Fe-Ti Oxides in Selected Volcanic Rocks of the České Středohoří Mts.

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The České středohoří Mts., volcanic hills, situated at the northwestern margin of the Bohemian Massif, were formed simultaneously with the formation of the Ohře Rift. The volcanic rocks consist of complexes of basic to acidic rock types. The Upper Cretaceous to Tertiary volcanism is characterized by two intraplate magmatic series: the older (75–50 Ma) unimodal ultramafic, ultra-alkaline melilite-bearing series, and the younger (40–18 Ma) bimodal (basanite – phonolite) alkaline rock series; the latter being characteristic of highly volcano-active rifts (Ulrych and Pivec, 1997).

This study is focused mainly on the Fe-Ti oxides occurring in the following basic neovolcanic rocks: basanite, tephrite, trachyte, basalt. In these rocks, the Fe-Ti oxides costitute important, first crystallizing minerals. The elemental composition of the Fe-Ti oxide phases has been studied in polished thin sections employing an energy-dispersive system Link ISIS 300 equipped with an electron microscope CamScan IV. The was operated at an accelerating voltage of 15 kV and sample current of 2.5 nA.

The oxide minerals were distinctly visible in silicate matrix on the BSE images, which also revealed the presence of chemically distinct lamellae or cores within some grains. The oxide weight percentages obtained by chemical analysis were recalculated to empirical formulae based on the assumption of 3 cations and 4 oxygens per formula unit (p.f.u.) in spinel group minerals, and 2 cations and 3 oxygens p.f.u. in ilmenite group minerals, respectively. Such approach allowed determination of contents of both Fe^{2+} and Fe^{3+}. In addition to spot chemical analyses, we have also acquired several elemental distribution maps and line-scans to evaluate the character of zoning in titanomagnetite grains.

Optical microscope observations in reflected light and the BSE images revealed that the spinel-group minerals and ilmenite occur as almost euhedral up to completely anhedral grains from < 5 mm to several hundreds mm in length. Generally, ilmenite-group minerals are less common than spinels. Large spinel grains often contain silicate and apatite inclusions; the latter being frequently subhedral to euhedral. In some samples, spinel phases displaying marked zoning were found (in the basanites from Most, Úpoř - Pohradická hora, Dolánky, Děčín - Bechlejovice, Dobkovičky, Prackovice and in the tephrite from Chvojno); here, the boundaries between the individual zones were either sharp or gradual. Several titanomagnetite grains also contained ilmenite lamellae of various size (in the basanites from Křemý•, Všechlapy, Ústí n. Labem - Bukov, •ďárek, in the tephrite from Velká Javorská and in the trachybasalt from Kukla). In the titanomagnetite grains in some rock samples, the lamellae were rather narrow and abundant, whereas in other rock samples the lamellae were wide and less abundant.

The chemical composition of the ilmenite group minerals is invariable within experimental errors in specific samples. Ilmenite end-member concentration varies only slightly (50.3–51.9 mol.%) even among individual samples, higher variability occurs in hematite (Hem) and geikielite (Geik) end-member contents: Hem ranges between 35 to 45 mol.% and Geik from 4 to 16 mol.%. Chemistry of the spinel group minerals is varyingeven more. There is a difference between larger and smaller titanomagnetite grains in certain thin section as well as a significant variation in chemical composition between margins and cores in some larger grains in several samples. Most titanomagnetites are characterized by $Mg/(Mg + Fe^{2+})$ ratio between 0.00 and 0.25, $Cr/(Cr + Al)$ ratio below 0.2, and $Fe^{3+}/(Fe^{3+} + 2Ti)$ ratio between 0.2 and 0.6. Such chemical composition corresponds well with the data for titanomagnetites from basaltic rocks given in literature (Lindsley, 1991). All these ratios have been usually higher in the chromium-rich cores of some titanomagnetite grains compared with their marginal zone. Besides these two types, however, there are some spinel group phases having $Mg/(Mg + Fe^{2+})$ ratio in excess of 0.6 or those with $Fe^{3+}/(Fe^{3+} + 2Ti)$ exceeding 0.9.

