemical composition, the biotites can be divided in three groups:

i. Biotites rich in Ti (2.5–3.16 wt % TiO_2), $Al^{4+}$and Al^{6+} metapelitic rocks. These biotites occur mostly in MVG and MSZ. No substatial differences in chemistry of biotites from either unit were observed.

ii. Biotites poor in Ti, Al^{4+}, Al^{6+}, but showing higher X_{Mg}, and consequently lower X_{Fe}, occur in rocks with tuffitic admixture and also in paragneisses in close proximity of carbonate layers (Třebonín, Koblasko). These rocks have biotites extremely poor in Ti.

iii.Biotites showing consistently higher X_{Fe}, high Ti and low Al occur mostly in augen gneisses and migmatites of GU. Their chemistry is close to magmatic biotites from granitoids or biotites from metagreywackes (Guidotti 1984).

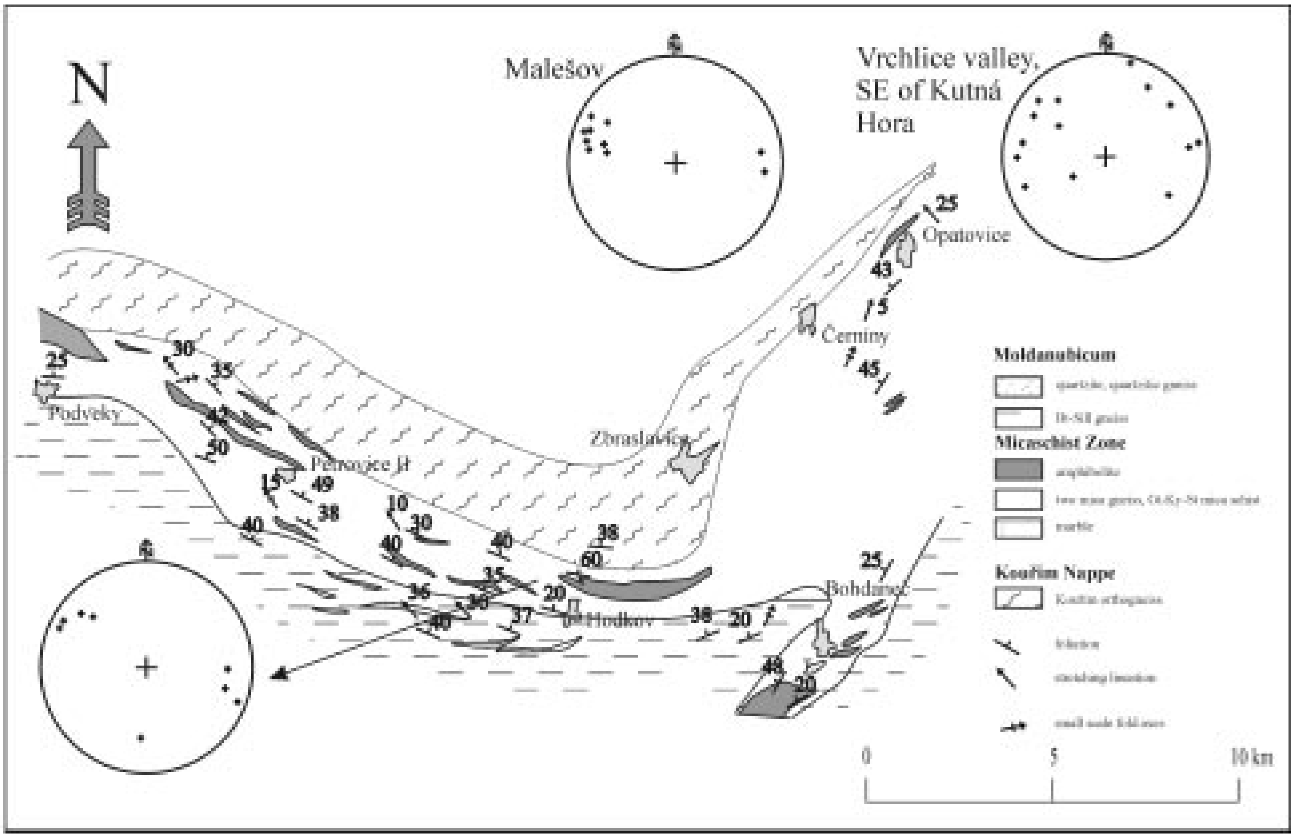


Fig. 23. Stretching lineation in the S an E part of MSZ and surrounding units. Points on equal area projection mark the dip direction of the stretching lineation.

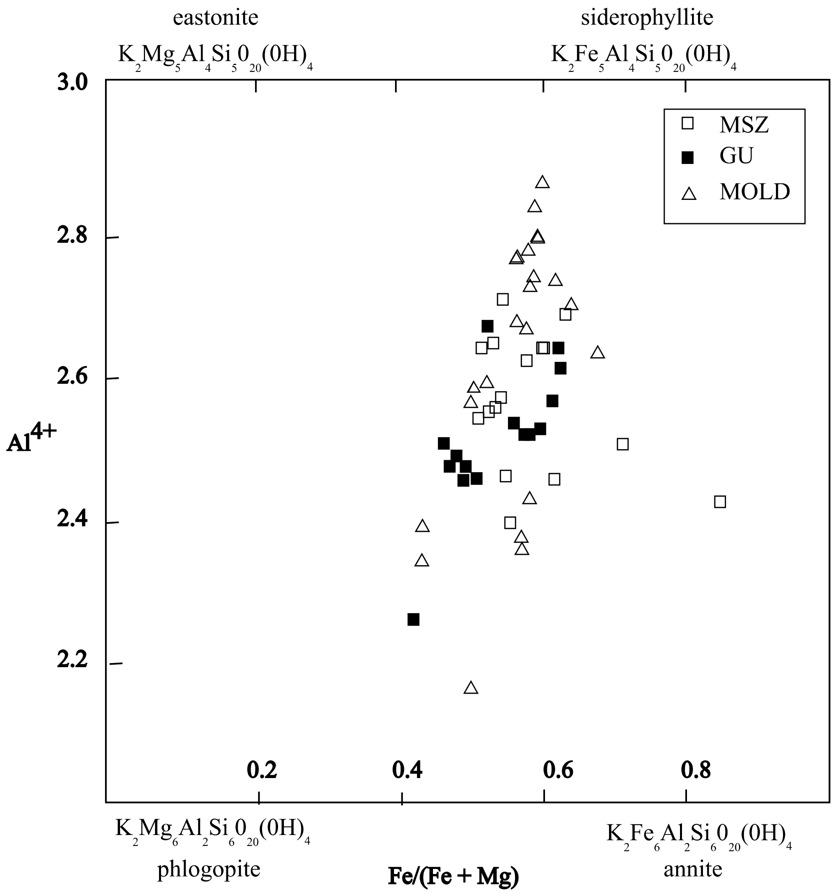


Fig. 24. Chemical composition of biotites from MSZ, GU and Moldanubicum.

Light mica

Light mica in the studied area is represented mostly by muscovite. It occurs particularly in gneisses and schists of MSZ, migmatites of GU and rarely also in some parts of Moldanubicum which suffered retrograde metamorphism (e. g., in the proximity of NNE-SSW trending shear zones which constitute parts of the Kouřim fault NW of Český Šternberk). Light mica together with biotite constitute the major foliation in MSZ. Light mica in porhyroclastic rocks of GU is confined to the matrix in which it envelopes feldspar clasts. Preferred orientation of mica flakes in these rocks is much less pronounced.

Muscovite represents the dominant component in light micas of all units. Its proportion exceeds 80 vol. %; paragonite (2–16 vol. %) and exceptionally also minor margarite are present in muscovite solid solution in rocks of MSZ. Higher contents of Si in tetrahedral coordination (3.1–3.2 pfu.) together with lower concentrations of Al (fig. 25), higher contents of Fe and Mg indicate higher share of celadonite in the structure of light mica which can be particularly observed in rocks of the Malín Series of GU and in MSZ. Celadonite in rocks of MVG is negligible. Margarite in the form of inclusions in garnets was earlier described by Oliveriová (1993).

Although the application of muscovite for thermobarometry is limited (e. g., contents of X_{Na}, and the share of celadonite are not exactly a function of P and T but also reflect the content of H_2O and bulk rock composition), the mineral can be in certain cases used as a rough indicator of metamorphic grade.

Figure 25 shows quite well negative correlation of Si and Al contents in tetrahedral position. Zoning of muscovites indicates a depletion of celadonite and paragonite components from the core toward the margin. Decrease in celadonite and paragonite content and also X_{Na} reflect the increase in temperature and probably contemporaneous decrease in pressure at decompression of rocks of all units during the M3 phase when rocks reach the sillimanite field of stability. Relationships of X_{Na} in muscovites and plagioclase correspond, when compared with literary data (e. g., Evans and Guidotti 1966, Guidotti 1974), to transition between the uppermost staurolite zone and lower part of sillimanite zone, which is in agreement with observed mineral assemblages and also with thermobarometric estimates. The dependence of muscovite chemistry on pressures can be documented on samples containing kyanite associated with garnet, staurolite, biotite and plagioclase which show systematically greater proportion of celadonite and paragonite components relative to mineral assemblage constisting of sillimanite, garnet and biotite. The problem is how to explain differences in composition of micas from MSZ and from Moldanubicum. The first alternative explanation indicates that during subduction rocks of MSZ were driven into greater depths than parautochtonous rocks of Moldanubicum. Alternatively Moldanubian rocks were better thermally reequilibrated. The content of paragonite considerably decreases at higher temperatures. This fact, however, is not completely in agreement with the results of geothermometric measurements. Consequently, the first explanation appears to be more reasonable.

Garnets

Garnets represent an important constituent of metamorphic mineral assemblages of all studied units. Large porphyroblasts (1 cm exceptionally even larger) of garnet occurring particularly in Al-rich lithologies of MSZ

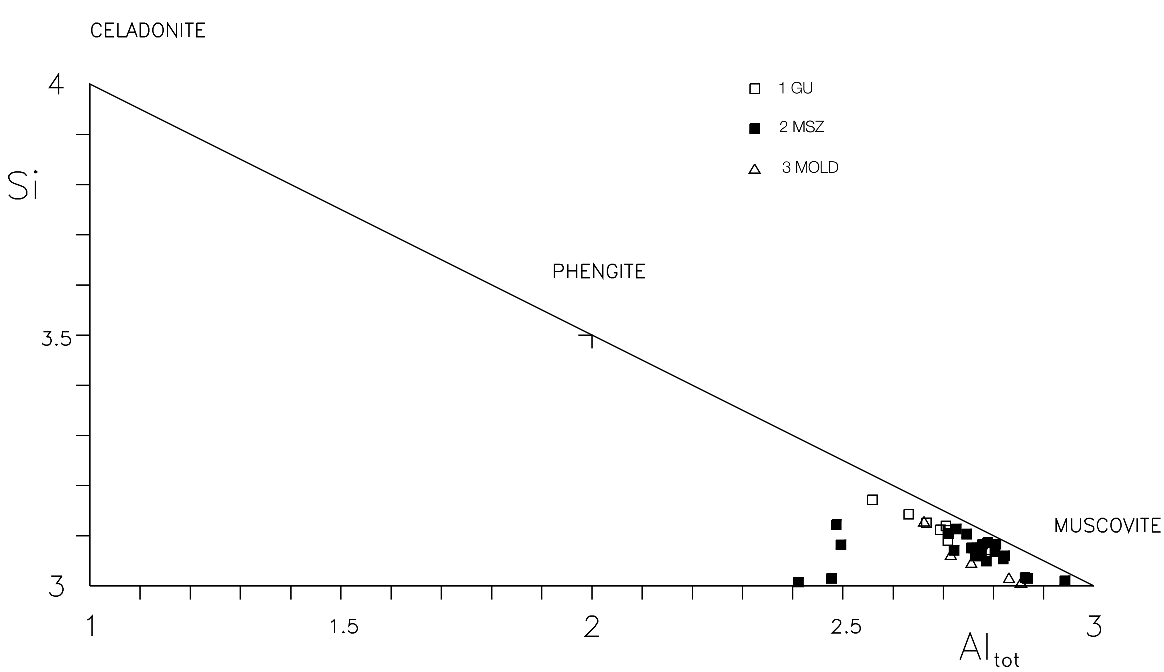


Fig. 25. Chemical composition of white mica from MSZ, GU and Moldanubicum.

Table 1. Representative analyses of biotite from MSZ, GU and Moldanubicum (Mold). Sample location: R-121 – Vrchlice River valley near Malešov – biotite garnetiferous migmatitic paragneiss, Malín Series; R-129 – biotite paragneiss which suffered weak retrograde metamorphism in the roof of carbonate layer, Třebonín – MSZ; R-126 – Klejnarka River valley, S of Chedrbí quarry, biotite paragneiss in the roof of amphibolites – MSZ; R-108 – 1 km SE of Drahňovice, muscovite-biotite migmatite – GU; R-105 – a meander of Sázava River near Přívlaky, two-mica paragneiss – MSZ; R-118 – abandoned small quarry in the Klejnarka River valley N of Chedrbí, amphibole-biotite finely laminated gneiss; R-112 – valley of the Křesice Creek, W of Drahňovice, augen gneiss – GU; R-103 – a hotel building site, SE margin of Český Šternberk – sillimanite-biotite paragneiss – Mold; R-137 – sillimanite-biotite paragneiss SE of Český Šternberk – Mold; R-58 – biotite paragneiss – Hodkov – Mold; R-95 – S of Ledečko railway station, augen gneiss – GU; R-109 – two-mica paragneiss strongly affected by retrograde metamorphism – Rataje – MSZ; R-85 – augen gneiss SE of Malovidy, GU ?; R-83 – biotite migmatite – Drahňovice, GU; R-131 – biotite-amphibole gneiss (metatuffite), Vrabov N of Český Šternberk – GU?; R-123 – amphibole-biotite paragneiss close to bodies of excavated limestones and calc-silicate rocks near Koblasko – Mold; R-125 – Klejnarka River valley SW of Dubina – Mold.

Sample	R-121	R-129	R-126	R-126	R-126	R-126	R-108	R-108	R-108	R-108	R-105	R-129	R-118	R-112	R-103
SiO_2	35.55	36.18	35.92	36.31	36.13	36.09	34.51	35.34	34.87	34.53	34.43	35.23	36.19	38.08	36.50
TiO_2	2.53	0.03	2.86	2.98	1.97	1.41	2.56	2.49	2.89	2.50	1.13	2.90	4.49	2.52	2.39
Al_2O_3	20.09	20.02	20.17	20.18	21.50	21.17	18.65	19.50	18.53	18.81	19.36	19.91	15.27	15.53	20.15
FeO	18.77	18.29	20.70	20.21	18.25	18.85	21.15	20.02	21.17	20.37	18.89	21.55	22.83	16.11	17.77
MnO	0.24	0.26	0.17	0.15	0.19	0.17	0.33	0.45	0.29	0.28	0.16	0.34	0.27	0.19	0.29
MgO	9.53	8.29	8.00	8.28	9.09	9.01	7.16	7.19	7.41	7.40	9.97	6.99	8.04	12.39	9.82
CaO	0.01	–	–	–	0.01	0.09	0.06	0.01	–	–	0.01	–	0.01	–	0.01
Na_2O	0.28	0.23	0.10	0.21	0.18	0.26	0.39	0.17	1.07	0.27	0.02	0.73	–	0.10	0.22
K_2O	9.19	9.32	9.21	9.22	9.20	7.01	8.96	9.07	9.32	9.17	8.62	9.36	9.20	9.44	9.26
Total	96.19	92.62	97.13	97.54	96.52	94.06	93.77	94.24	95.55	93.33	92.59	97.00	96.30	94.36	96.41
#Si^{IV}	5.332	5.612	5.370	5.389	5.361	5.442	5.398	5.448	5.371	5.407	5.368	5.323	5.555	5.746	5.422
#Al^{IV}	2.668	2.388	2.630	2.611	2.639	2.558	2.602	2.552	2.629	2.593	2.632	2.677	2.445	2.254	2.578
#Fe^{IV}	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
#Ti^{IV}	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
T^{site}	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
#Al^{VI}	0.884	1.271	0.924	0.919	1.121	1.205	0.837	0.991	0.735	0.879	0.925	0.868	0.318	0.508	0.950
#Ti^{VI}	0.285	0.003	0.322	0.333	0.220	0.160	0.301	0.289	0.335	0.294	0.132	0.330	0.518	0.286	0.267
#Fe^{+3}	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
#Fe^{+2}	2.354	2.372	2.588	2.508	2.265	2.377	2.767	2.581	2.727	2.668	2.463	2.723	2.931	2.033	2.208
#Mn^{+2}	0.030	0.034	0.022	0.019	0.024	0.022	0.044	0.059	0.038	0.037	0.021	0.044	0.035	0.024	0.036
#Mg	2.131	1.917	1.783	1.832	2.011	2.026	1.670	1.652	1.702	1.728	2.317	1.574	1.840	2.787	2.175
O^{site}	5.685	5.598	5.638	5.611	5.641	5.789	5.618	5.572	5.536	5.606	5.859	5.557	5.642	5.655	5.636
#Ca	0.002	–	–	–	0.002	0.015	0.010	0.002	–	–	0.002	–	0.002	–	0.002
#Na	0.081	0.069	0.029	0.060	0.052	0.076	0.118	0.051	0.320	0.082	0.006	0.214	–	0.029	0.063
#K	1.759	1.844	1.757	1.746	1.742	1.349	1.788	1.784	1.831	1.832	1.714	1.804	1.802	1.817	1.755
A^{site}	1.842	1.913	1.786	1.806	1.795	1.439	1.916	1.836	2.151	1.914	1.722	2.018	1.803	1.847	1.820
#OH	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Charge	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Sample	R-103	R-103	R-137	R-58	R-58	R-58	R-58	R-58	R-58	R-58	R-58	R-58	R-58	RZ-109	R-85
SiO_2	36.59	36.45	34.82	32.56	34.98	34.49	35.44	34.43	36.01	35.09	33.95	32.81	31.55	36.40	36.94
TiO_2	2.42	2.61	2.70	3.07	2.29	2.57	3.16	3.21	1.87	1.71	1.97	2.14	1.95	2.55	2.91
Al_2O_3	19.48	19.30	16.42	19.55	21.09	21.38	20.52	20.22	21.40	20.28	20.11	19.06	19.45	19.89	17.92
FeO	18.47	18.11	19.70	19.29	18.87	19.00	19.59	19.88	18.97	20.40	21.74	20.63	23.37	17.61	17.86
MnO	0.29	0.25	0.20	0.17	0.15	0.13	0.13	0.20	0.11	0.18	0.18	0.26	0.21	0.04	0.42
MgO	9.76	10.10	14.97	7.41	8.11	7.58	8.06	7.87	9.28	7.86	6.77	7.20	8.16	9.43	10.07
CaO	–	0.01	0.06	0.05	0.06	0.06	0.04	0.05	–	–	0.05	0.05	0.06	0.03	–
Na_2O	0.19	0.14	0.07	0.11	0.17	0.20	0.10	0.26	0.12	0.16	0.18	0.27	0.14	0.22	0.06
K_2O	9.11	9.23	5.51	8.86	8.48	8.70	8.50	8.63	8.67	8.44	8.75	8.88	6.96	8.88	9.58
Total	96.31	96.20	94.45	91.07	94.20	94.11	95.54	94.75	96.43	94.12	93.70	91.30	91.85	95.05	95.76
#Si^{IV}	5.456	5.441	5.268	5.212	5.330	5.278	5.338	5.267	5.348	5.394	5.307	5.273	5.067	5.463	5.551
#Al^{IV}	2.544	2.559	2.732	2.788	2.670	2.722	2.662	2.733	2.652	2.606	2.693	2.727	2.933	2.537	2.449
#Fe^{IV}	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
#Ti^{IV}	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
T^{site}	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
#Al^{VI}	0.880	0.836	0.195	0.900	1.117	1.133	0.981	0.912	1.093	1.067	1.011	0.883	0.748	0.981	0.724
#Ti^{VI}	0.271	0.293	0.307	0.370	0.262	0.296	0.358	0.369	0.209	0.198	0.232	0.259	0.235	0.288	0.329
#Fe^{+3}	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
#Fe^{+2}	2.303	2.261	2.492	2.582	2.404	2.431	2.468	2.543	2.356	2.622	2.842	2.773	3.139	2.210	2.244
#Mn^{+2}	0.037	0.032	0.026	0.023	0.019	0.017	0.017	0.026	0.014	0.023	0.024	0.035	0.029	0.005	0.053
#Mg	2.170	2.247	3.376	1.768	1.842	1.729	1.810	1.795	2.055	1.801	1.578	1.725	1.954	2.110	2.256
O^{site}	5.665	5.668	6.405	5.643	5.650	5.609	5.641	5.650	5.730	5.716	5.690	5.685	6.106	5.597	5.607
#Ca	–	0.002	0.010	0.009	0.010	0.010	0.006	0.008	–	–	0.008	0.009	0.010	0.005	–
#Na	0.055	0.041	0.021	0.034	0.050	0.059	0.029	0.077	0.035	0.048	0.055	0.084	0.044	0.064	0.017
#K	1.733	1.758	1.063	1.809	1.648	1.698	1.633	1.684	1.643	1.655	1.745	1.821	1.426	1.700	1.836
A^{site}	1.788	1.800	1.094	1.854	1.711	1.768	1.669	1.769	1.677	1.706	1.818	1.925	1.486	1.774	1.854
#OH	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Charge	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Table 1. *(continued)*

Sample	R-85	R-85	R-85	R-85	R-83	R-83	R-83	R-131	R-123	R-123	R-123	R-125	R-125	R-129
SiO_2	36.75	36.62	36.61	36.76	36.16	36.34	35.91	37.38	35.63	36.64	37.35	35.42	36.21	35.60
TiO_2	2.73	2.79	2.75	2.52	2.93	2.79	2.73	0.04	0.02	0.02	0.02	0.04	0.04	0.04
Al_2O_3	17.93	17.97	18.24	17.87	18.95	19.28	19.67	15.59	20.11	16.57	17.15	19.33	19.62	20.36
FeO	17.69	16.77	16.74	17.45	19.97	19.44	18.41	18.75	18.77	17.89	17.49	19.59	18.63	17.90
MnO	0.54	0.31	0.34	0.39	0.26	0.36	0.23	0.29	0.28	0.08	0.01	0.27	0.30	0.26
MgO	10.26	10.65	10.51	10.35	7.83	7.90	8.11	10.74	9.58	13.44	13.11	7.90	7.94	8.28
CaO	0.02	0.01	0.02	–	0.01	0.01	0.02	0.04	0.11	0.51	–	0.10	–	0.07
Na_2O	0.16	0.18	0.16	0.23	0.19	0.05	0.22	0.15	0.16	0.17	0.42	0.21	0.18	0.24
K_2O	9.41	9.62	9.51	9.54	9.46	9.36	9.23	9.43	9.54	8.26	8.30	9.08	9.29	9.57
Total	95.49	94.92	94.88	95.11	95.76	95.53	94.53	92.41	94.20	93.58	93.85	91.94	92.21	92.32
$\#Si^{IV}$	5.537	5.530	5.524	5.551	5.483	5.498	5.467	5.847	5.458	5.611	5.663	5.577	5.647	5.546
$\#Al^{IV}$	2.463	2.470	2.476	2.449	2.517	2.502	2.533	2.153	2.542	2.389	2.337	2.423	2.353	2.454
$\#Fe^{IV}$	–	–	–	–	–	–	–	–	–	–	–	–	–	–
$\#Ti^{IV}$	–	–	–	–	–	–	–	–	–	–	–	–	–	–
T^{site}	8	8	8	8	8	8	8	8	8	8	8	8	8	8
$\#Al^{VI}$	0.720	0.728	0.767	0.732	0.870	0.937	0.997	0.721	1.089	0.602	0.727	1.164	1.253	1.285
$\#Ti^{VI}$	0.309	0.317	0.312	0.286	0.334	0.317	0.313	0.005	0.002	0.002	0.002	0.005	0.005	0.005
$\#Fe^{+3}$	–	–	–	–	–	–	–	–	–	–	–	–	–	–
$\#Fe^{+2}$	2.229	2.118	2.112	2.204	2.532	2.460	2.344	2.453	2.405	2.291	2.218	2.580	2.430	2.332
$\#Mn^{+2}$	0.069	0.040	0.043	0.050	0.033	0.046	0.030	0.038	0.036	0.010	0.001	0.036	0.040	0.034
#Mg	2.304	2.397	2.364	2.330	1.770	1.782	1.841	2.504	2.188	3.069	2.963	1.854	1.846	1.923
O^{site}	5.631	5.600	5.600	5.614	5.543	5.549	5.523	5.734	5.733	5.975	5.929	5.655	5.587	5.580
#Ca	0.003	0.002	0.003	–	0.002	0.002	0.003	0.007	0.018	0.084	–	0.017	–	0.012
#Na	0.047	0.053	0.047	0.067	0.056	0.015	0.065	0.045	0.048	0.050	0.123	0.064	0.054	0.072
#K	1.809	1.853	1.831	1.838	1.830	1.807	1.793	1.882	1.864	1.614	1.605	1.824	1.848	1.902
A^{site}	1.859	1.908	1.881	1.905	1.887	1.823	1.861	1.934	1.941	1.748	1.729	1.905	1.903	1.986
#OH	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Charge	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Table 2. Representative analyses of muscovite from MSZ, GU and Moldanubicum. Sample location: R-134 – muscovite-garnet-kyanite gneiss 500 m W of Nový Dvůr near Rataje; R-111– expressway cut 2 km SW of Šternov, biotite-sillimanite paragneiss (chloritized, muscovitized) strongly affected by retrograde metamorphism, Mold; R-90 – meander of the Sázava River near Přívlaky, 800 m NW of Ledečko, two-mica paragneiss – MSZ, for location of other samples see table 1.

Sample	R-121	R-121	R-121	R-121	R-121	R-134	R-134	R-134
SiO_2	47.17	47.76	48.36	48.15	48.41	46.01	45.56	47.19
TiO_2	0.45	0.98	1.04	0.83	0.77	0.70	0.74	0.08
Al_2O_3	36.37	35.61	35.09	33.04	34.47	37.15	36.87	39.24
FeO	0.94	1.09	1.11	1.93	1.30	1.00	1.07	1.00
MnO	–	–	–	0.02	–	0.04	–	–
MgO	0.90	1.17	1.20	1.50	1.43	0.49	0.45	0.42
BaO	0.09	–	–	0.01	–	0.08	0.13	0.32
CaO	–	–	–	–	–	0.06	0.05	0.03
Na_2O	0.75	0.85	0.74	0.71	0.77	1.10	1.06	0.13
K_2O	10.12	9.91	9.71	9.77	9.88	9.47	9.20	10.30
Total	96.79	97.37	97.25	95.96	97.03	96.10	95.13	98.71
$\#Si^{IV}$	6.153	6.190	6.260	6.353	6.295	6.041	6.039	6.029
$\#Al^{IV}$	1.847	1.810	1.740	1.647	1.705	1.959	1.961	1.971
T^{site}	8	8	8	8	8	8	8	8
$\#Al^{VI}$	3.744	3.629	3.614	3.490	3.578	3.790	3.798	3.938
$\#Ti^{VI}$	0.044	0.096	0.101	0.082	0.075	0.069	0.074	0.008
$\#Fe^{+3}$	–	–	–	–	–	–	–	–
$\#Fe^{+2}$	0.103	0.118	0.120	0.213	0.141	0.110	0.119	0.107
$\#Mn^{+2}$	–	–	–	0.002	–	0.004	–	–
#Mg	0.175	0.226	0.232	0.295	0.277	0.096	0.089	0.080
#Li	–	–	–	–	–	–	–	–
O^{site}	4.066	4.069	4.067	4.083	4.072	4.069	4.080	4.133
#Ba	0.005	–	–	0.001	–	0.004	0.007	0.016
#Ca	–	–	–	–	–	0.008	0.007	0.004
#Na	0.190	0.214	0.186	0.182	0.194	0.280	0.272	0.032
#K	1.684	1.639	1.604	1.644	1.639	1.586	1.556	1.679
A^{site}	1.878	1.852	1.789	1.827	1.833	1.879	1.842	1.731
#O	20	20	20	20	20	20	20	20
#OH	4	4	4	4	4	4	4	4

Table 2. *(continued)*

Sample	R-134	R-134	R-134	R-134	R-134	R-126	R-126	R-108	R-108	R-108	R-105	R-105	R-105	R-129	R-103
SiO_2	49.51	42.34	44.24	46.40	46.91	47.13	47.32	46.30	46.39	46.24	45.61	46.02	46.06	47.10	46.72
TiO_2	0.03	0.31	0.98	0.42	0.76	0.95	0.91	0.73	0.72	0.66	0.24	0.52	0.67	0.59	1.14
Al_2O_3	34.96	28.87	30.92	31.44	36.84	36.15	36.10	34.15	34.36	34.05	35.79	35.27	34.20	36.60	33.81
FeO	2.49	9.51	7.66	6.04	1.09	1.74	1.12	1.18	1.14	1.36	1.06	1.04	1.14	1.19	1.03
MnO	0.02	0.17	0.19	0.02	0.02	0.05	0.03	0.01	0.06	0.02	0.02	0.04	0.06	–	–
MgO	1.21	3.34	3.02	1.85	0.44	0.87	0.83	0.83	0.79	1.04	0.58	0.62	1.01	0.61	0.83
BaO	0.11	0.12	–	0.25	0.12	0.07	0.03	–	–	–	0.21	0.17	0.08	0.05	–
CaO	0.12	0.14	0.02	0.13	0.02	0.02	–	–	–	–	–	–	–	0.08	0.01
Na_2O	0.13	0.03	0.03	0.13	1.19	0.37	0.36	0.23	0.54	0.45	0.76	0.71	0.59	1.32	0.56
K_2O	9.40	8.06	8.50	9.47	9.14	9.06	10.29	10.17	10.16	10.04	9.85	9.69	9.81	9.75	10.06
Total	97.98	92.89	95.56	96.15	96.53	96.41	96.99	93.60	94.16	93.86	94.12	94.08	93.62	97.60	94.18
$\#Si^{IV}$	6.367	6.024	6.039	6.253	6.116	6.151	6.162	6.249	6.231	6.233	6.129	6.176	6.218	6.107	6.267
$\#Al^{IV}$	1.633	1.976	1.961	1.747	1.884	1.849	1.838	1.751	1.769	1.767	1.871	1.824	1.782	1.893	1.733
T^{site}	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
$\#Al^{VI}$	3.666	2.865	3.014	3.247	3.778	3.711	3.702	3.680	3.670	3.642	3.797	3.754	3.660	3.700	3.611
$\#Ti^{VI}$	0.003	0.033	0.101	0.043	0.075	0.093	0.089	0.074	0.073	0.067	0.024	0.052	0.068	0.058	0.115
$\#Fe^{+3}$	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
$\#Fe^{+2}$	0.268	1.132	0.874	0.681	0.119	0.190	0.122	0.133	0.128	0.153	0.119	0.117	0.129	0.129	0.116
$\#Mn^{+2}$	0.002	0.020	0.022	0.002	0.002	0.006	0.003	0.001	0.007	0.002	0.002	0.005	0.007	–	–
#Mg	0.232	0.708	0.615	0.372	0.086	0.169	0.161	0.167	0.158	0.209	0.116	0.124	0.203	0.118	0.166
#Li	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
O^{site}	4.171	4.759	4.626	4.344	4.059	4.169	4.077	4.056	4.036	4.074	4.059	4.052	4.067	4.037	4.010
#Ba	0.006	0.007	–	0.013	0.006	0.004	0.002	–	–	–	0.011	0.009	0.004	0.003	–
#Ca	0.017	0.021	0.003	0.019	0.003	0.003	–	–	–	–	–	–	–	0.011	0.001
#Na	0.032	0.008	0.008	0.034	0.301	0.094	0.091	0.060	0.141	0.118	0.198	0.185	0.154	0.332	0.146
#K	1.542	1.463	1.480	1.628	1.520	1.508	1.709	1.751	1.741	1.726	1.689	1.659	1.690	1.613	1.721
A^{site}	1.597	1.499	1.491	1.694	1.830	1.608	1.802	1.811	1.882	1.844	1.898	1.853	1.848	1.958	1.868
#O	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
#OH	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

Sample	R-103	R-101	R-58	R-58	RZ-109	RZ-109	RZ-109	R-123	R-123	R-129	R-111	R-111	R-90	R-90	R-90
SiO_2	46.11	44.97	44.06	43.96	47.41	47.02	46.11	45.85	46.31	45.68	45.33	45.68	45.97	45.92	46.18
TiO_2	0.89	–	0.70	0.59	0.57	0.65	0.66	0.01	0.01	0.01	1.25	1.24	0.69	0.38	0.81
Al_2O_3	35.24	33.98	35.18	35.51	35.30	35.40	35.55	35.63	35.58	35.35	34.88	34.45	35.33	35.00	34.81
FeO	0.94	3.74	1.31	1.25	1.07	1.09	1.10	1.12	1.04	1.00	1.47	1.13	1.24	1.21	1.19
MnO	0.04	0.11	–	0.04	0.03	–	–	0.02	0.09	0.03	–	0.05	–	–	0.13
MgO	0.69	1.19	0.75	0.61	0.75	0.69	0.78	0.78	0.90	0.55	0.88	0.96	0.95	0.93	1.11
BaO	0.05	–	0.40	0.40	0.22	0.26	0.24	0.38	0.10	–	–	–	0.30	0.14	0.24
CaO	–	0.18	0.07	0.07	–	0.03	–	0.09	0.04	0.02	–	0.01	0.02	–	–
Na_2O	0.52	0.21	0.83	1.08	0.97	0.79	1.07	0.57	0.49	0.46	0.22	0.35	0.44	0.49	0.53
K_2O	10.10	8.84	9.11	8.97	9.55	9.37	9.46	10.00	10.01	10.42	10.15	10.77	10.32	10.55	10.13
Total	94.58	93.27	92.43	92.50	95.88	95.30	95.02	94.59	94.60	93.59	94.18	94.71	95.26	94.66	95.32
$\#Si^{IV}$	6.160	6.173	6.041	6.022	6.236	6.216	6.134	6.145	6.182	6.175	6.102	6.133	6.128	6.160	6.151
$\#Al^{IV}$	1.840	1.827	1.959	1.978	1.764	1.784	1.866	1.855	1.818	1.825	1.898	1.867	1.872	1.840	1.849
T^{site}	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
$\#Al^{VI}$	3.709	3.485	3.726	3.755	3.709	3.731	3.708	3.772	3.780	3.807	3.636	3.585	3.679	3.694	3.615
$\#Ti^{VI}$	0.089	–	0.072	0.061	0.056	0.065	0.066	0.001	0.001	0.001	0.127	0.125	0.069	0.038	0.081
$\#Fe^{+3}$	–	0.005	0.002	0.002	0.001	–	0.005	0.015	0.003	0.007	–	0.007	–	0.004	0.020
$\#Fe^{+2}$	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
$\#Mn^{+2}$	0.105	0.429	0.150	0.143	0.118	0.121	0.122	0.126	0.116	0.113	0.165	0.127	0.138	0.136	0.133
#Mg	0.005	0.013	–	0.005	0.003	–	–	0.002	0.010	0.003	–	0.006	–	–	0.015
#Li	0.137	0.857	0.153	0.125	0.147	0.136	0.155	0.156	0.179	0.111	0.177	0.192	0.189	0.186	0.220
O^{site}	4.045	4.490	4.104	4.091	4.034	4.053	4.057	4.072	4.090	4.043	4.104	4.042	4.075	4.058	4.084
#Ba	0.003	–	0.021	0.021	0.011	0.013	0.013	0.020	0.005	–	–	–	0.016	0.007	0.013
#Ca	–	0.026	0.010	0.010	–	0.004	–	0.013	0.006	0.003	–	0.001	0.003	–	–
#Na	0.135	0.056	0.221	0.287	0.247	0.202	0.276	0.148	0.127	0.121	0.057	0.091	0.114	0.127	0.137
#K	1.721	1.548	1.594	1.568	1.603	1.580	1.606	1.710	1.705	1.797	1.743	1.845	1.755	1.806	1.721
A^{site}	1.859	1.630	1.846	1.886	1.861	1.800	1.894	1.891	1.843	1.920	1.800	1.937	1.887	1.940	1.871
#O	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
#OH	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

near Rataje and eclosing numerous inclusions were used to study their chemistry in relation to P-T evolution of host rocks. Similar coarse garnet porphyroblasts were studied at Hodkov in Moldanubicum where no signs of late retrograde metamorphism were observed. Garnets from GU in the vicinity of Drahňovice and from a long outcrop in the Vrchlice River valley N of Malešov were investigated for correlation of individual units. Inclusions in garnets consist of abundant quartz, zoned plagioclase, biotite, muscovite, ilmenite and rutile. Oliveri-

Table 3. Representative analyses of garnet from MSZ, GU and Moldanubicum. Sample location: R-113 – outcrops near highway intersection Talmberk – Čekánov, SE of Sázava nad Sázavou – mica gneiss affected by strong retrograde metamorphism; R-88 – a quarry at Stříbrná near Český Šternberk – biotite-sillimanite gneiss with garnet which suffered retrograde metamorphism – Mold, for location of other samples see tables 1 and 2.

