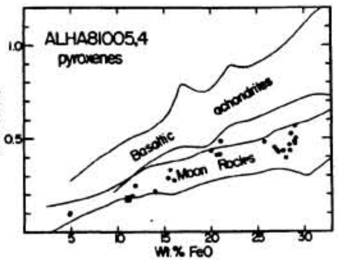
REGOLITH BRECCIA ALHA81005: EVIDENCE OF LUNAR ORIGIN, AND NATURE OF PRISTINE AND NONPRISTINE CLASTS. Paul H. Warren, G. Jeffrey Taylor and Klaus Keil, Department of Geology and Institute of Meteoritics, University of New Mexico, Albuquerque, NM 87131

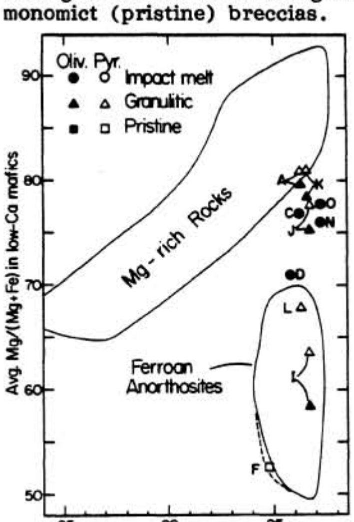
Summary: On the basis of MnO/FeO ratios in pyroxenes and the texture and composition of Antarctic meteorite ALHA81005, we conclude that the rock is of lunar rather than asteroidal origin. This conclusion is confirmed by the work of others on oxygen isotopic composition [1] and noble gas contents [2]. Since Apollo and Luna missions have sampled only a small portion of the near side of the Moon, ALHA81005 probably is a sample from a heretofore unsampled site. The origin of the rock by impact ejection from the Moon lends further credence to the suggestion [3-5] that SNC achondrites were derived by impact ejection from Mars.

Lunar origin: We have studied a 210 mm^2 polished thin section (ALHA81005,4). The most convincing evidence we discovered for a lunar rather than asteroidal origin comes from the MnO/FeO ratio. It is distinctively lunar, as indicated by analyses of pyroxenes (Fig. 1: the fields for Moon rocks and basaltic achondrites are based on diagrams in [6] and [7]). The rock's bulk MnO/FeO [8] is also distinctly lunar (the rock contains very little Fe-metal; practically all Fe is present as FeO). The pyroxenes of SNC group achondrites have MnO/FeO ratios similar to those of basaltic achondrites [3]. Taken as an isolated phenomenon, the MnO/FeO ratios would not constitute proof of lunar origin, but considering the evidence from oxygen isotopic [1] and noble gas [2] data, there is virtually no doubt that the rock is lunar.



Additional evidence for a lunar origin comes from the texture of the rock and the composition of its constituent glasses and clasts. ALHA81005 is a regolith breccia, as is indicated by the presence of abundant brown, swirly glass, almost certainly of agglutinitic origin. Our section also contains one colorless glass sphere (FeO = 5.7 wt.%), also typical of regolith breccias. The rock also has high contents of solar-wind rare gases [2]. These are additional arguments for lunar origin because non-lunar regolith breccias always contain vastly lower abundances of agglutinitic glass and solar gases. The mineralogical and chemical compositions of the lithic clasts (see below) are very similar to lunar highland rocks, another indication of lunar provenance.

Description of the rock and its clasts: The matrix consists of very fine grained mineral fragments and brown glass. The glass is essentially uniform in composition, averaging (in wt.%) SiO_2 - 43.7, TiO_2 - 0.24, Al_2O_3 - 28.1, Cr_2O_3 - 0.14, FeO - 4.5, MnO - 0.06, MgO - 5.6, CaO - 15.7, Na_2O - 0.34, K_2O - 0.06, P_2O_5 - 0.03. Not surprisingly, this composition is close to that of the whole rock [8]. The glass composition yields a CIPW norm with 78% plag (An96.1), 10% pyroxene (mainly low-Ca), and 9% olivine (Fo70). The whole rock analysis is slightly less plag-normative. Most of the abundant lithic clasts belong to one of three categories, in order of abundance: granulitic breccias, impact melt breccias, and monomict (pristine) breccias.



