Perpendicular fabrics in the Orlické hory orthogneisses (western part of the Orlice-Sněžník Dome, Bohemian Massif) due to high temperature E-W deformational event and late lower temperature N-S overprint

Kolmé stavby v ortorulách Orlických hor (západní křídlo orlicko-kladské klenby, Český masiv) - výsledek vysokoteplotní deformace směru V-Z a nízkoteplotního přetisku S-J (Czech summary)

(8 text-figs.)

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A dominant structural pattern of the mostly granitic core of the Orlice-Sněžník Dome is N-S stretching associated with general top-to-the-north oriented shearing. Detailed microstructural study of deformed granitic rocks has shown a more complicated structural evolution.

The early D_i ductile deformation is accompanied by partial anatexis. This E-W stretching is developed either in anatectic orthogneiss as a dominant feature or in deformed granites as a relict structure.

Dominant N-S linear fabric of D_{ii} overprints D_i structures so that they are scarcely macroscopically visible at few places. Dominant D_{ii} northward non-coaxial shearing reactivates original S planes in older granites as well as deforms originally unstrained rocks.

The complicated structural pattern of the Orlice-Sněžník Dome orthogneisses indicates two independent tectonometamorphic events from which the first one could be pre-Variscan. The second compressional event is undoubtedly Variscan in age.

Key words: orthogneiss, K-feldspar deformation, quartz fabric, structural evolution, Orlice-Sněžník Dome, Bohemian Massif

Introduction

The problem of origin of two perpendicular stretching lineations has been extensively discussed during the last decade (Cannat - Bouchez 1986, Burg et al. 1987, Melka et al. 1992).

Several lines of arguments imply that two mutually perpendicular stretching and mineral lineations can develop during continuous transition from thrusting to wrenching due to e.g., corner effect (Burg et al. 1987). The model of transpression (Sanderson - Marchini 1984) offers the possibility of development of perpendicular linear fabrics during single tectonic event (Melka et al. 1992).

However, other authors argued that the perpendicular fabrics had developed during two independent events under different thermal conditions (Bouchez et al. 1984, Cannat - Bouchez 1986). For instance, the main stretching lineation related to compressional event is commonly perpendicular to the direction of late orogenic extension (Malavieille 1987, Burg et al. 1994).

The granitic and migmatitic rocks forming a core of the Orlice-Sněžník Dome (OSD) were affected by strong ductile deformation during the Variscan orogeny (Zelazniewicz 1988, Cymerman 1992). Two mutually perpendicular linear fabrics lying on the same foliation plane were recognized in these rocks.

The aim of this paper is description of microstructures associated with individual linear fabrics, estimation of thermal conditions of their origin and the determination of chronological relationships between them. We try to discuss the possibility of the development of both orthogonal linear fabrics during single but complex Variscan deformation event or as a result of Variscan deformational overprint of pre-Variscan deformation.

Geological setting

The OSD is a large scale geological structure situated in the northeastern part of the Bohemian Massif (Fig. 1). The dome itself presents easternmost termination of Lugicum (Suess 1926). This region involves two different main units, the mostly granitic core and its metasedimentary mantle. The core is built of strongly deformed granitic rocks of the Sněžník Group and medium-grade micaschists of the Stronie Group. The western margin of the core is flanked by the low-grade metavolcano-sedimentary Nové Město part of the Zábřeh Unit. Going to the south, the medium-grade metavolcano-sedimentary Zábřeh Unit occurs in the superficial position on the OSD core. At the east under the OSD core, the NE-SW trending Staré Město meta-ophiolite unit occurs consisting of exhumed gabbro cumulates, metasediments and eclogites.

Three main generations of mesoscopic structures have been observed in metamorphic rocks of the Orlice-Sněžník Dome (Fajst 1976). The first one is represented by the foliation S_1, stretching lineation L_1 and isoclinal tight folds F_1. All these structures, trending N-S, are only developed in the core units.

