The evidence for Late Variscan nappe thrusting of the Mariánské Lázně Complex over the Saxothuringian terrane (West Bohemia)

Geologicko-stukturní doklady pro pozdně variské nasunutí mariánskolázeňského komplexu na saxothuringikum (Czech summary)

(4 text-figs., 4 plates)

VÁCLAV KACHLÍK

Přírodovědecká fakulta University Karlovy, Albertov 6, 128 43 Praha 2

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Recent investigations and geological mapping in the W surroundings of the Mariánské Lázně metaophiolite Complex (MLC) led to a redefinition of the boundary between the Teplá–Domažlice (ZTT) area and Saxothuringicum. The metabasites cropping out W of the Vlčí hřbet ridge serpentinite body till now considered to be a part of the MLC (Vejnar - Zoubek 1962, Zoubek et al. 1963), do not belong to this MP unit with relics of HP eclogites.
The metabasites are newly interpreted as being part of the Kladská unit. The term Kladská unit (Fiala - Vondrová 1963) is re-defined here.
The Kladská unit represents a suite of low- to high-grade metasediments (muscovite-chlorite schists, biotite - andalusite hornfelsic schists with garnet and biotite–andalusite + cordierite + K-feldspar hornfelses) with intercalations of cherts and weakly metamorphosed calc-alkaline to alkaline basalts, trachybasalt and trachyandesites with preserved relics of primary magmatic textures.
During the LP-HT late orogenic phase (aproximately 330-320 Ma - Kreuzer et al. 1989) MP rocks of the MLC, containing HP relics, were thrust over the paraautochthonous rocks of the Kladská unit on a minimal distance of 6 km. Serpentinite, and possibly some metadiorite bodies scattered to the west of the MLC represent outliers of the MLC nappe resting on the Saxothuringian paraautochthon. The thrust plane separating the MLC and the Kladská unit is thought to represent a major terrane boundary between the Saxothuringicum and MLC.

Introduction

The studied area lies in the western surroundings of the Mariánské Lázně metaophiolite Complex (MLC) defined by Kastl, Tonika (1984) in the SW part of the Slavkovský les Mts. (Kaiserwald) between Mariánské Lázně, Lázně Kynžvart, Lazy and Prameny to the NW of Mariánské Lázně. The MLC in the opinion of many authors (Röhlich - Šťovíčková 1968, Polanský 1978, Mísař et al. 1984), lies on the boundary between the Saxothuringian and Teplá–Barrandian regions. The boundary may be formed by the Litoměřice deep-seated fault (Röhlich - Šťovíčková 1968) which is manifested by a steep gravimetric gradient (Polanský 1978) and occurrences of serpentinites and eclogites.

The Teplá–Barrandian unit comprises a Cadomian basement with a Lower Palaeozoic cover, strongly reactivated during the Variscan orogeny. Based on several features, such as a supposed metamorphic transition from 4anchimetamorphosed Upper Proterozoic of the Barrandian area (Kettner 1917, Zoubek 1948, Cháb - Suk 1978), and a close relationship to the Upper Proterozoic volcanism (Fiala 1978), the MLC was previously considered to be a part of the Teplá–Barrandian region.

New investigations carried out in the SW part of the Bohemian Massif in connection with the KTB drilling program in Bavaria (Weber - Vollbrecht 1986) and a new radiometric dating (Bowes - Aftalion 1991) showed that Lower Palaeozoic elements may occur here. Structural position, metamorphic development (relics of medium to HP rocks) and radiometric data (not indicating a Late Variscan thermal event near to 330-320 Ma) led several autors (Behr et al. 1982, Franke 1984 a,b; Weber - Vollbrecht 1986, Matte et al. 1990) to the incorporation of this unit into the Teplá–Domažlice Zone, which may be part of a complex nappe pile on the Moldanubian–Saxothuringian boundary.

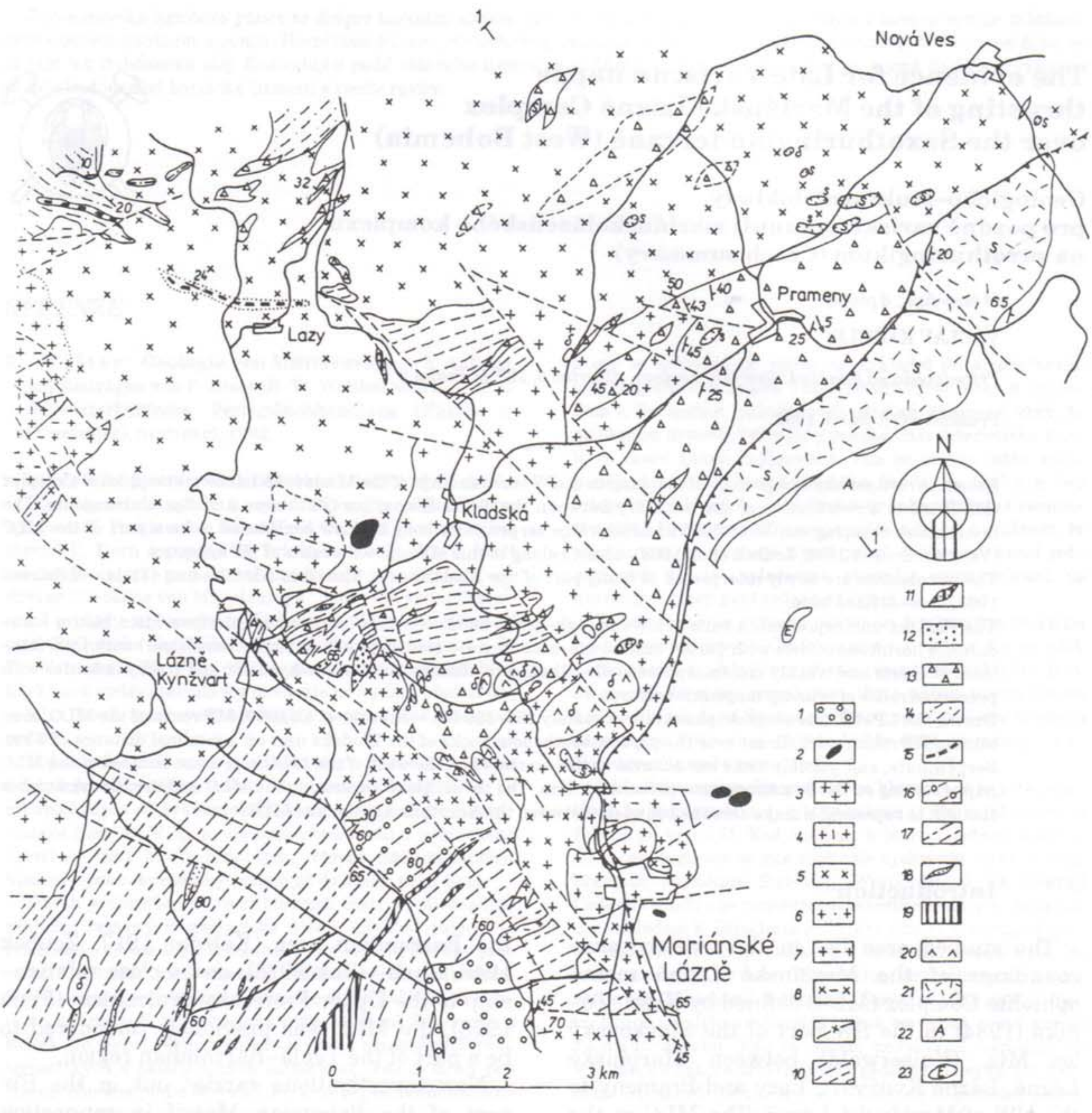

Fig 1. Geological map of the W surroundings of the ML Complex (Kachlík 1991) based on the new concept of the Kladská unit. Structural lines of some diorite bodies forming outliers of the ML Complex on Saxothuringian autochthon are not plotted because of their small size.

