DEPTH OF FORMATION OF LUNAR AND TERRESTRIAL ANORTHOSITES AND GABBROS FROM COMPOSITIONAL PROFILES OF EXSOLVED PYROXENES I. S. McCallum and H. E. O'Brien, Department of Geological Sciences, AJ-20, University of Washington, Seattle, WA 98195

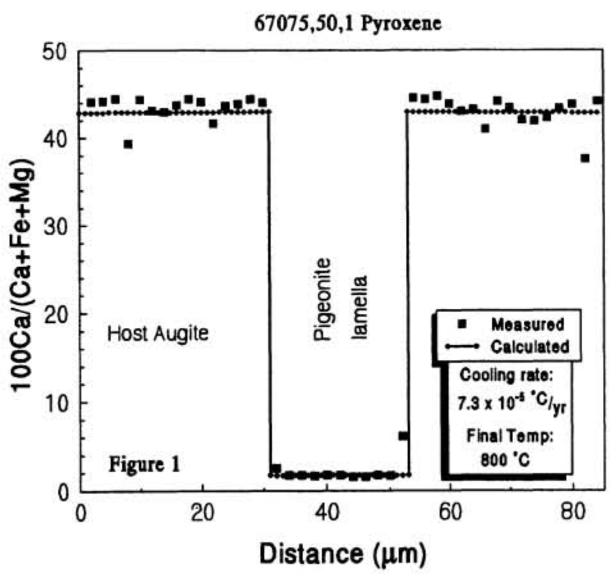
Detailed examination of the ejecta blankets associated with large multi-ringed basins reveals that the lunar crust is heterogeneous both laterally and vertically (Davis and Spudis, 1985; Spudis and Davis, 1986). The model of lunar crustal stratigraphy that has emerged from this work shows an anorthositic upper crust (Al_2O_3 = 26-28 wt %) making up from 30 to 50% of the total crustal volume. This unit is underlain by a noritic lower crust (Al_2O_3 = 20 wt %) which extends to the crust/mantle boundary. Mg-suite rocks (troctolites, norites, gabbronorites), which are believed to occur as slightly younger intrusive bodies throughout the crust, form a minor but important part of the crust. This model is not universally accepted and we have attempted to use mineralogical data to provide some independent confirmation of the gross lunar stratigraphy.

The width, spacing, crystallographic orientation, structural state, and composition of exsolved host--lamellae pairs in pyroxenes is a function of cooling rate. Cooling rate, in turn, is primarily a function of depth of burial. To determine depth of burial at the time of formation, we have been examining in detail exsolution features in pyroxenes from lunar crustal samples. Geothermometric studies on host--lamellae pairs indicates that the closure temperature for exsolution is around 700°C (McCallum et al., 1975). Extraction of cooling rates from compositional profiles requires (1) knowledge of Ca--MgFe diffusion coefficients along various crystallographic direction (or at least along c), (2) an accurate thermodynamic model of the pyroxene solvus as a function of T, P and composition, (3) precise compositional profiles across adjacent host--lamellae pairs, (4) bulk composition of the pyroxenes. Ca-MgFe diffusion coefficients in augite and pigeonite have been measured by Fujino (personal communication) at 1200°C, 1100°C and 1000°C and we have extrapolated these to 700°C using an activation energy recommended by Fujino. This rather long extrapolation introduces an unknown uncertainty into the calculations. PTX of the pyroxene solvus has been recalculated recently by Sack and Ghiorso (1994); their solvi differ in significant ways from earlier solvi due, in large part, to the inclusion of the effects of Fe-Mg ordering. For ease of computation, a digitized version of the pigeonite--augite solvus with equilibrium tie lines was prepared. Fick's Second Law of diffusion was solved by numerical methods under the appropriate boundary conditions (Sanford, 1982). A variety of cooling models were employed from linear to asymptotic to exponential.

Translation of calculated cooling rates to depths of burial is the most difficult part of the process since this requires more information than is generally available. Measured values for thermal diffusivity vary considerably and this problem is particularly severe in the lunar case because of the presence of thick regoliths that existed early in lunar history. Material in regoliths might be expected to have significantly lower thermal diffusivities. Even though absolute depth of burial may not be known with sufficient precision, the method we use provides a useful relative scale. As a check of the cooling rate versus burial depth curve, we have measured composition profiles in similar pyroxenes from the Stillwater Complex. In this case, independent estimates of the depth of burial can be obtained by thermobarometry.

Three typical profiles are shown in Figures 1- 3. In each case, care was taken to correct for the effects of overlap at the boundary between host and lamellae (Ganguly et al., 1991). The calculated profiles are based on a linear cooling rate. In the case of the two pyroxenes from anorthosite 67075 (Figs. 1, 2), a calculated cooling rate of 7.3×10^{-5} °C/year corresponds to a depth of burial of approximately 11 km (based on a thermal diffusivity of .005 cm^2/sec). Coincidentally, the best fit calculated profile for an inverted pigeonite from the Stillwater Complex (Fig. 3) gives an identical cooling rate and depth of burial. The depth to the base of the Stillwater Complex, based on olivine--orthopyroxene--quartz equilibria in iron formation just below the complex (Labotka, 1985), is 13 km and the estimated thickness of cover at the time of pigeonite formation is approximately 10 km.

References: Davis, P.A. and Spudis, P.D. (1985) PLPSC 16, D61-D74; Ganguly, J. et al. (1988) Amer. Min., 73, 901-909; Labotka, T.C (1985) Montana Bur. Mines Spec. Pub. 92, 70-76; McCallum, I.S. et al. (1975) EPSL, 26, 36-53; Sack, R.O. and Ghiorso, M.S. (1994), in press; Sanford, R.F. (1982) Computers and Geosciences, 8, 235-263; Spudis, P.D and Davis, P.A. (1986) PLPSC, 17, E84-E90.



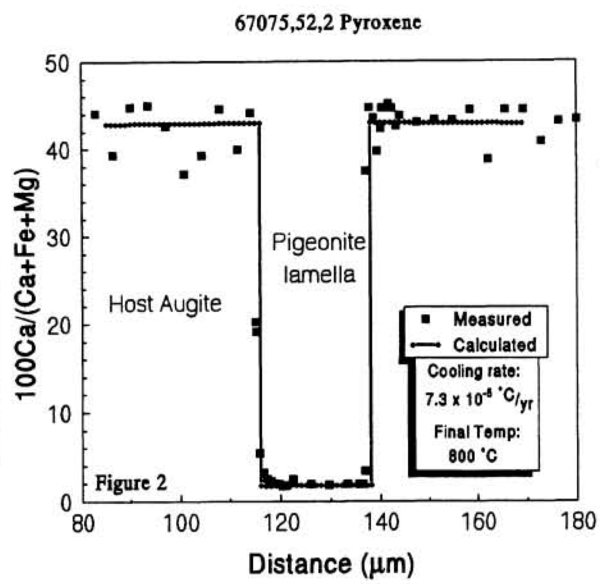


Figure 1. Quantitative step scan profile (2µm steps) across a high-Ca pyroxene from 67075,50. Calculated 100Ca/(Ca+Mg+Fe) is superimposed on measured profile.

Figure 2. Same as Fig. 1, with 1µm steps across a high-Ca pyroxene from 67075,52. Host augite in this grain contains a second set of thin (001) low-Ca lamellae.

Figure 3. Quantitative step scan profile (1µm steps) across Stillwater pigeonite. Calculated 100Ca/(Ca+Mg+Fe) is superimposed on measured profile.