however, contain some constituents observed only in minute quantities in the breccias. First, the above-mentioned splinters of iron and globules of iron and troilite, and so on are different. Baddeleyite and dysanalyte are abundant in this fraction and may be studied in detail. Last we discovered well-developed octahedral crystals, distinctly zoned, in all properties (polishing, reflectivity, color, up to details of the natural faces) very similar to magnetite; very probably a new spinel (Fig. 1D).

The iron spherules in the dust also have their pecularities. Some spherules contain a radiating structure of troilite and silicate inclusions (in the form quite similar to enstatite chondrules). In others the ratio Fe : FeS and their intergrowth varies strongly. One splinter of schreibersite was observed with idiomorphic kamacite crystals.

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Search for Magnetite in Lunar Rocks and Fines

Abstract. *Magnetite crystals larger than 2 micrometers are absent from rocks and fines. Smaller opaque spheres in the fines can tentatively be identified as magnetite. Their concentration is not higher than 1 × 10^{-6} particle per particle smaller than 1 millimeter. In the fines from the sampling site, the contribution of material similar to type 1 carbonaceous meteorites is insignificant, either because it never existed, or because it was evaporated or comminuted by impact or was diluted by indigenous material. Other magnetite habits typical of carbonaceous meteorites or possibly of cosmic dust or comets were also sought without success—such as rods, platelets, framboids, spherulites, and idiomorphic crystals.*

The magnetite in Wiik's type 1 carbonaceous meteorites shows well defined crystal habits, some of which are exclusively found in these meteorites (*1*). These habits are easily recognizable under the reflecting microscope; their properties emerge sufficiently and thus the specific particles are quickly discernible, even when in small proportions in mixtures.

This mineral may thus be used as a path-finder for Orgueil-like materials, either indigenous or foreign. The discovery on the moon of materials belonging to this type is very important for the theories of the moon, planets, meteorites, comets, and cosmic dust (*2*). We thus undertook a search for the typical magnetite crystals in lunar materials, with the fines representing a mixture of indigenous and foreign materials and the hard rocks providing a good basis of comparison with materials of lunar origin.

Our results do not prove any theory and must be considered as part of a series dealing with sampling sites with various histories.

We studied rocks 10060,40 and 10072,31 and fines 10084,96. The rocks were analyzed by photonic microscopy (transmitted and reflected light), electron microprobe, x-ray diffraction, and scanning electron microscopy. An original method of mounting and polishing small quantities of micron-sized particles was devised (*3*). Control of contamination was attained by mounting the fines in the glove box, filtering all fluids on Millipore, and running blanks concurrently with all the experiments.

The only oxide in sample 10072,31 that could superficially be confused with magnetite was ilmenite. It occurs as idiomorphic laths (sections of thin platelets) and as larger poikilitic monocrystals (0.1 to 1 mm) with an idiomorphic tendency. Optical properties are those which may be observed and measured on pure ferriferous members in terrestrial rocks. A decisive property for differentiating ilmenite from magnetite is the pleochroism in air and oil (*4–6*). Table 1 summarizes the data obtained for lunar and terrestrial ilmenites, as well as terrestrial magnetite. The ilmenite in this hard rock is never twinned. Two other oxides were found: rutile as fine exsolutions and rare chromite.

Rock 10060,40 is very friable, made up of a loose conglomerate of all the rock and mineral fragments found in the fines.

From fines sample 10084,96, transparent polished sections were prepared as follows: (i) The powder was sieved at less than 1 mm; (ii) the size fractions obtained by sieving under a CCl_4-jet were 1 to 0.250 mm, 0.250 to 0.100 mm, 0.100 to 0.044 mm, and less than 0.044 mm; (iii) the heavy liquid centrifugates obtained from each size fraction had densities (g/cm^3) of $d<2.8$, $2.8<d<3.3$, and $d>3.3$. Magnetic separations were tried without noticeable success. The calculated concentration factor for the heaviest fraction of grain smaller than 0.044 mm is about 30.

Several free opaque or half-opaque minerals were found: ilmenite, sulfides, metallic iron, hematite, and goethite (?). Sulfides and iron are often altered into transparent, red, or brown low-reflecting oxides, which seem to be at least partially due to artifacts.

Ilmenite occurs in the fines as irregular fragments with conchoidal fractures. It is transparent under intense illumination (different from magnetite) and often twinned. Spheres of ilmenite have never been found, but opaque spheres of very low reflectivities are frequent (chromite and glass of various composition?). No one opaque mineral whose optical and morphological properties could fit in with those of magnetite has been found. Because the number of scanned heavy particles comes to at least 1×10^6, the concentration of typical magnetite crystals does not exceed 1 in 3×10^7 particles smaller than 1 mm.

Table 1. Reflectivity of magnetite and ilmenite. Not determined, N.D.

Sample	Reflectivity at 546 nm (%) (with maximum absolute error)	
	In air	In oil ($n_{546} = 1.517$)
SiC standard	20.61 ± 0.01	7.51 ± 0.01
Magnetite from Bisperg, Sweden	19.2 ± 0.5	6.9 ± 0.4
Ilmenite from Ilmen Mts., U.S.S.R. (R_0)*	20.1 ± 0.7	7.5 ± 0.7
Three Mg-free ilmenites (R_0)		
Miask, U.S.S.R.†	19.9	N.D.
Ilmen Mts, U.S.S.R.†	20.1	N.D.
Bodenmais, Germany†	19.5	N.D.
Ilmenite from lunar sample 10072,31 (R_0)	19.3 ± 0.5	6.9 ± 0.2

* See (*5*). † See (*6*).

