CR 115312

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

LUNAR SAMPLE ANALYSIS PROGRAM

"Metallographic and Electron-Microprobe Studies of Returned Lunar Samples with Significant Amounts of Metallic Fe-Ni"

Final Technical Progress Report
for
Contract NAS 9-10401

by

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November 29, 1971

(work continued on Grant NGR 39-007-056)
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Final Report
Prepared under Contract No. NAS 9-10401

by

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for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Manned Spacecraft Center

(NASA-CR-115312) METALLOGRAPHIC AND ELECTRON-MICROPROBE STUDIES OF RETURNED LUNAR SAMPLES WITH SIGNIFICANT AMOUNTS OF METALLIC Fe-Ni Final J.I. Goldstein (Lehigh Univ.) 29 Nov. 1971 9 p CSCL 03B G3/30

N72-15753

Unclas
13349

FACILITY FORM 602
9 (ACCESSION NUMBER) | 63 (THRU)
(PAGES) | (CODE)
CR-115312 (NASA CR OR TMX OR AD NUMBER) | 30 (CATEGORY)

TITLE

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ABSTRACT

Metal particles from the Apollo 11 and 12 soil are both meteoritic and lunar in origin. In the Apollo 12 soil, most of the metal particles are meteoritic, based on their Ni-Co contents. On the other hand, there is a much smaller proportion of meteoritic metal among the metallic inclusions in the lunar soil particles.

The structures and compositions of the phases present in many of the remelted metal particles indicate either slow cooling or a reheating of those samples on the moon's surface in the 500-600°C temperature range for a year or more. Most of the meteoritic particles studied were probably originally pieces of chondrites.

DESCRIPTORS

GENERAL - metal particles, lunar soil, meteoritic, shock, reheating

SPECIFIC - scanning electron microscopy, electron probe microanalysis, troilite, phosphide, deformation bands, dendrites Ni, Co, P, S, Fe, Apollo 11, Apollo 12, chondrite, eutectic

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SUMMARY

The object of this study is to help define the time-temperature-pressure history of both lunar material containing significant amounts of Fe-Ni and of lunar soil and breccia containing metallic meteorite fragments. Appropriate lunar samples were studied by metallographic, X-ray and microprobe techniques. The results of these studies were compared with data on the structure, composition and origin of iron meteorites, iron inclusions in chondrites and reheated iron and chondritic meteorites.

Two types of metallic particles were found in the lunar soil of the Apollo 11 and 12 sites. One type is lunar in origin and the other type is meteoritic in origin. In the Apollo 11 material, the metal particles with high Ni contents were probably derived from meteorites (iron, chondrites) of different sizes which impacted with varying degrees of intensity on the lunar surface. In the Apollo 12 soil, much of the metal of lunar origin overlaps the range of Ni contents found in meteoritic metal. However, the Co content of Apollo 12 metal particles from the igneous rocks is greater than values for meteoritic metal. In the case of metal in the Apollo 12 soil, meteoritic metal was differentiated from lunar metal on the basis of Ni-Co contents. Using this criteria the majority of Apollo 12 metal particles >125 μm in size are of meteoritic

origin. On the other hand, over 80% of the metallic inclusions in lunar soil particles are lunar, and were derived from the lunar igneous rocks. Meteoritic inclusions in the lunar soil particles were added by low velocity impacts in the lunar soil during major meteoritic bombardment on the moon.

Several metallic particles were studied in detail to determine their time-temperature-pressure history. The largest metallic particle studied was the "Mini-moon" separated from lunar fines in sample 10085-17M. The particle was a solidified globule with a composition about 77 wt% Fe, 17 wt% Ni, 6 wt% S, 0.1 wt% P. The structure of the globule consists of 40 μm sized Fe-Ni dendrites in a matrix of troilite. The dendrites showed Ni segregation and the troilite contained 0.1 - 1.5 wt% Ni and is in disequilibrium. A high Ni rim region was found at the troilite-dendrite interface. This region is taenite containing 29 - 46 wt% Ni and about 0.3 wt% S and was created by the rejection of Ni from the troilite. Globules of mini-moon composition were synthesized in the laboratory. The same structure was obtained and the rate of solidification was determined as 2.5°C/sec. This globule probably was created by the impact of a chondrite on the moon.

