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THE SEPARATION AND DISTRIBUTION OF SOME LUNA 24 CORE MATERIALS

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CONTENTS

Three soil samples from different horizons of a core recovered from the Moon's surface by the Soviet Space mission Luna 24 have been separated according to size, visual appearance, density and magnetic properties. Appropriate samples have been distributed to a number of British laboratories for detailed investigations.

Introduction

On 26 May 1977 the Royal Society received from the Soviet Academy of Sciences representative samples from four different depths of the long core of lunar soil collected by the automated Russian space mission, Luna 24. These materials were recovered by using a rotary drill which penetrated the lunar surface to a depth of over 2 m. The core was retracted from the drill into a flexible plastic sleeve of unspecified composition for intermediate storage and transportation back to Earth. On opening the core the upper *ca.* 50 cm were found to be empty (Florensky *et al.* 1977) and there is evidence from rare gas measurements (Bogard & Hirsch 1978) to suggest that the drill did not penetrate the Moon vertically. Nevertheless, samples are identified by integers that denote their nominal distance in centimetres below the surface of the lunar regolith. Thus, the specimens supplied for investigation in British laboratories were 24090, 24125, 24170 and 24196, which came from the 90, 125, 170 and 196 cm levels respectively. A schematic diagram of the core, identifying the levels sampled, is given by Florensky *et al.* (1977).

Since the maximum sample size available was only *ca.* 0.3 g it was decided that each specimen would be subdivided according to size, density and magnetic properties to afford portions

specifically suited to the various investigations planned. The philosophy of the approach was to minimize wastage or redundancy of material. The separation scheme adopted was based on previous experience with Luna 16 and 20 and devised by an allocation committee comprising Professor G. Eglinton, F.R.S., Professor G. M. Brown, F.R.S., Professor R. Hide, F.R.S., Professor S. K. Runcorn, F.R.S., Dr G. Turner and Dr C. T. Pillinger, after consultations with interested investigators. In making an allocation, an effort was made to schedule non-destructive techniques first so that the maximum information could be obtained before a sample was melted, dissolved or otherwise destroyed. This paper documents the sample processing carried out at Cambridge.

Sample handling

All sample processing was carried out in a clean room facility similar to that described by Abell *et al.* (1970).

The specimen 24170, which originated from an unusually coarse layer in the core, may have derived from a gabbroic fragment which was broken during drilling (Florensky *et al.* 1977). A binocular microscopic examination revealed that the sample received was more than 95% freshly crushed crystalline fragments, which tends to confirm the above hypothesis. However, at least three secondary particles (agglutinates) were observed during a brief survey. The sample contained very little ilmenite and no shocked feldspar. There was very little evidence of intergrown grains and the fine grained component was missing, consistent with the sample's having already been sieved with a 95 μm mesh at the Soviet Academy of Sciences. Since only 9 mg of this sample was available, no further processing was attempted and it was allocated in total for age determination by $^{39}Ar/^{40}Ar$ measurement.

Sieving

The three soil samples 24090, 24125 and 24196 were wet sieved in three stages, with spectroscopic grade methanol as the liquid phase. The first step involved the use of 500, 250, 150, 106 and 75 μm stainless steel meshes, fractions coarser than 500 μm being reprocessed dry through a 1 mm nylon screen. The recovered samples (except fractions finer than 75 μm) were placed in stainless steel pans covered with aluminium foil and allowed to dry at room temperature in a clean air hood. The fractions finer than 75 μm were dried in an oven (*ca.* 100 °C for 10–15 min) and stored for several weeks before a further sieving at 53, 40 and 30 μm. These fine fractions were recovered as described for the coarse particle size ranges. Each sample also afforded a 'smoke sized' fraction, material finer than 10 μm which remained in suspension when methanol was decanted from the grains finer than during the first sieving. Smoke sized grains were dried and stored separately. Before each sieving operation, sieves and sieve bodies were cleaned ultrasonically and visually inspected by binocular microscope for extraneous particles.

None of the sieved fractions obtained was weighed on the sieves because a balance having a sufficiently wide dynamic range was not available. Instead, masses of the individual size fractions were obtained after complete recovery. Consequently, only an approximate particle size distribution is available for the samples since unavoidable handling losses must have occurred. Losses from fractions coarser than 150 μm are likely to be minimal; the finest material (finer than 75 μm) will have suffered the greatest loss. The distribution of particle sizes is shown in figure 1.

