Alkali Anorthosite 14305,303: Evidence of magma mixing using trace element data from zoned plagioclase.
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Introduction: Understanding igneous processes that have affected the lunar crust is difficult due to the subsequent cataclasis and reequilibration by meteorite impact of many highlands samples. Shervais and McGee [1] reported the reverse zoning of large "phenocrysts" of plagioclase in alkali anorthosite probe mount 14305,303 (Figs. 1 and 2).

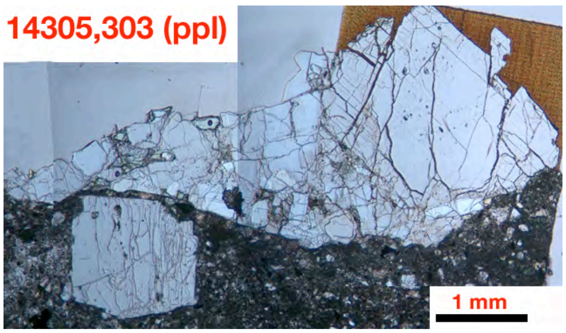

Figure 1: Photomicrograph of 14303,305.

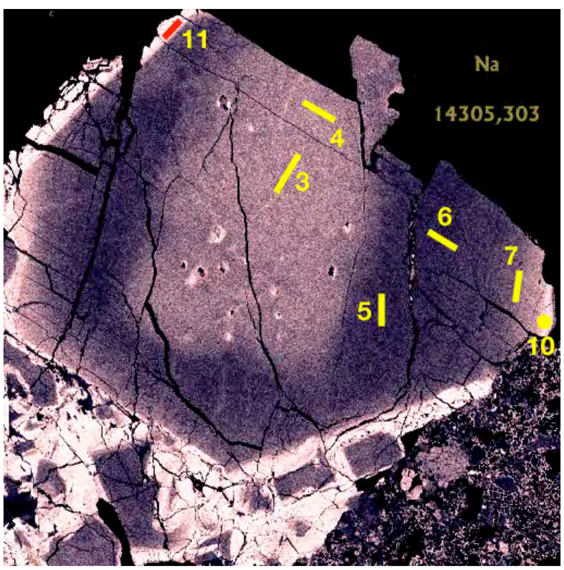

Figure 2: Na map of the large plagioclase "phenocryst", which is ~2 mm in the largest dimension. Lighter shades = more Na. Numbers = LA-ICP-MS analyses.

The zonations in the larger plagioclase crystals (Fig. 3) are not seen in the smaller grains, which exhibit only weak normal zonations. The reversed zonation was explained by [1] as:

"Mixing of an evolved alkali suite magma with a hotter, more primitive, and probably more calcic magma will result in a mixed magma that is hotter than the original alkali suite magma and has a higher Ca/Na ratio. Such a magma would crystallize a mantle of more calcic plagioclase over the more sodic core, thanks to its hotter liquidus temperature. Subsequent fractionation of the mixed magma would result in the formation of an outermost rim that is more evolved than the mantle, and in the formation of additional "groundmass" plagioclase as the magma solidified."

This magma mixing could have occurred through influx of new, primitive magma into an evolved magma chamber, or convective mixing in a zoned magma chamber.

In order to test the magma-mixing hypothesis, we quantified the trace element contents of different zones in the large plagioclase and also the smaller "groundmass" plagioclase crystals.

Methods: Electron microprobe (EMP) data were collected by [1] and showed the large plagioclase "phenocrysts" contained cores of An [100*(Ca/(Ca+Na+K))] 83-85 zoning to an An 89-91

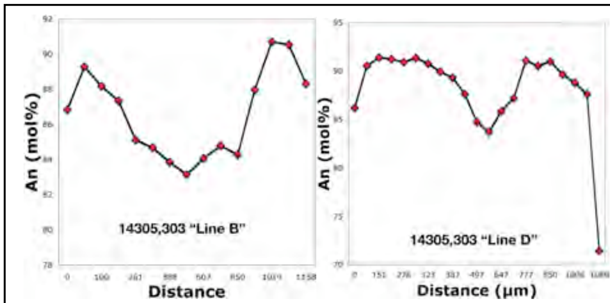

Figure 3: Traverses "Line B" and "Line D" of [1] across the large plagioclase shown in Figure 2.

(Fig. 3) with the extreme rim being An 71-88. The EMP data were used to calibrate the laser ablation – inductively coupled plasma – mass spectrometry (LA-ICP-MS) data, as CaO was used as an internal standard. A New Wave 213 nm quintupled Nd:YAG laser was used with a Thermofinnegan ELEMENT 2 high resolution ICP-MS. The NIST 612 glass [2] was used as an external standard following the method of [3]. Line scans were used (Figs. 2 and 4) to obtain a stable signal over a longer period of time to increase preci-

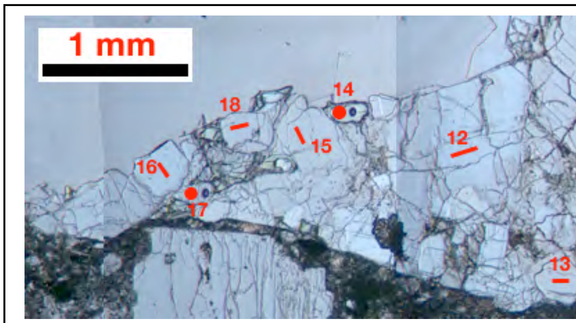

Figure 4: LA-ICP-MS data analyses of 14305,303.

sion. The following elements were quantified by LA-ICP-MS: Ti, Fe, Ga, Rb, Sr, Y, Ba, La, Ce, Nd, Sm, Eu, Gd, Dy, Er, and Yb. Detection limits were generally less than 50 ppb for all elements. Accuracy and precision were determined by repeat analyses of NIST-612 and were estimated to be generally better than 8% on elements present at <1 ppm and better than 5% for elements with concentrations >1 ppm.

