Quantification of chemical species mobility in volcanic rocks during low-grade metamorphism: application of the isomass method.

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Abstract. Quantitative estimation of the mass transfer of species (oxides and elements) together with the behaviour of immobile-mobile species, based on whole rock chemical concentrations of unaltered and altered rocks, is presented. As Grant (1986) revamped Gresens' (1967) version about isochemical equations, we present here the isomass methodology starting from a mass balance equation for a selected 100g of unaltered rock. The example shown is from a well known Miocene lava flow affected by zeolite facies burial-geothermal fluid alteration. The recognition and grade of immobile/mobile behaviour is evaluated. The contribution to the mass transfer process of each species can be determined. The isomass methodology should become a powerful quantitative chemical tool for the study of open system geological processes.

Keywords: Mass transfer, quantitative mobility, isomass.

1 Introduction

The mass transfer process operating in open systems has been a subject of investigation and debate in the last seventy years (Brinkley, 1946, 1947; Giggenbach, 1984; Karpov et al., 1997, among others). Gresens (1967) opened a line of thought for the theory of mass transfer in metasomatic processes. Grant (1986) revamped the equations used by Gresens and proposed the so called *isocon* methodology. Since then, a number of authors have worked, mathematically and geochemically, in order to estimate the elements mobility represented by *isocons* in the mass transfer processes. We have modified the approach of Grant (*1986*) changing the focus of attention to the whole mass estimation of the alteration product. Based on the concentration of the analysed species we can quantify the effect alteration events for each species. The mass difference of species between unaltered and altered rock, will provide a quantitative estimate of mobility. This approach is not restricted to an specific alteration process because it could be applied also to any kind of mass transfer process would it be magmatic, metasomatic, metamorphic or other.

2 Method, Samples, and Results

2.1 Method

In a mass transfer process we have that $m_i^s = m_i^p + dm_i$, where m_i^s represents the mass of component i in the altered rock, m_i^p represents the mass of component i in the unaltered rock and dm_i represents the infinitesimal mass variation of the i-th component. Grant (1986) derived the isocon equation ($C_k^s = \frac{M^p}{M^s} * C_k^p$). This theoretical formulation estimates the mobility of elements given the distance to the line defined by the isocon slope ($\frac{M^p}{M^s}$). We have redistributed the terms in Grant's formulae obtaining a mass estimate of the altered system (M^s). As a consequence it is now possible to estimate the mass of each species in the altered system for an arbitrary unaltered mass (e.g.100g of unaltered rock). If the species from which the mass estimation of the altered system has been made is immobile, then that species will have a nil mass difference. Those species overrating the mass value of the altered system relative to the value of the immobile species are referred to as *removed* components (oxides or elements). Those species underrating this value, are referred to as *included* components. After identifying the immobile mass, we can estimate the mass of each species in the alteration products. In this way it is possible to know if one species has been an *included* ($dm_i > 0$) or a *removed* ($dm_i < 0$) one. At the same time the degree of mobility of each species -as a percentage rate relative to the initial mass- can also be established. Finally, the amount of mass contributing to the total *included/removed* mass during the process is obtained for each species.

2.1 Samples

Rock samples from four zones of a Miocene lava flow from the Farellones Formation in the La Parva locality, central Chile Principal Cordillera, were taken: a) the most fresh , b) the most altered, c) one in between and d) one from the flow top. The flow is a plagioclase-clinopyroxene, olivine (pseudomorphs) and magnetite bearing basaltic-andesitic calcalkaline lava. Fractures, veinlets and amygdales are filled mainly with laumontite. Subordinate interstratified mafic phyllosilicate and chalcedony are also present in different proportions. There is a variable replacement of glass by oxidized clays, and a mixture of zeolite-mafic phyllosilicate (including celadonite) as revealed by microscope petrography, XRD and microprobe analyses. The rock samples represent a non pervasively oxidized zone that is considered here as a "fresh" zone (LP11-06), nearly devoid of amygdales and away from veins and major fractures (low fluid to rock ratio). Altered zones are: a highly fractured, amygdaloidal and veinlet-bearing zone (LP11-04; high fluid to rock ratio); and intermediate fluid to rock ratio samples from the centre (LP11-05) and the top of the flow (LP11-07). From the volume of the most altered sample (LP11-04) we have chosen four sub-samples (LP11-04-1A, LP11-04-02, LP11-04-03, LP11-04-05) to represent each departure from homogeneity in the sample. Major and trace elements were analysed, including lost on ignition weight percent with .

2.1 Results

When sample LP11-06, the unaltered rock, is compared with each one of the rest of the samples in the lava flow, the isomass method indicates that the trace element Co behaves as the immobile species ($dm_{Co} = 0$) during the alteration event within this system. Co shows the best correlation coefficient with Gd in the lava flow. However, in general a coherent behaviour between them is not characteristic. In fact, Gd is not an immobile species in this system since $dm_{Gd} \neq 0$. The present model of Co-immobile system yielded an estimated mass after the alteration event for each sample, all species considered, as follows: 113.56g (LP11-04-1A), 113.69g (LP11-04-02), 104.34g (LP11-04-03), 113.61 (LP11-04-05), 131.41 (LP11-05) and 104.03g (LP11-07). An increased of their masses is apparent in all the samples. The overall mass transfer estimation indicates that major elements *removed* are the alkaline metals (K_2O-Na_2O) along with divalent iron (FeO) and MnO. while SiO_2, CaO and MgO were *removed* in lower proportion. The *included* major elements are trivalent iron (Fe_2O_3) alkaline earth metals (CaO-MgO), TiO_2, Al_2O_3, SiO_2 and P_2O_5. Regarding trace elements, the *removed* species are alkaline metals (Ba-Sr), transition metals (Ni-Cu) and LREE. The *included* trace elements are: HREE, MREE and transition metals (Cr, Sc, Zn, Zr, V, Y) and LOI is always *included.* For per cent mobility estimations relative to the initial mass see Figure 1.