Tertiary: *1* – clay, gravel; *2* – basalt; Late Variscan intrusives of the Karlovy Vary pluton: *3* – autometamorphosed fine grained granite; *4* – tourmaline-bearing medium-grained granite; *5* – biotite granite; *6* – coarse-grained muscovite-biotite granite; *7* – coarse-grained porphyritic biotite granite; Variscan granitoids of the Bory pluton: *8* – amphibole-biotite granodiorite to quartz diorite; Kladská unit: *9* – banded andalusite hornfelses with quartzitic layer *10* – muscovite – biotite + – garnet + – andalusite schists; *11* – cherts; *12* – metagreywackes, metapsammites; *13* – metabasite (brecciated lavas, massive metabasalts); the Slavkovský les crystalline unit: *14* – biotite-sillimanite gneiss with magnetite bearing quartzite intercalation and black shales; *15* – muscovite – biotite quartzitic hornfelsic gneiss; the Dyleň unit: *16* – two-mica quartzitic banded schists; the Tirschenreuth-Mähring Zone: *17* – two-mica gneisses eastwards partly retrogressed; *18* – quartzite; *19* – black mostly silicified black shales; *20* – diorite in the ZTM; the Mariánské Lázně Complex: *21* – serpentinite; *22* – amphibolite; *23* – eclogite

The Saxothuringian Zone in the W part of the Bohemian Massif is composed of two structural units: a lower autochhtonous to paraautochthonous unit and an upper allochthonous unit (Franke 1989). The epizonal to mesozonal (HT–LP) autochthonous unit consists of Lower Palaeozoic members (Ordovician to Lower Carboniferous) in the Thuringian facies (Gandl et al. 1986, Franke 1989). A Pre-Ordovician sequence (? Upper Proterozoic to Cambrian) may be represented by the Arzberg Group (Von Gaertner 1942, 1951). This unit crops out near the contact with Moldanubicum s.s. in Bavaria (the Zone Tirschenreuth-Mähring is probably a transition zone between these two units - Kreuzer et al. 1989, Vejnar 1991b). Equivalents of the Pre-Ordovician Arzberg Group may occur in the Czech part below the Tertiary cover in the Cheb basin (Vejnar 1991a) and also in the Slavkovský les Mts. (Zoubek et al. 1963, Neužilová - Vejnar 1963, Kreuzer et al. 1989).

The upper allochthonous unit is preserved in the form of several tectonic outliers on the former unit. The biggest tectonic outlier is the Münchberg gneiss complex. It differs from the underlying unit in the development of the Lower Palaeozoic which is developed generally in the deep-water Bavarian facies and in its metamorphic history. The Münchberg klippe consists of several tectonic slices with inverted metamorphic zonation. The HP to MP metamorphism is older than 365 Ma (Gebauer - Grünefelder 1979, Kreuzer et al. 1989, Franke 1989, Quadt 1990, Kreuzer et al. 1992). Unlike the lower paraautochthonous unit, the highest MP units with relics of HP rocks were not affected by the Late Variscan tectonothermal event.

Tectonostratigraphic units of the studied area

The following tectonostratigraphic units were distinguished in the studied area (Fig. 1):

The highest structural position is occupied by the MLC which may represent a terrane separating Saxothuringian from Moldanubian terranes (Matte et al. 1990). It consist of serpentinites which are overlain by amphibolites and metagabbros with small lenses of eclogites. Small intercalations of gneisses are also present. Metabasites of this unit represent relics of Lower Palaeozoic oceanic crust (492±2 Ma, Bowes - Aftalion 1991) involved in the Early Variscan collisional HP-LT event. During the Early Devonian (386-362 Ma - Kreuzer et al. 1992), the original eclogite facies rocks underwent retrogression in the amphibolite facies conditions.

The Saxothuringian zone is represented by the Kladská unit, Slavkovský les and Dyleň crystalline units.

The main object of the investigation, the so called "Kladská unit" underlies the MLC. Two different lithologies were distinguished by Fiala - Vondrová (1963):

1. metapelite and metasiltstone with intercalations of a light or dark coloured quartzite, belonging probably to the Upper Ordovician
2. "the graphitic formation" - dark greyish or black laminated metapelite and metaaleurite with layers of metalydite which are comparable with cherts in the Silurian of the Bavarian facies (Vondrová 1963). Fiala (1958) reported also small lenses of metabasalt interlayered in fine grained muscovite-biotite micaschist near an abandoned uranium mine at Smrkovec, SW of Prameny.

On the SW slope of the Slavkovský les Mts between Lázně Kynžvart and Mariánské Lázně, micaschist to biotite-sillimanite paragneiss with intercalations of black shales and dark- or light-coloured quartzite crop out. These lithologies can be correlated with the Dyleň unit and with the Tirschenreuth-Mähring Zone defined by German geologists (Kreuzer et al. 1989). The relationship of these units with the Kladská unit is difficult to ascertain, because the primary contact of these units is obliterated by an intrusion of Variscan granitoids on which only a few relics of the mantle are preserved.

Redefinition of the Kladská Group

Recent investigations showed that the original definition of the Kladská unit given by Fiala - Vondrová (1963) and the conception used in geological maps on scale of 1:200 000, sheet Karlovy Vary and Mariánské Lázně (Vejnar - Zoubek 1962, Zoubek 1963), should be reinterpreted for several reasons:

1. The Kladská unit does not consist only of metasediments; metabasites considered originally as a part of the MLC exposed W of the line Nová Ves - M. Lázně (Fig. 1), are an integral part of this unit.
2. The Kladská unit does not form small syncline preserved as denudation remnant on Variscan granitoids; It underlies rocks of the MLC, which are thrust on the top of this unit.
3. Metasediments extended in the W surrounding of Lazy village have closer lithological and metamorphic relations to the rocks of the Slavkovský les crystalline unit; they do not belong to the Kladská unit.

According to proposed concept, the Kladská unit consists of (Fig. 1):

1. low-grade to medium-grade metasediments with intercalations of metabasalts (their maximal thickness reaches several tens of meters) which extend from the northern margin of Lázně Kynžvart to the SW surroundings of Kladská,
2. several hundred meters wide stripes of

metasediments with one layer of metabasalts; andalusite-bearing two-mica schists, cut by two transversal faults of a NW-SE strike between Lazy and Prameny,
3. low-grade metasediments preserved as large (several hundred meters) relics of mantle on granitoids of the Karlovy Vary pluton on the foothill of the Krušný hill W of Lázně Kynžvart,
4. metabasites extending from Nová Ves to the SE surroundings of the village Prameny which are in tectonic contact with the MLC, and
5. metabasites preserved as large denudation relics on granitoids between Prameny and Lazy, in the northern surroundings of Lazy, and between Lázně Kynžvart and Mariánské Lázně.

Metasediments of the Kladská unit

Metasediments of the Kladská unit represent a group of low-to high-grade, originally banded clastic rocks, which were strongly affected by Variscan LP-HT metamorphism. It resulted in the origin of hornfelse textures of the majority of rocks. They can be divided in two distinct groups (Fig. 2):
1. dark grey to black laminated to banded metapelites to metaaleurites with milimeters up to centimeters thick light quartzitic layers. They scarcely contain intercalations of greywackes and cherts, and
2. banded light yellow to brown metapsammites, metagreywackes passing rarely into fine-grained metaconglomerates.

The rocks of the first group crop out in the western part of the studied area, underlying the second sequence of metasediments. The relationship of these two members (? stratigraphic or tectonic superposition) is not clear due to the lack of outcrops in the critical area. With regard to older interpretations of Fiala - Vondrová 1963) and Zoubek (1960), as for the stratigraphic position of these constituents of the Kladská unit (Ordovician age for the light-coloured rocks of the second group, Silurian for the dark-coloured rocks of the first group), it is obvious that the stratigraphic sequence appears to be inverted.

