lation. These 11 values were then averaged. The relations between the assimilation of each sample and the baseline assimilation were then used to determine the amounts of assimilation necessary in each sample. The results for some REE and other trace elements are given in Table 2. Approximately 7.5% assimilation of neoKREEP is required to produce the baseline group A basalt, and the entire array of group A compositions can be generated by 7.5–15% assimilation of neoKREEP with the composition in Table 2.

Comparison of NeoKREEP with Known Lunar Materials: The neoKREEP composition given in Table 2 and shown in Fig. 4 is more evolved than the postulated high-K KREEP composition given by Warren [14], but is not as evolved as materials such as the quartz monzodiorites from Apollo 15 (e.g., [16]). In addition, the chondrite-normalized REE slope is less than that of both high-K KREEP and the quartz monzodiorites, more akin to some lunar granites (e.g., 73215c, 14321,1027 in [17]). Warren et al. [17] noted the possibility that some lunar granites may be the late-stage remnants of younger, smaller intrusions formed through partial melting of the deep interior, which is essentially what we envisage as the origin of neoKREEP. Internal isochrons for granite 14321,1027 give ages of 4.09 ± 0.11 Ga and 4.11 ± 0.20 Ga from Rb-Sr and Sm-Nd, respectively [18], coinciding with our estimated age of neoKREEP of 4.15 Ga. Our neoKREEP composition is enriched in the REE over that of lunar granite. If neoKREEP represents some "pure" differentiate, perhaps the lunar granites reflect some dilution of similar material in the same way that KREEP basalts represent dilution of the "pure" differentiate urKREEP.

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POSSIBLE PETROGENETIC ASSOCIATIONS AMONG IGNEOUS COMPONENTS IN NORTH MASSIF SOILS: EVIDENCE IN 2–4-mm SOIL PARTICLES FROM 76503.

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Studies of Apollo 17 highland igneous rocks and clasts in breccias from the North and South Massifs have described magnesian troctolite, norite, anorthositic gabbro, dunite, spinel cataclasites (e.g., [1,2]), and granulitic lithologies that may have noritic anorthosite or anorthositic norite/gabbro as igneous precursors [3], and have speculated on possible petrogenetic relationships among these rock types. Mineral compositions and relative proportions of plagioclase and plagioclase-olivine particles in sample 76503 indicate that the precursor lithology of those particles was troctolitic anorthosite, not troctolite. Mineral and chemical compositions of more pyroxene-rich, magnesian breccias and granulites in 76503 indicate that their precursor lithology was anorthositic norite/gabbro. The combination of mineral compositions and whole-rock trace-element compositional trends supports a genetic relationship among these two groups as would result from differentiation of a single pluton.

View from the Soil: Although highland igneous lithologies in Apollo 17 materials have been described previously, the proportions of different igneous lithologies present in the massifs, their frequency of association, and how they are related are not well known. In this abstract, we consider the proportions of, and associations among, the igneous lithologies found in a North Massif soil (76503), which may represent those of the North Massif or a major part of it. Soil 76500 was collected far from any boulders [4] that might have added components to the soil. We assume for this exercise that the proportions of lithologies in the 2–4-mm fraction (76503) reasonably represent those of their igneous precursors. Some soil particles are polymict impact-melt breccias; we also seek to constrain the composition of igneous materials that were incorporated into them.

Based on a geochemical survey of 243 2–4-mm particles, soil at the base of North Massif comprises mainly impact melt breccias, regolith or glassy breccias, admixed high-Ti mare basalt and orange glass fragments, and surviving fragments of highland igneous lithologies [5]. Some 25 particles retain highland-igneous textures or have compositions indistinguishable from those that do. A subset of these igneous fragments comprises coarse single crystals or aggregates that have unshocked igneous or shocked, relict igneous textures. Some 40 particles are polymict breccias or are recrystallized and have granulitic or polygonal textures. The polymict particles are dominated by igneous lithologies that are more pyroxene rich (anorthositic norite/gabbro) than those of the first group; they include two magnesian and one ferroan granulitic breccia groups (see [3]).

On the basis of a mixing-model calculation on the composition of <1-mm soil, [6] concluded that there must be some 15% of a high-Mg' (Mg/Mg + Fe) and low-ITE (incompatible trace element) component in addition to 36% of an anorthositic-norite component (roughly equivalent to gabbroic-anorthosite component of [7]). This is of special interest because the South Massif soils do not require the high-Mg' component in similar mixing models [6]. High-Mg' lithologies, however, are present in samples from both massifs.