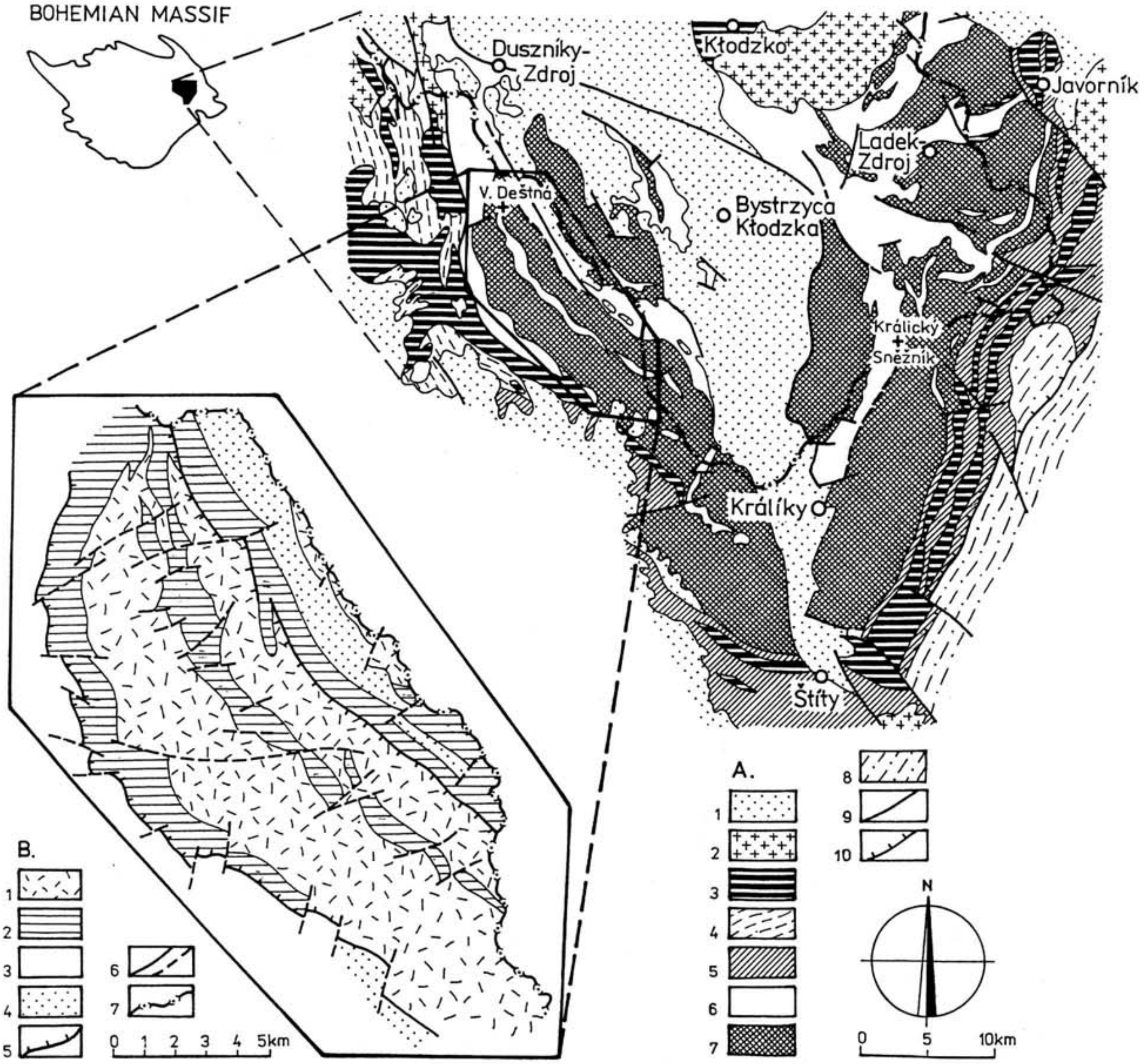


Fig. 1. Simplified geological map of the Orlice-Sněžník Dome (after Fajst 1976)
A. *1* - Upper Cretaceous; *2* - igneous rocks; *3-5* - mantle units (Zábřeh, Nové Město and Staré Město Units); *6-7* - core units: *6* - Stronie Unit, *7* - orthogneisses of the Sněžník Unit and migmatites of the Gieraltow Unit; *8* - the Jeseníky Mts. crystalline units; *9* - faults; *10* - Ramzová Overthrust
B. Key to inset (original by R. Přikryl) *1* - otrhogneisses and migmatites; *2* - mica schists; *3* - mantle units; *4* - sedimentary cover; *5* - Olešnice-Uhřínov Overthrust; *6* - faults; *7* - Czech-Polish boundary

The second stage producing S_2, L_2 and F_2 structures is typical for the surrounding mantle units, but exceptionally is also present in the core units. Last F_3 structures originated as asymmetrical flexural-slip folds and associated kinking.

The most prominent north-south stretching is explained by north-oriented shearing (Cymerman 1992) during the Variscan orogeny. Nevertheless, predominance of associated L to L>>S fabrics led Zelazniewicz (1988) during his research in polish part of Orlice-Sněžník Dome to assumption of N-S irrotational stretching due to E-W compression.

The whole rock Rb/Sr isochrone 489±11 Ma (van Breemen et al. 1982) records probably an intrusion of granitic body into the Stronie sedimentary group, while data of Steltenpohl et al. (1993) (Ar-Ar 329 Ma for muscovite from Sněžník Orthogneiss) record cooling of medium-grade metamorphism and deformation during the Variscan orogeny. This tectonometamorphic episode affected mostly the granitic core by strong deformation and mylonitisation and converted it to orthogneiss complex.

Rock types studied

The studied area is composed of heterogenous orthogneissic and migmatitic rocks of the Sněžník Group. Three principal groups of orthogneisses were recognized, differing substantially from each other in structural and metamorphic history.

Group I - anatectic fine- to medium-grained muscovite orthogneiss forms small outcrops near Rokytnice. Lenticular, strongly elongated aggregates consisting of recrystallized K-feldspar grains, 0.2 mm in size, are surrounded by matrix composed of quartz, plagioclase and muscovite ranging from 0.1 to 1 mm in size. The boundaries between feldspar aggregates and surrounding matrix are diffuse (Fig. 2a).

Group II - several large bodies of augen orthogneiss have been found in the OSD. Mica-rich layers alternate with monomineral quartz ribbons and lenticular aggregates composed of recrystallized K-feldspars or plagioclase. Sharp contacts between monomineral layers are well developed (Fig. 2b, c).

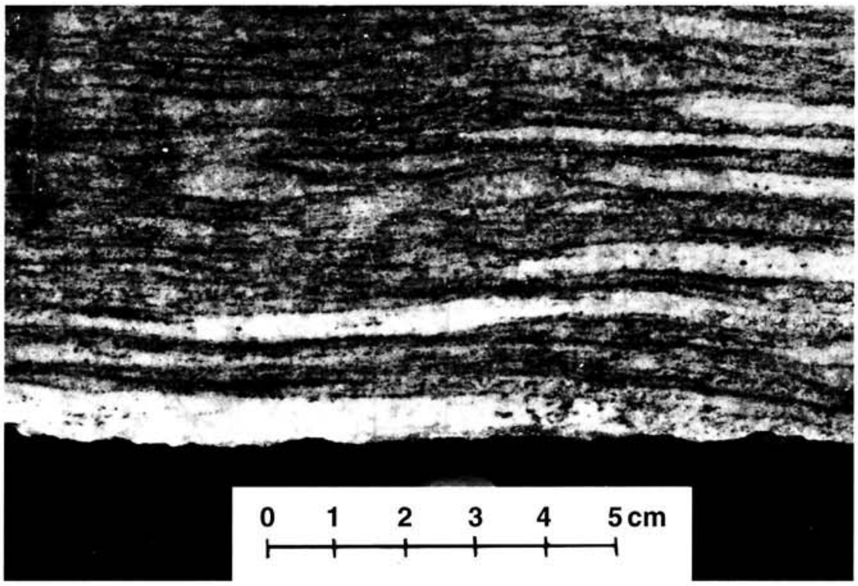
Group III - porphyroclastic coarse-grained orthogneiss is a dominant rock type in the Sněžník Group. Depending on the intensity of the deformation, two stages of granite deformation are distinguished - common porphyroclastic augengneiss (Fig. 2d) and strongly deformed mylonitic orthogneiss (Fig. 2e), consisting of pencil-like layers several millimetres thick. These rocks are built of K-feldspar, plagioclase, quartz and muscovite grains only. The porphyroclasts, usually 0.X-2 cm in size, are formed by perthitic feldspar.

The differences between these rock types are further explained by their diverse structural and deformational development.

