BIBLIOGRAPHY

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(Articles in Journals received from September 1 to December 31, 1977)

1. Motion of the Moon and Dynamics of the Earth–Moon System; Shape and Gravity Field of the Moon

Akim, E. L. (Academy of Sciences, Inst. of Applied Math., Moscow V-71, U.S.S.R.) and Vlasova, Z. P.: 'Model of Lunar Gravitational-Field According to Observation of Motion of Its Artificial Satellites Luna-10, 12, 14, 19 and 22' (in Russian), *Akademia Nauk SSSR Doklady* **235**, 38–41. (1977)

Ananda, M. P. (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA) Ferrari, A. J., and Sjogren, W. L.: 'An Improved Lunar Moment of Inertia Determination: A Proposed Strategy', *The Moon* **17**, 101–120. (1977)

The current error of 0.0025 on the lunar homogeneity parameter I/MR^2 is dominated by the uncertainties in the C_{20} and C_{22} gravity harmonics. This error level is equivalent to a 4.20 gm cm^{-3} density uncertainty for a lunar interior model having a core 300 km in radius. Covariance analyses are performed using Doppler data from the relay satellite of the proposed Lunar Polar Orbiter mission to determine an optimum reduction strategy which obtains an order of magnitude improvement in the gravity estimates. Error studies show the long-arc reduction method obtains results which are an order of magnitude more accurate than the short-arc technique. The nominal 4000 km circular orbit of the relay satellite is very sensitive to the unmodeled effects of gravity harmonics of degree 5 through 9. Results from this orbital geometry indicate that it may not be possible to achieve the desired order of magnitude accuracy improvement. A modified orbit having the identical orbital conditions as the nominal one, but with a larger semi-major axis of 7000 km is studied. Results show the desired order of magnitude improvement can be achieved when a complete fourth degree and order model and some fifth and sixth degree terms are estimated while considering the unmodeled effects of the remaining harmonics through degree and order eight. Studies also show a 50% additional improvement in C_{22} can be achieved if differential differenced Doppler is also processed with the direct Doppler. The improved uncertainty in I/MR^2 reduces the core density error from 4.20 gm cm^{-3} to 0.1 gm cm^{-3} for the case of a lunar density model having a 300 km core radius.

Aryutkina, A. A. and Radzievskii, V. V.: 'Annual and Monthly Variations of the Jacobi-integral Constant for the Moon', *Solar System Res.* **11**, 88–91. (1977)

From astronomical-yearbook data published by the Academy of Sciences of the U.S.S.R. for the years 1972–1978, the Jacobi-integral constants C for the Moon have been calculated with the Hill

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approximation. The presence and the character of yearly and monthly variations of C have been detected. It has also been determined that the 'constant' reaches a maximum value when the Moon is in quarter-moon phase in winter and in new-moon or full-moon phases in summer. An expression with a corrective empirical term and with a practically invariable 'constant of integration' has been derived for the Jacobi integral.

Dvorak, J. (Div. of Geol. & Planetary Sciences, Calif. Inst. of Tech., Pasadena, CA 91125) and Phillips, R. J.: 'The Nature of the Gravity Anomalies Associated with Large Young Lunar Craters', *Geophys. Res. Letters* **4**, 380–382. (1977)

The negative Bouguer anomalies (i.e., mass deficiencies) associated with four young lunar craters are analyzed. Model calculations based on generalizations made from studies of terrestrial impact structures suggest that the major contribution to the Bouguer anomaly for these lunar craters is due to a lens of brecciated material confined within the present crater rim crest and extending vertically to at least a depth of one-third the crater rim diameter. Calculations also reveal a systematic variation in the magnitude of the mass deficiencies with the cube of the crater diameter.

Evans, D. S. (University of Texas, Austin, TX 78712): 'Photoelectric Observing of Occultations – II', *Sky Telesc.* **54**, 289–292. (1977)

Details of photoelectric observations of occultations are described, namely the diffraction of starlight at the lunar limb, the indirect measurement of stellar diameters and the resolution of very close double stars, as well as, how the angular diameters of stars can be calculated from their yellow and red magnitudes.

Froeschle, M (C.E.R.G.A., Grasse, France): 'Determination of the Position of Crater Mösting A using Photographic Plates of the Moon with a Stellar Background', *The Moon* **17**, 47–57. (1977)

The reduction of 126 photographic plates from the Moon on stellar background, gives a new determination from the Mösting A coordinates with respect to the Lunar inertial system. This determination is based on: the Eckhardt theory for the physical libration, and the ephemeride ($j = 2$) derived from Brown's theory. The S.A.O. star catalog for the star positions, is used for this reduction.

Giganti, J. J. (Dept. of Physics & Astronomy, University of Maryland, College Park, MD 20742), Larson, J. V., Richard, J. P., Tobias, R. L., and Weber, J.: 'Lunar Surface Gravimeter Experiment Final Report', NASA-CR-151203, 25 pp. (1977) Available from National Technical Information Service as *N77-18981* $3.50

The lunar surface gravimeter used the Moon as an instrumented antenna to search for gravitational wave predicted by Einstein's general theory of relativity. Tidal deformation of the Moon was measured. Gravitational radiation is a channel that is capable of giving information about the structure and evolution of the Universe.

Kroitzsch, V. (Akademie der Wissenschaften der D.D.R., Zentralinstitut fur Physik der Erde, D.D.R.-15 Potsdam, Telegrafenberg) and Treder, H. J.: 'Comments on Einstein's Calculations Concerning the Periodic Fluctuations of the Length of Day Caused by Partial Tides of the Moon', *Beitr. Geophys.* **86**, 97–100. (1977)

A. Einstein calculated the fluctuations of the inertial momentum and of the rotational velocity ω of the Earth, which are caused by the partial tides of the Moon with periods of 14 days and 18.6 years

(Saros). However, Einstein and A. v. Brunn proved – in Einstein's days – that the calculated amplitudes of these fluctuations are too small as to be verified by observations. Independently, H. Jeffreys made the same calculations of the periodical fluctuations of the Earth's rotation generated by the partial tides of the Moon and Sun, and all the subsequent papers on these problems are based on Jeffreys' work. Today, we are able to verify these periodical fluctuations of the Earth's rotation by atomic clocks.

Rizvanov, N. G. (Dept. of Astronomy, University of Kazan, U.S.S.R.): 'Topocentric Aberration of the Moon', *The Moon* **16**, 335–337. (1977)

Aberrational displacement of the observed topocentric positions of the Moon differ from the aberrational effect in its apparent ephemeris geocentric coordinates. The differential aberrational corrections due to the mutual positions of the observer and the Moon, may account to 0.″3. The reduction method of astrometric observations of the Moon, which takes into account this effect, is proposed.

Singer, S. F. (University of Virginia, Charlottesville, VA 22903): 'The Early History of the Earth–Moon System', *Earth-Sci. Rev.* **13**, 171–189. (1977)

The study of the Earth–Moon system provides the connecting link between purely astronomical studies of the origin of the solar system and its planets, and geophysical and biological studies of the evolution of the Earth's geology, its surface features, atmosphere and hydrosphere, and of terrestrial life.

A coherent account is presented here, based on the hypothesis that the Moon formed separately and was later captured by the Earth. The adoption of this hypothesis, together with the observed depletion of iron in the Moon, sets some important constraints on the development of condensation and agglomeration phenomena in the primeval solar nebula, which led to the formation of planetesimals, and ultimately to planets.

Capture of the Moon also defines a severe heating event within the Earth, whereby its kinetic energy of rotation is largely dissipated internally by the mechanism of tidal friction. From this melting event dates the geologic, atmospheric, and oceanic history of the Earth. An attempt is made to account for the unique development of the Earth, especially in relation to Mars and Venus, its neighboring planets.

Zhuravlev, S. G.: 'On the Stationary Points of the Gravitation Fields of the Earth, the Moon, and Mars', *Astron. Zh.* **54**, 909–914. (1977)

Coordinates of stationary points of the gravitation fields of the Earth, the Moon and Mars as singular points of a surface of zero-velocity have been found. The problem was solved with a computer, using recent dynamical and geometrical data of the above-mentioned planets.

2. Physical Structure of the Moon; Thermal and Stress History of the Moon

Binder, A. B. (Institut fur Geophysik, Neue Universität, Kiel, F.R.G.): 'On the Thermal History of a Moon of Fission Origin', *The Moon* **17**, 29–45. (1977)

Model calculations show that the thermal history of a Moon which originated by fission from the proto-Earth is the same as that for the Moon as it is currently understood. In particular, a fissioned Moon currently has a small percent of partial melt or at least near solidus temperatures below depths of 800 km in accord with the seismic data which show that the deep interior of the Moon has a very low Q. The models have moderate (20–50%) degrees of partial melting in the upper mantle (depths < 300 or 200 km) in the period between 3 to 4×10^9 yr ago and, therefore, can account for the mare filling epoch. Finally the heat flow of the models is 18 erg cm^{-2} s^{-1} which is close to the average of 19 erg cm^{-2} s^{-1} derived from the Apollo heat flow experiments. These findings add further support for the fission origin of the Moon.

Brown, G. M. (Department of Geological Sciences, University of Durham): 'Two Major Igneous Events in the Evolution of the Moon', *Roy. Soc. London. Phil. Trans.* **A286**, 439–451. (1977)

An understanding of the origin of the Moon is strongly dependent upon a knowledge of its bulk composition and thermal history. Both aspects require a detailed consideration of the composition and origin of the lunar crust and of the mantle-derived lunar basalts. The evidence for two major igneous events is discussed, the first being a large-scale melting and fractionation into crust and mantle at −4.6 to −4.5 Ga, and the second a partial melting of the uppermost mantle at −3.8 to −3.2 Ga. The distribution of uranium is used to place constraints on the minimum extent of initial melting and on the depth at which the mare basalts were generated, using recent lunar heatflow data for a bulk-Moon uranium content of 30 parts 10^9. The model favours melting of at least 90% by volume, and a concentration of the high U-contents of the crust and upper mantle by formation of a thick lower mantle of mafic adcumulates 'barren' in heat-producing elements. The 'fertile' mafic orthocumulates from which the mare basalts were generated are restricted by the model to depths of less than 200 km.

A downward revision of the bulk U-content of the Moon results in down-scaling of the other refractory lithophile elements by analogy with the solar-nebula condensation models. This means that the bulk Moon is fairly close in composition to that of the Earth's mantle, including its iron content but excluding the volatile elements which are strongly depleted in the Moon. Low contents of siderophile and chalcophile elements, and high contents of lithophile refractory elements in the lunar basalts are attributable to the large-scale fractionation into a core, mantle and crust.

The hypothesis of an origin for the Moon by fission from a proto-Earth is revived. Earth layering by a heterogeneous accretion sequence would account for non-equilibrium between core and mantle (e.g., nickel distribution) and an outer veneer of volatile-rich condensate that would contribute to subsequent generation of a granitic crust. Early collision with a large body may have caused fission and formation of a proto-Moon from the Earth's iron-poor, proto-mantle, with loss of volatiles. Early melting of most of the proto-Moon led to strong fractionation such that the crust and mantle-derived basalts appear to have more extreme compositions, relative to Earth basalts, than is indicated by the likely bulk composition of the Moon.

Butt, R. V. J. (Dept. of Physics, Queen Mary College, London, U.K.) and Bastin, J. A.: 'Latitude Effects in Lunar Thermal Evolution', *The Moon* **16**, 339–347. (1977)

A simple analytical model is developed from which we have calculated the temperature throughout the lunar interior resulting from internal heat sources and the imposition of surface temperature boundary conditions. The surface temperature is determined almost entirely by the balance of solar heating and surface reradiation; as a consequence this temperature is latitude dependent, decreasing towards the lunar poles. The internal solution shows that the latitude effect exists almost undiminished to great depths within the Moon.

It is suggested that this dependence on latitude may have a significant effect on the Moon's thermal evolution. Using the liquefaction model the high concentration of lunar maria at low latitudes may be explained.

Cordell, B. M. (Lunar and Planetary Laboratory, University of Arizona, Tucson, ARIZ. 85721) and Strom R. G.: 'Global Tectonics of Mercury and the Moon', *Phys. Earth Planet. Interiors* **15**, 146–155. (1977)

Lobate scarps on Mercury have been studied to determine the nature of the surface stress history and implications for the planet's early tectonic history. Morphologic and transection relations indicate that most Mercurian scarps are tectonic in nature and are due to compressive stresses in the surface layer. The azimuthal distribution of lobate-scarp trends is compatible with an early predominantly compressive global stress field due to thermal shrinkage of the planet. Superposition relations indicate that the contractive phase was largely a pre-Caloris process. The effects of stresses due to planetary despinning were either negligible, predate the scarps, or were largely obscured by cratering or volcanism. The tectonic history of Mercury as recorded in the lobate scarps is different from that which caused the system of lineaments on the Moon.

Dainty, A. M. (Dept. of Earth & Planetary Sciences, Massachusetts Inst. of Tech. 24-414, 77 Massachusetts Avenue, Cambridge, MA 02139) and Toksöz, M. N.: 'Elastic Wave Propagation in a Highly Scattering Medium – A Diffusion Approach', *J. Geophys.* **43**, 375–388. (1977)

The principle of conservation of energy, in the form of the equation of radiative transfer, is used to treat the case of strong scattering of elastic waves. If the medium is isotropic, if all the energy present has been scattered many times, and if the time and distance scales of the problem are long compared to the time and distance scales of the scattering process, then the average flow of energy is described by the diffusion equation with an additional term representing linear dissipation to heat. Model seismic experiments using holes drilled in aluminum plates as scatters confirm the applicability of the formalism. The diffusion formalism has been successfully applied to lunar seismograms and to some Earth data. The results of studies of lunar seismograms show that the zone of strong scattering on the Moon is confined to a near surface zone.

Golombek, M. P. (Department of Geology and Geography, University of Massachusetts Amherst, MA 01003) and McGill, G. E.: 'Straight and Arcuate Lunar Rilles as Indicators of Shallow Crustal Structure', *EOS: Trans. Amer. Geophys. Union* **58**, 1180. (1977)

It has been demonstrated by a number of workers that straight and arcuate lunar rilles are grabens with bounding facults that dip ~ 60°. These faults are shear fractures inclined towards each other, and the depth at which they intersect is probably determined by some change in crustal mechanical properties. Assuming 60° dips, faults bounding lunar grabens intersect at depths below the surface on the order of 1 to 3 km. *Local* changes in graben width in areas of high relief indicate that the bounding fractures dip ~ 60°, assuming a locally constant depth to fault intersection. However, plots of graben width vs. elevation for the *total lengths* of many lunar grabens require that either (1) the average dips of the bounding faults vary widely and may be as low as 30°, or (2) the depth at which the bounding faults intersect is variable. Because the first alternative is mechanically unsound, we believe that detailed graben geometry reflects variations in thickness of a surface layer. Thicknesses determined correlate with (1) areal geology, (2) theoretically predicted thicknesses of total ejecta and (3) the major seismic discontinuity at the Apollo-17 site. Thus faults bounding lunar grabens very likely intersect at the base of a layer of fractured or brecciated rock.

Gusev, G. A. and Kuklachev, M. I.: 'On the Possibility of Observing the Microseismic Background on the Moon', *Akademiia Nauk SSSR. Izvestiya. Phys. Solid Earth* **12**, 789–790. (1977)

The possibility of using a high-quality mechanical oscillating system as a lunar seismometer is considered. The response of such a seismometer to the variations of the microseismic background is calculated. It is suggested that such a seismometer might be capable of recording gravitational waves at a frequency of 1 Hz.

Hughes, H. G. (Los Alamos Scientific Laboratory, Los Alamos, N. M. 87545), App, F. N., and McGetchin, T. R.: 'Global Seismic Effects of Basin-Forming Impacts', *Phys. Earth Planet. Interiors* **15**, 251–263. (1977)

Models of the thermal evolution of the Moon and the terrestrial planets suggest that basin-forming impacts occurred when the planets had partially molten interiors overlain by thickening lithospheres, comparable in thickness to the basin radii. We are investigating the effects of large impacts on planetary surfaces using a Lagrangian computer program which treats shock wave propagation and includes the effects of material strength, elastic–plastic behavior and material failure. In this paper we describe the computer code and some physical details of our numerical techniques, and report the results of several initial calculations. We study the global seismic effects for cratering energies (10^{24} and 10^{25} J) intermediate between the Copernicus and Imbrium events on the Moon, and compare the phenomenologies for assumed solid and molten planetary interiors.

The principal results are as follows:

(1) Far-field effects are largely independent of cratering mechanisms (e.g., simulated impact vs. buried explosion).

(2) Antipodal seismic effects are significantly enhanced by focusing and are of substantial magnitude. Vertical ground motion may be on the order of kilometers, and accelerations approach one lunar gravity.

(3) The most violent activity occurs at significant depth beneath the antipode, considerably after the passage of the initial compressive/rarefactive shock wave, and results from complex interations with the free surface.

(4) Seismic effects are decidedly more pronounced for a molten planet than for a solid one.

(5) Tensile failure may occur at depths of tens of kilometers beneath the antipode, and may also occur over the entire surface, although at shallower depths.

These results support the suggestion of Schultz and Gault that the unusual terrains antipodal to large planetary basins may have been catastrophically modified by seismicity generated by the basin-forming impacts. We would further suggest that these impacts may in fact have pervasively and repeatedly brecciated the entire lithospheres of the terrestrial planets as these lithospheres formed and thickened.