Sample	R-121	R-121	R-121	R-121	R-121	R-121	R-121	R-134	R-134	R-134	R-126	R-126	R-126	R-126	R-58
Point	1	2	3	4	5	6	8	1	2	5	1	2	3	4	55
SiO_2	37.58	37.71	37.74	38.23	38.30	38.29	37.91	37.99	37.63	39.99	38.09	38.34	38.19	38.01	36.62
TiO_2	0.05	–	0.02	0.02	0.02	0.06	0.01	0.08	0.03	0.05	0.02	0.05	0.01	0.07	0.01
Al_2O_3	21.78	21.70	21.97	21.88	21.52	21.79	21.69	21.66	21.51	22.76	21.91	21.50	21.15	21.36	22.25
FeO	31.02	29.37	30.13	28.50	29.43	28.87	31.02	31.44	32.94	26.99	28.62	28.93	28.88	32.15	33.66
MnO	3.54	5.76	3.35	3.33	5.08	3.83	3.08	1.32	1.40	1.84	6.79	4.10	5.57	1.74	2.75
MgO	4.53	3.87	5.60	6.67	3.98	5.78	4.54	2.84	2.21	2.87	2.10	2.27	2.55	1.53	2.52
CaO	1.46	1.46	1.02	1.22	1.40	1.31	1.69	4.49	4.10	4.18	2.47	4.60	2.84	4.96	2.08
Total	99.95	99.86	99.83	99.84	99.94	99.93	99.94	99.83	99.81	98.68	100.00	100.02	99.90	99.98	99.90
$\#Si^{IV}$	5.940	5.960	5.930	5.970	6.000	5.980	5.970	5.980	6.000	5.980	5.960	6.000	6.000	6.000	5.830
$\#Al^{IV}$	0.060	0.040	0.070	0.030	–	0.020	0.030	0.020	–	0.020	0.040	–	–	–	0.170
$\#Al^{VI}$	3.990	4.000	4.000	4.000	3.970	3.990	4.000	3.990	4.040	3.990	4.000	3.970	3.920	3.970	4.000
$\#Ti^{VI}$	0.010	–	–	–	–	0.010	–	0.010	–	0.010	–	0.010	–	0.010	–
$\#Fe^{+3}$	–	–	–	–	0.020	–	–	–	–	–	–	0.030	0.080	0.020	–
$\#Fe^{+2}$	4.100	3.880	3.960	3.720	3.860	3.770	4.090	4.140	4.390	3.380	3.740	3.790	3.790	4.240	4.480
$\#Mn^{+2}$	0.470	0.770	0.450	0.440	0.670	0.510	0.410	0.180	0.190	0.230	0.900	0.540	0.740	0.230	0.370
#Mg	1.070	0.910	1.310	1.550	0.930	1.350	1.070	0.670	0.530	0.640	0.490	0.530	0.600	0.360	0.600
#Ca	0.250	0.250	0.170	0.200	0.240	0.220	0.280	0.760	0.700	0.670	0.410	0.770	0.480	0.840	0.360
#mg_Grt	0.210	0.190	0.250	0.290	0.190	0.260	0.210	0.140	0.110	0.160	0.120	0.120	0.140	0.080	0.120
Alm	69.6	66.8	67.2	62.9	67.7	64.5	69.9	72.0	75.6	68.6	67.5	67.2	67.6	74.7	77.2
Sps	8.0	13.3	7.6	7.4	11.8	8.7	7.0	3.1	3.3	4.7	16.2	9.6	13.2	4.1	6.4
Prp	18.1	15.7	22.3	26.2	16.3	23.0	18.2	11.6	9.1	13.0	8.8	9.4	10.6	6.3	10.3
Grs	4.1	4.3	2.9	3.4	3.5	3.7	4.9	13.0	12.0	13.5	7.4	12.8	6.3	14.2	6.1
Ti-Grs	0.2	–	0.1	0.1	0.1	0.2	–	0.3	0.1	0.2	0.1	0.2	–	0.2	–
Adr	–	–	–	–	0.6	–	–	–	–	–	–	0.8	2.2	0.5	–
Alm+Sps	77.6	80.1	74.8	70.3	79.5	73.2	76.9	75.1	78.9	73.3	83.7	76.9	80.8	78.8	83.6

Sample	R-108	R-108	R-105	R-134	R-134	R-105	R-129	R-129	R-129	R-129	R-129	R-58	R-105	R-105	R-58
Point	1	2	1	3	4	4	1	2	3	4	5	1	2	3	6
SiO_2	38.27	38.11	38.10	39.48	38.81	38.40	38.01	37.58	37.83	37.81	37.36	36.46	37.72	38.21	36.47
TiO_2	0.01	–	0.11	–	0.02	0.12	0.05	0.08	0.06	0.03	0.04	0.05	0.09	0.02	0.12
Al_2O_3	21.64	21.52	21.35	21.30	21.60	21.43	21.87	21.70	21.89	21.83	21.64	21.74	21.02	21.37	21.96
FeO	29.90	29.73	30.12	28.71	29.76	28.82	31.27	31.76	31.69	31.38	29.93	33.38	31.24	30.47	28.89
MnO	7.02	7.31	3.41	3.08	1.40	4.49	1.31	1.61	1.53	2.03	3.73	2.24	4.21	3.44	4.27
MgO	2.16	2.18	2.70	2.56	3.23	2.03	2.37	1.78	1.84	1.49	2.38	2.13	2.85	2.79	1.07
CaO	0.99	1.03	3.95	2.74	4.62	4.41	5.13	5.14	5.12	5.33	4.23	3.98	2.34	3.32	7.09
Total	99.99	99.92	99.94	99.48	99.96	100.03	100.00	99.70	100.00	99.94	99.56	99.99	99.88	99.99	99.90
$\#Si^{IV}$	6.000	6.000	6.000	6.000	6.000	6.000	5.960	5.940	5.940	5.940	5.920	5.870	6.000	6.000	5.840
$\#Al^{IV}$	–	–	–	–	–	–	0.040	0.060	0.060	0.060	0.080	0.130	–	–	0.160
$\#Al^{VI}$	4.000	3.990	3.960	3.820	3.940	3.950	3.990	3.980	3.990	3.990	3.960	3.990	3.940	3.960	3.980
$\#Ti^{VI}$	–	–	0.010	–	–	0.010	0.010	0.010	0.010	–	–	0.010	0.010	–	0.010
$\#Fe^{+3}$	–	0.010	0.020	0.180	0.060	0.040	–	–	–	–	–	–	0.050	0.040	–
$\#Fe^{+2}$	3.920	3.910	3.970	3.650	3.850	3.770	4.100	4.200	4.160	4.130	3.970	4.490	4.160	4.000	3.870
$\#Mn^{+2}$	0.930	0.970	0.450	0.400	0.180	0.590	0.170	0.220	0.200	0.270	0.500	0.310	0.570	0.460	0.580
#Mg	0.510	0.510	0.630	0.580	0.740	0.470	0.550	0.420	0.430	0.350	0.560	0.510	0.680	0.650	0.260
#Ca	0.170	0.170	0.670	0.450	0.770	0.740	0.860	0.870	0.860	0.900	0.720	0.690	0.400	0.560	1.220
#mg_Grt	0.110	0.120	0.140	0.140	0.160	0.110	0.120	0.090	0.090	0.080	0.120	0.100	0.140	0.140	0.060
Alm	71.0	70.2	69.3	72.0	69.4	67.5	72.0	73.6	73.5	73.1	69.0	74.9	71.6	70.6	65.3
Sps	16.9	17.5	7.9	7.8	3.3	10.7	3.1	3.8	3.6	4.8	8.7	5.1	9.8	8.1	9.8
Prp	9.2	9.2	11.1	11.4	13.4	8.5	9.7	7.3	7.6	6.2	9.8	8.5	11.6	11.5	4.3
Grs	3.0	3.0	10.8	3.4	12.1	11.9	15.0	14.9	15.0	15.7	11.6	11.3	5.4	8.7	20.2
Ti-Grs	–	–	0.3	–	0.1	0.4	0.2	0.2	0.2	0.1	0.1	0.2	0.3	0.1	0.4
Adr	–	0.2	0.6	5.5	1.7	1.1	–	–	–	–	–	–	1.3	1.1	–
Alm+Sps	87.8	87.7	77.2	79.8	72.7	78.2	75.1	77.3	77.1	77.9	77.7	80.0	81.4	78.6	75.0

ová (1993) identified inclusions of Ca-mica (margarite), epidote and clinozoisite (assemblage M1 in MSZ) which were not found in other units. Moreover, kyanite was identified in garnets from the Malín Series. Thus, garnets enclose minerals of M2 and M3 assemblages of which are they themselves components. Synkinematic growth of garnet in relation to M2 and M3 was not observed.

Garnets in MSZ often occur in the form of strongly resorbed porphyroblasts which suffered retrograde processes (chloritization, biotitization). In some cases only tectonically boudinaged and partly dissolved relics of original mineral grains can be observed. Some large garnet grains are rimmed by plagioclase enclosing hypidiomorphic flakes of biotite and occasionally also long prismatic sillimanite.

Table 3. *(continued)*

Sample	R-58	R-58	R-58	R-58	R-58	R-58	R-58	R-58	R-58	R-58	R-58	R-58	R-58	R-58	R-58
Point	7	8	9	10	11	12	2	3	4	5	17	18	19	20	21
SiO_2	35.64	36.12	35.90	35.60	36.42	35.82	36.65	37.03	36.67	36.44	36.13	35.88	36.06	35.62	35.80
TiO_2	0.12	0.18	0.20	0.11	0.09	0.11	0.10	0.13	0.31	0.11	0.13	0.09	0.12	0.15	0.12
Al_2O_3	21.92	21.64	21.81	21.72	21.63	21.96	21.99	21.86	21.62	21.75	22.01	21.85	21.87	21.63	21.56
FeO	28.95	30.77	30.50	30.29	30.05	29.06	28.33	28.51	28.89	29.00	28.55	28.43	28.44	27.56	27.42
MnO	4.41	4.25	4.24	4.61	4.32	4.79	4.33	3.98	3.85	4.43	4.99	5.21	5.32	5.64	6.12
MgO	1.13	1.24	1.44	1.23	1.14	0.94	1.47	1.14	0.95	1.03	0.90	0.86	0.93	0.90	0.84
CaO	7.15	5.56	5.55	5.66	6.28	6.95	7.10	7.18	6.82	7.20	7.19	7.23	7.04	7.51	7.29
Total	100.06	99.96	99.97	100.02	99.99	99.94	99.97	99.84	99.12	99.96	99.90	99.98	99.94	100.05	100.01
$\#Si^{IV}$	5.740	5.840	5.790	5.750	5.870	5.780	5.850	5.890	5.880	5.860	5.810	5.780	5.810	5.740	5.780
$\#Al^{IV}$	0.260	0.160	0.210	0.250	0.130	0.220	0.150	0.110	0.120	0.140	0.190	0.220	0.190	0.260	0.220
$\#Al^{VI}$	3.890	3.950	3.940	3.890	3.980	3.950	3.990	3.980	3.960	3.990	3.980	3.940	3.970	3.860	3.880
$\#Ti^{VI}$	0.010	0.020	0.020	0.010	0.010	0.010	0.010	0.020	0.040	0.010	0.020	0.010	0.010	0.020	0.010
$\#Fe^{+3}$	0.090	0.020	0.040	0.090	–	0.030	–	–	–	–	–	0.050	0.010	0.130	0.100
$\#Fe^{+2}$	3.900	4.160	4.110	4.090	4.050	3.920	3.780	3.790	3.870	3.900	3.840	3.830	3.830	3.720	3.700
$\#Mn^{+2}$	0.600	0.580	0.580	0.630	0.590	0.650	0.590	0.540	0.520	0.600	0.680	0.710	0.730	0.770	0.840
#Mg	0.270	0.300	0.350	0.300	0.270	0.230	0.350	0.270	0.230	0.250	0.220	0.210	0.220	0.220	0.200
#Ca	1.230	0.960	0.960	0.980	1.080	1.200	1.210	1.220	1.170	1.240	1.240	1.250	1.220	1.300	1.260
#mg_Grt	0.060	0.070	0.080	0.070	0.060	0.050	0.080	0.070	0.060	0.060	0.050	0.050	0.060	0.050	0.050
Alm	64.9	69.2	68.4	68.2	67.5	65.2	63.7	65.0	66.6	65.0	64.2	63.8	63.8	61.9	61.6
Sps	10.0	9.7	9.6	10.5	9.8	10.9	9.9	9.2	9.0	10.1	11.4	11.9	12.1	12.8	13.9
Prp	4.5	5.0	5.8	4.9	4.6	3.8	5.9	4.7	3.9	4.1	3.6	3.4	3.7	3.6	3.4
Grs	18.0	15.1	14.6	13.7	17.7	18.8	20.2	20.7	19.5	20.5	20.4	19.3	19.6	18.1	18.1
Ti-Grs	0.4	0.6	0.6	0.3	0.3	0.3	0.3	0.4	1.0	0.3	0.4	0.3	0.4	0.5	0.4
Adr	2.2	0.5	0.9	2.4	–	0.8	–	–	–	–	–	1.3	0.3	3.2	2.6
Alm+Sps	74.9	78.8	78.1	78.7	77.3	76.1	73.6	74.2	75.6	75.1	75.6	75.7	75.9	74.7	75.6

Sample	R-58	R-58	R-58	R-58	R-58	R-58	R-58	R-58	R-58	R-58	R-58	R-58	R-58	R-58	R-58
Point	13	14	15	16	28	29	30	31	32	22	23	24	25	26	27
SiO_2	36.27	35.89	35.32	36.17	35.92	35.56	36.27	36.82	37.42	36.05	35.52	35.92	36.07	35.76	35.49
TiO_2	0.11	0.12	0.16	0.13	0.09	0.04	0.06	0.15	0.04	0.14	0.11	0.12	0.13	0.08	0.13
Al_2O_3	21.82	21.91	21.64	22.02	21.73	21.73	21.90	22.02	21.81	21.70	21.75	21.99	22.04	21.27	21.72
FeO	28.66	28.18	28.13	28.41	33.48	32.96	32.89	28.73	31.72	27.70	27.39	27.47	27.83	32.52	33.94
MnO	5.06	5.06	5.30	4.99	2.31	2.30	3.06	4.29	3.84	6.35	6.83	6.44	5.99	4.19	3.19
MgO	0.86	1.03	0.94	0.95	2.02	2.50	2.71	0.99	2.84	0.80	0.94	0.90	0.87	2.03	2.16
CaO	7.00	7.38	7.26	7.23	3.93	3.65	2.99	6.84	2.27	6.90	6.58	6.94	7.04	3.06	2.58
Total	99.79	100.01	100.10	99.91	100.00	99.68	100.00	99.85	99.94	99.88	100.01	99.88	99.98	100.04	100.00
$\#Si^{IV}$	5.840	5.780	5.700	5.810	5.800	5.740	5.830	5.850	5.920	5.820	5.740	5.790	5.800	5.790	5.740
$\#Al^{IV}$	0.160	0.220	0.300	0.190	0.200	0.260	0.170	0.150	0.080	0.180	0.260	0.210	0.200	0.210	0.260
$\#Al^{VI}$	3.990	3.930	3.820	3.980	3.930	3.880	3.980	3.980	4.000	3.960	3.880	3.970	3.980	3.850	3.890
$\#Ti^{VI}$	0.010	0.010	0.020	0.020	0.010	–	0.010	0.020	–	0.020	0.010	0.010	0.020	0.010	0.020
$\#Fe^{+3}$	–	0.050	0.160	–	0.060	0.110	0.020	–	–	0.020	0.100	0.010	–	0.140	0.090
$\#Fe^{+2}$	3.860	3.790	3.800	3.820	4.520	4.450	4.420	3.820	4.200	3.740	3.700	3.700	3.750	4.400	4.590
$\#Mn^{+2}$	0.690	0.690	0.720	0.680	0.320	0.320	0.420	0.580	0.510	0.870	0.930	0.880	0.820	0.570	0.440
#Mg	0.210	0.250	0.230	0.230	0.490	0.600	0.650	0.230	0.670	0.190	0.230	0.220	0.210	0.490	0.520
#Ca	1.210	1.270	1.250	1.250	0.680	0.630	0.510	1.170	0.390	1.190	1.140	1.200	1.210	0.530	0.450
#mg_Grt	0.050	0.060	0.060	0.060	0.100	0.120	0.130	0.060	0.140	0.050	0.060	0.060	0.050	0.100	0.100
Alm	64.7	63.1	63.2	63.9	75.2	74.2	73.6	65.8	72.8	62.3	61.6	61.7	62.5	73.4	76.5
Sps	11.6	11.5	12.1	11.4	5.3	5.3	6.9	10.0	8.9	14.5	15.6	14.7	13.6	9.6	7.3
Prp	3.4	4.1	3.8	3.8	8.1	10.0	10.8	4.0	11.6	3.2	3.8	3.6	3.5	8.2	8.7
Grs	20.0	19.6	16.4	20.6	9.6	7.6	8.1	19.7	6.6	18.9	16.0	19.4	20.0	5.3	4.8
Ti-Grs	0.3	0.4	0.5	0.4	0.3	0.1	0.2	0.5	0.1	0.4	0.3	0.4	0.4	0.3	0.4
Adr	–	1.4	4.1	–	1.5	2.7	0.4	–	–	0.6	2.6	0.3	–	3.4	2.3
Alm+Sps	76.2	74.6	75.2	75.2	80.5	79.4	80.6	75.8	81.7	76.8	77.2	76.3	76.1	82.9	83.8

Garnets from all three units are chemically and by type of zoning very similar. Larger garnet grains are homogeneous due to intracrystalline diffusion which argues for high temperatures during which garnet originated, corresponding to sillimanite zone. Older growth zoning is preserved in the form of relics in cores of larger garnets (elevated contents of Ca, Mn, lower contents of Fe, Mg – see fig. 28, sample R-58). Garnet margins are affected by later retrograde processes particularly along the contacts with Fe- and Mg-minerals when an exchange of Fe and Mg cations took place between garnet and biotite and/or resorption of garnet due to growth of biotite which is indicated by increased contents of Mn and decreased concentrations of Fe and Mg (Tracy et al. 1979). A slightly different chemical profile is shown by garnets from the Malín Formation which contain more pyrope component in their cores, whereas proportion of the grossular component is lower and the course of chemical profile is slightly concave (fig. 28). However, correct interpretation of these observations would involve studies of a large number of samples supplemented by profiling of An component in plagioclase.

Table 3. *(continued)*

Sample	R-58	R-58	R-58	R-58	R-58	R-58	R-58	R-58	R-58	R-58	R-58	R-58	R-58	R-58	R-58
Point	40	41	42	34	35	36	37	38	39	51	52	53	46	47	48
SiO_2	38.05	36.87	36.54	37.33	36.79	37.16	37.36	36.15	40.18	36.66	37.00	36.42	37.21	36.32	36.86
TiO_2	0.01	0.03	0.08	–	–	–	0.02	0.05	0.02	–	0.24	0.02	0.03	0.09	0.03
Al_2O_3	21.91	22.01	22.22	21.82	22.00	22.07	22.28	21.47	21.51	22.01	21.81	22.31	21.87	22.18	22.07
FeO	31.97	32.89	33.37	34.39	34.67	33.51	32.61	33.99	28.37	32.89	33.99	33.84	32.20	29.27	30.83
MnO	3.49	3.61	1.20	1.33	1.37	1.89	3.09	2.01	1.56	2.13	1.58	2.96	3.13	5.06	3.72
MgO	1.87	1.88	1.55	2.60	3.01	2.62	2.25	2.35	1.95	2.50	2.83	2.68	2.00	0.74	1.08
CaO	2.25	2.20	5.05	2.53	2.13	2.65	2.18	3.32	3.19	2.81	2.05	1.68	3.40	6.02	5.20
Total	99.58	99.49	100.00	100.00	99.99	99.90	99.79	99.96	98.66	99.79	99.52	99.91	99.85	99.69	99.81
#Si^{IV}	5.950	5.870	5.820	5.920	5.860	5.880	5.870	5.830	6.000	5.860	5.880	5.810	6.000	5.810	5.860
#Al^{IV}	0.050	0.130	0.180	0.080	0.140	0.120	0.130	0.170	–	0.140	0.120	0.190	–	0.190	0.140
#Al^{VI}	4.000	4.000	3.990	4.000	4.000	4.000	4.000	3.920	3.790	4.000	3.970	4.000	4.160	3.990	3.990
#Ti^{VI}	–	–	–	–	–	–	–	–	–	–	0.030	–	–	0.010	–
#Fe^{+3}	–	–	–	–	–	–	–	0.070	0.210	–	–	–	–	–	–
#Fe^{+2}	4.180	4.380	4.440	4.560	4.620	4.440	4.290	4.590	3.540	4.500	4.520	4.510	4.340	3.910	4.100
#Mn^{+2}	0.460	0.490	0.160	0.180	0.180	0.250	0.410	0.270	0.200	0.290	0.210	0.400	0.430	0.690	0.500
#Mg	0.440	0.450	0.370	0.610	0.720	0.620	0.530	0.570	0.430	0.590	0.670	0.640	0.480	0.180	0.260
#Ca	0.380	0.380	0.860	0.430	0.360	0.450	0.370	0.570	0.510	0.480	0.350	0.290	0.590	1.030	0.890
#mg_Grt	0.090	0.090	0.080	0.120	0.130	0.120	0.110	0.110	0.110	0.120	0.130	0.120	0.100	0.040	0.060
Alm	76.6	77.0	76.1	78.9	78.5	77.1	76.6	76.4	75.6	76.7	78.4	77.3	74.4	67.4	71.4
Sps	8.5	8.6	2.8	3.1	3.1	4.4	7.4	4.6	4.2	4.9	3.7	6.9	7.3	11.8	8.7
Prp	8.0	7.8	6.3	10.6	12.2	10.7	9.4	9.4	9.3	10.1	11.6	10.9	8.2	3.0	4.5
Grs	6.8	6.5	14.6	7.4	6.1	7.8	6.5	7.6	4.0	8.2	5.5	4.9	9.9	17.5	15.3
Ti-Grs	–	0.1	0.3	–	–	–	0.1	0.2	0.1	–	0.8	0.1	0.1	0.3	0.1
Adr	–	–	–	–	–	–	–	1.8	6.8	–	–	–	–	–	–
Alm+Sps	85.1	85.5	78.9	82.0	81.7	81.5	84.0	81.0	79.8	81.6	82.1	84.2	81.7	79.1	80.1

Sample	R-58	R-58	RZ-109	RZ-109	RZ-109	R-131	RZ-109	RZ-109	RZ-109	RZ-109	RZ-109	R-129	R-113	R-113	R-113
Point	49	50	6	7	8	9	1	2	3	4	5	17	1	3	4
SiO_2	36.59	36.76	38.24	38.99	38.75	39.09	38.92	39.19	38.17	39.81	38.78	38.37	37.98	38.49	38.17
TiO_2	0.08	0.05	0.06	0.05	0.03	–	–	0.04	0.15	0.01	0.10	–	0.03	0.06	0.05
Al_2O_3	22.04	22.20	21.79	20.93	21.31	21.70	20.24	22.62	20.67	20.81	20.90	21.64	21.60	21.47	21.52
FeO	32.03	32.76	31.42	29.34	29.69	26.10	29.19	29.84	30.77	28.33	29.75	28.73	29.02	28.38	29.01
MnO	2.34	1.54	2.41	3.01	1.90	2.47	1.59	2.56	3.06	2.51	2.71	4.40	3.77	2.84	3.28
MgO	0.85	1.33	3.19	3.23	2.45	2.37	3.02	3.06	3.31	3.29	3.33	2.69	2.93	2.82	3.08
CaO	5.95	5.30	2.54	2.77	4.98	7.53	4.43	2.46	2.39	2.81	2.98	3.74	4.55	5.44	4.75
Total	99.93	99.94	99.66	100.03	100.04	99.90	100.17	99.81	99.82	100.25	100.07	99.66	99.96	99.92	99.91
#Si^{IV}	5.840	5.840	5.980	6.000	6.000	6.000	6.000	5.950	6.000	6.000	6.000	6.000	5.980	6.000	6.000
#Al^{IV}	0.160	0.160	0.020	–	–	–	–	0.050	–	–	–	–	0.020	–	–
#Al^{VI}	3.980	3.990	3.990	3.800	3.890	3.930	3.680	3.990	3.830	3.700	3.810	3.990	3.990	3.940	3.990
#Ti^{VI}	0.010	0.010	0.010	0.010	–	–	–	–	0.020	–	0.010	–	–	0.010	0.010
#Fe^{+3}	–	–	–	0.190	0.110	0.070	0.320	–	0.150	0.300	0.180	0.010	–	0.050	0.010
#Fe^{+2}	4.270	4.350	4.110	3.780	3.840	3.350	3.760	3.790	4.050	3.570	3.850	3.760	3.820	3.700	3.810
#Mn^{+2}	0.320	0.210	0.320	0.390	0.250	0.320	0.210	0.330	0.410	0.320	0.350	0.580	0.500	0.380	0.440
#Mg	0.200	0.320	0.740	0.740	0.570	0.540	0.690	0.690	0.780	0.740	0.770	0.630	0.690	0.660	0.720
#Ca	1.020	0.900	0.430	0.460	0.830	1.240	0.730	0.400	0.400	0.450	0.490	0.630	0.770	0.910	0.800
#mg_Grt	0.040	0.070	0.150	0.160	0.130	0.140	0.160	0.150	0.160	0.170	0.170	0.140	0.150	0.150	0.160
Alm	73.5	75.3	73.3	70.3	70.1	61.5	69.7	72.7	71.7	70.2	70.3	67.2	66.1	65.6	66.0
Sps	5.4	3.6	5.7	7.3	4.5	5.9	3.9	6.3	7.2	6.3	6.5	10.4	8.7	6.7	7.6
Prp	3.5	5.5	13.3	13.8	10.3	9.9	12.9	13.3	13.8	14.6	14.0	11.2	11.9	11.6	12.5
Grs	17.1	15.5	7.5	2.9	12.1	20.7	4.6	7.5	2.7	–	4.0	10.9	13.0	14.7	13.5
Ti-Grs	0.3	0.2	0.2	0.2	0.1	–	–	0.1	0.5	–	0.3	–	0.1	0.2	0.2
Adr	–	–	–	5.4	2.9	1.8	8.9	–	4.1	8.9	4.9	0.3	–	1.3	0.1
Alm+Sps	79.0	78.9	79.1	77.6	74.6	67.4	73.6	79.0	79.0	76.5	76.8	77.6	74.8	72.2	73.6

Garnets from all three units are a mixture of almandine, pyrope and grossular. The proportion of the andradite component in garnets is negligible (table 3, figs 26, 27) show that garnets from GU are relatively enriched in the pyrope and partly also spessartite components, and depleted in the grossular component. On the other hand, the proportion of grossular is larger particularly in greywacke paragneisses of MSZ and in MVG. The composition of garnet is obviously influenced by chemistry of the protolith (in addition to metamorphic conditions). Similar to biotite, variations in chemistry of garnets from MSZ and those from Moldanubicum are negligible which indicating very close metamorphic evolution of both units during the M2 and M3 phases.

Staurolite

Tiny hypidiomorphic columns of accessory staurolite occur in Al-rich metapelites of MSZ. Similar grains of staurolite in MVG were identified only in a rock of similar lithology near Hodkov. No staurolite was found in rocks of GU.

Table 3. *(continued)*

Sample	R-113	R-88	R-88	R-88	R-88	R-58	R-58	R-123	R-123	R-113	R-113	R-113	R-113	R-113	R-129
Point	12	1	2	3	4	45	56	12	13	11	7	8	9	10	16
SiO_2	37.82	38.62	39.17	38.44	38.67	38.14	36.48	38.08	38.18	38.18	38.49	38.49	38.50	37.95	38.36
TiO_2	0.03	0.03	0.07	0.04	0.01	0.20	0.03	–	–	0.01	0.05	0.01	0.03	0.01	–
Al_2O_3	21.40	21.88	21.72	21.53	21.40	23.47	21.89	21.75	21.54	21.37	21.64	21.62	21.49	21.27	21.29
FeO	28.42	24.18	23.02	23.94	23.44	28.83	33.49	26.79	27.69	27.75	28.55	28.06	28.06	28.07	29.40
MnO	5.68	5.40	5.93	6.60	7.39	1.90	1.32	9.34	8.09	6.54	2.66	3.86	6.97	6.42	3.63
MgO	3.30	2.79	2.76	2.52	2.72	1.63	2.79	2.77	3.17	2.94	3.14	2.93	2.43	2.92	2.60
CaO	3.22	6.99	6.62	6.50	5.61	3.42	3.85	1.02	1.23	2.89	5.33	4.81	3.05	2.91	4.03
Total	99.86	99.89	99.90	99.86	99.97	97.65	99.95	99.83	99.99	100.01	100.02	100.01	99.96	99.86	99.94
#Si^{IV}	6.000	6.000	6.000	6.000	6.000	5.780	5.850	5.970	6.000	6.000	6.000	6.000	6.000	6.000	6.000
#Al^{IV}	–	–	–	–	–	0.220	0.150	0.030	–	–	–	–	–	–	–
#Al^{VI}	4.000	4.010	3.920	3.960	3.910	3.970	3.990	3.990	3.990	3.960	3.980	3.970	3.950	3.960	3.920
#Ti^{VI}	–	–	0.010	–	–	0.020	–	–	–	–	0.010	–	–	–	–
#Fe^{+3}	–	–	0.060	0.030	0.090	–	0.010	–	0.010	0.040	0.020	0.020	0.040	0.030	0.070
#Fe^{+2}	3.770	3.140	2.950	3.130	3.040	3.650	4.490	3.510	3.640	3.650	3.720	3.660	3.530	3.710	3.850
#Mn^{+2}	0.760	0.710	0.770	0.870	0.970	0.240	0.180	1.240	1.080	0.870	0.350	0.510	0.920	0.860	0.480
#Mg	0.780	0.650	0.630	0.590	0.630	0.370	0.670	0.650	0.740	0.690	0.730	0.680	0.570	0.690	0.610
#Ca	0.550	1.160	1.090	1.090	0.930	0.560	0.660	0.170	0.210	0.490	0.890	0.800	0.510	0.490	0.680
#mg_Grt	0.170	0.170	0.180	0.160	0.170	0.090	0.130	0.160	0.170	0.160	0.160	0.160	0.140	0.160	0.140
Alm	64.3	55.5	54.2	55.1	54.6	75.6	74.8	63.0	64.2	64.1	65.4	64.7	63.9	64.5	68.6
Sps	13.0	12.6	14.2	15.4	17.4	5.0	3.0	22.3	19.0	15.3	6.2	9.0	16.7	14.9	8.6
Prp	13.3	11.4	11.6	10.3	11.3	7.6	11.1	11.6	13.1	12.1	12.8	12.0	10.2	12.0	10.8
Grs	9.3	20.5	17.9	18.2	14.4	10.8	10.7	2.8	3.4	7.5	15.1	13.5	7.8	7.6	10.0
Ti-Grs	0.1	0.1	0.2	0.1	–	0.7	0.1	–	–	–	0.2	–	0.1	–	–
Adr	–	–	1.7	0.9	2.3	–	0.3	–	0.3	1.1	0.5	0.6	1.1	0.9	2.0
Alm+Sps	77.3	68.0	68.4	70.5	72.0	80.6	77.8	85.3	83.2	79.4	71.5	73.7	80.5	79.4	77.2

Sample	R-129	R-113	R-123	R-134	R-123	R-105	R-58	R-58	R-58	R-58	R-58
Point	15	6	11	4	14	3	3	14	23	35	44
SiO_2	38.49	38.27	37.94	38.81	38.30	38.21	37.03	35.89	35.52	36.79	34.94
TiO_2	–	0.09	–	0.02	–	0.02	0.13	0.12	0.11	–	0.10
Al_2O_3	21.64	21.60	21.84	21.60	21.74	21.37	21.86	21.91	21.75	22.00	22.59
FeO	28.94	28.45	27.74	29.76	27.67	30.47	28.51	28.18	27.39	34.67	33.58
MnO	4.45	3.08	7.85	1.40	7.71	3.44	3.98	5.06	6.83	1.37	1.67
MgO	2.98	2.85	3.04	3.23	3.10	2.79	1.14	1.03	0.94	3.01	1.76
CaO	3.28	5.52	1.47	4.62	1.40	3.32	7.18	7.38	6.58	2.13	4.78
Total	99.98	99.97	99.93	99.96	99.92	99.99	99.84	100.01	100.01	99.99	99.98
#Si^{IV}	6.000	6.000	5.960	6.000	5.990	6.000	5.890	5.780	5.740	5.860	5.630
#Al^{IV}	–	–	0.040	–	0.010	–	0.110	0.220	0.260	0.140	0.370
#Al^{VI}	3.980	3.990	4.000	3.940	4.000	3.960	3.980	3.930	3.880	4.000	3.920
#Ti^{VI}	–	0.010	–	–	–	–	0.020	0.010	0.010	–	0.010
#Fe^{+3}	0.020	–	–	0.060	–	0.040	–	0.050	0.100	–	0.070
#Fe^{+2}	3.770	3.730	3.640	3.850	3.620	4.000	3.790	3.790	3.700	4.620	4.520
#Mn^{+2}	0.590	0.410	1.040	0.180	1.020	0.460	0.540	0.690	0.930	0.180	0.230
#Mg	0.690	0.670	0.710	0.740	0.720	0.650	0.270	0.250	0.230	0.720	0.420
#Ca	0.550	0.930	0.250	0.770	0.230	0.560	1.220	1.270	1.140	0.360	0.830
#mg_Grt	0.160	0.150	0.160	0.160	0.170	0.140	0.070	0.060	0.060	0.130	0.090
Alm	67.4	65.0	64.5	69.4	64.7	70.6	65.0	63.1	61.6	78.5	75.3
Sps	10.5	7.1	18.5	3.3	18.3	8.1	9.2	11.5	15.6	3.1	3.8
Prp	12.4	11.6	12.6	13.4	12.9	11.5	4.7	4.1	3.8	12.2	7.0
Grs	9.1	15.6	4.3	12.1	4.2	8.7	20.7	19.6	16.0	6.1	11.8
Ti-Grs	–	0.3	–	0.1	–	0.1	0.4	0.4	0.3	–	0.3
Adr	0.5	–	–	1.7	–	1.1	–	1.4	2.6	–	1.7
Alm+Sps	77.9	72.1	83.0	72.7	82.9	78.6	74.2	74.6	77.2	81.7	79.1

Yellowish staurolite occurring in association with garnet and kyanite is considered a product of the older M2 metamorphic event. It grows often in immediate neigbourhood of garnets or its tiny grains are enclosed in garnet. Staurolite is free of inclusions, except for an opaque mineral. In more intensely deformed rocks of MSZ, relics of staurolite together with resorbed garnets and kyanite are disseminated in mostly muscovite-biotite matrix alternating with quartz bands.

Staurolite is rich in Fe (X_{Fe} 0.79–0.88), whereas the content of Mg is relatively low. Zinc was not analyzed. X_{Mg} of staurolite is mostly higher than X_{Mg} in coexisting garnet or is slightly overlapping. Characteristic chemical analyses of staurolite are summarized in table 4.

Chlorite

Mostly grassy green, blue-green to light green chlorite flakes are intergrown with muscovite and biotite in the major foliation. Chlorite originated through retrograde processes during the M4 phase at the expence of biotite and garnet, mostly in its fractures. Chlorites occur in rocks of all three units but most abundant are in rocks of MSZ which suffered most intense retrograde metamorphism.

According to chemical composition, chlorites can be divided into four groups (see table 5):

i. Chlorites with low X_{Mg} value varying between 0.37 and 0.49, and low contents of Si (2.8–3.1 pfu). These chlorites belong to the ripidolite-pycnochlorite series. They occur mostly in gneisses affected by strong retrograde metamorphism. Chlorites originated through retrogression of older Fe and Mg minerals,

ii. Chlorites with high content of Al, enhanced contents of Si (3.4–3.5 pfu.), low concentrations of Mg and Fe (X_{Mg} 0.57–0.65) are much less abundant than chlorites of the first group. They are confined mostly to pelites close to carbonate bodies (Koblasko, Třebonín), and were also identified in rocks of the Malín Series near Malešov,

iii. Chlorites in gneisses with a volcanic admixture (Vrabov near Český Šternberk) characterized by high contents of Fe and Mg (X_{Mg} varying between 0.55 and 0.57),

iv. Chlorites which originated during retrograde processes in granitoids of CBP. They are characteristic of higher X_{Mg} values (0.5–0.6).

Chlorites from metabasites are described in the following paragraph. Similar to other minerals, the chemical composition of chlorites is a function of rock chemistry and type of metamorphic alterations. However, to decide which factor played the most important role influencing the chemistry of chlorites would deserve more detailed investigation.

Kyanite and sillimanite

Both minerals were indentified in all studied units. Mostly older kyanite occurs in association with staurolite and garnet in which it is occasionally enclosed (Malešov). Very coarse long prismatic poikilitic grains of kyanite were observed in thin sections from the area of Hodkov. It also envelopes quartz. The mineral is sometimes oriented obliquely to the dominant foliation D3 and M3 in which it occurs as relics of larger partly disintegrated grains. Kyanite affected by later retrogression was identified in Al-rich rocks in MSZ, particularly in its western part. It forms often characteristic folded grains of kink band type. In rocks which suffered from even stronger retrogression the mineral is replaced by a mixture of muscovite and sericite forming pseudomorphs after kyanite.

Sillimanite occurs as hypidiomorphic long prismatic to needle-like grains. Coarse prismatic habit of sillimanite was observed in pelites. Fibrous aggregates intergrown with biotite were identified in Moldanubian paragneisses. Sillimanite together with biotite and garnet constitutes the dominant foliation. In rocks of MSZ, sillimanite grows at the expense of biotite. Locally it originated directly from kyanite. Sillimanite in intensely retrogressed rocks of MSZ was almost completely replaced by muscovite which shows thin leaf-like habit. Relics of sillimanite were found in bands rich in muscovite in the western part of MSZ.

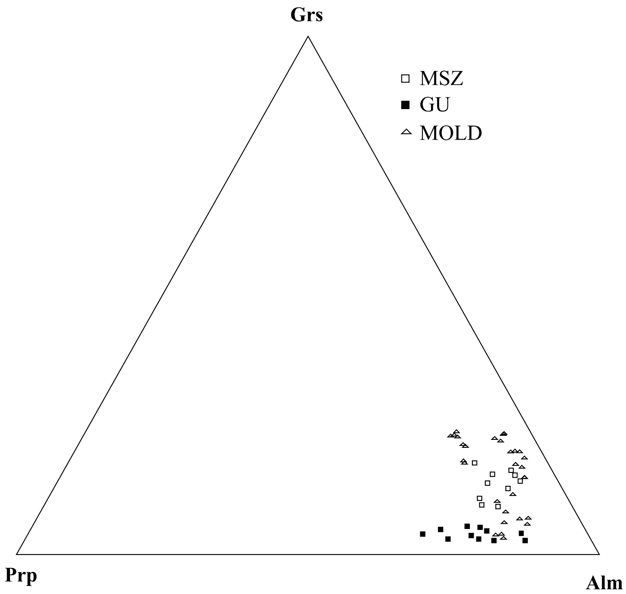


Fig. 26. Content of the almandine, grossular and pyrope components in garnets from MSZ, GU and Moldanubicum.

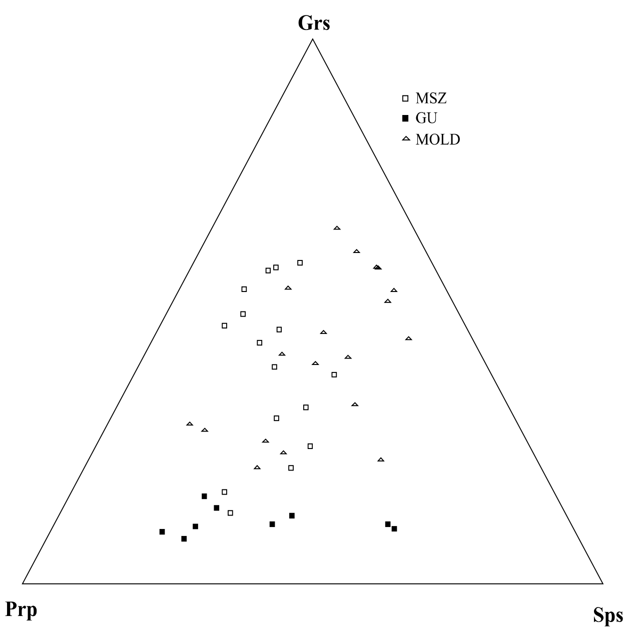


Fig. 27. Content of pyrope, spessartine and grossular components in garnets from MSZ, GU and Moldanubicum.

Feldspars

Plagioclase is a common constituent of gneisses of MSZ, GU and MVG rocks. Potassium feldspars are abundant only in augen gneisses and migmatites of GU.

