ANCIENT CRUST FORMATION AT THE APOLLO 14 SITE. J.W. Shervais and J.J. McGee, Department of Geological Sciences, University of South Carolina, Columbia, SC 29208 (shervais@sc.edu, jmcgee@sc.edu)

Introduction: The western lunar highlands are dominated by plutonic igneous rocks that post-date the lunar magma ocean. These rocks formed by serial intrusion of the pre-existing ferroan anorthosite crust, much of which must have been removed by basin-forming impacts [1]. Many of the lithologies which occur there are not found at other highland sites or represent unique variations of more common lithologies. Apollo 12 highland samples, although rare, have petrologic and geochemical affinities with the Apollo 14 highlands suite and the two sites taken together constitute what can be called the Western Highlands Province. Rocks of the Western Highlands Province are geochemically distinct from similar lithologies found at eastern highland sites. An understanding of how the Western Highlands Province formed and why it differs from highland crust in the east is crucial to our overall understanding of primordial lunar differentiation and petrogenesis.

Plutonic rocks found at the Apollo 14 site comprise four lithologic suites: the magnesian suite, the alkali suite, evolved lithologies, and the ferroan anorthosite suite (FAN). Rocks of the magnesian suite include troctolite, anorthosite, norite, dunite, harzburgite; they are characterized by plagioclase ≈An95 and mafic minerals with mg#s 82-92. Alkali suite rocks and evolved rocks generally have plagioclase ≈An90 to ≈An40, and mafic minerals with mg#s 82-40. Lithologies include anorthosite, norite, quartz monzodiorite, granite, and felsite. Ferroan anorthosites have plagioclase ≈An96 and mafic minerals with mg#s 45-70.

Geochemistry: Whole rock geochemical data show that most magnesian suite samples and all alkali anorthosites are cumulates with little or no trapped liquid component. Norites may contain significant trapped liquid component, and some alkali norites may represent cumulate-enriched, near-liquid compositions, similar to KREEP basalt 15386 [2]. Evolved lithologies include evolved partial cumulates related to alkali suite fractionation (quartz monzodiorite), immiscible melts derived from these evolved magmas (granites), and impact melts of pre-existing granite (felsite). Plots of whole rock mg# versus whole rock Ca/(Ca+Na+K) show a distinct gap between rocks of the magnesian suite and rocks of the alkali suite, suggesting either distinct parent magmas or distinct physical processes of formation (figure 1). Chondrite-normalized REE patterns show that rocks of both the magnesian suite and alkali suite have similar ranges, despite the large difference in major element chemistry (figure 2).

Mg Suite: Hunter and Taylor [3] were first to notice a compositional gap between two troctolite subgroups. Group I troctolites tend to have more mafic-rich modes and more magnesian phase compositions (olivine Fo85-90); Group II troctolites are more felsic modally and have more Fe-rich mineral compositions (olivine Fo74-81). Spinel (Cr-pleonaste) is a common accessory phase in the more magnesian, Group I troctolites, where it occurs both as discrete grains and in enstatite-spinel symplectites.

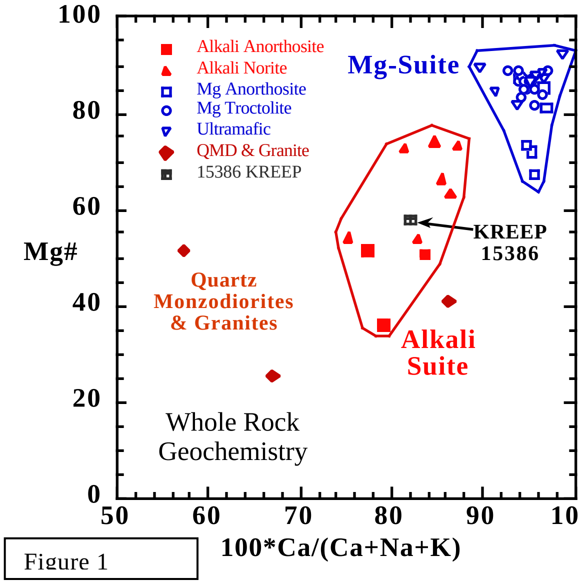

Figure 1

Rocks of the magnesian suite appear to represent two dominant modes of intrusion: deep-seated crustal intrusions crystallized at relatively high pressures, and shallow intrusions into the middle and upper crust. The deep crustal intrusions formed Group I troctolites, spinel-bearing troctolites, and associated Mg-anorthosites. The shallow intrusions formed the series dunite–troctolite–norite, with more ferroan Group II troctolite [2]. SIMS analyses of Mg-suite cumulates imply a parent magma with KREEP-like incompatible element concentrations, despite the primitive nature of their major element compositions [4,5].

