THE PETROGENESIS OF APOLLO 12 MARE BASALTS, PART 2: IDENTIFICATION OF DISTINCT OLIVINE & PIGEONITE SUITES, AND OPEN-SYSTEM EVOLUTION. Clive R. Neal and Matthew D. Hacker - Dept. of Civil Eng. & Geological Sciences, University of Notre Dame, Notre Dame, IN 46556; Lawrence A. Taylor - Dept. of Geological Sciences, University of Tennessee, Knoxville, TN 37996; Roman A. Schmitt & Yun-Gang Liu - Deps. of Chemistry & Geosciences, Oregon State University, Corvallis, OR 97331.

Mare basalts returned by the Apollo 12 mission from the Ocean of Storms are of the low-Ti variety (< 6 wt% TiO2). James & Wright [1] subdivided these basalts into 3 suites: 1) olivine-pigeonite; 2) ilmenite; & 3) feldspathic. Subsequently, Rhodes et al. [2] assigned the olivine & pigeonite to separate groups because of an apparent hiatus between them, although these authors still concluded that they were co-magmatic. Crystallogages for all Apollo 12 basalts generally overlap, but average ages suggest the ilmenite basalts are slightly older (3.25 Ga) than the olivines (3.21 Ga) & the pigeonites (3.19 Ga). Neal et al. [3] have demonstrated that the feldspathic subdivision is fictitious, probably based upon unrepresentative sampling of either olivine, pigeonite, or ilmenite basalts.

**CLASSIFICATION** - Neal et al. [3] have reported the whole-rock chemistry of 5 previously unanalyzed Apollo 12 mare basalts, as well as duplicate analyses of 9 other basalts. By combining these with the present data base, petrogenetic interpretations may now be made. In order to correctly classify the new data, distinctive chemical signatures, in combination with petrographic features, must be highlighted. We propose a chemical classification for the Apollo 12 mare basalt suite on the basis of Rb/Sr ratio & MG# (Fig. 1). Note that all Rb/Sr ratios were obtained by isotope dilution techniques (e.g., 4-5). Olivine & pigeonite basalts have similar Rb/Sr ratios, but olivine basalts have a higher MG# (>43) than the pigeonites (<43). The ilmenite basalts exhibit MG#'s similar to the range of both the olivine and pigeonite suites, but have lower Rb/Sr ratios (<0.007-0.0075). The subdivision of Apollo 12 basalts on this basis is generally consistent with petrographic observations (i.e., olivine basalts are olivine-rich, etc.). The circled samples indicate that the analysis is unrepresentative of the basalt [3].

**REPRESENTATIVE & UNREPRESENTATIVE ANALYSES** - Care must be taken in the interpretation of whole-rock data, especially from coarse-grained samples; the problem of representative sampling within our new data base has been addressed in the companion abstract [3]. The new whole-rock data have been incorporated into the Apollo 12 mare basalt data base as follows: in order that one sample can be represented by one data point, we have averaged all reported analyses for each basalt, but only if variation between these analyses did not exceed the variation exhibited by the suite to which it was assigned. If the sample exhibited variation which overlapped with another group, the sample is represented by the extremes of this variation (i.e., 2 points). This is the case for 12006, which is a coarse-grained olivine basalt, and we have also represented 12015 (also an olivine basalt) by 2 points in order to highlight the heterogeneous nature of this vitrophyre sample.

The identification of a heterogeneous vitrophyre in the Apollo 12 suite demonstrates that just because a sample is fine-grained or quenched, any analysis may not automatically be representative. Therefore, additional evidence is required in order to judge the "representativity" of any analysis. As such, we have used "plotting consistency" (i.e., does a sample plot consistently on an apparent fractionation trend using a number of different compositional parameters) & initial isotopic ratios. This approach has identified 5 basalts, in addition to 12006 and 12015, which may be unrepresentative: 1 olivine (12036); the remaining feldspathic (12031); 1 pigeonite (12038 - formerly classified as feldspathic); and 2 ilmenites (12005 & 12040). As demonstrated isotopically by Nyquist et al. [5], 12031 is a plagioclase-rich pigeonite basalt, but the whole-rock analysis is unrepresentative of its pigeonitic parentage. In our companion abstract, another member of the feldspathic suite (12072) was shown to be of olivine basalt parentage. By extrapolation, we also suspect that 12038 is a plagioclase-rich variant of an ilmenite/olivine/pigeonite basalt, especially as the thin section exhibits heterogeneous plagioclase distribution. Both 12031 (pigeonite) & 12038 (feldspathic) fall in the ilmenite field (Fig. 1). The olivine (12036) and two ilmenites (12005 & 12036) are classified as unrepresentative, because they do not consistently plot along the apparent fractionation trends in Figs. 2-5. Further study of these samples is underway to
substantiate these suppositions, but it is important to note that each of these "unrepresentative" basalts is coarse-grained. Study of corresponding thin sections demonstrate heterogeneities in all except 12015 and 12038.