A second Apollo 11 metal particle containing about 5 wt% Ni, 1 wt% P with variable amounts of S and C was extracted from breccia sample, 10046-18A. The particle was apparently solidified and cooled slowly with the rock acting as a kind of crucible. The metal regions of this particle contain 2 wt% Ni, 1 wt% P, 0.3 wt% Co, balance Fe. The eutectic regions are of phosphide with fine intergrowths of kamacite, troilite and carbides. Cooling to lunar temperatures was relatively slow--a few weeks--as indicated by the continued precipitation of microphosphides around the eutectic at lower temperatures. The particle has a meteoritic origin but its original structure is unknown.

Six individual metal particles >125 μm in size from the Apollo 12 soil were studied. Four of the six particles are meteoritic. Two of the meteoritic particles exhibit deformation bands produced by peak shock pressures <150 kb. The other two meteoritic particles ~ 1/2 mm in diameter were remelted during impact on the moon. Dendrites of Fe-Ni are visible in one and a phosphide-kamacite eutectic structure is present in the other. The structures and compositions of the phases present in these two particles indicate either slow cooling or a reheating of these samples on the moon's surface in the 500-600°C temperature range for a year or more. Most of the meteoritic particles studied were probably originally pieces of chondrites.

INTRODUCTION

Prior to the Apollo flights to the moon the principal investigator proposed that, since iron and chondritic meteorites have impacted on the moon as they have on the earth, at least a small amount of metal phase will be present on the lunar surface. Since the chemistry and mineralogy of iron phases in meteorites are relatively simple, it has been possible to determine the time-temperature-pressure history for the growth of the metallic phases, to produce the metallic meteoritic structures in the laboratory and to describe the shock histories of this class of meteorites. Therefore if metallic iron-nickel or iron fragments of meteorites are present among the lunar soil and breccia, it may be possible to tell a great deal about the history of the metallic particles and/or the impacting body.

The purpose of the investigation therefore was to help define the time-temperature-pressure history of both lunar material containing significant amounts of Fe-Ni and of lunar soil and breccia rocks containing metallic meteorite fragments. Appropriate samples were extracted from the lunar soil and breccia and were studied by metallographic, X-ray and microprobe techniques. The results of these studies were compared with data on the structure composition and origin of iron meteorites, iron inclusions in chondrites and reheated iron and chondritic meteorites.

As the scope of the work developed, several experiments on solidifying pseudo lunar globules in the laboratory were executed. Calculations of radiation heat flow from solidifying bodies were also made. In addition scanning electron microscopy was used to examine the morphology of the metal particles before metallographic preparation.

BODY OF REPORT

The study of lunar samples with significant amounts of metallic Fe-Ni has yielded a large amount of detailed chemical and structural information about the samples. In addition the time-temperature history of many of the lunar and meteoritic metal particles has been determined. This information bears most strongly on the problem of the evolution of the lunar soil and rocks.

Four technical papers have been published by the P. I., J. I. Goldstein, and Co- I., H. Yakowitz as a result of the studies which have been carried out under contract NAS-910401. Copies of these papers are enclosed and constitute the body of the report which the principal investigator is submitting.

The papers are:

1. "Electron Microprobe Studies of Apollo 11 Lunar Samples," Proc. Apollo 11 Lunar Sci. Conf., Geochim. Cosmochim. Acta Suppl. 1, Vol. 1, (1970), pp. 87-92, Pergamon, with I. Adler, L. S. Walter, P. D. Lowman, B. P. Glass, B. M. French, J. A. Philpotts, and K. J. F. Heinrich.

2. "Investigation of Lunar Metal Particles," Proc. Apollo 11 Lunar Sci. Conf., Geochim. Cosmochim. Acta, Suppl. 1, Vol. 1 (1970), pp. 499-512, Pergamon, with E. P. Henderson and H. Yakowitz.

3. "Study of Metal in the Lunar Soil," Proc. of Fourth Annual S.E.M. Symposium, IIT Research Institute (1971), pp. 169-176, with D. B. Ballard and H. Yakowitz.

4. "Metallic Inclusions and Metal Particles in the Apollo 12 Lunar Soil," Proc. Second Lunar Science Conference, Vol. 1 (1971), pp. 177-191, M.I.T. Press with H. Yakowitz.