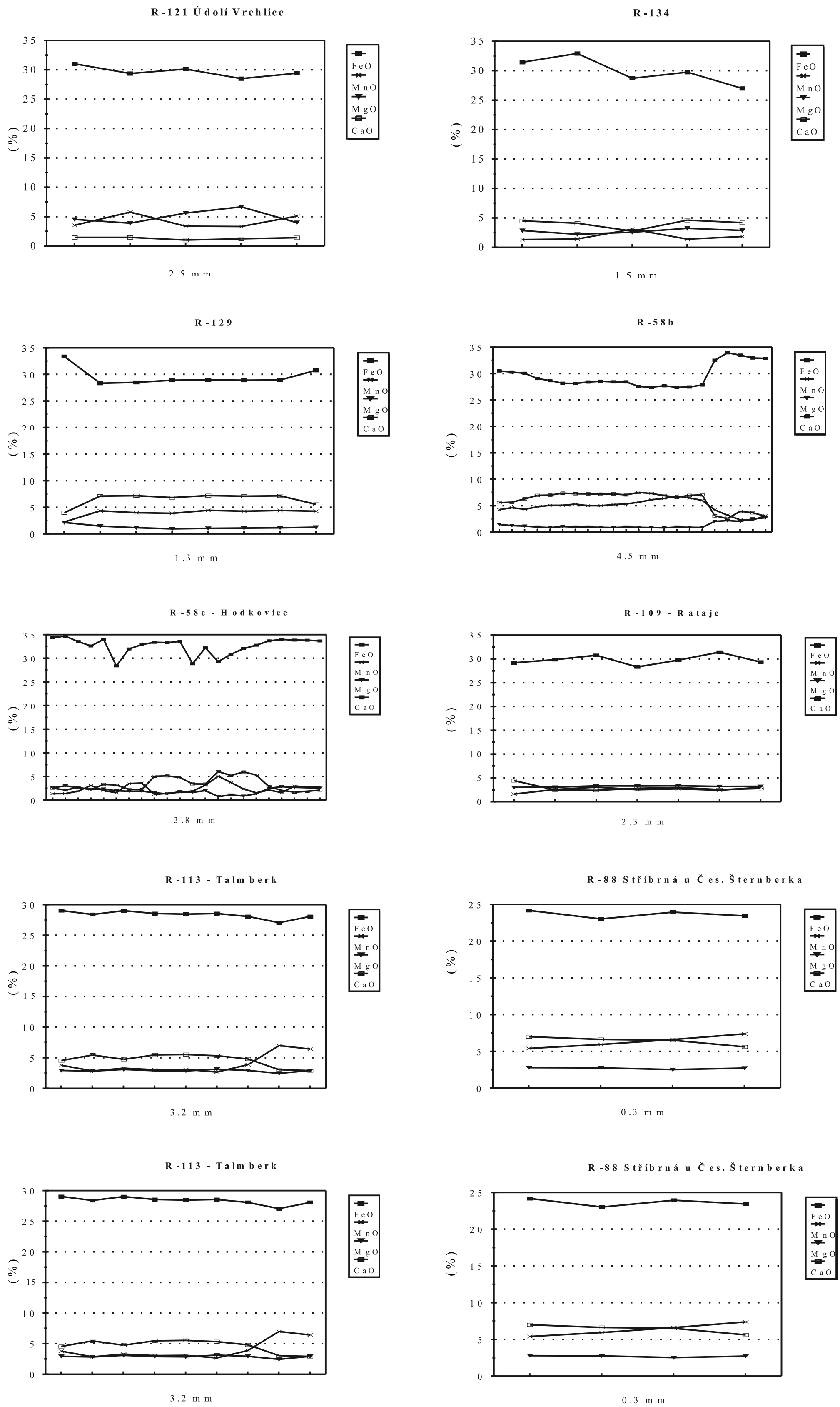


Fig. 28. Chemical profiles across garnet porphyroblasts from MSZ, GU and Moldanubicum. Sample location: R-121 – biotite-garnetiferous paragneiss, Vrchlice River valley N of Malešov, Malín Formation, two-mica gneiss affected by retrograde processes; R-134 – Nový Dvůr near Rataje; R-126 – biotite-sillimanite paragneiss with garnet, Klejnárka River valley, 1 km SE of Chedrbí, Mold; R-129 – two mica paragneiss, Třebonín – MSZ; R-58 – garnet-biotite paragneiss with kyanite and sillimanite, Sv.Václav near Hodkov; R-109 – two-mica paragneiss, outcrops in a railroad tunnel at Rataje – MSZ; R-113 – two-mica paragneiss, outcrops near highway intersection Talmberk – Čekánov – MSZ; R-88 – biotite paragneiss with garnet, Stříbrná N of Český Šternberk – Mold.

Table 4. Representative analyses of staurolite from two-mica gneisses of MSZ. RZ-109 two-mica gneiss with kyanite and staurolite, outcrops above the railroad tunnel in Rataje.

Sample	RZ-109	RZ-109	RZ-109	RZ-109	RZ-109
SiO_2	28.94	29.01	29.45	37.26	29.00
TiO_2	51.32	53.41	53.41	49.20	53.14
Al_2O_3	10.22	10.54	10.22	9.82	10.33
MnO	0.17	0.27	0.28	0.31	0.23
MgO	1.42	1.51	0.99	0.84	1.17
CaO	–	0.04	0.02	0.01	0.02
Total	92.76	95.43	95.10	98.11	94.53
$\#Si^{IV}$	8.386	8.183	8.304	10.052	8.245
$\#Al^{IV}$	17.526	17.756	17.749	15.643	17.806
$\#Fe^{+3}$	–	–	–	–	–
#Ti	0.150	0.138	0.155	0.136	0.137
O^{site}	17.681	17.900	17.911	15.786	17.950
$\#Fe^{+2}$	2.477	2.486	2.410	2.216	2.456
#Mn	0.042	0.065	0.067	0.071	0.055
#Mg	0.613	0.635	0.416	0.338	0.496
#Ca	–	0.012	0.006	0.003	0.006
A^{site}	3.132	3.231	2.999	2.672	3.021
#H	3	3	3	3	3
#O	48	48	48	48	48
Charge	–	–	–	–	–
#mg	0.199	0.203	0.147	0.132	0.168

Plagioclase

The distribution of plagioclase in gneisses of the studied units is erratic. It is most abundant particularly in "dense" greywacke paragneises of the Variegated Šternberk-Čáslav Group of Moldanubicum and also in the eastern part of MSZ in the area of the Čáslav sigmoidal fold. Less abundant is plagioclase in metasediments of MSZ rich in Al and analogous Moldanubian rocks near Hodkov. High contents of plagioclase show also augen gneisses of GU. Plagioclases together with perthitic potassium feldspars form porphyroblasts which are partly dynamically recrystallized along their margins. The metacrysts are enveloped by matrix minerals which are softer for deformation processes. Larger porphyroblasts often enclose hypidiomorphic flakes of biotite. Hypidiomorphic plagioclases are relatively often enclosed in large garnets of MSZ and also in MVG rocks.

Chemical composition of plagioclase in gneisses varies between An_3 and An_{61} – see table 6. The majority of paragneisses, however, contain plagioclase with a composition between oligoclase and andesine. Considerable variation in composition of plagioclase was observed in individual samples which is likely due to incomplete reequilibration of rocks during polymetamorphic processes.

The plagioclase composition is again dependent to a large degree on chemical composition of the protolith of metasediments. Sodic plagioclases ($An_{3\text{-}12}$) were identified as inclusions in garnets and in form of plagioclase rims of garnets in Al-rich gneisses of MSZ and Moldanubian equivalents of these rocks from Hodkov, and occasionally also in gneisses of the Malín Series in the Vrchlice River valley near Malešov. The composition of plagioclase is partly influenced by originally low content of Ca in the rock (1.4 wt %). However, metamorphic processes also played a certain role as follows from correlation of grossular proportion in some garnets and the

Table 5. Representative analyses of chlorites from MSZ. Sample location: R-110 – long outcrop along the roadcut (expressway Praha – Brno) near Šternov, Moldanubian paragneiss affected by retrograde processes, for location of other samples see tables 1–4.

Sample	R-121	R-121	R-134	R-137	R-123	R-129	R-87	R-87	R-87	R-88	R-88	R-88	R-112	R-112	R-110
SiO_2	36.02	26.05	25.08	28.07	36.36	36.38	27.58	27.35	27.44	26.41	25.40	25.57	26.92	26.91	26.04
TiO_2	0.30	0.09	0.12	0.03	0.01	0.01	0.02	–	0.03	0.06	0.05	0.03	0.06	0.05	1.03
Al_2O_3	31.61	18.64	21.06	17.97	34.26	31.13	19.34	19.88	20.09	17.57	19.71	19.90	20.80	20.16	20.79
FeO	7.20	27.56	29.76	24.12	6.21	7.77	23.44	23.09	23.60	27.43	25.71	25.55	21.18	20.26	23.81
MnO	–	0.54	0.56	0.50	–	0.07	0.28	0.20	0.21	0.28	0.33	0.46	0.48	0.55	0.32
MgO	8.25	11.87	9.99	16.94	6.63	6.44	16.70	16.22	16.33	13.21	13.37	13.66	16.90	17.20	12.41
CaO	0.14	0.10	0.05	0.07	0.52	0.47	0.06	0.04	0.10	0.06	0.07	0.05	0.03	0.02	0.25
Na_2O	2.97	–	0.03	–	2.03	2.14	0.05	0.05	0.05	0.01	–	0.18	–	0.07	0.07
K_2O	0.03	0.10	0.08	0.03	–	0.04	0.03	0.01	0.04	0.02	0.01	0.03	0.02	0.01	0.35
Total	86.52	84.95	86.73	87.73	86.02	84.45	87.50	86.84	87.89	85.05	84.65	85.43	86.39	85.23	85.07
$\#Si^{IV}$	3.368	2.882	2.744	2.935	3.373	3.475	2.876	2.866	2.848	2.913	2.789	2.781	2.811	2.839	2.812
$\#Al^{IV}$	0.632	1.118	1.256	1.065	0.627	0.525	1.124	1.134	1.152	1.087	1.211	1.219	1.189	1.161	1.188
T^{site}	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
$\#Al^{VI}$	2.851	1.312	1.460	1.149	3.119	2.979	1.253	1.321	1.306	1.197	1.339	1.331	1.371	1.347	1.459
#Ti	0.021	0.007	0.010	0.002	0.001	0.001	0.002	–	0.002	0.005	0.004	0.002	0.005	0.004	0.084
$\#Fe^{+3}$	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
$\#Fe^{+2}$	0.563	2.550	2.723	2.109	0.482	0.621	2.044	2.023	2.049	2.530	2.361	2.324	1.850	1.788	2.151
$\#Mn^{+2}$	–	0.051	0.052	0.044	–	0.006	0.025	0.018	0.018	0.026	0.031	0.042	0.042	0.049	0.029
#Mg	1.150	1.957	1.629	2.640	0.917	0.917	2.596	2.534	2.527	2.172	2.188	2.215	2.631	2.706	1.998
#Ca	0.014	0.012	0.006	0.008	0.052	0.048	0.007	0.004	0.011	0.007	0.008	0.006	0.003	0.002	0.029
#Na	0.538	–	0.006	–	0.365	0.396	0.010	0.010	0.010	0.002	–	0.038	–	0.014	0.015
#K	0.004	0.014	0.011	0.004	–	0.005	0.004	0.001	0.005	0.003	0.001	0.004	0.003	0.001	0.048
O^{site}	5.141	5.903	5.897	5.957	4.936	4.973	5.941	5.912	5.928	5.942	5.933	5.963	5.905	5.911	5.812
#O	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
#OH	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
mg	0.670	0.430	0.370	0.560	0.660	0.600	0.560	0.560	0.550	0.460	0.480	0.490	0.590	0.600	0.480

Table 5. *(continued)*

Sample	R-110	R-90	R-90	R-90
SiO_2	26.96	28.79	24.46	26.53
TiO_2	0.02	9.56	–	0.11
Al_2O_3	21.86	15.34	20.92	21.16
FeO	26.15	18.72	25.53	25.67
MnO	0.29	0.29	0.35	0.34
MgO	13.49	9.27	14.20	14.28
CaO	0.12	8.39	0.07	0.08
Na_2O	0.07	–	0.02	0.05
K_2O	0.08	0.21	0.06	0.04
Total	89.04	90.57	85.61	88.26
$\#Si^{IV}$	2.794	2.922	2.658	2.775
$\#Al^{IV}$	1.206	1.078	1.342	1.225
T^{site}	4	4	4	4
$\#Al^{VI}$	1.465	0.758	1.337	1.384
#Ti	0.002	0.730	–	0.009
$\#Fe^{+3}$	–	–	–	–
$\#Fe^{+2}$	2.267	1.589	2.320	2.246
$\#Mn^{+2}$	0.025	0.025	0.032	0.030
#Mg	2.084	1.403	2.300	2.227
#Ca	0.013	0.912	0.008	0.009
#Na	0.014	–	0.004	0.010
#K	0.011	0.027	0.008	0.005
O^{site}	5.881	5.444	6.009	5.920
#O	10	10	10	10
#OH	8	8	8	8
mg	0.480	0.470	0.500	0.500

anorthite component in plagioclase which envelope garnets or plagioclases that are in direct contact with the garnet. Consequently, the thermobarometry is rather difficult to apply. It is also difficult to select coexisting garnet-plagioclase pairs unless studies of zonation using backscattered electrons or cathodoluminiscence can be carried out. Therefore there is a considerable scatter in obtained values of temperature and pressure with two maxima (see paragraph 6.3).

The larger part of two-mica paragneisses contains plagioclases whose composition corresponds to oligoclase (An_{12-20}). More calcic sometimes antiperthitic plagioclases (An_{42-43}) are typical of augen gneisses of GU from Drahňovice and Mělník NE of Sázava nad Sázavou. Similar relatively calcic plagioclases (An_{40-60}) were found in gneisses with tuffitic admixture (Vrabov) and in gneisses close to limestone bodies (Třebonín, Koblasko).

The proportion of the orthoclase component in plagioclase varies between 0 and 34 vol. % – see table 7, but mostly between one to several per cent. Higher contents of orthoclase component in plagioclases is seen in augen gneisses of GU and plagioclases in Al-rich metapelites at the contact with garnets which represent a mixture of albite and orthoclase components. The proportion of anorthite is small.

Potassium feldspars

Potassium feldspars are most abundant in augen gneisses of GU where they form the major constituent of these rocks. They have perthitic and occasionally myrmekitic character along margins of larger porphyroblasts. They mostly contain several per cent of the albite component. The proportion of anorthite is of an order of 0.X % with a maximum of 3 mol. % – see table 7. Potassium feldspars are most abundant in augen gneisses and migmatites of GU, "dense" Moldanubian gneisses and also occasionally in two-mica gneisses of MSZ affected by retrograde processes.

6.2. Metamorphic mineral assemblages in paragneisses

Paragneisses of the MVG, MSZ and Malín Formation of GU underwent polyphase metamorphic evolution which was connected with Variscan processes of crustal shortening of single units at the periphery of the Moldanubian Zone as documented by Variscan ages of closing isotopic systems (Beard et al. 1991, Oliveriová et al. 1995). Since the metamorphic evolution of single units differs in individual phases, the metamorphic mineral assemblages in single units will be described and defined separately.

Variegated Group of Moldanubicum

At least three metamorphic events can be observed in Moldanubian gneisses. The oldest mineral assemblage,

Table 6. Representative analyses of plagioclase from MSZ, GU and Moldanubicum. Sample location: R-108 – migmatite of Gföhl type NE of Drahňovice – GU; R-85 – outcrops along the Sázava River valley, 500 m SW of Malovidy – augen gneisses to migmatites – GU; R-103 – excavation for hotel construction in Český Šternberk, SE margin of the township, biotite-sillimanite paragneiss – Mold; R-109 – outcrops at railroad tunnel exit in Rataje nad Sázavou, kyanite-garnetiferous gneiss – MSZ; R-128 – Podveky, higway intersection – "dense" biotite gneiss with muscovite – Mold; R-131 – Vrabov, N of Český Šternberk – garnet biotite paragneiss with amphibolite bands – Mold?, for location of other samples see tables 1–5.

Sample	R-121	R-121	R-134	R-126	R-126	R-108	R-108	R-108	R-108	R-105	R-105	R-105	R-129	R-129	R-129
SiO_2	63.30	62.14	67.51	62.85	60.22	64.31	63.35	63.57	63.68	62.15	61.53	65.05	58.24	58.33	60.15
Al_2O_3	23.51	22.70	21.10	24.29	24.28	21.48	21.27	21.57	21.86	23.04	23.01	21.88	27.24	26.88	24.33
CaO	3.57	4.08	0.49	2.30	4.93	2.66	2.50	2.71	3.12	4.24	3.54	2.29	8.51	8.25	4.44
Na_2O	9.71	8.84	10.85	8.53	7.50	8.95	8.90	8.91	8.88	8.90	8.83	8.77	6.63	6.05	8.58
K_2O	0.37	0.11	0.61	0.85	0.61	0.22	0.45	0.33	0.24	0.10	0.13	0.75	0.16	0.10	0.30
Total	100.46	97.87	100.56	98.82	96.29	97.62	96.47	97.09	97.78	98.43	97.04	98.74	100.78	99.61	97.80
#An	16.5	20.2	2.3	12.3	25.6	13.9	13.1	14.1	16.0	20.7	18.0	12.0	41.1	42.7	21.8
#Ab	81.4	79.2	94.1	82.3	70.6	84.7	84.1	83.9	82.5	78.7	81.2	83.3	58.0	56.6	76.4
#Or	2.0	0.6	3.5	5.4	3.8	1.4	2.8	2.0	1.5	0.6	0.8	4.7	0.9	0.6	1.8

T a b l e 6. *(continued)*

Sample	R-129	R-58	R-58	R-58	R-58	R-58	R-58	R-58	R-58	R-58	RZ-109	RZ-109	RZ-109	RZ-109	RZ-109
SiO_2	57.27	60.06	62.39	61.47	60.91	62.33	63.39	60.90	63.24	62.24	61.20	64.53	61.92	62.81	63.31
Al_2O_3	29.53	23.94	23.25	24.23	23.88	23.18	23.71	22.48	23.13	24.12	24.38	22.27	24.83	22.54	24.37
CaO	4.97	4.87	2.65	4.57	4.57	2.39	0.50	3.24	1.82	1.84	3.16	1.09	1.04	0.54	0.97
Na_2O	5.46	7.14	7.65	7.46	7.49	7.36	7.60	8.55	8.40	9.09	7.36	8.63	5.90	5.79	7.35
K_2O	3.58	0.25	0.86	0.21	0.20	1.04	1.92	0.09	0.15	0.29	1.50	1.78	5.14	4.88	3.65
Total	100.81	96.26	96.80	97.94	97.05	96.30	97.12	95.26	96.74	97.58	97.60	98.30	98.83	96.56	99.65
#An	26.0	26.9	15.1	24.9	24.9	14.1	3.0	17.2	10.6	9.9	17.3	5.8	5.8	3.2	5.2
#A	51.7	71.4	78.9	73.7	73.8	78.5	83.2	82.1	88.3	88.3	72.9	82.9	59.8	62.1	71.3
#Or	22.3	1.6	5.8	1.4	1.3	7.3	13.8	0.6	1.0	1.9	9.8	11.2	34.3	34.4	23.3

Sample	RZ-109	R-85	R-85	R-85	R-85	R-85	R-85	R-85	R-83	R-83	R-83	R-83	R-83	R-83	R-83
SiO_2	63.46	58.27	57.76	57.82	59.58	60.26	59.34	58.70	63.94	64.69	63.21	64.08	64.18	65.41	64.49
Al_2O_3	24.42	25.76	26.38	26.30	26.09	25.19	25.85	25.87	22.03	22.09	22.03	22.39	22.25	22.78	22.53
CaO	3.72	8.17	8.34	8.78	7.98	6.50	7.92	7.70	3.66	2.09	3.47	3.50	3.67	0.76	3.64
Na_2O	7.32	6.42	6.13	6.28	6.29	6.91	6.59	6.34	8.97	8.90	8.09	8.75	8.68	8.48	8.52
K_2O	1.56	0.33	0.34	0.16	0.32	0.27	0.32	0.23	0.30	0.94	0.36	0.37	0.24	1.63	0.32
Total	100.48	98.95	98.95	99.34	100.26	99.13	100.02	98.84	98.90	98.71	97.16	99.09	99.02	99.06	99.50
#An	19.8	40.5	42.0	43.2	40.4	33.6	39.2	39.6	18.1	10.8	18.7	17.7	18.6	4.2	18.7
#A	70.4	57.5	55.9	55.9	57.6	64.7	59.0	59.0	80.1	83.4	79.0	80.1	79.8	85.0	79.3
#Or	9.9	1.9	2.0	0.9	1.9	1.7	1.9	1.4	1.8	5.8	2.3	2.2	1.5	10.7	2.0

Sample	R-83	R-128	R-128	R-128	R-131	R-131	R-131	R-123	R-123	R-123	R-123	R-123	R-123	R-123	R-123
SiO_2	65.38	63.29	62.98	63.19	58.54	57.49	53.08	63.36	63.94	64.16	63.97	61.69	62.45	67.33	63.96
Al_2O_3	21.03	23.15	23.09	23.01	26.92	27.77	30.37	23.28	23.12	23.30	23.50	24.51	24.66	21.32	22.63
CaO	0.63	3.76	3.87	3.95	8.07	9.19	12.12	4.03	3.75	3.80	1.55	5.48	3.01	1.15	3.34
Na_2O	9.09	9.26	9.13	9.13	6.43	5.96	4.18	8.68	8.95	9.09	8.57	8.10	8.34	10.34	8.99
K_2O	1.17	0.17	–	–	0.03	0.06	0.14	0.32	0.26	0.08	1.72	–	0.77	0.39	0.39
Total	97.30	99.63	99.07	99.28	99.99	100.47	99.89	99.67	100.02	100.43	99.31	99.78	99.23	100.53	99.31
#An	3.4	18.1	19.0	19.3	40.8	45.8	61.1	20.0	18.5	18.7	8.1	27.2	15.8	5.7	16.6
#A	89.0	80.9	81.0	80.7	58.8	53.8	38.1	78.1	79.8	80.9	81.2	72.8	79.0	92.1	80.8
#Or	7.5	1.0	–	–	0.2	0.4	0.8	1.9	1.5	0.5	10.7	–	4.8	2.3	2.3

Sample	R-123	R-123	R-123	R-123	R-125	R-125	R-125	R-125	R-129	R-129	R-129	R-129	R-129	R-92	R-92
SiO_2	60.33	58.47	60.29	59.20	63.07	63.61	62.15	63.97	59.10	58.04	59.33	59.48	57.80	64.39	64.52
Al_2O_3	25.83	27.26	25.79	26.75	23.73	23.44	23.21	23.26	25.96	26.72	26.26	26.52	26.88	23.18	22.80
CaO	6.75	8.66	6.90	7.92	4.44	4.16	4.16	2.42	7.14	8.08	7.37	7.70	8.25	1.00	3.80
Na_2O	7.46	6.58	7.28	6.88	8.51	8.69	8.27	9.08	7.14	6.39	6.87	6.95	6.40	9.38	8.55
K_2O	0.06	–	–	0.03	–	0.29	0.15	0.48	0.05	0.29	0.25	0.10	0.26	1.68	0.39
Total	100.43	100.97	100.26	100.78	99.75	100.19	97.94	99.21	99.39	99.52	100.08	100.75	99.59	98.63	100.06
#An	33.1	42.1	34.3	38.6	21.9	20.6	21.6	12.4	35.5	40.4	36.7	37.8	40.9	5.0	19.2
#A	66.3	57.9	65.5	60.6	76.1	77.7	77.5	84.4	64.2	57.9	61.9	61.7	57.4	85.0	78.4
#Or	0.4	–	–	0.2	–	1.7	0.9	2.9	0.3	1.7	1.5	0.6	1.5	10.0	2.4

Sample	R-92	R-92	R-92	R-92	R-113	R-113	R-113	R-113	R-113	R-113	R-113	R-113	R-88	R-88	R-88
SiO_2	64.12	64.31	63.99	64.14	58.30	59.20	59.77	60.42	58.82	59.91	58.85	60.53	66.48	60.87	64.94
Al_2O_3	22.62	22.92	22.64	22.58	25.20	25.77	25.92	25.99	25.49	25.91	26.42	25.25	19.89	24.95	20.86
CaO	3.96	3.81	3.79	3.73	6.67	7.16	7.33	3.71	6.86	6.66	7.62	6.67	2.17	0.79	0.95
Na_2O	9.23	9.75	9.07	9.80	6.75	7.55	7.16	6.60	7.40	8.58	7.37	7.93	9.82	8.00	9.80
K_2O	0.13	0.26	0.33	0.25	0.20	0.08	0.07	2.61	0.17	0.33	0.06	0.10	0.08	2.88	0.77
Total	100.06	101.05	99.82	100.50	97.12	99.76	100.25	99.33	98.74	101.39	100.32	100.48	98.44	89.49	97.32
#An	19.0	17.5	18.4	17.1	34.9	34.2	35.9	19.8	33.5	29.5	36.2	31.5	10.8	4.2	4.8
#A	80.2	81.1	79.7	81.5	63.9	65.3	63.5	63.6	65.4	68.8	63.4	67.9	88.7	77.4	90.5
#Or	0.7	1.4	1.9	1.4	1.2	0.5	0.4	16.6	1.0	1.7	0.3	0.6	0.5	18.3	4.7

Sample	R-88	R-88	R-112	R-112	R-112	R-89	R-89	R-111	R-111	R-102	R-102	R-103	R-103	R-58	R-88
SiO_2	60.75	55.90	60.43	61.65	61.50	62.21	63.93	58.66	59.75	55.82	56.15	65.11	75.32	60.02	62.52
Al_2O_3	23.79	26.73	26.11	24.68	25.88	22.09	23.74	25.57	25.70	29.00	28.97	22.08	13.08	24.13	21.65
CaO	5.31	8.69	3.08	6.43	2.69	3.99	1.44	7.06	7.26	10.61	10.60	3.21	1.39	4.85	0.83
Na_2O	8.15	6.29	7.58	7.61	7.42	9.35	9.83	7.62	7.67	5.26	5.46	9.55	8.28	7.28	9.45
K_2O	0.25	0.23	2.11	0.40	2.01	0.08	1.90	0.26	0.30	0.06	0.06	0.19	0.13	0.12	1.57
Total	98.25	97.84	99.31	100.77	99.50	97.72	100.84	99.17	100.68	71.75	101.24	100.14	98.20	96.40	96.02
#An	26.1	42.7	16.0	31.1	14.5	19.0	6.7	33.4	33.8	52.5	51.6	15.5	8.4	26.7	4.2
#A	72.5	55.9	71.0	66.6	72.5	80.6	82.8	65.2	64.5	47.1	48.1	83.4	90.6	72.5	86.4
#Or	1.5	1.3	13.0	2.3	12.9	0.5	10.5	1.5	1.7	0.4	0.3	1.1	0.9	0.8	9.4

which is only scarcely preserved in relevant Al-rich lithologies (e. g., Hodkov), consists of:

Grt-Ky-St-Bt-Ms-Pl-Qtz ± Ilm, Tur (fig. 9)

This assemblage is equivalent with the M2 metamorphic assemblage in MSZ.

The dominant assemblage (fig. 29) includes:

GrtII-Sil-BtiII-Pl-Qtz ± Kfs

which can be correlated with M3 assemblage in MSZ, and which is likely to have originated at the expense of M2 reaction:

Grt + Ms = Sil + BtiII + Qtz

In contrast to gneisses of MSZ, the peak metamorphic assemblage reaching the grade of sillimanite zone was only slightly affected by subsequent retrogression connected with the growth of muscovite and chlorite (in MSZ considered and marked by Synek and Oliveriová 1993 as M4). Metamorphic assemblages of Moldanubian gneisses show in the first phase a prograde PT path in the stability field of kyanite which was followed by a decrease in pressure with probably a gentle increase in temperature and a weak retrogression under conditions of green schistfacies.

Micaschist Zone

Four metamorphic phases can be distinguished in metasediments of MSZ (Synek, Oliveriová 1993). The oldest phase is characteristic of MSZ but was not documented in the remaining two units which may be due to a lack of suitable samples. Larger amounts of quartz, plagioclase and occasionally even muscovite in the form of inclusions in large garnets from Moldanubian rocks were identified but no indicator minerals were found to justify the occurrence of an older metamorphic mineral assemblage. Oliveriová (1993) identified the following minerals in inclusions in garnets:

Ma-Ep-St-Chl-Qtz-Ilm

which together with garnet represent the oldest M1 assemblage corresponding to transition from greenschist facies to epidote amphibolite facies.

The M2 assemblage is equivalent to the assemblage in MVG, and represented by:

GrtI-Ky-St-BtI-Ms-Pl-Qtz ± Kfs, Ilm and Tur

This assemblage corresponds to the increase in temperature and pressure due to crustal thickening. The occurrence of staurolite and kyanite inclusions in garnet may have resulted from a reaction:

St + Qtz = Grt + Ky + H_2O,

which provides evidence of an increase in temperature during prograde metamorphism (Thompson 1976). Similarly, the decrease in the content of paragonite component in muscovite at simultaneous increase in albite component in plagioclase matrix, in relation to inclusions of plagioclase in garnets, gives another evidence of

Table 7. Representative analyses of potassium feldspars from MSZ, GU and Moldanubicum. Sample location: R-92 – outcrops along the Křešice Creek valley, Jedlavka cottages 700 m SW of Čeřenice – GU; porphyroclastic biotite orthogneiss; R-89 – long exposure at a bend of Sázava River N of Český Šternberk, migmatite – GU; R-114 – 250 m SE of Chedrbí, Klejnarka River valley, biotite augengneiss – GU, for location of other samples see tables 1–6.

Sample	R-108	R-108	R-108	R-108	R-83	R-83	R-131	R-131	R-92	R-92	R-85	R-85	R-88	R-88
SiO_2	63.67	64.02	64.50	64.26	65.60	65.05	65.42	58.05	64.88	63.60	61.57	64.59	55.53	64.18
Al_2O_3	18.43	21.99	18.32	18.28	18.47	18.33	18.42	25.55	18.58	19.06	20.34	19.06	18.65	18.99
BaO	0.23	–	0.14	0.29	0.41	0.38	0.12	0.14	0.47	0.45	0.28	0.23	0.31	0.34
CaO	0.02	3.22	0.01	–	0.02	–	0.06	0.57	–	0.04	2.44	0.77	0.65	0.04
Na_2O	0.59	8.45	1.23	1.22	0.91	0.88	0.20	1.34	0.76	0.89	2.69	0.88	4.63	1.41
K_2O	14.40	0.23	14.27	13.99	15.08	15.18	16.07	12.53	15.31	14.19	10.05	14.85	8.12	13.68
Total	97.34	97.91	98.47	98.04	100.49	99.82	100.29	98.18	100.00	98.23	97.37	100.38	87.89	98.64
#An	0.1	17.1	0.1	–	0.1	–	0.3	3.2	–	0.2	12.6	3.8	3.5	0.2
#Ab	5.8	81.4	11.6	11.6	8.3	8.0	1.9	13.5	7.0	8.6	25.1	7.9	44.5	13.4
#Or	93.6	1.5	88.1	87.8	90.8	91.3	97.6	83.1	92.2	90.3	61.8	87.9	51.4	85.7

Sample	R-88	R-88	R-88	R-89	R-89	R-89	R-89	R-89	R-89	R-89	R-114	R-111	R-90	R-95
SiO_2	63.87	63.42	64.63	64.46	64.47	64.44	64.57	64.89	64.29	64.18	63.03	59.42	65.04	60.28
Al_2O_3	18.30	18.31	18.67	17.87	17.79	18.22	17.67	18.13	17.88	17.95	18.15	26.92	18.83	23.94
BaO	0.35	0.28	0.41	0.34	0.37	0.40	0.41	0.36	0.32	0.23	0.15	0.01	0.12	0.17
CaO	0.05	0.02	0.03	–	–	–	–	–	–	–	–	1.00	0.04	0.04
Na_2O	1.33	0.62	0.67	1.20	0.73	1.00	2.04	1.49	0.92	1.12	0.32	6.49	1.56	2.25
K_2O	13.56	15.22	14.72	14.78	15.53	15.25	14.04	14.34	14.97	14.78	15.49	4.88	13.8	11.14
Total	97.46	97.87	99.13	98.65	98.89	99.31	98.73	99.21	98.38	98.26	97.14	98.72	99.39	97.82
#An	0.3	0.1	0.2	–	–	–	–	–	–	–	–	5.4	0.2	0.2
#Ab	12.9	5.8	6.4	10.9	6.6	9.0	18.0	13.6	8.5	10.3	3.0	63.3	14.6	23.4
#Or	86.2	93.6	92.6	88.5	92.7	90.3	81.3	85.8	90.9	89.3	96.7	31.3	85.0	76.1

an increase in temperature (fig. 30). These observations support the following reaction to have occurred (Thompson et al. 1977):

Pg + Qtz = Ky + Kfs + Ab+ H_2O

The M3 assemblage, which is also coincident with rocks of MVG, corresponds to decompression phase during which rocks of MSZ reached the stability field of sillimanite. The M3 assemblage consists of:

GrtII-BtII-Sil-Ms-Pl-Qtz

In contrast to Losert's (1967) map of isograds, sillimanite was also identified in the western part of MSZ (Rataje, Petrovice), which indicates that in the entire MSZ the sillimanite isograd was intersected. The absence of sillimanite in most samples of paragneiss in the western part of MSZ is believed to have resulted from later retrogression (muscovitization) during which sillimanite intergrown with biotite was replaced by muscovite. The reaction of potassium feldspar and sillimanite with water could have led to reverse formation of muscovite and quartz. Němec (1968) interpreted in similar manner the muscovitization in the Svratka Crystalline Complex.

The youngest retrograde phase (M4) is connected with the growth of muscovite and chlorite at the expense of older minerals (fig. 10). Strong retrogression imprinted a micaschist habit on local rocks which actually defined this unit as a retrograde product of underlying Moldanubicum (Koutek 1933). Signs of retrograde processes in the remaining units are either weak or missing (Běstvina Formation – Synek, Oliveriová 1993).

Gföhl Unit

Only gneisses in the Vrchlice River valley below the dam near Malešov were studied from GU. These rocks are considered a part of the Malín Formation, which together with samples from the vicinity of Drahňovice, SW of Ledečko, come from a relic of GU. Metapelites of GU differ from rocks of the former units by abundant perthitic K-feldspar, that is missing in rocks of MSZ and MVG, and by intense migmatization. The M2 and M3 assemblages, similar to those in MSZ and Moldanubicum, were identified in gneisses from the above-mentioned locality of the Vrchlice River valley, with the exception of K-feldspar. No signs of M2 phase were observed in samples from the relic of GU (kyanite was missing in all studied thin sections). The later retrograde phase M4 seems to have played a great role in this area, particularly along the contact with the underlying rocks. This can be documented by the growth of muscovite and chlorite in those parts of rocks which suffered from more intense deformation. Field observations showed that the retrogression increased toward the footwall to the tectonic contact with rocks of MVG and also rocks of MSZ.

6.3. P-T conditions of metasediment metamorphism

Conditions under which gneisses were metamorphosed were studied on 14 samples from MSZ, MVG and GU

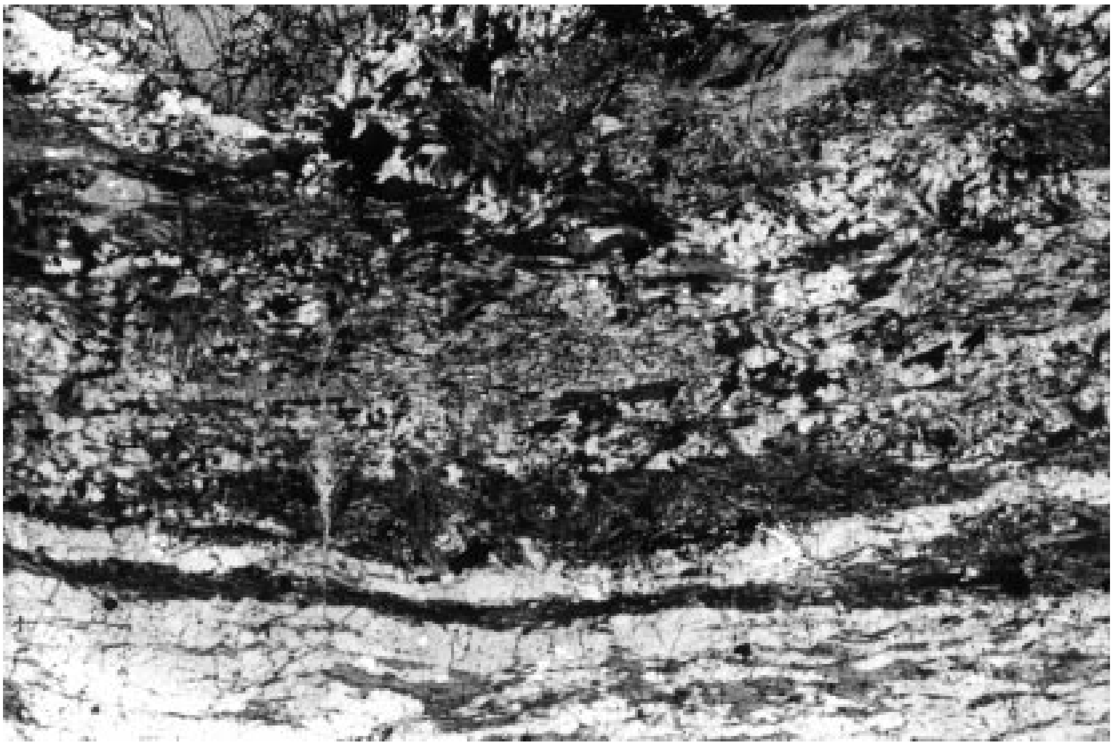


Fig. 29. Peak metamorphic mineral assemblage M3 represented by sillimanite, biotite and garnet, in the centre there are large porphyroblasts of kyanite (M2), R-58 Hodkov, Mold; magn. 10x.

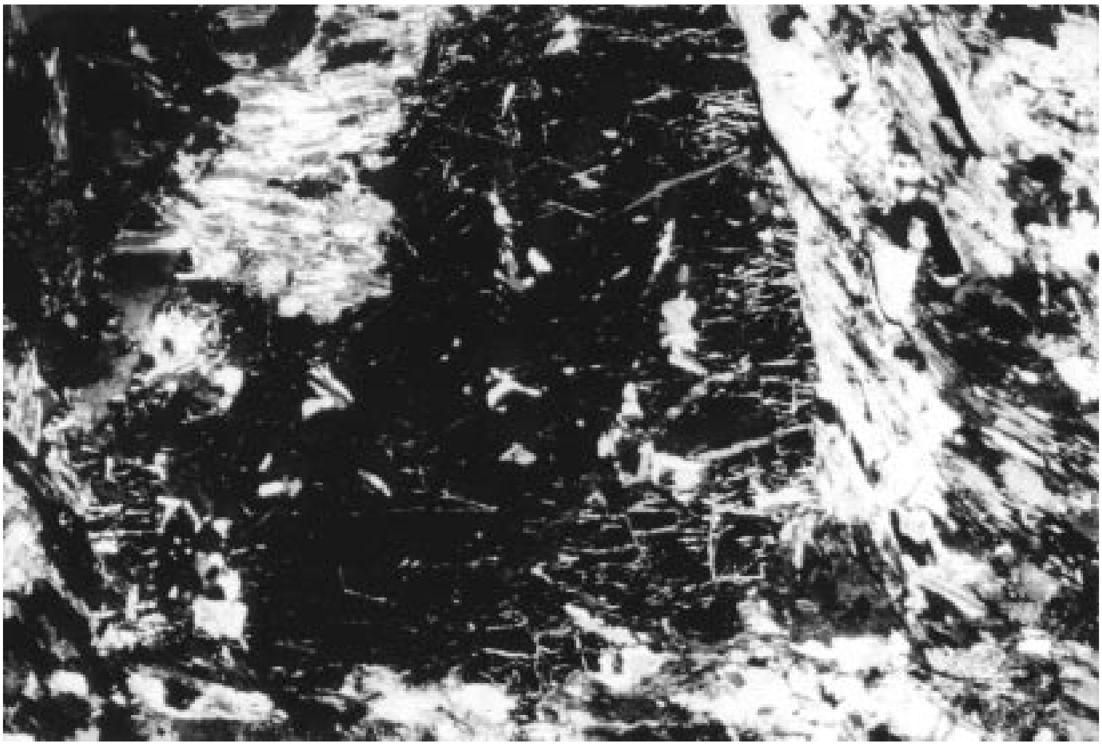


Fig. 30. Inclusions of albite plagioclase in garnets which are abundant in rocks of MSZ and also Moldanubicum. magn. 35x.

(Malín Series and occurrences of GU near Sázava nad Sázavou and S of Ledečko). A few hundred points were measured. The thermometer by Williams and Grambling (1990) was applied to estimate thermal conditions of metamorphism. It is based on Fe-Mg exchange between garnets (cores and margins) at the contact with biotite. A thermometer by Hoish (1990), based on muscovite-biotite equilibrium, was aplied to samples containing both micas. Equilibria between garnet-plagioclase-Al_2SiO_5 and quartz (GPAQ – Koziol, Newton 1988) and between garnet-plagioclase-biotite and muscovite (GBMP) after Holdaway et al. (1988) were used to estimate the pressure conditions. A MINCALC program (Melín et al. 1992) was used for the calculations. The temperatures were calculated for pressures of 6 kb, and pressures were then derived from these temperatures. The P-T paths reconstructed on the base of thermobarometry for individual units are given in fig. 31.

Results derived from Hoishe's (1990) thermometer and Grt-Bi thermometer by Williams and Grambling (1990) provide relatively comparable values but the scatter in values using Grt-Bi thermometer is greater which seems to be more sensitive to retrograde changes particularly in garnet. This leads often to lower values than those obtained using Hoishe's thermometer.

Values obtained from both thermometers show greater scattering. Geobarometer of Holdaway et al. (1988) gave mostly lower pressures relative to GPAQ barometer by Koziol and Newton (1988).

