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Porphyric granitoids in the western part of the Slovenské rudohorie Mts.: Emplacement and deformation in shear zones

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Abstract. The paper is aimed at an analysis of the relationship of intrusion and deformation in porphyric granitoids of Veporicum. In the area under study, the following ductile deformation stages may be identified:

- Paleohercynian (at high temperature and leaving traces only in the hybrid complex)
- Mesohercynian (we registered especially a record of the transition from compressional to transpressional regime at higher greenschist facies conditions),
- Neohercynian transtensional and extensional stage (its structural record is relatively difficult to define due to the superimposed Alpine extension),
- Paleoalpine stage (represented especially by the inventory of transpressional, less compressional structures, while in the fundament there have been utilised Hercynian structures).

The subsequent deformational stages took place already in brittle conditions.

Intrusions of porphyric granitoids are associated probably with the end of the Mesohercynian stage, using for their ascent sinistral transpressional shear zones. The contemporary and subsequent deformations modified their structural position.

Key words: Slovenské rudohorie Mts., Veporicum, porphyric granitoids, intrusion system, deformation.

Introduction

The so far published works concerning granitoids of the Veporicum were aimed mostly at the characterisation of individual varieties (from the best known we should mention the types Sihla, Hrončok, Vepor, Ipeľ, Rimavica, Rochovce) and their petrographic-mineralogical investigation (ZOUBEK 1936, HOVORKA 1960, KAMENICKÝ 1977, KRIST 1979, 1981, KLINEC et al. 1980 etc.)

Most recently, the granitoids have been classified according to their geological setting, petrographic-geochemical characteristics and relative age succession by BEZÁK & HRAŠKO (1992). They distinguished four basic granitoid groups (hybrid, porphyric, Sihla, leucocratic) and they also showed their approximate extent in space.

Structural study of the Veporicum granitoids was carried out by SIEGEL (1982), who discovered a structural discordance of Hercynian foliation inclined predominantly to the north and the superimposed Alpine mylonite foliation inclined to the south. Deformed granitoids and their metamorphism have been studied especially by VRÁNA (1966), on the Hrončok granite by PITOŇÁK & SPIŠIAK (1994) and in the Kohút Zone by HRAŠKO (in press).

The Hrončok type granite was in the last time the subject of structural as well as petrologic studies. PETRÍK et al. (1995) interpreted this granite type as a system of intrusions in a Hercynian shear zone, showing the effects of Hercynian and superimposed Alpine deformations. Contrary to this, HÓK & HRAŠKO (1990) considered all deformation structures to be Alpine.

Recently there appeared works characterising the deformation structures in the granites from the viewpoint of the effects of the Alpine extension (HÓK et al., 1993 and others). Indirect evidence (analogy with the Hercynian development in other regions, Upper Paleozoic basins and volcanism, extensional Hercynian quartz veins, rapid exhumation of the granitoid) however points to a very probable late Hercynian extension. The separation of older structural records from the superimposed Alpine ones, however, has always been a big problem in Veporicum, due to their similarity in direction and metamorphism.

The aim of this work is a contribution to the solution of the above problem and filling the gap in the knowledge of the structural position of one of the most frequently occurring granitoid type in Veporicum - porphyric granite. At the same time, it is an attempt to explain its relationship to other granitoids, the mode of emplacement and the relationship to the subsequent deformations.

Porphyric granitoids occupy large monotonous structural areas in Veporicum and, on the other hand, they form smaller bodies among hybrid types. More suitable for the study of structural relationships is the second type, therefore, a region of this character was selected for the study. It is the area north of Klenovec, between Klenovecká and Tisovecká Rimava. Geological setting of the region is shown in Fig. 1.

