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Low-temperature water-rock interaction in basaltic rocks - using secondary mineral assemblages to receive information on the thermal, structural, and fluid evolution of altered basaltic provinces

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The secondary mineral assemblages of very low-grade basaltic rocks, characterized by mafic phyllosilicates and zeolites, are sensitive indicators of the thermal history of volcanic provinces. These minerals are frequently served as metamorphic indicators in very low-grade metabasalts. Detailed textural (i.e. cross-cutting relationships), mineralogical, and geochemical investigations on a small scale can provide appropriate information about the thermal evolution of basaltic rock piles. In general, several mineral assemblage stages are identified: (1) celadonite at near surface alteration; (2) mafic phyllosilicates (chlorite/smectite mixed layers) with increasing burial; (3) zeolite assemblage during burial, and (4) zeolite assemblages by later tectonic and hydrothermal events. Furthermore, a careful study of mineral assembles of individual stage can give information about the fluid evolution with time.
Two examples are presented to illustrate that information derived from careful field and laboratory studies in combination with phase diagram calculation can give knowledge about the thermal, structural, and fluid evolution history of the basaltic piles. (1) The basalts in the Hvalfjördur area in Western Iceland are affected by progressive low-temperature metamorphism, caused by the burial of the lava succession and higher heat flow from nearby central volcanoes. Low-grade zeolite facies metamorphism of basaltic lavas in the Hvalfjördur area results in two distinct mineral paragenesis that can be correlated to events in the burial and hydrothermal history of the lava pile. Stage Ia represents syn-eruptive near surface alteration in which celadonite and silica were precipitated along primary pores. During regional burial metamorphism (Stage Ib), hydrolysis of olivine and glass led to the formation of mixed-layer chlorite/smectite clays. The chlorite content of stage Ib phyllosilicate vesicle rims increases with increasing burial depth and temperature. Stage II occurred after burial and is marked by zeolite mineralization caused by higher heat flow from the Laxárvogur and Hvalfjördur central volcanoes. In total, three separate depth and temperature-controlled "zeolite zones" occur in the Hvalfjördur area. (2) The Kahrizak volcanic field in Iran has experienced variable degrees of alteration due to the regional low-grade metamorphism (Stage I) and hydrothermal activity (Stage II). Stage I alteration, which occurred in response to the burial of volcanic rocks, is characterized by the formation of low-temperature zeolite facies minerals in vesicles consisting of mafic phyllosilicates and various zeolites. Stage II alteration occurred due to the activity of hydrothermal fluids that formed large zeolite crystals along with quartz and calcite in cavities and fractures. The change from mafic phyllosilicates to zeolites species is caused by the decrease of Mg and Fe fluid activities. Low-temperature zeolite assemblage of stage 1 shows the general sequential order: chabazite, thomsonite, gonnardite, and natrolite. The sequence is consistent with a hypothetical fluid evolution path increasing in Na^{+} activity relative to Ca^{2+} activity. The change to stage 2, which consists of zeolites species formed at elevated temperatures, can be attributed to a temperature increase and fluid influx caused by hydrothermal activity.