Relatively large variation in pressures and also in temperatures is due to the fact that in the diagrams the results of garnet (core) and biotite and/or muscovite (enclosed in garnet or at the contact with it) couples are jointly plotted and the results obtained from garnet (margin)-biotite or muscovite couples in matrix. Pressures and temperatures derived from the core of large garnets differ from each other considerably, particularly in rocks of MSZ strongly affected by retrograde processes. Values derived from garnet cores in combination with muscovite or biotite correspond to much higher temperatures and pressures. The accuracy of the results from rocks affected by polyphase metamorphic evolution is influenced by the existence or non-existence of equilibria between minerals.

Gföhl Unit

Temperatures established by application of both thermometers vary from 620 to 860 ˚C when using Hoish's thermometer and from 530 to 830 ˚C when using grt-bt thermometer. Maxima in both measurements lie are between 620 and 740 ˚C. Temperatures derived from garnet cores are higher varying between 800 and 830 ˚C.

Pressures established using the GPAQ barometer show considerable scatter in values. They vary between 9 and 15 kb with maximum around 9–12 kb for the couples garnet core-plagioclase enclosed in garnet, and also for some plagioclases in matrix. It is possible that some mineral couples were not completely equilibrated. Values derived from garnet margin- plagioclase matrix show maxima between 6.5 and 7.5 kb. Pressures obtained from GBMP are on average lower and vary between 5 and 8.5 kb with two maxima around 5.5 kb and 7.5 kb.

Variegated Group of Moldanubicum

Similar to the previous unit, different temperatures were established for garnet cores coexisting with muscovite and for garnet margins coexisitng with biotite or muscovite. The latter, however, are very scarce in Moldanubian rocks. Calibration after Hoish (1990) provided results between 650 and 800 ˚C with two maxima around 650–700 ˚C and 770–830 ˚C. Results derived from the biotite-garnet couple seem to be more influenced by retrograde processes, and consequently the established temperatures are lower varying between 500 and 800 ˚C with a similar maximum at 650–680 ˚C.

Pressures derived from GAPQ barometer applied to rocks of MVG vary between 6 and 14.5 kb with only one more conspicuous maximum around 7–7.5 kb. Higher values were again obtained from plagioclase inclusions in garnets. Pressures calculated from GBMP barometer vary from 5 to 9.5 kb with one maximum around 5.5–6 kb, and another less pronounced maximum around 7.5–8.5 kb. Thus, the frequency maximum is shifted by about 1 kb to lower pressures. Rare muscovites in Moldanubian paragneisses are products of retrograde processes, and thus equilibrated at lower temperatures and pressures. In spite of that, two maxima in the calculated values can be also observed.

Micaschist Zone

Temperatures established using the thermometer of Hoish (1990) in gneisses of MSZ vary between 620 and 890 ˚C with maximum frequency in an interval between 620 and 710 ˚C which is a slightly higher value than that for rocks of GU and MVG. Values obtained using the thermometer of Grambling and Wiliams (1990) are somewhat lower and scattered between 530 and 770 ˚C with a maximum around 590–620 ˚C. The results may be affected by a smaller number of measurements and also by the fact that garnets were strongly replaced, and rocks in general suffered from retrograde processes.

Similar large scatter show pressures which, when using the GBMP barometer, vary from 4.5 to 6.5 kb, thus indicating possible later retrograde processes. The GAPQ barometer showed higher values varying between 6.5 and 17.5 kb with calculated two clusters at 6.5–9.5 kb and 11–14.5 kb. These values, however, should be considered problematic due to disequilibration of the garnet-plagioclase couple, the latter being rich in albite (An_3). More reliable seem to be the values of the first interval. Relics of a HP mineral assemblage (Mg-staurolite, chloritoid, phengitic muscovite, talc) in garnets were not found in contrast to MSZ at the contact between Moldanubicum and Moravicum where they were described by Johanová et al. (1990).

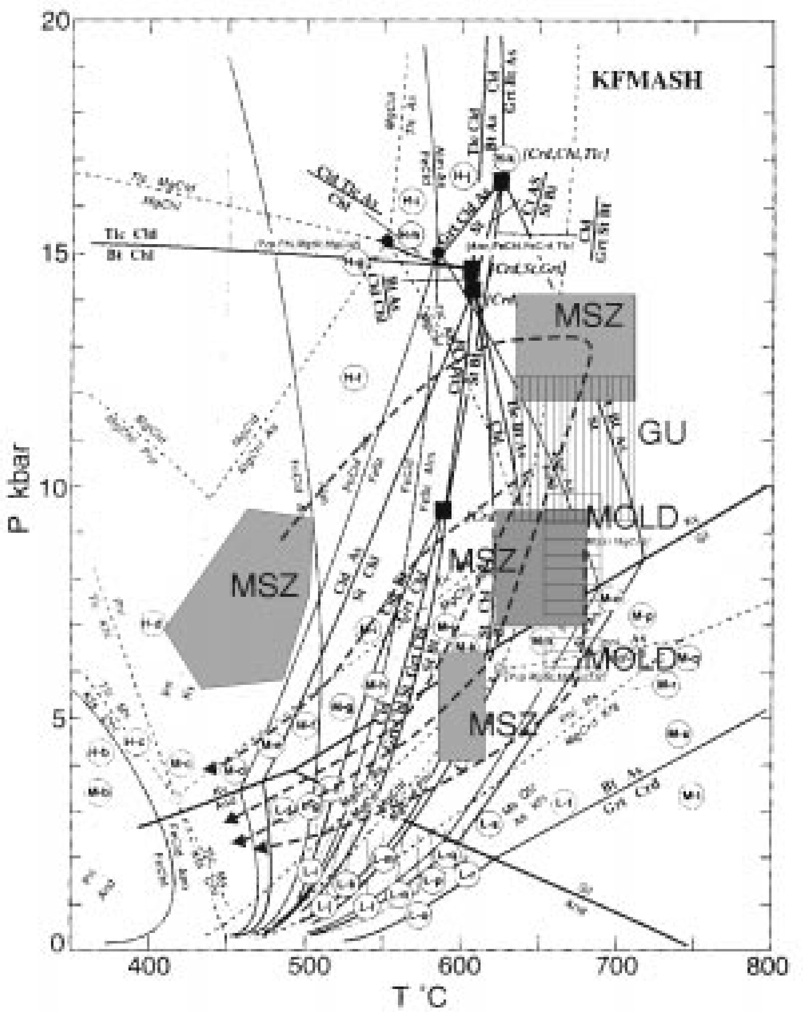


Fig. 31. Interpretation of P-T evolution of MSZ, GU and Moldanubicum based upon results of thermobarometric measurements. P-T box for the oldest metamorphic phase in MSZ was constructed according to the stability field of margarite in CASH (Oliveriová 1993).

6.4. Metamorphic mineral assemblages in metabasites of the Micaschist Zone, GU and Moldanubicum

Metabasites form most common intercalations in paragneisses of Moldanubicum and also in mostly two-mica and "dense" gneisses of MSZ. Amphibolites which can explicitly be classed among GU rocks are less abundant because some bodies E of Český Šternberk, are difficult to be included among any of the above-mentioned units. Metabasites and accompanying ultramafic rocks (Vraník, Poříčko) confined to the interior of a migmatite complex near Drahňovice can be reliably classed among GU metabasites. From the viewpoint of texture, the metabasite can be divided in two groups:

i. banded metabasites (amphibolites),

ii. coarse-grained gabbro amphibolites with relict igneous textures which occur at the base of GU and in Moldanubicum.

Mineralogy and petrography of metabasites of MSZ and Moldanubicum is almost identical. On the other hand, metabasites of GU contain s smaller amount of products of retrograde metamorphism (epidote, chlorite and/or biotite), rare relict pyroxenes, show on average a more calcic plagioclase and higher Mg value of the rock.

Basic mineral assemblage in metabasites of MVG and also MSZ consists of amphibole (mostly Mg-amphibole to tschermakite; pargasite amphibole is more abundant in amphibolite gneisses of MSZ and Moldanubicum – see fig. 32 and plagioclase (oligoclase to andesine). Labradorite is more abundant in GU (table 9). Besides these minerals which are indicative of amphibolite facies, common accessories such as titanite, epidote, rare clinozoisite ± K-feldspar, chlorite and ilmenite were indentified.

Microstructural investigations revealed that actinolite, epidote and chlorite are mostly products of retrograde reactions which occurred under conditions of epidote amphibolite facies and/or greenschist facies. Literary data indicate that the chlorite stability in commom lithologies of metabasites is at about 550° C and 6 Kb (Apted and Liou 1983). At a higher Mg value of protolith and lower fugacity of oxygene, the stability field of chlorite extends into higher temperatures so that chlorite can be stable even under conditions of amphibolite facies. This is supported by higher contents of Al in some chlorites indicates higher pressures during their origin. Higher Mg values in chlorites which overlap with Mg values in amphiboles and Mg value of bulk rock, also indicate that at least some chlorites could have been equilibrated with plagioclase and amphibole. Similarly also epidote, which at higher pressures and higher fugacity of oxygene can be stable at temperatures reaching as much as 650–700 °C. Consequently, it is possible that some of these minerals could have equilibrated with plagioclase and amphibole and thus originated already under conditions of amphibolite facies.

6.5. Mineralogy of metabasites

More attention was paid only to minerals which are important for reconstruction of metamorphic evolution and mutual correlation of individual units.

Amphibole

Amphiboles of metabasites are represented by the Na-Ca varieties. Their composition is given in table 8 and fig. 32. Mg-amphiboles (X_{Mg} 0.6–0.8) to tschermakite amphiboles are most abundant in all three units. In addition, metabasites of Moldanubicum and MSZ contain amphiboles corresponding to the pargasite variety and Fe-pargasite amphibole (fig. 32) which are also characterized of enhanced contents of Na which is in agreement with higher alkalinity of amphibolites in MSZ, particularly in its eastern part.

Common amphiboles, due to retrograde processes, are replaced by tremolite and actinolite amphibole and/or actinolite, thus amphiboles with lower content of Al which are characteristic minerals for the greenschist facies and epidote amphibolite transition facies. Retrograde metamorphism of amphiboles in all three units can be documented by quite well correlation between Al^{IV} and Al^{VI} and also supported by decreasing content of Na_B. Individual stages of amphibole alteration can also be observed in microscope when margins of originally blue-green amphiboles are replaced by colourless amphiboles or by their thin prismatic aggregates. These observations revealed that the metamorphic evolution of amphibolites in the final phase was common for all three units. Retrograde stages of amphibole development can be seen particularly in coarser-grained types of amphibolite.

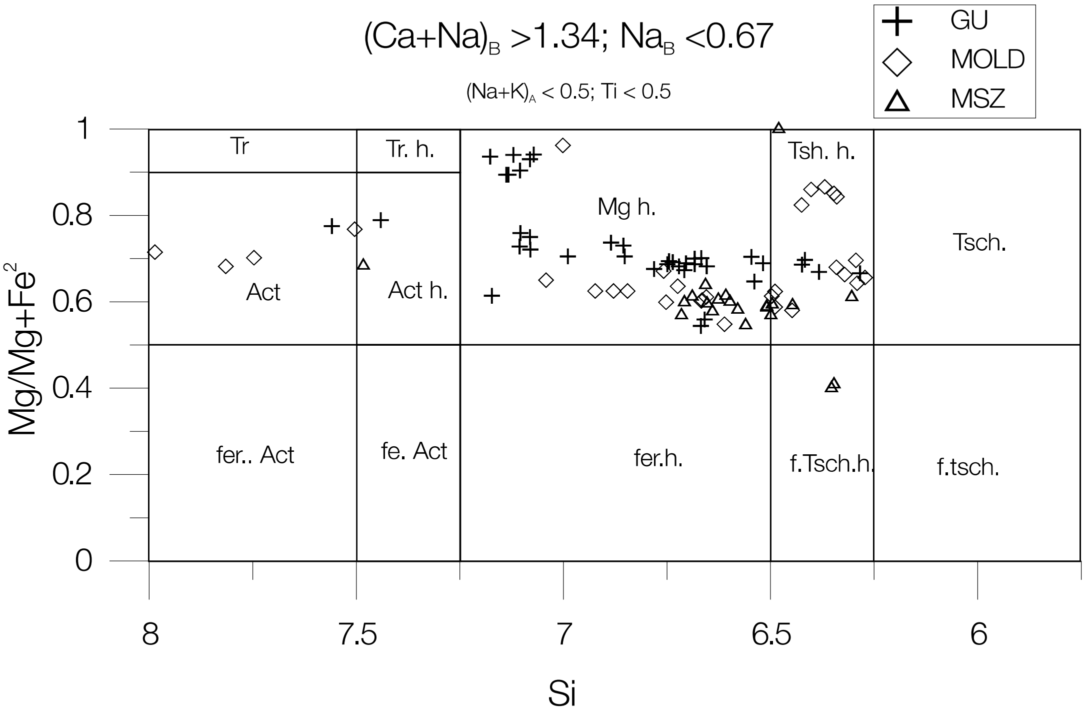
Comparison of chemical composition of amphiboles from the Micaschist Zone, Gföhl Unit and Moldanubicum

Chemical composition of amphiboles from all three units overlapps in basic parameters (fig. 32, table 8). Considerable scatter of Si and Al in amphiboles of Moldanubian amphibolites may reflect a lesser degree of reequilibration of rocks which better record later stages of retrograde alterations. Moreover, it was shown that the chemistry of amphiboles is also influenced by chemical composition of the protolith in addition to impacts of metamorphic processes. For example, amphibolites of GU and MVG from the vicinity of Český Šternberk show higher Mg values because they were derived from Mg-rich tholeiitic types of basalt. Amphibolites of GU are also richer in Al^{VI} and Na content in B position, whereas Moldanubian amphibolites show similar relation of Na in B position.

Higher contents of Fe and alkalies are characteristic of amphibolites in MSZ which reflect their generaly higher alkalinity documented also by the presence of potassium feldspar in some types.

Slightly different is chemical composition of amphibole from amphibole gneisses occuring close to calc-silicate rocks and limestone bodies both in Moldanubicum and MSZ. Amphiboles from these gneisses show high contents of Al (mostly tschermakite to Fe-tschermakite varieties of amphibole), low contents of Mg and also TiO_2 similar to those in biotites from the same gneisses.

Different chemistry reveal amphiboles from metatuffites from Vranov N of Český Šternberk which, similar to other minerals from metatuffites, are poor in Mg and show enhanced contents of Al and Na in B structural position. As follows from comparison of amphiboles from MSZ and from Moldanubicum, their chemical composition is almost identical. However, amphiboles from GU are distinct due to different chemical composition of the



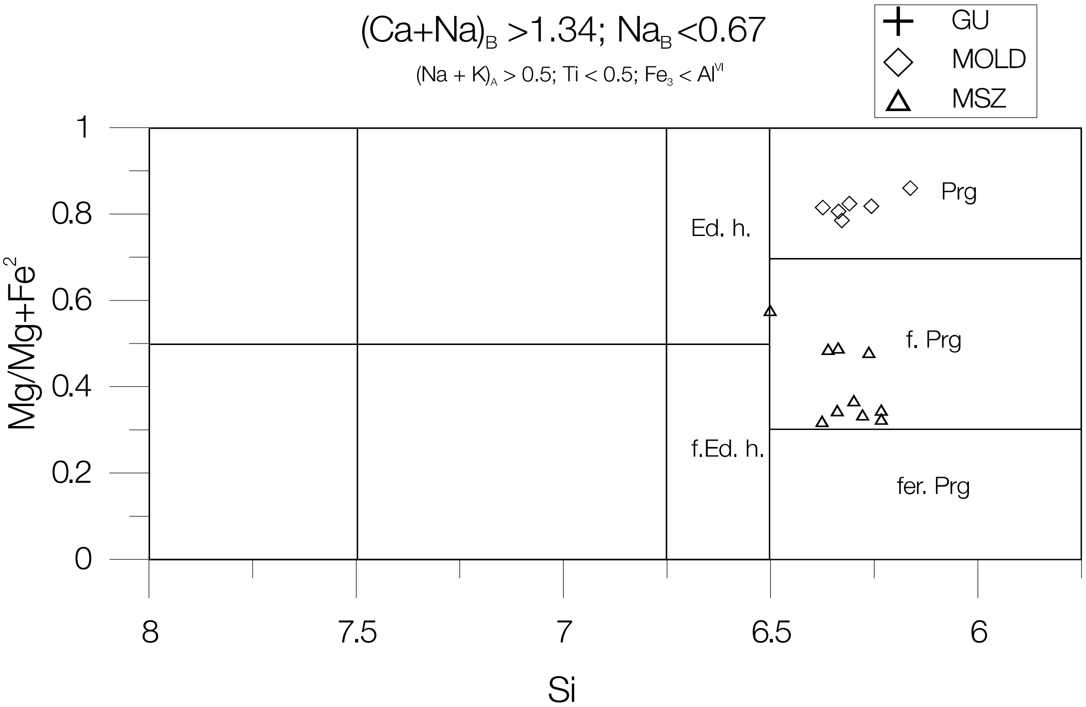


Fig. 32. Classification of amphiboles (Leake 1979) in MSZ, GU and Moldanubicum.

Table 8. Representative analyses of amphiboles from metabasites of MSZ, GU and Moldanubicum. Sample location: R-51-19 – outcrops in a creek SE of Čeřenice – pyroxenite; R-82-121, Šternov quarry in forest towards Drahňovice; RZ-12-28 – creek valley towards Vraník, metagabbro from Ledečko railway station; R-84-93 – Poříčko SE of Malovidy; R-106-12 – outcrops in road S of Křesetice Creek, NE of Drahňovice; R-131-39 – Český Šternberk, rock exposures N of a mill, volcano-sedimentary rocks; R-86-61 – Český Šternberk, parking lot near castle; R-104-69 – Český Šternberk, SE margin, outcrops above railroad tracks; R-102-5 – Český Šternberk – outcrops above railroad tracks 1.5 km SE of the township; R-123-43 – Koblasko, 1.2 km SE of the township, Mold; R-87-56 – Vrabov, N of Český Šternberk; R-102-2 – Český Šternberk, outcrops above railroad tracks, 1.5 km SE of the township; R-87-57 – Vrabov, N of Český Šternberk; R-102-1, Český Šternberk, outcrops above railroad tracks, 1.2 km SE of the township; R-91-108 – Rataje Creek; R-116-33 – Paběnice Creek, SE of Třebonín; R-118-48 – Chedrbí, outcrops at N border of the village – Klejnárka River; R-116-31 – Paběnice Creek, SE of Třebonín; R-118-49 – Chedrbí, outcrops at N border of the village – Klejnarka River; R-137-13 – Čestín quarry.

Sample	R-51-19	R-51-20	R-51-21	R-51-18	R-82-121	R-82-120
SiO_2	48.91	51.49	51.80	49.73	42.96	44.67
Al_2O_3	9.06	10.42	9.72	9.93	14.14	12.27
FeO	4.76	5.16	5.31	4.84	16.19	15.19
MgO	17.47	17.04	17.81	16.95	9.90	10.82
CaO	11.11	10.96	11.00	10.88	10.77	10.68
Na_2O	1.51	1.81	1.72	1.78	1.45	1.23
K_2O	0.20	0.20	0.26	0.18	0.46	0.30
TiO_2	0.32	0.37	0.29	0.31	1.02	0.74
MnO	0.06	0.08	0.11	–	0.22	0.23
Total	93.4	97.53	98.02	94.61	97.11	96.13

Sample	R-51-17	R-51-22	R-82-119	R-82-118	R-82-114	RZ-12-26	R-51-24	RZ-12-28	RZ-12-27	R-82-122	R-84-93
SiO_2	52.33	50.69	44.40	43.71	44.25	49.32	51.65	44.45	43.70	45.26	47.23
Al_2O_3	9.12	9.71	13.38	13.65	12.22	8.07	10.32	11.62	11.38	11.32	9.66
FeO	5.21	5.24	15.92	16.26	15.64	16.16	5.48	16.79	16.67	15.35	11.49
MgO	18.14	17.09	10.34	9.90	10.63	11.08	17.51	9.15	8.95	10.91	13.81
CaO	11.15	10.89	10.57	10.48	10.63	11.09	11.04	10.80	10.69	10.66	12.11
Na_2O	1.70	1.78	1.44	1.44	1.30	0.71	1.72	1.04	1.18	1.21	1.16
K_2O	0.22	0.33	0.47	0.49	0.38	0.53	0.20	1.03	1.02	0.59	0.55
TiO_2	0.29	0.43	0.91	0.85	0.77	0.29	0.37	0.77	0.67	0.66	0.71
MnO	0.10	–	0.31	0.27	0.11	0.36	0.06	0.44	0.35	0.27	0.26
Total	98.26	96.16	97.74	97.05	95.93	97.61	98.35	96.09	94.61	96.23	96.98

Sample	R-84-92	R-84-91	R-84-94	R-84-97	R-84-96	R-84-95	R-84-89	R-84-84	R-84-83	R-82-123	R-84-85
SiO_2	48.49	45.51	49.20	53.50	52.22	48.84	46.14	47.71	48.65	45.22	47.85
Al_2O_3	7.90	10.91	7.42	4.32	4.91	8.34	10.65	9.60	7.64	12.63	8.87
FeO	10.99	11.56	11.15	10.42	10.19	10.82	12.12	11.41	12.10	16.83	11.40
MgO	14.36	12.63	14.82	16.32	16.12	14.23	12.68	13.90	13.96	10.06	13.81
CaO	11.94	11.94	12.16	12.41	12.13	12.28	12.12	12.05	12.17	10.75	12.10
Na_2O	0.78	1.04	0.82	0.29	0.60	0.85	1.19	1.12	0.68	1.39	1.20
K_2O	0.46	0.68	0.44	0.21	0.25	0.51	0.63	0.56	0.36	0.34	0.52
TiO_2	0.61	0.83	0.55	0.25	0.36	0.66	0.72	0.67	0.28	0.62	0.61
MnO	0.20	0.27	0.30	0.22	0.47	0.29	0.22	0.34	0.24	0.31	0.14
Total	95.73	95.37	96.86	97.94	97.25	96.82	96.47	97.36	96.08	98.15	96.50

Sample	R-84-88	R-84-87	R-84-86	R-106-12	R-106-11	R-106-10	R-106-6	R-106-9	R-106-8	R-106-7	R-131-39
SiO_2	45.96	45.37	45.81	45.67	47.01	46.08	45.72	45.83	45.98	43.97	46.01
Al_2O_3	10.83	10.63	10.93	11.66	10.76	12.11	12.00	12.05	12.20	13.94	10.89
FeO	11.66	12.31	11.86	13.45	12.89	13.45	13.42	13.25	12.75	13.46	15.01
MgO	12.97	12.70	12.79	11.77	12.20	11.82	11.52	11.54	11.63	11.19	11.23
CaO	12.24	12.21	12.06	11.31	11.29	11.35	11.27	11.12	11.08	11.19	11.00
Na_2O	1.30	1.27	1.24	1.17	1.04	1.22	1.15	1.29	1.44	1.44	1.14
K_2O	0.61	0.86	0.61	0.46	0.36	0.44	0.48	0.49	0.48	0.69	0.90
TiO_2	0.70	0.78	0.70	0.52	0.46	0.54	0.57	0.40	0.49	0.67	–
MnO	0.23	0.25	0.25	0.28	0.22	0.26	0.29	0.30	0.24	0.28	0.42
Total	96.50	96.38	96.25	96.29	96.23	97.27	96.42	96.27	96.29	96.83	96.61

Sample	R-131-40	R-131-37	R-131-38	R-131-41	R-86-61	R-86-60	R-86-63	R-86-62	R-104-69	R-104-70	R-104-81
SiO_2	45.40	43.75	43.71	43.78	46.29	44.47	46.23	46.25	48.65	42.25	44.09
Al_2O_3	11.76	12.91	13.19	12.46	9.91	11.61	10.05	9.59	8.49	16.14	14.66
FeO	14.79	16.54	16.53	16.54	14.00	14.41	14.21	13.60	8.85	8.34	8.10
MgO	10.60	9.57	9.40	8.93	11.25	10.43	11.24	11.34	16.08	13.74	13.86
CaO	11.09	10.75	11.12	10.86	10.99	10.86	10.87	11.19	10.92	11.21	11.30
Na_2O	1.12	1.33	1.27	1.31	1.50	1.59	1.68	1.29	0.69	2.60	2.24
K_2O	0.86	1.00	1.12	1.18	0.48	0.61	0.53	0.45	0.19	0.27	0.20
TiO_2	–	–	–	–	1.06	1.17	1.13	1.01	0.16	0.36	0.40
MnO	0.40	0.68	0.55	0.55	0.27	0.28	0.28	0.30	0.22	0.14	0.12
Total	96.03	96.54	96.90	95.62	95.75	95.43	96.22	95.02	94.25	95.05	94.97

Table 8. *(continued)*

Sample	R-104-65	R-104-66	R-104-68	R-104-79	R-104-73	R-104-72	R-104-71	R-104-78	R-104-75	R-104-74	R-102-5
SiO_2	43.07	43.57	43.46	42.89	43.77	43.54	42.89	51.60	42.88	43.18	56.46
Al_2O_3	15.83	15.02	15.43	15.41	14.58	14.13	15.09	5.30	14.68	14.51	0.89
FeO	8.45	8.08	8.32	8.39	8.26	8.51	8.49	9.06	8.42	8.19	12.01
MgO	13.58	13.98	13.44	13.11	14.13	13.88	13.52	15.85	13.65	13.71	16.24
CaO	11.36	11.11	10.69	11.14	11.12	11.04	11.05	12.16	11.17	11.29	12.52
Na_2O	2.59	2.39	2.47	2.6	2.29	2.09	2.57	0.53	2.72	2.41	0.06
K_2O	0.29	0.28	0.35	0.27	0.24	0.21	0.23	0.18	0.26	0.23	–
TiO_2	0.38	0.37	0.41	0.47	0.34	0.37	0.42	0.22	0.40	0.43	0.04
MnO	0.19	0.11	0.19	0.17	0.19	0.15	0.13	0.21	0.12	0.20	0.14
Total	95.74	94.91	94.76	94.45	94.92	93.92	94.39	95.11	94.30	94.15	98.37

Sample	R-123-43	R-123-42	R-86-64	R-123-46	R-123-45	R-123-44	R-87-56	R-102-2	R-102-3	R-102-4	R-87-57
SiO_2	43.07	43.14	47.75	42.63	42.52	42.94	45.90	43.62	54.29	53.93	44.96
Al_2O_3	13.94	14.01	8.72	14.29	14.10	13.95	11.27	13.77	3.12	3.27	11.86
FeO	18.62	18.09	13.79	18.83	19.57	18.73	14.14	14.03	12.19	11.88	14.13
MgO	8.77	8.86	11.91	8.48	8.00	8.92	11.02	10.24	15.19	14.32	10.71
CaO	10.03	9.64	11.17	9.90	9.43	9.90	11.51	11.60	12.25	12.15	11.23
Na_2O	1.56	1.56	1.25	1.42	1.43	1.51	1.48	1.77	0.37	0.30	1.57
K_2O	0.18	0.51	0.31	0.58	0.61	0.09	0.73	0.70	0.11	0.09	0.83
TiO_2	–	–	0.75	–	–	–	1.06	1.30	0.14	0.14	1.04
MnO	0.50	0.52	0.32	0.58	0.50	0.41	0.17	0.14	0.23	0.25	0.20
Total	96.68	96.34	95.97	96.72	96.17	96.46	97.28	97.17	97.89	96.33	96.53

Sample	R-87-58	R-102-1	R-91-108	R-91-109	R-91-107	R-91-105	R-91-106	R-91-113	R-91-113	R-91-112	R-91-110
SiO_2	45.09	44.56	43.97	44.22	44.08	47.95	43.79	41.14	42.71	44.42	43.78
Al_2O_3	12.09	13.22	11.37	10.96	10.78	8.61	11.38	13.84	12.19	11.15	11.02
FeO	13.96	14.06	15.55	15.89	15.13	15.18	15.32	14.75	16.27	15.72	16.35
MgO	10.59	10.91	10.24	9.71	10.73	17.13	10.31	9.61	9.79	10.26	9.80
CaO	11.17	11.66	11.37	11.27	11.35	11.52	11.35	11.00	11.61	11.49	11.42
Na_2O	1.54	1.86	1.17	1.15	1.13	0.95	1.22	1.68	1.23	1.23	1.19
K_2O	0.82	0.59	0.59	0.53	0.45	0.32	0.54	0.66	0.65	0.52	0.56
TiO_2	1.06	1.09	0.65	0.65	0.57	0.49	0.66	0.70	0.71	0.72	0.55
MnO	0.41	0.21	0.17	0.25	0.26	0.33	0.31	0.24	0.36	0.29	0.30
Total	96.73	98.16	95.08	94.63	94.48	102.48	94.88	93.62	95.52	95.80	94.97

Sample	R-91-111	R-116-33	R-116-32	R-116-36	R-118-48	R-118-47	R-114-98	R-114-100	R-114-99	R-116-31	R-116-30
SiO_2	43.57	42.72	42.36	43.33	41.17	40.27	39.89	40.70	40.04	42.40	50.91
Al_2O_3	12.70	11.86	11.69	12.85	12.69	13.07	11.76	11.66	11.49	11.53	4.70
FeO	16.28	15.48	15.80	16.44	22.48	22.70	19.67	18.36	19.11	15.24	13.09
MgO	9.51	9.92	9.18	9.34	5.36	5.61	7.69	8.36	7.91	10.16	13.78
CaO	11.49	11.35	11.28	10.99	11.13	10.79	10.93	11.38	10.75	11.56	12.07
Na_2O	1.32	1.22	0.75	1.33	1.52	2.45	1.51	1.67	1.68	1.02	0.39
K_2O	0.63	1.60	1.49	0.91	1.67	1.69	1.42	1.43	1.50	1.45	0.27
TiO_2	0.75	0.91	0.84	–	0.92	1.28	1.16	0.92	0.68	0.77	0.20
MnO	0.31	0.36	0.32	0.45	0.40	–	0.31	0.27	0.32	0.46	0.42
Total	96.56	95.42	93.71	95.65	97.34	97.86	94.34	94.75	93.48	94.59	95.83

Sample	R-118-49	R-137-13	R-118-55	R-137-14	R-137-16	R-137-15	R-118-51	R-118-50	R-118-52	R-118-54	R-118-53
SiO_2	40.51	43.41	45.41	43.86	43.39	44.89	40.29	40.55	40.97	41.18	40.85
Al_2O_3	13.09	10.71	11.31	11.06	11.46	10.44	11.73	13.29	12.21	12.82	12.62
FeO	22.32	16.31	14.22	15.93	16.27	15.94	22.11	22.39	21.58	22.59	22.01
MgO	5.44	10.22	10.88	10.29	10.2	10.64	6.23	5.65	6.35	5.91	5.60
CaO	11.06	11.60	11.48	11.31	11.6	11.16	11.04	11.16	10.76	11.22	11.04
Na_2O	1.34	1.04	1.37	1.04	1.07	1.15	1.03	1.49	1.01	1.31	1.25
K_2O	1.73	1.34	0.86	1.34	1.50	1.29	1.31	1.74	1.45	1.46	1.65
TiO_2	1.19	0.82	1.22	0.74	0.85	0.70	0.36	1.19	1.03	0.89	1.22
MnO	0.32	0.30	0.28	0.35	0.37	0.39	0.33	0.38	0.31	0.39	0.45
Total	97.00	95.75	97.03	95.92	96.71	96.6	94.43	97.84	95.67	97.77	96.69

protolith and possibly also due to different metamorphic evolution.

Plagioclase

Plagioclases together with amphiboles represent the major constituents of metabasites in all three studied units. Their proportion, however, varies in both the foliated and massive coarser-grained amphibolites which often contain sections with preserved relict magmatic textures.

Plagioclase together with amphibole also constitutes the matrix in which rare relict phenocrysts are preserved. The majority of plagioclases are at least partly recrystallized but follows the primary structure. Alternation of layers rich and poor in plagioclase defines the foliation particularly in foliated types of metabasites. Foliation in darker and more massive types is less pronounced and defined by preferred orientation of columnar amphibole and plagioclase. Planar structures occasionally pass into planelinear structures.

The proportion of An component in plagioclases from amphibolites varies considerably ($An_{8\text{-}98}$) – see table 9. The most calcic plagioclases of anorthite composition occur as accessories in a pyroxenite from Poříčko. Some samples show considerable variation in composition which is due to the occurrence of several generations of plagioclase. Most amphibolites contain plagioclase of oligoclase to andesine composition (table 9), but andesine is most abundant in metabasites of all units. More calcic plagioclases corresponding to labradorite were found in amphibolites of GU. The proportion of potassium feldspar in plagioclase varies between 0 and 1 mol. %, rarely in the first tens of per cent. Potassium feldspars were, besides plagioclases, identified in metabasites of MSZ (Třebonín, Rataje) which corresponds with elevated alkalinity of these types of amphibolite.

Chlorite

Chlorites in metabasites originated at the expense of amphibole and occasionally of biotite in some types of amphibolite. Chlorite in foliated types of amphibolite occurs in the form of xenomorphic flakes often growing in pressure shadows behind larger grains of amphibole. Chlorites occurring in metamorphosed gabbroid rocks form larger metacrysts which replace original Fe-Mg minerals in the form of pseudomorphs. Chlorites are mostly accessories. Chlorites confined to metabasites differ from those in gneisses by elevated contents of Mg and

Table 9. Representative analyses of plagioclase from metabasites of MSZ, GU and Moldanubicum. Sample location: R-102 – 2 km SE of a bridge in Český Šternberk, amphibolite – Mold; R-137 – 2 km SE of a bridge in Český Šternberk, coarse-grained amphibolite – Mold; R-51 – Poříčko, SE of Čeřenice, pyroxenite – GU; R-12 – exposed rocks SE of the Ledečko railway station, creek valley towards Vraník, matagabbro – GU; R-131– Vrabov N of Český Šternberk, amphibolite bands in paragneiss – Mold ?; R-118 – N of Chedrbí – amphibolite – MSZ; R-86 – parking lot at Český Šternberk castle – amphibolite with quartz – Mold; R-104 – outcrops above railroad Český Šternberk to Soběšín – amphibolite – Mold; R-84 – Poříčko, SE of Čeřenice, gabbroamphibolite – GU; R-82 – Drahňovice, quarry at the highway to Šternov – amphibolite – GU; R-91– Živý Creek valley SE of Rataje, amphibolite – MSZ; R-106 – 1.2 km NE of Drahňovice, amphibolite – GU.

Sample	R-102	R-102	R-102	R-137	R-137	R-137	R-137	R-51	RZ-12	RZ-12	RZ-12	RZ-12	RZ-12	RZ-12	RZ-12
SiO_2	57.57	53.51	54.95	63.76	54.64	56.90	56.15	51.48	57.16	58.22	56.57	60.77	63.22	59.10	58.23
Al_2O_3	27.35	31.31	29.84	22.57	30.24	27.21	27.62	0.60	24.91	25.25	28.16	26.30	23.19	25.98	26.04
CaO	9.18	4.54	11.24	4.05	9.13	8.67	9.70	20.85	8.30	8.27	1.31	6.38	2.64	8.77	9.00
Na_2O	6.14	2.41	4.40	9.13	4.30	5.52	5.47	0.22	5.46	6.03	3.85	5.73	5.48	5.72	5.74
K_2O	0.08	5.51	0.18	0.14	2.07	0.82	0.21	–	0.20	0.17	5.93	1.47	4.59	0.15	0.16
#An	45.0	29.3	57.9	19.5	47.1	44.1	48.9	98.1	45.1	42.7	8.5	34.5	14.6	45.4	46.0
#Ab	54.5	28.2	41.0	79.7	40.2	50.8	49.9	1.9	53.6	56.3	45.3	56.1	54.7	53.6	53.0
#Or	0.5	42.4	1.10	0.8	12.7	5.0	1.3	–	1.3	1.0	45.9	9.5	30.1	0.9	1.0

Sample	RZ-12	RZ-12	R-131	R-131	R-131	R-118	R-118	R-118	R-86	R-86	R-86	R-86	R-86	R-86	R-104
SiO_2	59.30	59.54	58.54	57.49	53.08	61.54	61.39	61.10	61.62	61.19	62.11	60.67	61.85	63.15	55.00
Al_2O_3	26.06	25.96	26.92	27.77	30.37	24.26	24.54	25.09	23.48	23.84	23.55	24.48	23.42	24.27	27.52
CaO	8.70	3.53	8.07	9.19	12.12	5.54	5.18	6.44	5.53	5.80	5.43	6.51	5.76	1.77	10.14
Na_2O	5.51	5.12	6.43	5.96	4.18	7.67	8.15	7.61	8.76	8.82	8.65	7.93	8.67	9.40	5.78
K_2O	0.21	3.17	0.03	0.06	0.14	0.38	0.48	0.25	0.13	0.14	0.12	0.14	0.13	2.23	0.03
#An	45.9	21.3	40.8	45.8	61.1	27.9	25.3	31.4	25.7	26.5	25.6	31.0	26.7	8.3	49.1
#Ab	52.6	55.9	58.8	53.8	38.1	69.8	71.9	67.1	73.6	72.8	73.7	68.2	72.6	79.3	50.7
#Or	1.3	22.8	0.2	0.4	0.8	2.3	2.8	1.5	0.7	0.8	0.7	0.8	0.7	12.4	0.2

Sample	R-104	R-104	R-104	R-104	R-84	R-84	R-84	R-84	R-84	R-84	R-91	R-82	R-114	R-114	R-91
SiO_2	55.68	56.03	55.58	60.13	54.82	55.20	60.48	53.95	55.18	55.48	57.54	56.23	61.84	60.82	57.27
Al_2O_3	27.57	26.00	26.31	24.49	27.80	28.04	22.66	28.34	27.69	27.83	24.92	27.50	23.29	23.19	26.87
CaO	10.11	8.39	9.17	6.72	9.87	10.15	5.35	10.46	10.13	10.00	6.81	9.03	4.50	4.23	8.58
Na_2O	5.65	6.43	6.13	8.13	5.74	6.02	9.14	5.50	5.85	5.64	7.54	6.26	8.51	8.18	6.36
K_2O	0.05	0.35	0.07	0.10	0.13	0.13	0.14	0.12	0.10	0.12	0.09	0.11	0.17	0.35	0.08
#An	49.6	41.0	45.1	31.2	48.3	47.9	24.2	50.9	48.6	49.1	33.1	44.1	22.4	21.7	42.5
#Ab	50.1	56.9	54.5	68.3	50.9	51.4	75.0	48.4	50.8	50.2	66.4	55.3	76.6	76.0	57.0
#Or	0.3	2.0	0.4	0.6	0.8	0.7	0.8	0.7	0.6	0.7	0.5	0.6	1.0	2.1	0.5

Sample	R-91	R-91	R-91	R-102	R-102	R-106	R-102	R-102	R-102	R-102	R-106	R-106	R-106	R-106	R-106
SiO_2	55.45	56.54	43.25	58.93	54.69	46.77	55.04	55.82	56.15	54.95	45.77	57.23	52.32	56.82	55.68
Al_2O_3	26.02	27.13	12.84	29.67	28.35	33.38	29.94	29.00	28.97	29.84	13.04	29.02	30.21	27.85	27.19
CaO	59.33	8.82	11.39	2.03	10.29	13.69	11.68	10.61	10.60	11.24	11.38	9.71	12.97	10.01	9.31
Na_2O	7.35	6.66	1.29	5.01	4.86	1.59	4.96	5.26	5.46	4.40	1.77	5.89	3.53	5.28	5.65
K_2O	–	0.10	0.76	4.86	0.24	1.31	0.06	0.06	0.06	0.18	0.62	0.25	0.07	0.05	0.04
#An	81.7	42.0	77.9	12.0	53.1	75.5	56.4	52.5	51.6	57.9	74.3	47.0	66.7	51.0	47.5
#Ab	18.3	57.4	16.0	53.7	45.4	15.9	43.3	47.1	48.1	41.0	20.9	51.6	32.9	48.7	52.2
#Or	–	0.6	6.2	34.3	1.5	8.6	0.3	0.4	0.3	1.1	4.8	1.4	0.4	0.3	0.2

T a b l e 1 0 . Representative analyses of chlorite in metabasites of MSZ, GU and Moldanubicum. Sample location: R-51– creek valley W of Poříčko, pyroxenite affected by retrograde processes – GU; R-116, Paběnice Creek valley 2 km S of Třebonín – banded amphibolite: R-131 – Vrabov N of Český Šternberk, amphibolite bands in a paragneiss – GU?; R-118 – quarry at Chedrbí, amphibolite – MSZ; R-86 – outcrops at the parking lot below the Šternberk castle – amphibolite – Mold ?; R-84 – S of recreation area Poříčko, SE of Malovidy, amphibolite – GU?; R-114 – quarry at Chedrbí, strongly deformed banded amphibolite – MSZ; R-82 – quarry on the left hand side of the highway Šternov –Drahňovice, amphibolite – GU?; R-86 – outcrops close to the parking lot near the Český Šternberk castle – amphibolite – Mold?