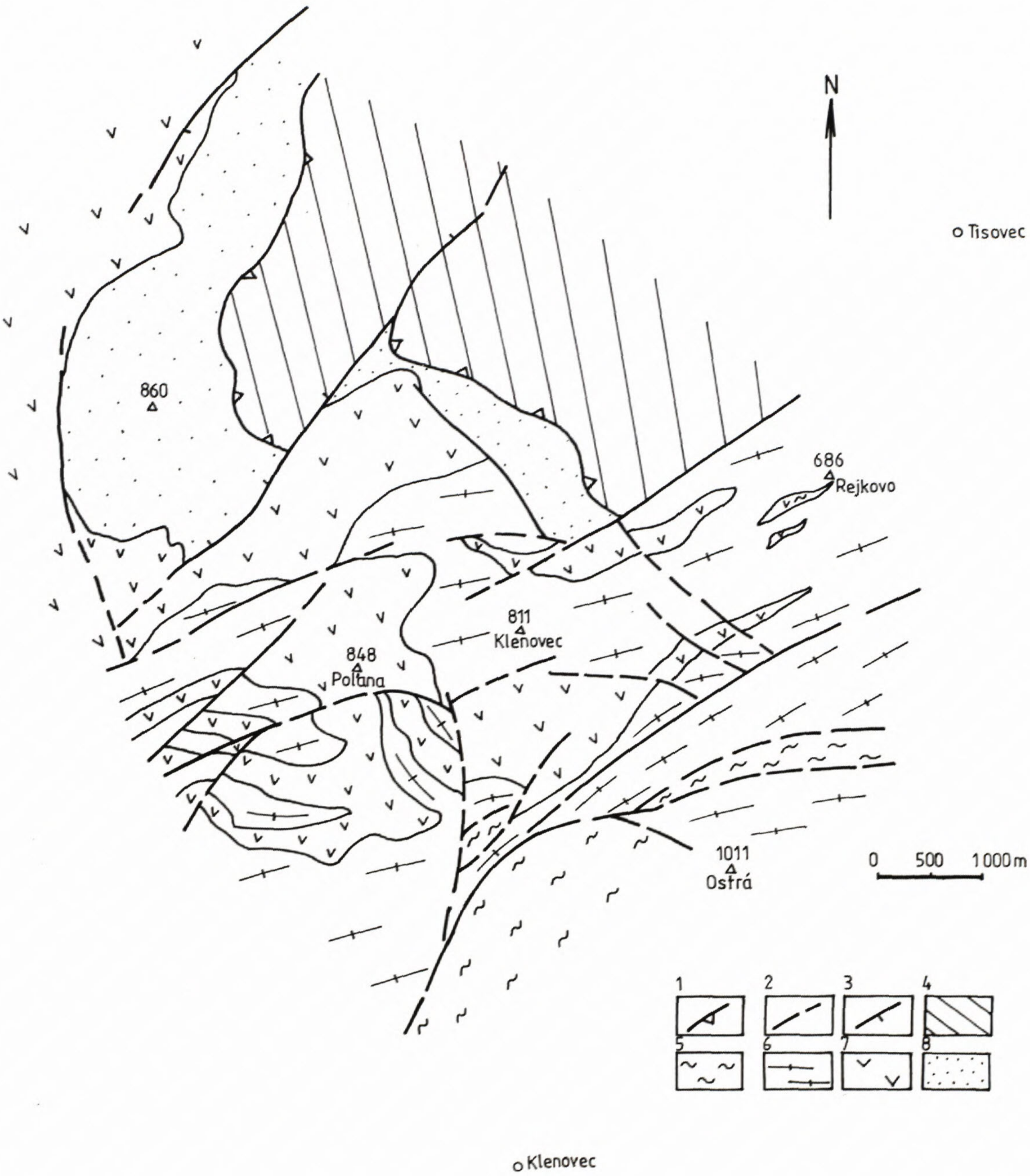


Fig.1. Geological map of the area northwards from Klenovec
1- overthrusts, 2 - faults of undifferentiated sense of movement, 3- normal faults, 4 - nappes of Gemericum and Silicikum, 5 - mica schists, 6 - hybrid complex (deformed granitoids, migmatites, enclaves of gneiss), 7 - porphyric granitoids, 8 - Mesozoic cover (Foederata group)

Porphyric granitoids form in the area studied smaller, steeply inclined bodies among hybrid types, but in the northern part often also extensive sub-horizontal bodies. Moreover, Mesozoic cover occurs here too, serving as a marker for distinguishing Alpine structures.