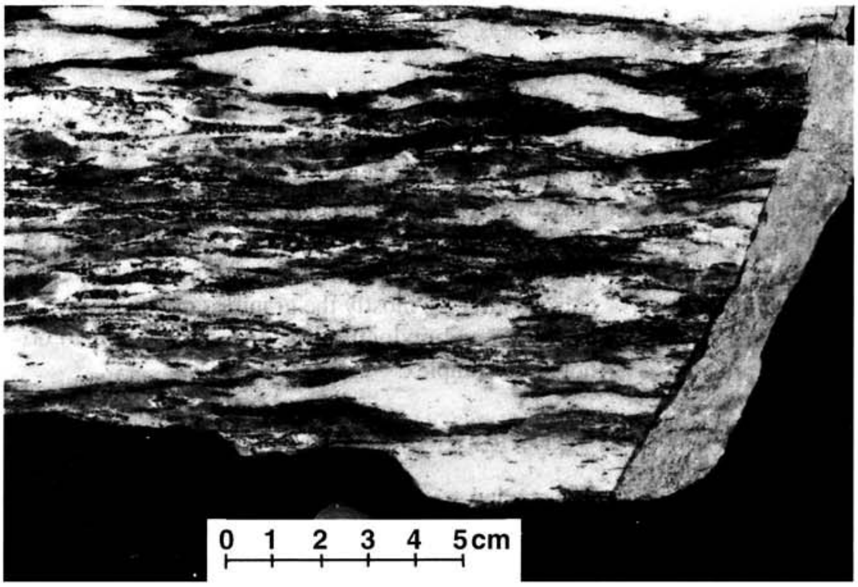
Planar and linear fabrics

One major planar structure has been recognized during the field work - metamorphic foliation S. This gneissic banding is marked by alternation of mica-rich layers with planar aggregates of quartz and augen feldspars. The foliation plane in the studied area strikes NW-SE and dips gently to the SW (Fig. 3).

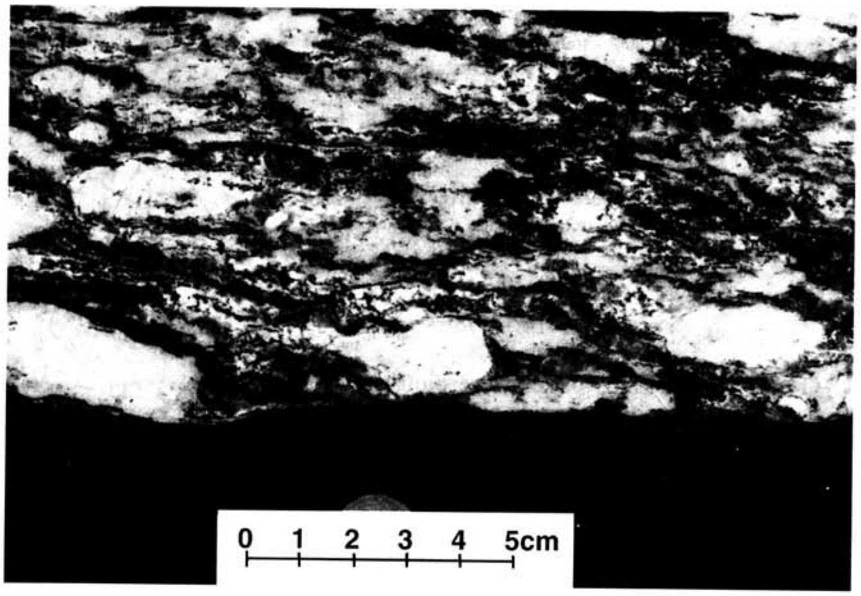
Fig. 2.



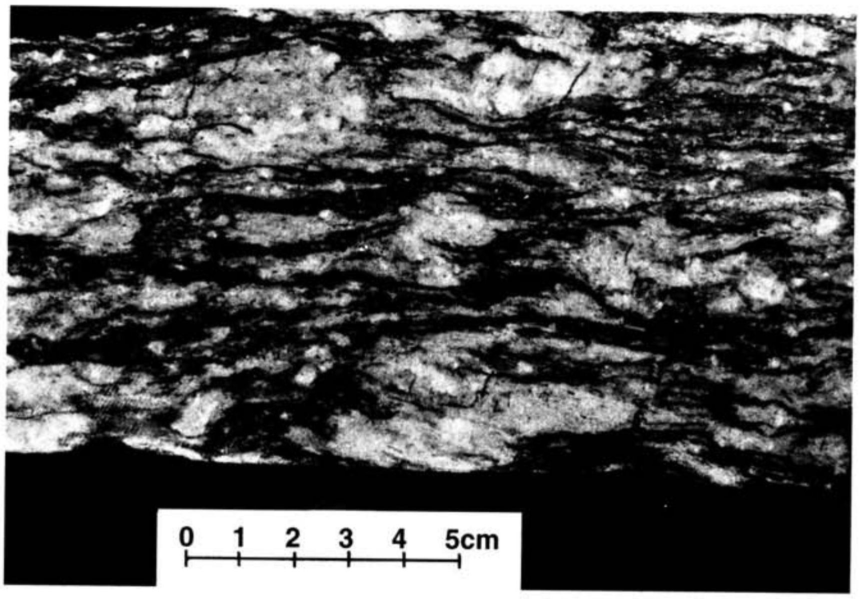
a - XZ section of anatectic orthogneiss (group I). Several bands elongated in E-W direction consist of fine-grained K-feldspar aggregates (Panské Pole near Rokytnice);



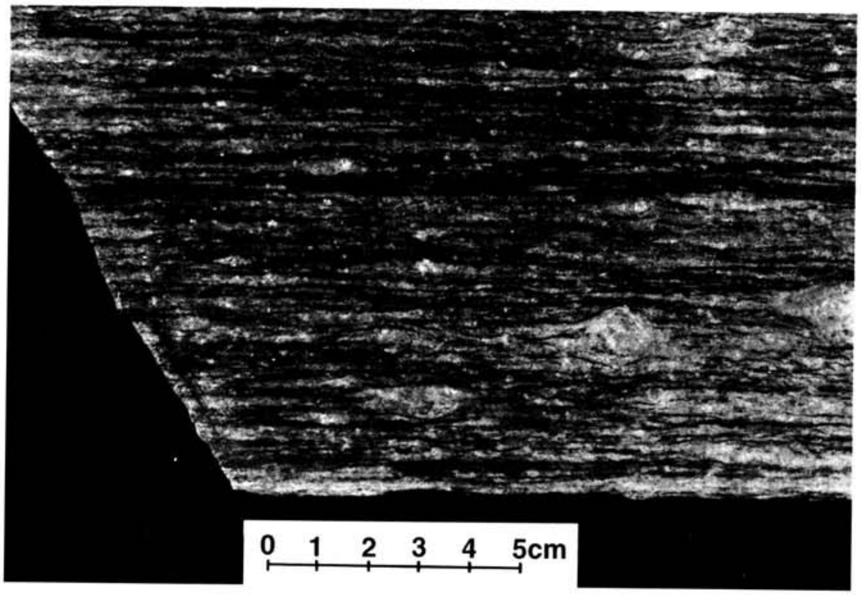
b - Coarse-grained orthogneiss with sheared K-feldspar aggregates (the E-W direction) (Panské Pole near Rokytnice);



c - In perpendicular section the K-feldspar aggregates show only slightly flattened shapes. In this section the quartz layers are strongly elongated parallel to L_{ii} stretching lineation (same sample as b);



d - Weakly deformed orthogneiss of type III (section XZ of D_{ii} finite strain ellipsoid) (Komáří vrch);



e - The XZ section of strongly deformed pencil-like orthogneiss of group III. Note the relict K-feldspar phenocrysts (Orlické Záhoří)