Sample	R-51	R-116	R-116	R-131	R-118	R-86
SiO_2	44.04	26.75	30.53	27.14	25.76	28.10
TiO_2	0.44	0.05	1.39	–	1.51	0.09
Al_2O_3	9.55	17.80	16.06	19.48	17.49	18.09
FeO	5.40	20.69	18.35	25.21	27.20	22.26
MnO	0.09	0.34	0.28	0.40	0.23	0.22
MgO	16.24	16.08	14.99	14.35	10.90	15.58
CaO	10.80	0.09	0.12	0.21	1.37	0.06
Na_2O	1.67	0.09	0.02	–	–	–
K_2O	0.27	0.03	2.48	0.12	0.04	0.06
Total	88.51	81.92	84.22	86.91	84.50	84.46
$\#Si^{IV}$	4.172	2.953	3.258	2.882	2.876	3.016
$\#Al^{IV}$	–	1.047	0.742	1.118	1.124	0.984
T^{site}	4.172	4	4	4	4	4
$\#Al^{VI}$	1.066	1.269	1.277	1.320	1.177	1.304
#Ti	0.031	0.004	0.112	–	0.127	0.007
$\#Fe^{+3}$	–	–	–	–	–	–
$\#Fe^{+2}$	0.428	1.910	1.637	2.239	2.540	1.998
$\#Mn^{+2}$	0.007	0.032	0.025	0.036	0.022	0.020
#Mg	2.293	2.647	2.385	2.272	1.814	2.493
#Ca	1.096	0.011	0.014	0.024	0.164	0.007
#Na	0.307	0.019	0.004	–	–	–
#K	0.033	0.004	0.338	0.016	0.006	0.008
O^{site}	5.261	5.896	5.792	5.907	5.849	5.837
#O	10	10	10	10	10	10
#OH	8	8	8	8	8	8
mg	0.840	0.580	0.590	0.500	0.420	0.560

Sample	R-86	R-86	R-84	R-114	R-82	R-86
SiO_2	29.22	28.33	30.95	26.06	33.62	27.05
TiO_2	0.63	0.14	0.02	0.02	3.24	0.09
Al_2O_3	17.09	18.59	19.13	19.14	17.60	20.64
FeO	21.19	22.56	17.83	21.78	17.83	19.26
MnO	0.14	0.19	0.25	0.53	–	0.07
MgO	15.33	16.54	19.10	16.81	11.94	18.53
CaO	0.08	0.17	1.79	0.06	0.35	0.07
Na_2O	–	0.07	0.02	0.03	0.07	–
K_2O	0.44	0.12	–	–	2.42	–
Total	84.12	86.71	89.09	84.43	87.07	85.71
$\#Si^{IV}$	3.131	2.965	3.067	2.811	3.413	2.814
$\#Al^{IV}$	0.869	1.035	0.933	1.189	0.587	1.186
T^{site}	4	4	4	4	4	4
$\#Al^{VI}$	1.289	1.259	1.301	1.244	1.518	1.344
#Ti	0.051	0.011	0.001	0.002	0.247	0.007
$\#Fe^{+3}$	–	–	–	–	–	–
$\#Fe^{+2}$	1.899	1.975	1.478	1.965	1.514	1.675
$\#Mn^{+2}$	0.013	0.017	0.021	0.048	–	0.006
#Mg	2.449	2.581	2.822	2.703	1.807	2.873
#Ca	0.009	0.019	0.190	0.007	0.038	0.008
#Na	–	0.014	0.004	0.006	0.014	–
#K	0.060	0.016	–	–	0.313	–
O^{site}	5.769	5.892	5.816	5.974	5.451	5.914
#O	10	10	10	10	10	10
#OH	8	8	8	8	8	8
mg	0.560	0.570	0.660	0.580	0.540	0.630

Fe and slightly lower contents of Al. The X_{Mg} value varies between 0.41 and 0.84 (see table 10) strongly depending on chemical composition of the protolith. The highest values of X_{Mg} were found in chlorites of pyroxenites which experienced retrograde metamorphism.

Titanite

Titanite is an accessory mineral in metabasites of all three studied units. It mostly occurs as xenomorphic grains or clusters near a contact of amphibole with plagioclase. Titanite grains show only sporadically preferred orientation along the main foliation. Selected analyses of titanite are given in table 11.

6.6. P-T metamorphic conditions of metabasite

Metamorphic conditions under which metabasites originated were examined by some additional methods:

i. temperatures of equilibration of amphibole-plagioclase were estimated using the thermometer by Blundy and Holland (1994) based on reactions:

edenite + 4 quartz = tremolite + albite

edenite + albite = riebeckite + anorthite (suitable for Si undersaturated rocks)

As this calibration is very sensitive to the content of Fe^{3+}, which is impossible to establish using electrom microprobe measurements, a method suggested by same authors was applied to reduce errors in calculation of the content of ferric iron. However, geologically unrealistic temperatures of equilibration were obtained for amphiboles high in Fe^{3+} and high contents of Si and Al. This was the case particularly with amphiboles from amphibole gneisses from MSZ and Moldanubicum. The results are also relatively strongly influenced by the content of An in plagioclase, although to a lesser extent than the content of ferric iron. Low contents of An enhance calculated temperatures,

ii. application of Plyusnina thermobarometer (1982) which exploits experimentally established correlations between Al and Ca in amphiboles coexisting with plagioclase. This geobarometer and geothermometer can be used only for a very rough estimate of temperatures and pressures,

iii. correlation of amphibole chemistry from various geotectonic environments, in which P-T conditions of amphibole origin were checked by other independent parameters, with chemical composition controlled by P-T metamorphic conditions (Laird and Albee 1981).

Temperatures calculated using the geothermometer by Blundy and Holland (1994) are statistically evaluated and summarized in fig. 34. Temperatures were calculated at an anticipated pressure of 6 kb. The results, similar to gneisses show two maxima, particularly in metabasites of GU, whereas maxima for the remaining two units are less pronounced.

Table 11. Selected analyses of titanite from metabasites of MSZ, GU and Moldanubicum. Sample location: R-116 – 2 km S of Třebonín, amphibolite – MSZ; R-87 – Vrabov N of Český Šternberk – amphibolite bands in biotite garnetiferous gneiss, Mold? For location of other samples see tables 8–10.

Sample	R-102	R-102	R-116	R-118	R-118	R-87	R-84	R-84	R-91	R-91
SiO_2	31.36	31.15	30.40	31.01	31.18	30.45	30.84	30.66	29.5	30.14
TiO_2	34.81	34.26	33.83	35.62	34.97	35.71	36.92	37.12	36.51	35.99
Al_2O_3	1.93	1.82	1.56	1.73	1.72	1.28	1.34	1.12	2.37	1.90
Cr_2O_3	0.15	–	0.10	0.13	0.11	0.05	0.01	0.01	–	–
FeO	0.71	0.66	0.47	0.74	0.06	0.31	0.15	0.21	0.04	0.35
MnO	–	0.05	0.01	0.01	0.13	0.06	0.01	–	0.01	0.15
CaO	28.07	27.82	28.09	27.97	27.95	27.33	28.16	27.94	28.13	28.11
Total	97.04	95.81	94.53	97.36	96.21	95.42	97.47	97.08	96.64	96.80

The first maximum recorded in all three units ranges between 760 and 820 °C, with the exception of amphibolites of MSZ where it is shifted to unrealistically high temperatures. The maximum corresponds to equilibration temperatures under conditions of the upper amphibolite facies. Petrakakis (1986a, b) Carswell (1991), Petrakakis and Jawecki (1995) report similar values for GU and the Variegated Group of the Austrian Moldanubicum. Calculated values of equilibration of metabasites are thus higher than those established for gneisses based on Grt-Bti and Ms-Bt thermometers.

The second maximum (620–500 °C), which shows a variable width and intensity in various units, is likely to reflect conditions under which decompression and cooling of the system occurred. Temperatures calculated for this retrograde phase overlap with data for the eastern Austrian part of Moldanubicum (Petrakakis 1986a, b) and also with the data obtained for gneisses.

According to the geothermometer and geobarometer of Plyusnina (1982), based on equilibrated reaction: anorthite + zoisite + H_2O + CO_2 = plagioclase + calcite + quartz, the temperatures of reequilibration of amphibole-plagioclase couple vary between 650 and 530 °C (fig. 34) at pressures of 7–2 kb. This method seems to provide the least reliable results. Quite well correlation between Al^{IV} and Al^{VI} and Al^{IV} and Na_B indicate that amphiboles in all three units underwent the same metamorphic evolution during decompression connected with exhumation. Chemical composition of amphiboles (Laird and Albee 1981) corresponds to metamorphic conditions of low to medium pressures and higher temperatures (Abukuma and Dalradian type – fig. 35). In contrast to mineral assemblages in gneisses, amphibolites were more intensely reequilibrated during the younger tectonic deformations M3 and bear no significant signs of an earlier higher pressure event.

6.7. Comparison of metamorphic evolution of the Micaschist Zone, Gföhl Unit and Moldanubian Variegated Group

These units represent polymetamorphic domains with a complex PT-t history and structural evolution. Metamorphic and structural evolution, however, can be reconstructed only partly in appropriate lithologies because the earlier metamorphic events are overprinted by intense processes during the younger tectonometamorphic phases. The protoliths of MVG and Rataje Zone are ge-

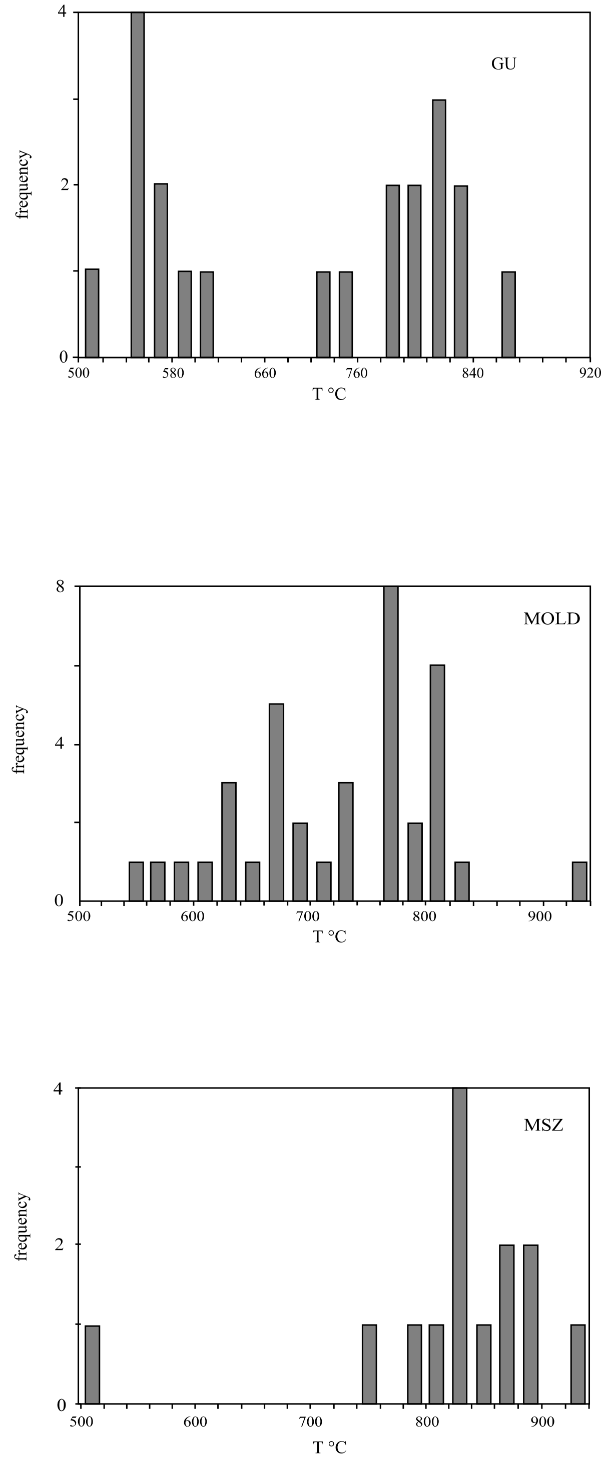


Fig. 33. Statistically evaluated results of thermometric measurements and calculations based on the amphibole-plagioclase equilibration using a thermometer by Blundy and Holland (1990).

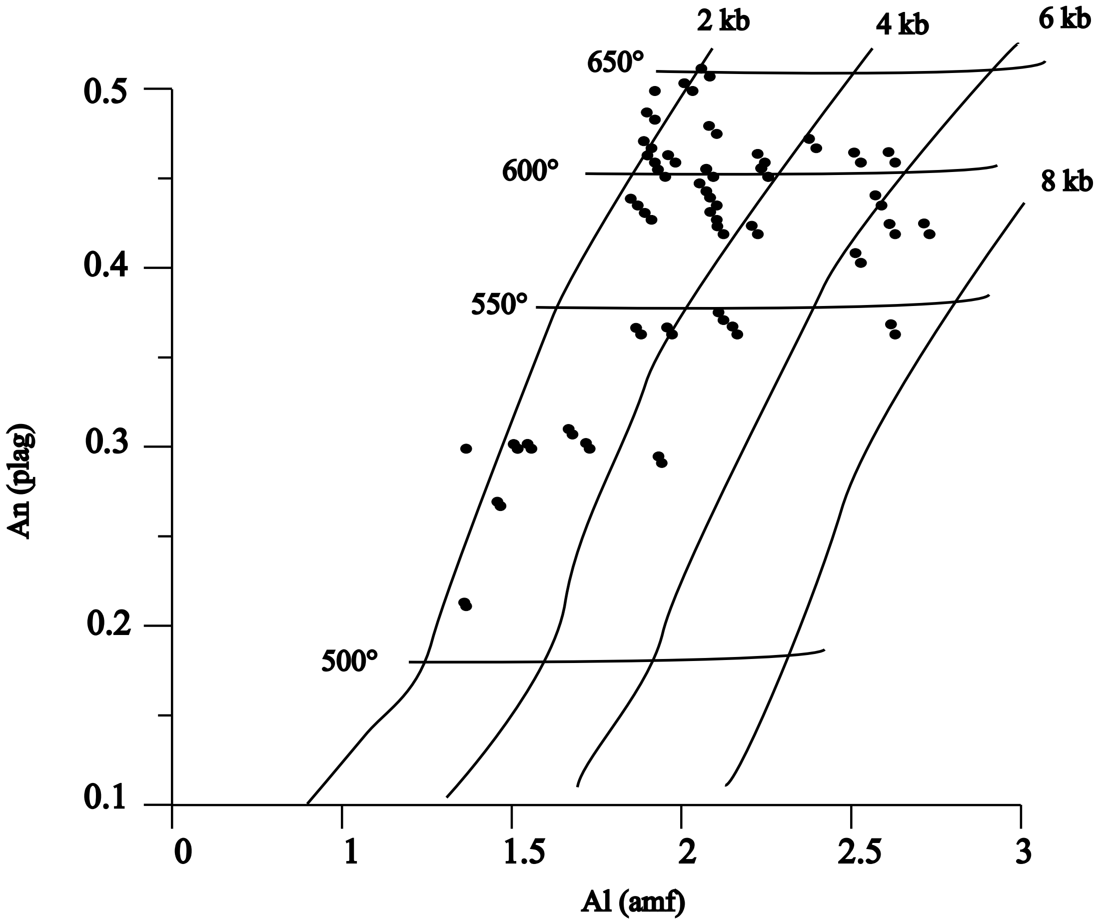


Fig. 34. Results of thermobarometrical studies of metabasites from the MSZ, GU and Moldanubicum, using a thermobarometer by Plyusnina (1982).

ochemically close to each other, but GU is different as far as the chemistry and also age of the protolith are concerned. GU itself is a complex melange of partial segments which Synek and Oliveriová (1993) tried to distinguish when separated the unit into three formations showing distinct metamorphic evolution.

The P-T evolution of the above-mentioned units was already discussed by Synek and Oliveriová (1993). Figure 31 shows P-T paths of rocks from the studied units based on thermobarometric measurements and identified mineral assemblages. The P-T box for MSZ is plotted basing on the stability of margarite in CASH and CNASH systems (Chatterjee et al. 1984). Since the thermobarometric data are not completely reliable, due to possible disequilibrium between minerals, they should be considered only as a certain approximation of actual values. Since the number of relevant data is high, and because the data were statistically treated, the obtained results should not be too far from reality. This is also supported by basic parameters which are consistent with P-T paths established for rocks of GU from the Austrian Moldanubicum.

The most complete reconstruction of P-T evolution can be obtained from gneisses of MSZ which underwent a prograde evolution connected with subduction of the unit into deeper crustal parts that culminated in M2 phase by temperature and pressure peaks (fig. 31). Almost isothermal decompression (possibly with a gentle increase in temperature) followed the pressure relaxation which was then succeeded by cooling and exhumation of the unit. The M1 phase in MVG is apparently not recorded in garnet inclusions as it was demostrated in MSZ. Moreover, rocks of this unit, as follows from the results of thermobarometry (fig. 31), were not burried in such a great depth as in the case of MSZ. Further evolution during the M2 and M3 was very similar to that of MSZ as well as the overlying GU.

This evolution can be interpreted as a decompression connected with thrusting of the Gföhl Nappe over the underlying units which generated differential movements along appropriate lithological boundaries in the underlying units. These movements resulted in a complex nappe structure at the boundary between Moldanubicum and KHCU.

The onset of these movements can be dated at around 370 Ma (Brueckner et al. 1991, Beard et al. 1991) judging from the age of eclogite metamorphism and mantle peridotites enclosed in rocks of GU. Cooling of eclogites and peridotites under conditions of amphibolite facies, dated at 340 Ma (Brueckner et al. 1991, Beard et al. 1991), provides evidence that rocks hosting ultramafics and eclogites (migmatites and granulites) moved into a higher crustal level. Tectonic ascent of these units was facilitated by extreme ductility of the Kouřim orthogne-

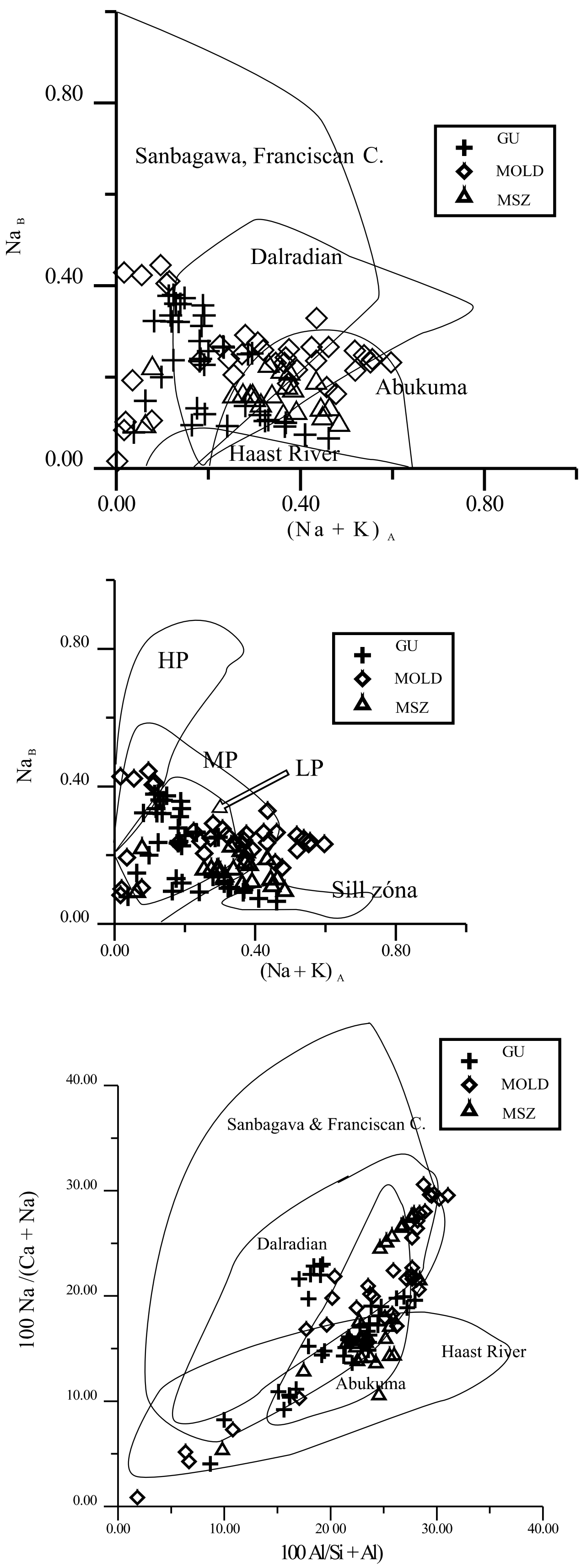


Fig. 35. Comparison of chemical composition of amphiboles from MSZ, GU and Moldanubicum and amphiboles from various geotectonic environment (data from Laird and Albee, 1981.

iss along which the lower crustal and mantle rocks were exhumed. Since the rocks of GU and later on even rocks of the Kouřim Nappe constituted the uppermost plate, the retrograde paths accompanied by relatively considerable drop in temperatures and pressures are characteristic of these units. However, each partial unit demonstrates different course of paths. Whereas rocks of the Malín Formation were affected by retrogression and migmatization in the stability field of kyanite, the P-T path of migmatites of GU from Drahňovice is closer to the path of the Plaňany Formation (fig. 31) where migmatization took place in the stability field of sillimanite. Then a shift in differencial movement along the border between Moldanubicum and MSZ occurred which led to decompression and cooling of structurally lower units.

Oblique E-W oriented thrusting of structurally higher units over Moldanubicum was, however, compensated by movements on sinistral strike-slip faults of NW-SE strike, dated by Ar-Ar method on biotites at 325 Ma (Matte et al. 1990) which explains the absence of notable increase in pressure in the underlying units. These movements may be even older with respect to rejuvenation of K-Ar system in KHCU (Oliveriová et al. 1995). A reorientation of mineral lineation from N-S to NW-SE direction took place during the above-mentioned movements in Moldanubicum (Synek, Oliveriová 1993). The temperature maximum for Moldanubian pelites in the decompression stage was found to be slightly higher than that for rocks of the overlying Rataje Zone which is in agreement with the structural position of MVG. The Ar-Ar cooling ages of Moldanubian amphibolites are clustered around 340–355 Ma, whereas cooling ages in the overlying allochtonous units were established at 325 Ma (Oliveriová et al. 1995). However, an unambiguous explanation for this slight discrepancy is missing. A rejuvenation may be considered, which was triggered by later movements along the Železné hory master fault (Oliveriová et al. 1995) or by thermal processes related to the hypothetical Kutná Hora-Říčany Pluton. Since the chemical composition of amphiboles from metabasites and also the geochemistry of amphibolites of both units are very close to each other, it would be problematic to consider this as a case of two completely different geological units which were brought into mutual contact only as a result of tectonic advance.

7. Geochemistry of selected rocks of the Micaschist Zone, Gföhl Unit and Moldanubian Variegated Group

The objectives of geochemical studies of selected rocks of MSZ, GU and MVG were:

i. to establish tectonomagmatic environment of metabasites and geotectonic type of basinal environment in which the protolith of metasediments was deposited with respect to recostruction of palaeogeographic and palaeotectonic evolution of individual units,

Table 12. List of analysed samples of metabasites from MSZ, GU, Moldanubicum and the Central Bohemian Pluton (Stříbrná Skalice). For sample location, laboratory and analysts see tables 15 and 16.

ii. to find out whether protoliths of gneisses and metabasites in the above-mentioned units correspond to each other or differ to such an extent which would exclude their origin in the same environment and time interval; in the case of detrital sediments on the type of the source area could be obtained,

iii. to investigate tectonomagmatic origin of some smaller bodies of metabasite and metamorphosed granitoids in close neighbourhood of the contact between the above-mentioned units and the Bohemicum (Teplá-Barrandian Unit) and/or CBP (i. e., in the area between Sázava nad Sázavou and Český Šternberk), and to verify their consanguinity with GU or CBP,

iv. as for the hybrid rocks and migmatites penetrated by granitoids (later deformed) in the area between Drletín and southern vicinity of Drahňovice, to verify whether these rocks belong to GU, and to exclude the possibility that we deal with strongly deformed durbachitic rocks of CBP (Kachlík 1992).

For the analysis representative bulk samples (3–5 kg) of metabasites, gneisses and metagranitoids, along the contact between MVG, MSZ and CBP were selected.

The list of analyzed samples according to the main rock types is given in tables 12, 13 and 14. Sample location of all samples is given in table 15.

The results of studies of metabasites were supplemented with published data from other localities in MVG (e. g., Český Krumlov Variegated Group – Patočka 1991, western Moravia – Matějovská 1987, Český Šternberk region – Suk 1971) which may throw some light on whether the occurrences of variegated groups in various parts of Moldanubicum are comparable, and originated in a basin with a similar tectonic and sedimentary regime and supply of similar material.

Data on metabasites from the NE part of CBP in the area of Stříbrná Skalice (Palivcová 1966) are also quoted for correlation.

The analyzed samples of gneisses from MSZ, GU and Moldanubicum were supplemented by published data on equivalent rocks from the Český Krumlov Variegated Group (Patočka 1991), Nepomuk region (Součková 1989), Strakonice region (Mráz 1990) and broader vicinity of Tábor (Venera 1990). Some data also come GU which is exposed in the Moravian part of Moldanubicum (Souček et al. 1992) and from a paper by Dudek et al. (1974) dealing with petrography and geochemistry of the protolith of this unit. Since correlation of Moldanubian units with the Bohemicum has been a subject of lenghty discussions (Vejnar 1965, Suk 1973, Chlupáč 1992), parameters of Proterozoic metagraywackes and shales from the SE flank of the Teplá-Barrandian Unit (Huspeka 1989), and Islet Zone (Košler 1988, Kachlík 1992) were also plotted.

Analyses of deformed granitoids from the area between Stříbrná Skalice and Český Šternberk were co-

Sample	R-2	R-7	R-8	R-9	R-10	R-14
SiO_2	45.84	51.33	57.79	48.59	47.37	51.89
TiO_2	1.19	0.98	0.84	0.49	1.95	1.28
Al_2O_3	15.99	17.34	15.73	18.08	15.58	14.87
Fe_2O_3	2.06	2.68	2.61	1.84	3.18	2.87
FeO	6.68	5.76	3.42	3.87	7.00	6.55
MnO	0.13	0.14	0.12	0.09	0.19	0.14
MgO	7.11	4.40	4.49	8.62	7.20	6.50
CaO	12.67	9.19	7.71	12.25	9.64	7.92
Na_2O	2.32	2.98	4.52	2.26	3.08	3.40
K_2O	1.10	2.39	1.09	0.70	1.14	1.66
P_2O_5	0.27	0.43	0.21	0.10	0.31	0.11
H_2O^+	1.54	1.78	0.80	1.88	2.18	1.82
CO_2	2.56	0.38	0.14	0.59	0.98	0.42
H_2O^-	0.20	0.24	0.16	0.12	0.26	0.16
Total	99.66	100.02	99.63	99.48	100.06	99.59
Cr	461	28	37	800	353	253
Ni	197	17	58	122	96	78
Co	63	30	29	38	6	37
Sc	32	25	19	32	29	29
V	288	268	156	166	311	275
Cu	–	–	–	–	–	–
Pb	5	16	12	9	8	17
Zn	–	–	–	–	–	–
W	0.3	0.7	34.4	15.5	21.7	2.6
As	–	–	–	–	–	–
Rb	9	17	26	43	49	69
Cs	9	5	1	60	5	6
Ba	93	857	692	1653	197	372
Sr	289	565	436	382	274	335
Ga	–	–	7	–	–	–
Li	23	25	7	37	38	6
Ta	0.13	0.34	0.26	0.83	0.72	0.82
Nb	1.4	5.3	3.1	0.8	1.3	5.4
Hf	–	–	–	–	–	–
Zr	–	–	–	–	–	–
Y	19	2	15	7	26	3
Th	0.3	5.5	2.3	0.7	1.8	2.4
U	0.3	2.4	0.8	0.2	1.6	2.9
La	3	4	11	1	13	4
Ce	7	6	25	3	33	11
Pr	1.5	5.8	2.6	0.4	3.6	1.2
Nd	5.8	24.6	11.1	2.6	17.6	5.7
Sm	2.0	4.8	2.7	0.7	4.7	2.6
Eu	0.9	1.6	1.1	1.4	1.4	0.8
Gd	2.9	4.2	2.4	0.8	3.8	1.8
Tb	0.57	0.84	0.54	0.20	0.93	0.57
Dy	3.5	3.9	2.8	1.2	4.8	3.5
Ho	0.74	0.76	0.57	0.26	0.97	0.75
Er	1.47	1.64	1.21	0.53	1.86	1.54
Tm	0.33	0.32	0.23	0.11	0.37	0.34
Yb	1.99	2.15	1.52	0.66	2.38	2.17
Lu	0.29	0.32	0.24	0.13	0.37	0.33
Th/La	0.10	1.48	0.21	0.63	0.13	0.58
Nb/La	0.51	1.42	0.28	0.70	0.10	1.31
Ta/La	0.05	0.09	0.02	0.73	0.05	0.20
alk index	7.08	3.79	2.23	3.11	5.68	3.35
K/Rb	1011	1150	344	133	89	197
K/Ba	98	23	13	3	22	37
Sr/Rb	32.11	33.24	16.77	8.88	5.59	4.86
Zr/Rb	–	–	–	–	–	–
La/Ce	0.38	0.58	0.44	0.39	0.41	0.36
Ta/Yb	0.07	0.16	0.17	1.26	0.30	0.38
Zr/Nb	–	–	–	–	–	–
Th/Yb	0.14	2.57	1.53	1.09	0.74	1.09
Y/Nb	13.57	0.38	4.84	8.75	20.00	0.56
Ta/Yb	0.63	0.16	0.17	0.13	0.34	0.39
Ce/Yb	3.63	3.00	16.64	4.38	13.91	5.22
Ba/La	34.07	229.76	62.17	1450.00	14.65	90.29
La/Sm	1.37	0.78	4.08	1.56	2.89	1.60

Table 12. *(continued)*

Sample	RZ-82	RZ-84	R-86	R-87	R-91	R-94	VK-775	VK-770	VK-779	RZ-136	RZ-141	RZ-142	RZ-146	RZ-149
SiO_2	56.85	50.87	53.45	48.65	48.29	47.27	52.77	49.68	50.04	38.83	46.33	45.71	47.44	46.80
TiO_2	0.65	0.81	1.40	2.16	1.02	1.37	0.85	0.39	0.64	0.40	1.53	1.58	1.72	0.97
Al_2O_3	15.24	15.64	14.71	14.68	15.19	15.29	15.29	11.59	13.68	1.81	15.60	15.60	15.21	15.96
Fe_2O_3	2.90	2.07	2.58	11.27	2.74	3.71	2.23	3.06	2.55	6.13	1.71	2.24	1.25	0.81
FeO	5.80	5.47	7.03	0.06	7.42	6.79	2.68	5.86	8.47	1.13	7.48	7.40	8.12	8.55
MnO	0.13	0.13	0.13	0.15	0.14	0.14	0.08	0.19	0.27	0.10	0.14	0.16	0.14	0.16
MgO	5.09	8.62	5.96	6.69	7.66	7.86	3.59	11.93	7.60	35.73	7.56	8.47	8.31	8.57
CaO	7.95	10.71	8.02	9.70	11.60	11.78	13.18	10.62	10.88	1.09	13.20	12.27	11.57	12.62
Na_2O	2.75	2.67	3.56	2.69	2.75	1.95	2.04	1.30	1.58	0.70	2.65	2.60	2.74	1.82
K_2O	0.50	0.79	0.83	1.56	0.46	0.97	1.47	0.27	1.15	0.12	0.65	0.88	0.50	0.76
P_2O_5	0.08	0.01	0.18	0.29	0.15	0.14	0.34	0.05	0.13	0.19	0.32	0.50	0.44	0.23
H_2O^+	1.28	1.41	1.64	1.44	1.70	2.05	4.46	3.28	1.88	12.68	1.63	1.86	1.54	1.61
CO_2	0.23	0.26	0.12	0.50	0.24	0.21	–	–	–	–	–	–	–	–
H_2O^-	0.22	0.24	0.22	0.24	0.27	0.28	0.51	0.45	0.45	–	–	–	–	–
Total	99.67	99.70	99.83	100.08	99.63	99.81	99.49	98.67	99.32	98.90	98.78	99.28	98.98	98.88
Cr	122	337	20	197	337	394	183	653	50	2934	313	117	290	229
Ni	37	45	32	44	94	144	14	126	94	2582	124	66	73	56
Co	35	40	6	57	62	61	2	4	36	15	7	56	56	53
Sc	4	24	43	52	14	4	–	–	–	–	–	–	–	–
V	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cu	14	250	18	37	25	62	–	–	–	40	95	95	79	38
Pb	–	27	–	–	–	–	–	–	–	–	–	–	–	–
Zn	55	74	87	9	93	82	10	80	14	60	9	75	10	83
W	–	–	–	–	–	–	–	–	–	–	–	–	–	–
As	1	11	8	6	8	–	–	–	–	–	–	–	–	–
Rb	14	36	2	45	18	34	66	12	36	6	6	8	6	2
Cs	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ba	137	13	144	113	–	117	431	92	325	–	–	54	–	–
Sr	129	28	295	191	172	216	687	19	16	6	179	28	188	95
Ga	1	11	14	14	11	13	17	8	11	–	–	–	–	–
Li	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ta	–	–	–	–	–	–	–	–	–	0.19	0.23	0.72	0.62	0.12
Nb	1.2	13.3	15.3	2.4	16.4	19.5	19	8.3	5.1	–	–	–	–	–
Hf	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Zr	5	17	119	147	99	95	167	16	27	–	84	86	86	–
Y	27	25	36	34	34	31	50	17	35	–	29	23	22	10
Th	–	–	–	–	–	–	–	–	–	–	–	–	–	–
U	–	–	–	–	–	–	22.0	2.7	2.4	–	–	–	–	–
La	–	–	–	–	–	–	–	–	–	1	6	13	12	2
Ce	–	–	–	–	–	–	–	–	–	2	19	4	29	4
Pr	–	–	–	–	–	–	–	–	–	0.3	2.6	3.9	3.8	0.6
Nd	–	–	–	–	–	–	–	–	–	0.9	–	–	–	3.5
Sm	–	–	–	–	–	–	–	–	–	0.2	4.5	5.2	4.7	1.1
Eu	–	–	–	–	–	–	–	–	–	0.4	1.5	1.6	1.5	0.9
Gd	–	–	–	–	–	–	–	–	–	0.2	4.1	4.4	4.6	1.5
Tb	–	–	–	–	–	–	–	–	–	0.30	0.80	0.75	0.83	0.29
Dy	–	–	–	–	–	–	–	–	–	0.2	4.9	5.2	5.8	2.3
Ho	–	–	–	–	–	–	–	–	–	0.57	1.30	1.93	1.11	0.50
Er	–	–	–	–	–	–	–	–	–	0.16	2.86	2.88	2.86	1.5
Tm	–	–	–	–	–	–	–	–	–	0.20	0.39	0.50	0.42	0.19
Yb	–	–	–	–	–	–	–	–	–	0.16	2.77	3.30	2.73	1.25
Lu	–	–	–	–	–	–	–	–	–	0.30	0.47	0.47	0.46	0.22
Th/La	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Nb/La	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ta/La	–	–	–	–	–	–	–	–	–	0.16	0.04	0.06	0.05	0.07
alk index	–	2.59	2.47	4.42	3.57	4.02	2.11	1.38	2.28	–	5.82	7.57	4.30	3.99
K/Rb	293	180	3403	284	210	234	183	185	262	164	888	902	1183	3116
K/Ba	30	498	47	113	–	68	28	24	29	–	–	134	–	–
Sr/Rb	9.21	0.78	147.50	4.24	9.56	6.35	10.41	1.58	–	1.00	29.83	3.50	31.33	47.50
Zr/Rb	2.86	0.49	5.81	3.26	5.33	2.79	2.58	1.25	0.74	–	13.50	1.37	13.83	–
La/Ce	–	–	–	–	–	–	–	–	–	0.48	0.33	3.61	0.41	0.42
Ta/Yb	–	–	–	–	–	–	–	–	–	1.19	0.08	0.22	0.23	0.10
Zr/Nb	4.17	1.28	7.78	61.25	6.04	4.87	8.79	1.93	5.29	–	–	–	–	–
Th/Yb	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Y/Nb	22.50	1.88	2.35	14.17	2.07	1.59	2.63	2.05	6.86	–	–	–	–	–
Ta/Yb	–	–	–	–	–	–	–	–	–	1.19	0.83	0.24	0.22	0.96
Ce/Yb	–	–	–	–	–	–	–	–	–	15.31	6.73	1.06	10.53	3.36
Ba/La	–	–	–	–	–	–	–	–	–	–	–	4.27	–	–
La/Sm	–	–	–	–	–	–	–	–	–	5.09	1.38	2.44	2.50	1.56

Table 13. List of analysed samples of paragneisses from MSZ, GU and, Moldanubicum. For sample location, laboratory and relevant analyst see tables 15 and 16.

