Kontinentales Tiefbohrprogramm der Bundesrepublik Deutschland

Schwarzwald, Oberpfalz; Stable Isotopes

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One of the main projects of KTB is the investigation of fluids in the deeper crust and their interactions with rocks. **O,H isotope analysis** combined with **microthermometric research** and mineral analysis of **retrograde phases** are important indicators of water/rock interactions. Questions related to the origin of fluids, temperatures of interaction and chemical exchange processes can thus be answered. Within the framework of the reconnaissance studies of KTB, four granitic plutons of the SE-Schwarzwald (St. Blasien and Albtal: biotite granites, Schluchsee and Bärhalde: two mica granites) and one pluton of the Oberpfalz (Falkenberg) have been investigated.

Results:

Normal magmatic O,H isotope composition of granitic rocks vary in the range 6.0 to >10.0‰ and from -50 to -80‰, respectively. Any rock with lower ^{18}O or D content must have exchanged isotopes with a low (^{18}O, D)-reservoir which is restricted to meteoric water only. In **figure 1** the ^{18}O data of constituent minerals (Qz, Fsp, Ms and Bi) are compiled. The fractionations between the minerals are not in magmatic equilibrium (T≥600°C) as illustrated by the uppermost line: quartz, if at all, is depleted to a very small extent, whereas feldspar and biotite are most depleted due to their fast exchange rates. The most

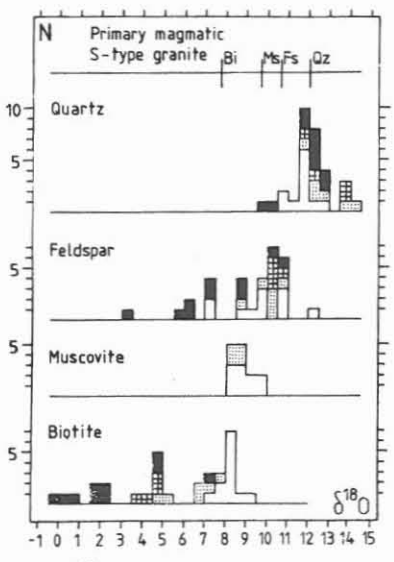

Fig.: 1 $\delta^{18}O$ histogram of minerals from SE-Schwarzwald granites. (Symbols: GBH open, GSCH pointed, GA crossed, GSB filled.)

depleted biotite has a $\delta^{18}O$ value as low as -0.4‰. This disequilibrium patterns can be explained by isotope exchange in an open system at temperatures lower than 600°C and different water/rock ratios.

In terms of ternary feldspar thermometry temperatures between 250° and 350°C for two mica granites and between 400° and 550°C for biotite granites were calculated. Fluid inclusion thermometry yields several maxima in a broad spectrum of homogenization temperatures (not corrected for pressure). One maximum between 250° and 290°C occurs in two mica granites. Such temperatures are rare in biotite granites. Temperatures between 320° and 390°C are very abundant in both types of granites. Thus, different events of hydrothermal activity at different subsolidus temperatures are supposed to be involved in fluid/rock interaction.

With respect to hydrogen, whole rock, biotite/chlorite, muscovite/sericite and fluid inclusion H_2O in quartzes have been analyzed. As shown in **figure 2** the most depleted phase is biotite which is recrystallized to varying extents to chlorite. The higher the chlorite content the larger is the depletion in D and ^{18}O. The initial D isotope composition of the fluid phase can be obtained by direct analysis of fluid inclusions in quartz (average of several generations) which yields a δD value of about -90‰. This value suggests an initial $\delta^{18}O$ value of -12‰ for the meteoric water whose $\delta^{18}O$ and δD values are correlated with geographic altitude by the meteoric water line (MWL) as shown in **figure 2**. Although the most depleted biotites/chlorites are in D/H equilibrium with this meteoric fluid, $^{18}O/^{16}O$ equilibrium is not reached because of slower exchange rates and higher concentrations of oxygen in the minerals. Water/rock ratios as high as 0.5 to 1.0 atom-% oxygen are required for this degree of depletion. Optical evidence for this high grade fluid infiltration arises from cathode luminiscense.