The proportions of highland lithologies after removal of mare basalt and orange glass components and of regolith breccias and agglutinates whose compositions reflect mare-basalt admixture are as follows: 39 wt% noritic impact melt breccias, 18% magnesian granulitic breccias, 5% ferroan granulitic breccias, 9% other breccia lithologies that have generally anorthositic-norite compositions, and 29% troctolitic and noritic anorthosite fragments, including ~5% coarse, unshocked plagioclase crystals.

Olivine-Plagioclase Lithology: Trace-element and mineral compositions indicate that the coarse-grained plagioclase crystals found in the 2–4-mm size fraction and the fragments of coarse plagioclase and olivine ± orthopyroxene are closely related to those of 76535 troctolite [8,9], 76335 troctolitic anorthosite [10], and a troctolitic clast in 76255 [11] (Fig. 1). The mass weighted mean composition of this group of fragments, however, is substantially more anorthositic (~85–90% plagioclase) than bulk 76535, suggesting that these derive from a more anorthositic body of rock, such as 76335. We have not found coarse olivine fragments in troctolitic proportion, nor is olivine present in sufficient abundance in finer soil fractions [12] to indicate a parent of troctolitic bulk composition. The proportion of troctolitic-anorthosite component in 76503 (19% on a regolith-breccia-free basis) is greater than expected from previous investigations. This component is part of the high-Mg' component of [6] and appears to be more prevalent in the local North Massif soil than in the breccia boulders from higher on the Massif and more prevalent than in the

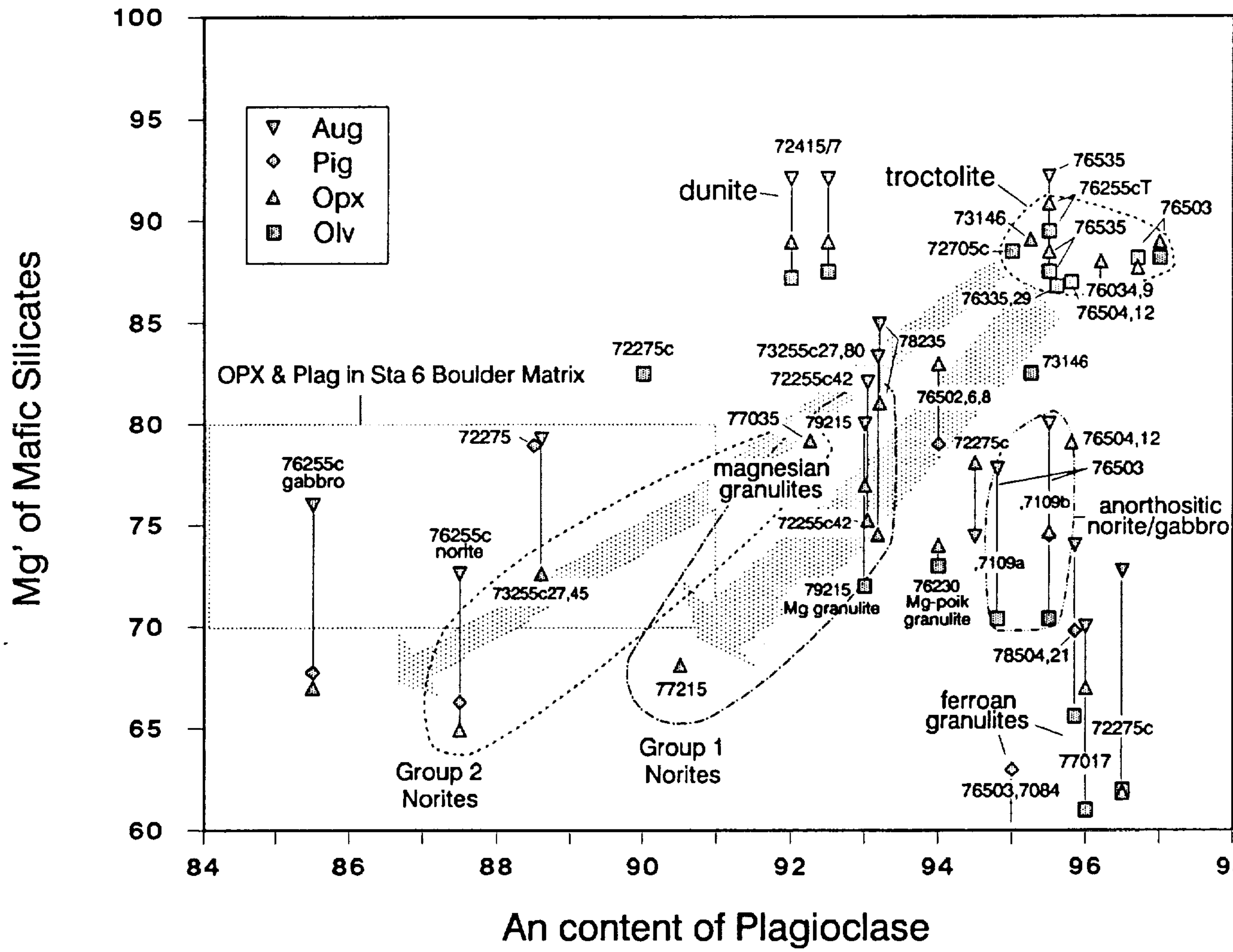

Fig. 1. Plagioclase and mafic silicates, Apollo 17 highlands.

