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Chemical potential diagrams—a window to understand alkali metasomatism of natural rocks

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Fluid-rock interaction studies have important bearing to nuclear waste disposal programs. Isothermal-isobaric chemical potential diagrams constructed using the natural mineral data can be used as a tool to understand the metasomatic process.

1. Introduction

Study on fluid rock interaction (FRI) at different crustal level is important for its possible application in identifying suitable host rock for disposal of high-level nuclear waste. In this study we document the petrological evolution of metasomatic pelitic rocks (Chimakurthy, Andhra Pradesh) using chemical potential diagram constructed following Korzhinskii's method [1]. Initially the area was a pelitic (sedimentary) terrane that got invaded successively by mafic-ultramafic and alkaline suite of rocks. Alkaline rocks were emplaced along N-S and E-W trending shear zones and caused extensive alteration of the associated rocks.

2. Analysis of the samples

Detailed petrography of the samples was carried out using optical microscopes. Representative samples were analyzed by Electron Probe Micro-Analyzers (EPMA) with 15 kV acceleration voltage and 15 nA beam current. For quantitative analysis natural mineral standards were used and the raw intensity data were corrected for atomic number (Z), absorption (A) and fluorescence (F) using standard software.

3. Petrography and mineral chemistry

Major phases of unaltered pelite are garnet (Grt), plagioclase (Pl), spinel, corundum, ilmenite, magnetite, sillimanite, orthopyroxene (Opx), cordierite (Crd), quartz (Qtz) and k-feldspar (K-fs). Within or close to shear zones, biotite (Bt) — fibrolite (Als) intergrowths (without Qtz) are found to replace and / or pseudomorph porphyroblastic Crd and Opx. Similar replacement of porphyroblastic Grt by Bt-Als is noted at places in presence or absence of porphyroblastic Crd. Pl showed normal zoning in the shear zone. A relatively fine intergrowth of non-aluminous Opx+ Als replaced porphyroblastic Crd. Based on the above textural and mineral chemistry several balanced mineralogical equations could be formulated, which are used to construct the chemical potential diagram. It is evident from these equations that the mineralogical and compositional changes along the shears were brought about by addition of K_2O and H_2O. Absence of Qtz in the product of the above reactions probably indicates that SiO_2 was removed either as a volatile species like $Si(OH)_4$ [2] or as a soluble species like $SiO_2 \cdot nH_2O$. The maximum effect of alteration is noted in pelitic xenoliths caught up within alkaline rocks. These xenoliths are almost completely converted to biotite schist with more than 50 vol% of phlogopitic biotite.

4. Discussion

Geothermobarometric calculations indicate that the metasomatic alterations of pelites took place under 5 ± 1 kbar and $650+500^\circ$C.

Judging from petrography and mineral chemistry, phase assemblages of the study area can be defined in K_2O-FeO-MgO-Al_2O_3-SiO_2-H_2O (KFMASH) system. Of which FeO, MgO and Al_2O_3 acted as inert components and K_2O, SiO_2 and H_2O acted as perfectly mobile components. Since in this case total six phases participated in the metasomatic reactions (Grt, Opx, Crd, Bt, Als, fluid) so the system has one negative degree of freedom and hence multiple invariant points. The invariant point of interest in the present case is k-feldspar (K-fs) absent phase assemblage and is marked in Fig. 1 as [K-fs]. The slopes

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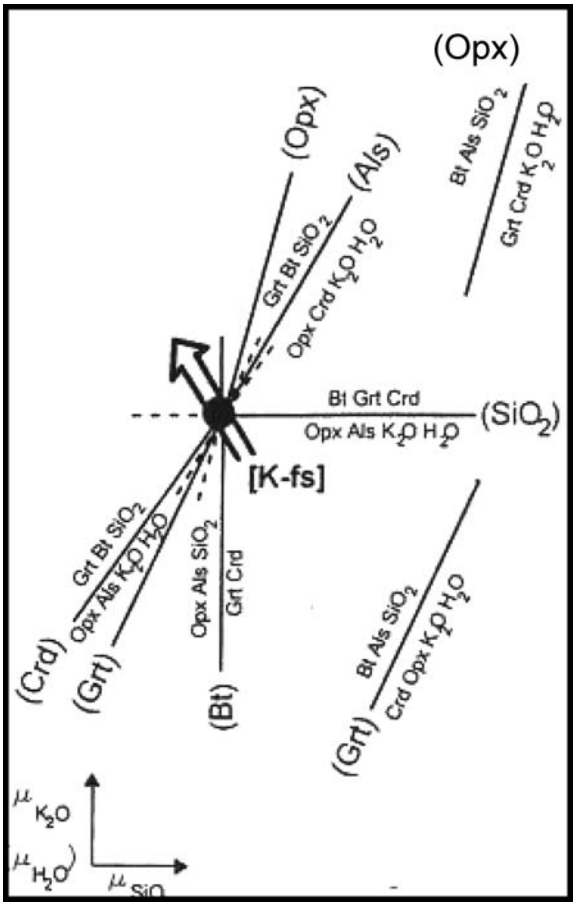

Figure 1 Chemical potential diagram showing the disposition of selected mineral equilibria. Arrow indicates the evolutionary path for the assemblages. (Opx: orthopyroxene, Crd: cordierite, Grt: garnet, Bt: biotite, Als: aluminosilicate).

of the univariant equilibria are calculated following Ferry and Burt [3].

As in all reactions K_2O and H_2O participated as reactants and SiO_2 was produced so topologically μK_2O-μSiO_2 is equivalent to μH_2O-μSiO_2. Thus a single isothermal-isobaric chemical potential diagram i.e. μK_2O (μH_2O)-μSiO_2 has been constructed (Fig. 1). The assignments of the reactants and the products along the univariant reaction have been done following Schreinemaker's rule.

It is apparent from Fig. 1 that Grt+Bt+Als assemblage is stable at higher μK_2O [and independent of μSiO_2] whereas Opx+Crd assemblage is stable at lower μK_2O. The association of Opx+Als, on the other hand, is independent of μK_2O, and is stabilized at lower μSiO_2 relative to Grt+Crd. The association Bt+Als+SiO_2 is stabilized at lower μSiO_2 relative to Grt+Crd+Opx, but at widely varying μK_2O. In the studied rocks, Bt+Als is found to appear without quartz. All these reactions can be considered as divariant related to (Grt, Kfs) and (Kfs, Opx), and are schematically shown in Fig. 1. However, if SiO_2 is removed in an open system, the univariant reaction (K_2O) and (Grt) can adequately explain evolution of the studied assemblages. In all the mineral associations described above, metasomatism caused stabilization of Als+Bt+Opx (non-aluminous variety) at the expense of Grt+Crd+Opx (aluminous variety). In the constructed grid, this would imply an increase in μK_2O and possibly decrease in μSiO_2. Similarly, an increase in μH_2O and concomitant decrease in μSiO_2 could result in stabilization of these metasomatic assemblages. Increase in μK_2O and μH_2O is best documented by the development of Grt+Bt assemblage (at the cost of Opx+Crd+Grt) within the pelite at the contact of alkaline rocks. Combining the interpretations from the grid, it is concluded that the studied pelitic rocks were metasomatised in a partially open system under increasing μK_2O and μH_2O and decreasing μSiO_2 conditions.

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