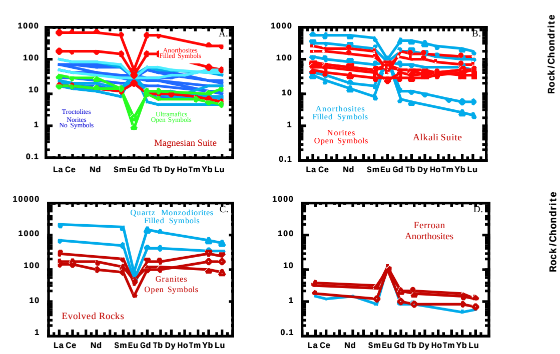

Figure 2

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These data suggest that the magnesian suite parent magma formed by partial melting of early magma ocean cumulates (olivine + pyroxene), perhaps in conjunction with metasomatism by small volume partial melts of the primitive lunar interior [2]. The resulting primary komatiite parent magma then mixed with highly fractionated, residual urKREEP to form the "true" parent magma of the magnesian suite cumulates (figure 3, [2]).

Alkali Suite: Rocks of the alkali suite all appear to have formed in shallow crustal intrusions (figure 3). SIMS analyses of alkali suite cumulates show that the parent magma assimilated older anorthosites, resulting in fractionated incompatible elements, enrichment in plagiophile elements, and positive Eu anomalies relative to KREEP [6]. The alkali parent may be derived from the magnesian suite parent by combined processes of fractional crystallization and anorthosite assimilation [2]. Assimilation will force plagioclase saturation and increase the volume of plagioclase crystallized at any temperature. It can also suspend the parent magma in the plagioclase volume, suppressing pyroxene crystallization and promoting monomineralic anorthosite cumulates [6]. Alkali suite norites may represent cumulates or, in some cases, cumulate-enriched melts. Evolved rocks (QMDs, granites) most likely represent the alkali suite parent magma after extensive fractional crystallization.

Discussion: Current models for the origin of the magnesian suite call for a komatiitic parent magma derived from early magma ocean cumulates; these melts must assimilate plagiophile elements to form troctolites at low pressures, and must assimilate a highly-enriched KREEP component so that the resulting mixture has REE concentrations similar to high-K KREEP. There are as yet no plausible scenarios that can explain these unusual requirements. We propose that partial melting of a primitive lunar interior and buffering of these melts by ultramagnesian early magma ocean cumulates provides a more reasonable pathway to form magnesian troctolites. Alkali anorthosites and norites formed by crystallization of a parent magma with major element compositions similar to KREEP basalt 15386 [7]. If the parent magma of the alkali suite and evolved rocks is related to the magnesian suite, then that magma must have evolved through combined assimilation-fractional crystallization processes to form the alkali suite cumulates.

References:[1] Shervais & Taylor (1986) in *Origin of Moon*, 173–202, [2] Shervais and McGee (1999) *JGR.*,in press, [3] Hunter & Taylor (1983) *JGR*, *88*, A591-A602–1345, [4] Papike et al, *GCA*, 60, 3967-3978, [5] Shervais and McGee, *GCA*, in press, [6] Shervais and McGee, *American Mineral*., in press, [7] Snyder et al (1995) *GCA* 59, 1185-1203.

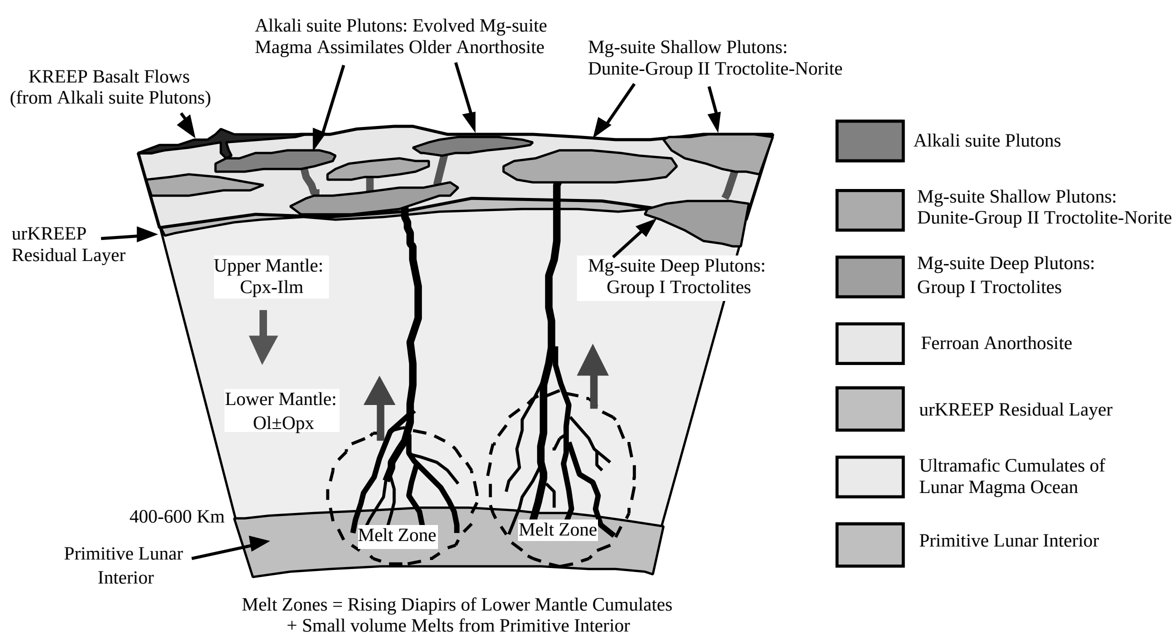

Figure 3. Schmatic model for the formation of post-magma ocean igneous suites.