The only objects that could possibly correspond to magnetite are small opaque spheres of steel-gray shine and with reticulated surface. Diameters do not exceed 1 or 2 μm. Their concentration, measured in the total powder and in the concentrates, is less than 1×10^{-6}.

Ilmenite has been found everywhere with a series of habits and dimensions in broken pieces of crystalline rocks. Some fragments have their ilmenites strongly cataclazed and twinned, whereas others show no shock effects at all. The only other oxides found are rutile, chromite, and pseudobrookite (?), all associated with ilmenite.

One of the most frequent varieties of glass is that with spherical inclusions of iron-nickel, twinned ilmenite, bubbles, and flow structures. The ilmenite crystals have their usual fracture form, but with a little rounding of the sharp edges. They have therefore not been completely melted, as opposed to iron and glass (*7*).

Minerals from conglomeratic fragments are made up of all the minerals, rock fragments, and spheres in the fines. The ilmenites are often twinned.

About 50 oxide grains from rock 10072,31 and about 100 from the fines 10084,96 were analyzed by electron microprobe for Fe, Ti, Mg, Cr, and Mn. We did not find any mineral that had Fe as a major element, and that had less Ti than ilmenite. Two high Ti minerals have been found associated with ilmenite: rutile and a gray mineral similar to pseudobrookite (*7*). A few percent of Mg and traces of Mn are generally present in the ilmenites. These elements do not vary very much in relation to habits.

Under the scanning electron microscope the vuggy rock 10072,31 shows black opaque minerals of two basic forms: hexagonal platelets and octahedra. As both are undoubtedly ilmenite, the last pseudo-form can immediately be interpreted as a combination of a trigonal rhombohedron $(10\bar{1}1)$ (?) with the basis (0001) (*8*). Etch pits are absent from both habits, but pseudo-octahedra show a strong tendency to grow as skeletons.

A powder diagram of a pseudo-octahedra group gave all the ilmenite lines and no others (*9*), which confirms the homogeneity observed under the photonic microscope. X-ray diffraction patterns obtained from the heavy fraction showed ilmenite to be the sole constituent.

Concerning the absence of magnetite in crystalline rocks, it has been shown that high concentrations of Ti and low oxygen pressures prevent the separation of a magnetite phase (*10*).

It is difficult at this time to interpret the negative results in relation to the specific problems of carbonaceous meteorites. If the absence of magnetite is confirmed in other indigenous materials, the interpretation of later magnetite finds in the lunar fines from other sites will be made easier.

The total absence in the fines of magnetite crystals typical of carbonaceous meteorites confirms the uniqueness of these materials and suggests that one or more very selective phenomena are active. Several hypotheses may be considered. (i) Indigenous lunar rocks of composition similar to type 1 carbonaceous meteorites are absent from the sampling site. The preservation of ilmenite included in rocks, glass, and conglomerates shows that if such magnetite-bearing rocks had ever existed, this mineral could have withstood impacts at both low and high velocities. (ii) Meteorites of type 1 impinging on the moon with cosmic velocities are completely volatilized. But one may point out that the occurrence of just slightly rounded ilmenite in vesicular glass (see above) and of almost undisturbed magnetites in basalts which have undergone nuclear shocks (*11*) testifies to a good preservation of meteoritic magnetites. (iii) Carbonaceous meteorites of type 1 are rare objects in the solar system. Mixed with very high quantities of indigenous material, the typical crystals could not be found in the fines, even after being concentrated 30 times.

The absence of magnetites of typical habits, and of magnetite in general, shows that Orgueil-like materials are probably not common rocks on the moon's surface. This result gives us a comparison term for the study of other sampling sites, where the specific phenomena responsible for the appearance of Orgueil-like materials could have occurred, such as falls of comets or cosmic dust-balls.

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Quantitative Optical and Electron-Probe Studies of the Opaque Phases

Abstract. *Ilmenite, chrome-titanium spinel, ulvöspinel, troilite, native iron, iron-nickel alloy, and native copper are present. In addition mackinawite is provisionally identified. Three additional opaque phases are present but not identified. Modal analysis indicates that the breccia is enriched in iron relative to ilmenite and troilite, and the high nickel content of this iron suggests that it is largely of meteoritic origin. The bulk composition of liquids corresponding to iron/troilite droplets in the rocks indicates an oxygen fugacity no greater than $10^{-15.5}$ and a sulfur fugacity of 10^{-6} bar. Complete melting of rocks produced a glass containing complex iron/troilite globules and skeletal ilmenites.*

Optical and electron-probe studies of opaque phases in samples 45.35.5, 48. 42, 58.23, 72.46, 84.5, and 85.4 indicate the presence of ilmenite, chrome-titanium spinel, ulvospinel, troilite, native iron, iron-nickel alloy, and native copper. In addition mackinawite is tentatively identified. Two phases, one with very low reflectance, the other with higher reflectance, form fine lamellas in