

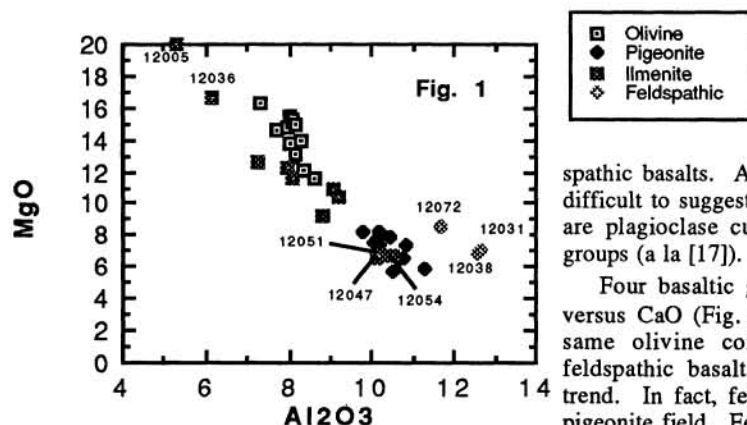
A RE-EVALUATION OF APOLLO 12 MARE BASALT CLASSIFICATION AND PETROGENESIS: SOME EMPIRICAL OBSERVATIONS USING THE CURRENT DATA BASE Clive R. NEAL, Dept. of Earth Sciences, University of Notre Dame, Notre Dame, IN 46556.

The Apollo 12 mare basalt suite allows the only substantive look at basaltic volcanism on the western side of the Moon. Although basalts have been extensively studied at Apollo 14 (e.g., [1-4]), these samples are clasts extracted from breccias and are on the order of milligrams, rather than grams as in the Apollo 12 basalt suite. The Apollo 12 basalt suite contrasts compositionally with the high-alumina and VHK compositions found at Apollo 14 [5-7].

Most of the analyses of Apollo 12 mare basalts were conducted straight after the missions return (e.g., [8-13]), using a variety of analytical methods. However, little petrogenetic interpretation was undertaken at this time. James and Wright [14] identified three major basalt groups at the Apollo 12 site: 1) olivine-pigeonite basalts; 2) ilmenite-bearing basalts; and 3) feldspathic basalts. Rhodes et al. [15] undertook the largest single study of Apollo 12 basalts to date, analyzing 20 basalts. These authors identified a distinct compositional hiatus between the olivine and pigeonite basalts (Fig. 1) and assigned them to separate groups, although they concluded that these basalts were probably co-magmatic. Rhodes et al. [15] also classified previously analyzed basalts into this four-fold classification. These authors concluded that the within-group variation exhibited by these basalts was a result of olivine (+ minor Cr-spinel) fractionation (with pigeonite replacing olivine in the pigeonite basalts) within thick (up to 40m) flows. Rhodes et al. [15] concluded that the parental compositions for each basaltic group were represented by the vitrophyres, with the formation of complimentary olivine cumulates and more evolved end-members.

The feldspathic basalts are the least numerous basaltic type found at Apollo 12 (3 have been reported to date), and were described in detail by Beaty et al. [16]. These authors argued for the presence of two types of feldspathic basalt on the basis of mineralogy, each requiring a distinct source region, and that one of these feldspathic basalt types was probably exotic to the Apollo 12 site. Nyquist et al. [17] concluded, on the basis of Sr isotopic evidence, that feldspathic basalt 12031 was in fact a plagioclase-rich pigeonite basalt, and that the pigeonite basalts could not have been derived from the olivine basalts by differentiation within a single flow.

This present study is a re-evaluation of the existing analyses from the Apollo 12 mare basalt suite and is designed to test the above conclusions. The diagrams presented here are those which were used by previous authors allowing them to arrive at the above conclusions.

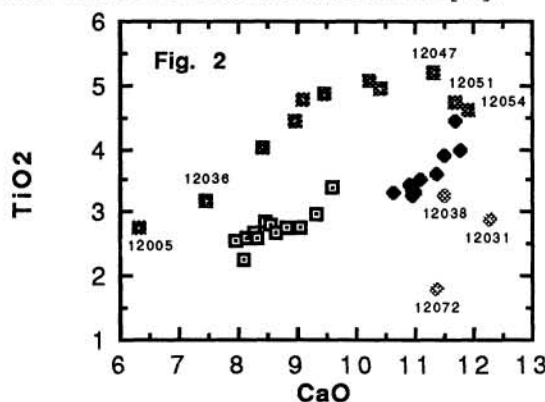


DISCUSSION - As can be seen from Fig. 1, the four groups of Apollo 12 basalts are not readily apparent. This diagram, used by Beaty et al. [16], can be interpreted as indicating similar liquid lines of descent for each of the basalt groups, except for the feldspathic basalts. As this group only contains three members, it is difficult to suggest whether these are related by a fractionation or are plagioclase cumulates of one (or more) of the other three groups (a la [17]).

