OXYGEN COMPOSITION OF QUARTZ AND CALCITE IN AMYGDULES OF BASALTS AS EVIDENCE OF COMPLEX ALTERATION HISTORY DURING LOW TEMPERATURE-HYDROTHERMAL METAMORPHISM

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The North Shore Volcanic Group in northern Minnesota, USA consists of an 8 km thick sequence of subaerial basaltic lava flows of Precambrian age and has experienced low temperature-hydrothermal metamorphism from a zeolite through prehnite-pumpellyite to beginning greenschist facies. Besides various Ca-Al-silicates, quartz and calcite are important alteration minerals and occur in amygdules mainly in the massive flow interiors.

Ten flows were selected within the various metamorphic zones and their quartz and calcite amygdules were analyzed for carbon and oxygen isotope composition using conventional and the in situ method. In addition, the least altered whole rock was analyzed.

The stable isotope values for oxygen (SMOW) in calcite in amygdules and veins obtained by conventional analysis range between 22.9‰ and 8.7‰. The values decrease with stratigraphic depth. Within a single flow, the differences vary depending on the regional metamorphic grade and the morphological flow unit. The $\delta^{18}O$ values in the amygdaloidal flow top are lower than in the massive flow interior. In the zeolite zone, differences of up to 2‰ are observed between flow top and massive flow interior whereas in the lowermost beginning greenschist facies differences of up to 9‰ are observed. The oxygen isotope values for quartz as analyzed by the conventional method follow a similar trend becoming lighter with stratigraphic depth and are in the range from 22.5 to 15.3‰ and the D values from -83 to -73‰. The values for zeolites (mainly scolecite) are in the range between 22.4 and 26.3‰.

Eight quartz amygdules have been analyzed by the in situ method from different depth of burial. Various trends can be observed within the amygdules. 1) The $\delta^{18}O$ value of quartz becomes lighter from the rim to the center of the amygdule which is consistent with an increase in temperature during formation. This quartz generation I only occurs in flows of lowest metamorphic grade. 2) A wide range of $\delta^{18}O$ values is observed and no clear trend in composition between rim and core is evident. Flows with quartz type II are also located in the lowest metamorphic zones. 3) The $\delta^{18}O$ values of quartz type III first decrease from the rim to the center and then increase again. This trend is shown by amygdules of flows of highest metamorphic grade or the prehnite-pumpellyite and beginning greenschist facies.

Figure 1 shows a possible scenario for the formation of quartz amygdules. Only the last quartz generations are considered. The precipitation process of quartz can vary great-

ly in the various amygdules within an individual lava flow. In the first stage of alteration of the zeolite zones, quartz precipitated from a meteoric fluid (quartz type I and II). In some amygdules, the composition developed according to a temperature increase due to burial metamorphism (quartz type I). Quartz characterized by oxygen patterns of type III can be explained by an increase in temperature during formation followed by a late input of mineral-derived water with a heavy oxygen isotope composition. This heavy meteoric water could have been derived from the breakdown of early formed OH-minerals such as smectites or zeolites which are not stable under the conditions of the beginning greenschist facies and will release their water content.

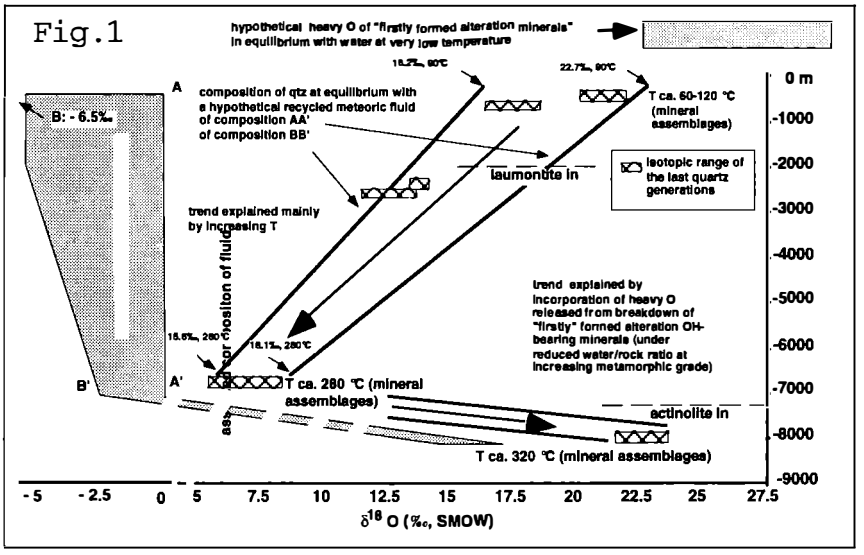

Fig. 1.
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