Nakamura, Y. (Geophysics Laboratory, Marine Science Inst., University of Texas, 700 The Strand, Galveston, TX 77550): 'Seismic Energy Transmission in an Intensively Scattering Environment', *J. Geophys.* **43**, 389–399. (1977)

For describing transmission of seismic energy through a medium in which seismic waves are intensively scattered, a statistical approach provides an attractive alternative to the conventional, deterministic approach. The energy transmission in such a medium with a given size distribution of scatterers is generally governed by a diffusion equation with a frequency-dependent diffusivity, rather than wave equations as in the conventional approach. By applying this theory, we can explain many unusual characteristics of lunar seismic signals, including those generated by surface impacts at near and far ranges and by continuous movement of the Lunar Rovers. The size distribution of scatterers can be estimated from the frequency dependence of diffusivity. Predominantly rectilinear particle motions observed indicate that the scattered energy is transmitted as body waves. When intensive scattering is limited to only a part of the transmitting medium, as in the case of far impacts on the Moon, a more general theory combining the two approaches is required. The theory is also useful for interpreting certain characteristics of terrestrial seismic signals because, while frequently ignored, appreciable scattering exists even for terrestrial cases.

O'Keefe, J. D. (Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena 91125) and Ahrens, T. J.: 'Meteorite Impact Ejecta: Dependence of Mass and Energy Lost on Planetary Escape Velocity', *Science* **198**, 1249–1251. (1977)

The calculated energy efficiency of mass ejection for iron and anorthosite objects striking an anorthosite planet at speeds of 5 to 45 kilometers per second decreases with increasing impact velocity at low escape velocities. At escape velocities of $> 10^5$ and $> 2 \times 10^4$ centimeters per second, respectively, the slower impactors produce relatively less ejecta for a given impact energy. The impact velocities at which ejecta losses equal meteorite mass gains are found to be approximately 20, 35, and 45 kilometers per second for anorthosite objects and approximately 25, 35, and 40 kilometers per second for iron objects striking anorthosite surfaces for the gravity fields of the Moon, Mercury, and Mars.

Pai, S. I. (Maryland University, College Park, MD 20742) and O'Keefe, J. A.: 'Similarity Laws of Lunar and Terrestrial Volcanic Flows', NASA-TM-X-72610, 36 pp. (1977) Available from National Technical Information Service as *N77-26049* $4.00

A mathematical model for the volcanic flow in planets is proposed. This mathematical model, which is one-dimensional, steady duct flow of a mixture of a gas and small solid particles (rock), has been analyzed. We apply this model to the lunar and the terrestrial volcanic flows under geometrically and dynamically similar conditions. Numerical results for the equilibrium two-phase flows of lunar and terrestrial volcanoes under similar conditions are presented. The main results of our theoretical model are (1) the lunar crater is much larger than the corresponding terrestrial crater, (2) the exit velocity from the lunar volcanic flow may be higher than the lunar escape velocity but the exit velocity of terrestrial volcanic flow is much less than that of the lunar case. This result supports the hypothesis that Australian tektites came from the Moon, as a stream of a mixture of rock and gas of extremely high speed and (3) the thermal effects on the lunar volcanic flow are much larger than those of the terrestrial case.

Ringwood, A. E. (Research School of Earth Sciences, Australian National University, Canberra, Australia): 'Basaltic Magmatism and the Bulk Composition of the Moon Part I. Major and Heat-Producing Elements', *The Moon* **16**, 389–423. (1977)

The lunar interior is comprised of two major petrological provinces: (1) an outer zone several hundred km thick which experienced partial melting and crystallization differentiation 4.4–4.6 b.y. ago to form the lunar crust together with an underlying complementary zone of ultramafic cumulates and residua, and (2) the primordial deep interior which was the source region for mare basalts (3.2–3.8 b.y.) and had previously been contaminated to varying degrees with highly fractionated material derived from the 4.4–4.6 b.y. differentiation event. In both major petrologic provinces, basaltic magmas have been produced by partial melting. The chemical characteristics and high-pressure phase relationships of these magmas can be used to constrain the bulk compositions of their respective source regions.

Primitive low-Ti mare basalts (e.g., 12009, 12002, 15555 and Green Glass) possessing high normative olivine and high Mg and Cr contents, provide the most direct evidence upon the composition of the primordial deep lunar interior. This composition, as estimated on the basis of high pressure equilibria displayed by the above basalts, combined with other geochemical criteria, is found to consist of orthopyroxene + clinopyroxene + olivine with total pyroxenes > olivine. 100 MgO/(MgO + FeO) = 75–80, about 4% of CaO and Al_2O_3 and 2 × chondritic abundances of REE, U and Th. This composition is similar to that of the Earth's mantle except for a higher pyroxene/olivine ratio and lower 100 MgO/(MgO + FeO).

The lunar crust is believed to have formed by plagioclase elutriation within a vast ocean of parental basaltic magma. The composition of the latter is found experimentally by removing liquidus plagioclase from the observed mean upper crust (gabbroic anorthosite) composition, until the resulting composition becomes multiply saturated with plagioclase and a ferromagnesian phase (olivine). This parental basaltic composition is almost identical with terrestrial oceanic tholeiites, except for partial depletion in the two most volatile components, Na_2O and SiO_2. Similarity between these two most abundant classes of lunar and terrestrial basaltic magmas strongly implies corresponding similarities between their source regions. The bulk composition of the outer 400 km of the Moon as constrained by the 4.6–4.4 b.y. parental basaltic magma is found to be peridotitic, with olivine > pyroxene, 100 MgO/(MgO + FeO) ~ 86, and about 2 × chondritic abundances of Ca, Al and REE. The Moon thus appears to have a zoned structure, with the deep interior (below 400 km) possessing somewhat higher contents of FeO and SiO_2 than the outer 400 km. This zoned model, derived exclusively on petrological grounds, provides a quantitative explanation of the Moon's mean density, moment of inertia and seismic velocity profile.

The bulk composition of the entire Moon, thus obtained, is very similar to the pyrolite model composition for the Earth's mantle, except that the Moon is depleted in Na (and other volatile elements) and somewhat enriched in iron. The similarity in major element composition extends also to the abundances of REE, U and Th. These compositional similarities, combined with the identity in oxygen isotope ratios between the Moon and the Earth's mantle, are strongly suggestive of a common genetic relationship.

Ringwood, A. E. (Research School of Earth Sciences, Australian National University, Canberra, Australia) and Kesson, S. E.: 'Basaltic Magmatism and the Bulk Composition of the Moon Part II. Siderophile and Volatile Elements in Moon, Earth and Chondrites: Implications for Lunar Origin', *The Moon* **16**, 425–464. (1977)

Abundance patterns of siderophile and volatile elements imply that the Moon was derived from the Earth's mantle after the core had segregated. The relative abundances of siderophile and volatile elements in the Moon and in the Earth's mantle are obtained from a comparison of their abundances in terrestrial ocean-floor basalts and lunar low-Ti mare basalts. The abundances of a group of siderophile elements Ni, Co, W, Ir, Os, P, S and Se are found to be very similar in ocean-floor tholeiites and low-Ti mare basalts and this similarity is believed to extend to their respective source regions in the Earth's mantle and lunar interior. The abundances of the above siderophile elements in the Earth's mantle have been determined by the interaction of several complex processes *unique to the Earth*, which relate to core formation and non-equilibrium distribution of elements between metallic and silicate phases. Since these factors could not possibly have operated separately within the Moon, the similarity in siderophile element abundances therefore implies that *the Moon was derived from the Earth's mantle after the Earth's core was formed.*

Abundance patterns of volatile elements in the Moon differ dramatically from those in ordinary chondrites and from those to be expected from condensation of a nebula of solar composition. These differences imply that the Moon was not formed from components which themselves had condensed directly from the solar nebula. For these reasons, current versions of the capture and binary planet hypotheses of lunar origin, which maintain that the Moon formed independently by accretion in the solar nebula, can be rejected. The drastic depletion of many volatile elements in the Moon compared to the Earth implies that the separation of material from the Earth's mantle to form the Moon occurred at very high temperatures. Depletions of this magnitude are best explained by the hypothesis that material from the Earth's mantle was totally evaporated, and then selectively recondensed, whilst the more volatile components were lost. The Moon then formed in Earth orbit by accretion from this volatile-depleted, mantle-derived condensate.

Schultz, P. H. (Lunar Science Institute, 3303 NASA Road 1, Houston, Texas 77058) and Mendell, W.: 'Thermal Signatures of Primary and Secondary Crater Fields', *EOS: Trans. Amer. Geophys. Union* **58**, 1180. (1977)

The Apollo 17 Infrared Scanning Radiometer (ISR) experiment resulted in high resolution (thermal and spatial) records of the lunar night-time surface that contain important information on the physical structure of the upper surface layer. The thermally brightest, and therefore blockiest, regions are typically associated with relatively recent impact craters. For small craters (less than 5 km in diameter), thermal enhancements commonly extend well beyond the crater wall and reflect the blocky (greater than 30 cm) nature of the crater ejecta. Such enhancements associated with large, recent craters, (e.g., Aristarchus and Kepler) however, are generally restricted to the crater interior and inner rim region. Beyond 1/2 to 1 crater radius from the crater rim, observed night-time temperatures return to values the same as or lower than average mare surfaces. Moreover, individual secondary craters and bright crater rays associated with these large craters commonly do not exhibit pronounced ($\Delta T > 2$ K) thermal enhancements. These observations suggest that the primary/secondary ejecta near the parent crater are composed of extensively comminuted debris or have undergone a sorting process depositing the finer debris at the surface. Additionally, the thermally bland secondary craters and rays suggest that the formation of secondary craters is different from the formation of primary craters of equivalent size and age, which typically exhibit strong thermal enhancements. Such differences may result from extended secondary projectile systems composed of highly comminuted and dispersed debris or relatively late arrival of small size ejecta.

Smith, J. V. (University of Chicago, IL 60637): 'Possible Controls on the Bulk Composition of the Earth: Origin of Earth and Moon', *Meteoritics* **12**, 363–364. (1977)

The Ganapathy–Anders model for the bulk Earth is examined in terms of geophysical, geochemical and cosmochemical constraints. A simpler model is proposed in which the 'early condensate,' 'silicate' and 'metal' components of the Ganapathy–Anders model are accreted *in toto* while the 'lithophile and siderophile volatiles 1300–600 K' are depleted 6.6 and 1.95 times, the 'volatiles < 600 K' 32 times and H, C and N 507 times. The core is assigned 0.14 ± 0.05? wt. fraction S to satisfy the density. The bulk U content of 14 ppb requires reexamination of models relating heat flow to concentration of radioactive elements. The bulk Fe content of 0.28 can be accommodated within the density constraints, especially if $3Fe(II \rightarrow Fe(O) \downarrow + 2Fe(III)$ in the mantle. The cosmic Mg/Si ratio can be obtained if Mg-rich perovskite dominates the mantle. Other element assignments include (a) most C and N to core (b) Na to greater depth (pyroxene, garnet, perovskite?) than K (phlogopite, pyroxene).

The chemistry of the Earth is envisaged in terms of slow, *cool* accretion from planetesimals with continued outward differentiation of basaltic material, inward migration of Fe, S-rich material, and transformation of deep-seated periodotite to high-P assemblages. K does not enter the core. Late-accreting material does not reach equilibrium because of diffusion barriers. Volatile elements are lost mainly before accretion, and there is no need for extensive loss of Si by the Earth.

Fission and volatilization models for the Moon are unacceptable until developed to explain how volatile (e.g., K) and siderophile elements can remain in high concentration in Earth's crust and upper mantle. The depletion factor for K and Rb is only 7 times w.r.t. devolatilized C.

Simultaneous accretion and disintegrative capture offer various possibilities for explaining distinctive chemical features of the Moon (e.g., low Fe and volatiles) while allowing the Earth to retain most accreted volatiles and to have incomplete differentiation of its outer mantle.

Solomon, S. C. (Department of Earth and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, Mass. 02139): 'The Relationship Between Crustal Tectonics and Internal Evolution in the Moon and Mercury', *Phys. Earth Planet. Interiors* **15**, 135–145. (1977)

Faulting and volcanism on a planetary surface can be closely related to the thermal evolution of the planetary volume. Interior warming leads to global expansion, surface extensional tectonics and a crustal stress system that aids surface volcanism. Interior cooling leads to contraction, compressional tectonics and crustal stresses that act to shut off surface volcanism. Limits on the sign and magnitude of the change in volume of Mercury and the Moon since the period of heavy bombardment on both bodies restrict possible early thermal histories. Mercury began hot throughout most of its volume, in order to have completed core–mantle differentiation in the first 0.6 b.y., and has cooled and contracted since. Solidification of an inner core in Mercury of up to 60% of the outer core radius is permitted by current limits on total contraction of the planet. The Moon began with a 200–300 km thick outer shell at near melting conditions and a relatively cold deep interior, resulting in modest expansion for the first 2 b.y. and subsequent slight contraction. The duration of plains volcanism on a planet may be controlled by the length of the period of volumetric expansion and crustal extension in the planet's history. On this basis the youngest major units of plains volcanics on Mercury are predicted to be older than the youngest major mare units on the Moon.

Wänke, H. (Max-Planck-Institut für Chemie, 65 Mainz, BRD): 'Fractionation of the Chemical Elements in the Solar Nebula: Bulk Composition of the Moon and on the Moon–Earth System', *Meteoritics* **12**, 375–377. (1977)

Since some time it has been well known that in the solar nebula all the refractory elements condense unfractionated from each other as a group at temperatures above the condensation temperature of the Mg-silicates.

3. Morphology of the Lunar Surface; Origin and Stratigraphy of Lunar Formations; Mapping of the Moon

Allen, C. C. (Department of Planetary Sciences, University of Arizona, Tucson, AZ 85721): 'Rayed Craters on the Moon and Mercury', *Phys. Earth Planet. Interiors* **15**, 179–188. (1977)

Many fresh craters on the Moon and Mercury exhibit systems of bright rays. Statistical comparison of the diameter/density distributions of fresh craters and rayed craters on these two bodies indicate that the rayed-crater populations are representative samples of the larger populations of fresh craters. The rayed-crater population on Mercury, however, is not similar either to the rayed- or to the fresh-crater population on the Moon.

Photogeological interpretation of the best available lunar imagery indicates that 'ray material' is indeed ejected from the primary craters, and should be present in the lunar soil. Although the distribution of the ray material may be patchy, it probably occurs in deposites of thickness greater than the characteristic depth to which subsequent impact processes overturn the regolith. The time needed to darken a ray system thus may be more dependent on the thickness of the ray material than on the rates of the various darkening processes, and darkening rate may be a function of crater size.

Ray darkening on the lunar surface is an inefficient process at present. The rays of craters more than 1 b.y. old are still bright, whereas the rays of craters older than Class 1 have generally faded to imperceptibility.

Arthur, D. W. G. (U.S. Geological Survey, Flagstaff, AZ 86001): 'Combined Position and Diameter Measures for Lunar Craters', Note. *Icarus* **32**, 127–129. (1977)

The note addresses the problem of simultaneously measuring positions and diameters of circular impact craters on wide-angle photographs of approximately spherical planets such as the Moon and Mercury. The method allows for situations in which the camera is not aligned on the planet's center.

Basilevsky, A. T. (Vernadsky Institute, U.S.S.R. Academy of Sciences, Moscow, U.S.S.R.) and Ronca, L. B.: 'A Possible Lunar Outcrop: A Study of Lunokhod-2 Data', *The Moon* **17**, 19–28. (1977).

The remotely controlled vehicle Lunokhod-2 travelled extensively around the edges of a linear depression unofficially called Fossa Recta. The edges of the Fossa are marked by elongated boulder fields. Three lines of reasoning suggest that the boulder fields are not the usual 'erratic' boulders found on a normal mare surface, but are bedrock protuberances: (1) The morphology of many boulders is reminiscent of primary lava features; (2) toward the edge of the Fossa the regolith thins out; (3) a model of lunar 'gardening' indicates that no regolith is to be expected in the upper portion of a non-impact cliff.

Bronshten, V. A. (Vsesoiuznoe Astronomo-Geodezicheskoe Obshchestvo, Moscow, U.S.S.R.): 'Impact and Explosion Meteorite Craters on the Earth and Moon', *Astron. Vestnik* **11**, 78–84. (1977)

The transition from impact craters to the explosive ones takes place in the range of impact velocities $v = 3$ to $10\,\text{km s}^{-1}$. One can admit conventionally as criterion of the explosive formation of a crater $v > 6\,\text{km s}^{-1}$. Minimal terminal masses of the meteorite, m, and minimal diameters of the crater, D, were calculated for different values of v and of the form-change index μ. It is showed that the minimal diameter of explosive craters on the Earth is 25–30 m. The relation between quantities of primary and secondary craters on the Moon in kilometer's range is discussed. It is concluded that the number of primary craters with $D \geqslant 3$ km is two orders greater than the number of secondary ones in accord with Öpik's counts.

Chugunov, I. G. (Astronomicheskaia Observatoriia, Kazan, U.S.S.R.): 'Relief Maps of the Lunar Limb Region from Stellar Occultation Observations', *Pis'ma v Astron. Zh.* **3**, 182–183. (1977)

Basic methodic questions of calculations of heights in the marginal zone of the Moon from observations of stellar occultations are discussed. Results of analysis of marginal zone maps obtained from these heights are given. It is shown that the system of heights is similar with sufficient degree of accuracy to the system connected with the center of the mass of the Moon.

Fielder, G. (Head, Lunar and Planetary Unit at the University of Lancaster): 'Surveying the Moon', *Nature* **270**, 563. (1977)

A summary of the U.S. Geological Professional Paper 880 – *U.S. Geological Survey*, 1970 – is presented.

