COOLING HISTORIES OF LUNA 24 LOW-Ti FERROBASALTS AND FERROGABBROS;
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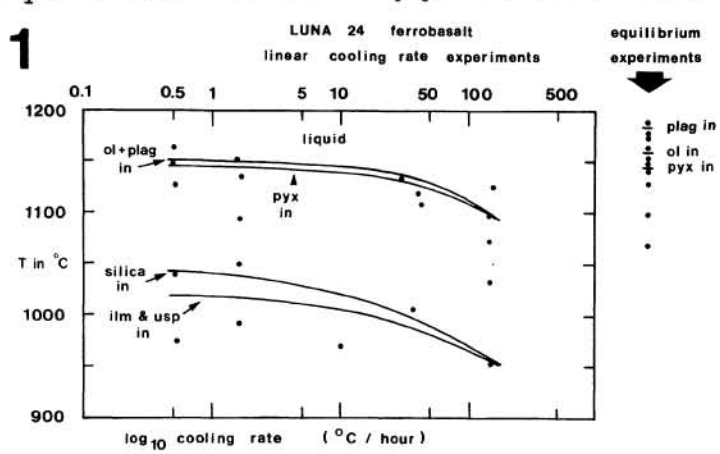
A very low Ti, iron-rich mare basalt is the dominant component in the LUNA 24 core [1]. We have characterized the LUNA 24 ferrobasalts and ferrogabbros [2,3,4], estimated the bulk composition of LUNA 24 ferrobasalt and carried out reversed experiments in iron capsules held in evacuated silica tubes [5] on a synthetic analog of this material. It was concluded that the LUNA 24 ferrobasalt is nearly multiply saturated with plagioclase, olivine and pyroxene at near lunar surface conditions. Linear controlled cooling rate experiments have been performed on this LUNA 24 ferrobasalt composition in iron capsules held in evacuated silica glass tubes. The objectives of this study are to set limits on the cooling histories of LUNA 24 ferrobasalts and ferrogabbros, understand their geologic setting at the Crisium landing site and to compare the effects of cooling rate on crystallization behavior of this nearly multiply-saturated basalt type with other mare basalts [6,7].

Experiments. Linear controlled cooling rate experiments were carried out over the range 150°C/hr to 0.5°C/hr. Each experiment was held at 1200° ± 3°C for 20 min (approximately 20°C above the equilibrium liquidus) cooled at a particular rate to a desired temperature and quenched into water. The results are summarized in Fig. 1 on a $\log_{10}$ cooling rate vs. temperature plot, where the dots indicate the cooling rate and quench temperature for each experiment and lines indicate the temperature below which a phase is present. Equilibrium experiments are presented for comparison.

Effects of Cooling Rate on LUNA 24 Ferrobasalt Crystallization. The effect of cooling rate on LUNA 24 ferrobasalt is to lower the liquidus by ∿ 30°C at 0.5°C/hr and by 75°C at 150°C/hr. In contrast to equilibrium experiments where a 25°C interval exists between liquidus plagioclase and the appearance of olivine, dynamic crystallization causes olivine and plagioclase to appear simultaneously at 0.5°C/hr. Olivine, pyroxene and rare plagioclase laths appear simultaneously at 150°C/hr.

The effects of dynamic crystallization on this LUNA 24 composition are somewhat different than the effects on an Apollo 12 picrite [6] and an Apollo 15 quartz-normative basalt [7]. In these latter two compositions the appearance temperatures of the liquidus phases are not affected appreciably by increasing cooling rate, but the appearance temperatures of later phases (especially plagioclase) are significantly depressed. It might be expected that a composition with liquidus plagioclase would also show significant undercooling of plagioclase, and that phase appearances might be reversed at rapid cooling



rates (e.g., olivine and pyroxene might precede plagioclase). However, the observed effect of cooling rate is suppression of plagioclase to the point of olivine appearance, where both phases occur simultaneously. If a reversal of phase appearance occurs as a function of cooling rate, the temperature interval of the reversal is modest (a maximum of 10°C at 0.5°C/hr and 25°C at 150°C /hr) over the range of cooling rates studied.