Rocks of the first group are transformed into mostly black, quarzitic banded schists and schistose hornfelses. The black colour is caused by fine-grained sulphidic pigment and by dispersed organic matter. In rocks of the lower metamorphic grade, sedimentary structures such as lamination, graded bedding and slump balls are often preserved. In coarser grained rocks, clastic grains can be recognized. (Pl. I/1). Quartz and plagioclase grains are mostly not recrystallized. In greywackes, psammitic lithoclasts were found to be formed by cherts and quartzites.

Basic metavolcanites and small lenses of acid tuffs are present in the upper part of this formation.

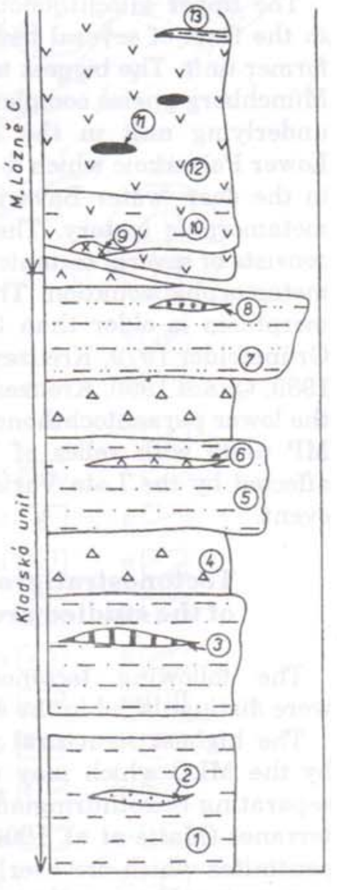

Fig 2. Tectonostratigraphic scheme of the Kladská unit (1-8) and lower part of the overthust MLC (9-13) cropping out in the studied area (orig):
1 - dark-grey banded metapelite with light-coloured quartzitic bands, passing to metaaleurite; 2 - metagreywacke; 3 - cherts; 4 - metabasite (lava flow breccias); 5 - grey to brownish metaaleurite; 6 - acid tuff; 7 - metaaleurite to metapsamite; 8 - conglomeratic sandstone; 9 - metagabro, metadiorite; 10 - serpentinite; 11 - eclogite; 12 - amphibolite; 13 - biotite-sillimanite paragneiss

The overlying sequence extends into the area E of Lázně Kynžvart. A lighter colour, higher content of psammitic fraction and parallel arrangement of the platy minerals, resulting in a gneissose structure of these rocks, are typical.

Quartz and plagioclase grains are mostly coarsely recrystallized, some grains have preserved features of inner deformation. In some places, e.g., at the Holina hill E of Lázně Kynžvart, these banded rocks pass into fine-grained conglomeratic sandstones. Partly preserved quartz clasts are as much as 4 mm large in diameter.

Metabasites of the Kladská unit

Metabasites of the Kladská unit represent a distinct group of metabasalts differing by chemistry, metamorphic grade and structural features from metabasites of the MLC. In comparison with amphibolites of the MLC, metabasites of the Kladská unit have higher contents of alkalies and mostly CaO and Al_2O_3. Most of the rocks fall into the field of calc–alkaline to alkaline rocks ranging from basalts to trachyandesites in La Maître's (1984) classification diagram (detailed petrochemistry will be discused in another prepared paper). A futher difference is very good preservation of primary magmatic textures in the less metamorphosed types of metabasalts. Some relics of ophitic, amygdaloidal and porhyritic textures were found (Pl. I/2, 3; Pl. II/1).

Metabasalts of the Kladská unit can be divided into two petrographically and petrostructurally distinct groups:

a) **massive metabasalts**, slightly metamorphosed and deformed with preserved relics of the primary magmatic fabric,

b) **banded metabasalts**, coarser-grained, strongly sheared, mostly completely recrystallized with well developed planar or planolinear fabrics.

Within the former group, following types of metabasalts can be distinquished:

1. slightly recrystallized lava flow breccias (Pl. II/3) with relics of primary magmatic fabric,
2. massive, fine-grained, heterogenously deformed and schistose metabasalts, sometimes with amphibole porphyroblasts,
3. massive, moderately recrystallized metabasites with up to 2 cm long deformed recrystallized ellipsoidal phenocrysts of plagioclase enclosed in fine-grained amphibole-plagioclase matrix.

Metamorphosed lava flow breccias (metamorphosed fragmentites)

This type of metabasalts crops out in two stripes several tens of metres thick and aproximately 2 km long; stripes alternating with massive fine-grained metabasalts in the metasediments of the Kladská unit between Lázně Kynžvart and SW surroundings of the village Kladská (Fig. 1). Slightly coarser-grained and strongly recrystallized types of these metabasalts extend along the road Mariánské Lázně – Lázně Kynžvart. They were also scarcely found inside the tectonically bounded block of metasediments which occurs NW of the village Kladská. Towards the E, this rock type passes with increasing metamorphic imprint into massive metabasalts described below.

The rock is composed of mainly angular rock fragments (1 to 30 cm in size) – Pl. II/2, the shape of which depends on the intensity of deformation and on section observed.

Individual fragments are surrounded by fine-grained matrix and do not touch each other, even if present in large numbers. They are composed of brown-green hornblende, irregular to tabullar grains of plagioclase, spots of the epidote group minerals and disseminated grains of opaque minerals. Most of the fragments have the same or very similar composition as the matrix. Some are formed by more basic rocks in which amphibole prevails over plagioclase. Usually they are more strongly recrystallized than the surrounding matrix. The fragments are often densely fractured (Pl. III/1), fractures being filled by garnet, plagioclase, pale blue-green amphibole, klinozoisite, calcite and scarsely by chlorite. The lithoclasts formed by basalts with amygdaloidal structure are quite frequent while small lithoclasts of metasediments are very rare.

Massive, fine-grained heterogenously deformed and foliated metabasalts sometimes with amphibole porphyroblasts

Metabasalts of this type are the most frequent rock type in the studied area. They alternate with the first type and are futher preserved as denudation remnants on granitoids in the area between Lazy and Prameny. Closer to the top of the Kladská unit and to the tectonic contact with the overlying MLC, the slightly schistose metabasalts pass into strongly foliated and banded metabasalts.

These scarcely to moderately foliated dark green to black massive types are characterized by stronger recrystallization of hornblende, plagioclase (0.25 – 0.3 mm rarely up to 3 mm in size) and by better developed deformational fabric. Primary magmatic textures were destroyed by these processes. Fractures filled by plagioclase, garnet, amphibole, and clinozoisite are rather scarce. The mineral assemblage of these rocks is very similar to that of the first group.

The brown-green hornblende has recrystallized into blue-green hornblende. Several stages of the hornblende recrystallization could be observed. The youngest grains are hypidiomorphic, mostly tabular, without any features of preferred orientation. They reach the size of up to 4 mm, forming fan-like aggregates. Their growth is related to the thermal effect of the Karlovy Vary pluton. Original plagioclase phenocrysts are frequently recrystallized into fine-grained mozaic. Larger clinozoisite grains originated by decomposition of plagioclase. Titanite, zircon and biotite are accessory.

Massive, moderately recrystallized metabasites with ellipsoidal phenocrysts of plagioclase

Occurences of this type of metabasalts are restricted only to several localities in the NE surroundings of Lázně Kynžvart. The main difference from the above described types is the presence of biotite and chlorite in the matrix, partly due to a higher content of alkalies and retrogressive reaction during deformation in steeply inclined narrow shear zones. Another different feature is porphyritic and more coarse-grained texture of the matrix. The original phenocrysts of plagioclase (oligoclase) are mostly recrystallized into a fine grained equigranular mosaic (0.0X mm in diameter) of new grains. The deformed ellipsoidal aggregates of recrystallized plagioclases up to 3 cm in size are good marker indicating ductile deformation of the rocks in relatively thin (up to 0.X dm) shear zones. The contacts of these rock types with those described above are not sharp due to recrystallization and deformation of the rock. Both cases of space-time relationship were observed: small (up to 20 cm in diameter) xenoliths of fine-grained massive metabasalts enclosed in the porphyritic type and vice versa. Consequently, these rocks, probably porphyritic dykes, (cf. Fiala 1958) originated in a relatively short time in one tectonomagmatic period.