Flavill, R. P. (Space Sciences Laboratory, University of Kent) and McDonnell, J. A. M.: 'Laboratory Simulation of Secondary Lunar Microcraters from Micron Scale Hypervelocity Impacts on Lunar Rock', *Meteoritics* **12**, 220–225. (1977)

Laboratory micron scale hypervelocity impact of iron spheres on lunar rock has shown that for the following reasons: (a) merging of observable cratering parameters for submicron impacts on lunar rock and glass over a wider velocity range than at larger size scales. (b) a possible although a yet undefined increase of the fraction of high velocity ejecta produced from micron scale hypervelocity impacts compared with larger sizes, and (c) reduced slope of the observed lunar microcrater distribution below $100\,\mu$m pit diameter a large percentage of submicron craters on the lunar regolith may be of secondary origin. This implies a further discrepancy between present day *in situ* measured micrometeorite fluxes and those derived from lunar microcrater counts for particles down to 10^{-16} g.

Frey, H. (Geophysics Branch, Goddard Space Flight Center, Greenbelt, MD 20771): 'Origin of the Earth's Ocean Basins', *Icarus* **32**, 235–250. (1977)

The Earth's original ocean basins are proposed to be mare-type basins produced 4 billion y.a. by the flux of asteroid-sized objects responsible for the lunar mare basins. Sealing upward from the observed number of lunar basins for the greater capture cross-section and impact velocity of the Earth indicates that *at least* 50% of an original global crust would have been converted to basin topography. These basins were flooded by basaltic liquids in times short compared to the isostatic adjustment time for the basin. The modern crustal dichotomy (60% oceanic, 40% continental crust) was established early in the history of the Earth, making possible the later onset of plate tectonic processes. These later processes have subsequently reworked, in several cycles, principally the oceanic parts of the Earth's crust, changing the configuration of the continents in the process. Ocean basins (and oceans themselves) may be rare occurrences on planets in other star systems.

Martelli, G. (Plasma and Space Physics Group, School of Mathematical and Physical Sciences, The University of Sussex, Brighton, Sussex, U.K.), and Newton, G.: 'Hypervelocity Cratering and Impact Magnetisation of Basalt', *Nature* **269**, 478–480. (1977)

Suitably modified explosive shaped charges have been used to produce small hypervelocity projectiles ($v \sim 15\ \text{km s}^{-1}$) to study e.m. effects associated with high-velocity cratering of basalts, thus simulating in a terrestrial environment some features of meteoritic impact on the lunar surface. The experiments have shown that plasma is formed during impact and that an external field can be impressed in the basalt.

McCauley, J. F. (*U.S. Geological Survey*, Flagstaff, AZ 86001): 'Orientale and Caloris', *Phys. Earth Planet. Interiors* **15**, 220–250. (1977)

Applications of experimental explosion-crater data to Orientale and recent geologic mapping of the basin have produced a new stratigraphy and genetic model for Orientale that are also applicable to Caloris.

The inner-basin scarp of Orientale is thought to be a bench separating the upper parts of the basin from its deep bowl-shaped interior. The elongated and complexly fractured domes of the basin floor formed by inward compression in the terminal stages of the cratering sequence. The Inner Montes Rook are considered a central peak ring. The Montes Rook and the nonlineated knobby and associated smoother materials that overlie the Cordillera scarp around much of its circumference are the uppermost parts of the overturned rim flap which formed early in the cratering event. The knobs and smaller massifs are probably coherent blocks quarried from deep within the Moon. They were among the last materials to leave the basin and had little radial momentum unlike the lineated Hevelius which formed earlier by disaggregation of the rim flap, secondary cratering, and the ground surge. The Cordillera scarp, best seen on the east side of the basin but poorly developed and discontinuous on the west, is a primary feature formed early in the crater excavation process by basinward motions of the walls and the fractured zone beyond the rim of the expanding cavity. The Cordillera scarp is overlain by ejecta over most of its extent, and post-basin internal slumping, previously thought to be important, must be a subordinate process in development of the scarp.

The basin fill in Caloris has no counterpart in Orientale but the materials between the most prominent scarp and the weakly developed outer scarp appear to be the degraded and possibly mantled equivalents of the massifs and knobs associated with the Montes Rook. The radially lineated terrain that generally lies beyond the outer scarp of Caloris is considered the subdued counterpart of the Hevelius Formation, which generally shows the same relation to the Cordillera scarp at Orientale. Thus, the prominent innermost scarp of the Caloris basin is the equivalent of the Montes Rook. Beyond this scarp is the overturned flap covered by large blocks and massifs derived from a deep horizon in Mercury where the bedrock is more coherent than the upper impact-brecciated layers. The radially lineated deposits, as in Orientale, are earlier-arriving basin ejecta and secondary-crater materials mixed with the pre-basin surface all of which were modified by the ground surge. This comparison between Orientale and Caloris suggests that one or more buried ring structures should be present inside Caloris and that Mercury is also layered internally as is the Moon. The differences in spacing and development of the ring structures or circumferential scarps of Orientale and Caloris are probably gravitational effects.

Mohan, S. (Jet Propulsion Laboratory, Pasadena, CA 91103): 'Determination of New Farside Lunar Radii from Apollo Photography', *EOS: Trans. Amer. Geophys. Union* **58**, 1181–1182. (1977)

The global distribution of existing lunar topography suffers from a lack of measures of farside radii due to the sparsity of data types in the non-equatorial regions. This paper presents preliminary results of determination of farside lunar radii based on reduction of photogrammetric measures derived from selected Apollo 16 Trans-Earth phase photographs. The regions covered in this analysis are west of

Mare Moscoviense and lie between longitudes 90° to 135° E and latitudes 10° to 60° N. The determinations are made using precise a priori knowledge of select lunar radii at control points, established from NASA topographic Orthophotomaps, which are also visible in the Apollo 16 photographs. The estimated lunar radii are referred to these control points and determined with a relative accuracy of 500 m. The new lunar radii are used to generate a topographic map covering the area of investigation. Topographic variations obtained from these new results are compared to previous photogeologic results. Comparisons are also made with farside gravity variations in this surveyed region.

Mottmann, J. (Dept. of Physics, Califonia Polytech. State Univ., San Luis Obispo, CA): 'Origin of the Late Heavy Bombardment', *Icarus* **31**, 412–13. (1977)

Cratering data from the Moon, Mars, and Mercury have been interpreted by some as evidence that the inner solar system underwent a period of intense bombardment that ended about 4×10^9 yr ago. Planetary perturbations of small objects within the solar system seem unable to account for the effect. This paper suggests that stellar perturbations from members of the original open cluster within which the Sun formed triggered the brief flux of objects responsible for the bombardment.

Roeder, P. L. (Geological Sciences, Queen's University, Kingston, Ontario, Canada K7L 3N6), Dixon, J. M. and Campbell, I. H.: 'Plagioclase Flotation and Lunar Crust Formation: Comment', *Geology* **5**, 712. (1977)

The authors point out an error in a paper by D. Walter and J. F. Mays, published in *Geology* **5**, 425–428. A short reply by Walter and Mays follows this comment.

Schaber, G. G. (U.S. Geological Survey, Flagstaff, AZ 86001), Boyce, J. M., and Trask, N. J.: 'Moon–Mercury: Large Impact Structures, Isostasy and Average Crustal Viscosity', *Phys. Earth Planet. Interiors* **15**, 189–201. (1977)

Thirty-five craters and basins larger than 200 km in diameter are recognized on the imaged portion (45%) of Mercury. If the unimaged portion of the planet is similarly cratered, a total of 78 such impact features may be present. Sixty-two craters and basins 200 km in diameter are recognized on the Moon, a body with only half the cross-sectional area of Mercury. If surface areas are considered, however, Mercury is cratered only 70% as densely as the Moon. The density of impact craters with diameters greater than 400 km on Mercury is only 30% of that on the Moon, and for craters with diameters between 400 and 700 km, the density on Mercury is only 21% of the lunar crater density.

The size–frequency distribution curve for the large Mercurian craters follows the same cumulative-2 slope as the lunar curve but lies well below the 10% surface saturation level characteristic of the lunar curve. This is taken as evidence that the old heavily cratered terrain on Mercury is, at least presently, not in a state of cratering equilibrium. The reduced density of large craters and basins on Mercury relative to the Moon could be either a function of the crater-production rates on these bodies or an effect of different crustal histories. Resurfacing of the planet after the basin-forming period is ruled out by the presence of 54 craters and basins 100 km in diameter and larger (on the imaged portion of Mercury) that have either well-defined or poorly-defined secondary-crater fields.

Total isostatic compensation of impact craters ~ 800 km in diameter indicates that the average viscosity of the Mercurian crust over the past 4^+ aeons was the same as that for the Moon (~ $10^{26.5}$ P). This calculated viscosity and the distribution of large craters and basins suggest that either the very early crustal viscosity on Mercury was less than that of the Moon and the present viscosity greater, or the differences in large crater populations on the two bodies is indeed the result of variations in rates of crater production.

Schubert, G. (Dept. of Earth & Space Sciences, University of California, Los Angeles, CA 90024), Lingenfelter, R. E., and Terrile, R. J.: 'Crater Evolutionary Tracks', *Icarus* **32**, 131–146. (1977)

A description of crater morphology based on rim height/depth (h/d) and depth diameter (d/D) ratios provides a quantitative method for assessing the relative importance of competing crater modification processes. Different classes of processes produce distinctive evolutionary tracks on an h/d vs d/D diagram. We have calculated such tracks for three general classes of crater modification: those processes which add material to the crater, those which redistribute material within the crater vicinity, and those which remove material from the crater vicinity. New morphometric data, from Earth-based radar scans and Mariner 9 images of Mars and Apollo metric photography of the Moon, are presented for Martian and lunar craters. We have compared h/d and d/D ratios for craters on the Earth, Moon, and Mars with theoretical evolutionary tracks for the general classes of crater modification. Lunar and terrestrial craters occupy similar regions of the h/d vs d/D diagram, whereas Martian craters lie distinctly apart. This implies that Martian craters fall on a different evolutionary track from terrestrial or lunar craters. The evolution of the lunar and terrestrial craters can be modeled by a combination of filling and slumping processes. Martian crater evolution, however, cannot be understood on the basis of these two classes of crater modification alone. Instead, a process such as eolian erosion, which removes material from the crater rims, must have been the principal form of modification, and evolutionary tracks based on such a model coupled with weak eolian deposition within the crater can indeed fit the Martian h/d vs d/D data.

Schultz, P. H. (Lunar Science Institute, Houston, TX 77058): 'Endogenic Modification of Impact Craters on Mercury', *Phys. Earth Planet. Interiors* **15**, 202–219. (1977)

Surface resolution of Mercury from Mariner-10 images is insufficient for identifying volcanic forms analogous to most of those on the Moon. Consequently, other criteria must be used in order to assess the possibility of Mercurian volcanism. One criterion is the presence of internally modified impact craters similar to floor-fractured and mare-filled craters on the Moon. Such craters typically occur near or within the lunar maria and exhibit features (fractures, shallow floors, dark-haloed craters, mare units) that either are resolvable at Mariner-10 resolutions or are detectable by indirect means, e.g., albedo and color contrasts. Mariner-10 images reveal several plausible examples, which, as on the Moon, most commonly occur near plains-filled basins. The color-ratio images by Hapke, Danielson, Klaasen and Wilson indicate that some of the Mercurian craters exhibit red plains materials on their floors. Such distinctive units may correspond either to lavas analogous to mare basalts within certain lunar craters or to compositionally distinct subsurface material retained in the impact crater. Indicators used to recognize crater modification also can be used to recognize basin modification. Specifically, several basins exhibit photometric contrasts between basin-filling plains and basin exterior; moreover, several impact craters superposed on the interior plains exhibit dark haloes suggesting excavation of compositionally distinct material. Despite the generally poor surface resolution, possible endogenic features are recognized, including irregular rimless depressions. Mercurian volcanism may have occurred and in certain regions may resemble that of the Mare Australe region on the Moon.

Scott, D. H. (U.S. Geological Survey, Flagstaff, AZ 86001): 'Moon–Mercury: Relative Preservation States of Secondary Craters', *Phys. Earth Planet. Interiors* **15**, 173–178. (1977)

Geologic mapping of the Kuiper quadrangle of Mercury and other geologic studies of the planet indicate that secondary craters are much better preserved than those on the Moon around primary craters of similar size and morphology. Among the oldest recognized secondary craters on the Moon associated with craters 100 km across or less are those of Posidonius, Atlas and Plato; these craters have been dated as middle to late Imbrian in age. Many craters on Mercury with dimensions, morphologies and superposed crater densities similar to these lunar craters have fields and clusters of fresher appearing secondary craters. The apparent differences between secondary-crater morphology and parent crater may be due in part to: (1) rapid isostatic adjustment of the parent crater; (2) different impact fluxes between the two planets; and (or) (3) to the greater concentration of Mercurian secondaries around impact areas, thereby accentuating crater forms. Another factor which may contribute to the better state of preservation of Mercurian secondaries relative to the Moon is the difference in crater ejecta velocities on both bodies. These velocities have been calculated for fields of secondary craters at about equal ranges from lunar and Mercurian parent craters. Results show that ejection velocities of material producing most of the secondary craters are rather low ($< 1\ \mathrm{km\,s^{-1}}$) but velocities on Mercury are about 50% greater than those on the Moon for equivalent ranges. Higher velocities may produce morphologically enhanced secondary craters which may account for their better preservation with time.

Strom, R. G. (Department of Planetary Sciences, Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721): 'Origin and Relative Age of Lunar and Mercurian Intercrater Plains', *Phys. Earth Planet. Interiors* **15**, 156–172. (1977)

Differences in the diameter/density distribution of craters in the size range 7–100 km between heavily cratered areas and areas of intercrater plains indicate the deposition of both lunar and Mercurian intercrater plains has preferentially obliterated craters $\lesssim$ 30 km diameter. This obliteration has altered the original lunar population distribution function from qbout a -1.3 slope to about a -0.7 slope. At least a significant portion of both the lunar and Mercurian intercrater plains appear to be volcanic deposits emplaced during the later stages of heavy bombardment on each body rather than basin ejecta or an ancient primordial surface. The very widespread distribution of intercrater plains on Mercury compared to the Moon may be related to Mercury's core formation which would have resulted in a large radius increase leading to widespread extensional fracturing to provide egress for the eruption of volcanic deposits on a global scale. This was followed by a radius decrease due to contraction of the lithosphere to produce thrust faulting represented by Mercury's lobate scarps.

Woronow, A. (Lunar & Planetary Lab., Univ. of Arizona, Tucson, AZ): 'Crater Saturation and Equilibrium: a Monte Carlo Simulation', *J. Geophys. Res.* **82**, 2447–56. (1977)

Conditions of crater saturation and equilibrium have been simulated with a Monte Carlo computer program which utilizes a generating function of the form $N = b.D^{-1}$. The following conclusions have been deduced from the results of the model: (1) saturation and equilibrium for large craters occur at crater densities substantially greater than those observed on the Moon, Mars, and Mercury, an indication that the observed populations are essentially production populations; (2) generating functions with $a > 2$ lead to final crater populations with $a = 2$; (3) generating functions with $2 \geqslant a \geqslant 1.5$ lead to crater populations with the parameter a approaching 1.0; and (4) changes in the slope of crater populations occur gradually and over a wide interval of crater densities and diameters as saturation is approached, not as is often visualized, instantaneously upon reaching a critical crater density.

Zisk, S. H. (NEROC Haystack Observatory, Westford, MA 01886), Hodges, C. A., Moore, H. J., Shorthill, R. W., Thompson, T. W., Whitaker, E. A., and Wilhelms, D. E.: 'The Aristarchus–Harbinger Region of the Moon: Surface Geology and History from Recent Remote-Sensing Observations', *The Moon* **17**, 59–99. (1977)

The region including the Aristarchus Plateau and Montes Harbinger is probably the most diverse, geologically, of any area of comparable size on the Moon. This part of the northwest quadrant of the lunar near side includes unique dark mantling material; both the densest concentration and the largest of the sinuous rilles; apparent volcanic vents, sinks, and domes; mare materials of various ages and colors; one of the freshest large craters (Aristarchus) with ejecta having unique colors and albedos; and three other large craters in different states of flooding and degradation (Krieger, Herodotus, and Prinz). The three best-authenticated lunar transient phenomena were also observed here.

This study is based principally on photographic and remote sensing observations made from Earth and Apollo orbiting spacecraft. Results include (1) delineation of geologic map units and their stratigraphic relationships; (2) discussion of the complex interrelationships between materials of volcanic and impact origin, including the effects of excavation, redistribution and mixing of previously deposited materials by younger impact craters; (3) deduction of physical and chemical properties of certain of the geologic units, based on both the remote-sensing information and on extrapolation of Apollo data to this area; and (4) development of a detailed geologic history of the region, outlining the probable sequence of events that resulted in its present appearance.

A primary concern of the investigation has been anomalous red dark mantle on the Plateau. Based on an integration of Earth- and lunar orbit-based data, this layer seems to consist of fine-grained, block-free material containing a relatively large fraction of orange glass. It is probably of pyroclastic origin, laid down at some time during the Imbrian period of mare flooding.

4. Chemical Composition of the Moon; Lunar Petrology, Mineralogy, and Crystallography

Akhmanova, M. V. (Akademiia Nauk SSSR, Fizicheskii Institut, Moscow, U.S.S.R.), Dement'ev, B. V., and Markov, M. N.: 'Near-Infrared Reflection Coefficient of a Lunar Soil Core Sample Obtained by the Luna 24 Probe', *Pis'ma v Astron. Zh.* 3, 178–181. (1977)

Profiles of the reflection coefficient R along lunar soil column from Mare Crisium for five spectral intervals in 0.97–2.2 mcm region are obtained. In the upper third of the column R is nearly constant and then increases with depth due to changes in regolith composition and decrease of the amount of modificated particles in it. By its R value the regolith near the surface is similar to sea samples and at the bottom of the column – to highland samples of the lunar soils.