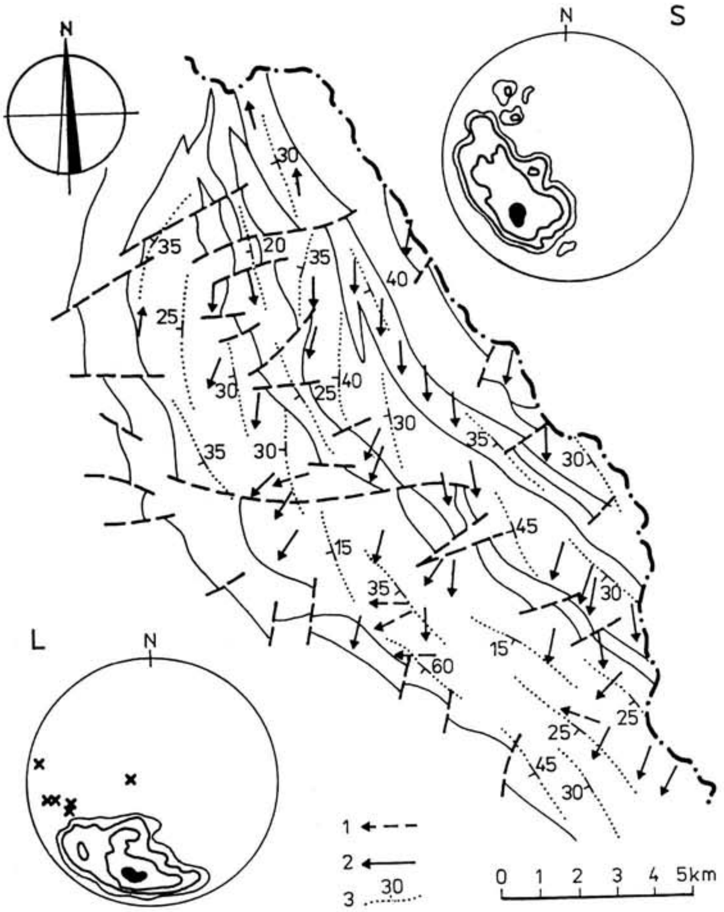


Fig. 3. Structural sketch of studied area
1 - trends of L_i lineation; *2* - trends of L_{ii} mineral and stretching lineation; *3* - trends of S gneissic banding
Contour diagram above the figure shows dip of the foliation planes S (271 measurements, contours at 1, 1.2, 3.8 and 12.1 %). Diagram in the lower part indicates the orientation of L_{ii} lineation (66 measurements, contours at 1, 2.5, 6.3 and 16 %), and L_i lineation, respectively (crosses), lower hemisphere equal area projection

Two different linear patterns were observed in the studied rocks. Lenticular aggregates of feldspathic grains in group I orthogneisses oriented E-W (L_i lineation, Fig. 3) correspond to the dominant structure of this rock type. Nevertheless, other components such as quartz lenses are elongated in the same direction.

Two mutually perpendicular mineral lineations appear in the foliation plane S in group II orthogneiss. L_i marked by elongation of large pinkish K-feldspar aggregates plunges to the W at low angles. Preferred orientation of quartz and mica grains defines the prominent N-S stretching (L_{ii}) on the same foliation plane (S, Fig. 3).

The structural pattern of group III orthogneisses exhibits exclusively N-S lineation (L_{ii}) on the S foliation plane marked by elongated and partly fractured K-feldspar clasts, mica and quartz grains.

Finite strain

Lenticular feldspathic aggregates (L_i lineation in orthogneisses of type I and II) and K-feldspar clasts of the orthogneisses with L_{ii} (N-S) lineation have been used as finite strain markers. Macroscopic measurements have been conducted in XZ and YZ sections of finite strain ellipsoid. X-axis of deformation is supposed to be parallel to the N-S trending stretching lineation (L_{ii}) for group III of orthogneiss or to the E-W direction (L_i lineation) for group I and II orthogneisses respectively.

Axial-strain ratio has been determined by "cord-method" (Robin 1977) using randomly oriented strain markers of unknown initial shape. Two orthogonal lines a_i, b_i were measured through weight-point of each object parallel to two axes of strain ellipse of the respective section. The axial-strain ratio is the logarithmic average of all a_i/b_i. K coefficients were plotted on the K-graph (Flinn 1962), (Fig. 4).

The resulting fabric ellipsoids calculated from average ratios fall into the apparent constriction field (Fig. 4). The E-W fabrics in orthogneisses I and II are plane strain to prolate with heterogeneous fabric intensity. N-S fabrics are strongly constrictional, which is in agreement with fabric study of Zelazniewicz (1988).

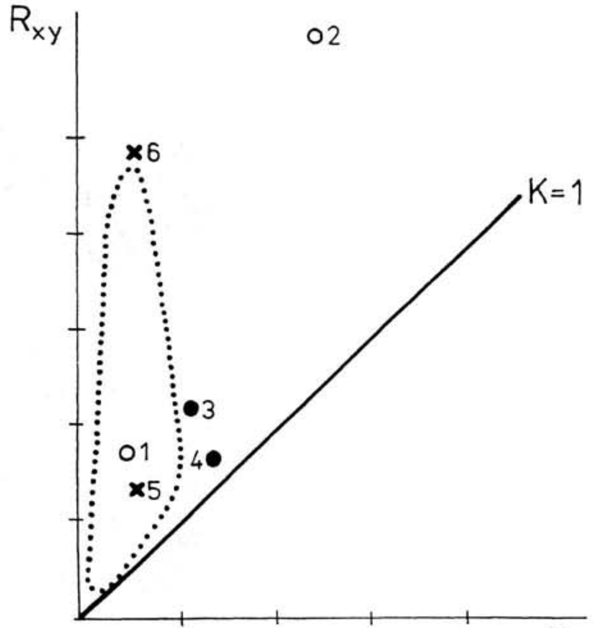


Fig. 4. Flinn (1962) K graph with results of strain analyses from the Orlice-Sněžník Dome orthogneisses
Circles indicate fabric ellipsoid of group I orthogneiss (1, 2 - orthogneiss near Panské Pole). *Black dots* show typical fabric for K-feldspar aggregates from group II orthogneisses (3 - orthogneiss from Panské Pole, 4 - orthogneiss near Bartošovice). *Crosses* show strain that affected group III orthogneisses (5 - coarse grained orthogneiss from Komáří vrch, 6 - strongly deformed pencil like orthogneiss near Orlické Záhoří). Dotted area indicates fabric ellipsoids according to the data of Zelazniewicz (1988)

Microstructures and crystallographic preferred orientations

Thin sections from each rock type were cut parallel to the XZ and YZ plane of the finite strain ellipsoid. The deformational microstructures, recrystallization mechanisms and crystallographic orientations of quartz and feldspars were studied. The orientation of quartz c-axes and optical directions of K-feldspar were measured optically using a universal stage and plotted onto lower hemisphere equal area projection.