Sample	R-1	R-12	RZ-4	RZ-8	R-85	R-88	R-89	R-90	RZ-138	RZ-139	RZ-143	RZ-144	RZ-145	RZ-148	RZ-150
SiO_2	65.08	68.43	67.00	62.89	64.82	65.61	65.15	67.25	61.50	58.31	63.84	64.40	62.01	65.27	70.71
TiO_2	0.69	0.36	0.57	0.79	0.70	0.66	0.61	0.61	0.88	0.87	0.79	0.79	0.90	0.75	0.39
Al_2O_3	15.62	13.91	14.78	15.91	14.74	14.77	14.65	14.55	17.29	20.09	16.32	16.53	16.76	14.82	14.05
Fe_2O_3	1.51	1.30	2.10	2.40	2.06	1.75	1.35	2.21	3.27	1.65	1.34	0.75	0.95	0.64	0.31
FeO	3.69	1.75	2.80	4.39	3.68	3.17	1.73	2.75	3.09	5.35	3.74	3.52	4.38	3.95	1.69
MnO	0.04	0.03	0.06	0.07	0.11	0.05	0.04	0.05	0.34	0.32	0.05	0.22	0.08	0.09	0.06
MgO	1.80	2.09	1.83	2.90	2.94	2.37	2.62	1.89	1.57	2.01	1.70	1.84	2.10	1.70	0.62
CaO	2.10	1.87	2.60	1.90	3.14	2.13	2.24	2.13	1.10	1.09	1.79	1.54	2.65	3.17	1.82
Na_2O	2.42	2.92	3.21	2.87	2.43	3.34	2.46	2.48	1.30	1.30	2.47	1.10	2.69	2.69	1.72
K_2O	4.79	4.06	2.70	2.49	3.05	3.72	6.72	2.80	6.74	6.02	6.18	6.79	5.50	5.10	7.72
P_2O_5	0.14	0.06	0.14	0.19	0.16	0.12	0.33	0.15	0.28	0.37	0.27	0.42	0.30	0.35	0.45
H_2O^+	1.40	1.51	1.62	2.65	1.49	1.73	1.45	2.04	3.03	3.30	2.12	2.77	2.53	1.86	1.60
CO_2	0.34	1.19	0.10	0.13	0.33	0.30	0.28	0.43	–	–	–	–	–	–	–
H_2O^-	0.20	0.12	0.30	0.26	0.24	0.26	0.20	0.26	–	–	–	–	–	–	–
Total	99.82	99.60	99.81	99.84	99.89	99.98	99.83	99.60	100.39	100.67	100.61	100.68	100.87	100.39	101.15
Cr	131	51	–	–	80	63	101	72	69	108	60	28	74	80	5
Ni	32	18	–	–	26	–	76	31	41	45	27	21	39	46	11
Co	12	7	–	–	5	2	–	–	25	28	12	10	17	16	11
Sc	11.75	12.4	–	–	–	–	–	–	–	–	–	–	–	–	–
V	107	41	–	–	–	–	–	–	–	–	–	–	–	–	–
Cu	–	–	–	–	36	8	14	31	29	39	28	6	32	59	12
Pb	9	35	–	–	16	24	80	19	–	–	–	–	–	–	–
Zn	–	–	–	–	108	84	74	88	96	119	75	121	107	128	38
W	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–
As	–	–	–	–	2	–	7	–	–	–	–	–	–	–	–
Rb	146	163	–	–	129	103	252	102	120	123	178	139	117	111	176
Cs	11	6	–	–	–	–	–	–	–	–	–	–	–	–	–
Ba	906	–	–	–	791	806	–	577	844	718	696	840	738	786	670
Sr	125	170	–	–	146	122	279	134	125	127	101	93	119	94	149
Ga	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Li	46	47	–	–	–	–	–	–	–	–	–	–	–	–	–
Ta	0.92	0.93	–	–	–	–	–	–	1.41	1.43	1.51	2.32	1.15	0.95	1.30
Nb	12.3	11.4	–	–	27.6	20.5	31.7	19.6	18.5	16.4	12.2	23.5	18.3	18.1	13.0
Hf	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Zr	–	–	–	–	186	206	386	211	124	105	153	294	214	181	89
Y	13	18	–	–	39	36	30	33	5	26	20	31	38	30	24
Th	8.5	13.4	–	–	–	–	–	–	–	–	–	–	–	–	–
U	2.9	2.5	–	–	–	–	–	–	–	–	–	–	–	–	–
La	32	35	–	–	–	–	–	–	57	57	29	83	54	42	19
Ce	64	74	–	–	–	–	–	–	117	116	57	178	109	85	39
Pr	6.1	69.0	–	–	–	–	–	–	11.8	12.0	6.3	18.9	11.0	9.1	4.4
Nd	23.5	27.9	–	–	–	–	–	–	40.4	41.5	22.7	67.1	39.2	31.8	16.1
Sm	4.5	5.8	–	–	–	–	–	–	8.3	8.5	5.3	14.9	8.0	6.9	4.2
Eu	1.41	1.24	–	–	–	–	–	–	1.32	1.48	1.07	1.61	1.65	1.59	0.81
Gd	3.8	4.1	–	–	–	–	–	–	5.9	6.4	4.0	10.3	5.7	5.4	3.7
Tb	0.65	0.89	–	–	–	–	–	–	0.93	0.93	0.62	1.43	0.89	0.79	0.36
Dy	2.8	3.6	–	–	–	–	–	–	4.9	4.9	3.6	7.9	5.1	4.0	4.0
Ho	0.49	0.67	–	–	–	–	–	–	1.04	0.95	0.77	1.37	0.92	0.83	0.77
Er	1.04	1.45	–	–	–	–	–	–	2.76	2.51	1.93	3.44	2.43	2.34	2.19
Tm	0.20	0.24	–	–	–	–	–	–	0.40	0.39	0.31	0.49	0.33	0.35	0.33
Yb	1.36	1.76	–	–	–	–	–	–	2.76	2.67	2.19	3.12	2.04	2.24	2.27
Lu	0.23	0.30	–	–	–	–	–	–	0.46	0.42	0.29	0.49	0.35	0.36	0.35
SiO_2/Al_2O_3	4.17	4.92	4.53	3.95	4.40	4.44	4.45	4.62	3.56	2.90	3.91	3.89	3.70	4.40	5.03
Na_2O/K_2O	0.51	0.72	1.19	1.15	0.80	0.90	0.37	0.89	0.19	0.22	0.40	0.16	0.49	0.53	0.22
K_2O/Fe_2O_3	3.17	3.12	1.29	1.04	1.48	2.13	4.98	1.27	2.06	3.66	4.62	9.01	5.76	7.98	24.52
Al_2O_3/Na_2O	6.45	4.76	4.60	5.54	6.07	4.42	5.96	5.87	13.25	15.40	6.60	15.08	6.22	5.52	8.16
Nb/Y	0.96	0.65	–	–	0.71	0.57	1.07	0.59	3.60	0.64	0.60	0.77	0.49	0.61	0.55
Rb/Sr	1.17	0.96	–	–	0.88	0.85	0.90	0.76	0.96	0.97	1.77	1.49	0.98	1.18	1.18

rrelated with certain types of granitoid of CBP whose analyses were reported by Holub et al. (1995).

Analytical results within individual groups (i. e., matabasites, gneisses and metagranites) were statistically treated using cluster analysis which, verified the reliability of geological and petrological classification of single rocks among units, and also revealed internal variation within individual rock groups.

Table 13. *(continued)*

Sample	RZ-153	RZ-154	RZ-155
SiO_2	73.11	63.99	65.06
TiO_2	0.14	0.83	0.75
Al_2O_3	13.43	15.02	14.54
Fe_2O_3	0.49	0.55	1.45
FeO	1.28	4.56	3.39
MnO	0.03	0.08	0.06
MgO	0.99	2.10	1.87
CaO	1.11	2.00	2.28
Na_2O	2.74	2.83	2.69
K_2O	6.22	5.70	6.87
P_2O_5	0.10	0.33	0.36
H_2O^+	1.50	1.91	1.78
CO_2	–	–	–
H_2O^-	–	–	–
Total	101.15	99.91	101.11
Cr	5	62	63
Ni	7	21	27
Co	10	15	12
Sc	–	–	–
V	–	–	–
Cu	6	31	34
Pb	–	–	–
Zn	41	146	96
W	–	–	–
As	–	–	–
Rb	69	105	136
Cs	–	–	–
Ba	–	–	848
Sr	65	90	119
Ga	–	–	–
Li	–	–	–
Ta	0.55	0.85	0.84
Nb	10.9	11.2	14.1
Hf	–	–	–
Zr	106	153	180
Y	33	28	27
Th	–	–	–
U	–	–	–
La	44	42	44
Ce	35	84	88
Pr	8.7	8.7	8.8
Nd	31.0	31.9	31.4
Sm	6.9	7.0	6.8
Eu	1.07	1.50	1.38
Gd	4.7	4.5	4.5
Tb	0.73	0.70	0.68
Dy	4.3	3.9	3.8
Ho	0.87	0.75	0.75
Er	2.35	2.19	2.01
Tm	0.37	0.29	0.31
Yb	2.58	2.00	2.01
Lu	0.46	0.32	0.30
SiO_2/Al_2O_3	5.44	4.26	4.47
Na_2O/K_2O	0.44	0.50	0.39
K_2O/Fe_2O_3	12.80	10.33	4.74
Al_2O_3/Na_2O	4.90	5.31	5.40
Nb/Y	0.33	0.39	0.52
Rb/Sr	1.06	1.16	1.14

7.1. Geochemistry of metabasites

Metabasites (amphibolites) constitute the most common intercalations in the studied units. Their geological and petrological characteristics were described in section 3 and the definition of mineral assemblages and individual minerals was given in section 6. The petrographic investigation already revealed that metabasites can be separated into two basic groups:

i. banded metabasites among which banded amphibolites – metatuffites in garnetiferous biotite paragneisses around Vrabov and banded amphibolites with more abundant bodies of calc-silicate rocks occuring mostly in MSZ can be further distinguished,

ii. coarser-grained more massive matabasites with relics of original gabbroid structures. Bodies of these rocks, associated often with tiny boudins of pyroxenites, were observed in GU near Čeřenice and Poříčko.

Electron microprobe studies of the main rock-forming minerals showed that banded amphibolites of MSZ and MVG contain similar mineral assemblages. The only difference includes higher content of Na_A in amphiboles from metabasites from MSZ and occasional occurrence of accessory potassium feldspar. Amphibolites of GU differ from the remaining units by higher Mg values in amphiboles and chlorites, higher anortite content of plagioclases and by lower contents of titanite and epidote.

Variations in chemistry of individual minerals exist even between foliated and massive metabasites (gabbroamphibolites) whose occurrences are concentrated particularly in the area of Ledečko, Poříčko and SE of Český Šternberk. The majority of bodies are confined to basal parts of GU where they are closely associated with ultramafic rocks and pyroxene amphibolites. Smaller bodies of these rocks occur in a zone of amphibolites running NW-SE from Český Šternberk to Soběšín.

Results of geochemical studies are in agreement with petrological data. Geochemical investigation confirmed differences between the two main groups of amphibolite, i.e – coarse-grained gabbroamphibolites and foliated amphibolites. The latter, with the exception of problematic bodies in the Sázava River meander near Samopše and SE of Český Šternberk, can be classed as part of GU. These bodies show relatively strong affinity to rocks of CBP. Metabasites of MSZ and Moldanubicum exhibit very similar geochemical parameters, although the parent magmas of MSZ metabasites are geochemically more mature and enriched with crustal component. Detailed geochemistry of single groups of metabasites, including their correlation with metabasites of other areas of Moldanubicum, is discussed in the following paragraphs.

7.1.1. Major elements

The majority of metabasites of MSZ, GU and MVG correspond to basalts (fig. 36); only a smaller part falls in the field of basaltoandesites, exceptionally andesites (banded metatuffites from Vrabov, amphibolites with layers of limestones and calc-silicate rocks from a parking lot at Český Šternberk castle) in classification diagram by Le Baase et al. (1986). Enhanced contents of SiO_2 and alkalies were found in deformed granitoids of CBP from around Stříbrná Skalice and in some metamonzodioritic to metamorphosed gabbroid rocks from Ledečko, Poříč-

Table 14. List of analysed samples of metagranitoids of uncertain provenance and pearl gneisses of GU. For sample location, laboratory and relevant analyst see tables 15 and 16.

Sample	R-4	R-5	R-6	R-11	R-15	R-13	RZ-83	R-92	R-93	R-95	R-96	R-97	R-98	R-99
SiO_2	66.81	62.48	72.14	48.34	49.09	53.18	68.57	69.28	77.59	65.68	68.16	66.18	67.84	67.62
TiO_2	0.44	1.03	0.35	1.39	1.55	1.07	0.57	0.60	0.12	0.67	0.55	0.61	0.47	0.44
Al_2O_3	14.41	15.06	14.03	16.93	15.6	17.12	14.88	14.45	11.84	14.86	14.95	15.49	15.76	14.65
Fe_2O_3	0.29	1.07	0.37	2.89	3.73	3.50	1.84	1.91	1.62	1.92	2.29	2.79	1.73	1.24
FeO	1.31	2.22	1.30	7.44	5.10	5.76	2.15	2.23	0.20	3.23	2.39	2.58	1.55	0.75
MnO	0.03	0.05	0.02	0.15	0.13	0.20	0.05	0.05	0.03	0.07	0.05	0.04	0.03	0.02
MgO	2.06	3.01	0.55	6.68	4.66	3.58	1.18	1.29	0.42	2.46	1.77	2.06	1.41	2.22
CaO	1.22	2.37	1.10	8.56	6.42	5.74	1.38	1.46	0.52	2.88	1.80	0.84	2.02	1.29
Na_2O	2.36	2.00	3.16	1.89	2.92	3.49	2.93	2.45	2.04	2.56	2.54	2.30	3.37	2.41
K_2O	8.55	8.14	5.55	1.91	2.10	3.27	4.04	3.89	4.12	2.75	2.88	3.56	3.49	6.49
P_2O_5	0.58	0.96	0.17	0.16	0.24	0.45	0.21	0.19	0.02	0.20	0.11	0.15	0.13	0.32
H_2O^+	1.33	0.68	0.71	2.47	4.21	1.89	1.31	1.55	0.81	1.76	1.40	2.36	1.56	1.40
CO_2	0.53	0.28	0.23	1.15	3.56	0.44	0.22	0.24	0.30	0.29	0.40	0.25	0.13	0.35
H_2O^-	0.12	0.20	0.04	0.18	0.32	0.26	0.24	0.28	0.09	0.22	0.25	0.50	0.30	0.26
Total	100.04	99.55	99.72	100.14	99.63	99.95	99.57	99.87	99.72	99.55	99.54	99.71	99.79	99.46
Cr	162	19	42	426	261	9	42	38	5	76	55	55	16	79
Ni	6	8	8	97	79	11	12	12	5	31	21	29	11	61
Co	9	14	3	45	36	35	7	–	–	–	–	–	–	–
Sc	4	11	4	31	25	21	–	–	–	–	–	–	–	–
V	29	64	23	241	29	23	–	–	–	–	–	–	–	–
Cu	–	–	–	–	–	–	19	18	12	32	19	42	–	–
Pb	19	7	26	15	51	12	25	22	4	24	19	31	41	81
Zn	–	–	–	–	–	–	75	73	15	111	78	78	67	54
W	6	1	10	2	3	5	–	–	–	–	–	–	–	–
As	–	–	–	–	–	–	21	–	–	7	4	16	5	4
Rb	253	341	23	87	11	92	18	171	16	133	15	148	138	244
Cs	7	22	9	7	8	9	53	–	–	–	–	–	–	–
Ba	1446	188	923	29	263	957	681	624	683	795	75	958	89	157
Sr	383	392	14	195	272	594	18	11	75	159	9	113	22	331
Ga	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Li	28	38	6	67	18	3	–	–	–	–	–	–	–	–
Ta	4.39	3.46	1.42	0.42	0.90	0.31	–	–	–	–	–	–	–	–
Nb	34	37	11	6	13	5	2	23	17	24	19	3	22	34
Hf	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Zr	–	–	–	–	–	–	16	173	86	23	184	18	181	35
Y	11	29	16	25	32	35	37	38	46	36	45	35	29	25
Th	44.9	17.7	16.2	3.9	5.1	5.5	–	–	–	–	–	–	–	–
U	8.6	15.3	3.4	1.2	2.2	1.8	–	–	–	–	–	–	–	–
La	59	149	24	11	23	25	–	–	–	–	–	–	–	–
Ce	116	32	6	25	51	58	–	–	–	–	–	–	–	–
Pr	1.2	31.5	4.8	2.6	5.5	6.0	–	–	–	–	–	–	–	–
Nd	36.7	114.9	18.2	1.4	22.9	27.0	–	–	–	–	–	–	–	–
Sm	6.3	18.3	4.5	3.1	5.6	6.6	–	–	–	–	–	–	–	–
Eu	1.84	2.64	1.11	0.83	1.53	1.80	–	–	–	–	–	–	–	–
Gd	4.7	13.2	3.7	2.4	4.4	4.6	–	–	–	–	–	–	–	–
Tb	0.74	2.30	0.76	0.75	1.14	1.20	–	–	–	–	–	–	–	–
Dy	2.38	6.20	3.54	4.36	6.10	6.30	–	–	–	–	–	–	–	–
Ho	0.40	1.60	0.60	0.94	1.18	1.30	–	–	–	–	–	–	–	–
Er	0.97	2.44	1.11	1.87	2.40	2.60	–	–	–	–	–	–	–	–
Tm	0.13	0.34	0.19	0.42	0.48	0.52	–	–	–	–	–	–	–	–
Yb	0.95	2.24	1.22	2.80	3.17	3.50	–	–	–	–	–	–	–	–
Lu	0.13	0.30	0.17	0.43	0.47	0.53	–	–	–	–	–	–	–	–

ko and Samopše. They plot in the field of trachybasalts and trachyandesites.

The diagrams revealed that at least two compositional groups of metabasalts occur in the area of Marjánka. The first group, which includes strongly deformed foliated types of metabasites, is characterized of enhanced contents of quartz and lower concentrations of alkalies. The second group involves more basic, alkalies – and aluminium-richer coarser-grained basalts with relict gabbroid textures and signs of calc-alkaline composition. Geochemical character of these rocks is similar to that of gabbroamphibolites from Ledečko and Poříčko. The first group can be interpreted as relics of the mantle in dominating strongly deformed intrusive rocks of CBP, whereas rocks of the second group represent proper deformed magmatites of CBP.

Basic rocks confined specifically to GU are slightly more acidic and contents of alkalies are, with respect to higher concetrations of SiO_2, lower. Higher content of SiO_2 is manifested by accessory quartz in matrix. These

Table 15. Location of lithogeochemical samples of a) metabasites, b) paragneisses, c) granitoids of problematic provenance

a) sample	sampling site description
R-2	*amphibolite, outcrops in erosion gully, 150 m NW of highway intersection Talmberk–Ček nov, SE of S zava nad S zavou*
R-7	*metamonzogabbro, outcrops in valley of a creek flowing from Vran k toward Lede ko railroad station*
R-8	*banded amphibolite, S zava River meander near P vlaky*
R-9	*banded amphibolite, recreational area Bud n near Samopše*
R-10	*banded amphibolite, outcrop in roadcut of road S zava nad S zavou – Talmberk near branch off to the Bud n recreational area*
R-14	*medium-grained gabbroamphibolite, Bud n recreational area with bungallows, right bank of S zava River*
RZ-82	*amphibolite, quarry at forest border close to highway Šternov – Drah ovice*
RZ-84	*coarse–grained gabbroamphibolite, left bank of S zava River in recreational area Po ko*
R-86	*amphibolite with quartz admixture, parking lot at Česk Šernberk castle*
R-87	*banded amphibolite alternating with layers of garnet–biotite gneiss, Vrabov, N of Česk Šternberk*
R-94	*amphibolite, 200 m W of P vlaky*
R-91	*amphibolite with bands of calc–silicate rocks, Rataje, Živ Creek valley*
VK-770	*metadiorite, long outcrop along highway St brn Skalice – S zava nad S zavou, recreational area Marj nka*
VK-775	*metadiorite, long outcrop in Jevany Creek valley, at S border of St brn Skalice*
VK-779	*metadiorite, long outcrop in St brn Skalice*
RZ-136	*serpentinite, outcrop on a crest, S of recreational area Vran k, S of Lede ko*
RZ-141	*banded amphibolite, outcrops in abandoned quarry, Pab nice Creek valley, SE of T ebon n*
RZ-142	*banded amphibolite, Bohdane quarry*
RZ-146	*banded amphibolite, quarry S of the village*
RZ-149	*massive amphibolite, boudin in leucocratic migmatites, SW of Če enice*

b) sample	sampling site description
R-1	*greywacke gneiss, outcrops below Pirkštejn castle, Rataje nad S zavou*
R-12	*mylonitized finely laminated gneiss, W slope of Jest b hill, recreational area Bud n, SE of S zava nad S zavou*
RZ-4	*laminated slaty metasiltstone, N border of Chocerady*
RZ-8	*thinly laminated biotite metasiltstone, Seradov valley, SW of Hradov St imelice*
R-85	*augen gneiss, 500 m SE of Malovidy, S zava River valley*
R-88	*mylonitized greywacke biotite paragneiss, St brn , N of Česk Šternberk*
R-89	*migmatite with layers of metatect, long outcrop along S zava River, N of St brn*
R-90	*greywacke biotite gneiss, meander near P vlaky*
RZ-138	*greywacke gneiss, outcrops below highway near church in Rataje*
RZ-139	*garnetiferous micaschist with kyanite and staurolite, Rataje - railroad tunnel*
RZ-143	*two-mica gneiss, highway cut Malešov-Rozt ž*
RZ-144	*two-mica paragneiss, Lomec Creek valley N of T ebon n*
RZ-145	*biotite "dense gneiss", Petrovice II, RZ*
RZ-148	*biotite-sillimanite gneiss, SE of Hodkov, Moldanubicum*
RZ-150	*two-mica migmatite, SW of Če enice*
RZ-153	*two-mica quartzitic gneiss, Vodranty*
RZ-154	*biotite-sillimanite paragneiss, 1.1 km SW of Štrampouch, Klejnarka River valley, Moldanubicum*
RZ-155	*biotite paragneiss, Vrchlice valley, SW of Poli any*

c) sample	sampling site description
R-4	*ultrapotassic biotite leucocratic granitoid, outcrops in railroad cut W of Malovidy*
R-5	*outcrops in slope W of railway station Lede ko, S of Vran k recreational area*
R-6	*leucocratic aplitic two-mica metagranitoid*
R-11	*strongly deformed biotite-amphibole metagranitoid*
R-15	*mylonitized biotite metadiorite, W wall of limestone quarry near S zava nad S zavou*
R-13	*metamonzodiorite, outcrops in slope near highway intersection S zava nad S zavou, Nehyba, Talmberk*
RZ-83	*biotite metagranitoid to augen gneiss, outcrops in K ešice Creek valley, NW of Drah ovice*
R-92	*porphyric biotite metagranitoid, Jedlavka recreational area SE of Če enice*
R-93	*plagioclase gneiss, erosion gully N of Lede ko*
R-95	*biotite augen gneiss W of Lede ko railway station, valley towards Vran k*
R-96	*augen gneiss E of Horn Drlet n village*
R-97	*augen gneiss, western part of Pysko ely meander, NW of S zava nad S zavou*
R-98	*augen gneiss N of M ln k vilage*
R-99	*biotite-amphibole metagranitoid, outcrops underneath limestone bodies, quarry near S zava nad S zavou*

Samples in correlation diagrams are marked as follows: Český Krumlov Variegated Group CK and CKS (Patočka 1991), augen gneisses of GU in western Moravia XX (Souček et al. 1998), paragneisses from Tábor area Ve (Venera 1990), from Strakonice and Sušice regions MR (Mráz 1990), So (Součková 1989), from Islet Zone VK (Kachlík 1992).

Table 16. List of laboratories which carried out chemical analyses of individual samples.

Sample	major elements	trace elements	REE
R-1–R-15	Labs of Fac. of Sci. Charles Univ. (L. Mráz)	Analytika s.r.o.l. (J. Bendl)	Analytika s.r.o.l. (J. Bendl)
R-82–R-102	Labs of Fac. of Sci. Charles Univ. (L. Mráz)	Gematest s. r. o. Černošice (J. Štrůblová)	Gematest s. r. o. Černošice (P. Hanzlík)
R-136–R-155	Gematest s. r. o. Černošice (A. Manda)	Gematest s. r. o. Černošice (J. Štrůblová)	Analytika s.r.o.l. (J. Bendl)

rocks are accompanied by smaller bodies of peridotite (Vraník), pyroxenite and pyroxene amphibolite (Poříčko). Among these rocks, however, only one sample of serpentinite was analyzed.

Almost all metabasites, due to their content of SiO_2 and alkalies, fall in the field of subalkaline basalts in the discrimination diagram of Irvine and Baragar (1971) – fig. 37 and Winchester and Floyd (1977). Only part of samples from the NE border of CBP and the metamonzogabbro from Ledečko fall in the field of alkaline basalts. Mostly metabasalts of MSZ cluster near the border of both fields. Similar geochemistry is seen in samples not only from MVG in close proximity to MSZ but also from other areas (e. g., Votice and Strakonice regions).

The majority of studied metabasites, except for some gabbroamphibolites in the vicinity of Ledečko and Poříčko and some metabasites in NE part of the Central Bohemian Pluton near Štříbrná Skalice, correspond in various discrimination diagrams to tholeiitic basalts (e. g., Irvine, Baragar 1971 – fig. 37, Jensen 1976, Mullen 1983 – fig. 38, Pearce 1975 – fig. 39, Pearce, Cann 1975, Pearce, Norry 1979). Higher contents of Al and partly alkalies in gabbroid rocks and rocks of CBP indicate that these rocks are transitional to calc-alkaline rocks (e. g., Myiashiro 1974, 1975) which may reflect slightly different source.

Tholeiitic basalts proper of all three units also show some variation in their chemistry (see fig. 40). The Mg value varies between 45 and 70. Amphibolites from the Sázava River lobe near the recreational area Budín NE of Samopše, and metabasites from a zone outcropping in the Talmberk Creek valley SE of Sázava nad Sázavou belong specifically among the most primitive basalts. Basalts of GU in the vicinity of Poříčko and Čeřenice also exhibit higher Mg values.

When compared with tholeiitic basalts of mid-oceanic ridges, MSZ basalts in particular are enriched with K_2O and to lesser extent with Fe and Ti. Majority of basalts are relatively poor in MgO, even though the Mg contents are on average higher than those in amphibolites of the Český Krumlov Variegated Group. Depletion in Cr and Ni indicates that fractionation of olivine is likely to have played important role during the magma differentiation. Metabasites of MSZ and MVG show similar characteristics, whereas metabasites of GU are closer to primitive MORB basalts.

Some amphibolites are considerably enriched in lithofile cations with low charge (K, Rb, Ba), transient metals with high ionic potential and light REE indicating that crustal component or parent magmas from enriched mantle sections are likely to have played a prominent role during their petrogenesis. Tholeiites whose composition is close to recent N-MORB basalts are relatively rare representing rather transient basalts and P-MORB basalts enriched in a crustal component. If these rocks show an even higher admixture of a crustal component then they can be equivalent to intraplate tholeiites (e. g., fig. 42) which are known from recent ocean islands or from some volcanic provinces of plateau basalts.

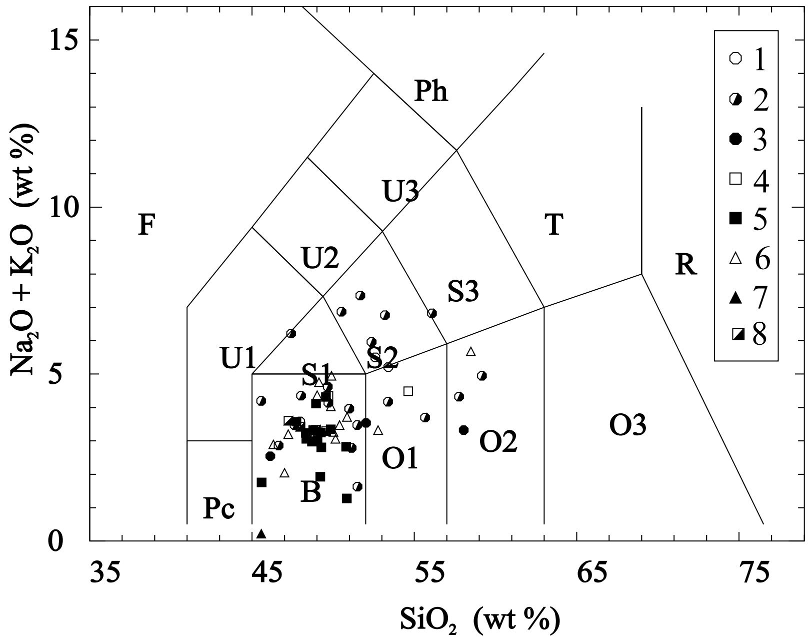


Fig. 36. Classification of metabasites of MSZ, GU and Moldanubicum after Le Maitre (1989). 1. amphibolite bodies near Samopše and Čekánov (R-2, R-7, R-8, R-9, R-10); 2. metagabbro metadiorite from the vicinity of Ledečko and Poříčko, biotite-amphibole metatonalite (R-13); 3. strongly deformed diorites of CBP – Marjánka locality; 3. amphibolites of GU (R-82, R-83, R-86); 4. banded amphibolites of MVG around Český Šternberk; 5. amphibolites of the Český Krumlov Variegated Group and from the rim of the Blanský les granulite massif (Patočka 1991); 6. amphibolites of the Strakonice and Votice Variegated Groups; 7. serpentinite, GU, Vraník SW of Ledečko; 8. amphibolites of MSZ. For symbols used in all Figures section 7 on metabasites see this figure. For sample location see table 15.

Contents of major elements related to SiO_2, as an indicator of magmatic fractionation of metabasites in all studied units, are given in fig. 40. All diagrams, perhaps with the exception of Ca vs SiO_2, show notable scatter in chemistry of samples from different units and regions. This indicates slightly different petrogenetic conditions of the origin of basalts possibly belonging to various magmatic cycles. Samples from MSZ and from various areas of MVG seem to cluster together. Slightly different behaviour is seen in metamonzodiorites and metamonzogabbros from the aera between Sázava nad Sázavou and Český Šternberk. Deformed metabasites of CBP from the area between Stříbrná Skalice and Marjánka quarry represent a separate group of metabasites.

Further differences can be observed in each of the major oxides. Contents of TiO_2 range between 0.1 and 3.8 wt %. The highest contents of Ti oxide were found in amphibolites from the Český Krumlov Variegated Group and from the Strakonice and Votice regions. Metabasites of MSZ show similar contents of TiO_2 (1.5–1.7 wt %), whereas rocks of GU and metabasites of CBP from the vicinity of Stříbrná Skalice are poor in TiO_2 (max. 1 wt %).

Aluminium contents show lesser scattering relative to other elements. Rocks with calc-alkaline trend to which belong the metabasites from Stříbrná Skalice and part of the coarse-grained gabbroamphibolites, have the highest concentrations of Al (in some samples exceed 16 wt %). Higher contents of Fe relative to Mg and particularly Fe^{3+} are characteristic of metabasites from MSZ and metatuffites from MVG near Vrabov where Fe_2O_3 prevails over FeO. This is also a typical feature of some metabasites in close spatial relationship with granulite bodies of GU in western Moravia (Matějovská 1987). Metabasites from the area SE of Sázava nad Sázavou (Budín, Samopše) display the highest contents of MgO (7–7.8 wt %) and CaO (12–3 wt %).

The smallest variations were found in contents of MnO (0.1–0.25 wt %). Higher contents of Na_2O and K_2O (over 2 wt %) exhibit gabbroamphibolites from Samopše, monzogabbros at the base of GU near Vraník and deformed metabasites of CBP from Stříbrná Skalice (Na_2O contents vary between 3.5–5 wt %, K_2O 1.1–1.7 wt %). The contents of K_2O in most other metabasites do not exceed 1 wt %, varying mostly between 0.5 and 0.9 wt %. Enhanced alkalinity of metamonzogabbros and a more conspicuous trend towards intraplate rocks is demonstrated by higher contents of P_2O_5 (as much as 0.44 wt %).

7.1.2. Trace elements and REE

Metabasites of the units studied can be separated in two groups:

i. banded metabasites of MSZ and MVG. Amphibolites of GU differ mostly by more primitive distribution of RRE, and relations between trace elements also indicate lower degree of their geochemical differentiation. The chemistry of slaty metabasites is almost

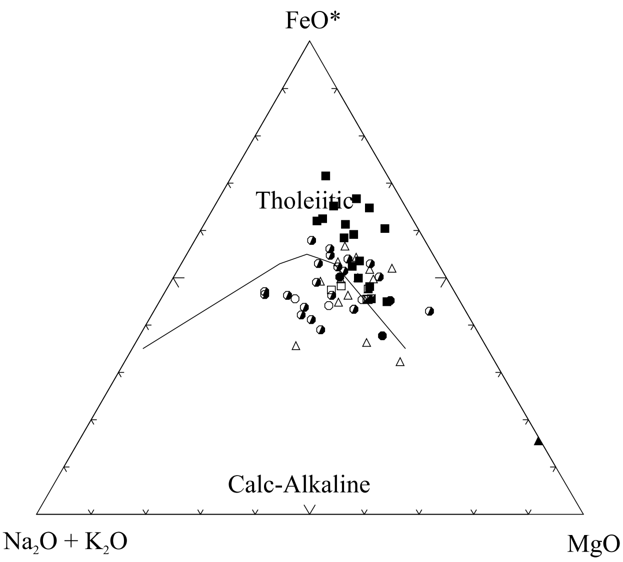


Fig. 37. Discrimination digram after Irvin and Bagar (1971) for distinguishing rocks of tholeiite and calc-alkaline series.

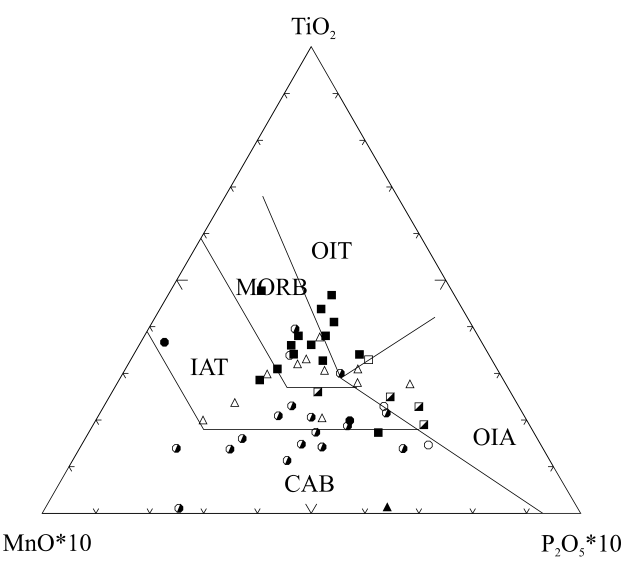


Fig. 38. Discrimination diagram by Mullen (1983) for recognition tectonomagmatic affinity of basalts (for symbols see fig. 36).

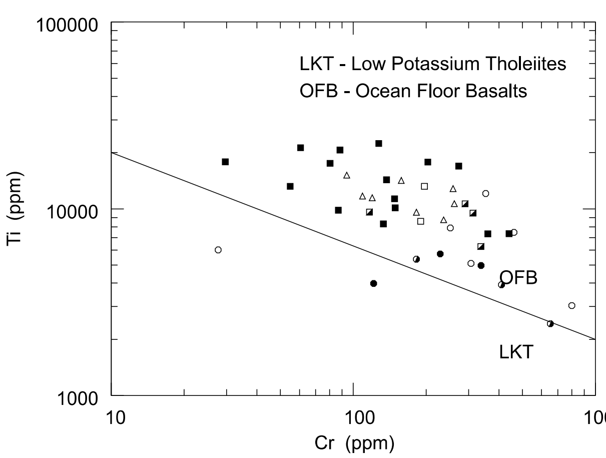


Fig. 39. Discrimination diagram of Pearce (1975) to distinguish oceanic tholeiites from low potassium tholeiitic basalts of island arcs.

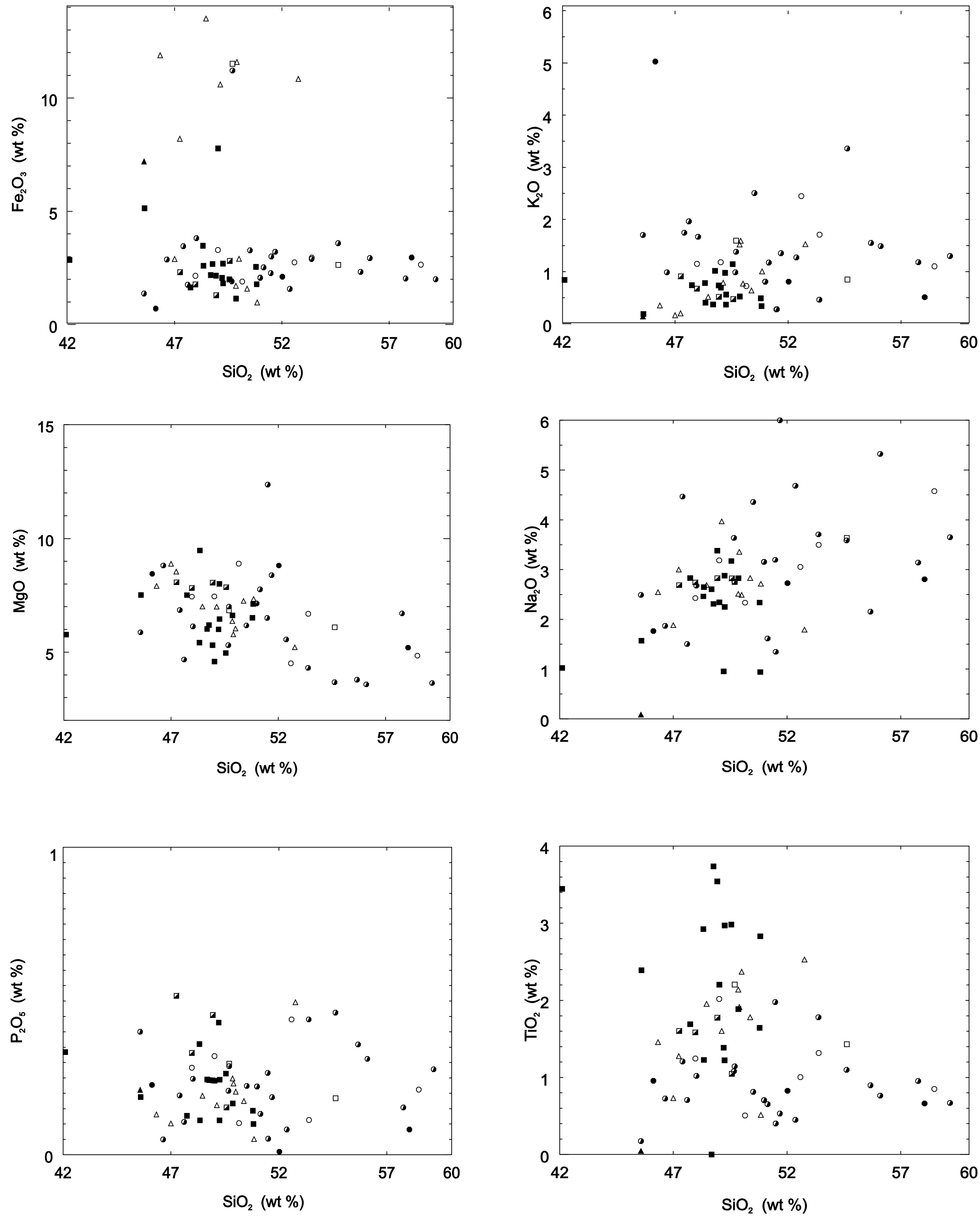
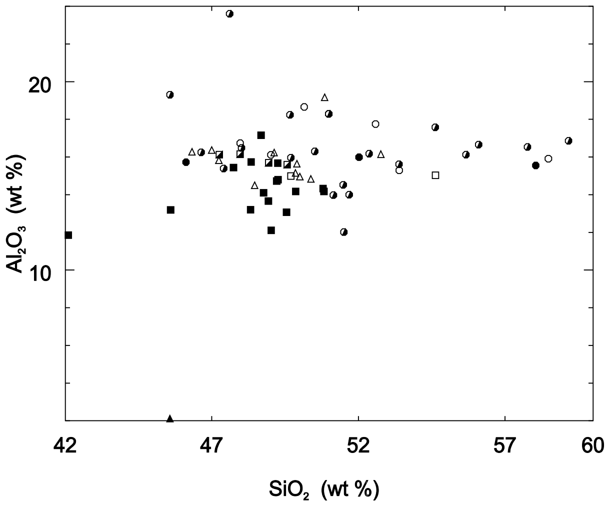


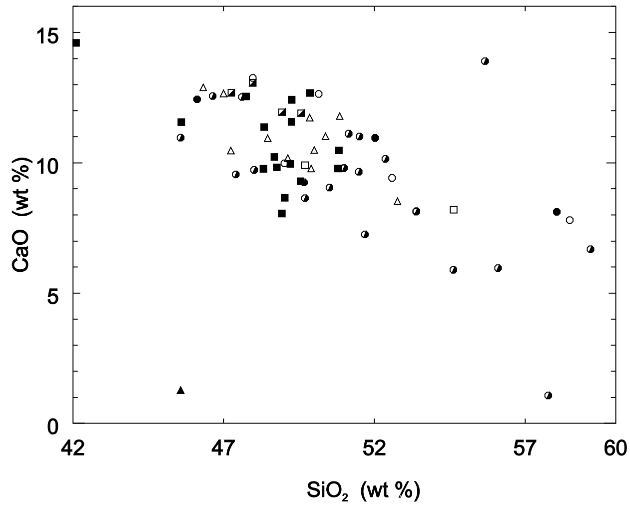
Fig. 40. Major element chemistry of metatabasites of MSZ, GU and Moldanubicum in comparison with other parts of Moldanubian Variegated Groups and sourrounding Bohemicum. (for symbols see fig. 36).