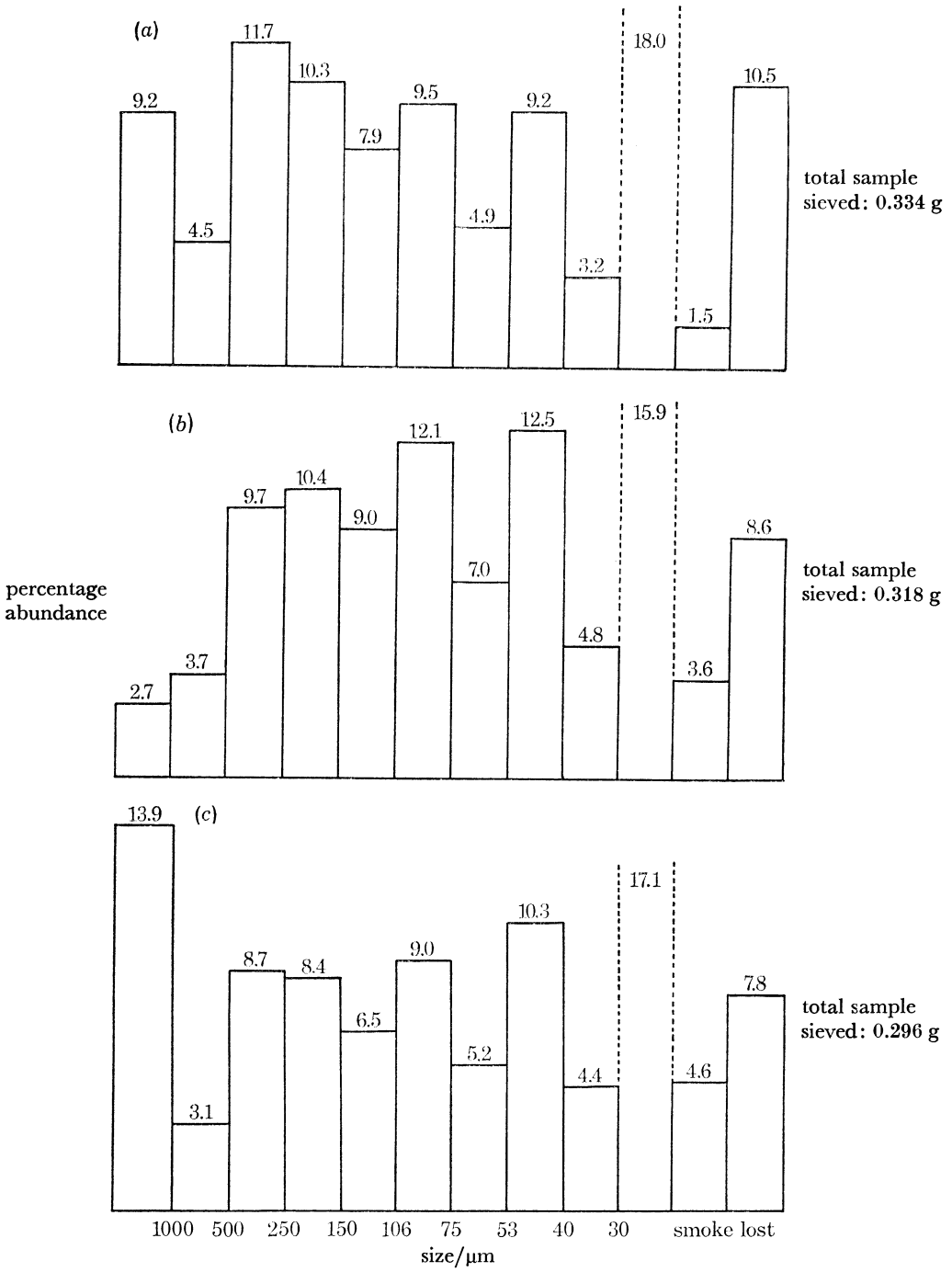

FIGURE 1. Particle size distribution obtained by sieving samples 24090 (*a*), 24125 (*b*) and 24196 (*c*).

Hand picking

The fraction coarser than 1 mm of each of the three sieved soils was sorted under the binocular microscope and individual particles classified according to their external appearance. Descriptions of all the particles as given by Dr S. O. Agrell are included in table 1. It should be appreciated that the characterizations given were without the benefit of polished thin section and

TABLE 1. CHARACTERIZATION† OF FRAGMENTS COARSER THAN 1 mm HAND PICKED FROM LUNA 24 SOILS

description	number of grains	total mass‡ mg
24090		
basaltic fragments	7	4.7
basaltic fragment with feldspathic glass splash	1	0.7
glass fragment (not Mare glass)	1	2.3
glass splashed agglutinates	6	3.3
weakly sintered clods (low grade breccia)	7	6.5
poikilitic melt and rocks (more sintered than previous fraction)	6	8.9
shocked anorthositic norites	2	2.1
noritic anorthosite	1	1.5
24125		
coarse grained basaltic fragments	3	2.7
agglutinates or weakly sintered clods	8	5.8
24196		
fine grained granulitic anorthositic norites	4	23.9§
recrystallized anorthositic norites	4	6.1
as above but possibly more Fe-rich	2	1.3
devitrified glass fragments	4	6.3
weakly sintered clods	3	2.4

† By binocular microscope only by Dr S. O. Agrell.
‡ For individual masses see Pillinger & Fabian (1977).
§ One grain 17.6 mg.

therefore should be considered as tentative and subject to confirmation. Aliquots of 1000–500, 500–250 and 250–150 μm fractions were hand picked to yield crystalline material suitable for cosmic ray track investigations. Material in the same size ranges was exhaustively hand picked to afford a collection of glass spherules for impact crater population studies.