The porphyroblastic metabasalts show an assemblage of blue-green hornblende to pale actinolitic hornblende, plagioclase (oligoclase), biotite, chlorite, epidote and sulphidic ores. Titanite is mostly present as accesory. Metamorphic veinlets are filled, apart from the main constituents (plagioclase and hornblende), by garnet, chlorite, minerals of the epidote group and calcite. In contrast to fine-grained metabasites, the originally brown green hornblende is more intensively but inhomogenously recrystallized here. It becomes unstable in the matrix and is replaced by chlorite, biotite, epidote and opaque minerals.

Plagioclase forming up to 2 cm large ellipsoidal porphyritic grains (phenocrysts) and fine to medium (0.X mm) grains in the matrix is completely recrystallized into a fine grained (0.0X mm in size) mosaic of new grains showing often clear preferred crystallographic orientation. The sericitized plagioclases filling the veinlets are also strained and recrystallized.

Chlorite, epidote and biotite are concentrated in places of maximum strain and form slightly developed nonpenetrative foliation planes.

Coarser grained thinly layered strongly deformed mostly completely recrystallized metabasalts (amphibolites)

These layered, medium-grained amphibolites occur along the tectonic contact with MP rocks of the ML Complex, in the NE and SE surroundings of the village Prameny (Fig. 1).

Large areal extent of this type is due to a very gentle dip of metabasites under the SE dipping thrust plane. They originated from the same protolith as the previously described rock type, which as indicated by chemistry, mineralogy, whole rock habitus and existence of transitional members. Due to much more intense metamorphic and deformational imprint during thrusting episode, the original rock fabric was completely obliterated. Transitional members between slightly recrystallized metabasalts preserving primary magmatic textures and completely reworked metabasites occur as large denudation relics in the SW surroundings of the village Prameny.

The dark green to black medium-grained rocks are composed of blue-green tabular grains of hornblende, plagioclase (oligoclase to andesine) and epidote. Titanite and sulphide are present as accesories.

Asymmetric porphyroblasts of hornblende and plagioclase and the orientation of subgrains are associated with tectonic movements of the top from SE to NW. Asymmetric structures and wedging of the amphibole and epidote grains to the main deformation plane give rise to the S–C fabric (Berthé et al. 1979) (Pl. III/2). The strongly deformed and dynamically recrystallized grains of hornblende and plagioclase forming hornblende and plagioclase domains are often separated. In terms of deformation fabric, these rocks can be classified as high-temperature mylonites.

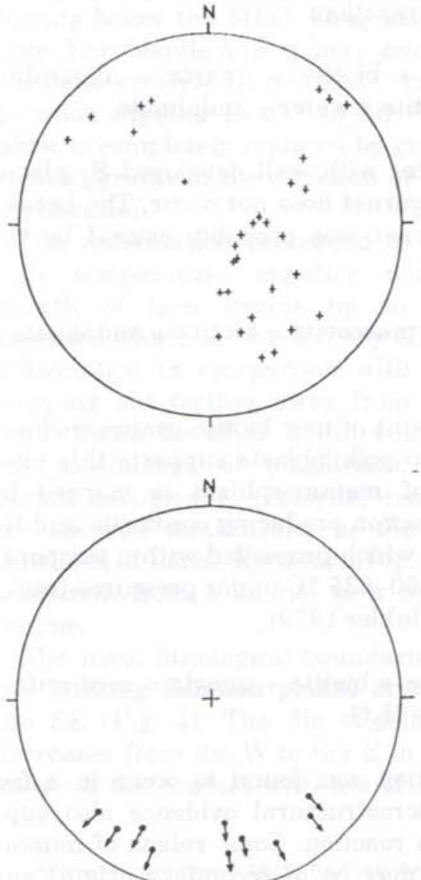

Fig 3. Diagram of dips of foliation planes (a) and stretching lineations (b) in the Kladská unit. Variations in foliation dips are due to younger folding postdating the thrusting episode and due to anastomosing development of foliation between the strike-slip zones

Acid tuff

Acid crystalloclastic tuffs forming small intercalations in the dark-grey pelitic schist of the Kladská unit were found in several places near the old uranium mine NE of Lázně Kynžvart, closely underlying eastern stripe of metabasalts. Their presence in the rocks of the Kladská unit is important from the point of view of their geotectonic position and correlation with other volcanic suites in adjacent areas. Crystalloclastic tuffs are light-grey, fine-grained massive rocks composed of very fine-grained submicroscopic mosaic of plagiolase and quartz, brown-green chlorite, green biotite and sometimes yellow-green to pale hornblende and sulphide pigment. Larger partly recrystallized or non-recrystallized quartz grains (up to 1.5 mm in diameter) are rarely present in the fine grained matrix (Pl. III/3). Some of these grains preserve bipyramidal habitus typical of acid volcanics. In most cases, the original quartz grains are recrystallized in several subgrains. Sometimes these recrystallized quartz grains enclose sericitized plagioclase up to 0.3 mm in diameter.

The main constituents of the fine-grained matrix are quartz, plagioclase, green biotite and chlorite with anomallous bluish interference colours.

Metamorphism, structural pattern and tectonic interpretation of the Kladská unit

The Kladská unit differs from surrounding units (i.e., the Slavkovský les Mts., the Tirschenreuth-Mähring Zone and the MLC), mainly by its metamorphic and structural development, apart from some differencies in lithology.

Rocks of the Kladská unit are characterized by generally lower metamorphic grade, which was recognized already by Fiala, Vondrová l.c. in Zoubek (1963). The HT-LP metamorphic assemblage in metapelites and metabasites originated during the main Variscan tectonothermal event dated 330-320 Ma (Kreuzer et al. 1989). In contrast to the MLC and other terranes near the Saxothuringian - Moldanubian boundary, no relics of HP or MP metamorphism were found.

Retrogression in steep shear zones has only limited spatial extent. It is connected with younger brittle-ductile tectonic movements along the Mariánské Lázně fault zone and its accompanying structures following an intrusion of the Bory pluton and perhaps of some members of the Karlovy Vary pluton.

In relation to the generally monoclinal dip of the rocks of the Kladská unit to the SE (Fig. 3a), metamorphic zoning is inverted and metamorphic grade increases from W to E, i. e. from the bottom to the top.

The following metamorphic mineral assemblages occur in metapelites and metapsamites of the Kladská unit:

1. quartz, chlorite, sericite, biotite, sulphide, + plagioclase (partly recrystallized clastic grains); as accesories are apatite, tourmaline,
2. quartz, biotite, muscovite, andalusite, + garnet, plagioclase, suphides; tourmaline is accessoric
3. quartz, biotite, andalusite, plagioclase, ±

cordierite, ± K–feldspar; tourmaline is scarce. Chlorite together with sericite and a small amount of greenish biotite remained stable in the small relics of metasediments preserved in the granites on the SW foothill of the Kružný hill, 3 km W of Lázně Kynžvart. The pale-green chlorite often forms cumuloblasts. Matrix is very fine grained, chlorite and sericite display a weak preferred orientation. According to Bell - Rubenach (1983), the matrix is preserved mostly in the first or second stage of foliation development. The original alternation of psammitic and pelitic bands is sometimes preserved. The original bedding (S_0) is mostly nearly parallel to S_1 foliation plane in which chlorite and sericite grow (Pl. IV/1). These minerals, however, do not form penetrative layers (bands). Some of them are randomly oriented. It is not possible to draw a "chlorite out" isograd because the continuity of the metasedimentary rocks is disturbed by intrusion of granites of the Karlovy Vary pluton.