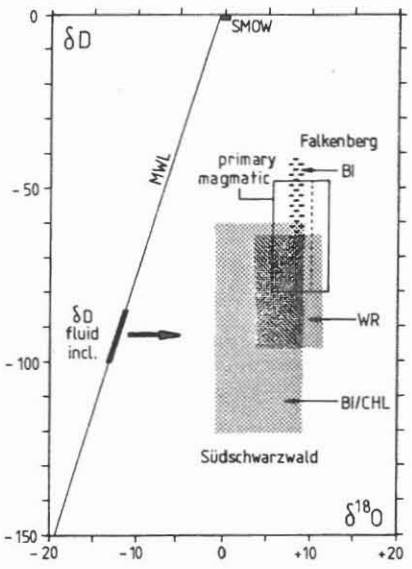

Fig.: 2 δD-$\delta^{18}O$ diagram of whole rocks and biotites from the Schwarzwald and Oberpfalz.

In normal magmatic assemblages muscovite is about +20‰ heavier in deuterium than coexisting biotite. However, in the two mica granites (Bärhalde and Schluchsee) muscovites are generally depleted in deuterium relative to biotites (up to -31‰). This can be explained by late stage D isotope exchange of biotite with isotopically heavy formation waters not affecting the D composition of the muscovite which was prior depleted by interaction with the meteoric fluid. In addition, feldspar exhibits in some samples of the Bärhalde pluton negative ^{18}O fractionation to quartz which may be also caused by exchange with formation waters. Thus, there is evidence for mixing of waters of different origin in the upper intrusion level of the two mica granites.

Secondary aqueous fluid inclusions in quartz are very abundant throughout the granitic rocks of the SE-Schwarzwald. They are low in salinity (<10% $NaCl_{equival.}$) and have homogenization temperatures between 200° and 450°C. Increasing average homogenization temperatures are directly linked with the degree of isotope depletion as it is shown in **figure 3** for biotites and to a lesser degree for quartz. Lower temperatures are consistent with high $\delta^{18}O$ values of biotite in the two mica granites. Parallel to a decreasing homogenization temperature an increase in salt content of fluid inclusion is observed which gives additional evidence for mixing with formation waters in upper parts of the two mica granites.

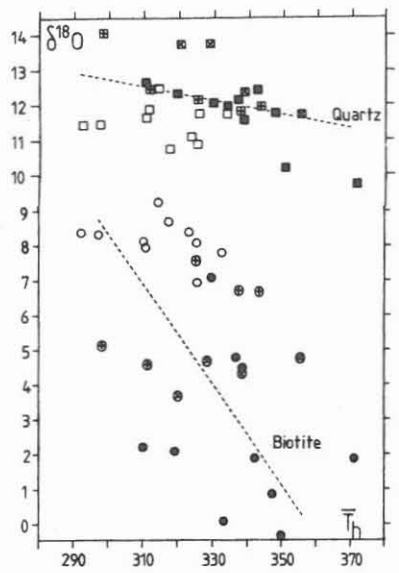

Fig. 3 Average homogenization temperatures of fluid inclusions related to $\delta^{18}O$ values of quartz and biotite from the SE-Schwarzwald. (Symbols: GBH open, GSCH + , GA x , GSB filled.)

Interaction of fluids with rock not only affects the isotope composition, but also controls the re-partition of elements or the retrograde recrystallization of minerals as can be shown for SE-Schwarzwald granitic rocks by microprobe analysis. The main reaction that occurs in the bioite granites is the disintegration of biotite to chlorite plus ilmenite ± sphene/rutile. Assuming the alumina content remains constant, losses of Si, Mg, Ba, K, Na, Rb, F and Cl are calculated within this reaction whereas Li, Cu and Pb are gained. Biotites of the two mica granites convert towards muscovite plus hematite with losses of Si, K, Na, Ba, Pb, Cl and F and gains of Li, Cu, Rb, Mg and Ca. Feldspars in both granites show sericitization and albitization which involves leaching of Ca, K, Ba, Sr and Pb and an increase of Na and Rb content as can be confirmed by analyzing feldspars that were altered to different extents.

A few number of biotites from the Falkenberg granite, Oberpfalz, were also analyzed. As shown in **figure 2** there is no evidence for interaction with a fluid of meteoric origin. The isotopic ratios are within the field of primary magmatic composition except one chloritized biotite with a δD value of -38‰ which may indicate the influence of formation waters.

Conclusion:

Granitic rocks of the SE-Schwarzwald have interacted with meteoric water after their solidification at temperatures between about 300° and 500°C. Late stage mixing of formation waters with meteoric waters in higher intrusion levels of the two mica granites at temperatures between 200° and 300°C is proposed. Granites from the Falkenberg, Oberpfalz, show no clear evidence for meteoric water interaction. However, interaction with formation water cannot be excluded.

More analysis of O,H isotope composit
rals and rocks will be carried ou
samples from the "Vorbohrung".