sampled materials from South Massif. More pyroxene-rich lithologies do occur among fragments in 76503; however, in almost all cases, they have textures altered by impact and thermal annealing.

Granulites: Granulitic breccias and other impact-modified rocks of similar composition constitute 25% of the highland lithologies in 76503. Compositionally, both ferroan and magnesian groups as defined by [3] are present (Fig. 2); these compositions correspond to anorthositic norite/gabbro. Mineral compositions of the magnesian granulites are most similar to those of group 1 norites as defined by [13] (Fig. 1). Some of the moderately magnesian granulitic breccias have mineral compositions displaced toward those of the ferroan-anorthositic suite (Fig. 1). One such sample, 76503,7109, contains compositionally similar clasts with granulitic texture and relict igneous (anorthositic gabbro) texture.

Crystallization of a melt parental to the troctolitic anorthosite could potentially produce the observed mineral compositions and trace-element chemistry of the magnesian granulites and group 1 norites (Fig. 1, lower stippled arrow). The common occurrence of clasts of troctolite and gabbro with a group 2 norite in 76255 [10] suggests that these may also be related (Fig. 1, upper stippled arrow); however, we support the argument, on the basis of trace-element concentrations and mineral compositions, that group 1 and 2 norites cannot be related by means of a common magma (see [2,12]).

Constraints from Polymict Noritic Breccias: The mass-weighted mean composition of noritic melt breccias in 76503 has lower ITE concentrations than the average matrix composition of station 6 melt breccias (Fig. 2); however, in calculating the mean composition for 76503 noritic melt breccias, we have included particles that obviously contain highland igneous clasts or components. The distribution of mixed compositions suggests that the highland igneous component(s) of the noritic breccias is (are) on average similar to anorthositic norite/gabbro, i.e., magnesian granulitic breccias, and not to the troctolitic-anorthosite component that we find as actual coarse fragments in 76503. We suggest that the anorthositic norite/gabbro precursors are widespread components, as suggested by [3], and that the troctolitic anorthosite lithology, although possibly petrogenetically related, is more restricted in occurrence, perhaps excavated only by impacts reaching deep plutonic levels.

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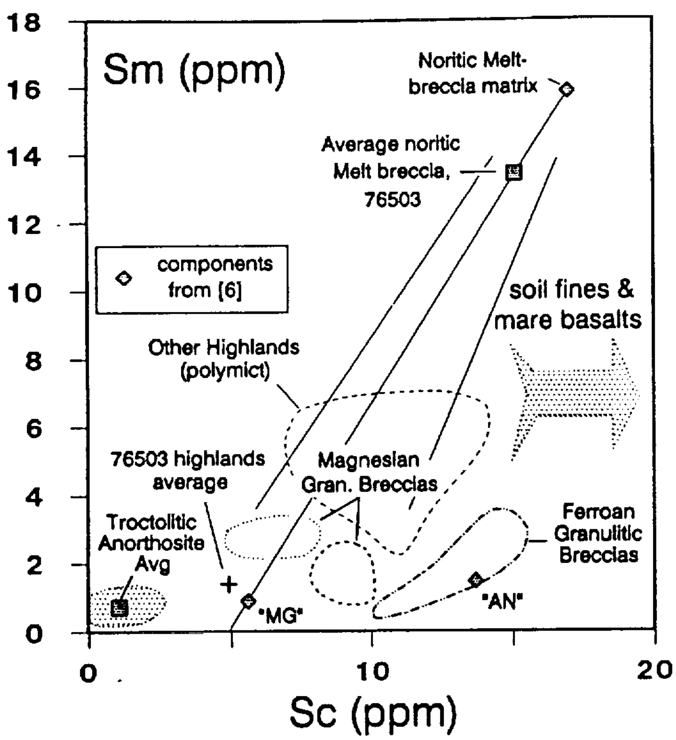

Fig. 2. Sample 76503, highlands.

