Crystallization temperatures of lunar FANs revealed by a new REE-in-plagioclase-clinopyroxene thermometer

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It has been widely accepted that ferroan anorthosites (FANs) in the lunar crust crystalize from a global lunar magma ocean (LMO) [1]. The crystallization temperature of FANs is thus crucial to understanding the thermal-chemical evolution of the LMO. Plagioclase (plg) and clinopyroxene (cpx) are major rock-forming minerals in mafic and ultramafic rocks including FANs. In this study, we show that partitioning of rare earth elements (REEs) between coexisting plg and cpx strongly depends on temperature and mineral compositions. We then develop a new thermometer based on the temperature dependent plg-cpx REE partitioning that can be directly applied to many mafic and ultramafic rocks including FANs. Due to the slow diffusion rate of REE in minerals, the REE-in-plg-cpx thermometer can potentially record apparent temperatures (T_{REE}) close to crystallization temperatures of cumulates in mafic and ultramafic magmas. This can be tested by comparing the liquidus temperatures of mafic cumulates in layered intrusions with those derived from the REE-in-plg-cpx thermometer.

We calculated T_{REE} for FANs using REE abundances reported in [2] and [3] and major elements reported in [4]. T_{REE} for all the FAN samples vary within a small range (1281 ~ 1361 ºC), and are about 50 ~ 100 ºC higher than the MAGFOX-derived plagioclase crystallization temperatures (1235 ~ 1261 ºC) in a LMO model [5]. The small temperature range for all FAN samples suggests that the high T_{REE} is a global feature for the lunar highland crust. If the high T_{REE} is the crystallization temperature of FANs in LMO, it indicates that anorthite becomes saturated in the LMO earlier than that predicted by MAGFOX. The early saturation of anorthite may result from more complicated LMO crystallization processes than that assumed in MAGFOX calculation or a difference in initial LMO composition from that used in MAGFOX calculation of [5]. Alternatively, the high T_{REE} may indicate a global thermal perturbation in the lunar highland crust, which reset the apparent temperature of REE-in-plg-cpx.

[1] Warren (1985) *Annu. Rev. Earth Planet. Sci.* **13**, 201-240. [2] Floss *et al* (1998) *GCA* **62**, 1255-1283. [3] James *et al* (2002) *GCA* **66**, 1269-1284. [4] McGee (1993) *JGR* **98**, 9089-9105. [5] Longhi (2003) *JGR* **108**, 5083.