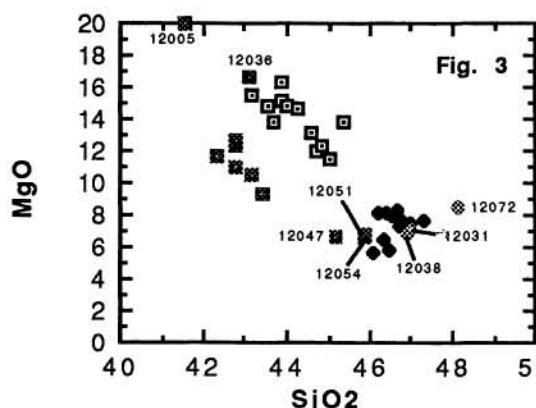
Four basaltic groups are clearly defined on a plot of TiO_2 versus CaO (Fig. 2). Olivine and pigeonite basalts fall on the same olivine control line, yet on the basis of this plot, feldspathic basalt 12031 is distinct from the pigeonite basalt trend. In fact, feldspathic basalt 12038 can be included in the pigeonite field. Feldspathic basalt 12072 is clearly distinct. Note also the compositional hiatus between the olivine and pigeonite basalts, consistent with the observation of Rhodes et al. [15].

The compositional groupings are not as distinct on a plot of SiO_2 versus MgO (Fig. 3). It is apparent from this diagram that the olivine-pigeonite basalts again fall on the same olivine control line, yet the ilmenite basalts are distinct. Furthermore, ilmenite basalts 12005 and 12036 fall in the olivine basalt field. In fact, this may also be the case in Figures 1 & 2. Also, ilmenite basalts 12047, 12051, and 12054 appear to be part of the pigeonite basalt suite on the basis of this diagram - likewise in Figures 1 & 2. Feldspathic basalts 12031 and 12038 also plot within the pigeonite basalt field, whereas 12072 appears distinct, but may be an extension of the pigeonite field. This is exemplified in Fig. 4, where TiO_2 is plotted against MgO . All feldspathic basalts could be interpreted as forming an extension of the pigeonite field, as could ilmenite basalts 12047, 12051, and 12054. As in previous figures, ilmenite basalts 12005 and 12036 plot close to the olivine basalt field.

The trace element data depict similar groupings. Unfortunately, no trace-element data is available for feldspathic basalt 12072. In Fig. 5, MgO is plotted against Sm . Note the almost vertical array of the pigeonite basalts. Ilmenite



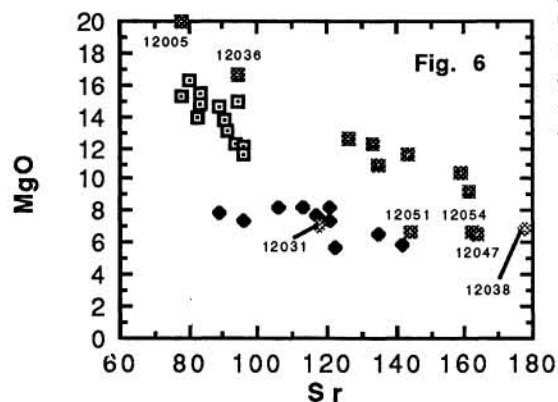
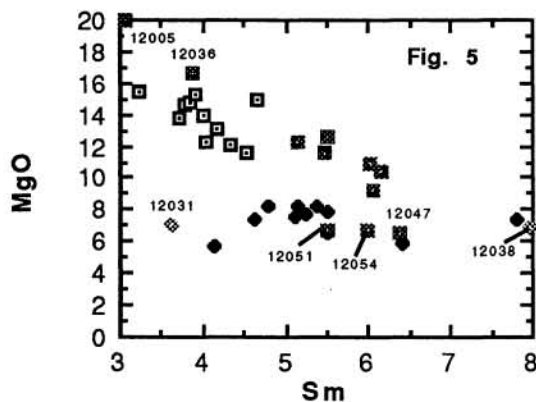
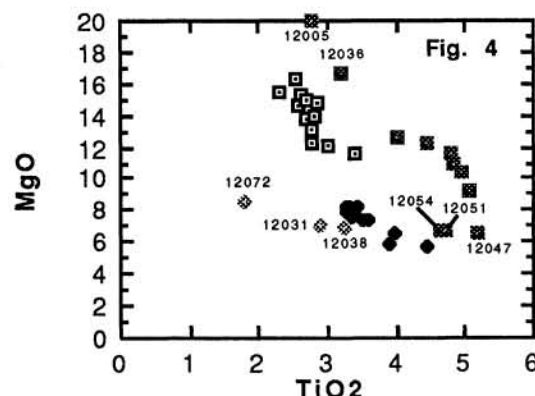
Apollo 12 Mare Basalt Petrogenesis: C.R. Neal



