POSSIBLE CONTACT METAMORPHISM OF THE POLYMICT EUCRITE PETERSBURG. P. C. Buchanan[1] and H. Kaiden[1,2], [1]Antarctic Meteorite Research Center, National Institute of Polar Research, 1-9-10 Kaga, Itabashi-ku 173-8515 JAPAN. [2]Department of Polar Science, School of Mathematics and Physics, The Graduate University for Advanced Studies, 1-9-10 Kaga, Itabashi-ku 173-8515 JAPAN. (e-mail: buchanan@nipr.ac.jp; kaiden@nipr.ac.jp)

Introduction: Calculations suggest that a km-sized spherical laccolith emplaced into the crust of 4 Vesta would have caused contact metamorphism of adjacent rocks for 10^3-10^4 years. In contrast, regional metamorphism would have heated the crust for a period of 10^6-10^8 years [1, 2, 3]. Heating of underlying material by a lava flow or layer of hot impact ejecta of moderate thickness would have lasted for a period of 1-10 years [1, 2]. Fragments of diogenitic orthopyroxene in the Petersburg polymict eucrite have edges that are altered to more Fe-rich compositions to a distance of ~30 µm. These alteration rims are consistent with heating of the breccia to a maximum of 850°C with cooling at 0.16°C/year to 400°C during a period of ~3000 years and are similar to effects expected from contact metamorphism.

Contact Metamorphism: Most of the metamorphic effects among HED meteorites have been attributed to either regional metamorphism [1, 2] or burial beneath a lava flow or a layer of hot impact ejecta [e.g., 4; see also 5, 6]. Another possible mechanism is contact metamorphism associated with the intrusion of a late-stage magma body into the crust of 4 Vesta. The thermal effects associated with the intrusion of a spherical laccolith of 1 km diameter were calculated, based on equations from Lovering [7] and Jaeger [8]. Results for a eucritic magma intruded into a spherical laccolith of 1 km diameter at 1.5 km depth are illustrated in Fig. 1. These results are part of a larger group of calculations reported in Buchanan [9]. Initial temperature of the magma was assumed to be 1200°C [10]. However, it must be noted that a diogenitic magma would be significantly higher in temperature (~1300°C) and, hence, this temperature is a minimum [10].

In an attempt to consider the effects of latent heat of crystallization, an effective initial temperature (T_0*) was calculated on the basis of the equation

$$T_0^* = T_0 + \frac{L}{c}$$

where T_0 is the initial temperature of the magma, L is latent heat of crystallization, and c is specific heat [8]. L was assumed to be 90 cal/g, which seems appropriate based on the discussion in Jaeger [8]. The specific heat of the magma was assumed to be 0.24 cal/g·°C. These calculations indicate that contact metamorphic effects associated with an intrusion of this size will last for 10^3-10^4 years with maximum temperatures of 800-850°C. These temperatures are comparable to, though slightly above, those suggested for metamorphic aureoles surrounding some terrestrial magma chambers [e.g., 11]. Temperatures of 400-600°C will be experienced by the surrounding wall rock as far as 100 m from the contact with the magma chamber. The volume of this metamorphic aureole is ~3.812×10^8 m^3 compared to a volume of ~5.236×10^8 m^3 for the magma chamber.

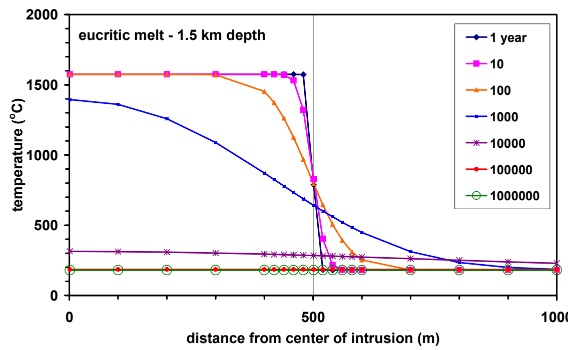

Fig. 1. Distance from the center of a spherical laccolith containing eucritic magma with a diameter of 1 km vs. temperature for a variety of time periods subsequent to emplacement.