Geology

The area under study is built predominantly of the hybrid complex and porphyric granitoids. Metamorphic rocks of the Kohút Zone and cover sequences occur to a lesser extent.

The **hybrid complex** is the oldest "building stone" of the area. It consists of the remnants of high-metamorphic gneiss-migmatite rocks "sunken" in hybrid granitoids. Two types of these granitoids may be distinguished.

The first type is markedly oriented (foliation and lineation is defined by biotite, it is mostly parallel with the foliation of migmatites). They are high-grade metamorphosed granitoids, even with local manifestations of anatexis. The second type is more or less homogeneous, and foliation is only very badly observable. Its composition corresponds to granodiorite to tonalite (BEZÁK & HRAŠKO, 1992). It has been observed that migmatites and metamorphosed granitoids "float" as blocks in this granitoid type. They sometimes have even the character of a breccia.

A characteristic feature of the hybrid complex is sometimes strong potassium metasomatism. Its manifestation is especially the growth of new K-feldspars (orthoclase), which usually enclose the original mineral assemblages, especially plagioclase, biotite and quartz. It must be noted that metasomatism is strongest near the intrusions of porphyric granitoids.

The hybrid complex underwent also retrograde metamorphism. In places where the foliation planes are steep, the retrograde effects are connected only with steep shear zones and typical sub-horizontal foliation is not developed. Retrograde metamorphism resulted usually in microclinisation, sericitisation of K-feldspars, albitisation and saussuritisation of plagioclases with the formation of epidote, clinozoisite or tiny phengitic muscovite, and in chloritisation of biotites.

Porphyric granitoids are a well-defined granitoid type, with white and pink K-feldspar phenocrysts. From the viewpoint of structural position they may be divided into two groups. The first are porphyric granitoids associated with the hybrid complex. They occur here in the form of dikes, several meters to tens of meters thick, penetrating the hybrid complex. We shall deal later with the emplacement mechanism and geometry of the intrusions in greater detail. The second group comprises porphyric granitoids on the NW margin of the area under study, forming the immediate underlier of the uppermost Paelozoic and Mesozoic sediments. Even more evidently than in the hybrid complex, differences may be observed in the development of the sub-horizontal extensional foliation, which has penetrative character in the sub-horizontally placed porphyric granites, while in the steep intrusions and dikes it is almost impossible to observe. Retrograde alterations, being the same process, are similar as in the hybrid granites.

On the NW margin of the area under study, **envelope sediments** of the uppermost Paleozoic belonging to the Foederata Group are lying on the porphyric granitoids. The lower part consists of an arkose and quarzite formation. The quartzites occur here as non-rhythmically repeating intercalations (several cm to tens of meters thick) in the arkoses, the transitions being quite frequently gradual. Lower Triassic shales have been preserved locally. The whole Foederata Group is characterised by metamorphism in the lower greenschist facies, at a temperature of about 350°C. In the tectonic overlier, with a marked tectonic jump, there are lying predominantly carbonate formations of the **Muráň Nappe** of the Silicicum.

In the SE part of the area there are **garnet micaschists** of the Ostrá complex, with sporadic metamorphosed products, especially of basic volcanism. They are separated from the hybrid complex by faults assigned to the Muráň system. Detailed mapping showed that the contact of the granitised complex and the Ostrá complex is very complicated. It is formed by a shear zone, in which, at several places, these complexes are overlapping in a scale-like way. Small bodies of amphibole diorite and leucocratic granitoid are associated with this zone. They are affected only by brittle deformations and hydrothermal alterations.