cussion has pointed out some inconsistencies with previous conclusions regarding basalt petrogenesis at the Apollo 12 site, not least of which is the fact that trace-element data suggest that the olivine and pigeonite basalts do not fall on the same liquid line of descent, and therefore cannot be co-magmatic. However, they may have been derived from similar sources which is consistent with the isotope data [17,18]. Ilmenite basalts 12047, 12051, and 12054 could be ilmenite-rich variants of the pigeonite suite, and 12005 and 12036 could be ilmenite-rich variants of the olivine suite. If this is true, then the compositional range of the pigeonite and olivine basalts is dramatically extended, but whether the feldspathic basalts should be considered as a separate group, rather than as feldspar-rich variants of the other suites is not as apparent. Isotopic evidence suggests that at least 12031 is related to the pigeonite suite. Whether 12038 is also, as suggested in Figs. 2, 3, and 4, is unclear. Isotopic evidence

basalts 12047 and 12054 fall within this field, but feldspathic basalts 12031 and 12038 plot at either end of this array. Clearly, if the feldspathic basalts are related to the pigeonite variants, the relationship is not one of simple crystal fractionation and accumulation. Note also, that in both Figs. 5 and 6, the olivine and pigeonite basalts do not fall on the same liquid line of descent, and ilmenite basalts 12047, 12051, and 12054 plot with the olivine basalts in both of these diagrams. However, in Fig. 6, where MgO is plotted against Sr, ilmenite basalts 12047, 12051, and 12054 plot outside the pigeonite basalt field, yet on an extension of the ilmenite basalt trend which leads towards feldspathic basalt 12038. Feldspathic basalt 12031 falls in the middle of the pigeonite field, consistent with the conclusions of Nyquist et al. [17].

OBSERVATIONS - When all data are considered, petrogenesis of the Apollo 12 basalts is clearly complicated. The above dis-



(Nyquist et al., [17]: Fig. 13) suggests a relationship with the ilmenite basalts - is 12038 really a plagioclase-rich ilmenite basalt, just as 12031 is a plagioclase-rich pigeonite basalt? Clearly, there are inconsistencies between whole-rock (Figs. 2 & 6) and Sr isotope data [17]. Such problems cannot be resolved at present, but work is underway to substantiate these empirical observations.

REFERENCES: [1] Warner et al. (1980) *PLPSC* 11th, 87; [2] Dickinson et al. (1985) *PLPSC* 15th, in *JGR* 90, C365; [3] Shervais et al. (1985) *PLPSC* 15th, in *JGR* 90, C375; [4] Neal et al. (1988) *PLPSC* 18th, 139; [5] Neal et al. (1989) *PLPSC* 19th, 147; [6] Shervais et al. (1985) *PLPSC* 16th, in *JGR* 90, D3; [7] Neal et al. (1988) *PLPSC* 18th, 121; [8] Brunfelt et al. (1971) *PLSC* 2nd, 1281; [9] Willis et al. (1971) *PLSC* 2nd, 1123; [10] Cuttitta et al. (1971) *PLSC* 2nd, 1217; [11] Taylor et al. (1971) *PLSC* 2nd, 1083; [12] Engel et al. (1971) *PLSC* 2nd, 431; [13] Compston et al. (1971) *PLSC* 2nd, 1471; [14] James & Wright (1972) *Bull. Geol. Soc. Am.* 83, 2357; [15] Rhodes et al. (1977) *PLSC* 8th, 1305; [16] Beatty et al. (1979) *PLPSC* 10th, 115; [17] Nyquist et al. (1979) *PLPSC* 10th, 77; [18] Nyquist et al. (1977) *PLSC* 8th, 1383.