Cooling Histories of LUNA 24 Ferrobasalts: Textures. The 0.15 to 0.5 mm LUNA 24 soil fraction contains a few lithic fragments with grain sizes on the order of 100 μm or so. It might be possible to use textural criteria in these fragments to infer cooling rate (e.g., nucleation density or crystal size [6,8]). Little confidence could be placed in the results, since the textural techniques require study of large representative surface areas. If textures produced in cooling rate experiments can be used to infer the textures of the crushed samples of LUNA 24 ferrobasalt, they indicate that useful textural information is unattainable in the < 0.5 mm fraction. The cooling rate experiments produce a rock with two distinct textural domains; an ophitic to graphic intergrowth of plagioclase, pyroxene and olivine and areas of individual euhedral plagioclase laths and subophitic olivine and pyroxene. In the 0.5°C/hr experiments the grain size of the individual minerals is ∿ 0.25 mm. If a rock with this variation in texture were broken up, the resulting fragments would be both lithic and monomineralic, and representative textures would not be preserved.

Pyroxene Chemistry. The minor element contents of LUNA 24 pyroxene record early cooling history and our experiments can provide a calibration. The early pyroxenes in the ferrobasalt and ferrogabbro are augitic (Wo_{36-38} En_{40-42}) (Fig. 2) and contain the maximum amount of the minor elements Al, Ti and Cr. As crystallization proceeds, the pyroxene becomes depleted in Ca and minor elements and enriched in Fe. The pyroxene zoning trends and minor element chemistry produced in the slower cooling rate experiments (Fig. 2) and those measured in the basalts [2] and gabbros [4] are identical. In the experiments the proportions of Ca-Fe-Mg in the first pyroxene do not vary as a function of cooling rate and the trend of Ca and Fe depletion is followed. Minor element contents, however, are quite sensitive to cooling rate and increase with increasing rate. The minor element contents for early high Ca pyroxene in the cooling rate experiments are plotted in Fig. 3 along with the early minor element contents from the ferrobasalt [2] and ferrogabbro [4] pyroxenes.

The ferrobasalt pyroxene lies between the 0.5°C/hr and 1.7°C/hr experiments while the ferrogabbro pyroxene contains less Al, Ti and Cr than the 0.5°C/hr experiments. The estimate of [9] based on the homogenization of initial compositional profiles in olivine crystals in a ferrobasalt fragment from the 77 cm level yields a cooling rate of 0.2°C/hr. The two rate estimates are consistent with normal cooling of the LUNA 24 ferrobasalt by processes of conductive heat loss; an initial cooling rate of ∿ 1°C/hr (recorded by early pyroxene) and a continuously decreasing cooling rate recorded over a range of temperature by olivine. The minor element chemistry recorded in the ferrogabbro pyroxene suggests that slowly cooled coarse-grained equivalents of the ferrobasalt are also present at the site.

Petrology of LUNA 24 Ferrobasalts. The proximity of the LUNA 24 ferro-

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basalt bulk composition to the low-pressure olivine-plagioclase-pyroxene cosaturation argues for an origin by near-surface fractionation of a more primitive basalt, possibly a green glass chemistry identified in the LUNA 24 soils [10]. The fractionation of this green glass magma at lunar surface conditions has been calculated [11]. Olivine is the liquidus phase at ∿ 1400°C and substantial olivine crystallization (∿ 40%) brings the LUNA 24 green glass to the olivine-plagioclase cosaturation curve and yields the approximate composition of LUNA 24 ferrobasalt. It is tentatively suggested that differentiation by olivine settling of a lava flow of LUNA 24 green glass bulk composition could yield LUNA 24 ferrobasalt. Walker et al. [12] have estimated the differentiation that occurs in a picritic liquid by olivine settling during crystallization in a lava flow. Their calculations indicate that all the olivine can be depleted from the upper portions of the flow and stored in cumulates at the base. Calculations are presently being performed on LUNA 24 green glass magmas to evaluate the possibility that LUNA 24 basalts represent crystallized liquids from the top of a basalt flow that has undergone extensive olivine settling.

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