Quartz

Two stages of quartz deformation have been recognized:

(1) high temperature deformation of quartz in anatectic orthogneiss (group I) near the solidus conditions. This microstructures are spatially related with the E-W L_i lineation,

(2) medium to low temperature deformation of group II and III orthogneisses connected with L_{ii} structural feature.

High temperature deformation

Quartz in group I of augen orthogneiss is present in the form of isolated subequant aggregates composed of large irregular grains with lobate boundaries indicating grain boundary migration recrystallization mechanism (Fig. 5a), (Urai et al. 1986, Gapais - Barbarin 1986). Characteristic intracrystalline features are prismatic subgrain boundaries parallel to the foliation as well as chess-board undulatory extinction (Blumenfeld et al. 1986).

The quartz c-axes form crossed girdle oblique with respect to Z axis of the finite strain with maximum distribution around Y. Small sub-maxima occur near L_i lineation (Fig. 6a). This type of c-axes distribution could be interpreted as combined prismatic <a> and basal <a> glide with presence of prism <c> slip (Bouchez - Pecher 1981, Blumenfeld et al. 1986).

Observed microstructures and possible presence of prism <c> glide suggests high temperature conditions during this deformation (Blumenfeld et al. 1986, Gapais - Barbarin 1986).

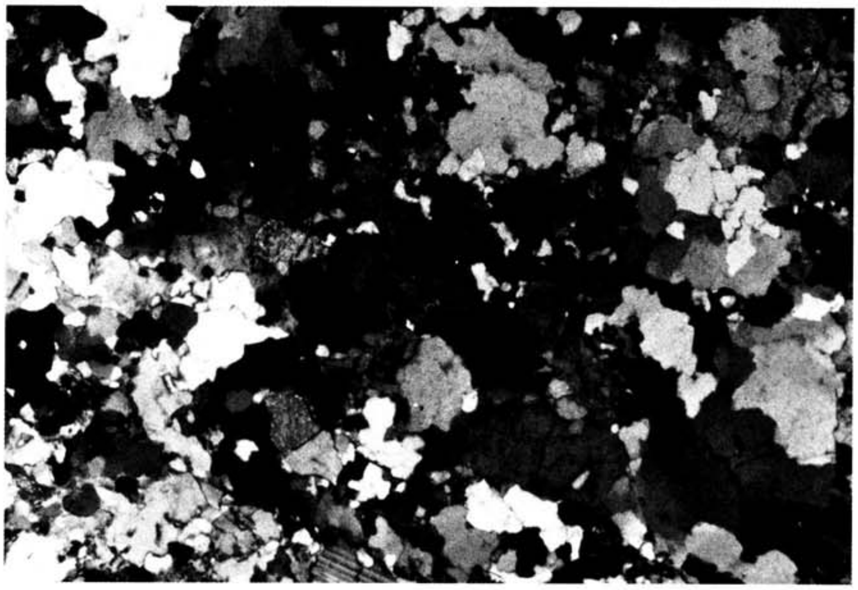
Low temperature deformation

The monocrystalline quartz ribbons of group II and III orthogneisses are composed of recrystallized grains with irregular grain size ranging from 0.1 to 0.5 mm. The recrystallized grains of irregular elongated shape form fabric oblique to ribbon boundaries. The grain boundaries are strongly serrated whereby indicating grain boundary migration recrystallization mechanisms (Fig. 5b). Numerous grains exhibit prismatic sub-grain boundaries oblique with respect to the grain elongation. Prismatic SGB form two groups with different orientation in XZ section parallel to L_{ii} which are symmetrically distributed with respect to grain elongation (Fig. 7a). The first dominant group is slightly inclined to the north from the Z axis and forms an angle of 60° with respect to grain foliation trace. The second group is also forming an angle of 60° with grain elongation but this angle is bissected by mesoscopic foliation trace. The prism SGB in YZ section perpendicular to L_{ii} are forming one dominant group slightly oblique with respect to foliation pole (Fig. 7b).

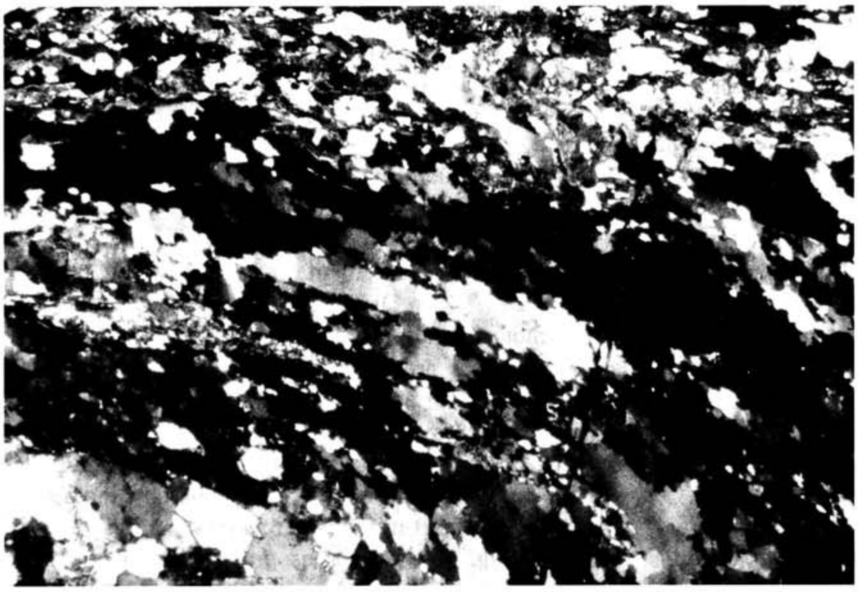
Quartz c-axes fabrics in orthogneiss group II form the characteristic type II crossed girdle pattern of Lister (1977) with a strong maximum parallel to the Y axis of the finite strain ellipsoid (Fig. 6b). This type of fabric is commonly interpreted as a result of dominant prism <a> glide (Bouchez - Pecher 1981).