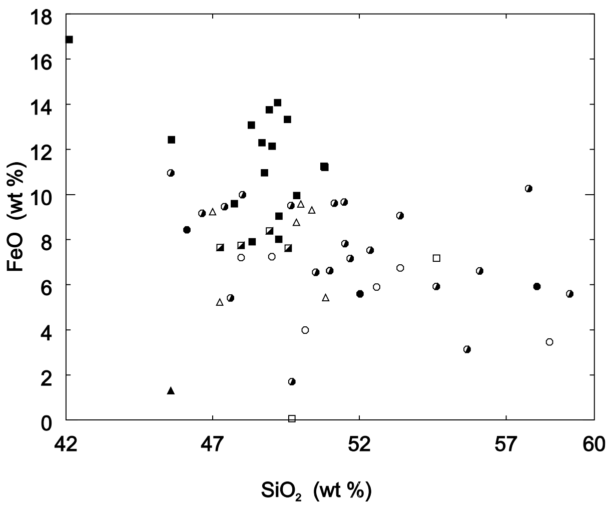
equivalent to N-MORB basalts. Separate position within the group of banded amphibolites is occupied by a metabasite from Vrabov N of Český Šternberk which is in many respect closest to some types of metabasites of GU and its rim in western Moravia (Matějovská 1987),

ii. coarse-grained gabbroamphibolites from the vicinity of Samopše and Ledečko which display some para-

Fig. 40 *(continued)*





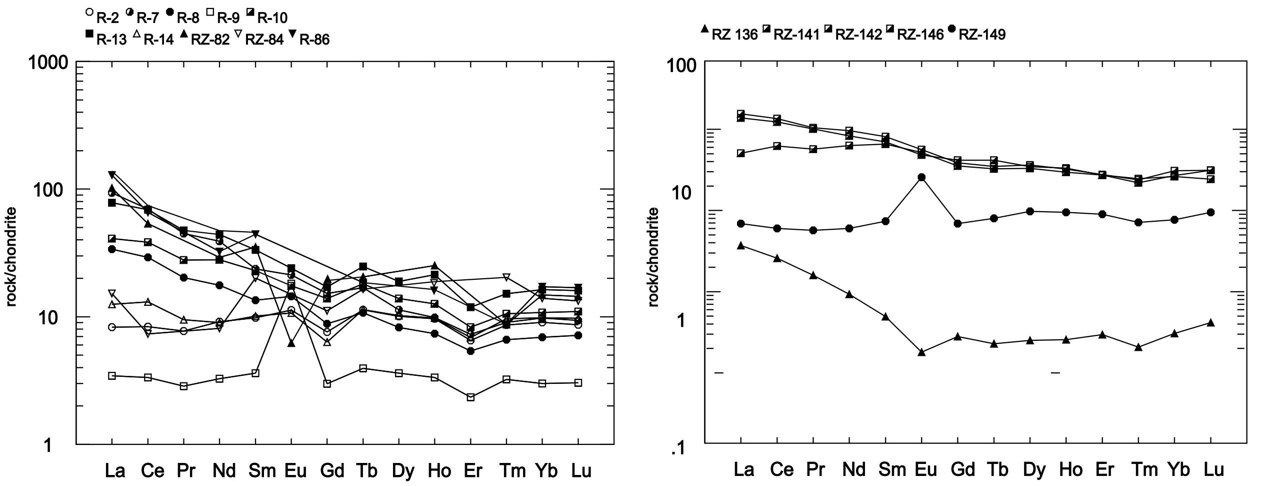


meters common with metabasites from around Stříbrná Skalice.

The majority of metabasites are characterized of low contents of REE (tab. 12) and flat curves of REE distribution (figs 41, 42). Amphibolites of GU SW of Čeřenice (17 ppm), banded amphibolites in Sázava River meander near Přívlaky in closest footwall of GU relic (22 ppm), and coarse gabbroamphibolite with relics of pyroxene near Poříčko (33 pm) exhibit the lowest concentrations of REE. Moldanubian metabasites from the vicinity of Český Šternberk display medium contents of REE(40–90 ppm), whereas metabasites for MSZ are characterized by the highest concentrations of REE (up to 127 ppm). REE contents correspond with Ce/Yb ratios (table 12) which reflect the degree of REE fractionation. Most common Ce/Y ratios in metabasites vary between 5 and 15 but may reach even 25 in geochemically most mature rocks. Rocks with the lowest concentration of REE – specifically rock GU, banded amphiboles in its footwall, and amphibolites with relics of pyroxene show the least fractionated pattern of of REE. Rocks of MVG and particularly metabasites of MSZ and metamonzogabbro from Vraník (fig. 42) exhibit steeper, more differentiated curves of REE.

Distribution of REE and trace elements in metabasites, normalized to contents in chondrites, mantle, MORB and OIB basalts indicates, in agreement with major element chemistry of rocks, that tholeiitic basalts differentiated to various degrees are most abundant in all units. Primitive tholeiitic basalts with flat curves can be distinguished within this group corresponding to recent MORB basalts (Basaltic volcanic study project 1981) – fig. 41, from basalts enriched with LREE and lithofile elements (K, Rb, Ba, Th, U) which correspond to recent basalts confined to anomalous segments of mid-oceanic ridges (P-MORB) – figs 41 and 42. Geochemically most mature and most differentiated basalts are close to recent intraplate tholeiites or, in the case of more alkaline types, to alkaline basalts of ocean islands. Th/La, Nb/La and Ta/La ratios partly overlap with continental tholeiites (Bertrand et al. 1982, Dostál et al. 1983). However, higher contents of Nb, Ta, Ti and other elements with high ionic potential, together with other data (e. g., La/Sm ratios), are inconsistent with an origin of basalts in the environment of island arc or continental margin. Distribution of REE and petrogenetically important trace elements together with transient to alkaline character of some basalts indicate rather their transition to intraplate magmas.

Majority of basalts, with the exception of most primitive tholeiites (meander near Přívlaky, Samopše – 400 and 800 ppm Cr, respectively) are strongly depleated of Ni and Cr (figs 41, 42, table 12), whereas contents of heavy REE (Y, Yb) are relatively high which indicates that these basalts were derived from mantle material with no garnet to which the above-mentioned elements would have been aconfined to. However, on average the Cr contents are higher than those in metabasites of the Český



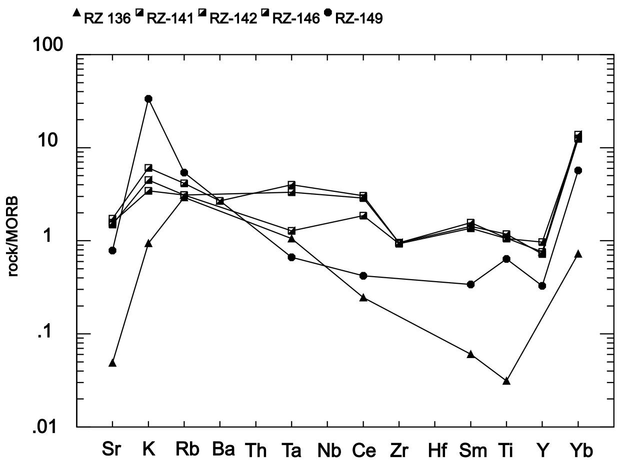


Fig. 41. Examples of REE and trace element distribution in metabasites of MSZ, GU and Moldanubicum normalized to chondrites (Sun 1980) and MORB (Pearce 1983). Also included is a serpentinite R-136. Fractionation of REE to various degree and also enrichment with lithofile elements to various degree are to be noted.

Krumlov Variegated Group. Consequently, we are mostly dealing with magmas modified by further petrogenetic processes (differentiation, crustal contamination, etc.), not with primary mantle magmas.

Higher contents of elements with low ionic potential (Rb, Ba, K, Sr) were recorded in coarse-grained gabbroamphibolites (valley running to Vraník, SW of Ledečko, Samopše). K/Rb ratios (table 12), due to generally low Rb, are high in primitive basalts depleted of LREE, and also due to higher contents of potassium even in coarse-grained metamonzogabbros from Vraník.

K/Rb ratios in a majority of metabasites in MSZ (table 12) are similar to those in recent P-MORB basalts. Mg-rich basalts from Ledečko and Samopše, and amphibolites of GU correspond to N-MORB basalts. Higher K/Rb ratios recorded in basalts rich in alkalies from the eastern part of MSZ seem to reflect rather the primary composition of magma than higher degree of magmatic differentiation. In this particular case, the K/Rb values should be higher.

Enrichment in Sr was recorded only in gabbroamphibolites, otherwise the majority of samples plotted in multivariant diagrams display a gentle depression against neighbouring elements. K/Rb ratios (table 12), the K/Ba ratios (23–60) are similar to those in P-MORB basalts of the recent mid-oceanic rigde basalts. K/Rb ratios in rocks of MSZ and adjacent Moldanubicum are lower relative to those in the Český Krumlov area (Patočka 1991) and also those recorded in Moldanubicum of western Moravia. K/Ba and Sr/Rb ratios (table 12) are mutually comparable.

One of the characteristic features of metabasites, particularly those in GU, are higher contents of Th and U. Anomalous concentrations of Th (31 ppm) were found specifically in coarse-grained gabbroamfibolite from Pořížčko. Uranium is a characteristic element of amphibolites and metadiorites from the area of Marjánka and from Stříbrná Skalice (fig. 43, table 12). The contents of these elements are higher relative to metabasites from the western Moravia and Český Krumlov region.

Contents of Nb, another petrogenetically important element, are higher relative to its concentration in MORB basalts. Contents of Nb usually correlate with Ta concentrations. All the above-mentioned facts indicate that the magma did not originate in subdution zones.

Zr occurs in relatively low concentrations ranging between 40 and 150 ppm. The highest contents were found in banded amphibolite from Vrabov near Český Šternberk. When compared with amphibolites of the Český Krumlov Variegated Group, the contents of Zr are on average lower but overlap with contents established in plagioclase amphibolites.

7.1.3. Interpretation of tectonomagmatic environment

A number of discrimination diagrams based on the contents of major elements, trace elements and REE were used for interpretation of tectonomagmatic environment. The mobility of mostly lithofile elements during meta-

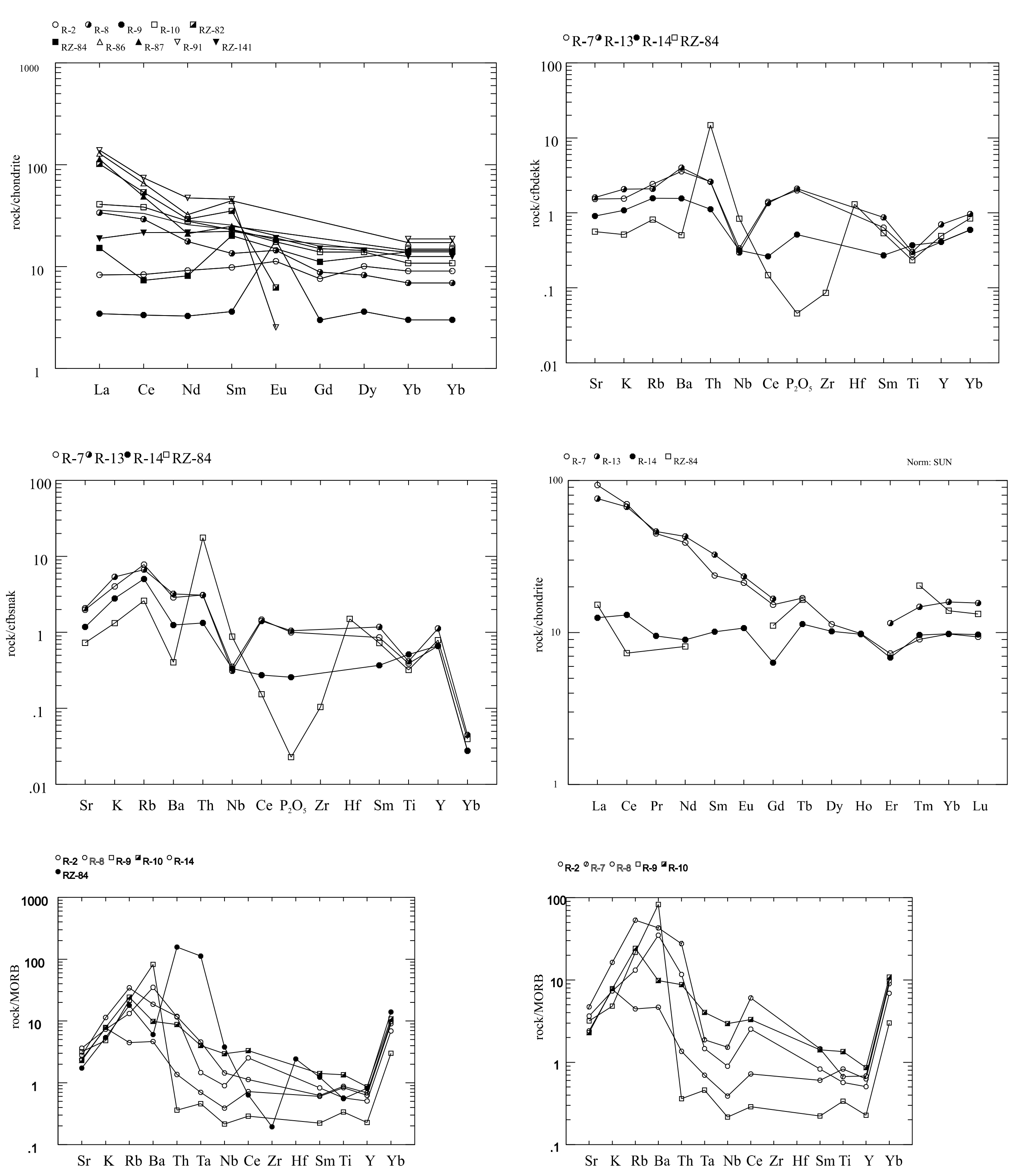
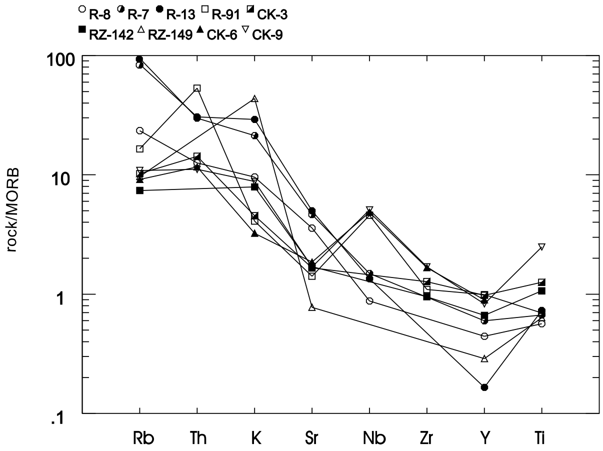
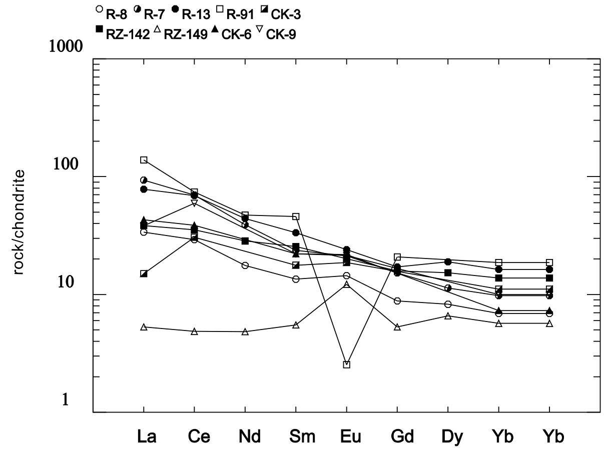


Fig. 42. Distribution of REE in amphibolites, metamonozodiorites and gabbroamphibolites of MSZ, GU and Moldanubicum normalized according to Nakamura (1974), cfbdekk – normalized to contents in Deccan plateau basalts (top right), cfbsnak – normalized to contents in plateau basalts of Snake River Province (middle left). Bottom part: Distribution of trace elements in metabasites of MSZ, GU and Mold. Samples from all units are strongly enriched with continental component (for sample location see table 15).

morphic processes or reactions of submarine volcanics with ocean water during which depletion of Na occurs (Seyfrid, Bishoff 1981) are to be considered when interpreting metabasites as polyphase metamorphic rocks. A low temperature alteration along fractures in metabasites is to be assumed when interpreting rocks of MSZ. Another problem includes ability of some of the discrimination digrams to define the tectonomagmatic setting precisely only based on their geochemical features. For example, geochemical variability of intraplate basalts which reflects various processes acting during the origin of metabasites can be so high that it is difficult to distinguish them from basalts from constructive plate boundaries (Wang, Glower 1992)





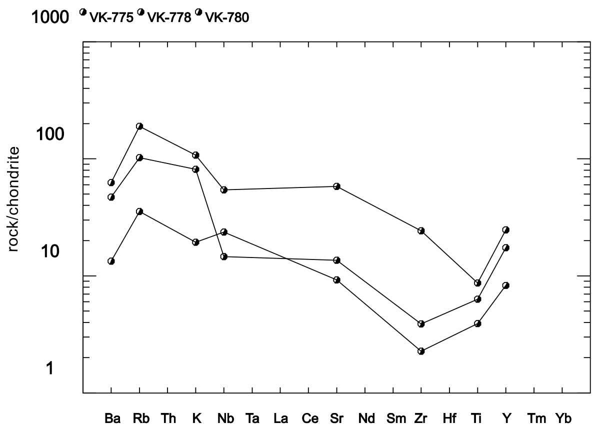


Fig. 43. Correlation between metabasites from MSZ, GU, Moldanubicum, metabasites of Český Krumlov Variegated Group (CK – Patočka1991) and Bohemicum. Normalized to contents in chondrites (Nakamura 1974, Sun 1990) and MORB basalts.

A number of earlier studies from various metamorphic domains alreday showed that, regardless of certain mobility of some elements, the general geochemical features of a single rock, characterized particularly by REE and some immobile elements remain preserved, and in spite of subsequent processes and overprinting may still mirror its petrogenesis (Patočka 1991 and other authors). This is supported by fair correlation of immobile elements (between Zr and Ce/Yb ratio, Mg value, etc.) which documents processes related to magmatic differentiation.

Geological position, shape of bodies and discrimination diagrams based upon Ni vs Zr/TiO_2 ratio (Winchester, Max 1982), including diagram by Kohler and Raatz (1958) and REE patterns and selected trace elements show that the majority of basalts represent metamorphosed magmatic rocks. Effusive equivalents and tuffs appear to be most abundant. Metamorphosed intrusives with relics of gabbroid structures are minor. Only samples of banded amphibolites with garnet alternating with thin layers of garnetiferous biotite gneisses near Vrabov contain higher sedimentary admixture.

Multivariation diagrams turned out to be most suitable to determine the petrogenetic and tectonomagmatic environment during which individual types of metabasite originated. The digrams based on ratios of less mobile elements simultaneously reveal a number of petrogenetic features of a given rock and also eliminate some errors which arise when using two or three major elements or combination of major and trace elements to study detailed petrogenetic relationships. However, despite of the usefulness of these diagrams, no unambiguous conclusions can be drawn. Various parameters, general geotectonic situation, lithofacies association of accompanying sediments and other features are to be considered in interpretation.

Digrams given in fig. 43 demostrate variations in chemistry of metabasites which belong to individual genetic groups of MSZ, Gföhl Unit, Moldanubicum and the Central Bohemian Pluton mantle. Samples from the Sázava River meander near Samopše and amphibolites from an amphibolite boudin in migmatites of the GU (R-149, Čeřenice) the most primitive distribution of REE, similar to that in recent tholeiites of mid-oceanic ridges (fig. 41). A coarser-grained gabbroamphibolite from the eastern section of a long outcrop in the meander between the Budín recreation area and Samopše, and a gabbroamphibolite near Poříčko (R-84) show similar characteristics (fig. 42). High Al, alkalinity index and other features characteristic of these rocks shift them to the field close to calc-alkaline rocks. On the other hand, characteristics based on major elements is sharply contrast with primitive tholeiitic distribution of REE. The characteristic positive Eu anomaly in these samples may indicate that higher contents of alkalies could have been caused by alterations. Sample R-14 in particular indicates that no fractionation of plagioclase occurred in parent magma.

Amphibolites from the central part of the Čáslav sigmoidal fold exhibit remarkably concurrent trends – fig. 41). They also coincide with some samples from the western part of MSZ (R-10, R-8). They are enriched with LREE which is characteristic of P-MORB basalts (cf. Novák, Vrbová 1996). The most differentiated curves show metabasites from the rim of GU near Český Šternberk which, on the other hand, are difficult to be classed either to GU (R-84, R-86, fig. 41) or MVG.

Among coarse-grained gabbroamphibolites, the metamonzogabbro from Vraník (R-7) is distinct from amphibolite metamonzodiorite (R-13) which occurs as a small body in augen gneisses E of Sázava nad Sázavou. The latter sample was included into this group to allow correlation of chemistry with the deformed granitoids. These rocks, can be classed in calc-alkaline suit. Consequently, they are thought to have been derived from different magmatic source.

Further discrimination diagrams (figs 41–43) specifically based on contents and ratios of REE and trace elements were used to find out in what environment the tholeiites originated (normal mid-oceanic ridges, ridges with high thermal flow – P-type ridges, tholeiites of island arcs or continental margins, rifts, ocean islands or continental tholeiites). From many characteristic features mentioned earlier, the absence of negative anomalies of Nb and Ta, indicative for the environment of convergent boundaries (Saunders et al. 1991), it can be concluded that these rocks show no affinity with island arc volcanics (cf. Montag, Höck 1994). Only metagabbros exhibit a calc-alkaline trend. Acid metavolcanics were not found to occur. Metabasites reveal, except for some samples from GU, low content of elements with high ionic potential (P, Zr, Hf, Y) which is a characteristic feature of island arc volcanics. However, the depletion is not so large, and moreover, this feature has been also observed in intraplate tholeiites (Thompson et al. 1983). In contrast an enrichment in HREE is not common in rocks of island arc affinity.

Since typical signs of rift magmatism are missing (i. e. bimodality, greater abundance of alkaline rocks, higher enrichment in REE) it is unlikely that amphibolites originated in such an environment. Therefore, attention was paid to discriminate between other possible types of environment in which tholeiitic magmas may be generated.

Analyses of banded metabasites were normalized to contents of elements in ocean island tholeiites from various provinces of plateau basalts (Snake River, Parana, Deccan). Banded amphibolites of MSZ, Gföhl Unit and Moldanubicum are enriched in lithofile elements (Rb, Ba, Th, partly K) relative to ocean island tholeiites. They are relatively poor in Sr and mostly in elements with high ionic potential (Ti, Zr, P, Nb). The comparison with continental tholeiites from the west coast of the USA (Snake River) and the Deccan plateau indicates that geochemically more mature and more differentiated rocks from MSZ, GU and Moldanubicum are similar to the Snake River tholeiites (fig. 42). Contents of Rb, Th, Ba and K are even slightly higher in our metabasites than those in Snake River tholeiites. Positive anomalies of Ta and Nb in some samples coincide even with alkaline rocks of ocean islands. However, the majority of samples show gentle depressions in the spider diagram which are characteristic features of continental tholeiites (Thompson et al. 1983).

Because of a limited number of studied samples and uncomplete analyses, it is difficult to decide in which environment these basalts originated. Due to the close relationship of these rocks with primitive and enriched tholeiites it seems to be more realistic that the basalts represent ocean tholeiites which originated in ocen ridges with anomalous thermal flow (P-MORB basalts). The extremely differentiated, more akaline basalts, due to their chemistry and other parameters, are already closer to ocean island tholeiites or recent plateau basalts (Karoo and Paráná provinces). Since the most prominent feature of most basalts, particularly those of MSZ and Moldanubicum in a close neighbourhood of GU, is their enrichment with crustal component (K, Rb, Ba, Th, U), it is most likely that they originated in a small spreading ocean basin rimmed with mature rocks of continental crust. This concept is also supported by composition of sediments which were derived from a mature continental crust, and also the occurrence of rocks of continental provenance in the the Gföhl Unit.

7.1.4. Correlation of metabasites of the Micaschist Zone, Gföhl Unit and Moldanubicum with analogous occurrences in other areas of Moldanubicum

Amphibolites of MSZ, GU and Moldanubicum were compared with amphibolites of the Český Krumlov Variegated Group, west Moravian metabasites confined to Gföhl Unit and adjacent Moldanubicum (Matějovská 1987) and metabasites from the vicinity of Stříbrná Skalice (Kachlík 1992).

As follows from the results of cluster analysis and from correlation of REE distribution in multivariation diagrams (fig. 43), the garnet-free or slightly garnetiferous amfibolites from the Český Krumlov Variegated Group and amphibolites from MSZ and Moldanubicum show good mutual correlation. Only a sample of tuffitic metabasite from Vrabov near Český Šternberk appears to be closer to west Moravian metabasites. High content of U is a prominent feature of metabasites from Stříbrná Skalice. These features, together with greater differences in the content major elements (higher acidity, higher contents of Ca and Al) suggest that metabasites from the Stříbrná Skalice represent a separate group, which belong, as indicated by their chemistry, obviously to CBP.

7.1.5. Summary of the main results

Geochemical investigation of metabasites confirmes affinity of banded amphibolites of MSZ and the Šternberk-Čáslav Variegated Group with amphibolites of some variegated groups in Moldanubicum (Český Krumlov and Strakonice regions). The investigation also demostrated that the separation of coarser-grained gabbroamphibolites in the area between Sázava nad Sázavou and Český Šternberk, which differ in mineral assmeblages, chemistry of important minerals and also in geochemistry of protolith, was probably correct.

In spite of many common features, some differences also exist, which in the case of west Moravian amphibolites (derived either directly from granulite bodies or from their close neighbourhood), indicate different character of GU protolith and/or influence of other petrogenetic processes. This supports or even proves the idea that the Gföhl Unit represents relatively a heterogeneous melange of rocks of oceanic and continental provenance accreted during Variscan convergent processes (cf. Stayer, Finger 1994, Montag, Höck 1994). According to Steyer and Finger, the Raab-Meisling unit consists of typical MORB basalts. Montag and Höck interpret the so-called Rehberg and Bushandelwald amphibolites which lie at the base and close above the base of GU in the Austrian part of Moldanubicum, as basalts which originated in a back-arc basin. They, however, admit that some types of basalt have an intraplate character.

Differences in the composition of sediments, e. g., carbonates (Houzar, Novák 1994) and metavolcanites of the variegated groups suggest variable environment during sedimentation in individual areas of its occurences. It also may reflect stratigraphic heterogeneity of this group in the Moldanubian Zone. However, it is to be noted that, e. g., including garnetiferous amphibolites from the southern rim of the Blanský les granulite massif (Patočka 1991) into Český Krumlov Variegated Group is highly problematic. Both units became close to each other during metamorphic processes, and there is not enough criteria allowing to class individual bodies with either unit (cf. Montag, Höck 1994). West Moravian amphibolites pose similar problems (Matějovská 1987). Their chemistry indicates that garnetiferous amphibolites are markedly different from garnet-free amphibolites enclosed in paragneisses and also from amphibolites of MSZ in the area of Český Šternberk.

7.2. Geochemistry of paragneisses

Geochemical investigation of paragneisses of MSZ, GU and Moldanubicum supplemented geochemical studies of metavolcanics. Its objective was to define the character of material deposited in single units, compare its composition and confirm whether geotectonic interpretations of metabasites correlate with the geochemistry of sediments.The metasediments of the Šternberk-Čáslav Group of Moldanubicum were correlated with metasediments of other localities of MVG rocks (Strakonice, Votice and Nepomuk regions) and with Late Proterozoic metasediments of the Bohemicum (SE flank of the Barrandian Unit and Islet Zone) in order to discuss possible lithological similarities or equivalence between MVG and both neighbouring regional units (Vejnar 1965, Suk 1973, Chaloupský 1978). Accessible samples from other occurrences of GU were also studied and correlated.

Paragneisses of the studied area were defined already on the basis of petrographic and field observations and classed among several categories differing from each other by the content of feldspars, micas and the degree of migmatitization.

Biotite sillimanite paragneisses with garnet, locally with bodies of "dense gneisses" rich in feldspars are most abundant in the Šternberk-Čáslav Variegated Group, whereas two-mica paragneisses prevail in MSZ. Markedly different are "micaschists or gneisses" rich in Al with large porphyroblasts of garnet. Gneises rich in feldspar are most abundant in the Čáslav sigmoidal fold. Bodies of amphibole-biotite gneiss were occasionally found in both units. Strongly migmatized, mostly two-mica or biotite migmatized paragneisses, augen gneisses and hybrid gneisses of GU differ distinctly from paragneisses of MVG and also from MSZ rocks.

7.2.1. Major elements

Occurrence and distribution of major elements is controlled primarilly by the mobility of mostly lithophile elements during metamorphic processes, and/or hydrothermal alterations which indicate the character of sedimentary processes (type of weathering, distance and character of transport, sedimentary conditions in the basin) and the source area. Figure 44 show that ratios of less mobile elements (Al, Ti, Mg) correlate quite well with SiO_2 whose content is derived from the share of detrital quartz in sediments and/or the amount of clay fraction. Relatively soluble, and consequently more mobile elements (Na, K, Ca) show less pronounced correlation or their contents are independent on the content of SiO_2, Fe_2O_3 and MnO contents which may reflect fast changing conditions during sedimentation, and/or changes in fugacity of oxygene during metamorphic processes exhibit similar large scatter.

The protolith of paragneisses (fig. 45) corresponds, according to classification based on SiO_2/Al_2O_3 vs alkalies ratio (Wimmernauer 1984), to pelitic greywackes and greywackes. It concern specifically Proterozoic rocks of the NE flank of the Barrandian and Islet Zone. Paragneisses of MSZ and Moldanubicum represent geochemically more mature metasediments (pelitic graywackes, metapelites, metaarkoses).

Contents and distribution of major elements are summarized in fig. 44 and table 13. Normalization according to Condie (1993), which considers areal distribution of single lithotypes in geological maps and also uneven erosion of the present earth's crust, was used when correlating content of major and trace elements with the composition of the upper crust.

Comparison of the content of major elements in rocks of MSZ, GU and Moldanubicum revealed that sediments relative to average composition of the upper continental crust in the interval 0.8–0.2 Ga years were enriched in K_2O and P_2O_5 in particular, relatively strongly depleted

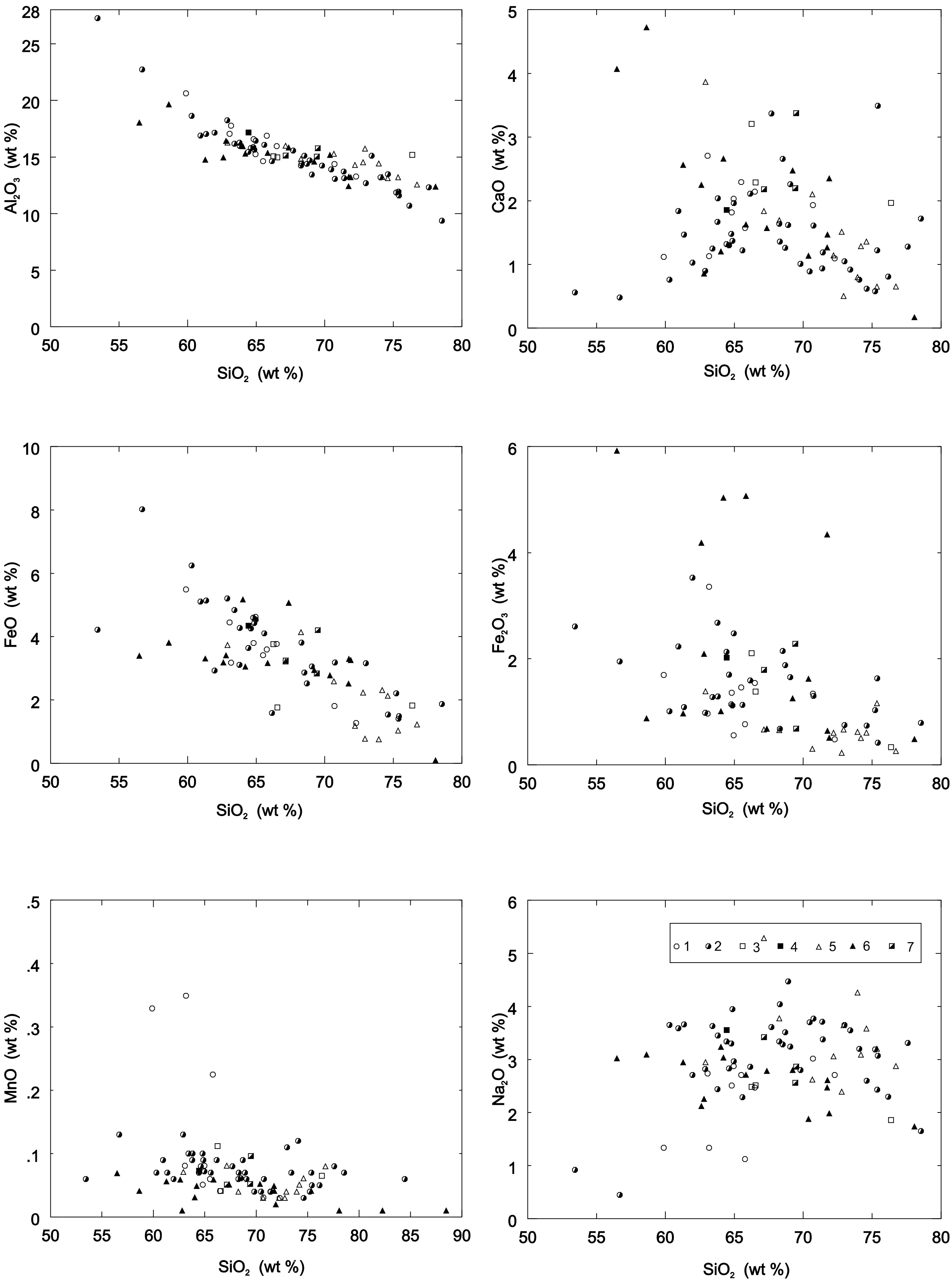
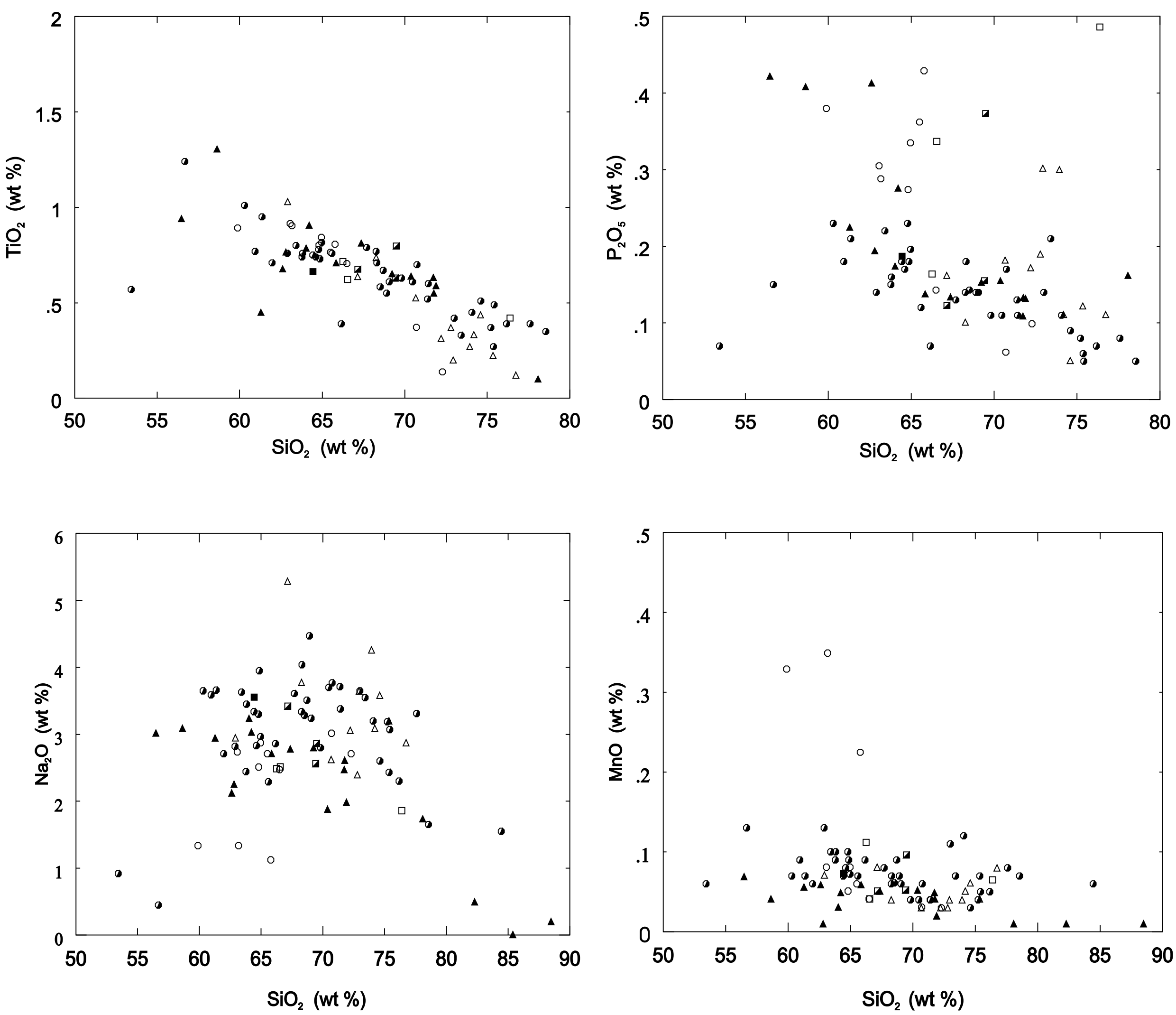


Fig. 44. Distribution of major elements in paragneisses of MSZ, GU and Moldanubicum in comparison with gneisses from other sectors of Moldanubicum (Variegated Group and Gföhl Unit), SE flank of Barrandian and Islet Zone. 1. biotite graywacke gneisses of MSZ; 2. Late Proterozoic graywackes of the SE limb of the Barrandian and Islet Zone; 3. pearl gneisses of GU; 4. biotite hornfelses of the Chocerady Islet; 5. pearl gneisses of the Moravian occurrences of GU; 6. sillimanite-biotite gneisses from variety of occurrences of variagated groups of Moldanubicum (except the Šternberk-Čáslav Variegated Group); 7. sillimanite-biotite gneisses of the Šternberk-Čáslav Variegated Group (same symbols are used in all figures except for spider diagrams).

Fig. 44. *(continued)*



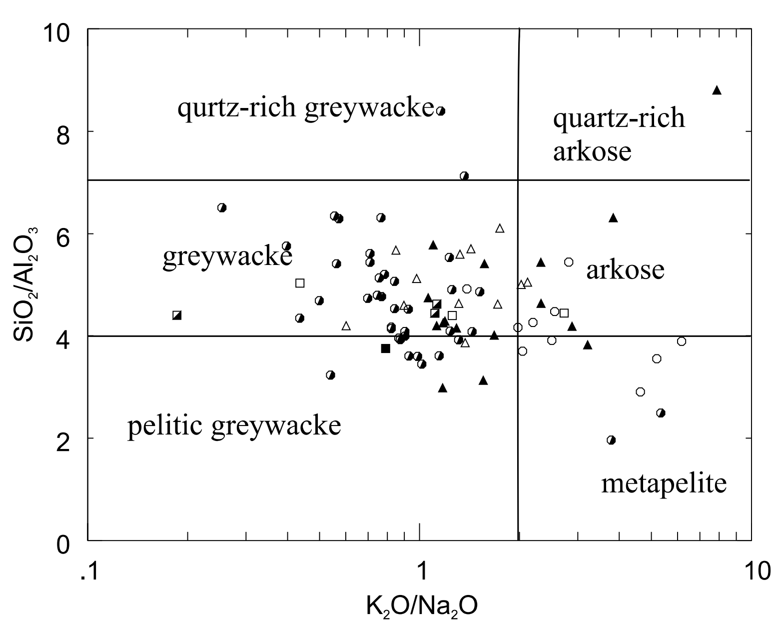


Fig. 45. Chemical classification of metapelites and metapsammites after Wimmernauer (1984) – (for symbols see fig. 44).