Density/magnetic separations

Particles in the size ranges 250–150 and 150–160 μm were subjected to density separation by centrifugation in the heavy liquid tetrabromethane (ρ = 2.96 g/cm³) according to the procedure described by Pillinger *et al.* (1978*a*). Each density fraction was then further processed in methanol with a micrometer-operated magnetic separator technique of the same authors.

The material ρ < 2.96 g/cm³ afforded two magnetic fractions: a highly magnetic fraction moving more than 2 mm to the separator (HM) and a moderately magnetic fraction moving between 0 and 2 mm (MT). A proportion of the material was insufficiently magnetic to be collected by the separator (NM). The amounts of material in each of the three fractions from each soil are listed in table 2. A microscopic examination of the HM fraction reveals that they may be considered as almost pure glassy agglutinates. Therefore the proportion of a sample occurring in the HM fraction can be considered as a measure of maturity. On this basis maturity decreases with depth in the core, i.e. 24090 > 24125 > 24196. This order is born out by carbon chemistry and magnetic susceptibility measurements (Pillinger *et al.* 1978*b*) but not by track studies (Durrani *et al.* 1980, this volume).

Only particles moving more than 4 mm (VHM) to the magnetic separator were collected from the ρ > 2.96 g/cm³ fraction. A very small number of individual grains had this very

Table 2. Relative abundance† of density/magnetic separates from Luna 24 soils

sample ...		24090	24125	24196
150–250 μm				
ρ‡ < 2.96	HM§	11.2	6.3	2.8
	MT	7.8	8.8	5.7
	NM	8.8	9.3	12.8
ρ > 2.96		63.1	71.5	72.6
	VHM	1 grain	1 grain	1 grain
106–150 μm				
ρ < 2.96	HM	11.7	7.5	3.1
	MT	8.7	8.3	3.8
	NM	8.6	9.9	13.0
ρ > 2.96		67.5	68.5	76.5
	VHM	4 grains	3 grains	2 grains

† As a percentage of each size fraction; difference from 100% is the loss during sample processing.
‡ Density, g/cm³.
§ See text for explanation of terms HM, MT, NM and VHM.

high magnetic susceptibility (table 2). Each particle was reserved for metallographic studies. The remaining ρ > 2.96 g/cm³ material has not yet been separated according to magnetic properties.

Table 3. Sample distribution scheme

	sample type			
study (investigator; institution)	bulk soil	hand picked grains	sieved fractions	density/magnetic separates
mineralogy and petrology				
(Hutchison; British Museum)	—	> 1 mm	75–106 μm	—
(Simpson; Institute of Geological Sciences)	—	> 1 mm	106–150 μm	—
$^{39}Ar/^{40}Ar$ ages				
(Turner; Sheffield)	—	> 1 mm†	—	—
magnetic properties				
(Runcorn, Stephenson; Newcastle)	—	> 1 mm	all	all
metallography				
(Axon; Manchester)	—	—	—	ρ > 2.96 g/cm³ v.h.m.
optical spectroscopy				
(Telfer; Lancaster)	24125 only	—	—	—
cosmic ray tracks				
(Durrani; Birmingham)	—	150–250 μm	< 75 μm‡	—
(Barber; Essex)	—	500–1000 μm, 250–500 μm	smoke	—
microcratering				
(McDonnell; Kent)	—	500–1000 μm, 250–500 μm, 150–250 μm	—	—
carbon and major element chemistry				
(Pillinger; Cambridge)	—	> 1 mm, 500–1000 μm	all	all

† Portions passed to Whitley, Scottish Reactor Centre, for chemical studies.
‡ For thermoluminescence investigations.

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Sample distribution scheme

Representative portions of appropriate fractions have been distributed to eleven laboratories in the United Kingdom for the detailed investigations listed in table 3. Results of some of the studies carried out are described in the accompanying papers. Other investigations, e.g. carbon chemistry (Pillinger *et al.* 1978*b*), magnetic properties (Stephenson *et al.* 1978) and high voltage electron microscope studies (Barber 1978) have been reported as part of the proceedings of a special conference dealing with Luna 24.

Summary

Although only 0.3 g samples of Luna 24 core materials were available (compared with 0.5 g for Luna 16 and 20), we have been able to increase the scope of the investigations carried out in British laboratories quite considerably. The improved coverage is due primarily to the superior analytical techniques now employed by most investigators, which have in turn allowed more extensive separations to be undertaken. Many investigators are now capable of working with, and in fact prefer to study, individual grains of well characterized material. The three bulk soils separated afforded between 37 and 57 distinct fractions. Approximately 200 portions were assigned to the eleven participating laboratories. Less than 25% of the original material has been destroyed or lost during the separation. The major portion of the samples has been exposed only to high purity methanol, heavy liquids or brief heating at 100 °C. Thus it remains in a condition suitable for numerous further investigations whenever the need arises.

We thank the Soviet Academy of Sciences for their generous gift of samples. We are grateful to the Royal Society and the Science Research Council for financial support. The efforts of Dr S. O. Agrell in characterizing the grains coarser than 1 mm are gratefully acknowledged.

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