In the NE surroundings of Lázně Kynžvart and in the relics of metasediments preserved W of village Kladská, garnet and andalusite porphyroblasts appear. Staurolite was not found, probably either due to unsuitable bulk composition of the pelitic rocks or due to lower-pressure which favoured growth of andalusite and garnet. Fabric of these metapelites differs strongly from chlorite-bearing metapelites. The original layering is mostly completely overprinted. Mica- and quartz-rich domains originated during metamorphic segregation due to solution transfer. The matrix preserves the third to sixth stage of shistosity development according to the scale of Bell - Rubenach (1983). Biotite and muscovite porphyroblasts show well developed preferred alignment parallel mostly with S_2 cleavage planes. Crenulation microfolds deforming S_1 foliation made up by muscovite, sulphide and quartz grains are exceptionally preserved. However, inclusion trails in garnet and andalusite formed by small sulphide and quartz grains show sometimes stage 1 or 2 of S_2 plane development (Pl. IV/2, 3). It appears that garnet and andalusite started to grow in relatively early stages of the foliation development. The differences in the stage of the matrix and the porphyroblasts development are caused by heterogeneity of the deformation between the matrix and porphyroblasts (Bell 1981, Bell - Rubenach 1980). It could be documented on the contacts of strongly corroded garnets with biotite. Garnet grains were dissolved in areas of relatively higher strain during later stages of S_2 development. The growth of garnet has probably proceeded through the reaction:

(1) chlorite + biotite + quartz = almandine garnet + biotite + water + andalusite,

In metapelites with well developed S_2 planes (stage 4–6) garnet does not occur. The breakdown of garnet was probably caused by the reaction:,

(2) garnet + muscovite = biotite + andalusite + quartz,

A large amount of new biotite grains enclosed in andalusite poikiloblasts supports this idea. The peak of metamorphism is marked by prograde reaction producing cordierite and K-feldspar (3), which proceeded within temperature range 560–635 °C under pressures from 1 to 3 kbar (Winkler 1979).

(3) muscovite + biotite + quartz = cordierite + K–feldspar + H_2O.

This reaction was found to occur in a few samples. Microstructural evidence also supports such a reaction. Some relicts of muscovite (which may be of secondary origin) and strongly corroded relicts of biotite are preserved in large cordierite poikiloblasts enclosing corroded irregular net-like grains. K-feldspar grains grow close to cordierite or are enveloped by large cordierite porphyroblasts. The hypidiomorphic grains of muscovite growing across the foliation planes and very fine-grained chlorite are products of later retrograde reactions connected with cooling, during which part of cordierite grains was replaced by micaceous aggregates.

A clear evidence of an increase in metamorphic grade toward the E can be found in metabasites. The grain size of plagioclase, hornblende and epidote increases progressively towards the E. Relicts of the primary magmatic textures are obscured by simultaneous recrystalization, during which penetrative schistosity developed. The mineral assemblage consists of brownish-green fine-grained hornblende, plagioclase (oligoclase to andesine) epidote or clinozoisite, titanite and scattered grains of opaque minerals. This mineral assemblage corresponds to medium-grade amphibolite-horfelse facies. At the tectonic contact of metabasalts of the Kladská unit with the MLC, the appearance of the rocks changes radically. The rocks obtain very strong penetrative planolinear fabric flatly dipping below the MLC. Long axes of plagioclase, hornblende and epidote grains show an excellent preferred orientation in NW – SE direction dipping 15–30° to SE. The original fabric is completely replaced by growth of new mineral grains in the direction of the stretching lineation.

The deformation proceeded at a relatively high temperature together with a quick growth of new grains up to 0.X mm in diameter which show relatively slight internal deformation in comparison with metabasalts cropping out farther away from the tectonic contact with the MLC. Brittle veins filled with the assemblage of plagioclase, clinozoisite, garnet hornblende, ±chlorite, ±calcite cutting the sheared metabasalts in the NE neighbourhood of Lázně Kynžvart (Fig. 1) indicate a transition from a ductile to a brittle–ductile regime.

The main lithological boundaries and NE – SW striking foliation planes dip generally to the SE (Fig. 4). The dip of foliation planes decreases from the W to the E to the minimal value at the contact with the MLC. Some irregularities in the dip of foliations can be explained by progressive uneven development of the main schistosity S_2 and by its younger overprinting by steeply dipping foliation formed during a later strike–slip episode.

Intrafolial tight to isoclinal folds evolved during the thrusting epidode. After this event, open folds of NE–SW direction with steeply dipping axial planar cleavage and subhorizontal axes originated. These folds are younger than the main thrust plane (the thrust plane is folded by them) along which the ML complex was overthrust on the top of the Kladská unit.

Three different stretching lineations were recognized (Fig. 3b). The dominant penetrative NNW–SSE lineation is developed mainly in metabasites close to the tectonic contact with the MLC and is connected with thrusting of the MLC on the Kladská unit. Both the NE–SW, and NW–SE trending subhorizontal stretching lineations marked by elongation of rocks fragments in the lava flow breccias are products of movements along steeply dipping strike slip zones. The time–space relations of these structural elements, however, cannot be studied directly in the field.

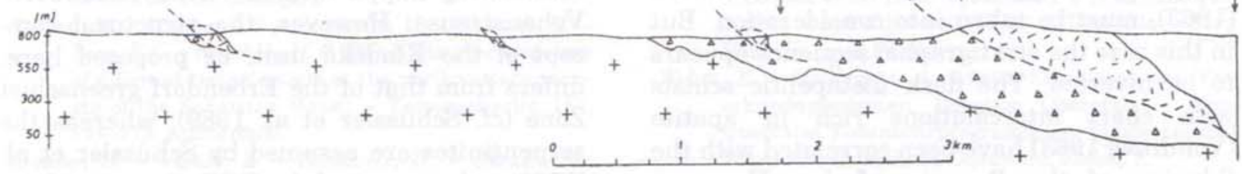

Fig 4. Schematic cross–section through the Kladská unit and lower part of the overthrust ML complex. For legend see Fig.1

Discussion and conclusions

Recent geological mapping in the W surroundings of the MLC along the presumed boundary between the Teplá–Barrandian and Saxothuringian regions brought new significant insights into the relationship between these units.

The metabasites extending W of Vlčí hřbet ridge, serpentinite body, presented earlier as part of the MLC (Vejnar – Zoubek 1962, Zoubek et al. 1963), appear not to belong to this unit. They are now interpreted (as opposed to Fiala – Vondrová 1963) as part of the Kladská unit (Fig. 1). This concept is supported by several lines of evidence.

1. In contranst to the rocks of the MLC, which show medium–pressure metamorphism with HP relics (eclogites), the metabasites and associated metasediments of the Kladská unit have undergone only low– to medium–grade LP–HT metamorphism (high grade assemblages are rarely observed), dated in the German part at 330–320 Ma – (Kreuzer et al. 1989).

2. The metabasites of the Kladská unit differ from those of the MLC by their calc–alkaline to alkaline chemistry. Some of the slightly recrystallized rocks preserve primary magmatic fabrics (ophitic, porphyritic, amygdaloidal, brecciated).

3. The metabasites and associated metasediments of the Kladská unit are separated from the rocks of the MLC by a flat–lying, SE dip–

ping ductile shear zone situated at the base of the Vlčí hřbet serpentinite body.

Incorporation of metabasalts into the Kladská unit, together with their chemistry, structural and metamorphic setting allows the following interpretation: During LP-HT phase (330-320 m.y. BP), the MP rocks with HP relics of the MLC were thrust over the autochthonous or paraautochtonous rocks of the Kladská unit over a minimal distance of 6 km (Fig. 4). Serpentinite and diorite bodies scattered to the west of the MLC and resting on the Saxothuringian autochton represent outliers of the MLC. With regard to the differences in the metamorphic grade between the Kladská and Slavkovský les crystalline units, a tectonic contact between these units cannot be ruled out. The NE and S to SE continuation of the thrust plane is obscured by the intrusion of Variscan granites and by Tertiary volcanics and by movements on the NW-SE trending strike-slip zones. Occurrences of serpentinites and metabasites in the Bory pluton and in the Tachov crystalline unit may indicate a continuation of this thrust plane to the SE.