**APOLLO 12 MARE BASALT PETROGENESIS** - A plot of TiO2 against Al2O3 demonstrates the now apparent overlap between the olivine & pigeonite basalts (Fig. 2). This is highlighted by our duplicate analyses of 12006 & 12015, as well as the analysis of "new" pigeonite basalt 12019 (the "squared" pigeonite basalt in Fig. 2). The ilmenite basalts exhibit compositions which span the range of both the olivine & pigeonite suites, but at elevated TiO2 contents, and appear unrelated to either the olivine or pigeonite suites. In these and subsequent plots, possible parental (i.e., vitrophyric) basalts are placed in squares. Vitrophyre 12015 is not "squared" in Fig. 2 because it is represented by two points (see above). Circled points again represent unrepresentative analyses. The overlap between the olivine & pigeonite groups suggests a single fractionation trend can explain the compositional variation in both suites. Note that the positions of the possible parental samples suggest that, apart from the vitrophyres, all olivine basalts are cumulates (supported by analyzed and calculated olivine Fo contents), and all pigeonite basalts are evolved fractionates, consistent with a single fractionation scheme (Fig. 2).

On the basis of Rb (ppm) versus Rb/Sr ratio and Al2O3 wt% (Figs. 3 & 4 - all Rb & Sr data are by isotope dilution), the olivine and pigeonite basalts formed positive yet parallel trends which cannot be related by simple fractionation. This indicates that although the major-element trends overlap and appear to be related, this is fortuitous, and we are witnessing the overlap of unrelated suites. In Figs. 3 & 4, the ilmenite basalts form an extension of the pigeonite trend, and the olivine suite appears to contain both evolved and cumulate variants, in contrast to Fig. 2. Note that in Fig. 4, all samples which we deemed unrepresentative plot away from apparent fractionation trends defined by the olivine, pigeonite, and ilmenite basalt suites.

In Figs. 2-4, apparent fractionation trends have been highlighted for the 3 mare basalt suites. In order to evaluate whether this fractionation was open- or closed-system, all initial 87Sr/86Sr data from the literature has been plotted against an arbitrary parameter, in this case Co (ppm) (Fig. 5). The ilmenite basalts exhibit a relatively constant & unradiogenic I(Sr), compared to the olivine & pigeonite variants. The range in I(Sr) for the pigeonite basalts (0.69940-0.69965) & the olivine basalts (0.69950-0.69985) indicates open-system behavior. The negative correlation between I(Sr) & Co (ppm) is especially striking for the olivine basalts. This suggests that as the parental magma evolved by olivine fractionation, a more radiogenic component was being incorporated into the magma (AFC?). Such a component would have a radiogenic Sr-isotopic signature & be fractionated (low Co contents). KREEP is a possible contaminant, but the LREE-depleted nature of all Apollo 12 mare basalts argue against it. The nature of this contaminant is being investigated.

**SUMMARY & CONCLUSIONS** - 1) Apollo 12 basalts may be classified into olivine, pigeonite, or ilmenite suites on the basis of Mg# and Rb/Sr ratio; 2) Although major-element correlations suggest a possible relationship, trace-element data demonstrate that the olivine and pigeonite suites are unrelated - any major-element correlation between these two suites is purely fortuitous; 3) The identification of heterogeneity within a vitrophyric basalt has required that other criteria be used in conjunction with petrography to indicate whether an analysis is representative of the whole-rock composition - we have used isotopic data (for the original feldspathic basalt 12038 - [5]) and our own observations of element-element relationships to identify unrepresentative analyses (further study of these unrepresentative samples is planned); 4) By using I(Sr) ratios, open-system evolution has been identified in the olivine and possibly the pigeonite suites - ilmenite basalts appear to have evolved through closed-system processes.