STRUCTURAL CONDITIONS

Hybrid complex

The dominant foliation is defined by the banding of migmatites, crystallisation schistosity of biotite gneisses and granitoids. The whole complex is strongly folded, the general direction of fold axes being E-W. Locally, folds with SE vergency have been preserved. In these places the lineation with NW-SE direction is preserved as well.

The second group are foliation types defined by retrograde alterations. The original assemblage - Or + Bi + Plg + Q $\pm$ Gr is partly or totally substituted by the assemblage Bi_2 + Q_2 + Mus + Ab + Chl + Ser $\pm$ Ep. They are associated exclusively with shear zones of E-W and NE-SW direction, the width of which varies from several millimetres to a few hundreds of meters. These rocks were in the past described as a different rock type (various schist types, micaschists etc.). After detailed mapping, their connection with the shear zones has been clearly proved. In some profiles it was possible to observe gradual transitions from migmatites to these mylonites, or the presence of non-deformed domains in which original rocks have been preserved.

The lineation is also of two kinds. The first is lineation of biotite in migmatites and biotite gneisses. It varies about E-W direction and it is sub-horizontal, with the exception of the already mentioned older lineation of NW-SE direction. Their dispersion is minimal in zones where the hybrid complex is penetrated by porphyric granitoids and their direction is identical with lineation in porphyric granitoids. Linear elements are very intensively developed in the shear zones of NE-SW direction and the rocks have a marked pencil structure. The second group is lineation of chlorite and sericite, which partly or totally substitutes biotite lineation. Their directions are often consistent and only exceptionally it was possible to observe on one outcrop a discordance in the direction of biotite and chlorite-sericite lineation.

Fig. 2. Foliation trajectories in crystalline and in cover of the Veporikum northwards from Klenovec
1 - overthrusts, 2 - faults (mostly strike-slip faults), 3 - normal faults, 4 - foliations, 5 - nappes of Gemerikum and Silicikum, 6 - Mesozoic cover

Porphyric granites

Similarly as in the hybrid complex, several types of foliation could be observed also in the porphyric granitoids. They are: 1) magmatic foliation connected with the deformation in the magmatic flow, defined by the preferential orientation of primary minerals (feldspar phenocrysts), their imbrication and also the presence of biotite schlieren or "fluvial textures"; 2) foliation generated by deformation in post-magmatic stage, defined by biotite lying in S-C structure, the presence of quartz ribbons etc., 3) foliation defined by retrograde alterations, especially into chlorite and sericite.

Mutual relationships of the foliation types in space are very varied and they were the main key to solving and understanding of the mechanisms of the emplacement of porphyric granitoids. In the majority of cases the foliations are sub-parallel. Exceptionally it was possible to observe microscopically the opposite direction of motion on the planar structures. The map of foliation trajectories clearly shows the copying of the hybrid complex structures and their basically identical distribution in space. Differences occur only where there is a discordant contact between the porphyric granitoids and the hybrid complex. The position of retrograde alterations is wholly identical with the hybrid complex, these alterations are associated with identical shear zones. Slightly more monotonous are porphyric granitoids lying immediately below Upper Paleozoic and Mesozoic sequences, where all three foliation types are sub-horizontal and having the same direction.

As the investigated rocks are porphyric granitoids, besides the study of biotite, chlorite and sericite lineation it was possible to observe also lineation defined by the long axis of porphyric feldspar phenocrysts. The lineation of chlorite and sericite are, similarly as in the hybrid complex, connected with zones of retrograde alterations. Their direction is generally identical with biotite lineation. An important discovery were the results of the study of kinematic indicators. In the first group, characterised by relatively steep foliation of E-W direction and sub-horizontal lineation, the deformations of feldspars and biotites show a sinistral sense of movement. The shear zones with which the retrograde alterations were associated suggest dextral movement on the E-W zones and sinistral movement on the NE-SW zones. This fact has clearly genetically separated the biotite and chlorite-sericite lineation, identical in direction.