3 Discussion and conclusion

The model presented here stands as a powerful quantitative tool to the understanding of the mass transfer processes. The zeolite facies alteration event in the La Parva lava flow indicates that Co was immobile while Ba was the most mobile element. The oxidation process affected near 40% of the original divalent iron and the interacting fluid included trivalent iron, major alkaline metals, transition metals and H-MREE. This fluid took away major alkaline metal oxides and trace alkaline earth metals along with Cu and Ni. The overall efect of the alteration (zeolite facies) event can be summarized as follows: Metals with ionic potential below 2 were *removed* along with transition metals with ionic potential below 4.Metals with a ionic potential above 2 and transition metals with ionic potential near 8 were *included* by a calcic-magnesium-ferric iron bearing oxidizing fluid. The major elements are those contributing the most to the *removed* or *included* mass, even though the most mobile elements seem to be the trace elements, Ba in our case.

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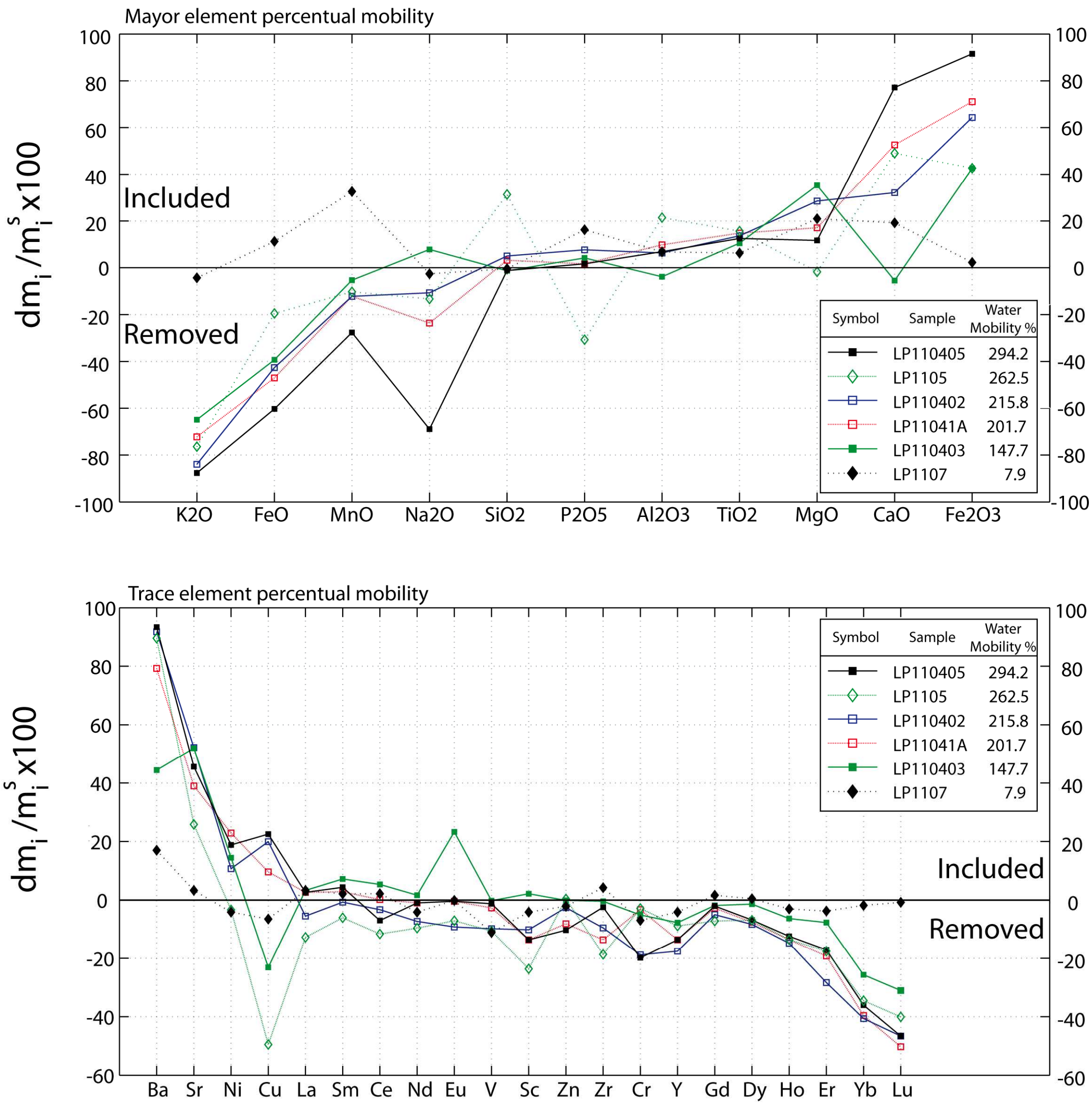

Figure 1. Species mobility as per cent of their initial mass for each altered sample, considering sample LP11-06 as the unaltered rock. In the ordinates each species is shown, major elements in the upper plot and trace elements in the lower plot. The inset shows the legend for each altered sample ordered by descending per cent amount of included water. Co is not shown as it is the immobile specie ($dm_{Co} = 0$).