In spite of the presented new findings, stratigraphic range, structural and geotectonic position of the Kladská unit are open for futher discussion. Upper Ordovician and Silurian ages suggested by Fiala - Vondrová (1963), must be taken into consideration. But in this case the stratigraphic sequence appears to be inverted. The dark metapelitic schists with chert intercalations rich in apatite (Vondrová 1963) have been correlated with the Silurian of the Bavarian facies. However, bimodal calc-alkaline to alkaline volcanism shows a close relation to metavolcanites of the Prasinite-Phyllit Series of the Münchberg nappe pile and Erbendorf greenschist Zone (EGZ). Especially conspicous is agreement in composition with the metabasites from Hohenkonden quarry (Okrush et al. 1986). However, according to Reitz in Franke (1989), metapelite of the Prasinite Phyllit Serie have yielded Late Proterozoic microflora. An unambiguous solution of the stratigraphic, structural and facies relevance requires futher detailed correlation of the units discussed above.

More attention should be paid to the structural and paleogeographic position of the MLC. The following questions remain to be answered: Is the MLC a tectonic slice preserved after a closure of the Saxothuringian ocean (Matte et al. 1990)? What is its paleogeographic and palaeotectonic relation to the Gföhl terrane (comp. discussion in Franke 1989)? Another open question is the relationship of the Krušné hory-, MLC- and Moldanubian eclogites.

Tectonometamorphic evolution and lithology of the Kladská unit showing inverted metamorphic zonation is different from the probably autochtohnous Slavkovský les crystalline unit. This demonstrates that the Saxothuringian - Teplá-Barrandian boundary represents a complicated Variscan stacking of nappes comparable in some features with the Münchberg klippe and the Zone Erbendorf-Vohenstrauss. However, the structural concept of the Kladská unit, as proposed here, differs from that of the Erbendorf greenschist Zone (cf. Schüssler et al. 1989): whereas the serpentinites are assumed by Schüssler et al. (1989) to be a part of the EGZ, they are identified here as the basal part of the MLC nappe, thrust over the Kladská unit.

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Geologicko-stukturní doklady pro pozdně variské nasunutí mariánskolázeňského komplexu na saxothuringikum

Nové geologické mapování, litostratigrafický, strukturní a geochemický výzkum v z. okolí mariánskolázeňského metaofiolitového komplexu (MLC) vedl k redefinici hranice mezi zónou - Teplá-Domažlice (ZTT) a saxothuringikem.

Metabazity vystupující z. od serpentinitového tělesa Vlčího hřbetu, dosud považované za součást mariánskolázeňského komplexu (Vejnar - Zoubek 1962, Zoubek et al. 1963), nejsou součástí uvedené jednotky, postižené devonskou (386-362 mil. let - Kreuzer et al. 1992) střednětlakou barrowienskou metamorfózou s relikty vysokotlakých eklogitů, ale jsou nově interpretovány jako součást jednotky definované Fialou - Vondrovou (1963) jako "synklinála Kladské", jejíž litostratigrafická náplň je redefinována.

Jednotka Kladské je souborem slabě až silně metamorfovaných sedimentů (chlorit-biotitických, biotit-andalusitických a biotit-andalusit-cordierit + K-živec rohovců) s vložkami lyditů a polohami alkalicko-vápenatých až alkalických bazaltů, trachybazaltů a trachyandezitů se zachovalými relikty primárních magmatických struktur.

Během pozdně variské nízkotlaké vysokoteplotní tektodeformační fáze (320-330 mil. let - Kreuzer et al. 1989) byly střednětlaké horniny mariánskolázeňského komplexu s vysokotlakými relikty přesunuty směrem k SZ přes paraautochtonní horniny jednotky Kladské na vzdálenost nejméně 6 km. Serpentinity a pravděpodobně i některé metadiority vystupující z. od serpentinitového tělesa Vlčího hřbetu jsou drobná tektonická bradla spočívající na paraautochtonu sasko-durynské příslušnosti. Násunová plocha je navrhována za novou hranici saxothuringika a mariánskolázeňského komplexu.

RECENZE

J. L. Briaud: **The pressuremeter.** - 336 str., nakl. A.A. Balkema, P.O. Box 1675, 75 US dolarů. Rotterdam, 1992.

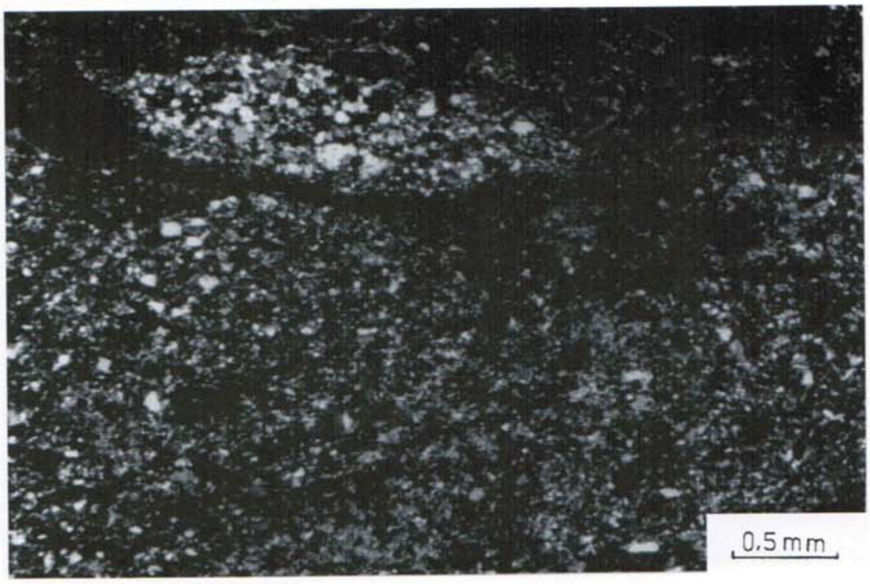
Měření deformací zemin i pevných hornin ve vrtech presiometrickou sondou je u nás již dobře známá, přesto však málo využívaná metoda ke zjišťování geotechnických vlastností základové půdy. Záznam změny tlaku a objemu sondy při zkoušce ve vrtu umožňuje stanovit presiometrický modul a vynést graficky vztah mezi napětím a deformací horninového prostředí v různé hloubce vrtu a z toho odvodit řadu důležitých mechanických vlastností pro vhodný návrh základové konstrukce.

Knihu, kterou napsal na vysoké odborné úrovni dlouholetý praktik a v současné době profesor univerzity v USA, lze plným právem označit titulem "Presiometr a jeho využití od A do Z". Obsahuje všechny technické údaje o přístroji, jeho nasazení při průzkumu v terénu i způsob využití výsledků měření při zpracování projektů různých základových konstrukcí, jak o tom svědčí jednotlivé kapitoly knihy: 1 - Druhy presiometrů, 2 - Kalibrace přístroje, 3 - Parametry vrtů pro měření, 4 - Průběh zkoušek a různé způsoby měření, 5 - Teoretické podklady pro vyhodnocení zkoušek, 6 - Stanovení geotechnických parametrů základových půd, 7 - Srovnání výsledků měření s jinými geotechnickými zkouškami, 8 - Návrh mělkých základů, 9 - Návrh svisle zatížených pilot, 10 - Návrh vodorovně zatížených pilot, 11 - Návrh opěrných zdí- 12 - Návrh injektovaných kotev, 13 - Návrh silničního spodku, 14 - Další aplikace presiometrických měření, 15 - Výhody a nevýhody presiometrických měření, ekonomický rozbor metody.Dodatky A až F, které tvoří druhou polovinu knihy, jsou velmi úspěšným doplňkem ke kapitolám 8 až 14. Obsahují praktické příklady návrhu konstrukce příslušného typu.