In the second group of porphyric granitoids, all three lineation types had the same direction and sense. These granitoids were emplaced at a higher level than the granites of the first group. An exception are transitional bodies between vertical and sub-horizontal ones. In view of the fact that they were directly connected with the sinistral regime in the shear zone of horizontal displacement, at their sub-horizontal emplacement they reveal once top to the east, other times top to the west movement, depending whether they were tipped to the north or to the south of the shear zone (Fig. 4).

Upper Paleozoic-Mesozoic cover

Rocks belonging to this group occur on the NW margin of the area under study. Their structural setting is, in comparison with other rocks, simple and monotonous. Their metamorphism is reaching the lower part of the greenschist facies and their typical feature is the dominance of extensional structures (systematically top to the east, in contrast to the underlying granitoids). They are represented by foliation with a low angle, dipping to the E-NE. Lineation is formed exclusively of chlorite and sericite and it varies between E-W and NE-SW direction. This dispersion has been caused by the non-existence of an older preferential orientation of minerals (in contrast to rocks deformed in the Hercynian orogeny), allowing the rocks to react more sensitively to local changes of regional stress. In quartzites there are often preserved older folds (extensional foliation is cutting across these folds). As linear elements, the direction of which would be perpendicular to the axes of these folds, have not been preserved, it is not possible to form an opinion on their vergency and they provide only information on the existence of an older deformation.