Allègre, C. J. (Laboratoire de Géochimie et Cosmochimie, Institut de Physique du Globe et Département des Sciences de la Terre, Universités Paris VI et Paris VII, 4, Place Jussieu 75230 Paris CEDEX 05, France), Albarède, F., Birck, J. -L., Joron, J. -L., Manhes, G., Richard, P., Treuil, M., and Stettler, A.: 'Chemistry and Chronology of the Luna 24 Soils and Rocks', *Meteoritics* **12**, 168. (1977)

Three hundred mg of soils from automatic Luna 24 mission have been studied for trace elements by isotope dilution and Instrumental Neutron Activation Analysis, for ^{87}Rb–^{87}Sr, ^{143}Nd–^{147}Sm, U–Pb and ^{39}A–^{40}A age determinations and geochemical evolution constraints.

The soil is extremely poor in K REE P component and very close to Luna 16 and 20 type with some original features. In ppm K = 440; Rb = 1.04; Sr = 142.05; Ba = 37; U = 0.126; Th = 0.43; Pb = 0.507; La = 2.7; Cu = 0.68; Tb = 0.41; Ni = 195; Cr = 2490; Hf = 1.49; Zr = 54; Ta = 0.19; Co = 52.9; Sc = 40.2.

Isotopic values ($^{87}Sr/^{86}Sr = 0.700\,32 \pm 11\ (2\sigma)$ $^{143}Nd/^{144}Nd = 0.511\,80$; $^{206}Pb/^{204}Pb = 75.3$; $^{207}Pb/^{204}Pb = 57.9$) are close to Luna 20 soils. All results are in agreement with the presence of an important highland component in these soils. $^{41}K/^{40}K$ corrected for mass fractionation = 557.2 ± 1.1 and gives exp. age of 500 m.y.

For the purpose of ^{39}A–^{40}A dating, two small fragments have been irradiated and in addition to the argon, the isotopic composition of helium and neon have been measured. The smaller sample (1.9 mg) was a glassy lava splash bearing xenocrysts and contained a large amount of trapped gases. The second sample is a 10 mg fragment of microdolerite, which is a likely product of impact melting as indicated by the occurrence of a crystal agglutinate and microlitic cavities. A well defined ^{39}Ar–^{40}Ar plateau age has been obtained at 3.66 ± 0.12 b.y. along with a $^{38}Ar/^{37}Ar$ exposure age of 600 m.y.

A ^{87}Rb–^{87}Sr isochron has been obtained on a 30 mg gabbro from level 171. T = 3.63 ± 0.7 b.y. (2σ) T = 0.699 09 ± 0.000 09 (2σ).

Asunmaa, S. K. (University of California San Diego, La Jolla, CA 92037) and Haack, R.: 'Distribution of Molecular Weight in Glyceride Polymerizates or Aggregates of Them after Contact with Lunar Grains', *The Moon* **16**, 325–334. (1977)

Increase in the statistical average molecular weight up to 1200–1300 in different fractions of glycerides from 250–300 starting value was determined by gel permeation chromatography for fractions kept in thin layer contact with lunar grains for two years at 25 °C. An additional shoulder maximum was present at $M = 2000$. This highest distribution fraction mean value indicates degrees of polymerization of 8, if the 250–300 non-aggregated fraction is a monoglyceride and the 800–810 fraction its trimer. Assuming that the 800–810 refers to a triglyceride, only a $DP = 3$ is characteristic of the $M = 2000$.

Spectrographic analysis was used for further elucidation of the distribution data; and reaction mechanisms are discussed.

The main conclusion is that the lunar grain surfaces have exerted a catalytic action for production of the high molecular weight species.

Information of this kind is of profound importance in evaluations of formation, i.e., synthesis of more complicated and especially CH-radicals containing molecules that have been spectroscopically identified in interplanetary and interstellar space and extensively discussed in recent literature. If heterogeneous nucleation and growth on catalytically active solid surfaces is found to be one feasible reaction mechanism for syntheses in space, the reaction yields will not necessarily depend on collision encounter reactions exclusively. Since the latter have low reaction cross sections even in resonating filaments of space molecular and ionic aggregates, the solid substrate anchored reactions might make an essential contribution to the final yield.

This mechanism will undoubtedly act also as a selector system so far that it via lattice isomorfism, epitaxy, and via a set of discrete surface energies will favor synthesis of preferred molecular bonds and aggregates and by this way guide the molecular 'evolution' along selected paths only.

Barsukov, V. L., Dmitriev, L. V., Tarasov, L. S., Kolesov, G. M., Shevaleevsky, I. D., Ramendik, G. I., and Garanin, A. V.: 'Geochemical and Petrochemical Peculiarities of Regolith and Lithic Clasts from Mare-Crisium – Preliminary Data' (in Russian), *Geokhimiya* **10**, 1477–1487. (1977)

Petrochemical and geochemical peculiarities of bulk sample regolith and lithic clasts from Luna-24 soil core have been considered. It was shown that along the core depth the composition of regolith is rather homogenic but only abundances of some trace elements vary. On petrochemical basis three main types of lithic clasts are distinguished in core material: (1) gabbro, (2) basaltes and dolerites, (3) melanocratic gabbro. All the varieties are low-titanium and low-alcaline. Types (1) and (2) belong to enriched in aluminium and high-aluminium series. Geochemical especiality of these lithologies consists in lowered abundances of some elements in lithic clasts and regolith as well as in pecularities of REE distribution. These data combined with the Luna 16 data permit to declare the existence of province of high-aluminium and enriched in aluminium rocks in the zone of contact between the crust of mare type and terra type in the eastern limb of nearside of the Moon.

Basu, A. (Lunar Science Institute, Houston, TX 77058): 'Biography of an Agglutinate', *Meteoritics* **12**, 174–175. (1977)

An agglutine is *born* when a primary micro-meteorite impact (velocity $\sim 20\ \mathrm{km\ s^{-1}}$) melts a little surface soil of the Moon and bonds together a large amount of soil grains (clast $\gg$ glass). The soil grains are captured both in flight as well as on ground by the primary melt and the outer rinds of the grains are vulnerable to a second stage of melting. Effects of agglutination include: dispersion of projectile metal in the total melt of the target; grain boundary resorption and differential assimilation of clasts; differential volatilization/condensation of major, minor, and solar wind implanted elements/isotopes; production of fine metal (< 300 Å); scavenging the fine grained tail of the lunar soil into agglutinates and thereby imparting a real chemical and mineralogical difference between the bulk soil and the agglutinate fraction, and, converting the surface correlated components of soil grains into volume correlated components.

Because secondary impacts (velocity $\lesssim 3\ \mathrm{km\ s^{-1}}$) are much more common than primary impacts an agglutinate in its *adolescence* is shattered and fragmented; some clasts spall off generating secondary non-agglutinates (clast > glass). When a fragmented agglutinate in its fertile *youth* is hit by a primary micrometeorite a part of it is totally melted and a new agglutinate is born; at the same time it is also fragmented with further spallation of secondary non-agglutinates and a small fraction of the original remains (clast $\gtrsim$ glass). Secondary impacts go on unabated and further fragmentation leads to *old age* (clast $\approx$ glass). An agglutinate *dies* when all the agglutinitic fragments are incorporated into new agglutinates to be cycled back into life (*Reincarnation*), or rarely, when they are metamorphosed having been incorporated in a hot ejecta blanket (*Nirvana*). Premature ageing and untimely death are unfortunate but facts of agglutinate life.

Belyaev, Y. I. (V. I. Vernadskii Geochem. and Anal. Chemical Institute, Moscow, U.S.S.R.): 'Analysis of Lunar Soil', *Analytical Chem. U.S.S.R.* **32**, 151–161. (1977)

Techniques used for the laboratory analysis of lunar samples brought back by the automatic landers Luna 16 and Luna 20 are described. Moreover a general account of the results obtained is presented.

Bence, A. E. (State University of New York, Stony Brook, NY), Grove, T. L., Papike, J. J., Vaniman, D. T., Friel, J., Goldstein, J., Haggerty, S., Roedder, E., and Weiblen, P.: 'Ferrobasalt and Ferrogabbro from Mare Crisium, Luna 24 FOCUS (Friends of Crisium Unmanned Sampling)', *Meteoritics* **12** 175–176. (1977)

Mare basalt and gabbro fragments of the Luna 24 drill stem crystallized from iron-rich liquids derived from an evolved source region. Fine-grained (< 0.2 mm) intersertal to subophitic basalts have modal proportions: 55–60% zoned clinopyroxene, ~ 30% plagioclase (An_{96}–An_{85}), 5–10% olivine (Fo_{58}–Fo_3), spinel (< 0.5%), ilmenite (< 0.5%), cristobalite (< 0.5%) and up to 12% K-rich glass. Fragments of coarse-grained gabbro (> 0.75 mm) have irregular grain boundaries and phase chemistries similar to the basalt. Pyroxene cores are $Wo_{37}En_{42}$, enriched in Al^{VI} and Cr and low in Ti, and suggest early plagioclase suppression. Subsequent crystallization of pyroxene + plagioclase (± olivine) is evidenced by early Ca-depletion (to $Wo_{12}En_{48}$) accompanied by Al and Ti depletion. Continued crystallization resulted in Ca, Fe, Ti and Al^{IV} enrichment and Cr depletion. Olivines range from Fo_{38} to Fo_8 in the gabbro and Fo_{58} to Fo_3 in the basalt. Oxide phases are Al chromites, Al–Ti chromites, ulvöspinel and low-Mg ilmenites. Gabbroic spinels have Al_2O_3 = 11.5–16.9 wt.%, MgO = 1.3–2.0 and TiO_2 = 1.7–4.5; associated ulvöspinel has 1.2–1.5 Al_2O_3 and MgO + Cr_2O_3 = 0.1–0.5. Fe-metal grains (Ni = 8.4%, Co = 0.4%, P = 0.8%, S = 0.7%) may be shock remelted highlands metal or meteoritic metal, foreign to mare Crisium basalts. Coincidence of phase compositional ranges indicates that the basalt and gabbro crystallized from similar high-Fe, low-Ti liquids. If the most magnesian olivine in the basalts represents the liquidus olivine, the Fe/(Fe + Mg) (atomic) ratio of the equilibrium liquid is 0.68–0.7 (assuming $K_D^{Fe/Mg}$ = 0.30–0.33). This is more iron-rich than any known mare basalt (0.4–0.6).

Benimoff, A. I. (Brooklyn, New York) and Pingitore, N. E., Jr.: 'Fe–Mg Differentiation in the Lunar Rocks: Resolution Through Factor Analysis', *Neues Jahrbuch für Mineralogie Monatshefte* **2**, 84–96. (1977)

Principal components factor analysis of 11 major chemical oxides in 1568 lunar rock samples provided the framework for an important lunar petrologic variation diagram. Using factors one and two as axes, the factor scores of each sample were plotted in the resultant factor space. Since factors one and two accounted for 41% and 22%, respectively, of the original oxide variance, this lunar variation diagram conveys considerably more information than conventional petrologic variation diagrams.

Visual comparison of the plots of lunar rocks and their closest terrestrial analogues, the layered intrusives, indicated a gross chemical similarity between these two groups of rocks. The lunar highland rocks plot close to the acidic trend of the Skaergaard; their somewhat higher magnesium content may be due to post-cooling addition of meteoritic material. The lunar maria basalts plot directly between the ferrous and basic trends of the Skaergaard, indicating incomplete Fe–Mg differentiation in the lunar material. The maria melts apparently cooled under turbulent conditions brought about by meteoritic bombardment; this prevented the Fe–Mg differentiation observed in terrestrial materials that have formed under quiet conditions.

Birck, J. -L. (Laboratoire de Géochimie et Cosmochimie, Université Paris-7, Paris, France), Lorin, J. -L., and Allégre, C.: 'Potassium Isotopic Determination in Some Meteoritic and Lunar Samples: Evidence for Irradiation Effects', *Meteoritics* **12**, 179–180. (1977)

Mass-spectrometric determination of K and Ca contents and isotopic compositions have been performed in meteoritic and lunar samples selected for high calcium to potassium ratio. $^{41}K/^{40}K$ isotopic ratios corrected for mass discrimination by normalizing the $^{39}K/^{41}K$ ratios to the terrestrial value (13.857) are reported, along with the corresponding K and Ca contents. The data are entirely consistent with the ^{40}K excesses being produced via the $^{40}Ca(n, p)$ reaction by cosmic-ray bombardment. Formal exposure ages calculated assuming ^{40}K production rate as in the Norton County aubrite, and an exposure age of 72 m.y. for this meteorite, are in fair agreement with those derived from rare gas data, and current rare gas production rates. This investigation shows two points of interest. First it is shown that, besides well documented fractionation effects, the K isotopic composition of lunar soils is affected by cosmic-ray secondary neutrons. Also it is shown that, allowance being made for nuclear effects related to the exposure of the meteoroid to cosmic-rays as well as to mass fractionation effects, any K isotopic anomaly in the Allende inclusions AL 17 and JFM 1 investigated here is below detection level, as is, in our present experimental conditions, any Ca isotopic anomaly in inclusions AL 15 and AL 17. This negative observations are in agreement with earlier reports.

Borg, J. (Laboratoire René Bernas du CSNSM, 9106 Orsay) and Dran, J. C.: 'High Voltage Electron Microscope Obaervations of Micron-Sized Grains Extracted at Depth 96 cm in the Luna 24 Core-Tube', *Meteoritics* **12**, 182. (1977)

We have previously defined two HVEM indices of solar wind and solar flare maturity: the proportion of μm-sized grains showing an amorphous coating of solar wind radiation-damaged material (AC) and the density of latent solar flare tracks (ρ_{SF}). With respect to these indices, the Luna 21 grains are similar to those extracted from the most mature lunar soil samples we previously investigated (10084, Luna 16, etc . . .). In particular we note that ~ 100% of the feldspar grains show a rounded habit with an AC whereas the ilmenite grains have angular habit with no AC. In addition the ρ_{SF} values of $\sim 5 \times 10^9$ tracks cm^{-2} are comparable to those observed in the most mature soils.

But two characteristics of the Luna 24 soil are clearly distinct from those of truly mature soils: 1. the proportion of glassy grains is at least 10 times smaller ($\lesssim 1\%$); 2. the proportion of welded aggregates is also much smaller. Consequently the Luna 24 sample investigated looks very odd, as it can be classified either as mature with respect to its irradiation record, or as immature on the basis of its content of glassy grains and aggregates.

A scenario that reasonably explains this mature *versus* immature character is proposed. In addition, possible ways of checking the validity of this scenario, as well as various implications of the present results to lunar science, are presented.

Butler, J. C. (Geology Department, University of Houston, Houston, TX 77004): 'Preliminary Analysis of Variation in Al, Mg and Si in Apollo-11, -12 and -15 Basalts and Regolith', *Phys. Earth Planet. Interiors* **15**, 275–286. (1977)

Chemical analyses of Apollo-11 basalts (28 samples), Apollo-11 fines (21 samples), Apollo-12 basalts (55 samples), Apollo-12 fines (28 samples), Apollo-15 basalts (84 samples), and Apollo-15 fines (58 samples) have been extracted from the lunar data base and percentages of Al, Si and Mg computed. The correlations between these three variables and the ratios Al/Si and Mg/Si were computed and carefully examined to determine the nature of between and within mission variations. In all of the data sets except for the Apollo-11 fines the correlations between Al/Si and Al and Mg/Si and Mg exceed 0.94. This is a result of the fact that the coefficients of variation for Al and Mg are several times larger than that for Si. It can be demonstrated that the Al/Si vs. Al variation for the Apollo-12 and -15 samples (both basalts and fines) is nearly linear with a correlation of 0.977. The equation for the line of organic correlation is: $Al = 22.89\,Al/Si - 0.397$. Thus, remote-sensing measurements of Al/Si could be conceivably used to compute the Al content for areas covered by Apollo-12 and -15 types of regolith and basalts. Neither the Apollo-11 fines nor basalts appear to belong to the Apollo-12 plus -15 Al/Si vs. Al trend. However, previously published averages for Apollo-17 high-TiO_2 soils and basalts appear to define, along with the Apollo-11 high-TiO_2 basalts, an Al/Si vs. Al variation parallel to the Apollo-12 plus -15 variation.

The correlation between Al/Si and Mg/Si is shown to be a function of the correlation between the parent variables and the coefficients of variation of the parent variables. Observed Al/Si vs. Mg/Si correlations range from −0.509 for the Apollo-12 basalts to −0.052 for the Apollo-11fines and there is a considerable variation between basalts and regoliths from a given site. Plots of remote-sensed Al/Si vs. Mg/Si would be expected to exhibit a rather diffuse trend.

Interpretation of geochemical ratios from surveys of other planetary bodies will require either ground-truth observations or demonstration that relations exhibited by lunar and terrestrial materials are likely to be of universal applicability.

Davie, I. W. (Department of Physics, Unicersity of Birmingham, Birmingham B15 2TT, England), Bull, R. K., and Durrani, S. A.: 'Exposure History and Fission Track Ages of Apollo 15 Green Glass Spherules', *Meteoritics* **12**, 203. (1977)

A combined study of microcraters observed with a scanning electron microscope (SEM), and of etched tracks observed with SEM and optical microscopy revealed that a batch of Apollo 15 green glass spherules shows evidence of rather low exposures to both micrometeorites and heavy cosmic ray particles.

In scanning ~ 50% of the surfaces of 24 spherules, only 2 high velocity impact craters were observed, although one spherule showed a high density of shallow pits.

