Large fossil hydrothermal systems in Variscan granites and pre-Variscan gneisses of the Schwarzwald

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The Schwarzwald is part of the Moldanubium core zone of the Variscan fold belt. The basement consists of ortho- and paragneisses of Caledonian and of Precambrian age. S-type granites are exposed in four different regions of the Schwarzwald: north, central, southwest and southeast. The granites of each region form a granite series, the separate intrusions being chemically and temporally related within each region. According to the petrogenetic model of Emmermann (1977) the evolution of the granites commenced with the melting of plagioclase- and biotite-rich paragneisses, producing large volumes of parautochtonuous biotite granites. Later melting at deeper crustal levels formed K-rich, water-undersaturated magmas that intruded to higher crustal levels (two-mica granites). Extensive Rb-Sr and more limited K-Ar and U-Pb studies indicate that granite magmatism occurs between 330 and 300 Ma in the southern Schwarzwald and at about 290 Ma in the northern Schwarzwald.

Mainly through the work of H.P. Taylor and coworkers it has become well established that certain igneous intrusions have interacted with meteoric groundwaters on a very large scale. The interaction and transport of large amounts of meteoric water through hot igneous rocks have now been observed in many localities. The aim of this study is to demonstrate that a very large fossil hydrothermal system occurs in the Schwarzwald, which has been already demonstrated in earlier studies by Hoefs and Emmermann, 1983; Simon, 1990; Taylor *et al.*1991. In contrast to these earlier studies which have concentrated on the granites of the South Schwarzwald we present here additional data on granites from the Middle and Northern Schwarzwald and on gneisses from the Southern and Middle Schwarzwald, which support the earlier conclusions, but also indicate (1) that hydrothermal alterations do occur in a much larger area and (2) that the hydrothermal history is more complex than originally thought.

Results

Petrographically the most obvious signs of alteration are the chloritisation of biotite and the albitisation of primary plagioclase, although these changes are not observed in all samples. These alterations cause chemical changes, which can be monitored by the K/Na ratios in feldspars and K/Al ratios in biotites. The clearest affinity towards typical magmatic values with relatively little signs of alterations show the granites from the Nordschwarzwald. Granites from the South Schwarzwald are split into different groups showing distinct K-enrichment in feldspar and variable K/Al ratios in biotites. Still another group is described by two-micas granites which have high but constant K/Na ratios in feldspars but variable K/Al ratios in biotites.

Further signs of strong hydrothermal alterations are recognized in *REE* whole rock spectra of the granites from the South Schwarzwald: while biotite granites show more normal patterns (except 4 samples), two mica-granites show broad patterns with huge Eu anomalies, indicating large fluid/rock interactions.

Alteration temperatures can be bracketed within the temperature range between 500 and 200°C (Simon,1990). Abundant secondary fluid inclusions in quartz are another common characteristic of the rocks investigated. They contain almost pure water with little salt content. Homogenization temperatures vary between about 200 and 400°C with a distinct distribution: biotite granites have generally higher homogenezation temperatures than two mica granites. The latter show higher salt contents than the former.

Oxygen and hydrogen isotopes show a distinct regional distribution.

Granites from the Northern Schwarzwald are relatively uniform in isotope composition and close to values being typical for magmatic equilibrium conditions.

In the Middle Schwarzwald the two different suites analysed drastically differ in their oxygen isotope composition. While the Triberg granite (all samples

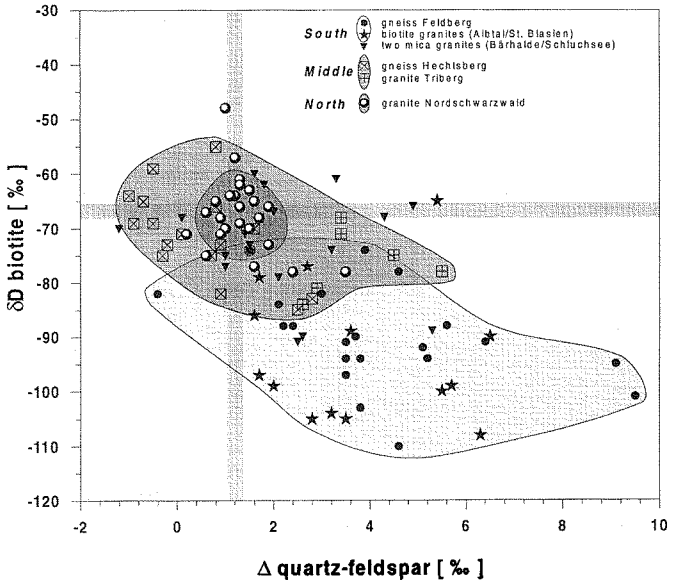

FIG. 1. δD of biotite *vs* Δ quartz-feldspar fractionation of granites and gneisses from different regions (south, middle, north) of the Schwarzwald.

are from a drill core) has a rather constant but very ^{18}O-depleted composition, orthogneisses from the Hechtsberg have a restricted more ^{18}O-rich quartz and feldspar isotope composition, but a rather large range in biotite/chlorite.

The Southern Schwarzwald exhibits a clear distinction between biotite and two-mica granites, as already described by Simon (1990). While the biotite granites (and the gneisses) show a large ^{18}O range with a characteristic ^{18}O-depletion, the younger two-mica granites are more ^{18}O-rich and have a restricted range with small fractionations among the minerals.

Hydrogen isotopes support this complex picture. Figure 1 combines quartz-feldspar fractionations, given as D-values, with δD-values of biotites. Figure 1 demonstrates the regional variation of δD-values rocks from the Schwarzwald. While the granites from the Northern Schwarzwald closely correspond to typical 'magmatic values', granites and gneisses from the Middle and Southern Schwarzwald are more depleted in D. Taking quartz-feldspar fractionations as an alteration index Fig. 1 shows different alteration trends which have a constant origin in common. The 'point of origin' of both alteration trends is reflected by the heaviest δD-values and quartz-feldspar fractionations of about 1 to 2 of the northern Schwarzwald granites. This isotopic composition can be regarded as the original composition of the very homogeneous precursor rocks of the granites and gneisses. The diversity in space indicates that fluids which differ in origin and evolution are involved during hydrothermal activity.

As Echtler and Chauvet (1991/92) have discussed the older biotite granites intrude within a compressional regime, whereas the younger two-mica granites are related to subsequent crustal extension. The change from a compressional to an extensional regime should facilitate access of surface waters to deeper parts within the crust. Thus the onset of the extensional regime might be regarded as the beginning of meteoric water penetration to deeper parts of the crust. $^{40}Ar/^{39}Ar$ dating on hydrothermally-formed adularia from various occurrences in the Schwarzwald give ages between 330 and about 150 Ma (Mertz, 1987). On some of these adularia the oxygen isotope composition has been determined. While adularia with Mesozoic ages have $\delta^{18}O$-values around 10‰, adularia with Variscan ages between 310 and 320 Ma have ^{18}O-values as low as −0.5‰ indicating the formation from meteoric waters in close connection with granite magmatism. Thus, in our view the main high temperature alterations occurred shortly after the intrusions of the granites.

The area affected by the described hydrothermal alterations is estimated to be at least in the order of 6000 km^2, which characterizes it as a very large system. However, at present it cannot be decided whether the alterations can be reduced to one event or to several ones being separated in space and time.