STRUCTURAL DEVELOPMENT OF THE TERRITORY AND MECHANISM OF INTRUSIONS OF PORHYRIC GRANITOIDS

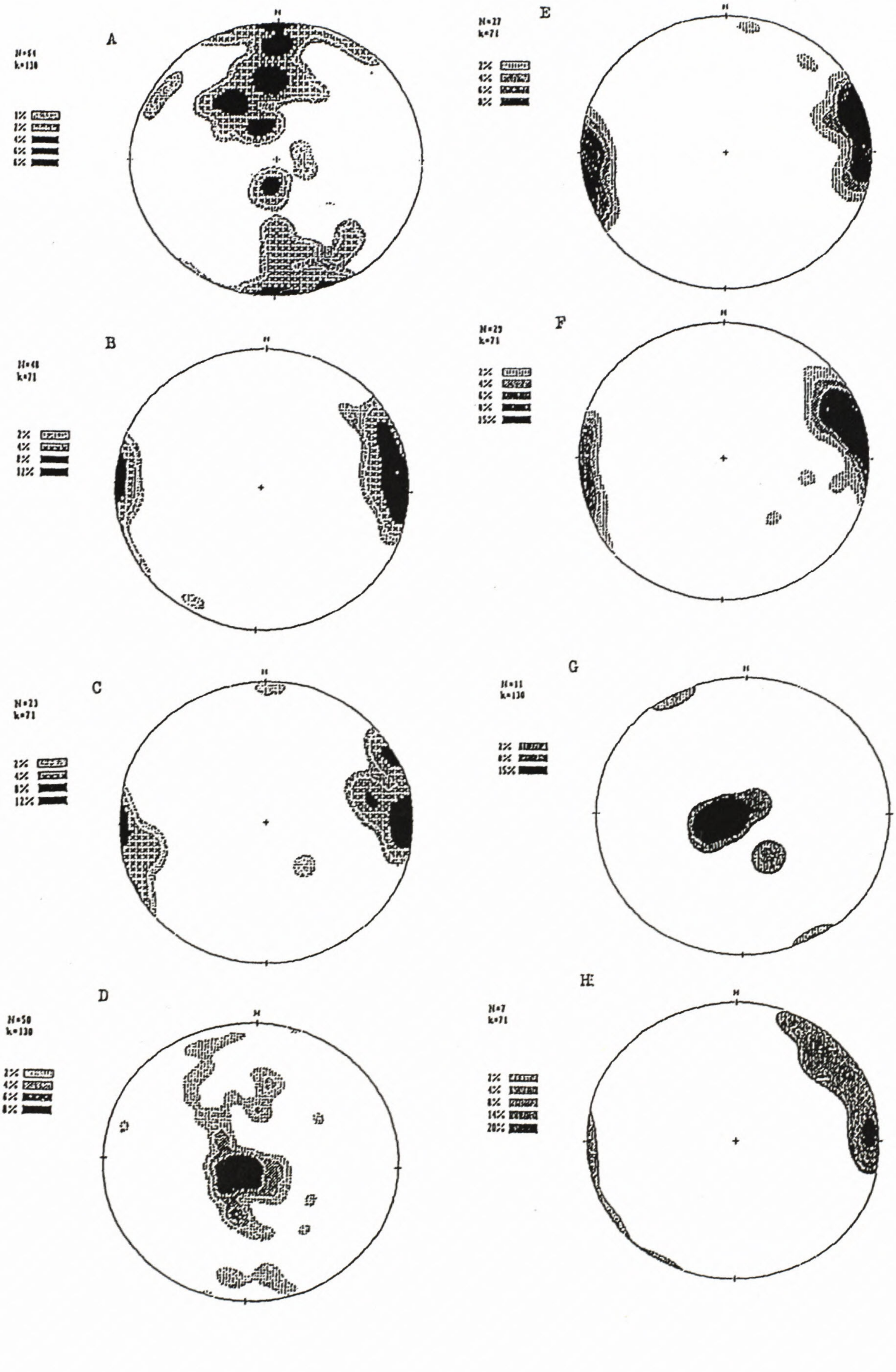
The oldest observed deformational stage are structures preserved in the remnants of a high-metamorphic cover complex and in older metamorphosed granitoids. It is mostly a considerably plastic deformation occurring in conditions near anatexis (BEZÁK 1991), probably at lower crust level. This stage includes the formation of hybrid granitoids. The formation of the dominant fold structures in the hybrid complex, with E-W fold axes, is connected with the progressing uplift of lower crust elements into mid-crustal levels and with thrust direction to S to SE.

Another deformation stage is connected with the intrusion of porphyric granitoids into the hybrid complex and their deformation in the magmatic stage. These intrusions are related to probably transpressional shear zones, having in present co-ordinates E-W direction and dipping mostly steeply to the north as well as to the south. E-W structures are a reflection of an older fold structure of the hybrid complex. The directions of superimposed shear zones are NE-SW. In zones of intensive shear, the structures of the hybrid complex have been rebuilt into this direction. The result of the overlapping of E-W and NE-SW structures is the typical S-shaped direction of the foliation.

Syntectonic emplacement of the porphyric granitoids is suggested especially due to the following phenomena:

- magmatic foliation in the marginal parts of porphyric granitoid intrusions are parallel to the margins of intrusions;
- the intensity of the development of magmatic foiation increases towards the margins of the intrusions;
- foliation in the surrounding rocks are more intensive towards the margins of the intrusions and they rotate from directions parallel with the margins of the intrusions.