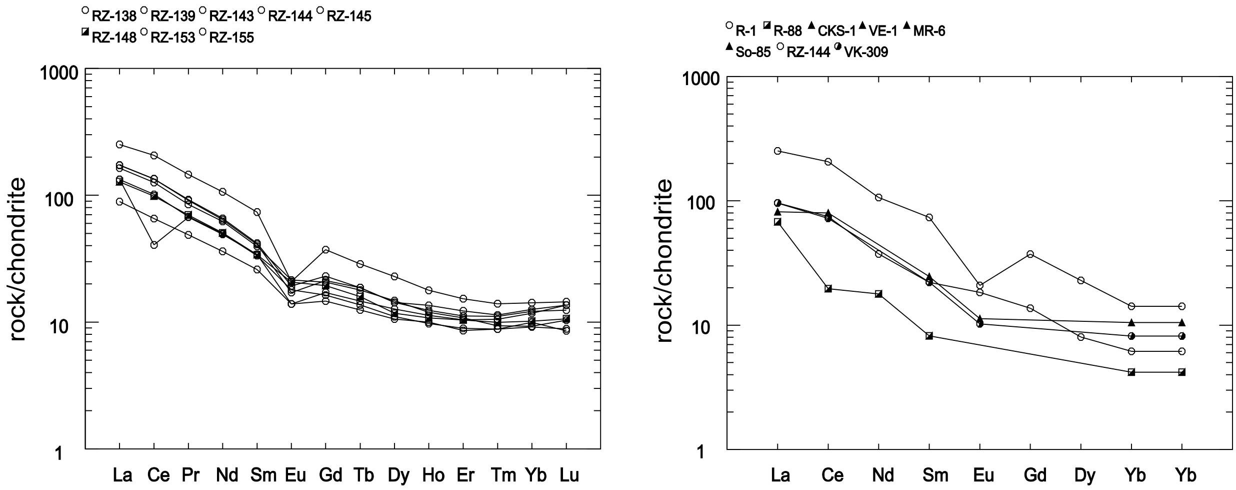
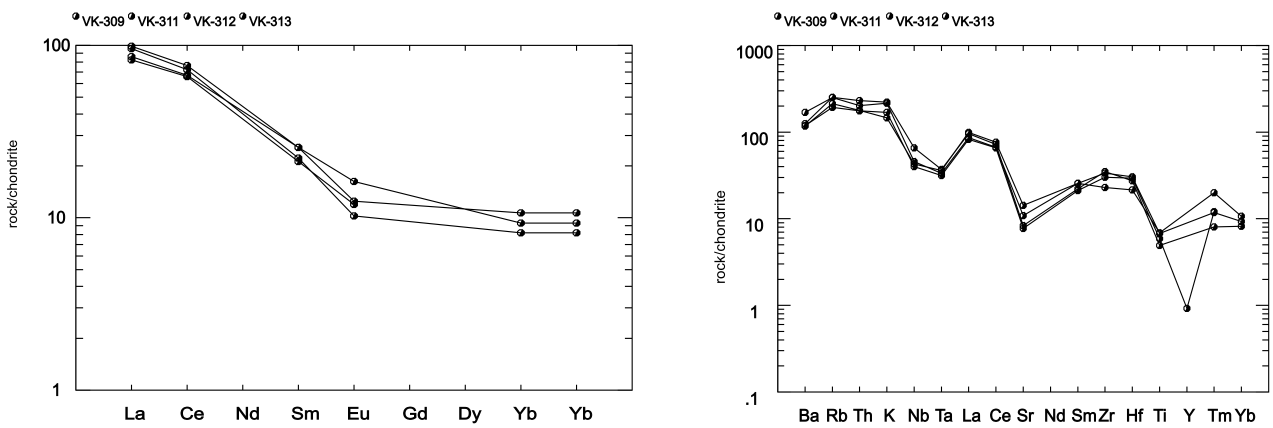


Fig. 46. Content of REE in paragneisses of MSZ GU and Moldanubicum normalized to their contents in chondrites (Sun 1990). Samples from other areas of Moldanubicum and neighbouring units are added for comparison.



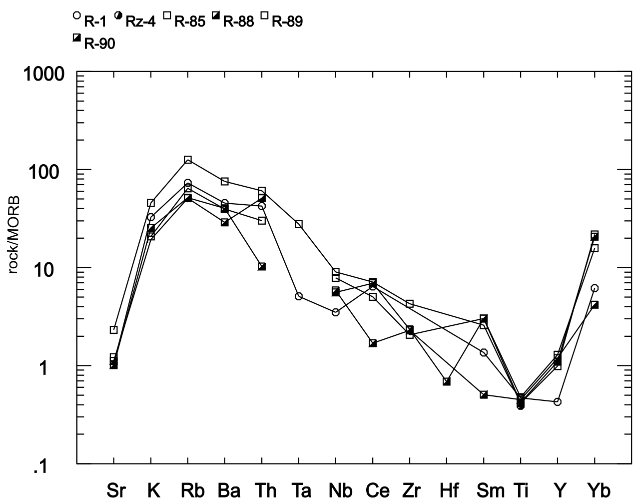


Fig. 47. Distribution of trace elements and REE in Late Proterozoic biotite hornfelses of the Islet Zone normalized to contents in chondrites according to Nakamura (1974) – upper sector, and to contents in MORB basalts after Pearce (1983).

in CaO and slightly depleted in Na_2O. The majority of samples, except for augen gneisses rich in alkalies, were found also slightly depleted in TiO_2. Other elements show a greater scatter. Only this simple comparison shows that sediments of these units represent, as far as their composition is concerned, rather Phanerozoic metasediments which are characteristic of an increase in elements confined to chemically more mature crust (Condie 1993), which is also supported by distribution and content of trace elements and REE. Only a negligible difference in composition was found between sediments of MSZ and MVG. Greater variations were observed in samples with incompatible proportion of detrital admixture. In spite of the generally concurrent trend in chemistry, some samples from GU differ in the content of major elements (higher contents of potassium and phosphorus, slightly lower contents of CaO and Na_2O). Na_2O/K_2O and Al_2O_3/Na_2O ratios in samples from the Islet Zone and Barrandian are different showing characteristic signs of sediments coming from geochemically less mature rocks. Cluster analysis showed that the tightest correlation exists between paragneisses and augen gneisses of MSZ and Moldanubicum. The second group includes gneisses rich in feldspar from MSZ and Moldanubicum and some augen gneisses from south Bohemian Moldanubicum. The third separate group is composed of migmatites of GU from the area of Sázava nad Sázavou and from west Moravia.

As follows from the comparison of these parameters (see figs 44, 46, table 13), the sediments of MSZ and Moldanubicum are obviously of completely different provenance than sediments from the SE flank of the Barrandian and from Islet Zone. K_2O always prevails over Na_2O in sediments of MSZ and Moldanubicum, whereas in Proterozoic sediments of central Bohemia the ratio is reverse. Sediments of GU show higher Na_2O/K_2O ratio, thus differring from the sediments of MSZ and Moldanubicum. Similar differences exist also in K_2O/Fe_2O_3 or Al_2O_3/Na_2O ratios which at the same time are a good indicator of the maturity of sediments (Kukal 1985). Proterozoic greywackes are thought to have had higher proportion of coarse psammitic fraction or lower proportion of clayey weathered material (SiO_2/Al_2O_3 ratios are on average lower than in rocks of MSZ, GU and Moldanubicum – cf. Jakeš et al. 1979, Cháb, Pelc 1973). Sediments are mineralogically less mature, derived from geochemically more primitive crust than mineralogically mature sediments of MSZ and Moldanubicum, whose protolith was built of mostly mature potassium rich clays alternating with psammitic metasediments rich in potassium feldspar. Basic geochemical parameters, based on the contents of major elements, unambiguously exclude lithological correlation between metasediments Moldanubian and MSZ and Late Proterozoic metasediments of the SE flank of the Barrandian Proterozoic and Islet Zone. On the other hand, these parameters are much closer to Early Paleozoic rocks of the Barrandian, whose characteristics were summarized in Kukal (1985) and Čadková (1982).

7.2.2. Trace elements and REE

Paragneisses of MSZ, GU and Moldanubicum exhibit very similar distribution of REE and trace elements as mafic metavolcanites (fig. 46, see also figs 42, 43), except for enrichment in Cr and Ni, which are likely to have been absorbed by clay minerals. In contrast to the upper continental crust, the paragneisses are notably enriched (Condie 1993) with lithophile elements (Rb, Ba, K, Th, U), to a lesser extent with elements showing high ionic potential (some samples are even depleted of these elements). A great majority of samples show elevated concentrations of LREE and also HREE relative to the average composition of the upper continetal crust. This is reflected in relatively flat distribution curves of lanthanides (fig. 46). The contents of transient metals (Cr, Co, Ni, except for some samples) lie slightly above their average content in the upper continental crust. An Eu anomaly appears to be characteristic of paragneisses, with the exception of augen gneisses enriched in alkalies, which suggest a considerable degree of differentiation of source material through fractionation of plagioclase. Another common feature of paragneisses of all units is considerable deficiency in CaO which correlates with low contents of Sr and Eu.

The degree of geochemical maturity of sediments is also documented by high contents of Rb (100–177 ppm) and Ba (700–1200 ppm) which were found in all units, but Rb contents are markedly lower in rocks of the Islet Zone and the Barrandian (70–100 ppm).

Zr contents vary considerably (fig. 48). Slightly higher concentrations were found particularly in paragneisses of MSZ which may reflect higher proportion of coarse detrital material (quartzitic paragneisses high in SiO_2). Varying contents of zircon reflect the share of coarser-grained detrital fraction which is usually enriched with zircon. High contents of zircon are characteristic of quartzitic paragneisses in particular.

Distribution of REE and trace elements is shown in figs 46, 47. Curves of REE in other units show similar trends but rocks of the Islet Zone and the Barrandian exhibit less pronounced negative Eu anomaly together with more substantial depletion in Nb and Ta and a elevated contents of elements with higher ionic potential. These features suggest that less mature rocks of an island arc played more important role in the origin of these Late Proterozoic sediments.

A notable coincidence in distribution of REE and trace elements between volcanitcs and metasediments in the studied units is likely to document their mutual close relationship. Judging from the character of sediments, some differentiated alkaline, basic, intermediate and acid rocks, which is reflected in their considerable enrichment with K, Rb, Th, La, Ce, Cr, Ni and HREE, occurred in source area. Rocks enriched in these elements are mostly a constituent of ocean arc volcanites or mature ensialic island arcs or continental margins with thick continental crust where calc-alkaline rocks are gradually replaced by potassium-rich rocks during a gravitational orogenic colaps.

Zr/Th, Zr/Nb and Nb/Y ratios together with contents of the above-mentioned elements are closest to values reported by Bhatia (1985) for ensialic island arcs or active continental margins.

Geochemistry of sediments indicates an intense synsedimentary volcanism either directly in the basin or its vicinity and/or fast erosion of geochemically more mature rocks rich in alkalies (magmatites, volcanites) from a magmatic front. This material is thought to have been mixed with more mature acid substance supplied from the continent (intercallations of quartzites in Moldanubian paragneisses).

7.2.3. Summary

Geochemical investigation of paragneisses has shown, together with petrographic and mineralogical studies, that the same protolith existed for the Šternberk-Čáslav Variegated Group of Moldanubicum and paragneisses of MSZ. Metasediments of GU exhibit slightly different features, based on geochemistry of trace elements and REE: Two types of gneiss can be distinguished: augen gneisses rich in alkalies (S of Ledečko) and migmatites rich in feldspar and hybride rocks. Greater variability was observed in rocks of GU, similar to that in metavolcanites, which may reflect its complex internal structure (tectonic melange of rocks of various provenance – ultramafic rocks, orthogneisses, migmatites). Comparison of other occurrences of MVG showed that the basic geochemical features, in spite of some differences, are the same.

The completely different character of protolith of metasediments confined to the SE flank of Barrandian and Islet Zone excludes any lithological equivalence between rocks of the SE margin of the central Bohemian region and MVG rocks. In spite of the fact that the composition of proterozoic metasediments of the Islet Zone was influenced by a supply of geochemically more mature material (Kachlík 1992), these rocks can be hardly correlated with Moldanubian paragneisses. Isotopic studies of detrial sedimentary/metasedimentary rocks of the two units show significant differences (Janoušek et al. 1995). Abundant pebbles of granitoids in Late Proterozoic conglomerates in the Islet Zone and SE flank of the Teplá-Barrandian Zone (Fiala 1948, Koutek 1925) indicate that the SE margin of this basin represented part of a basin close to which more mature continental crust occurred even though the majority of the material was likely to have been derived from island arcs.

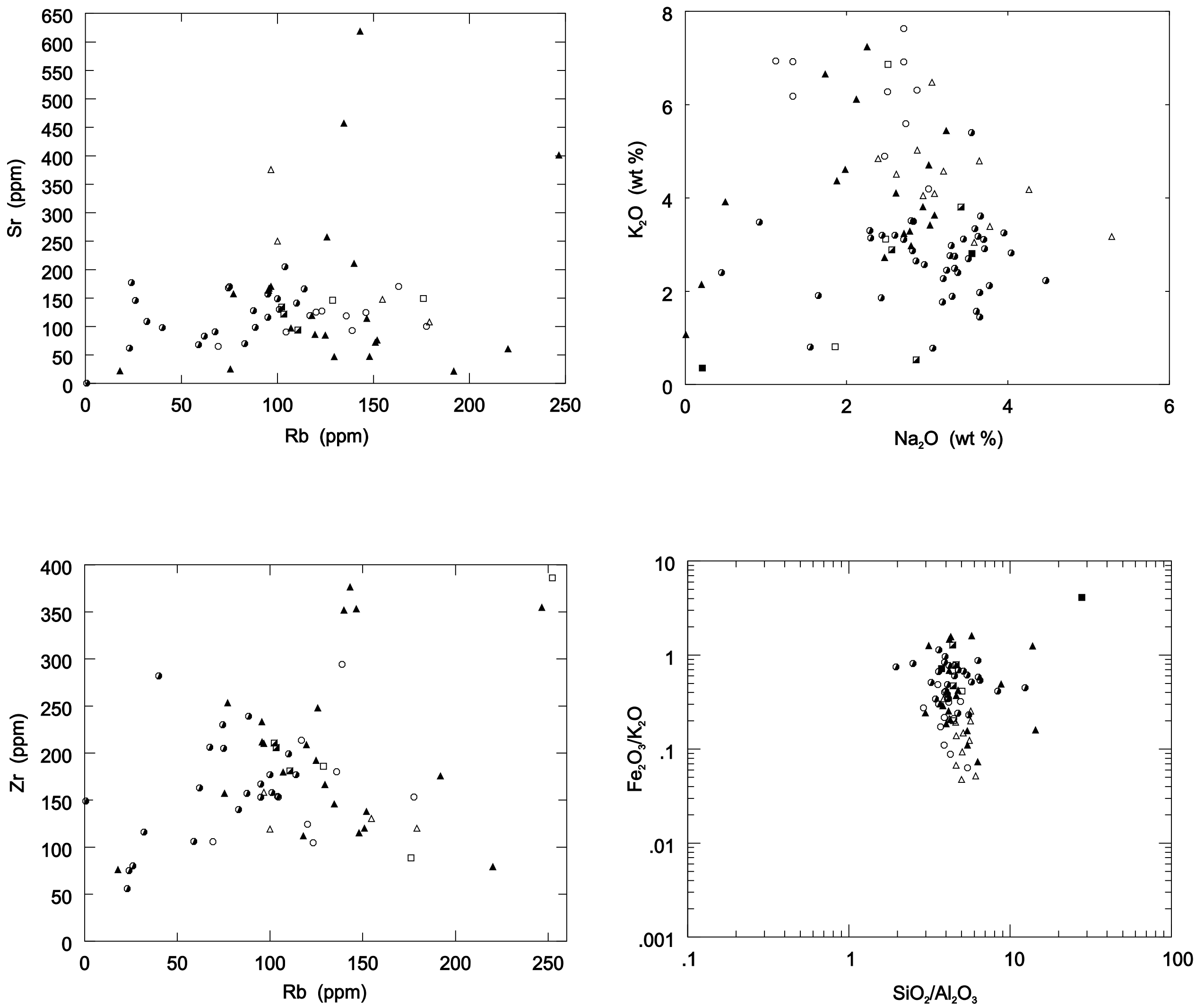


Fig. 48. Geochemical maturity of metasediments of MSZ, GU and Moldanubicum in comparison with other Moldanubian units, Islet Zone and SE flank of the Barrandian (for symbols see fig. 44). It is notable that gneisses of MSZ, Gföhl Unit and Moldanubicum can be distinguished from Islet Zone and SE flank of Barrandian by K_2O/Na_2 and Rb/Sr ratios and to a certain extent even by Fe_2O_3/K_2O ratio which is considered as indicator of mature sediments. For sample location see table 15.

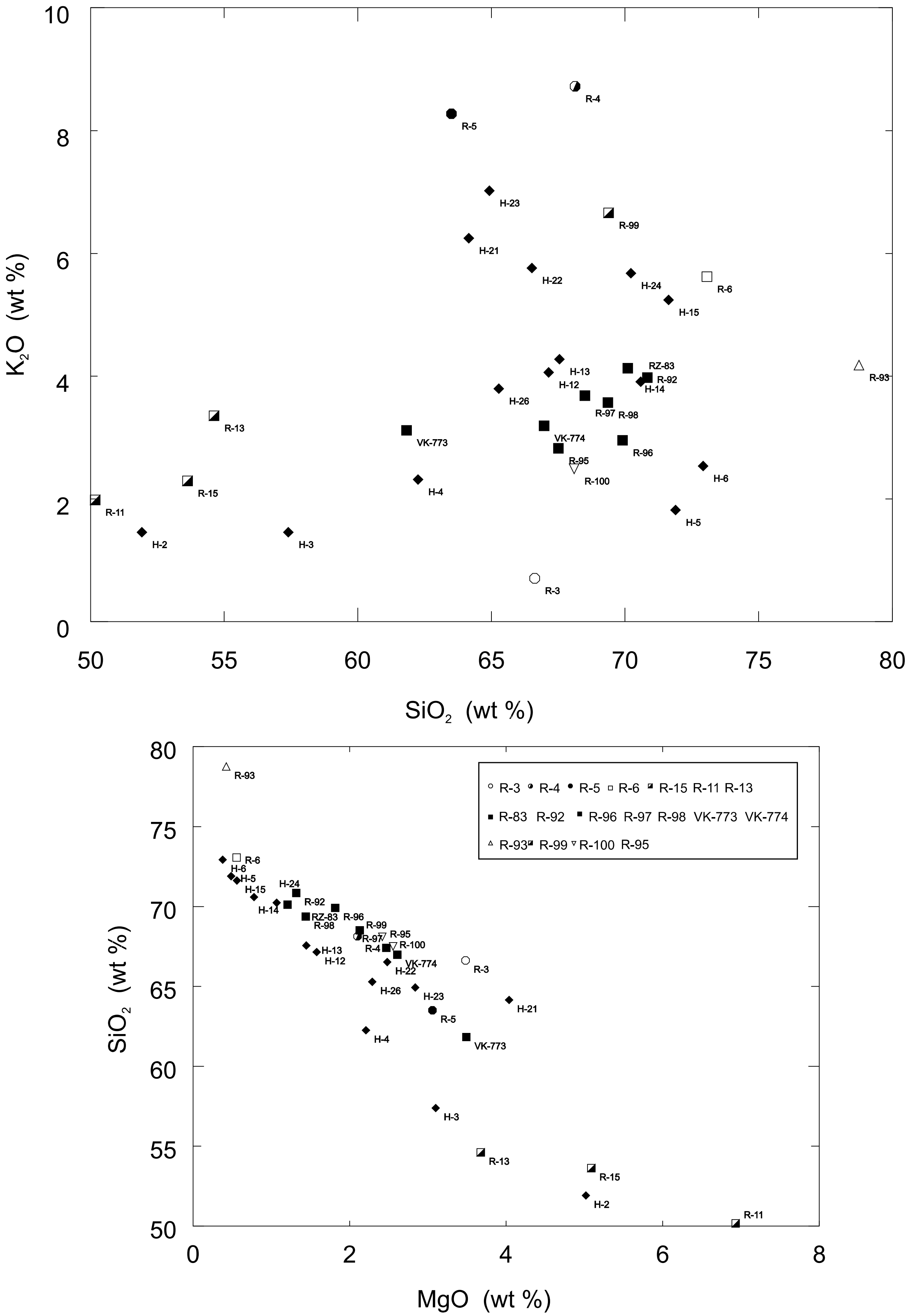


Fig. 49. SiO_2 vs K_20 and MgO vs SiO_2 diagrams used for distiguishing metagranitoids of unknown provenance which occur particularly in GU and Moldanubicum in the area between Sázava and Sázavou and Český Šternberk. Characteristic rocks of UK, HG and UK suite of CBP are included for comparison (Holub et al. 1995). These rocks are marked by H symbol. Same symbol as in fig. 49 are used for individual types of metagranitoids in the following figures (except for spider diagrams).

7.3. Geochemistry of deformed granitoids of unknown provenance confined to the Šternberk-Čáslav Variegated Group of Moldanubicum, Micaschist Zone and Gföhl Unit

Deformed and metamorphosed granitoids with preserved relics of primary magmatic structures and textures occur only near the contact of the above-mentioned units with deformed rocks of the NE margin of CBP in the area between Sázava nad Sázavou and Český Šternberk. Their petrographic characteristics was given in section 4.

Three genetically diferent groups of metagranitoids can be distinguished, based on combination of several geochemical parameters (specifically: contents of SiO_2, K_2O, MgO, Na_2O/K_2O ratios – table 14, fig. 49):

i. strongly deformed melanocratic ultra-potassic biotite-rich metagranitoids and their more leucocratic differentiates which are characterized by high Mg values, considerable enrichment in lithofile elements (K, Ba, Rb, Th, U), Cr and Ni, and conspicuous depletion in CaO and Sr. These rocks show parameters similar to those of primary alkaline magmas of mantle origin, and are similar to rocks occurring in CBP and Moldanubicum (Holub 1978, Holub et al. 1995),

ii. metagranitoids rich in potassium GU in the Křešický Creek valley form small bodies in migmatites and augen gneisses. Because of tight geochemical relationship with adjacent migmatites and augen gneisses, these rocks rather represent melts originated through anatexis. They are characteristic, in contrast to augen gneisses, the occurrence of a few cm large hypidiomorphic to indiomorphic feldspar phenocrysts. The rocks differ from the previous group by lower contents of K_2O and generally lower enrichment in hydromagmatophile (Ba, Rb) elements, and by substantially lower Mg values (0.3–0.4). These rocks correspond geochemically to potassium-rich calc-alkaline rocks to shoshonites (fig. 49)

iii. biotite to biotite-amphibole monzodiorites and monzogabbros which again form rather small bodies (except for the metagabbro body S of Ledečko) in migmatites and augen gneisses of GU. These rocks are characterized by markedly lower concentartions of SiO_2 and K_2O, and high contents of Ca and Sr, relative to the previous group. Distribution of REE, pronounced negative anomaly of Nb and Ta, typical of magmas derived through melting of mantle wedge and lower continental crust in the roof of a subducted ocean plate, together with previous features, allows to class these rocks unambiguously among calc-alkaline granitoids.

Another type of a metagranitoids, which were not studied in detail, is represented by leucocratic pegmatites discordant to the main metamorphic foliation, forming up to a few metres thick E-W elongate bodies E of Český Šternberk, and strongly mylonitized aplitic granitoids in MSZ in the SW vicinity of Talmberk and N of Ledečko (R-6, R-93). These rocks are granitoids rich in potassium but depleted in Ca showing some affinity to the previous rock group.

7.3.1. Ultra-potassic metagranitoids

Ultra-potassic metagranitoids are characteried by high contents of K_2O (more than 8 wt % – fig. 49), high Mg values and relatively high contents of Mg. Another characteristic feature includes enrichment in Rb, U, Th, Cr and Ni and depletion in Ca and Sr. Metagranitoids high in potassium show strongly fractionated curves of REE, particularly when extreme contents of LREE are present. These rocks, judging by their petrogenetic parameters, are similar to ultra-potassic rocks of CBP (Holub 1978, Holub et al. 1955). Ultra-potassic metagranitoids include metaalumina- and biotite-rich varieties (S of the Ledečko railaway station) and also light leucocratic differentiates which still bear fundamental signs of this group of rocks, i. e., high Mg values (0.8) and high Ni. Their plots in the classification diagram by Debon and Le Fort (1983) lie outside the field of quartz syenite rich in feldspar. Augen gneisses and migmatites – the most abundant rocks in GU – correspond to the granodiorite-adamelite-granite series (in terminology used by the above-mentioned authors). These rocks differ from potassium-rich granites by higher contents of REE, less pronounced Eu anomalies and higher contents of Cs, Rb, Ba and Th.

7.3.2. Granitoids rich in potassium

Granitoids rich in potassium are confined to a migmatite complex of GU. Relict magmatic structures were observed only rarely in the area of Křešický Creek N of Drahňovice.

K-rich granitoids in classification by Debon and Le Fort (1983) correspond to granites to granodiorites (fig. 50). Distribution of major and trace elements and REE in multivariation diagrams shows similar trends as those of the previous group but the enrichment with K_2O, P_2O_5, La, Ce, Co and Ni is markedly less distinct. Potassium-rich metagranitoids are geochemically close particularly to heterogeneously deformed porphyroclastic types of augen gneises of GU (Pyskočely meander, long

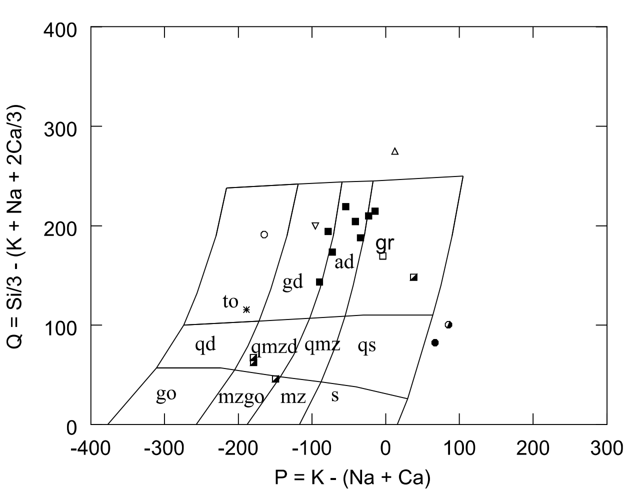


Fig. 50. Chemical classification of granitoid rocks after Debon and Le Fort (1983). For symbols see fig. 49.

outcrop of Sázava River valley near Malovidy. There are several reasons why these rocks were incorporated into GU. In contrast to the majority of potassium-rich granitoids of CBP, they are intensely folded (recumbent folds). Leucocratic parts parallel with prevailing foliation indicate that the rocks originated by anatexis of originally layered rock with varying composition. The associated bodies of monzodiorite, monzogabbro and ultramafic rocks support their affinity to GU.

7.3.3. Metamonzodiorites to metamonzogabbros

Biotite-amphibole monzodiorites to amphibole monzogabbros occur as several bodies confined to GU. A sample R-11 which, however, belongs to MSZ, exhibits the same chemistry.

In contrast to the previous groups, these rocks show lower contents of SiO_2 (50–55 vol. %) and K_2O, although potassium feldspar occurs in these rocks. On the other hand, these rocks exhibit higher concentrations of Al_2O_3, TiO_2, FeO, MgO and CaO. Contents of major elements correlate with enhanced concentrations of Rb, Th and Ba (fig. 51). Distribution of REE, a negative anomaly of Nb and Ta, in relation to their occurrence in chondrites, indicate their characteristic calc-alkaline trend. Consequently, this group of rocks represents a separate genetic category which is believed to be not comagmatic with previous groups. Apart from certain features similar with the tonalite suite of CBP (fig. 51), there exist differences in the content of K_2O, Rb and P_2O_5. Therefore, these rocks may be considered an integral part of GU. Similar types of rock occur in western Moravia (thin sections provided by A. Dudek).

7.3.4. Tectonomagmatic interpretation of intrusive rocks

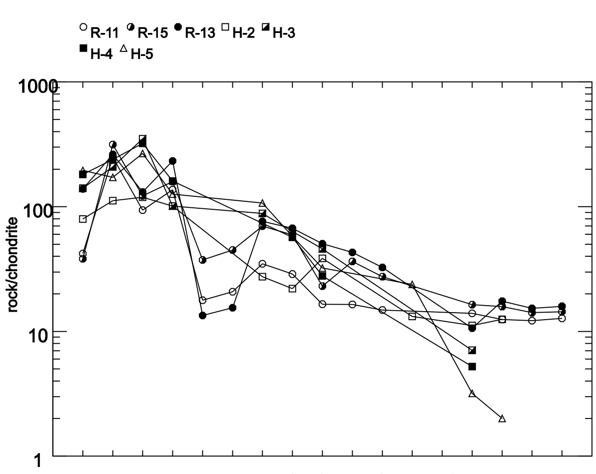
Intrusive rocks from the area between Sázava nad Sázavou and Český Šternberk mostly fall in the fields of granitoids which intruded in an environment of island arcs, syncollisional or intraplate granitoids. Apart from a relatively small number of analyzed samples, the observed features again point to complex petrogenetic processes which, in agreement with interpretation of metabasites and paragneisses, indicate that these rocks are likely to have originated in both the precollision and collision stages. All these rocks are enriched in the crustal component.

8. Conclusion

The new data on geological, structural, metamorphic and geochemical characteristic of rocks along the contact between the Bohemicum (Teplá-Barrandian Unit) and Moldanubicum suggest that:

a) Mineralogical and geochemical investigation of metabasites showed similar composition of the protolith of MSZ and that of the underlying MVG. Largely variable metabasites correspond to subalkaline tholeiitic basalts. The least abundant are N-MORB basalts which are concentrated in the Gföhl Unit and the adjacent part of MSZ. Geochemically more differentiated types of P-MORB basalt occur in the S and E part of MSZ. The most enriched basalts show strong affinity to continental tholeiites or alkaline basalts of ocean islands. Metabasites of the Gföhl Unit are different because of their mineralogy and chemical composition. In adition to primitive basalts corresponding to recent MORB basalts, in contrast a much more varied association of rocks occurs in GU.

b) Mineralogical and geochemical studies of metasediments of MSZ, GU and Moldanubicum showed a good coincidence between protoliths of MSZ and MVG. Metasediments of GU, similarly to metabasites, differ in lithology, metamorphic evolution and also in composition of the protolith. The protolith of MSZ and Moldanubian sediments, based on geochemical investigation, is thought to have been derived from relatively



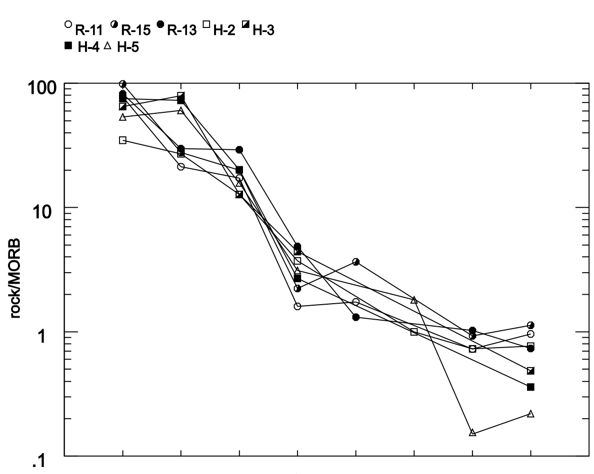


Fig. 51. Distribution of major and trace elements and REE in calc-alkaline granodiorites and monzonites of enigmatic provenance occurring, mostly in augen gneisses of the Gföhl Unit, smaller bodies also in MSZ paragneisses (Talmberk). Normalized to chondrites (Thompson et al. 1984) and MORB basalts.

mature crust of island arcs or active continental margins. As follows from the character of metabasites and metasediments, the basin in which sediments of both units were deposited can be interpreted as the margin of a spreading basin rimmed with island arcs and continental margins. These basins became closed during the Variscan collision of Moldanubicum with the Teplá-Barrandian and/or Saxothuringian Zone. The Šternberk-Čáslav Variegated Group can be roughly correlated with MVGs, although some local differences in composition of metabasites of the Český Krumlov Variegated Group exist.

Geochemistry of metasediments of MSZ and Moldanubicum and their mineralogical and geochemical maturity are in contrast with sediments of the Barrandian Late Proterozoic basin. Sediments of these units cannot be a lithological or to higher grade metamorphosed or stratigraphic equivalent of Proterozoic pelites of the Barrandian Proterozoic. Their lithological and geochemical character of both Moldanubian and MSZ paragneisses corresponds rather to Early Paleozoic age of the protolith of both units,

c) GU, owing to its composition, metamorphic evolution of sediments and metasediments, represents a complex heterogeneous unit which can be interpreted as a tectonic melange consisting of tectonic slices of various provenance,

d) Rocks of MSZ, GU and Moldanubicum underwent polymetamorphic evolution. Four tectonometamorphic and deformation phases can be distinguished in MSZ which is in agreement with observations of Oliveriová and Synek (1993). The oldest phase is specific for this unit. It was not recorded in Moldanubicum or GU, although if more samples with inclusions in garnet would be available, then the M1 associations may be possibly found even in MVG rocks which were not affected by M4 retrogression. Metamorphic and deformational evolution within the M2 and M3 phases, during which metamorphic processes culminated, was found in both neighbouring units. On the other hand, the metamorphic evolution in single partial units of GU turned out to be different (see Synek and Oliveriová 1993) which is documented by a variety of metamorphic assemblages in GU rocks near Drahňovice and the Vrchlice River valley near Kutná Hora.

Prograde development of metabasites in MSZ is belived to have been triggered by pushing the unit under the Kouřim and Gföhl Nappe thrusting from the east to the west or from the southeast to the northwest where decompression and gradual cooling took place. According to Beard (Beard et al. 1991) and Brueckner (Bruckner et al. 1991), the initial phases of this process occurred during an interval between 370 and 340 Ma which is shown by the age of retrogression of eclogites and peridotites under conditions of the amphibolite facies. The deformation later migrated (due to rheological conditions) to the more easily deformable MSZ and the border of MVG. The latter is paraautochtonous in relation to structurally higher units. This process was later succeeded by a tectonic uplift of all units connected with retrogression which affected all units with the exception of passively moving segments of GU (Běstvina Formation – Synek, Oliveriová 1993). Since movements of structurally higher units were compensated by strike-slip faults (Synek, Oliveriová 1993), and the erosion of overlying rocks was very fast, no conspicuous signs of prograde development were observed in the underlying Moldanubicum. Final movements and thrusting of slices of the Gföhl Nappe over MVG and MSZ in the area near Sázava nad Sázavou occurred only under conditions of greenschist facies that is documented by conspicuous retrogression of rocks along the contact of both units,

e) Relics of sillimanite observed in the western part of MSZ suggest that the metamorphic peak occurred in both units in the field of sillimanite stability (i. e., Rataje Zone and Moldanubicum). Rocks of MSZ suffered more from retrograde processes which faded away under greenschist facies conditions,

f) Tectonic advance and completion of major features of the nappe structure along the contact between Moldanubicum and Kutná Hora Crystalline Complex occurred prior to forced intrusion of CBP. Rocks of the latter unit, due to forward sliding of individual slices in the dextral transpressive shear zone, moved into the tectonic roof of MSZ and GU (cf. Kettner 1930, Košler 1995). According to new radiometric data (Košler et al. 1993, 1995, Holub et al. 1996), the major structural features were completed 340–330 Ma ago.

g) A new unit has been defined in the area between the southern border of Permocarboniferous filling of the Český Brod depression and Šternov which, because of its lithology and metamorphic evolution corresponds to the Gföhl Unit.

In a simplified way, the scenario of the major geological events at the border between the central Bohemian, Moldanubian and Kutná Hora domains is as follows: Sediments of MVG and MSZ were deposited most likely during the Early Paleozoic at least partly on Precambrian basement (Dobra Gneiss, Světlík Gneiss – 1.3 and 2 bill. Ma, respectively – Wendt et al. 1993, Kröner et al. 1988) and partly on ocean type crust in a narrow spreading basin. Gradual closing of the basin (Gföhl ocean?) occurred in Early Devonian times in connection with the collision of a Gondwana margin with Laurussia. The closing culminated in the Late Devonian to Early Carboniferous during continental collision of the Moldanubian plate with the Teplá-Barrandian block. During active subduction, a prograde metamorphism of gneisses and metavolcanics of MSZ, Moldanubicum, GU and Kouřim Nappe took place. Subsequently, during continental collission the rocks of the Gföhl Unit became part of an upper plate and exhibited a retrograde P-T-t path. This process was succeeded by migration of the major shear interface, at the border between Kouřim Nappe and Moldanubicum. Moldanubicum became a paraautochtonous unit in relation to thrusting of the overlying units. Almost isothermal decompression and cooling was in progress in overlying units. Completion of major features of shear structure then took place. Partition of deformation at oblique collision into frontal collision and into strike-slip faulting along important shear zones caused that no considerable increase in pressure and temperature occurred in the underlying plate. During the earlier stage sinistral movements occurred in the Central Bohemian shear Zone along which the Teplá-Barrandian block was shifted to the SW. During the younger stage, penecontemporaneous with intrusion of the major portion of the Central Bohemian Pluton, a reverse dextral movement occurred during which rocks of CBP moved into hanginwall of GU and MSZ whose configuration was already close to the present state.

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Vztahy mezi moldanubikem, kutnohorským krystalinikem a bohemikem (Střední Čechy, Česká Republika): výsledek variské polyfázové příkrovové tektoniky

V širším okolí Sázavy nad Sázavou se stýkají tři významné jednotky Českého masivu, moldanubikum s. s., kutnohorské krystalinikum a bohemikum. Jejich vzájemné vtahy jsou dosud předmětem polemických diskusí. Hluboké zářezy řeky Sázavy a jejích přítoků poskytují řadu přirozených odkryvů pro detailní studium litologických, strukturních a metamorfních vztahů těchto jednotek. Zatímco geochemické studium protolitu metabazitů a metasedimentů výše uvedených jednotek umožnilo rekontruovat prekolizní vztahy jednotek a geotektonické prostředí jejich utváření, strukturní a metamorfní výzkum přispěl k upřesnění obrazu tektodeformačního vývoje během variské kolizní etapy.

Na základě výše uvedených faktů mohly být definovány a směrem od strukturního podloží do nadloží následující litotektonické jednotky: pestrá šternbersko-čáslavská skupina moldanubika, ratajská „svorová“ zóna, kouřimský příkrov a gföhská jednotka, které se vzájemně liší protolitem i metamorfním vývojem.

Zatímco protolity amfibolitů a metasedimentů šternbersko-čáslavské skupiny moldanubika a retrográdně přeměněných hornin svorové zóny ukazují shodné rysy, protolity hornin gföhlské jednotky a svrchního proterozoika v plášti středočeského plutonu se od nich výrazně odlišují. Gföhlská jednotka i proterozoikum bohemika představují samostatné jednotky, které vznikaly v různých geotektonických prostředích, odlišných od pánve v níž se ukládaly horniny svorové zóny a moldanubika.

Dnešní konfigurace jednotek a inverzní metamorfní vývoj v jednotlivých jednotkách je výsledkem polyfázové variské příkrovové tektoniky (370–330 Ma). Násunová tektonika začíná výstupem střednokorových hornin gföhlské jednotky s uzavřenými relikty plášťových peridotitů a vysokotlakých hornin ve směru od JV k SZ. Rychlá tektonická exhumace této jednotky byla umožněna extrémně duktilním chováním tělesa kouřimské ruly. V další etapě migruje hlavní deformační rozhraní do strukturního podloží na rozhraní pestré skupiny a kouřimských ortorul a dává vznik retrográdním horninám svorové zóny. Násilná intruze starších členů sukcese středočeského plutonu (350–330 Ma) postdatuje hlavní etapu pohybů na rozhraní moldanubika a kutnohorského krystalinika. Během ní se v transpresním režimu dostávají horniny středočeského plutonu a jeho pláště do tektonického nadloží příkrovů tvořených vysoce metamorfovanými horninami gföhlské jednotky a kutnohorského krystalinika, spočívajícími na paraautochtonním moldanubiku. Tektometamorfní vývoj oblasti je v podstatě ukončen intruzí moldanubického plutonu (328–305 Ma). Některé variské oslabené zóny byly reaktivovány také v epivariské etapě.