Section ALHA81005,4 contains one clast (F), which, although brecciated, contains clear vestiges of a poikilitic cumulate texture, i.e., is almost certainly pristine (endogenously igneous). Pristine nonmare rocks from the Apollo collection fall into two genetically distinct groups, namely the ferroan anorthosites [9] and the Mg-rich rocks [10-12]. Based on Fig. 2, clast F appears to be ferroan. Its mode is not anorthositic: roughly 40% augite (original composition En37Wo32, containing exsolution lamellae too small to be resolved with an electron microprobe), 35% plagioclase (An92.4-96.7), and 25% pigeonite (originally about En48Wo11; now inverted, with high Ca exsolution lamellae up to ~3 µm across). But the clast is only 4.3 x 1.5 mm, and very coarse grained, so the mode is subject to extreme sampling errors. Plagioclase crystals, interwoven poikilitically with pyroxenes, are in optical continuity up to 1.5 mm apart. Pyroxenes are in optical continuity up to 1.7 mm apart. Brecciation has obscured the texture in places. The entire clast may consist of as few as two pyroxene crystals (one augite, one inverted pigeonite), plus parts of four plag crystals. Hence, the low plag content, by ferroan anorthosite standards, is probably not significant. Nevertheless, we know of no precedent among ferroan pristine Apollo rocks of an augite crystal even close to 1.7 mm across. Even if the augite is purely a product of trapped liquid (the range of plag composition, plus the mode suggest that trapped liquid content is relatively high), it suggests that the parental magma of this clast had a high Ca/Al ratio, compared to the other ferroan magmas.

Two other small clasts may be pristine. One of these is only 0.5 x 0.5 mm, but is an extraordinary mineral assemblage. It consists of fine-grained olivine (Fo43), pyroxene (En55Wo2.0), and troilite, with no plag or Fe-metal. The evidence that it is pristine is simply that this composition is highly improbable as a mixture of known lunar rock types. The other clast (L) has a granulitic texture, but contains Co-rich Fe-metal. It is a ferroan anorthosite, with roughly 20% low-Ca pyroxene.

Conceivably, some of the other granulitic clasts are also pristine. Only one (K) contained an Fe-metal grain large enough to be analyzed, but its low Co composition is indicative of meteoritic contamination (i.e., nonpristinity). The largest granulitic clast (A) is about 4 x 3.5 mm. Except for I and L, which are small ferroan anorthosites, these clasts are generally troctolites. They are probably nonpristine, albeit free of contamination by KREEP. Similar Apollo samples were reviewed by [13], who noted that they tend to plot in the gap between ferroan anorthosites and Mg-rich rocks on Fig. 2.

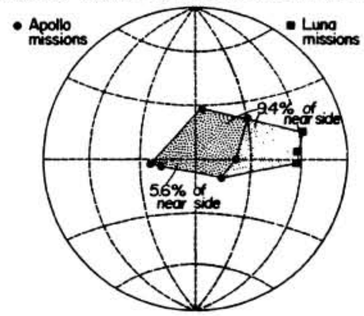
The rock's rare phosphates and K-rich phases are minor constituents of the impact melt clasts. Surprisingly, even these are troctolitic, often containing xenocrysts of pink spinel (even though a silica phase is also generally present). The largest (C: about 3.5 x 2 mm) is poikilitic with olivine oikocrysts. Surprising features of both types of magnesian nonpristine clasts (granulitic and impact melt) are the paucity of pyroxenes, and the exceedingly anorthitic nature of their plag (Fig. 2).

Implications: One of the most important implications of the lunar origin of ALHA81005 concerns the SNC achondrites. Numerous workers have suggested that these meteorites may come from Mars [e.g., 3-5]. One objection to this notion was that it seemed strange to find 9 meteorites from distant, much larger Mars, when none were known from the nearer, smaller Moon. That objection is now invalid. It has also been argued that removal of material from Mars would require melting, which would eliminate the chief argument for origin on a large planet, namely, the young ages of SNC meteorites. ALHA81005, however, was clearly not melted when it was propelled off the Moon. In fact, the rock is no more shocked than a typical Apollo regolith breccia; based on the rarity of shock features in plagioclase [14], the rock as a whole was probably never shocked beyond ~200 kb. Thus, impact melting or even high shock does not seem to be a requisite for impact ejection of a rock from the Moon.