Results: The large zoned plagioclase has been divided into (from center to edge) the core (C), rim (R) and overgrowth (O). See Figure 5 A-D. Sr is approximately constant in the core and rim, but increases in the overgrowth. Ba and Ga show a decrease from core to rim followed by a marked increase in the overgrowth. The light REE (apart from Sm) have approximately constant values in the core and rim, but exhibit a slight decrease in the overgrowth. The heavy REE, Sm, and Y exhibit decreasing abundances from core to rim to overgrowth. On the other hand, Eu shows increasing abundances from core to rim to overgrowth. The REE profiles are subparallel with the variation in the HREE accentuated because of the log scale (Fig. 6).

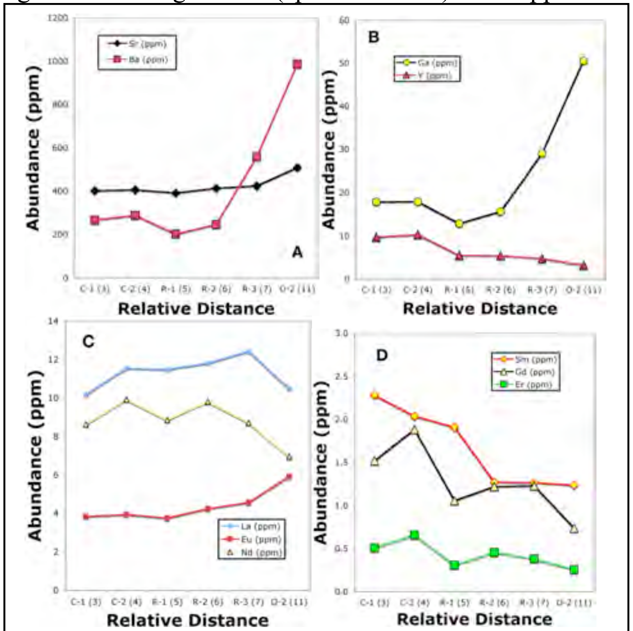

Figure 5: Core (C) to Rim (R) to Overgrowth (O) variations of trace elements in the zoned plagioclase depicted in Figure 2. The analysis number (corresponding to the numbers in Figures 2 and 4 are given in parentheses.

Discussion: The trace element data for the zoned plagioclase from 14305,303 support the magma-mixing hypothesis proposed by [1]. The rim data suggest that the core of the plagioclase was mixed with more primitive magma, probably from the same source. This is indicated by the decrease in Ba and Ga from core to rim (Fig. 5 a,b). The incoming magma had similar REE and Sr contents as the core parent magma, but crystallized plagioclase of significantly higher An content, possibly indicating a Mg-Suite parent. The decrease in HREE from the core is consistent with the co-crystallization of pyroxene. The overgrowth represents crystallization from intercumulus liquid, which reflects the influence of phosphate removal (2.5 modal % whitlockite was reported by [1]).

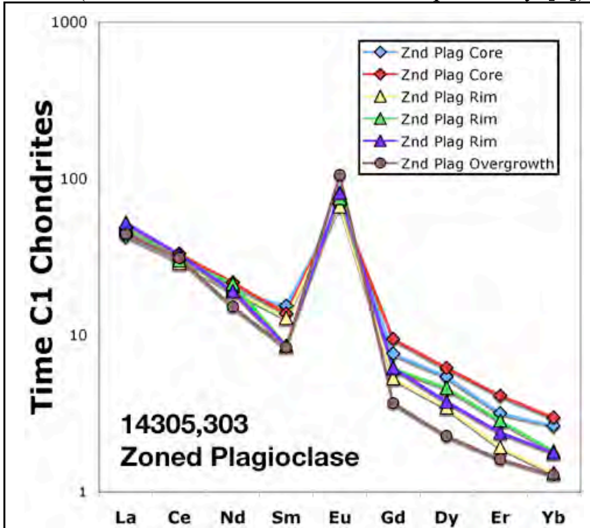

Figure 6: REE profiles of the zoned plagioclase depicted in Figure 2.

Interestingly, the bulk partition coefficient for both Sr and Eu during this crystallization was <1.

Summary & Conclusions: The initial interpretation of the trace element data determined by LA-ICP-MS supports a magma mixing petrogenesis for alkali anorthosite 14305.303. This demonstrates that primary igneous zonations are preserved by components forming the lunar crust. It also supports a connection between the Alkali Anorthosite and Mg-Suites of rocks preserved in the lunar crust [4,5]. Further work is underway to explore this hypothesis for this sample.

References: [1] Shervais J.W. and McGee J.J. (1998) *LPSC* **XXIX**, #1706. [2] Pearce N.J.G. et al. (1997) *Geostands Nwslttr* **21**, 115-144. [3] Jackson, S.E. (2001) *Min. Assoc. Canada Short Course Series* **29**, 29-45. [4] Snyder G.A. et al. (1995) *J. Geophys. Res*. **100**, E5, 9365. [5] Snyder G.A. et al. (1995) *Geochim. Cosmochim. Acta* **59**, 1185.