With the gradual uplift and slight decrease of P-T conditions there is connected also the continual process of transition from deformation in magmatic state into deformation in post-magmatic stage. This is supported by the following evidence: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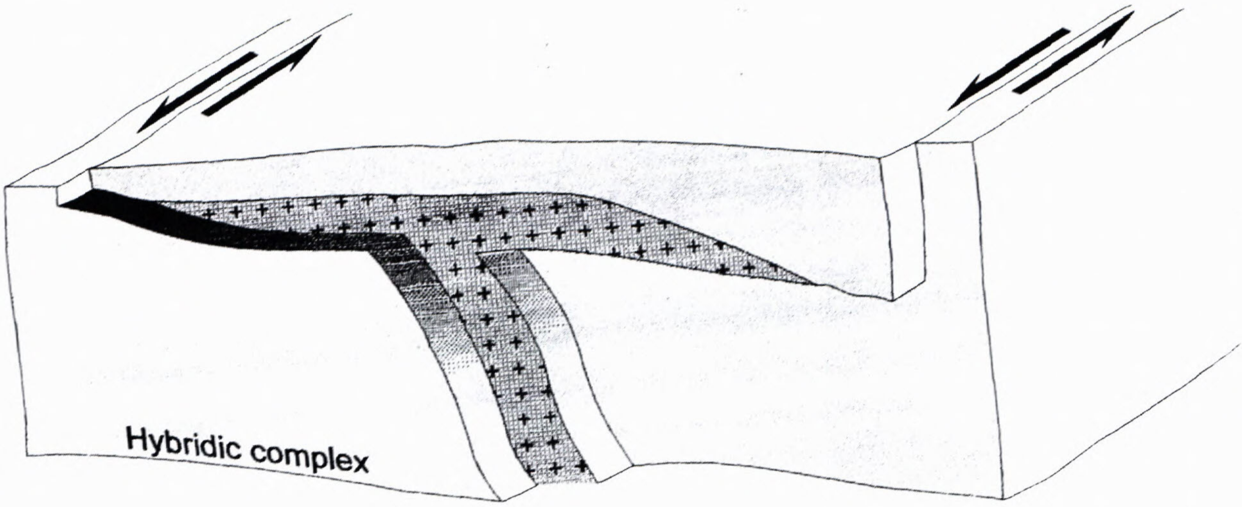

Fig. 4. Blockdiagram showing opposite sense of shear on the base of granitoid intrusion involved by regional sinistral transtension. Apparent change of kinematics during the intrusion of laccoliths regime (top to the East, top to the West) depending on the position of the part of intruding body.

- microscopic evidence of plastic deformation in magmatic plagioclases and biotites,
- a combination of grain-size reduction and marked elongation of fine-grained recrystallised aggregates into ribbon and spindle forms. The aggregates consist predominantly of feldspar and quartz, but also of new-crystallised muscovite or newly-formed biotite.

Metamorphic conditions of this deformation corresponded to the upper parts of the greenschist facies and they were similar to the metamorphic conditions of garnet micaschists (BEZÁK 1991).

With the above mentioned contact zone of the granitised complex and the Ostrá complex there are connected also the intrusions of leucocratic granites and amphibole diorites. This is evidence in favour of the important role of this zone in the Late Hercynian stage and they shift the foundation of the otherwise markedly Alpine line (Muráň fault system) at least to the Upper Paleozoic.

Structural manifestations of the Hercynian extension could not be unambiguously separated from the complex structural records, with the exception of sub-horizontally emplaced porphyric granites, where subsolidus and magmatic deformations are controlled by flattening, in some zones by shearing. This stage is indirectly indicated by the formation of Upper Paleozoic basins, volcanism, intrusions of leucocratic granitoids and strong hydrothermal activity.

Paleoalpine deformations resulted in the abundant development of sinistral transpressional shear zones in NE-SW direction. The compression was generally in N-S direction. E-W structures were rejuvenated again in this regime, acting as strike-slips. A typical feature of these shear zones is the with the deformation connected retrograde metamorphism in the lower greenschist facies. Compressional regime on E-W faults resulted in the formation of retrograde metamorphosed zones, several

Fig. 3. Diagrams of structural elements

A. Foliation in the hybrid complex. Direction generally E-W, in shear zones rotated to NE-SW.

B. Biotite lineation in the hybrid complex. Generally E-W, parallel with fold axes direction. In shear zones rotated into NE-SW direction. Locally preserved N-S lineation.

