Mineralogy and Thermobarometry of the Jawornickie Granitoids, Rychlebske Hory

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Determination of the temperature and pressure characterizing the formation and emplacement of intrusive rocks could be crucial for deciphering evolution of orogenic belts. This could be done from the character of the mineral assemblages in intruded country rocks, but there may be great uncertainties in this method, as discussed by Hodges and McKenna (1987). So the best way is to estimate final equilibration, i.e., consolidation of the magma, directly from magmatic mineral assemblages in the granitic rock. However, consolidation takes place over a range of P-T-f_{O2}-f_{H2O} conditions that could be imperfectly preserved in phase equilibrium or, more likely, still poorly understood. Further, some mineral assemblages commonly undergo subsolidus re-equilibration. Therefore, although thermometry and barometry of granitic rocks gave already considerable amount of information, a great care must be taken in interpretation of the results. In this paper, using available thermometers and barometers, the P-T conditions of emplacement and deformation of the Jawornickie Granitoids are determined.

Jawornickie granitoids, in the form of dikes and sills, are constituent of the Złoty Stok-Skrzynka tectonic zone. This zone consists predominantly of multiply deformed, medium-grade metasediments, gneisses and amphibolites. The details of evolution of the Złoty Stok-Skrzynka tectonic zone , such as amount of deformation episodes, spatial development of structures, the duration of the event, and the effects of granite emplacement processes are poorly understood. The same could be said about P-T conditions constrains. According to Kozłowska-Koch (1973) and Smulikowski (1979) dominant fabric has been developed under conditions typical of high-temperature amphibolite facies T = 650 – 700 °C and P = 2.0 – 2.5 kb. No further constrains have been made. The Jawornickie Granitoids are considered to be syn-tectonic on the basis of the field structural observations in the country rocks (Burchart 1958; Cwojdziński 1977). On regional scale, the margins of the main dike, 1–1,5 km thick, and smaller granitoid dikes are parallel to the country rock foliation. However, on the mesoscale these dikes locally crosscut the main foliation in the country rocks.

Analyzed plagioclase has the composition of oligoclase. Anorthite content varies in a range of 11 to 25%, with minor amount of K-feldspar (up to 0.6). Most of crystals are normally zoned, but grains with reverse zoning are also present. Biotites have quite uniform Fe/(Fe+Mg) ratios 0.4–0.55, and Ti content 0.11–0.15 (based on 11 O). Amphiboles have the composition of edenitic hornblende or pargasitic hornblende. White mica, if present, shows preferred orientation in foliated granites. Si atoms p.f.u. vary in range 6.14–6.22.

The temperature estimates derived from the calibration of reaction edenite-richterite of Holland and Blundy (1994), considered to be the lowest and most reliable, yield 660–730 °C. Al-in-hornblende barometer is not precise method for determining the depth of formation. However, as numerous analyse yield similar results, ~ 5,5 kbar, the reliability of the data increases considerably (the experimental calibration of Schmidt (1992) was used for barometric component). Pressures and temperatures obtained from the amphibolite sample collected in the Złoty Stok-Skrzynka tectonic zone yield 4.4–6 kbar and 620–660 °C.

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Development of Fracture Networks in the Melechov Massif and their Analysis

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Objective of the study is the determination of geometry of main fracture systems developed in the Melechov massif. We concentrate on genetic criteria of the fracture systems origin, their succession and behaviour during the later reactivation.

The internal part of the Melechov massif is composed of a complex of granitic bodies considered to be the northern part of the Moldanubian pluton. The marginal parts of the Melechov massif are built of fine- to medium-grained granites of the Kouty and Lipnice types which are exposed in several quarries and are objective of this study. The studied area, mainly located in the Lipnice type, lies in the eastern part of the massif near Dolní Město. Local rocks are represented by leucocratic granites composed of quartz, K-feldspar, plagioclase, biotite and muscovite exhibiting no solid-state deformation.