No spherules show track density gradients, which would have indicated irradiation on the top ~ 100 μm of regolith. Natural track densities are in the region of ~ 8×10^5 to 2×10^7 tracks cm^{-2} Crystals from the same soil sample show track densities higher by an order of magnitude than these values.

Accelerated Fe ions at normal incidence to the surface of polished spherules are found to produce etchable tracks at residual ranges of ~ 70 μm (cf. an etchable range of ~ 20 μm for Fe in pyroxene crystals). The lower natural track densities in the glass, thus most probably reflect thermal annealing of cosmic ray tracks, glasses being less retentive of tracks than crystals at any given temperature.

Diameter distributions of tracks in these glasses show a prominent peak at ~ 2 μm which is attributed to fission tracks. Uranium contents and fission track ages of some spherules are reported. Reactor irradiation of these glasses with thermal neutrons has been carried out.

Dikov, I. P. (Academy of Sciences U.S.S.R., Moscow V-71, (U.S.S.R.), Bogatikov, O. A., Alleshin, V. G., Nemoshkalenko, V. V., Barsukov, V. L., and Ivanov, A. V.: 'Reduced Silicon in Moon Regolith' (in Russian), *Dokl. Akad. Nauk S.S.S.R.* **235**, 1410–1412. (1977)

Dikov, Y. P., Bogatikov, O. A., Nemoshkalenko, V. V., Aleshin, V. G., Barsukov, V. L., Florenskii, C. P., and Ivanov, A. V.: 'Pecularities of State of Rock-Forming Elements in Surface-Layers of Luna-24 Regolith Particles' (in Russian), *Geokhimiya* **10**, 1524–1533. (1977)

The reduced forms of elements and structural-chemical parameters of surface layers of particles from the fine fractions of base samples taken from Luna 24 regolith have been studied by X-ray photoelectron technique using the stepwise etching by argon ions. The presence of iron, titanium, silicon, and aluminium reduced up to elemental forms has been revealed on the particles surfaces of all samples. The content of these reduced forms decreases to the interior of particles. According to some structural-chemical parameters of studied particles one can deduce that their surface is covered by amorphous film of different thickness. The revealed modifications of surface characteristics of regolith particles is mainly due to the action of cosmic radiation.

Florenskii, C. P., Basilevskii, A. T., and Pronin, A. A.: 'Geologic Setting of Vicinity of Luna-24 Landing Site, Southeast of Mare-Crisium' (in Russian), *Geokhimiya* **10**, 1449–1464. (1977)

The paper purposes to give the information of geologic setting of Luna-24 landing site. According to the geologicmorphologic analysis of photos covered the landing site six kinds of materials were waited to discover in returned samples: basalts of Mare Crisium surface (1), relatively deep-seated material of mare filling (2), material of wrinkle ridges and hills having the evidences of extrusive origin (3), material of dark patches and apparent cinder cones, probably of pyroclastic origin (4), terra material derived from near-by highlands (5), and ray material from distant large craters (6). The study of Luna 24 samples reveals the material only from a part of the sources deduced. The explanation of the situation has been resulted in hypothetical model according to which the landing site is placed on the ejecta blanket from rather large and recent postmare crater (Fahrenheit?) and the regolith layer sampled by Luna 24 core is the product of rather short reworking of this ejectas.

Gardiner, L. R. (Dept. of Mineralogy and Petrology, Cambridge University), Jull, A. J. T., and Pillinger, C. T.: 'Analysis of Carbon Species in Lunar Samples by Static Mass Spectrometry', *Meteoritics* **12**, 236. (1977)

A method has been developed for quantitation of gaseous carbon species by static mass spectrometry. Under the source conditions used, only CO_2 is appreciably pumped by the hot filament; CD_4, CH_4 and CO are unaffected in the time scale of the experiment (30 min), and stable ion currents allow quantitative determination. In addition it is possible to measure directly the $^{13}C/^{12}C$ ratio of carbon as CD_4. The method simultaneously provides limited information concerning light rare gases (He, Ne, Ar). The system consists of a heated glass manifold connected to a 6", 90° sector, single-focussing mass spectrometer, with an electron multiplier detector. Quantitation and isotopic comparison of CD_4 is achieved by measuring the ion currents at masses 20 and 19 (CD_4 and CD_3H) for a known amount of standard gas, run before and after each sample analysis. Other gases have been calibrated relative to CD_4. Reproducibility for consecutive standards is better than ± 3%. Background contributions to masses 4, 19, 20, 21, 22 and 36 are negligible, but connections are necessary at m/e 15, 16, 28, 40 and 44. The detection limit of the system is *ca* 10^{-12} g carbon, and a routine sample size of 0.5–1 mg of lunar sample is required. The high sensitivity of the instrument allows well-characterised, microscopically hand-picked fractions to be studied. The method has so far been used predominantly for the analysis of CD_4 and CH_4 (together with ^4He, ^{20}Ne and ^{36}Ar) released by DCl dissolution from a suite of size differentiated agglutinates taken from soil 15601. A limited number of mineral separates (ilmenite, plagioclase, and olivine/pyroxene) have also been investigated. The instrument should be capable of detecting easily the amounts of solar wind carbon likely to be released by stepwise or programmed prolysis of mineral separates. However, we have not yet restricted the background contamination accrued during sample preparation to a sufficiently low level to allow meaningful results to be obtained. In addition to its obvious lunar applications, we expect the method to be appropriate to a number of meteorite studies including the determination of carbon in meteoritic iron, and the investigation of solar-wind derived species in gas-rich meteorites.

Gibson, E. K., Jr. (SN/7 Geochemistry Branch, NASA Johnson Space Center, Houston, TX 77058):

'Production of Simple Molecules on the Surface of Mercury', *Phys. Earth Planet. Interiors* **15**, 302–312. (1977)

Lunar sample studies have shown that solar-wind irradiation of the lunar surface has produced a variety of low-molecular-weight compounds. Analysis of the lunar soils has revealed the presence of H_2, CH_4, H_2O, N_2, CO, CO_2, He, Ne and other components which are extralunar. Irradiation experiments on lunar materials and analogs have shown that solar-wind and solar-flare irradiation of the lunar surface produces selected low-molecular-weight components.

Solar-wind irradiation of Mercury's surface should also produce a wide variety of low-molecular-weight species because of the increased solar flux, which results from Mercury being nearer the Sun than the Moon. The thermal regime of Mercury's surface would result in thermal evaporation of low-temperature components followed by 'cold-trapping' on the night-time side of the planet. Such desorption–adsorption processes assist chemical weathering of Mercury's regolith.

Gopalan, K. (Physical Research Laboratory, Navrangpura, Ahmedabad 38009, India), Rao, M. N., and Venkatesan, T. R.: 'Neon and Xenon Spallation Components due to Solar Flare Protons in Lunar Fines', *Meteoritics* **12**, 242. (1977)

Lunar fines 10084 and 14163 were size-separated and these size fractions were etched in a controlled manner to remove the major portion of the surface-correlated solar wind so that the less abundant components due to solar and galactic cosmic ray spallation could be detected. The etched samples were mass-spectrometrically analysed for Ne and Xe by step-wise heating techniques. Neon isotopic data indicate the presence of a solar flare proton produced neon with a composition of $21/22 \sim 0.5$ and $20/22 \sim 3$. The xenon data for these fines, after correcting for GCR and fission contributions, yield significant Xe-132 excesses due to SCR interactions. Similar excesses are also observed in case of Xe-129 and Xe-131. The low energy spallation spectra of the solar flare proton produced xenon, deduced in the present work are compared with those obtained from the laboratory experiments with 38 and 50 MeV proton-induced spallation reactions on Ba. Solar flare exposure ages for 14263 and 10084 scoop samples are calculated to be about 50 and 100 m.y. respectively using production rates, based on Reedy–Arnold type of energy spectrum. The excitation functions used in these calculations are based on simple (p, α), $(P, 2p\ 2n)$, $(p, xp\ yn)$ reaction systematics.

Grögler, N. (Physikalisches Institut, University of Bern, Switzerland), Eberhardt, P., Geiss, E. J., Guggisberg, S., Stettler, A., Brown, G. M., and Peckett, A.: 'Correlation of Ar^{40}–Ar^{39} Ages with Textural Subunits in Lunar Mare Basalts', *Meteoritics* **12**, 245 (1977)

The systematic investigations of differences in Ar^{40}–Ar^{39} ages of mare basalts from Mare Tranquillitatis and Oceanus Procellarum have been continued. Previous results suggested the interpretation that age differences associated with distinct petrologic phases existed within the same rock. In a first approach we have attempted to decipher this complex feature by separating various textural and mineral phase from Apollo 11 mare basalt 10071.

Housley, R. M. (Science Center, Rockwell International Corp., Thousand Oaks, CA 91360): 'Lunar Samples Analysis Annual Report Feb. 1, 1976–Jan. 31, 1977', NASA-CR-151183, 8 pp. (1977) Available from National Technical Information Service as *N77-18979* $3.50

The surface composition of lunar fines, the solar wind sputtering process, and the profile of reduced Fe in lunar samples are reported. Atomic absorption studies of trace metal, especially lead, distribution in lunar fines samples are described.

Khazel, K. A. R. (Department of Physics, University of Birmingham, Birmingham, B15 2TT, England) and Durrani, S. A.: 'The Effects of the Temperature of Irradiation Upon the Sensitivity of Lunar Samples', *Meteoritics* **12**, 271–273. (1977)

Following the observation of the effect of irradiation temperature upon the thermoluminescence (TL) sensitivity of quartz, the phenomenon has been further investigated in some lunar samples. The sample principally used in this study was the shaded sample 76241, 23 which had been collected from the shadow of an Apollo 17 boulder (No. 4 at Station 6; ~ 5 × 4 × 3 m in size).

Khisina, N. R. (V. I. Vernadskiy Institute of Geochemistry and Analytical Chemistry, Academy of Sciences U.S.S.R., Moscow) and Makarov, E. S.: 'Subsolidus Thermal History of Pyroxenes from "Luna-20" Samples According to X-Ray Diffraction Investigation', *Geochem. International* **13**, 112–119. (1976)

Subcalcic augites 2001–No. 3 and 2001–No. 6 and bronzite 2001–No. 15 from the Luna-20 collection have been investigated by the single crystal X-ray diffraction method. The unit cell parameters have been determined and, with the aid of a nomogram, the compositions of the exsolved lamellae (augite and pigeonite) in the clinopyroxenes. The compositions correspond to equilibrium unmixing temperatures of 1100 ± 25 °C (2001–No. 3) and 1095 ± 45 °C (2001–No. 6) and indicate rapid quenching of the clinopyroxenes at temperatures close to the temperature of their crystallization (1150 °C). Bronzite 2001–No. 15 according to the X-ray data, is similar to other bronzites from the luna-20 collection. It came from the crystalline lunar crust and cooled slowly in the subsolidus region.

Kiesl, W. (Institute of Analyt. Chem., Univ. of Vienna, A-1010 Vienna, Austria), Scholl, H., Wichtl, M., and Grogler, N.: 'Chemism of Grain-Size Fractions of Lunar Rock 14305' (in German), *Fresenius Z. Anal. Chem.* **285**, 362–368. (1977).

A report is given on the chemism of the light–dark structure of the lunar breccia 14305 which was ascertained by means of INAA. NAA followed by radio-chemical separation of the nuclides as well as by microanalytical techniques (SiO_2, Mg). The results are discussed with respect to the distribution of the main and minor elements on the structure constituents of the breccia.

Kiko, J. (Max-Planck-Institut für Kernphysik, Heidelberg, Postfach 103980, F. R. Germany), Kirsten, T., and Warhaut, M.: 'He and Ne Depth Profiles in Olivine from Lunar Soil 71501,23', *Meteoritics* **12**, 274–275. (1977)

He- and Ne-concentration-profile measurements in lunar soil particles with the Heidelberg GIP were continued particularly on olivines from 71501. Among seven olivines investigated, two had solar wind contents below our detection limits. All the five others display a new type of double peak profile with a second maximum around ~ 500 Å depth.

Krupenio, N. N.: 'Lunar Soil Density Based on Direct and Indirect Measurements', *Cosmic Res.* **15**, 110–117. (1977)

A review of lunar soil density measurements made on the Earth and Moon and a comparison of the density of the Moon's outer layer over identical regions but using different techniques is presented. The Moon's outer layer agrees best with an exponential model for the variation of density with depth, with a surface density $\rho S = 1.2\,\mathrm{g\,cm^{-3}}$ and a regolith layer having a depth $D = 5$ m. Variations in ρS and D for different regions are as follows: $\rho S = 0.6$–$3.0\,\mathrm{g\,cm^{-3}}$, and $D = 0.4$–40 m.

Marvin, U. B. (Center for Astrophysics, 60 Garden St., Cambridge, MA 02138), Ryder, G., and McSween, H.: '24170: An Iron-Rich Basalt from Mare Crisium', *Meteoritics* **12**, 304. (1977)

Sample 24170 represents a thin layer of light-colored, coarse-grained rock and mineral fragments at a depth of 170 cm in the core recovered by the Soviet Union's Luna 24 mission to Mare Crisium. The fragments evidently resulted from crushing by the core drill of a fairly friable rock that was tentatively described as an unusual type of feldspathic gabbro. Thin sections were made of handpicked particles of this material. The analyses of two thin sections show that the reconstructed parent rock would be an aluminous Fe-rich mare basalt with a maximum grain size of about 1.5 mm. The principal minerals are metastable Ti-poor clinopyroxenes, Fe-rich olivines, and plagioclase. Also present are laths of a silicate mineral (tridymite?), and grains of Mg-poor ilmenite, chromite, and ulvöspinel. No glassy mesostases or KREEPy accessory minerals have been observed. The pyroxenes are zoned and show a trend from intermediate pigeonite toward ferrohedenbergite, as is typical of those in high-alumina mare basalts. Some of the olivines (Fo_{10-30}) fill a gap in the range of those previously analyzed in mare basalts. The unequilibrated nature of the mineral suite (zoned pyroxenes, Fe-olivines, tridymite (?)) indicates that the rock is a basalt rather than a plutonic gabbro. Studies of materials from additional levels in the core show that 24170 is chemically and mineralogically similar to the other Luna 24 mare basalts. These basalts form a new suite that is markedly more Fe-rich than the aluminous basalts collected from other landing sites on the Moon.

Maurer, P. (Physikalisches Institut, University of Bern, Switzerland), Eberhardt, P., Geiss, J., Grögler, N., Stettler, A., Brown, G. M., Peckett, A., and Krähenbuhl, U.: 'Pre-Cataclysmic Cratering of the Lunar Crust', *Meteoritics* **12**, 306–307. (1977)

We studied the petrology, chemistry, and Ar^{39}–Ar^{40} age curves of 45 individual 2–4 mm fragments from three Apollo 16 soils (63503, 67603, 67703). Nine fragments have ages from 4.12 to 4.21 AE, thirteen fragments from 3.89 to 4.02 AE, one has an age of 3.60 AE, and 6 are much younger (< 3 AE). The remaining 16 have curves which do not allow the assignment of an age. There is a clear correlation of lithology and chemistry with age groups. The oldest fragments ($\geqslant 4.12$ AE) are anorthositic breccias rich in Al and poor in Mg, Fe, K, and REE. A few samples with these chemical characteristics are in the younger age group (3.89–4.02 AE), but the majority in that group are enriched, often strongly in mafic and KREEP components relative to anorthosites. We propose that the cratering events that gave rise to the Apollo 16 breccia samples were of two magnitudes. The older craters ($\geqslant 4.12$ AE) were of medium size and excavated predominantly the feldspathic layer of the crust. The younger craters, presumably basin-forming events, excavated the deeper sited mafic and KREEP material and mixed these with the anorthositic layer of the crust.

Mayer, C., Jr. (SN7, Geochemistry Branch, NASA Johnson Space Center, Houston, TX 77058): 'Petrology, Mineralogy and Chemistry of Kreep Basalt', *Phys. Chem. Earth* **10**, 239–260. (1977)

KREEP basalt is an important lunar material that was formed in large quantities early in the evolutionary history of the Moon. Fragments of KREEP basalt were returned from all landing sites and make up most of the material of the Apollo 14 collection. These fragments have a wide variety of textures caused by various secondary processes but they are all characterized by a large and distinctive trace-element content. They are also characterized by a general basaltic composition that is similar to the olivine plagioclase pyroxene peritectic in the system silica–anorthite–olivine ($Fe/Fe + Mg = 0.3$). The origin of KREEP will be debated for many years.

Mikhail, R. S. (Dept. of Chemistry, State Univ. of New York at Buffalo, Buffalo, NY 14214) and Cadenhead, D. A.: 'Adsorption of Methanol and Water Vapor on Lunar Soil 15081,2', *J. Colloid Interface Sci.* **61**, 375–382. (1977)

Adsorption–desorption–resorption isotherms were measured for methanol vapor adsorption at 20 °C on an Apollo 15 lunar soil 15081,2 both before and after water vapor adsorption. Specific surface areas were calculated from all the isotherms obtained, and the data were analyzed by the n_S–n_R method recently proposed by the authors. Methanol measured a relatively small surface area, which essentially remained the same pre- and post-water adsorption. The major effect found was an increase in the total pore volume adsorbed at saturation following the water cycle. Water measures a much higher surface area than does methanol, though still lower than that measured by nitrogen. The results are discussed and are related to the microstructure of the adsorbent. It is proposed that the immediate outer layer of lunar materials exposed to solar wind, solar flare, and micrometeorite bombardment is microcrystalline rather than amorphous and that polar vapors are capable of penetrating and swelling such structures.