The orthogneiss of type III shows characteristic type I crossed girdle pattern (Lister 1977) with dominant maxima close to the periphery of the diagram and a

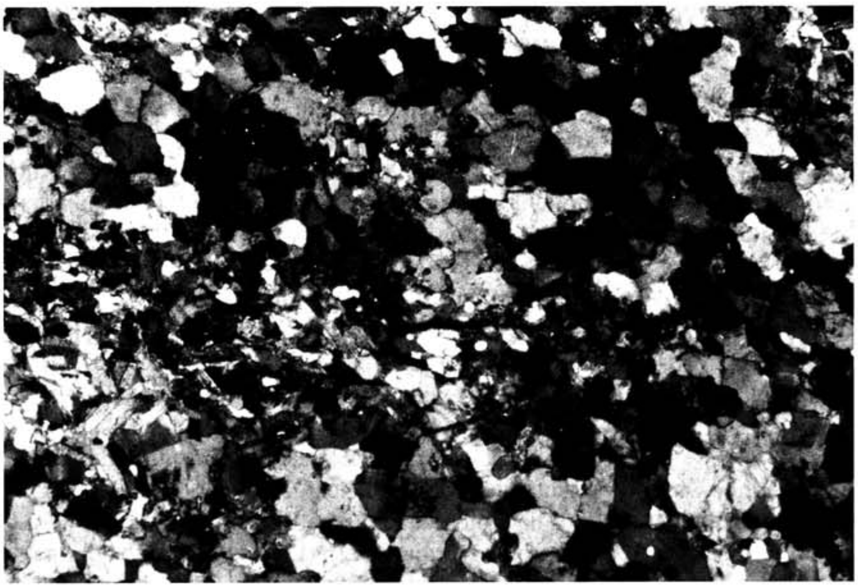
Fig. 5.



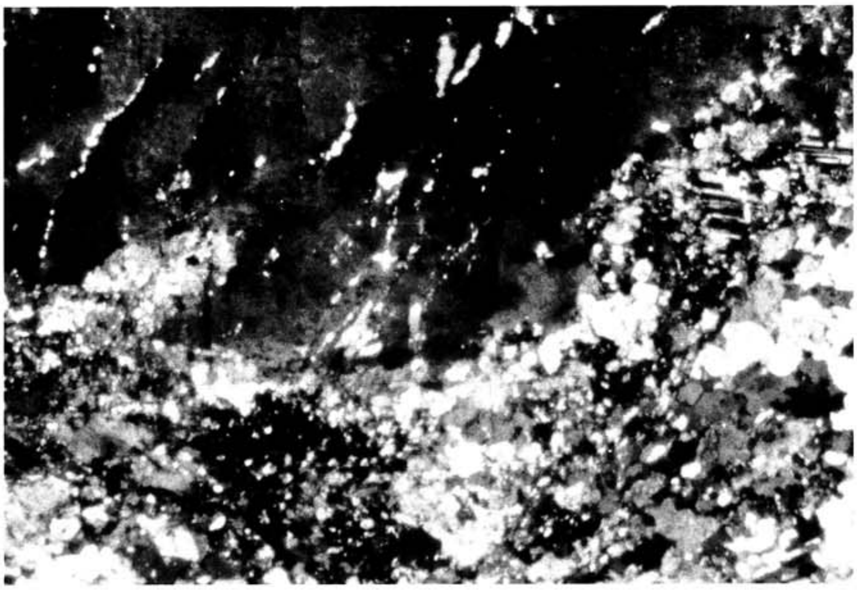
a - Micrograph of orthogneiss of type I showing irregular quartz aggregates with serrated-migrated boundaries and prismatic subgrain boundaries parallel to the foliation trace (orthogneiss near Panské Pole, magn. x23);



b - Micrograph of quartz microstructure in orthogneiss of type II shows recrystallized quartz grain by grain boundary migration mechanism. Note oblique grain shape foliation with respect to ribbon boundary (Panské Pole, magn. x23);



c - Micrograph of recrystallized K-feldspar aggregate showing high temperature texture marked by the tripple point network of well annealed recrystallized aggregate of K-feldspar crosscut by a thin shear zone decorated by destabilization products (white micas) (Panské Pole, mag. x23);



d - Micrograph of large K-feldspar clast in orthogneiss of type III showing kinkbands subparallel to fractures, oblique with respect to foliation plane (Orlické Záhoří, magn. x23)

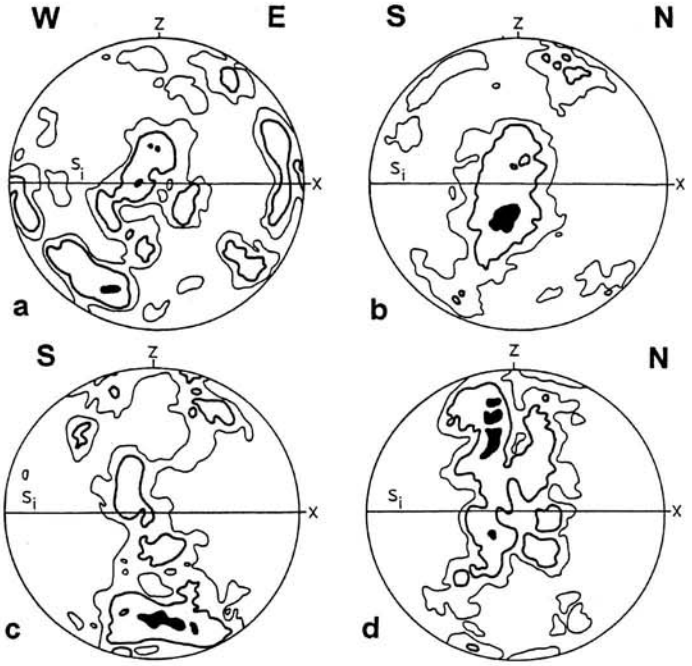


Fig. 6. Quartz c-axis patterns of all orthogneiss types. 200 measurements per plot, contoured by multiples of uniform distibution on lower hemisphere equal area projection
a - orthogneiss type I, measured parallel to L_i (Panské Pole area); b - orthogneiss type II, measured parallel to L_{ii} (Bartošovice area); c, d - orthogneiss type III, measured parallel to L_{ii} (Orlické Záhoří area)

weaker one close to the centre of the diagram. In such cases, quartz c-axes distribution may indicate presence of both basal <a> and prism <a> glides (Fig. 6c,d).

Asymmetrical distribution of quartz c-axes demonstrates non-coaxial character of the deformation (Schmid - Casey 1986) and indicates top-to-the-north oriented shearing. This is supported by orientation of the dominant group of prism SGB (Bouchez 1977).