The importance of this sample for lunar science can scarcely be overestimated. For technological and safety reasons, the samples returned by the U.S. Apollo and Russian Luna missions all came from a small area near the center of the near side (Fig. 3). A polygon surrounding all nine sites covers 4.7% of the Moon's surface; if Luna sites (which only returned soil samples) are excluded, the coverage shrinks to merely 2.8%. This situation is mitigated by the fact that the lunar crust was subjected to numerous impacts powerful enough to have ejected materials laterally over great distances. But petrochemical evidence indicates that lateral homogenization was far from complete over distances on the order of 1000 km [15]. The Moon's circumference is 10920 km.

Allowing for lateral transport via impact ejection, the coverage of the Apollo and Luna sites (Fig. 3) might be effectively double the nominal value; and ALHA81005 might just happen to be from the center of the near side. But it probably formed someplace thousands of km from any Apollo or Luna sample. In fact, its low KREEP content is independent evidence that it is probably not from the central part of the near side (the area of the Apollo landings), where remote sensing data [17] indicate soils generally have incompatible element contents at least 0.05 x those of high-K KREEP [18]. Apollo 16 regolith breccias generally have bulk compositions virtually indistinguishable from local soils [19], and like the soils, probably are end products of thorough homogenization of the local upper crust (plus a minor meteoritic component). We may safely assume that the same holds for ALHA81005.

EXTENT OF EXPLORATION OF THE MOON
NEAR SIDE
LAMBERT AZIMUTHAL EQUAL-AREA PROJECTION



(THE FAR SIDE IS COMPLETELY UNEXPLORED)

The portion of the lunar crust which spawned ALHA81005 was broadly similar to the highlands near the Apollo 16 site. The main low Mg/Fe rock type appears to be ferroan, pyroxene-bearing anorthosite; the main high Mg/Fe rock type appears to be magnesian troctolite. Some important differences are apparent, however. Not only KREEP, but most other "evolved," sodium-rich lithologies known from the explored area of the Moon seem to be comparatively rare (this petrographic observation is confirmed by the bulk analysis [8]: the Na content of ALHA81005 is only 0.64 x that of an average Apollo 16 soil [16]). The single unequivocally pristine clast contains a mineral assemblage (coarse high-Ca pyroxene + pigeonite + plag, of "ferroan" affinities) not seen before. Hopefully, more pristine clasts will be found when the rock is studied in greater detail.

References: [1] Clayton R.N. et al. (1983) This volume. [2] Bogard D. and Johnson, P. (1983) This volume. [3] Steele I.M. and Smith J.V. (1982) JGR 87, A375-A384. [4] Wood C.A. and Ashwal L.D. (1981) PLPSC 12, 1359-1375. [5] Grimm R.E. and McSween H.Y., Jr. (1982) JGR 87, A385-A392. [6] Dymek R.F. et al. (1975) GCA 40, 1115-1130. [7] Marvin U.B. and Warren P.H. (1980) PLPSC 11, 507-521. [8] Laul J.C. et al. (1983) This volume; Kallemeyn, G. W. and Wasson, J.T. (1983) This volume. [9] Dowty E. et al. (1974) EPSL 24, 15-25. [10] Warner J.L. et al (1976) Lunar Science VII, 915-917. [11] Warren P.H. and Wasson J.T. (1980) Proc. Conf. Lunar Highlands Crust, 81-99. [12] James O.B. (1980) PLPSC 11, 365-393. [13] Bickel C.E. and Warner J.L. (1978) PLPSC 9, 629-652. [14] Kieffer S.W. et al. (1976) PLSC 7, 1391-1412. [15] Warren P.H. and Taylor G.J. (1981) Proc. Conf. Multi-ring Basins, 149-154. [16] Korotev R.L. (1981) PLPSC 12, 577-605. [17] Metzger A.E. et al. (1977) PLSC 8, 949-999. [18] Warren P.H. and Wasson J.T. (1979) Rev. Geophys. Space Phys. 17, 73-88. [19] Ryder G. and Norman M.D. (1980) Catalog of Apollo 16 Rocks, NASA JSC Curatorial Branch Pub. No. 52 (JSC 16904).