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Tectono-Metamorphic Evolution of the Złoty Stok–Trzebieszowice Shear Zone – West Sudetes, SW Poland

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The Złoty Stok - Trzebieszowice shear zone (ZSTSZ), situated in the northern part of the Śnieżnik Metamorphic Unit is NE-SW trending belt which mainly consists of mica schists, gneisses and quartzo-feldspathic schists (the so-called “leptites”). This zone has attracted special attention as an important tectonic boundary identified by Bederke (1929) further to the south as the Variscan Ramzova Overthrust, which separates the West Sudetes and the East Sudetes. Other authors included the ZSTSZ into one tectonic line with the Niemcza Zone (Cloos, 1922). Rocks of the ZSTSZ underwent polyphase tectono-metamorphic evolution and show very complicated sequence of small scale structures. Classic structural studies, based on geometric analysis of the observed sequence of folds, were carried out by many investigators (e.g., Cwojdziński, 1976; Don, 1964; Dumicz, 1989). This led to separation of successive phases of tectonic deformation. Recently many authors, in the light of kinematic analysis, emphasized the importance of regional sinistral strike--slip movements at the contact of the East and West Sudetes (Aleksandrowski, 1995; Mazur and Puziewicz, 1995) or of (Cymerman, 1996) sinistral transpression, caused by the oblique collision of Variscan terranes.

The most characteristic lithological unit in the area are leptites. They are considered metamorphosed acid volcanoclastic rocks – tuffs and/or tuffites of rhyolitic type (Wojciechowska et al., 2001). Mica schists, adjacent to leptites, could have had similar protoliths. Their different mineralogical composition can be the result of stronger contamination of acid magma by clastic material.

The aim of this work is to combine geometric and kinematic approach of the structural analysis together with thermobarometric calculations based on mineral phases, the position of which is well-constrained in the analysed structures. The proposed scenario of a tectono-metamorphic evolution was established on the basis of field investigations, meso- and microstructural analysis and thermobarometric data. Two stages of plastic deformation were recognized. During the first stage (D1), parallel to the axial planes of folds F1, a penetrative foliation S1 was developed. Orientation of foliation S1 varies on small scale, showing maximum ~320/70. Relicts of folds F1 can be observed as intrafolial, isoclinal folds with thinned limbs. Their axes plunge at a low angle to the NE and NW.

Successive stage (D2) led, parallel to the transposed foliation, to shearing and mylonitization of rock masses in the entire area. This stage of deformation also led to the development of folds F2, deforming foliation S1. No penetrative foliation can be seen parallel to the axial surfaces of these folds, which only locally are accompanied by recrystallization or even fractures. Instead, parallel to their axial surfaces, shear band cleavage (S2) was developed. Stretching lineation L2S - plunging at low angle to NE and SW, lying on the great circle with axis ~125/15 – is seen on the S2 surfaces. Lineation L2i is due to intersection of S1 and S2. L2i lineation, together with F2 folds axes lie on the great circle of the stereographic projection with axis plunging at a low angle to the SE. According to the observations of shear sense indicators, which show the same kinematics in the entire area (lack of opposite shear senses on limbs of F2 folds), development of F2 folds can be connected with sinistral shearing, recorded by the stretching lineation L2S. Folds F2 might have originated before regional shearing took place but their geometry (tight to isoclinal, asymmetric, bivergent folds) indicates that they were formed in the same regime which caused the shearing. Anastomosing shear zones developed during D2 stage can be observed in the entire area under consideration. Heterogeneous shearing deformation led to the development of a lower strain areas between highly strained ones. The Bzowiec fold, recognised by Don (1964), being the largest fold structure within this area is situated in one of such low strain domains surrounded by the highly sheared zones.

The last stage of structural evolution in this area took place under low metamorphic conditions. Due to NE-SW shortening, open folds with NW-SE trending axes, together with kink bands with poles concentrated in opposite orientations 260/75 and 40-60/70 were developed.

In order to determine conditions of metamorphism, detailed petrographic and microprobe analyses of the studied rocks were performed. The mica schists comprise: st-grt-bt-ms-pl-and/sill-chl-kfs-qtz±ep. Peak metamorphic assemblage for these rocks is: st-grt-bt-ms-pl-chl-qtz. Subautomorphic garnet grains show chemical zoning: decrease in Ca and Mn with increase of Fe and Mg content from core to rim, which indicates their formation during progression of metamorphic conditions. Inclusions of biotite, muscovite, ilmenite and rutile are common in the central part of garnets whereas garnet rims are free of inclusions. Consequently,the garnet growth could be two-stage or it took place in changing chemical environment. Staurolite forms relics enclosed in blasts of andalusite. This suggests that the shearing took place under low pressure conditions at still high temperature. Leptites, considered to be metamorphosed acid volcanites, have poor mineral composition and consist of mu-pl-qtz±kfs±bt±sill/and.