K-feldspar

Microscopic observations show two different types of K-feldspar deformation. The deformation related to L_i shows features of HT deformation associated with dynamic recrystallization and annealing of feldspar while the L_{ii} lineation is related to feldspar destabilisation and fracturing.

HT deformation

Elongated feldspathic aggregates from group I and II orthogneisses contain almost equigranular mosaic of recrystallized K-feldspar grains 0.1 to 0.3 mm in size (Fig. 5c). Presence of tripple-points indicates extensive textural re-equilibration due to late- to post-tectonic annealing (Vernon 1974).

The U-stage study of crystallographic preferred orientation was performed in both type I and type II orthogneiss parallel to L_i lineation and showed the following features:

(1) ß-optical direction is distributed parallel to the elongation of whole feldspathic aggregate and lineation L_i (Fig. 8a,e);

(2) α-optical direction forms a strong maximum close to direction Y of D_i strain ellipsoid (Fig. 8b,f) and γ-optical direction is parallel with the pole of foliation plane (Fig. 8c,g).

Such a distribution of optical directions could serve as an indirect indicator of slip system in feldspars (Ji - Mainprice 1988) and may be interpreted as a combination of dislocation glide along (010) plane in <001> direction (Fig. 8d). The experimental work indicated possible activity of (010)<001> glide system at temperatures around 700°C (Tullis 1983). However, the experimental data are rather scarce and the dependence of slip systems on temperature is not clearly established by experimental work (Tullis 1990).

LT deformation

In K-feldspar porphyroclasts up to 2 cm long from group III orthogneiss, kink bands develop together with fracturing oblique to the grain elongation. Some fractures are filled with quartz. Feldspar clasts are affected by recrystallization at margins together with growth of strain-induced myrmekites along high pressure sides (Simpson - Wintsch 1989) (Fig. 5d).

The D_{ii} deformation is heterogeneously and rarely developed in recrystallized K-feldspar aggregates in orthogneiss of group II. Only some discontinous shear zones marked by growth of fine-grained white micas parallel to shear planes are present (Fig. 5c).

Discussion

The orthogneisses of similar mineralogical composition in the Orlice-Sněžník Dome have been subdivided

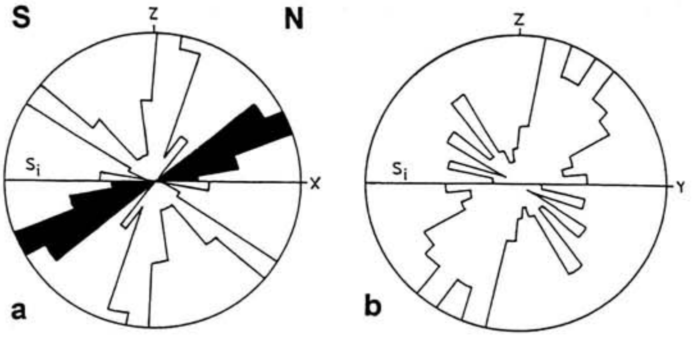


Fig. 7. Rose plot showing the distribution of prismatic subgrain boundaries orientation in XZ (a) and YZ (b) planes of D_{ii} deformation ellipsoid. *Black area* - field of grain shape orientations, empty areas - orientations of prismatic SGB. Note wide spectrum of orientations in YZ section (Orlické Záhoří area)

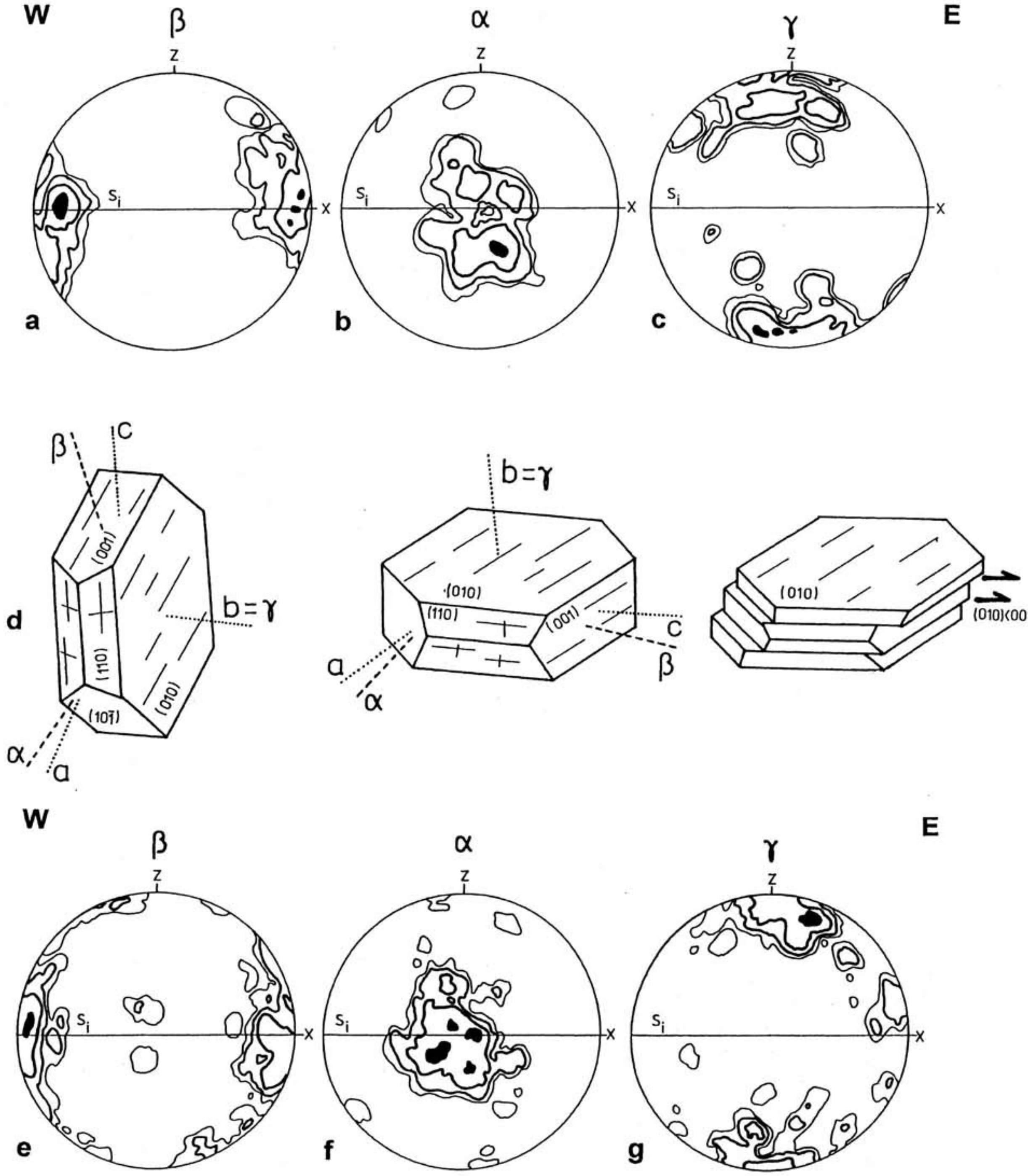


Fig. 8. Plots of K-feldspar crystallographic preferred orientation. Note the distribution of ß-optical direction parallel to the elongation of feldspathic aggregates in the E-W direction and γ-direction perpendicular to foliation plane. a, b, c - orthogneiss type I (66 measurements, contours at 1, 2, 4 and 8 %); e, f, g - orthogneiss type II (112 measurements, contours at 1, 2, 4.5 and 10 %). The possible slip system is suggested (d) [Bartošovice (a, b, c) and Panské Pole (e, f, g) area]

