LUNAR CRUSTAL STRATIGRAPHY INFERRED FROM COOLING RATE STUDIES OF EXSOLVED PYROXENES

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The distribution of lithologies in ejecta blankets around multi-ringed basins coupled with orbital geochemical data reveal that the lunar crust is heterogeneous both laterally and vertically (Spudis and Davis, 1986). A model of crustal stratigraphy, based in large part on the assumed excavation depths associated with basin-forming impacts, has been proposed in which an anorthositic upper crust (Al_2O_3 = 26-28 wt. %) comprising 30 to 50% of the crustal volume is underlain by a noritic lower crust (Al_2O_3 = 20 wt. %) which extends to the crust/mantle boundary (Spudis, 1993). Mg-suite rocks (troctolites, norites and gabbros) are believed to occur throughout the crust as slightly younger intrusive bodies. Since excavation depths for the large basin-forming impacts are not well known, it is important to develop independent tests of the model. To this end, we have attempted to determine cooling rates of crustal samples from which depths of formation can be calculated.

Last year we presented evidence that some lunar anorthosites had formed at depth of ~10 km within the lunar crust, consistent with their origin as products of crystallization of a lunar magma ocean. The depth of burial is based on a cooling rate which in turn is computed by modeling the kinetics of the exsolution process in pyroxenes. We have refined the computational procedure by using (1) more accurate determinations of bulk pyroxene compositions using image analysis techniques, (2) the revised pyroxene solvus function of Sack and Ghiorso (1994) and (3) a precise deconvolution procedure to correct for beam overlap at host--lamella interfaces (Ganguly *et al.*, 1988). The most intractable problem lies in translating a cooling rate to a depth of burial since there is no unique solution. Measured values of thermal diffusivity vary significantly and the problem is exacerbated in the lunar case because of the thick regolith that existed early in lunar history. Regolith material might be expected to have lower thermal diffusivities. To circumvent this problem we have used data on exsolved pyroxenes from the Stillwater Complex to calibrate the cooling rate/depth curve since, in this case, an independent measure of the depth of burial is provided by geobarometry. The thickness of cover at the time of crystallization of a variety of Stillwater pyroxenes is estimated to range from 13 to 9 km. This depth and computed cooling rate, based on an analysis of pyroxene exsolution, are used to determine the value of the constant in the equation $Z = C\sqrt{t}$ where Z is the depth in meters and t is the time in years. The calculated cooling rate for Stillwater pyroxenes gives a value of C = 5.2.

Profiles for some lunar crustal pyroxenes are shown in Figure 1 a-d together with best-fit calculated profiles. The calculated cooling rates and depths of burial are listed in Table 1. These results may change as the computational method is refined but it is unlikely they will vary by more than a factor of two. These data confirm the plutonic nature of the ferroan anorthosite suite and are in agreement with the suggestion of Ryder (1992) that Mg-suite samples formed in shallow level intrusions in the upper lunar crust. As yet, no samples we have examined show evidence of having been derived from the deeper lunar crust so we cannot, at this time, confirm the existence of a lower noritic layer in the lunar crust. Spudis *et al.* (1993) suggested that the Serenitatis impact excavated material from depths of 55 to 60 km with a significant amount of lower crustal material in the basin ejecta. If such material exists in the Serenitatis ejecta, we have not yet seen it but will continue the search.

References: Ganguly *et al.* (1988) Amer Min., 73, 901-909; Ryder (1992) PLPSC, 22, 373-380; Sack, R.O. and Ghiorso, M.S. (1994) Contrib. Mineral. Petrol.; Spudis, P.D. (1993) Geology of multi-ring basins. Cambridge Univ. Press; Spudis, P.D. and Davis, P.A. (1986) PLPSC, 17, E84-E90; Spudis, P.D. *et al.* (1993) LPS XXIV, 1341-1342.