Mints, R. I., Krivopishina, E. V., Petukhova, T. M., and Shaldybin, V. P.: 'Features of Dendritic Structures in a Metallic Fragment of Lunar Material' (in Russian), *Akad. Nauk S.S.S.R., Izvestiia, Metally 1977* (3), 174–177. (1977)

Elements of primary and secondary structure detected in lunar regolith included: recrystallized grains, elements subjected to shear forces, and particles exhibiting dendritic morphology. The dendritic regions are local and of homogeneous composition in one specimen, with the dendrites hosted in a metallic matrix. Martensite of dendritic morphology, Neumann bands in a dendritic pattern, and dendrites formed in crystallization from a melt show up. The features are attributed to crystallization following local melting, induced in turn by microimpacts and splashes of impacting meteoritic material. The local heating temperature is estimated at not below 1200 °C.

Moore, C. B. (Center for Meteorite Studies and Dept. of Geology, Arizona State University, Temple, AZ 85281) and Cripe, J. D.: 'The Distribution of Sulfur in Lunar Rocks and Its Relationship to Carbon Content', *The Moon* **16**, 295–310. (1977)

A summary of total sulfur abundances representative of the Apollo Missions is presented. Lunar crystalline rocks range from 0 to 3100 μg S g^{-1}. Lunar soils range from 310 to 1300 μg S g^{-1}. Rock mixing models evaluate the distribution of sulfur and define indigenous rock components and extralunar contributions of sulfur in lunar soils. Extralunar sulfur shows a positive correlation with a CCl like meteoritic component and solar wind derived total carbon content in the Apollo 16 and 17 lunar soils.

Morrison, D. A. (NASA, Johnson Space Center, Houston, TX) and Zinner, E.: 'New Lunar Standards for Solar flare Track and Microcrater Production', *Meteoritics* **12**, 320. (1977)

We report here on the calibration of the solar flare track production rate in lunar crystals for depths between 10 and 250 μ for which several different values exist and on the accurate determination of the mass distribution and flux of micro meteoroids.

Nefedov, V. I., Sergushin, N. P., Salyhn, Y. V., Urusov, V. S., and Zhavoronkov, N. M.: 'X-Ray Electron Study of Iron and Surface Characteristics of Lunar Regolith from Mare-Crisium' (in Russian), *Geokhimiya* **10**, 1516–1523. (1977)

X-ray electron study of samples from upper and lower parts of lunar regolith core returned by Luna 24 from Mare Crisium is made. Upper part comparing to lower one contains more nonoxidized Fe metal. Simultaneously silicon content increases and calcium content decreases on surface in comparison to volume. These differences are due to different degree of the action of outer cosmic factors onto upper and lower parts of the core. The high degree of homogeneity of surface film of regolith is demonstrated by the variations of angle of photoelectrons output from the sample. Nonoxidized silicon and titanum have been discovered in upper part of Luna 24 regolith as well as at Luna 16 regolith.

O'Hara, M. J. (Grant Institute of Geology, Edinburgh University) and Humphries, D. J.: 'Problems of Iron Gain and Loss During Experimentation on Natural Rocks: The Experimental Crystallization of Five Lunar Basalts at Low Pressures', *Roy. Soc. London Phil. Trans.* **A286**, 313–330. (1977)

It is extremely difficult to conduct melting experiments on iron-bearing silicate compositions under conditions where the oxygen fugacity and iron oxide content of the charges are controlled precisely at the relevant values, due to reactions between the charge, the container and the adjacent atmosphere. Possible effects are illustrated by discussion of the experimental data for five lunar basalts. At low oxygen fugacities the techniques using molybdenum capsules in an atmosphere whose oxygen fugacity is controlled by passage of a CO_2/H_2 mixture, and that of enclosing (better, sealing) the charge inside a high purity iron capsule inside a sealed, evacuated silica glass tube yield results which are relatively close to the desired run conditions.

Palme, H. (Enrico Fermi Institute and Department of Chemistry, University of Chicago, Chicago, IL 60637): 'On the Age of KREEP', *Geochim. Cosmochim. Acta* **41**, 1791–1801. (1977)

Many lunar highland rocks have been extensively metamorphosed during the late heavy bombardment of the Moon 3.9, 4.0 AE ago. Rubidium and other, more volatile elements were preferentially mobilized during this event, which resulted in a considerable scatter of Rb–Sr model ages. This scatter can be considerably reduced by estimating the original Rb content on the basis of Sm or other less mobile, incompatible elements. The principal uncertainty on the corrected model ages of 4.25–4.45 AE comes from the original Sm/Rb ratio.

Highland rocks enriched in incompatible elements in most cases are mixtures between KREEP-basalt and other highland rock types. After corrections for Rb mobilization 3.9–4.0 AE ago, slight isotopic differences among KREEP-enriched rocks from different landing sites becomes noticeable. These differences correspond to different meteoritic groups as defined by Morgan *et al.* Apparently there existed slightly different KREEP basalt reservoirs, with formation ages ranging from 4.25 to 4.45 AE. These reservoirs were partly exposed through impacts of basin-forming planetesimals 3.9–4.0 AE ago. The resulting impact melts were contaminated with meteoritic material from the bombarding planetesimals.

The 4.63 ± 0.1 AE Rb Sr isochron of trace element poor highland rocks is determined by a K, Rb- and Ba-rich component, which formed earlier and independently of KREEP basalts.

Pieters, C. (Dept. of Earth and Planetary Sci., Massachusetts Institute of Technology, Cambridge, MA 02139): 'Characterization and Distribution of Lunar Mare Basalt Types Using Remote Sensing Techniques', Ph.D. Thesis, 350 pp. (1977) Available from National Technical Information Service as *N77-27051* $12.00

The types of basal to be found on the Moon were identified using reflectance spectra from a variety of lunar mare surfaces and craters as well as geochemical interpretations of laboratory measurements of reflectance from lunar, terrestrial, and meteoritic samples. Findings indicate that major basaltic units are not represented in lunar sample collections. The existence of late stage high titanium basalts is confirmed. All maria contain lateral variations of compositionally heterogenous basalts; some are vertically inhomogenous with distinctly different subsurface composition. Some basalt types are spectrally gradational, suggesting minor variations in composition. Mineral components of unsampled units can be defined if spectra are obtained with sufficient spectral coverage (0.3 to 2.5 μm) and spatial resolution (approximating 0.5 km).

Pillinger, C. T. (Dept. of Mineralogy and Petrology, Cambridge), Gardiner, L. R., Jull, A. J. T., Woodcock, M. R., and Stephenson, A.: 'Some Constrains on the Origin of Finely-Divided Iron in Lunar Soil', *Meteoritics* **12**, 339. (1977)

Current ideas concerning the mechanism of formation of finely-divided metallic iron (Fe^0sp) in lunar soil are varied and confused. Most workers ignore the presence of carbon, although carbon studies were the first to demonstrate unequivocably that metal must be formed by an exposure-induced process involving Fe^{II} in silicates, and despite carbon content being the only positive information which exists concerning metal composition. Mechanisms proposed for the origin of Fe^0sp must take into consideration the nature and concentration of carbon. Numerous pieces of evidence, including electron diffraction data, identify Fe^0sp as the φ-phase. Studies of synthetic iron–carbon phases have shown that only carbon in solid solution is reactive to DCl dissolution (hence 'hydrolysable carbon'), and the deutero-carbons released by this method are close to a quantitative measure of the carbon present in φ-Fe. A plot of magnetic susceptibility data versus CD_4 for a series of fractions from soil 15601 confirms that Fe^0sp and hydrolysable carbon (C_{hyd}) are directly related. A conclusion which follows is that all the Fe^0sp in 15601 must have a remarkably uniform carbon content. Either all Fe^0sp and C_{hyd} were formed during one event, or the formation of these species is extremely reproducible. Studies on C_{hyd} and iron measured by FMR from a series of soils from all the Apollo landing sites, have shown that the correlation is not confined to a single soil. Thus, the formation of both iron and C_{hyd} seems to be reproducible over the lunar surface so far investigated and a co-genetic formation process is suggested. From the studies of 15601 an estimate of the minimum value for the absolute concentration of C_{hyd} in Fe^0sp can be made. Calibration factors suggest a value of $0.12 \pm 0.04\%$ by weight. This value is in excess of the equilibrium concentration (0.02% by wt.) possible for φ-Fe and suggests a non-equilibrium formation process. Mechanisms suggested for the formation of Fe^0sp will be discussed in the light of the above information. Preferential sputtering appears best able to account for the apparent paradoxical situation in which a non-equilibrium concentration is being reached reproducibly. Thermal events, diffusion and vapour deposition all appear less likely for observed concentrations of carbon in φ-iron.

Poupeau, G. (Centre des Faibles Radioactivitiés, BP 1, 91190 – Gif-sur-Yvette, France) and Mandeville, J-C.: 'Impact Microcraters and Cosmic Ray Tracks in Luna-16, -20 and -24 Soils', *Meteoritics* **12**, 340–341. (1977)

Impact microcraters and cosmic ray tracks were observed in feldspar crystals from Luna-16, -20 and -24 soils. In each soil, from 20 to 30 crystals, with grain size $\sim 100\,\mu m$ were observed. In Luna-16 and -24 soils, about respectively 30 to 50% crystals have impact microcraters in the range 0.1 to $1\,\mu m$ dia. In most cases, only a very few craters were found in a given crystal. Only in ~ 10–20% of the crystals were the density of microcraters of the order of 10^6 to $10^7\,cm^{-2}$, with a total number of craters of 50 to 100 per crystal. The cumulative distributions of crater dia. frequencies follow a proper law with a slope -2 in a log-log diagram. A first survey of Luna-20 soil seem to indicate a smaller fraction of cratered crystals. Cosmic ray track densities in Luna-16 and Luna-20 soils are well over $10^8\,cm^{-2}$ at the center of crystals. The track density gradients between the center of the crystals and a few microns from their edge is generally of less than a factor of 2 to 3. In Luna-24 soil, measurements are in progress.

Up to now, about 400 crystals have been observed in several Apollo and Luna soil samples with various degrees of maturity. Luna 16 and 24 show the same degree of microcratering as mature soils, e.g. soil 10084. As these soils show the same degree of microcratering as the relatively immature North Ray Crater soils 67481 and 67601 (with $\sim 50 \times 10^6$ yr spallation exposure age), it implies some equilibrium surface process (flakening?) acting during maturation. The track densities in the center of crystals, on the contrary, might show some continuous increase with maturation.

Prinz, M. (Dept. of Mineral Sciences, The American Museum of Natural History, New York, New York

10024) and Keil, K.: 'Mineralogy, Petrology and Chemistry of Ant-Suite Rocks from the Lunar Highlands', *Phys. Chem. Earth* **10**, 215–237. (1977)

Members of the anorthositic noritic-troctolitic (ANT) suite of the lunar highlands are the oldest and most abundant rocks on the lunar surface. They are very complex because most have been severely modified in texture and or composition by intense impact bombardment. These modified or secondary igneous and metamorphic rocks make up about 90% of the highlands, and much of the research on ANT rocks has been aimed at unraveling their original, primary textures and compositions in an attempt to understand their origin and, hence, the origin and evolution of the early lunar crust. In this review, we concentrate on a description of the mineralogy, petrology, bulk chemistry and origin of the best candidates for primary ANT-suite rocks, although even these are more or less modified by brecciation, mixing and recrystallization. Breccias, melt rocks, poikilitic rocks, etc., are discussed elsewhere in this volume. We first address the difficulties encountered in classification and terminology of lunar highland rocks which largely stem from their textural complexities as a result of impact modifications. Examples of textural and compositional classifications of lunar highland rocks are presented and, although much progress has been made in this field in recent years, it is clear that much more detailed work on statistically meaningful suites of rocks is required before a consistent, comprehensive, textural compositional classification can be derived. We then describe the mineralogy of ANT-suite rocks which are dominated by three minerals, plagioclase, olivine and pyroxene (mostly low-Ca). Minor minerals present in primary or near-primary rocks are spinel-group minerals (Mg Al spinels associated with troctolites, and chromites associated with rocks such as norites and anorthosites), ilmenite (usually 4.8% MgO), other oxides (baddeleyite, rutile, armalcolites, cristobalite, 'rust'), phosphates and phosphides (whitlockite, apatite, farringtonite, schreibersite), zircon, K-feldspar, metallic Ni–Fe, and troilite. Some of these phases may not be indigenous to the ANT rocks, but may have been introduced by secondary processes (e.g. 'rust', schreibersite). We then review the petrology of the best candidates for primary (cumulate) lunar highland rocks, including dunite 72415; spinel troctolites 67435, 65785, – troctolite 76535; norite (civet cat clast) in 72255; several anorthosites (including ferroan and spinel olivine anorthosites); anorthositic gabbro 77017; and troctolitic anorthosite 62237. Subsequently, we discuss the major element bulk composition of these rocks and note their low KREEP component contents, another indication for their primitive nature, in contrast to the majority of the more impact-modified and compositionally intermediate rocks from the lunar highlands. Models on the origin of the ANT-suite rocks are then summarized. Our own bias for the origin of ANT-suite rocks involves a parental liquid of high-alumina basalt composition with low Fe/Fe + Mg (~ 0.1). From this liquid formed spinel troctolites, troctolites and dunites as early cumulates, and norites and anorthositic rocks as later cumulates. This model is undoubtedly over-simplified, and the origin of anorthositic rocks, in particular, is open to discussion.

Rammensee, W. (Max-Planck-Institut für Chemie, Mainz, F.R.G.) and Wänke, H.: 'Tungsten Distribution Between Metal and Silicates and Its Implications on the Formation of the Earth–Moon System', *Meteoritics* **12**, 345–346. (1977)

Metal-silicate partition coefficients of specific trace elements can be used to reconstruct the details of a proposed metal–silicate fractionation process in planetary objects.

We studied with a radioactive tracer method the distribution of W, Au and Ir between metal and silicate at different temperatures, compositions and oxygen fugacities, at 1 atm total pressure.

The W partition coefficient V_W between metal and silicate showed a strong dependence on oxygen fugacity (resp. FeO content of the silicate), Ni content of the iron alloy and temperature. For Ir (V_{Ir} = 140 000–170 000) and Au (V_{Au} = 20 000–70 000) such dependence has not been found.

The experimentally obtained values of the W partition coefficients are compared with the W depletion on the Moon, Earth and achondrites as seen from the W/La correlation. Tungsten is depleted by a factor of 19, while other lithophile refractories are found in chondritic abundance ratios.

Only the experimentally verified siderophilic behaviour of W can explain this observation and the only feasible process appears to be removal with metallic iron.

With the measured W partition coefficient of 53 a required metal phase of 25 percent is calculated.

However, the low metal content of the Moon cannot explain this high depletion of 19. Different mechanisms will be discussed, but the only planetary body where this process could have happened seems to be the Earth.

With these constraints, this investigation favours models where the Moon and perhaps also the achondrites are derived from the Earth.

Rode, O. D., Ivanov, A. V., Tarasov, L. S., and Korina, M. I.: 'General Lithologic Morphologic Characteristics of Luna-24 Regolith Core' (in Russian), *Geokhimiya* **10**, 1465–1476. (1977)

Lithologic and morphologic study of regolith core returned by Luna 24 led to discovering of the stratification within the core. Complex character of this stratification as well as the observed diversity of types of the regolith particles reflect the complexity of geologic setting of landing site and the cyclic character of regolith formation. Soil from Mare Crisium differs significantly from soil from Mare Fecunditatis by its lighter colour and lower maturity as well as greater diversity of lithologic types of particles.

Ryder, G. (Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138), McSween, H. Y., and Marvin, U. B.: 'Lunar 24 Basalts and Metabasalts', *Meteoritics* **12**, 357–358. (1977)

Among the Luna-24 soil particles we have studied (mainly 250–400 μm) are several fine-grained basalts and metabasalts. Most other particles are evidently remnants of coarser-grained basalts.

Stöffler, D. (Institute of Mineralogy, University of Münster, D-44 Münster, Germany) and Knoll, H. -D.: 'Composition and Origin of Plagioclase, Pyroxene, and Olivine Clasts in Fra Mauro Breccias', *Meteoritics* **12**, 366. (1977)

The petrological provenance of the mineral clast population of crystalline (14006, 14066, 14311, 14320, 14321) are detrital (14063) Fra Mauro breccias is deduced from the chemical composition of plagioclase, pyroxene, and olivine clasts (80–140 analyses for each breccia). The proportions of the three major groupings of lunar igneous rocks in the clast population of each breccia (mare basalts = MB, anorthositic-noritic-troctolitic rocks = ANT, and KREEP and high alumina basalts = HAB) is calculated using the characteristic correlation of certain chemical components in the three types of minerals which was obtained from 6072 analyses in the literature.

Mineral clasts from these and from ultramafic rocks occur in all breccias in variable proportions. Olivine is predominantly derived from dunitic–troctolitic rocks, pyroxene and plagioclase mainly from HAB- and ANT-lithologies. A significant portion of the latter minerals fits an origin from pre-Imbrian MB-like rocks. A certain number of mineral clast analyses falls off the compositional range for the main silicates of those lunar igneous rocks which are documented by literature data. Mineral fragments derived from crystallized impact melt rocks with hybrid chemistry could possibly account for this effect.

The characteristics of the mineral clast provenance of the investigated Apollo-14 breccias favor previous interpretations in which the crystalline Fra Mauro breccias are considered to originate from high temperature impact formations produced in large local pre-Imbrian cratering events rather than in the Imbrian event itself.