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p-4

Among Apollo landing sites, Apollo 17 provides the best opportunity to study the efficiency of formation and evolution of regolith by impacts, both large and small. The mare-highlands interface is crucial to this endeavor, but the Light Mantle avalanche and presence of fine-grained pyroclastics offer additional constraints. Compositional variation among soils from different locations and depths provides a means to quantify the extent of mixing by larger impacts. Because of their variety and complex history, Apollo 17 soils have been important in establishing agglutinate abundance, mean grain size, and abundance of fine-grained iron metal (as measured by (I_s/FeO) as simple index of maturity (relative extent of reworking by micrometeorite impact at the surface) [7,9].

Surface Soils: Both the composition and modal petrography of the surface soils vary significantly across the site, and these variations are related in a reasonable way to the site geology. Soils from the valley floor are dominated by mare basalt, but even the most Fe-rich soils (stations 1, 5, LRV 12) contain ~15% highland material, and this proportion is greater in soils closer to the massifs (Fig. 1). Soil from the South Massif (stations 2, 2A, 3) contains only a small amount of mare basalt (<4%) and one regolith breccia from station 3 (73131) appears to consist entirely of highland material. Soils from the North Massif/Sculptured Hills area contain a larger proportion of mare material than those from the South Massif, and that proportion increases to the east from stations 6 to 7 to 8 [16,4,5].

Mass-balance models have been successful at quantifying the compositional variation in terms of differences in proportions of components representing major lithologies at the site. Early models used four components, two of mare affinity and two of highlands affinity: high-Ti mare basalt (HT), orange/black pyroclastic glass (OG), noritic impact-melt breccia (NB), and anorthositic norite (gabbro) (AN) [16,6]. An important observation of this early work was that the greater concentrations of incompatible trace elements (ITEs, e.g., Sm; Fig. 1) at the South Massif indicate that the NB:AN ratio (~1:1) is greater there than that at the North Massif (~1:2) [16]. This suggested that the massifs, which were assumed to be structurally similar, had a high proportion of noritic melt (NB, deposited by the Serenitatis impact) at the top, and that the lower slopes were dominated by "anorthositic norite" (AN, actually a potpourri of prebasin crustal lithologies such as granulitic breccias and anorthositic troctolites and norites) [16,5] (Fig. 2). The high NB:AN ratio of the Light Mantle soils reflects their derivation from the upper slope

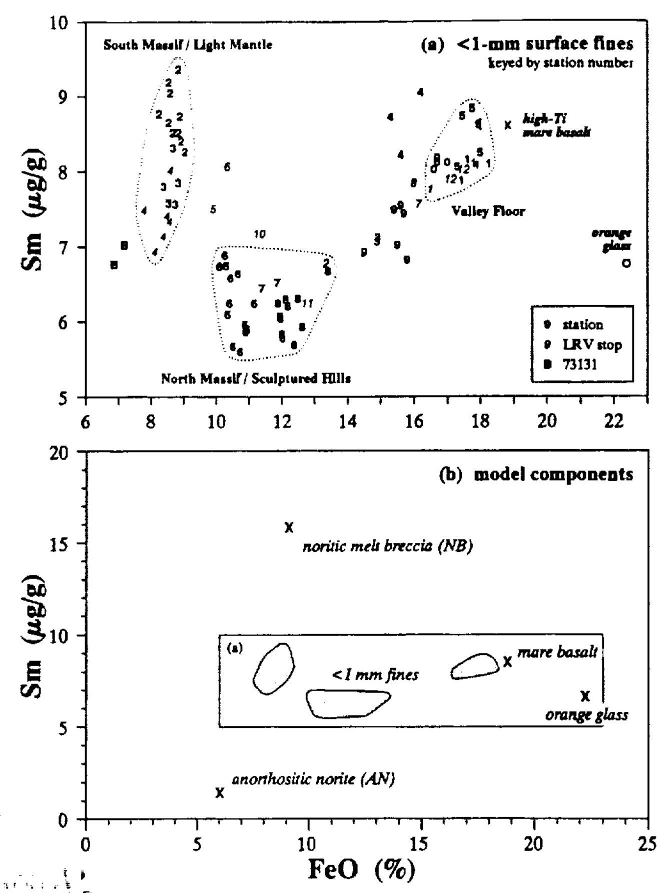

Fig. 1. (a) Compositional variation in Apollo 17 surface soils, from [5]. Sample 73131 is a regolith breccia from station 3. (b) Comparison of compositions of soils with the four major components of mass balance models [5]; inset box shows range of (a). No valley floor soil is devoid of highland material. The South Massif soils contain the least mare basalt and have a greater abundance of noritic melt breccia than the North Massif soil.