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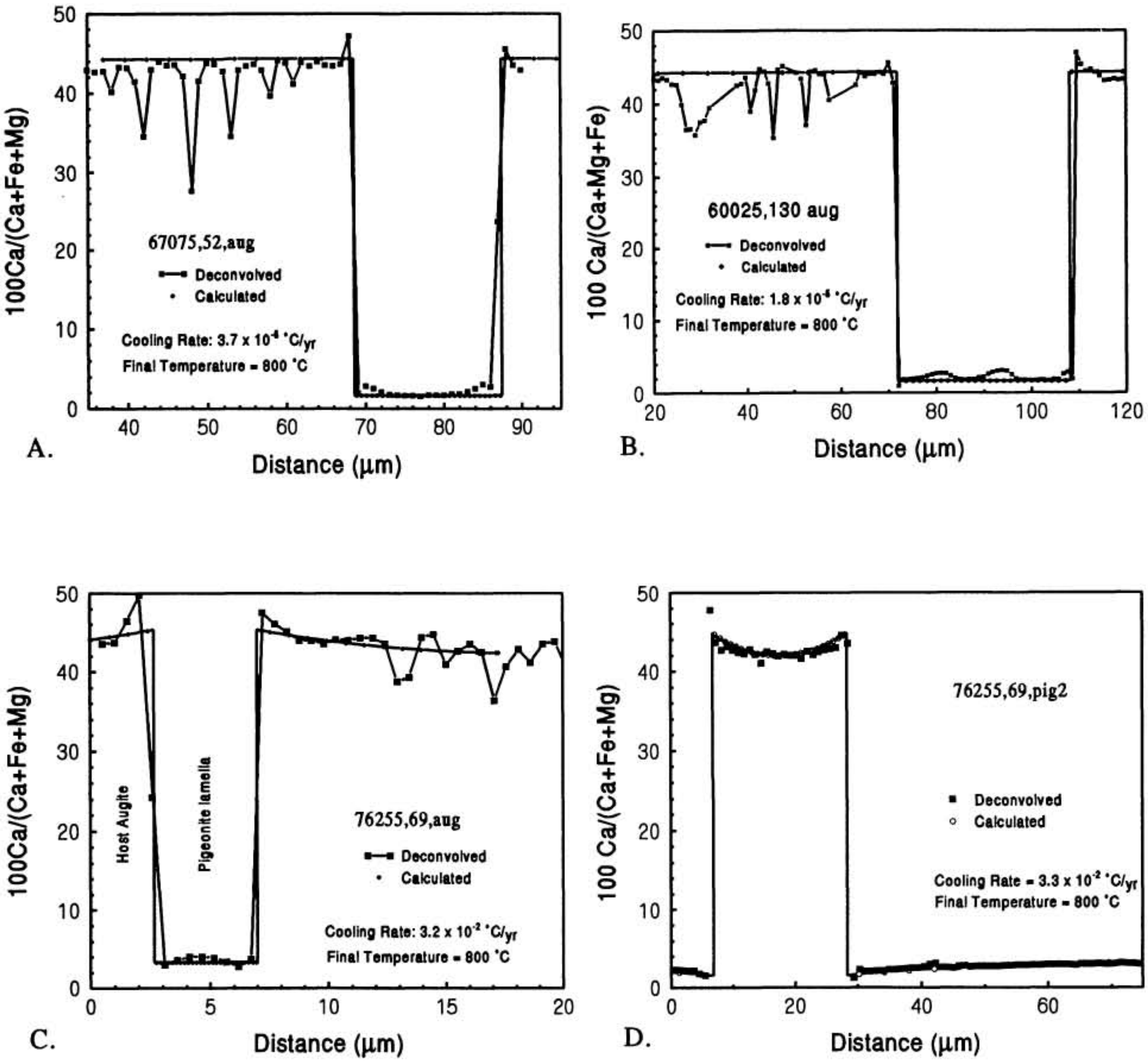

Figure 1. Compositional profile (deconvolved) on pyroxenes from lunar crustal samples. Calculated profile is superimposed on measured profile.
[a] Augite from ferroan anorthosite (FAS) 67075. [b] Augite from FAS 60025
[c] Augite from Mg-suite gabbronorite 76255. [d] Pigeonite from gabbronorite 76255

Table 1. Cooling rates and depths of burial

	T_i (°C)	T_f (°C)	Cooling Rate (°/yr)	Depth (km)
67075,52 Aug	1087	800	3.7×10^{-5}	14.5
60025,130 Aug	1097	800	1.8×10^{-5}	21.1
76255,69 Aug	1117	800	3.2×10^{-2}	0.5
76255,69 Pig	1136	800	3.3×10^{-2}	0.5