Surkov, Y. A. and Kolesov, G. M.: 'Anomalies of the Content of Certain Chemical Elements in Lunar Soil', *Cosmic Res.* **15**, 219–224. (1977)

The content of 30 rock-forming rare and rare-earth elements in core samples of soil is determined, which were obtained by stations Luna 16 and Luna 20, and spacecrafts Apollo 11, Apollo 12, Apollo

14, Apollo 15, Apollo 16, and Apollo 17 from the sea and continental areas of the Moon. A comparison is carried out of the results obtained with the literature data on the chemical composition of lunar soil in similar regions. It is shown that the abundance of many of the elements determined in the regolith from the sea and continental regions is different. Correlations are noted in the contents of certain macro- and microelements in samples of lunar soil. The data obtained reflect the composition of the principal petrogenetic (sea and continental) provinces of the Moon and indicate certain anomalies of accretion processes, partial melting, and differentiations of the lunar material.

Surkov, I. A. and Kolesov, G. M.: 'Abundance Peculiarities of Some Chemical Elements in Lunar Soil' (in Russian), *Kosmich. Issled.* **15**, 261–268. (1977)

Определено содержание 30 породообразующих, редких и редкоземельных элементов (РЗЭ) в колонках грунта, доставленного автоматическими станциями «Луна-16», «Луна-20» и космическими кораблями «Аполлон-11», «Аполлон-12», «Аполлон-14», «Аполлон-15», «Аполлон-16», «Аполлон-17» из морских и материковых районов Луны.

Проведено сравнение полученных результатов с литературными данными о химическом составе лунного грунта в аналогичных районах. Показано, что распространенность многих определяемых элементов в реголите морских и материковых областей различна. Отмечены корреляции в содержании некоторых макро- и микроэлементов в образцах лунного грунта.

Полученные данные отражают состав основных петрогенетических (морских и материковых) провинций Луны и указывают на некоторые особенности процессов аккреции, частичного плавания и дифференциации лунного вещества.

Surkov, Y. A., Moskaleva, L. P., Kharyukova, V. P., Manvelian, O. S., Dudin, A. D., and Trofimov, V. I.: 'Preliminary-Analysis of Radioactivity of Lunar Soil Returned by Luna-24 Probe From Mare Crisium' (in Russian), *Geokhimiya* **10**, 1510–1515. (1977)

Preliminary analysis of the results obtained using gammaspectrometer with coaxial Ge(Li)-drift detector having sensitive volume 74 cm^3 is given in the paper. The aim of experiment was to determine the abundances of natural and cosmogenic radionuclides in lunar soil returned by Luna-24 space probe. The description of the gamma-spectrometer as well as the characteristics of gamma-ray spectra of lunar soil at different energy ranges are prepared. The level of content for natural (U, Th, K) and cosmogenic (^{22}Na, ^{60}Co) isotopes is estimated.

Tarasov, L. S., Nazarov, M. A., Shevaleevsky, I. D., Kudryashova, A. F., Gaverdovskaya, A. S., and Korina, M. I.: 'Rock Types and Mineral Chemistry of Lunar Soil From Mare-Crisium' (in Russian), *Geokhimiya* **10**, 1488–1509. (1977)

Preliminary petrographic-mineralogic study of the sample of lunar soil returned by Luna-24 probe has been prepared. Fragments of primary rocks are represented by mare-type lithologies: gabbro, dolerite and basalt. The abundance of terra material is limited. The main rock-forming minerals are plagioclase An_{80-96}, clihopyroxenes of different compositions, and olivine Fa_{23-99}. Between the accesories minerals of spinel group, ilmenite, crystoballite, trydimite, apatite, witlokite, pyrexferroite, baddeleite, rutile, zirconolite (?), mineral similar to armalcolite, Cr–Ca silicate, Fe metal and troilite have been identified. According to mineralogic composition and chemistry two main types of rocks can be distinguished: crystoballite gabbro type and olivine gabbro type. Dolirites and rocks similar to them in chemistry can be considered as intermediate type. As a whole the rocks of Luna 24 can be characterized as enriched in Al_2O_3 low titanium basalts with low content of alkalies. Their close analogs are the low-titanium basalts from the samples of Luna 16 and Luna 20.

Taylor, G. J. (Department of Geology and Institute of Meteoritics, University of New Mexico, Albuquerque, NM 87131), Keil, K., and Warner, R. D.: 'Very Low-Ti Mare Basalts', *Meteoritics* **12**, 369–370. (1977)

Bulk compositions, petrology, and mineralogy of lithic fragments discovered in polished sections of Apollo 17 drill core samples 70007, 70008, and 70009, Apollo-17 rake soil breccia 78568, and Luna-24 soil 24077,43 are described. The fragments have unambiguous affinities to mare basalts, but are exceptionally low in TiO_2 (< 1 wt.% TiO_2). This characteristic led Vaniman and Papike to call them "very low-Ti mare basalts." Apollo 17 green glassy rock 78526 and Luna 24 sample 24170,7 (a crushed microgabbroic rock) are of similar composition. In addition to their low TiO_2 contents, very low-Ti mare basalts are distinguished from other mare basalts by higher Al_2O_3 (> 10 wt.%) and lower Na_2O (< 0.3 wt. 5) and K_2O (< 0.05 wt.%). Mineral compositions are consistent with these bulk chemical properties: Pyroxenes have low Ti contents and low Ti/Al; as Fe/(Fe + Mg) increases in pyroxenes, Ti increases, which indicates that ilmenite precipitated very late in the crystallization sequence. Plagioclase is consistently more calcic than An_{93}. As in other mare basalts, late-stage, residual glass is silica-rich but it contains < 0.05 wt.% K_2O; in other mare basalts, the mesostasis contains 4–6 wt.% K_2O.

Bulk compositional trends, such as the one shown in the figure, suggest that the entire suite of samples might be related to one another, and perhaps to Apollo-15 green glass. Petrologic mixing calculations suggest that green glass rock 78526 could represent a parental magma that the others were derived from by fractional crystallization of varying amounts of olivine, low-Ca pyroxene, and chromite. However, the samples could represent varying percentages of partial melting of a common source. The relationship (if there is one) between rock 78526 and Apollo-15 green glass is obscure. Mixing calculations give unsatisfactory fits for simple olivine fractionation. However, they might be related by partial melting.

Wänke, H. (Max-Planck-Institut für Chemie, Abteilung Kosmochemie D-6500 Mainz (F.R.G.), Kruse, H., Palme, H., and Spettel, B.: 'Instrumental Neutron Activation Analysis of Lunar Samples and the Identification of Primary Matter in the Lunar Highlands', *J. Radioanalytical Chem.* **38**, 363–378. (1977)

We describe the scheme of sequential neutron activation which was developed in our laboratory especially for the analysis of lunar samples and in which more than 50 elements are determined. Irradiations with 14 MeV, epithermal and thermal neutrons and both instrumental techniques and radiochemical separations were applied. It is shown that the achieved accuracy can compete with the best available analytical methods for most major and many trace elements. Besides the observation of 'correlated elements', the discovery of primary matter of the last accretion stage of the Moon in samples from the lunar highlands is discussed in some detail.

Warren, P. H. (Institute of Geophysics and Planetary Physics, University of California, Los Angeles, CA 90024) and Wasson, J. T.: 'The Origin of Lunar KREEP', *EOS: Trans. Amer. Geophys. Union* **58**, 1180. (1977)

We propose a new format for illustrating the relative abundances of incompatible elements in nonmare lunar rocks: normalization to the KREEP component which is ubiquitous among non-pristine highlands rocks. The component is approximated as the mean composition of a number of the KREEPiest rocks known. KREEP-normalized diagrams for KREEP-rich rocks are always practically flat. This holds for analyses by various groups of rocks from widely separated sites provided the rocks contain 10% of the KREEP component. This lack of fractionation of incompatibles is strong evidence that these nonmare rocks did not form by a series of equilibrium partial melting events. It is implausible that such partial melting could produce such diverse major element concentrations, yet such uniform concentrations of incompatibles. It can be shown that differences of a factor of 2 in the degree of partial melting of a *single* source result in La/Yb fractionations greater than any observed in high-KREEP samples.

The unfractionated incompatibles of KREEPy rocks were probably formed as a magma residuum from the initial differentiation. This magma (which we have named *urKREEP*) probably for a time underlay a substantial fraction of the near side of the Moon. The diverse major element compositions seen among non-pristine KREEPy rocks can be understood as a variety of mixtures of more uniform pristine KREEPy rocks with sundry low-KREEP crustal materials.

Very few pristine (i.e., of endogenous igneous origin) KREEPy rocks are known. We have new data on 15386 confirming that it is pristine. Major element compositions of pristine KREEPy magmas may have been produced via 'hybridization' – corrosion of hot, low-KREEP crustal rocks by still hotter demi-urKREEP liquids, percolating upward.

Weber, H. W. (Max-Planck-Institut für Chemie, D-65 Mainz, Germany), Schultz, L., and Hintenberger, H.: 'Noble Gas Record of Agglutinate and Bulk Grain Size Fractions Separated from Soil 15601', *Meteoritics* **12**, 383. (1977)

Concentration and isotopic composition of He, Ne, and Ar as well as the concentration of ^{84}Kr and ^{132}Xe have been measured in bulk and agglutinate grain size fractions separated from soil 15601. Our investigations are part of the European Consortium study of 15601. The samples have been prepared by the Cambridge group (Gardiner *et al.*). This paper presents additional measurements not included in our previous report (Schultz *et al.*). In addition to bulk and 'light' agglutinates ($\rho < 2.96$ g cm^{-3}) we have investigated a suite of grain sizes of 'heavy' agglutinates ($\rho = 2.96$–3.3 g cm^{-3}).

All agglutinates contain about 2 to 2.5 times more trapped Ar, Kr, and Xe compared to bulk samples of the same grain size. For He and Ne only the coarse size fractions show an enrichment over bulk samples. This is also true for 'repurified' agglutinate samples which should not contain a contamination by feldspathic grains.

Bulk and agglutinates show an anticorrelation between concentration C of trapped solar gases and grain size d. The experimental data of agglutinates can be fitted by a power law of the form $C = S(d/d_0)^n + V$ (S: surface correlated component of a reference grain size fraction d_0; V: volume correlated component). Best fits yield values of n between 0.8 and 1.1. The elemental ratios of the surface and volume correlated noble gases are equal within the limits of error, only the $^4He/^{20}Ne$ ratio is lower for the volume correlated component. For coarse grain sizes the concentration of trapped gases is higher in heavy agglutinates compared to light agglutinates.

Zook, H. A. (NASA Johnson Space Center, Houston, TX): 'Meteoroid Impact Pit Observations Require Lower Lunar Rock Exposure Ages', *Meteoritics* **12**, 390. (1977).

The ten hypervelocity impact pits found after flight on the windows of ten Apollo spacecraft provide a measure of the present meteoroid impact rate at one AU. These impacts are ideally suited for comparison with those on glass-coated lunar rocks as they are very similar in appearance and cross-calibration problems are minimized. The impact rate determined from the Apollo windows was 0.015 impacts/(cm^2 yr) for all impact pits larger than 20 μm in diameter. Using this rate, glass-coated lunar rocks 12054 and 15205, and rock 60015 are determined to have exposure ages about a factor of 5 less than the solar flare track ages reported for those rocks. These rocks are clearly not saturated with impacts and are therefore still in production. Age ratios that may be larger or smaller than 5 are obtained for other lunar rocks, but there are larger experimental and analytical uncertainties associated with most of them.

It does not appear probable that the meteoroid impact rate has varied greatly over the past 10^4 to 10^5 yr nor does it seem likely that the determination of the current rate is in error by factors exceeding 2. Therefore either the 'present' solar flare track production rate needs revision upwards or the production rate of solar flare tracks must vary with time. There is evidence for both alternatives. The time variable evidence indicates a strong increase in solar activity $\sim 2 \times 10^4$ yr ago.

5. Electromagnetic Properties of the Moon

Bader, V. A., Yakovlev, C. I., and Novichikova, E. I.: 'Radiowave Propagation Along Moon Surface' (in Russian), *Radiotekhnikai Elektronika* **22**, 2091–2096. (1977).

Bernhardt, P. A. (Radioscience Lab., Stanford University, Stanford, CA 94305), Antoniadis, D. A., and Da Rosa, A. V.: 'Determination of Lunar Tidal Winds from Simultaneous Measurements of the Geomagnetic Field and the Ionospheric Electron Content', *EOS: Trans. Amer. Geophys. Union* **58**, 683. (1977)

Magnetic field and electron content data contain variations produced by the lunar tides. The lunar magnetic variation is directly related to the current system. The lunar electron variation is produced by polarization electric fields set up by the lunar dynamo. These electrostatic fields map up magnetic field lines to the *F*-layer and modulate the electron content by moving the layer into regions with different loss rates. A digital filter is used to isolate the lunar fluctuations in the data. The lunar magnetic and electron content fluctuations are processed to provide an estimate of lunar currents and electric fields, respectively. The resulting currents and electric fields may be analyzed by using Ohm's law in conjunction with models of the *E*-region conductivity to yield the lunar tidal wind in the lower thermosphere.

Cassen, P. (Theoretical and Planetary Studies Branch, NASA – Ames Research Center, Moffett Field, CA 94035): 'Planetary Magnetism and the Interiors of the Moon and Mercury', *Phys. Earth Planet. Interiors* **15**, 113–120. (1977)

This paper reviews those aspects of the magnetic properties of the Moon and Mercury which are most readily related to the thermal evolutions of these bodies. Theories which involve magnetization by an internal dynamo, or, for Mercury, a presently active dynamo, have nontrivial energy requirements. A thermally convecting lunar dynamo, driven solely by solidification of the core, could last for almost 2 b.y., but only if solid convection in the mantle were inhibited. The maintenance of a thermally convecting dynamo in Mercury until the present probably requires an additional heat source in the core, assuming that the core formed within the first billion years of the planet's history. Dynamos driven by mechanisms other than thermal convection put less stringent constraints on thermal evolution, but their lifetimes depend sensitively on the melting properties of material at the core–mantle boundary, mantle rheology and mantle heat-source concentrations. The source of the energy required for early planetary-wide differentiation, and therefore core formation, has not been established. The most likely possibility, accretional heating, requires that the energy of impacting bodies be deposited in the interior of the planet.

Cisowski, S. M. (Dept. of Geological Sciences, University of California, Santa Barbara, CA 93106) and Fuller, M.: 'Magnetic Effects of Shock Waves on Natural Materials', *EOS: Trans. Amer. Geophys. Union* **58**, 727. (1977)

A secondary component of magnetization, apparently acquired at the time of passage of a shock wave, has been recognized and separated from the primary remanence through AF demagnetization, both in

terrestrial samples from suspected impact sites and in lunar samples. Low pressure experimental shock work on natural samples in the laboratory resulted in magnetic behavior that mimics that of samples presumed to have been shocked in nature.

These observations suggest that magnetic remanence studies can contribute to calibrating shock pressures seen in lunar samples and terrestrial samples from suspected impact sites, particularly in the low shock pressure range where optical shock effects are ambiguous or absent. This study's relevance to the magnetism of lunar samples is especially important, since the samples were all collected from an impact-produced regolith. Experimental shock work on lunar soils suggests that soil breccias are formed by *in situ* shock lithification, and that the production of extremely fine free iron may be a by-product of this process. Rocks from terrestrial impact sites considered here include samples collected from Lonar Crater, India, and Meteor Crater, Arizona.

Changes in hysteresis properties are also observed to occur in natural samples shocked from moderate to high pressure ranges, both in nature and in laboratory work.

Coleman, P. J., Jr. (University of California, Los Angeles, CA 90024), Weiss, H., and Hood, L. L.: 'The Importance of Cratered Associated Magnetic Fields', *EOS: Trans. Amer. Geophys. Union* **58**, 1179. (1977)

We have extended our spherical harmonic expansion of the magnetic field from our 'cratered shell' model of the Moon's crust to include higher order terms up to degree 40. The relationships of topographical features in the cratered shell to magnetic field structure are easily discerned in this higher order field. For example, edge effects associated with crater rims are, in most cases, well defined. These strong correlations between field structure and crater topography in our model are the lack of such correlations in the empricial data suggests that neither the craters nor mare fill are the principal sources of the lunar remanent magnetization seen at the altitude of the Apollo subsatellite.

Dubinin, E. M. (Space Research Institute A. N. U.S.S.R., Moscow, U.S.S.R. 117810), Podgorny, I. M., Potanin, Y. M., and Sonett, C. P.: 'Laboratory Simulation of a Diamagnetic Lunar Magnetosphere', *EOS: Trans. Amer. Geophys. Union* **58**, 1179. (1977)

The magnetic field distrubance created by the impingement of a supermagnetosonic collision-free plasma upon a hollow, electrically nonconducting body (lunella) has been studied in the laboratory using a plasma accelerator. Diamagnetic currents on the boundary of the downstream cavity which is formed are the source of these disturbances which fringe out within the lunella and extend on into the upstream flow to a distance of about the geometric mean Larmor radius. Additional field perturbations and associated currents appear over the upstream hemisphere. The results are in qualitative accord with lunar magnetometer data and bear upon the interaction of the solar wind with small non-magnetic bodies.

Dubinin, E. M. (Space Research Institute A. N. U.S.S.R., Moscow, 117810) and Sonett, C. P.: 'Laboratory Simulation of the Lunar Magnetosphere', *Geophys. Res. Letters* **4**, 391–394. (1977)

Properties of the energetic electron ($E \gtrsim 200$ keV) magnetopause layer along the distant magnetotail have been studied with Caltech instrumentation aboard IMP-8 for approximately 60 space-craft orbits. The cross-sectional area of the layer appears to increase by a factor of ~ 5 with increasing geomagnetic activity, and the average unidirectional electron flux within the layer increases by a factor of ~ 4. The energy carried by electrons $\gtrsim 200$ keV ranges from $\sim 10^{14}$ erg s^{-1} to $\sim 10^{15}$ erg s^{-1}. Extrapolation to include all electrons > 1 keV suggests total energy flow ranging from $\sim 3 \times 10^{15}$ erg s^{-1} at quiet times to $\sim 5 \times 10^{18}$ erg s^{-1} at magnetically disturbed times.