C. Chlorite and sericite lineation in the hybrid complex. Sub-horizontal lineation is predominant, having E-W to ENE-WSW direction.

D. Foliation in porphyric granitoids. In dikes it has E-W direction, in shear zones it is rotated into NE-SW direction. In laccoliths it is sub-horizontal.

E. Biotite lineation in porphyric granitoids. It is parallel with preferential orientation of feldspar phenocrysts. Kinematic indicators show sinistral movement in vertical bodies, at higher levels (subhorizontal bodies) is the interpretation of kinematics not unambiguous.

F. Chlorite and sericite lineation in porphyric granites. It is parallel with older lineation may be observed locally.

G. Foliation in cover arkoses and quartzites.

E. Chlorite and sericite lineation in cover arkoses and quartzites.

hundred meters wide, while the shear regime on NE-SW faults affected by the retrograde processes only several meters wide zones. A typical mineral assemblage is quartz + sericite + chlorite ± muscovite. In the crystalline complex, rocks affected by this deformation have usually the character of S-C mylonites, while the S-C structure is defined by the above mentioned mineral assemblage. This deformation stage is characterised by a transition from the transpressional regime into extension towards E to NE. In sub-horizontally emplaced porphyric granitoids in the uderlier of the cover, the extension resulted even in penetrative development of S-C mylonites, with the formation of the retrograde mineral assemblage quartz + sericite + chlorite. In the cover sequences the extension resulted in the dominant development of stretching lineation of chlorite and sericite, the indicators clearly and systematically indicating top to the east movement. At lower levels, where porphyric granitoids and the hybrid complex have vertical structure, extension resulted in further rejuvenation of E-W structures as dextral horizontal displacements. Sub-horizontal shear zones developed only sporadically.

In the Neoalpine stage the structural record of the continuation of the regime of extensive horizontal displacements are ambiguous (MARKO 1993). Tectonic development continued mostly in extensional regime connected with the development of Neogene basins, volcanism and downthrow of blocks on NW-SE and NE-SW faults.

Conclusions

Porphyric granotids intruded within E-W sinistral, probably transpressional shear zones, using older structural predisposition. They formed dike swarms parallel with the direction of the shear zone. At a decrease of the lithostatic pressure at higher levels the dikes passed into laccoliths, or similar intrusive forms, while at subsolidus and post-magmatic conditions flattening took place in the middle and shearing on the margins (transition into extension). In this way, these bodies reached the surface already in the Pre-Alpine time (unroofing) and the Mesozoic cover sedimented on them.

As far as the age of the studied porphyric granitoids is concerned, they probably belong to the end of the Meso-Hercynian tectonic stage (360-340 Ma, BEZÁK et al. 1995). They must be older than the intrusions of the Sihla granitoids (300 Ma, BIBIKOVA et al. I. 1990) and also older that the cooling of this part of the middle Hercynian lithotectonic unit in the sense of BEZÁK (1994) below 500°C (350-340 Ma, KRÁĽ et al. 1996). This magmatic pulse is indirectly indicated by the ages of leucoratic granitoid facies of the middle unit in Veporicum - about 350 Ma (BIBIKOVA et al. 1988).

The dike intrusions have been subsequently deformed within NE-SW oriented sinistral shear zones, the foundation of which is probably Neohercynian. This is supported by synkinematic mineral assemblages, which are higher-temperature than Alpine ones, and by the relationship of the Permian intrusion to such zones (PETRÍK et al. 1995).

The Paleoalpine deformation resulted in deeper zones in the formation of NE-SW transpressional shear zones (horizontal displacements) with local E-W strike slips and, in higher zones, thrusting. In the next stage of development, extension with transportation towards E to NE occurred on rejuvenated sub-horizontal planes, at lower levels also on inherited vertical E-W discontinuities. The movement on them was, in contrast to the Hercynian deformation, dextral and took place at lower P-T conditions.

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