Peak metamorphic conditions for mica schists were calculated at 620 °C and 8.7 kbar. Formation of the peak paragenesis is probably partly governed by the reaction grt + chl = st + bt. Conditions of later stage of metamorphism, estimated at 600 °C and 4,5–5 kbar, were inferred from mineral assemblage: bt-mu--pl-sill-qtz with garnet rim. The Si^{4+} content in white micas (phengite) is in good correlation with calculated pressures. Distribution of white micas, according to phengite geothermometry, gives two maxima at 4.8 and 9 kbar. The obtained P-T values show, that after the peak metamorphism under conditions of upper amphibolite facies, almost isothermal decompression took place.

Structural analysis confirmed the polyphase deformation and prograde metamorphism of rocks in the studied area. Progressive deformation under sinistral simple shear conditions of stage D2 controlled the majority of tectonic features observed in this area. The structural and thermobarometric data reveal that after D1 stage of deformation, leading to development of the S1 foliation, the studied rocks were subjected to burial corresponding to conditions of 8.7 kbar and 620 °C of the metamorphic peak. The second stage of deformation, connected with the development of the F2 folds and sinistral shearing, is characterized by lowering pressures at constant high temperature. Last stage of the structural evolution of the studied zone took place under low metamorphic conditions of ductile/brittle transition. Due to NE-SW shortening, open folds and shear bands were developed. The peak metamorphic conditions are probably connected with subduction-related burial during the Variscan convergence, whereas later decompression with progressive exhumation was caused by sinistral transpression.

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Structure and Episodic Tectonic Evolution of the Lower Crustal Accretionary Wedge: from Deep Retro- to pro-Wedge Orogenic Fabrics

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We reconstruct a cross-section (50 km – E-W) from the deepest part of the Moldanubian root zone represented by the Monotonous series to the west and Varied group to the east in the northern Waldviertel (valley of the German Thaya). In this section of the Moldanubian zone, the general orogenic fabric is traditionally interpreted in terms of a thin Gföhl gneiss and granulite klippen (relics of a lower crust nappe) overlying the middle crust sequences represented by the Monotonous series to the west and Varied series to the east (Fuchs, 1976a,b; Matte et al., 1991; Dallmayer et al., 1992).

The orogenic wedge structural pattern can be described as follows: The westerly Monotonous series metasediments show steep east dipping metamorphic fabrics. The adjacent western border of the Gföhl unit is represented by a sheet of ultrabasic rocks and amphibolites juxtaposed to strongly mylonitized Gföhl orthogneiss steeply dipping to the east. Towards the east the Gföhl gneiss becomes more anatectic and abruptly changes the dip direction to the west. The structural observations indicate that the west dipping anatectic fabrics overprint the east dipping ones. The western border of the Gföhl gneiss is limited by sheets of felsic kyanite-bearing granulites, mafic granulites showing the decompression textures of the assemblage clinopyroxene-garnet to orthopyroxene-plagioclase and kinzigites composed of sillimanite, garnet and hercynite. This thrust sheets occur in the hanging wall of the eastward Raabs volcanosedimentary unit which shows increasing degree of anatexis towards the east. The fabric of the Raabs unit is monotonously dipping to the west under intermediate angles. Locally, the main anatectic and isoclinaly folded fabric is refolded by late folds with east dipping axial surfaces.

This structural pattern is interpreted in terms of episodic evolution of a lower crustal accretionary wedge. Using the terminology by Ellis et al.(1999), the eastern part of this crustal scale structure represents pro-wedge side and its fabric is associated with westward underthrusting/subduction of the Brunovistulian foreland. We interpret the Gföhl unit as the deepest lower crustal part of the wedge symmetrically extruded over the mid-crustal units (uplifted central plug). The Monotonous series is seen as a retro-wedge behind the underthrusting zone. The retro-shearing along the border of the Monotonous unit (overlying rigid retro--lithosphere block) is responsible for the exhumation of the deepest part of the lower crust and upper mantle slivers. The pro-shearing affects the eastern part of the lower crust low-viscosity materials (granulites), which overthrust easterly located anatectic domain. The mineral assemblages of initially HP granulites indicate decompression and thrusting in relatively shallow crustal levels but still at very high temperatures. The extruding steep or intermediate dipping fabrics on the pro-wedge side are affected by late flat shear zones accommodating the gravitational collapse of the whole wedge structure. Therefore, the gravitational spreading on top of the extruded plug (Koyi, 2000) may be responsible for transition from vertical to horizontal fabrics in low-viskosity partially molten rocks of the Raabs and Gfohl unit.

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