Detailed study of the outcrops shows that granite body is intensively fractured. We established several sets of fractures (joints and faults). Joints can be divided in to several sets basing on the field observations or statistically, using the orientation-based cluster method. Field analysis of joint sets allows determining of the density (or spacing), length and character of joints morphology (geometry of plume structures, twisted hackles, etc.). The temporal succession of the joints has been determined using criteria of relative joint age: i.e., younger joints terminate on the older ones, which can be assigned directly in the field. Sometimes, the relative geometrical relationships between joints cannot be established directly in the filed, so that the map of joints has been constructed using photographs. Such maps are further processed by special software.

The first (and oldest) determined set is nearly orthogonal system of vertical fractures commonly extending size of the outcrops (quarries). Individual fractures of two major directional groups non-systematically end-up on each other, so that we suggest their contemporaneous origin. Orientation of each group is spatially dependent and juridicates a concentric zonation of the massif. Origin of these fractures has been interpreted as a result of combined effect of isotropic thermal contraction, fabric anisotropy and/or regional stress.

The second determined set of fractures is represented by sub-horizontally oriented sheeted fractures and exfoliation planes. They are younger than vertical ones (as documented by systematic termination criteria) and their origin is related to an uplift and residual stress relaxation. The system of sheeted fractures developed deeper than the exfoliation. Exfoliation planes reach first tens of metres of depth, whilst sheeted fractures can range up to first hundreds of metres.

The final form of fracture network is intensively modified by tectonic (alpine?) reactivation. Surfaces of fractures are modified, showing numerous kinematic criteria (usually striations and fibers), and density of fractures locally markedly increases. Using the Angelier and Mechler (1977) method, generally north--south orientation of regional stress in time of reactivation was established.

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Metamorphic Evolution of the High Himalaya in the Makalu Region – Constraints from P-T Modelling and in-situ Th-U-Pb Monazite Dating

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The migmatitic gneisses in the Makalu – Arun Valley section (E Nepal) record a polyphase metamorphic evolution of the High Himalayan Slab. Syn- and post-kinematic garnet porphyroblasts in the gneisses are compositionally zoned and often contain inclusions of alumosilicates, plagioclase, micas, monazite and allanite that are suitable for P-T modelling and for Th-U-Pb spot-dating by laser ablation ICPMS.

An early high-pressure event is documented by the presence of kyanite relics in the garnet-biotite-sillimanite gneisses. The high-pressure event was followed by decompression and an increase in temperature that resulted in the kyanite to sillimanite transformation, and cordierite formation by reaction grt+sill+qtz+H_2O=crd. The partial melting of the High Himalayan rocks and their migmatitization is associated with decompression at the temperatures in the sillimanite stability field. The pressure and temperature conditions calculated for the garnet-biotite-sillimanite-cordierite-bearing gneisses correspond to 3.2–4.0 kbar and 600 ± 25 °C and they are interpreted as reflecting closure of the Fe-Mg exchange between garnet and biotite on the cooling path. Corresponding conditions (680 °C and ~ 4 kbar) have been reported from the host biotite-cordierite-sillimanite gneisses of the Makalu granite (Hubbard 1989).

In situ laser ablation dating of monazite inclusions in biotite, sillimanite, feldspar and quartz from the High Himalayan gneisses shows a record of polyphase metamorphic evolution between 35–21 Ma. The older monazites constrain a maximum age limit of ca 35 Ma for the sillimanite grade Barrovian metamorphism, while the younger monazite ages (~ 21 Ma) reflect a thermal event associated with the intrusion of the Makalu granite at 21.7–24.4 Ma (Schärer 1984). There is no correlation between the size of monazite inclusions in different metamorphic minerals, their ages, and location of samples relative to the granite intrusion. Maximum age of the Barrovian metamorphism recorded by Th-U-Pb isotopic systems in monazite from the Makalu region corresponds to the timing of prograde metamorphism reported from the Everest region (36–28 Ma; Simpson et al. 2000) and Garhwal and Zanskar Himalaya (37–29 and 35–25 Ma; Vance and Harris 1999). It is, however, somewhat younger compared to monazite ages from the Nanga Parbat – Haramosh Massif (44–36 Ma; Foster et al. 2000). The age difference may be a result of propagation of deformation and metamorphism from west to east related to diachronous collision of India and Asia.

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