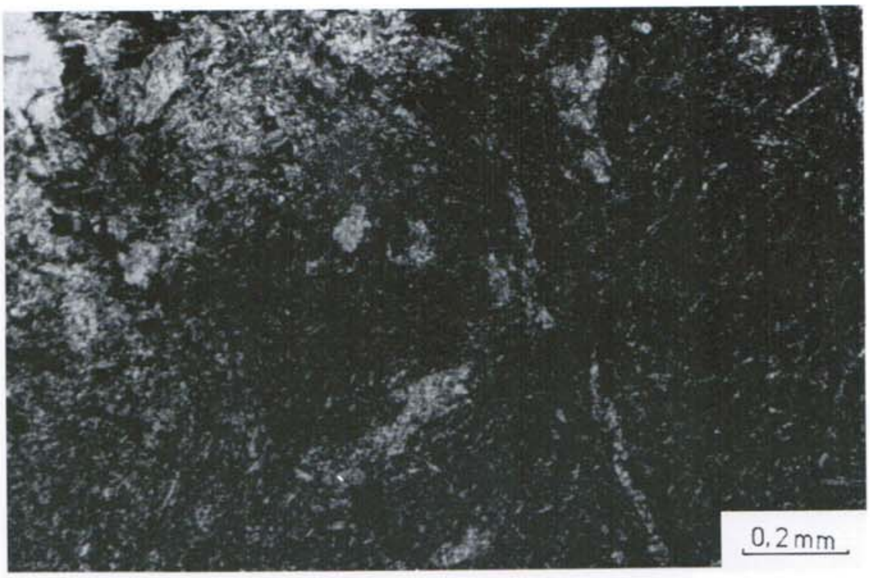
Knihu lze vřele doporučit jak průzkumným podnikům s presiometrickou sondou pracujícím, tak projekčním organizacím, které hodnoty z presiometrrických měření používají při navrhování staveb, neboť v naší odborné literatuře nic podobného neexistuje.

Josef Zajíc

V. Kachlík: The Evidence for the Variscan nappe thrusting .. (Pl. I)



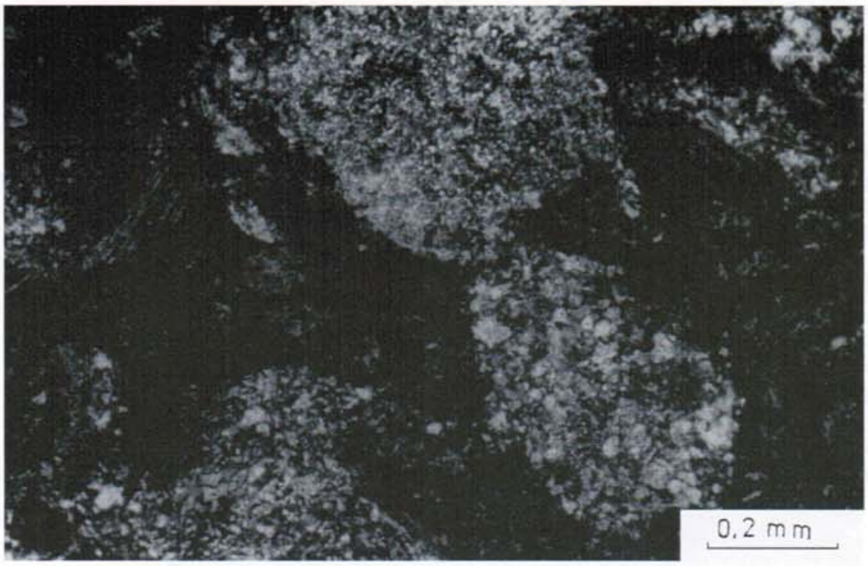
1. Quartzite lithoclasts in graywackes of the lower part of the Kladská unit, the Krušný Hill, 3 km W of Lázně Kynžvart, size 1 mm



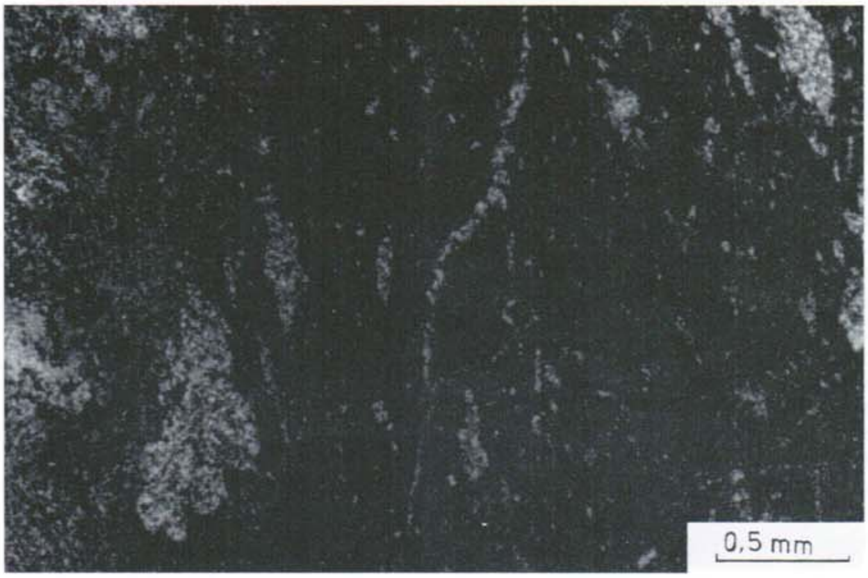
2. Relics of primary magmatic fabric in the metabasalts of the Kladská unit. Ophitic texture of the matrix between lava fragments, NE of Lázně Kynžvart

3. Amygdaloidal structure in the metabasite fragment enclosed in the matrix with relicts of primary ophitic texture. NE of Lázně Kynžvart

V. K a c h l í k : The Evidence for the Variscan nappe thrusting .. (Pl. II)



1. Porphyritic fabric in the metabasite, NE of Lázně Kynžvart. Some of porphyric plagioclase grains are recrystallized into a fine grained mosaic of new grains. Ellipsoidal shape is caused by shearing of the rocks

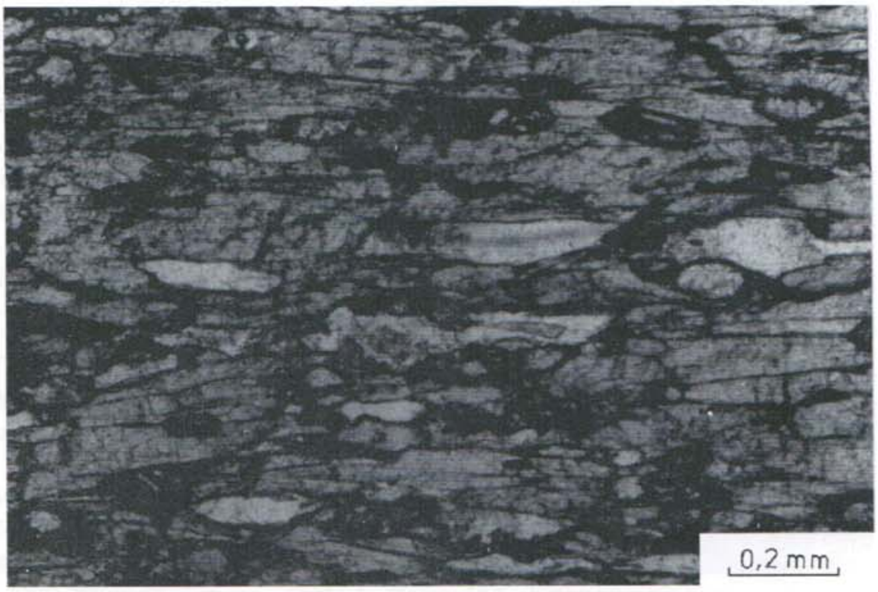


2. Contact of a lava fragment with matrix preserving relics of magmatic fabric, favour the magmatic origin of these fragmentites belonging to the Kladská unit., NE of Lázně Kynžvart

