
Recently many workers have emphasized the metamorphic features of eucrites (1-4) as well as their brecciated texture (5). Takeda et al. (1983) (4) have proposed a new thermal metamorphism scale which is based on the degree of homogenization of eucritic pyroxenes. We have examined the Mg-Fe chemical zoning of pyroxenes in eucrites and calculated the expected homogenization of the chemical zoning to test the proposed new scale.

Polished thin sections of Pasamonte and Juvinas were examined by using a JEOL scanning electron microscope with a PGT energy dispersive spectrometer (EDS). We observed chemical zoning of pyroxenes by back scattered electron image (BEI) and measured their Mg-Fe variations by EDS. We examined a large number of zoned pyroxenes in Pasamonte because the thin section is a two-dimensional surface, whereas the chemical zoning is three-dimensional phenomenon.

We found that the chemical zoning of Pasamonte pyroxenes can be classified into three types: [1] from Mg$_{54}$Fe$_{30}$Ca$_{5}$ core composition to Mg$_{19}$Fe$_{55}$Ca$_{26}$ rim composition (Fig. 1), [2] from Mg$_{65}$Fe$_{30}$Ca$_{5}$ to Mg$_{29}$Fe$_{55}$Ca$_{16}$, and [3] from Mg$_{65}$Fe$_{30}$Ca$_{5}$ to Mg$_{33}$Fe$_{56}$Ca$_{5}$. The Ca concentration in types [1] and [2] changes gradually in going from core to rim, but that in type [3] is almost constant. Type [3] pyroxenes are common in matrix. The rim composition in type [1] shows a lower Mg concentration (2) than that reported by Takeda et al. (4). However, the measured rim composition of a zoned pyroxene is strongly dependent on the spatial resolution of a microprobe so the extreme rim composition may be even lower in Mg than that measured by us or by Takeda et al. (4). Many zoned pyroxenes are present in Pasamonte which show a narrower range of Mg-Fe zoning than these three types. These results seem to be due partly to the two-dimensional cut of the zoned pyroxenes. In general, a random cut through a zoned pyroxene should show less than the maximum zoning of a cut directly through the center of the core.

On the basis of these Mg-Fe-Ca variation data, we have calculated the path of homogenization of zoned type [1] pyroxenes by numerically solving a diffusion equation. The diffusion process in three-component system is complex. We assume that each kind of atom diffuses independently. Pyroxenes often show exsolution phenomena. However, we have neglected the exsolution phenomena to simplify our model because our purpose is to examine the degree of homogenization of Mg-Fe zoning.

The Mg-Ca diffusion coefficient in pyroxene has been reported to be $6 \times 10^{-16}$ cm$^2$/s at 1200°C (6). The Mg-Fe diffusion coefficient in pyroxene has not been accurately determined. Its upper limit reported is $4 \times 10^{-14}$ cm$^2$/s at 1200°C (7). It is known that in olivine the Fe diffusion coefficient is larger than the Ca diffusion coefficient (8). Therefore, we assume $5 \times 10^{-15}$ cm$^2$/s at 1200°C for Mg-Fe diffusion in pyroxene. Activation energy for diffusion is assumed to be 86.25 kcal for both Mg and Ca diffusion (6).

The homogenization process calculated for type [1] pyroxene is shown in Fig. 1. The final homogenized bulk-composition (Mg$_{37}$Fe$_{48}$Ca$_{15}$) is similar to that of Juvinas (4). Annealing temperature is assumed to be 1000°C on the basis of a pyroxene geothermometer (9). It takes about $3 \times 10^4$ yrs at 1000°C to homogenize the Mg-Fe zoning of the Pasamonte-type pyroxene to that of the Juvinas pyroxenes, which show a limited range of Fe/(Fe+Mg) = 0.53-0.63 atomic ratio (4). Fig. 1 shows that metamorphic heating results in "steeper" Ca zoning in partly homogenized pyroxenes (3) because of the difference of atomic...
diffusion coefficients between Fe and Ca. The homogenization of type [2] zoned pyroxene yields the bulk composition \((\text{Mg}_{59}\text{Fe}_{41}\text{Ca}_9)\) similar to that of the pyroxene reported by Delaney et al. (1982) (3).

We also calculated the burial depth needed to produce the homogenized pyroxene. We assume a spherical cooling body with radius 500 km and initial temperature of 1200°C. If a rock-like thermal diffusivity of \(k = 0.004 \text{ cm}^2/\text{s}\) (10) is assumed, a Pasamonte-type pyroxene buried deeper than about 200 m will be homogenized. The overall cooling rate is about 0.3°C/yr. If it is located at less than 50 m in depth, it cools too rapidly for significant change in its Mg-Fe zoning. Another model is a cooling regolith sheet with \(k = 0.00001 \text{ cm}^2/\text{s}\) (11) and initial temperature 1000°C. If about 100 m thick regolith-like material covers the Pasamonte-type pyroxene, the pyroxene is homogenized (12,13).

Subophitic textures of Juvinas and Pasamonte suggest rapid cooling from an initial molten state (14). Our diffusion calculations, however, indicate that much slower cooling is necessary to homogenize the zoned pyroxene. Therefore, homogenization could not have taken place during initial cooling (autometamorphism). Homogenization must be related to later reheating events (3, 4, 12, 13). A relatively thin, hot regolith blanket could provide sufficient insulation for homogenization of pyroxene.

![Diagram of homogenization process](image)

References: