N94-16281

AN IRIDIUM-RICH IRON MICROMETEORITE WITH SILICATE INCLUSIONS FROM THE MOON. BRADLEY L. JOLLIFF, RANDY L. KOROTEV, AND LARRY A. HASKIN, DEPARTMENT OF EARTH AND PLANETARY SCIENCES & MCDONNELL CENTER FOR THE SPACE SCIENCES, WASHINGTON UNIVERSITY, ST. LOUIS, MO 63130.

We have found a 0.1 mg iron micrometeorite containing meteoritic silicate inclusions in an agglutinate from 2-2.5 cm deep in regolith core 60014. The metal is 93% iron, 6.5% nickel, 0.5% cobalt, ~150 ppm iridium, and <2 ppm gold. Although the Ir concentration is higher than that reported previously for any iron meteorite group, it lies on the extrapolation to low Ni and high Ir concentrations of several meteorite groups on Ni,Ir plots (groups IIC,D,E, and IIIAB,E,F) [1,2]. Tiny, subrounded silicate inclusions comprise low-Ca pyroxene (En_{83}), olivine (Fo_{80}), and albitic and potassic feldspars, as mixtures of minerals or glasses. Minor phases include oldhamite (CaS) and, tentatively, hercynite ($FeAl_2O_4$). The inclusions have pyroxene FeO/MnO of ~25 and olivine FeO/MnO of 40-60. In comparison with known iron meteorites, the inclusions are most similar to those in type IIE, e.g., Weekeroo Station, Colomera, and Kodaikanal [3-7]. As far as we know, this is the first observation of an iron meteorite with silicate inclusions from a lunar sample. No metal fragments with meteoritic, nonmetallic inclusions were reported in several previous, exhaustive studies of soil particles [8-10].

Observations. We isolated the particle from an anomalously Ir-rich split of 60014,19 [11]. The metal fragment is ~0.3 × 0.4 mm in cross section and appears to be compositionally uniform under electron backscatter. It constitutes ~67 wt.% of its enclosing particle of typical agglutinatic glass with fine-grained, entrained soil. The bulk metal composition is typical of meteoritic metal particles in Apollo 16 polymict samples [e.g., 8,9]; i.e., it is similar to the Fe-Ni metal in Apollo 16 soils (avg 94% Fe, 5.6% Ni, 0.36% Co) [9,10,12,13] and mafic melt breccias (5.2-6.8% Ni, 0.32-0.43% Co) [14]. Its Ir concentration, however, is 150 ppm as determined by INAA on the isolated particle, ~100× higher than that of typical Apollo 16 metal. We find by EMPA that the Ir is uniformly distributed in the metal (Fig. 1). Electron microprobe scans failed to detect Pt and Os (detection limit ~50 ppm).

Nonmetallic inclusions within the micrometeorite are 1 to 30 μm long and have rounded to cuspate morphologies. They are disseminated irregularly throughout the metal, constituting <5% of the volume. We interpret their compositions to mean that distinct mineral grains and polycrystalline aggregates were present in the meteorite before its collision with the Moon (as in Weekeroo-Station types, [5-7]) and that these were subsequently melted or shocked into their present, presumably glassy state; however, we have seen the particle only in reflected light in thick section and do not know whether any of the silicates retain crystalline structure. The most common inclusions have bronzite composition (Table 1). Next most common are mixtures dominated by sodic feldspar and olivine compositions as tiny, separate "phases" that are difficult to resolve individually by EMP (e.g., Table 1, Incl. 1) (as in Kodaikanal, [5]). Isolated inclusions with olivine composition are rare (Table 1, Incl. 7). Most analyses of the alkali-feldspar composition include some Fe and Mg, (beam overlap onto olivine?) or excess Fe (beam overlap onto the host metal or hercynite). The "purest" sodic-feldspar phase has 8.3% Na_2O and 2.5% K_2O (Table 2); the highest K_2O concentration is 3.82%. Alkali-rich spots yield variable Na_2O/K_2O, suggesting that the original material contained both K-feldspar and albite (cf. Colomera and Kodaikanal [5]). Only one inclusion (Table 2, Incl. 5) has high CaO and Al_2O_3 concentrations suggestive of plagioclase feldspar (Table 2, Incl 5). Oldhamite and hercynite (tentative) occur singly in one isolated inclusion each. No augite, Cr and Ti oxides, or whitlockite were found in the exposed inclusions.

Implications. We do not know whether the micrometeorite, when it fell, caused the enclosing agglutinate to form or whether the metal is a surviving chunk of a larger impactor and became incorporated into the agglutinate during a later impact. The metal fragment may be part of a small, recently fallen iron meteorite, unrelated to the general geology of the Apollo 16 site. Nevertheless, because its Fe-Ni-Co composition is dissimilar to metal in ordinary chondrites, but typical of metal found in ancient Apollo 16 melt rocks, it is tempting to speculate that, despite its high Ir concentration, it might be an artifact of the impactors [13,14] that shaped the Apollo 16 region, and that its silicate inclusions provide information about those impactors. Silicate inclusions of similar mineralogy within an iron meteorite have been dated at 3.8 and 4.5 Ga [3,4]. We infer that silicate inclusions of meteoritic origin were somehow incorporated into the metal as the meteorite parent body formed and differentiated, but not by impact at the time of fall. Perhaps their isotopic clocks would be reset by shock heating so that age measurements on such inclusions would indicate the time of lunar impact. No intercommunication between lunar and meteoritic silicate is evident from our analyses. The search for, and characterization of, such micrometeorites may be a fruitful avenue of future investigations.

Acknowledgements. We thank Dan Kremser for assistance with the electron microprobe. This work was supported in part by NASA under grant NAG 9-56.

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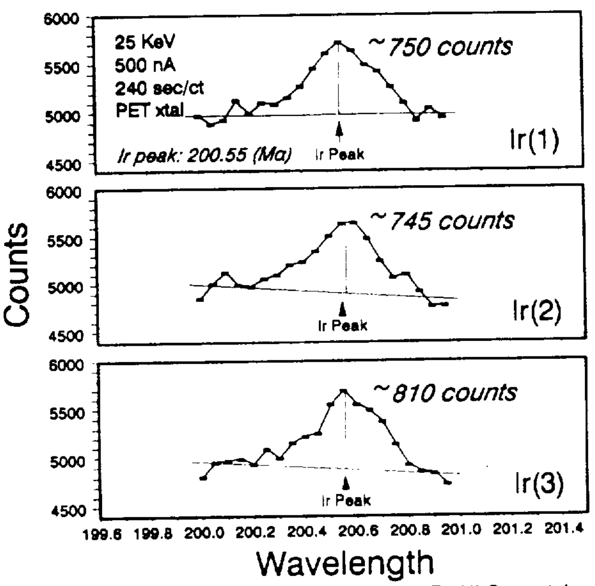

Figure 1. Ir concentration of 60014,19 Fe-Ni-Co metal. The average concentration obtained by comparison to a pure Ir metal standard is 160 ppm. Beam: 10 microns.

Table 1. Silicate inclusions in iron micrometeorite in 60014,19 (,133).

	Low-Ca Px average n=4	Oliv Incl 7	Oliv Inc 1-7	Albite Incl 16-1	Hercynite see note Incl 6	Oliv+ Herc Incl 8	Alk Fs plus ? Incl 1B	Alk Fs plus ? Incl 2	Mix/Gls Av (n=5) Incl 1	Glass? Incl 5	Glass? Incl 5-5
SiO2	56.60	39.13	39.5	66.37	0.23	35.24	66.09	62.24	52.16	35.02	40.75
TiO2	0.10	0.00	0.00	0.09	0.00	0.01	0.06	0.01	0.03	0.19	0.39
Al2O3	0.11	0.04	0.25	18.93	64.86	1.51	18.53	18.11	9.90	21.84	24.31
Cr2O3	0.09	0.40	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.03	0.04
FeO	11.47	18.25	17.90	2.50	35.96	22.19	4.90	5.34	11.36	26.16	13.75
MnO	0.48	0.47	0.31	0.00	0.00	0.42	0.02	0.03	0.26	0.10	0.09
MgO	30.87	42.16	42.12	0.00	0.02	39.12	4.35	3.67	23.47	6.09	5.19
CaO	0.52	0.00	0.05	0.69	0.07	0.02	0.57	0.69	0.27	9.56	14.08
Na2O	0.01	0.01	0.04	8.27	0.01	0.00	5.56	5.22	2.06	0.94	0.44
K2O	0.00	0.01	0.00	2.46	0.00	0.00	0.46	2.32	0.50	0.07	0.11
Sum	100.25	100.47	100.17	99.32	101.15	98.51	100.54	97.65	100.00	100.00	99.15
Mg'	83	80	81			76	61	55	79	29	40
FeO/MnO	24	39	58			53			43	260	153

Notes: CaS (oldhamite) also observed (one inclusion), but not quantitatively analyzed.
Ca-rich phase or glass is present in one inclusion, but analysis was compromised apparently by beam overlap on Fe-metal.
Inclusion 5 glass appears to be a mixture of plagioclase, olivine, bronzite, hercynite, and metal. Analysis normalized to 100% after compensation for metal overlap.
Identification of hercynite is tentative due to small inclusion size.