into three groups according to their different deformational history.

(1) Orthogneisses indicating exclusively a high temperature deformation (group I) show the predominant prism <c> glide in quartz and plastic deformation of K-feldspar marked by strong dynamic recrystallization accommodated by activation of (010)<001>. These microstructures show dislocation creep deformation mechanisms and indicate temperatures of deformation around 600 °C. E-W stretching of mostly feldspar aggregates is connected with prolate strain fabrics.

(2) Orthogneisses of group II which exhibit the polyphase tectonometamorphic development. The E-W relict stretching related to the high temperature deformation is documented by intense plastic reworking of K-feldspar accompanied with dynamic recrystallization and development of the strong crystallogarphic preferred orientation. This fabric is overprinted by

dominant N-S linear fabric affecting weak quartz domains and micaceous matrix. Quartz is strongly recrystallized and exhibits dominantly prism <a> and subordinate basal <a> glide.

(3) Orthogneisses of group III were affected by the medium to low temperature deformation connected with northward shearing. Basal <a> and subordinate prism <a> glide in quartz as well as brittle-ductile deformation of feldspathic clasts and growth of muscovite suggest conditions of lower amphibolite facies. N-S stretching exhibits prolate strain fabric.

A complicated fabric development of deformed granitic rocks in the Orlice-Sněžník Dome could be explained by the model of two independent deformational regimes. Early E-W ductile deformation D_i affected anatectic rocks under HT conditions. Thermal conditions of deformation could be hardly assessed but prism <c> slip in quartz and HT microstructures as a grain boundary migration and chess board extinction may be indicative of conditions near granite solidus (Gapais - Barbarin 1986). A high activation energy of K-feldspar recrystallization, large size of recrystallized grains as well as their high degree of textural equilibration are consistent with HT conditions of deformation. Moreover, the texture of the type I orthogneiss is characteristic for migmatitic orthogneiss near the granite solidus.

The orthogneiss of type II was originally a porphyritic granite strongly deformed under HT metamorphic conditions and later affected by medium to low grade deformational event. Early deformation of this rock type is preserved exlusively in E-W elongated feldspar aggregates. Dynamic recrystallization of K-feldspars produced the same crystallographic fabric pattern as in feldspars of type I orthogneisses. However, this fabric is macroscopically scarcely visible due to dominant quartz and micas alignment in N-S direction. Quartz domains in this rock type are interconnected and show an intense plastic deformation with an oblique grain shape fabric and crystallographic pattern parallel to N-S lineation.

We suggest that this rock type was strongly deformed during D_i deformation and feldspars and quartz have been mechanically separated into monomineralic domains. The weak quartz ribbons have been further used during D_{ii} as pathways of easy deformation while the feldspars were not affected by ductile deformation. This structure is of the interconnected weak layer type (Handy 1994) characterized by relatively small amount of weak fraction and high viscosity contrast. This particular texture and its inherited geometry is responsible for a strong concentration of viscous deformation into quartz layers during D_{ii}.

The orthogneisses of type III show only features of low temperature deformation characterized by brittle-ductile deformation of feldspars and dynamic recrystallization of quartz accompanied by basal <a> slip. We suggest that these rocks were not deformed prior to D_{ii} event. The dominant basal <a> slip in quartz in orthogneiss type III is explained by a higher stress concentration in interconnected quartz layers in orthogneiss of type II responsible for strong flow partitioning (Handy 1994).

Recent geochronological results show zircon ages around 500 Ma for most of rocks of OSD (Oliver et al. 1993) while the Ar/Ar ages for muscovite and hornblende (Steltenpohl et al. 1993) indicate cooling near 330 Ma through the 500° and 300 °C isotherms. Slightly older Nd/Sm ages (Brueckner et al. 1991) correspond to OSD eclogitic event. From this dating and structural studies of Cymerman (1992) follows that during the Visean times the eclogites had been transported into supracrustal levels along ductile shear zones and that the exhumation associated with orogenic collapse followed slightly later (Steltenpohl et al. 1993). However, these events are related to N-S oriented tectonics and are probably not associated with high temperature E-W fabrics in orthogneisses.

We suggest that the OSD basement rocks represent exhumed pre-Variscan continental crust characterised by pre-Variscan metamorphic and structural HT records. The relict high temperature E-W fabric (D_i) is most probably independent on N-S compressive Variscan event (D_{ii}). The strong anisotropy of deformed pre-Variscan rocks enhanced the later northward movements so that the early planar fabric was preserved and only new lineation developed by deformation of weak minerals.

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Kolmé stavby v ortorulách Orlických hor (západní křídlo orlicko-kladské klenby, Český masiv) - výsledek vysokoteplotní deformace směru V-Z a nízkoteplotního přetisku S-J

Hlavním strukturním rysem převážně granitického jádra orlicko-kladské klenby je sj. protažení spojené s pohybem na S. Podrobný výzkum mikrostruktur deformovaných granitických hornin odhalil mnohem komplikovanější strukturní vývoj jednotky.

První D_i duktilní deformace je doprovázena částečným natavením. Toto vz. protažení je vyvinuto jak v anatektických ortorulách jako hlavní strukturní prvek, tak i v deformovaných granitech jako reliktní struktura.

Převládající sj. lineární stavba D_{ii} přetiskla D_i struktury. Ty jsou proto rozeznatelné jen na několika málo místech. Dominantní D_{ii} nekoaxiální pohyb směrem k S využil původní metamorfní foliaci S v granitech, ale také postihl původně nedeformované horniny.

Komplikovaná strukturní stavba ortorul v orlicko-kladské klenbě ukazuje na dvě nezávislé tektonometamorfní události, z nichž první mohla být prevariská. Pozdější deformace je nepochybně variského stáří.