The Petersburg polymict eucrite: Several features suggest that the polymict eucrite Petersburg experienced an episode of post-brecciation thermal metamorphism. Hewins [4] suggested that compositions and textures of metal in the matrix of the meteorite were the result of metamorphism caused by burial beneath a layer of hot impact ejecta or beneath a lava flow. Podosek [12] and Podosek and Huneke [13] determined that ^{39}Ar release patterns for Petersburg are similar to those expected for diffusive loss, possibly caused by metamorphism. Buchanan and Reid [14] noted that the edges of diogenitic fragments, which are up to 1.5 mm in diameter in the available thin sections, were altered to more Fe-rich compositions to a distance of ~30 µm and this alteration was the result of Mg-Fe interdiffusion between the brecciated matrix of the meteorite and the orthopyroxene grains. Pyroxene fragments that are smaller than 50-60 µm in diameter in the brecciated matrix of the meteorite also have compositions that suggest equilibration with the bulk composition of the meteorite.

Fe-Mg interdiffusion calculations: In an effort to determine whether these alteration zones could have been caused by contact metamorphism, we calculated the compositional profile caused by Fe-Mg interdiffusion for the expected temperatures and time period using the diffusion coefficient data contained in Ganguly and Tazzoli [15]. Results are compared in Fig. 2 with EPMA analyses acquired at the edge of a 1.5 mm grain of diogenitic orthopyroxene in the Petersburg breccia. Although these conditions probably do not result in a unique compositional profile (i.e., different temperatures and time periods may give similar profiles), a good fit was provided by assuming a maximum temperature of 850°C cooling to 400°C at a linear rate of 0.16°C/year over a period of ~3000 years.

Several limitations are obvious for this treatment. First, it is unlikely that the cooling rate will be constant, but will decrease with dropping temperature. Second, the maximum temperature of the wall rock is almost certainly overestimated, because the latent heat of crystallization will be released over the entire crystallization interval of the magma, rather than during the initial stages of crystallization, as is assumed by calculating the effective initial temperature in this manner. Hence, the cooling path will be more complicated than either linear or exponential cooling. Nevertheless, these calculations provide a rough estimate of the time period and temperature range required to generate this compositional profile.

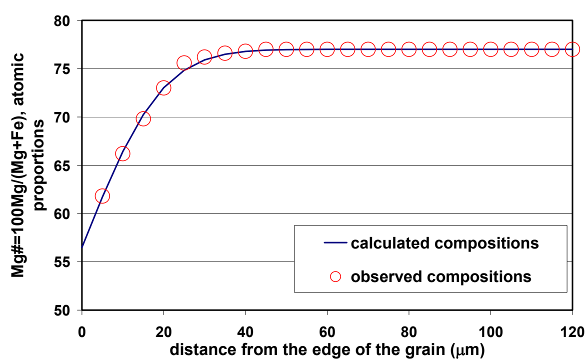

Fig. 2. Calculated zoning profile for an orthopyroxene grain that experienced thermal metamorphism similar to that expected adjacent to an intruded eucritic magma body compared to EPMA data acquired at the edge of a diogenitic fragment in Petersburg. See text for details of calculations.

Conclusions: Compositional zoning profiles at the edges of diogenitic pyroxenes in the Petersburg polymict eucrite are similar to those calculated assuming conditions expected for contact metamorphism. These conditions, and especially the period of time expected for metamorphism (10^3-10^4 years), are quite different from those suggested for regional metamorphism (10^6-10^8 years) and burial of surficial materials by a lava flow or a layer of hot impact ejecta of moderate thickness (1-10 years). This suggests the possibility that Petersburg represents a breccia that was metamorphosed by intrusion of a late-stage magma body into the shallow crust of Vesta.

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