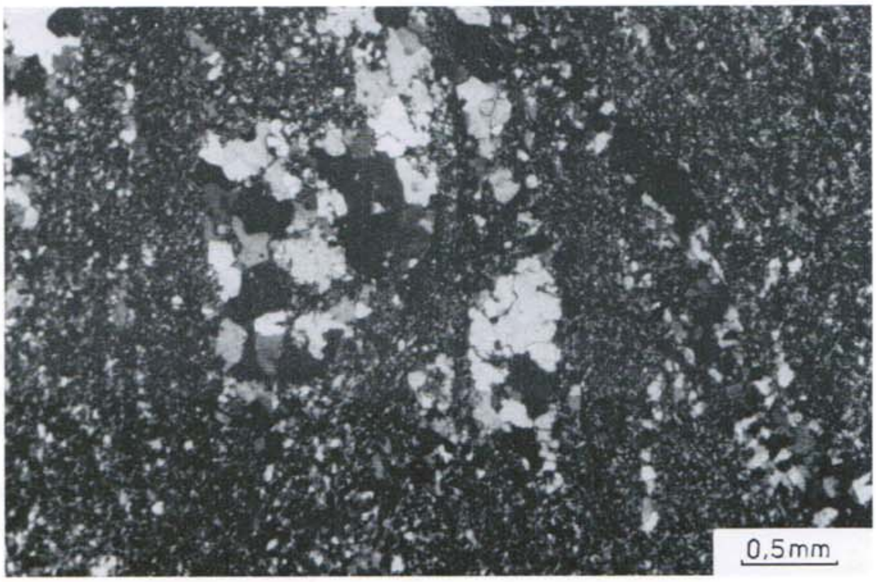
3. Metamorphosed fragmentites interpreted as lava flow breccias, "brecciated lavas", 500 m NE of Lázně Kynžvart

V. Kachlík: The Evidence for the Variscan nappe thrusting .. (Pl. III)

1. Fractured brecciated lavas of the Kladská unit. Late syntectonic veins filled with plagioclase, hornblende, garnet, clinozoisite and scarcely with calcite, chlorite and sulphides. Transition from ductile to brittle deformation., NE of Lázně Kynžvart

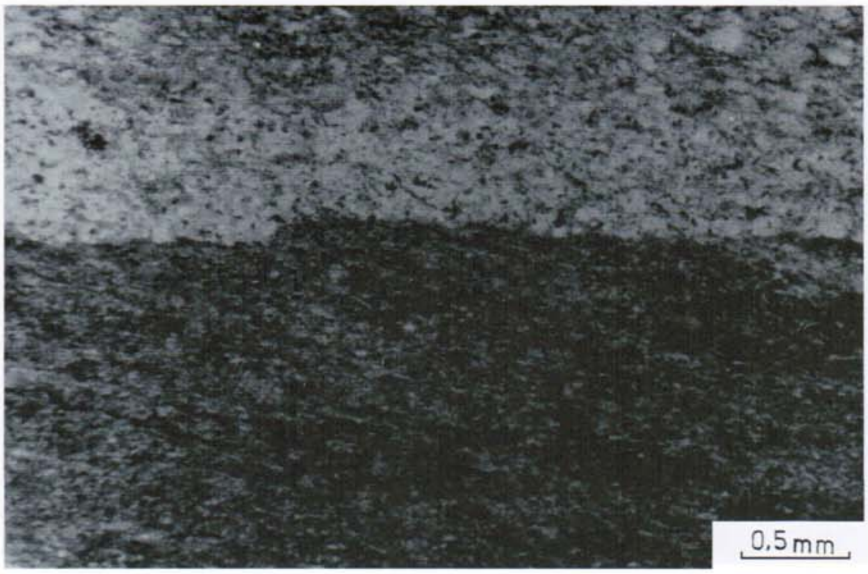


2. Strong shearing of the metabasites of the Kladská unit several metres below the trust plane (XZ plane) produced exclusive preferred orientation of plagioclase, hornblende and epidote grains. Compare the intensity of strain and recrystallization with Pl.I/1, 2, 3

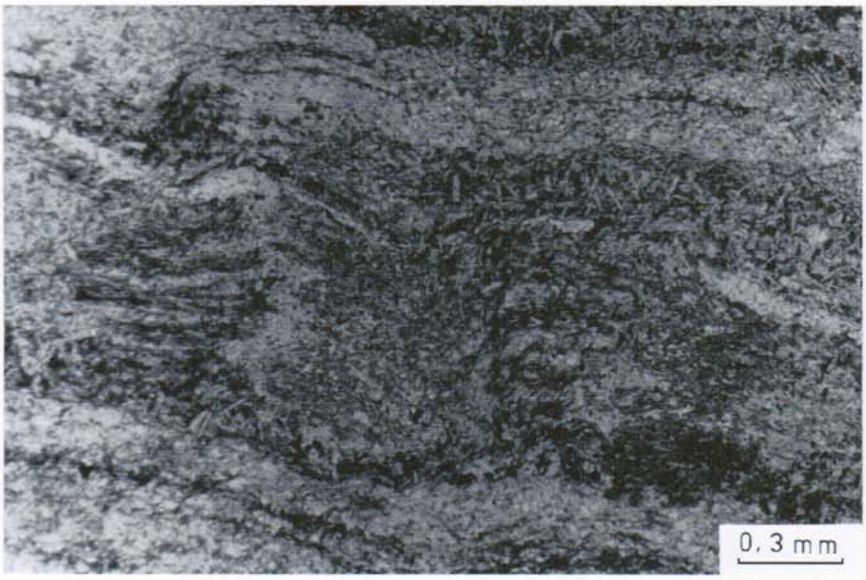


3. Fine-grained crystalloclastic acid tuf composed of quartz, plagioclase, chlorite and biotite. Recrystallized, originally magmatic dipyramidal quartz grains are sometimes preserved

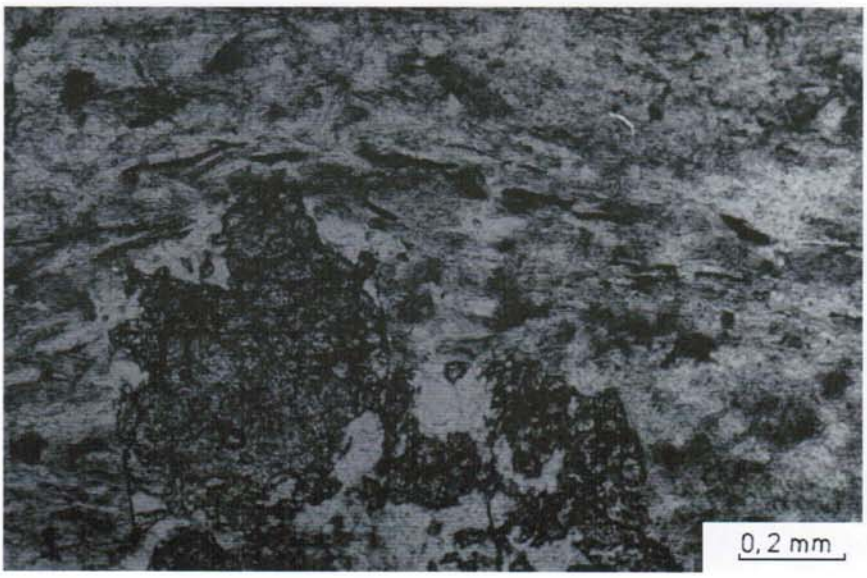
V. Kachlík: The Evidence for the Variscan nappe thrusting .. (Pl. IV)



1. Relationship of the sedimentary bedding (S_0) plane with the S_1 plane marked by growth of sericite, chlorite and sulphide minerals. Chlorite-sericite schist of the Kladská unit, SW foothil of the Kružný Hill, 3 km W of Lázně Kynžvart



2. Inclusion trails in andalusite porphyroblasts showing stage 2 of cleavage development (Bell - Rubenach 1983)



3. Strongly corroded garnets on the contact with biotite. Inclusion trails show that garnet porphyroblasts have grown in the early stage of the S_2 foliation development