Dyal, P. (NASA/Ames Research Center, Moffett Field, CA 94035), Daily, W. D., Barker, W. A., and

Parkin, C. W.: 'A Thermoelectric Model for the Origin of Lunar Magnetism', *EOS: Trans. Amer. Geophys. Union* **58**, 743. (1977)

A thermoelectric generator model is presented as a magnetic field source for thermoremanent magnetization of the lunar crust during its solidification and cooling. Magnetic fields from 1000 to 20 000 gammas are calculated for various crater and crustal geometries. The Seebeck generator circuit consists of cooling lava basins formed in the lunar crust during its early formation ~ 4.6 b.y. ago and the solar wind plasma which provides a current path from the top of one lava basin to the other. The molten subsurface lava completes the electrical circuit and the Seebeck electromotive force produced by the two lava basin-solar wind junctions at two different temperatures provides the potential difference. Model calculations show that for a typical thermoelectric potential of $1000\,\mu V\,°C^{-1}$, and two lava basins of 100 km diameter separated by 50 km, magnetic field of 6000 gammas are generated. The solidifed crustal material between the two basins that cool through the iron curie temperature in the presence of such a field would have the thermoremanent magnetization measured in many lunar samples.

Gorshkov, E. S. (LO Izmiran, Leningrad, U.S.S.R.) Gus'kova, E. G., and Pochtarev, V. I.: 'Peculiarities of Lunar Rocks Magnetic History', *EOS: Trans. Amer. Geophys. Union* **58**, 742–743. (1977)

Magnetic properties of lunar rocks fragments delivered by ALS 'Luna-16' and 'Luna-20' are investigated. The average values of magnetic susceptibility of marine secondary rocks are two times higher, than those of the continental secondary rocks; the difference of average values of natural remanence (NRM) amount to 5. The modelling of artificial magnetization of various kinds reduces this difference to 2, that is in concordance with two fold difference of expositional ages of the secondary rocks. The NRM difference is explained by calculation of mechanism of cyclic magnetization, which is very real for the Moon conditions. The experimental results show, that the role this mechanism is already essential in a magnetic field $2000\,\gamma$.

Hobbs, B. A. (Institute of Geophysics and Planetary Physics, Scripps Institution of Oceanography, University of California at San Diego, La Jolla, CA 92093): 'The Electrical Conductivity of the Moon: An Application of Inverse Theory', *Geophy. J. Roy. Astron. Soc.* **51**. 727–744. (1977)

Inverse theory of Backus and Gilbert is used to analyse the day-side electromagnetic response of the Moon to magnetic fluctuations in the solar wind. The data consist of two transfer functions. both tangential to the lunar surface, and in the theoretical development, the required Fréchet kernels corresponding to these transfer functions are determined. The ensuing calculations show that the data are sufficiently good to determine the conductivity down to a depth of about 600 km. The results are very encouraging and it is suggested that as newer theories of lunar induction are developed to consistently interpret the day- and night-side measurements, they should be used in the above enlightened manner.

Hood, L. L. (Department of Earth and Space Sciences, University of California, Los Angeles, CA 90024) and Coleman, P. J., Jr.: 'A Study of Lunar Farside Magnetic Anomalies', *EOS: Trans. Amer. Geophys. Union* **58**, 1179–1180. (1977)

An approximate forward inversion of Apollo subsatellite vector magnetometer data is attempted in order to obtain estimates for the locations, dimensions, and magnetization characteristics of relatively strongly magnetized crustal materials. In line with the possibility that thin, highly magnetized layers of ejecta deposits are responsible for the observed anomalies, source regions are modeled as polygonal plates at the lunar surface one kilometer thick and with variable lateral dimensions. Construction of a contour map catalog of magnetic fields at subsatellite altitudes due to such bodies for various magnetization levels and directions allows one to make good initial estimates of the source region characteristics required to explain the real anomalies if the assumed model is correct. Contour maps of the artificial field components are then generated according to these estimates and compared to similar maps of the real permanent lunar magnetic field. Indicated corrections are made and the process is repeated until a reasonably good fit to the data is achieved. The study is limited to the lunar farside where a maximum of low-altitude data is available and where the strongest anomalies have been recorded.

Preliminary results indicate that adjacent regions on the lunar surface may be magnetized in quite different directions. The directions of magnetization are, however, prevented from exhibiting total randomness by their strong tendency to lie in or near a plane perpendicular to the present lunar spin axis. The latter observation is consistent with the long-noted depletion of north-south permanent fields relative to other components. Implications for the origin of lunar magnetism will be discussed, if time permits.

Lui, A. T. Y. (Geophysical Institute, University of Alaska, Fairbanks, AK 99701), Meng, C. I., and Akasofu, S. I.: 'Search for the Magnetic Neutral Line in the Near-Earth Plasma Sheet 3. An Extensive Study of Magnetic Field Observations at the Lunar Distance', *J. Geophys. Res.* **82**, 3603–3613. (1977)

In this paper we have extended our search for the magnetic neutral line in the magnetotail to the lunar distance on the basis of the Explorer-35 magnetic field observations from July 1967 to December 1970. The sign of the B_z component is found to be predominantly positive during satellite crossings of the midplane (or the so-called neutral sheet) during the substorm expansive phase. Thus combining the present and the earlier results, we conclude that there is no supporting evidence for the formation of a neutral line within the lunar distance during the expansive phase of most substorms. We also discuss in detail a rare event during the geomagnetic storm of February 2–4, 1969 ($Dst \sim -180\,\gamma$). The magnetic field was observed to be pointing nearly 90° southward with a magnitude of 20–32 γ for an extended period.

Parkin, C. W., (Dept. of Physics, University of Santa Clara, Santa Clara, CA 95053), Dyal, P., and Daily, W. D.: 'Electrical Conductivity of the Lunar Crust and Interior', *EOS: Trans. Amer. Geophys. Union* **58**, 736. (1977)

The electrical conductivity of the lunar crust and interior have been investigated by analysis of simultaneous surface and orbiting lunar magnetometer data. The interior conductivity profile is calculated from induced poloidal response of the Moon to transients in the geomagnetic tail. An upper limit is placed on the average crustal conductivity from an investigation of toroidal ($\mathbf{V} \times \mathbf{B}$) induction in the Moon. The components of the toroidal field $\mathbf{B}_T = \mathbf{B}_A - \mathbf{B}_E$, where $\mathbf{B}_A$ and $\mathbf{B}_E$ are total response field at the surface and the field external to the Moon, respectively, are expressed as functions of the motional solar wind electric field $\mathbf{E} = \mathbf{V} \times \mathbf{B}_E$ in an upeast–north (z–y–x) coordinate system at the surface, as follows: $B_{Tx} = 0$, $B_{Ty} = AE_z$, $B_{Tz} = -AE_y$, where A is a function of conductivity and $\mathbf{V}$ is velocity of the Moon relative to the solar wind. The upper limit of the slope A is determined from slopes of curves relating components of $\mathbf{B}_T$ to those of E, using 10-minute data intervals selected from a total of 5 lunations when $\mathbf{V}$ and $\mathbf{B}_E$ are approximately constant. A preferred crust thickness can be chosen consistent with geochemical, seismic, and magnetic constraints. For an average global crust thickness of ~ 80 km, our upper limit on A corresponds to a crust electrical conductivity upper limit of $\sim 10^{-8}$ mhos m^{-1}. This crust upper limit places an important constraint on our most recent poloidal eddy-current results for interior conductivity, which are most accurate at intermediate depths of 300 to 800 km, and much less accurate for shallower depths. The toroidal induction results lower the crust surface conductivity upper limit by approximately four orders of magnitude.

Pelizzari, M. A. (Lunar Science Institute, 3303 NASA Road 1, Houston, TX 77058) and Criswell, D. R.: 'Patchy Photoelectric Charging of the Lunar Terminator Terrain', *EOS: Trans. Amer. Geophys. Union* **58**, 1180. (1977)

Photoelectric charging of lunar features is numerically simulated in detail for a two dimensional geometry. Orbits for a two component spectrum of photoelectron energies are followed sequentially from a sunlit strip, and the strip's surface charge is seen to evolve to a very nearly conductor-like distribution, characterized by intense electric fields at the edges. Maximum field strength is limited by the diffuse nature of the sunlit strip edges and by the photosheath's temporal response to electric field changes. An effective surface conductivity governing the latter effect is derived, and can be used to calculate sheath currents. Rapid numerical simulations, in which the low energy photoelectron component is not followed by simply assumed to keep the sunlit surface at constant potential, can be modified to treat nonconstant potentials by including these currents.

Results support the suggestion that the fields generated are strong enough to life dust from centimeter-sized features near the lunar terminator. Charged lunar dust grains are influenced by the edge fields merely to cross the light–dark boundary, but upon sunset intensification of charging, their orbits may reach heights necessary to explain observations of lunar horizon glow.

Runcorn, S. K. (School of Physics, The University, Newcastle upon Tyne, NE1 7RU) and Stephenson, A.: 'Magnetism of Lunar Rocks and Meteorites', *Meteoritics* **12** 356–357. (1977)

The discovery of remanent magnetisation in the rocks returned from the Apollo project and in meteorites was unexpected for, unlike terrestrial palaeomagnetism, no fields exist today which could be identified as a magnetising agent. However, in other respects, the lunar rocks and meteorites seemed to possess, in many cases, stability comparable with terrestrial igneous rocks and the properties of the remanent magnetisation seemed not dissimilar to the thermoremanent magnetisation in terrestrial basalts. It has thus been concluded that a lunar magnetic field existed between 3.2 b.y. and 4.0 b.y. and that in the early solar system magnetic fields existed, capable of magnetising the meteorites. Palaeo-intensity studies have, both in the case of meteorites and in the case of the earliest moon rocks, given values of about 1 gauss for the ambient field.

In the case of the Moon, there is strong evidence that this field originated in a dynamo process in an iron core of radius of about 400 km, the existence of which is still not definitely proved. The value of palaeointensity falls between 4.0 b.y. and 3.2 by 2 orders of magnitude. This must reflect the decay of the radioactivate heat source driving the dynamo. In the case of the meteorites, the magnetising field would appear to be that retained by the solar system nebula during its contraction from a dust cloud associated with a weak galactic magnetic field. Such a field may be important in the formation of the solar system.

Runcorn, S. K. (Institute of Lunar & Planetary Sciences, School of Physics, The University, Newcastle upon Tyne, NE1 7RU, UK): 'The Lunar Dynamo', *EOS: Trans. Amer. Geophys. Union* **58**, 737. (1977)

The general magnetization of the lunar crust attested by the natural remanent magnetization of the returned crystalline rocks and the local magnetic fields on the Moon, mapped by magnetometers and the reflected electron studies, require an ancient magnetic field far more intense than any associated with the Moon today. Intensification of the transient solar wind field by meteoritic or cometary impact remain a possibility especially through the ignorance of what the transient stresses and associated physical phenomena might play in magnetization processes. However, the fields from Rimus Sirsalis are not in accord with these hypotheses. The zero value of a present lunar magnetic dipole along with the above facts are best explained in terms of an early lunar dynamic in a small iron core. Palaeointensity values from 4.0×10^9 to 3.2×10^9 yr show a decrease of nearly two orders of magnitude. The total cessation of dynamo action later is probably due to the falling of the magnetic Reynolds number below the critical value, but the earlier decrease must be interpreted in terms of the early lunar thermal history.

Sonett, C. P. (Lunar & Planetary Lab., Univ. of Arizona, Tucson, AZ 85721) and Wiskerchen, M. J.: 'A New Source of Lunar Electromagnetic Induction: Forcing by the Diamagnetic Cavity', *Geophys. Res. Letters* 4, 307–310. (1977)

A new source of electromagnetic excitation of the Moon is identified. It is distinct from the known spherical transverse electric (TE) mode forced by time variations of the interplanetary magnetic field. This new source is a consequence of the extension of the diamagnetic cavity field into the lunar interior and is detected on the sunlit lunar surface as a strong induction signal, directed preferentially east and west, and superimposed upon the global TE mode. The induction signal is hypothesized to be the time-dependent part of the diamagnetic cavity fringing field within the Moon. The signal results from overall expansion and contraction of the lunar cavity measured here in the frequency range of $10^{-5} \leqslant f \leqslant 10^{-4}$ Hz. This 'breathing' mode of the Moon-cavity system is in turn based upon large scale hydromagnetic pressure variations of the solar wind. Confinement of the cavity fringing field to the lunar interior results in the lines of force being folded over just above the lunar surface and swept downstream above a region of reduced field intensity in the cavity walls. This is consistent with earlier observation. The associated current layer extends upstream over the face of the Moon. The diamagnetic contribution to induction seen on the sunlit lunar surface also suggests a resolution of the long-standing difference between the excess induction noted experimentally on the dark-side of the Moon and that computed from TE mode theory.

Srnka, L. J. (The Lunar Science Institute, 3303 NASA Road 1, Houston, TX 77058) and Martelli, G.: 'Magnetic Field Generation in Hypervelocity Impacts', *EOS: Trans. Amer. Geophys. Union* **58**, 1179. (1977)

At sufficiently high impact powers ($\geqslant 10^{15}\,\mathrm{Wm}^{-2}$) spontaneous electrical currents may appear in the ionized parts of the ejecta cloud. Theory predicts that the transient magnetic fields of such current systems can exceed 1 G (10^{-4} T) near the impact. At least three major sources for these fields can be identified for impacts onto planetary surfaces: (1) chemical gradients in the impact area (e.g. layering), which produce non-aligned plasma density and temperature gradients; (2) structural control of the crater shape by regional geology, leading to non-uniform expansion of the plasma cloud; and (3) thermal instabilities at the expanding plasma front for very high temperatures, due to the dependence of the electron thermal conductivity on magnetic field. Magnetic remanence in solid material near the impact could occur by transient thermal or stress effects in the presence of the spontaneous fields. Such mechanisms may be responsible for some of the permanent magnetization of the lunar surface.

Preliminary experiments have been performed to search for such fields. An impact experiment using a shaped-charge propulsion scheme has produced local transient magnetic fields at impact velocities of 12–14 km s^{-1}, for metallic projectiles into basalt targets. Further results will be discussed, and will be compared with the theoretical predictions.

Strangway, D. W. (Department of Geology, University of Toronto, Ont. Canada): 'The Magnetic Fields of the Terrestrial Planets', *Phys. Earth Planet. Interiors* **15**, 121–130. (1977)

A single model for the terrestrial planets based upon the structure inferred for the lunar interior is developed, which subdivides them according to size. It is probable that planetary bodies smaller than the Moon have never melted but they could still carry a memory of an early intense solar-system field. The magnetic fields of Mercury, Mars and Venus can be explained in terms of a crustal remanence which is a memory of a primitive internal or external field. The Earth's present field, on the other hand, is due to an active internal dynamo.

Vanyan, L. L. (Soviet Geophysical Committee, Moscow, U.S.S.R.): 'About the Interaction of the Solar Wind with Lunar Magnetic Anomalies' (in Russian), *The Moon* **16**, 317–320. (1977)

Рассмотрена упрощенная модель взаимодействия холодного солнечного ветра с лунными магнитными аномалиями. Поскольку на освещенной стороне Луны динамическое давление солнечного ветра существенно превышает магнитное давление аномалий, распространение лунного поля вверх возможно лишь с помощью диффузии. Этот процесс зависит не от скорости, а от концентрации солнечного ветра и от характерного размера аномалий. Теоретические расчеты сравниваются с данными Аполлона-12 и Эксплорера-35.

Vanyan, L. L. (Soviet Geophysical Committee, Moscow, U.S.S.R.) and Egorov, I. V.: 'The Lunar Lithosphere From Electromagnetic-Sounding Data', *The Moon* **17**, 3–9. (1977)

Four sets of published data are used; frequency dependence of the day-side horizontal magnetic amplification, the same for the dark-side vertical decrease, the day-side transient amplification and the dark-side transient decrease. Transient data are transformed into the frequency domain and the dark-side data are transformed into the corresponding day-side horizontal amplification. Finally, all experimental results are presented in the form of the day-side frequency response. The summarised apparent resistivity curve is obtained by this response. It corresponds to the model with resistivity about several hundreds of $\Omega \cdot m$ to the depths of 700–800 km. It suggests the absence of significant amounts of molten material to these depths.

Vanyan, L. L. (Soviet Geophysical Committee, Moscow, U.S.S.R.), Eroshenko, E. G., Lugovenko, V. H., Okulessky, B. A., Popov, A. G., and Kharitonov, A. L.: 'Comparison of the Anomalous Magnetic Fields of the Moon and Earth' (in Russian), *The Moon* **16**, 281–287. (1977)

В данной работе проводится сравнительный анализ аномального магнитного поля Луны, полученного в результате съемки на высоте 100 км, осуществленной с помощью субсателлита Аполлона-15, с аномальным магнитным полем Земли, полученным по данным разновысотных съемок (до 500 км над земной поверхностью). Проведен спектральный анализ указанных аномальных магнитных полей, в результате которого показано, что основное различие спектров аномальных магнитных полей заключается в пониженной интенсивности длиннопериодных лунных аномалий и повышенной скорости их затухания с высотой, что связывается с отсутствием в лунных породах индуктивной намагниченности.

Vanyan, L. L. (Soviet Geophysical Committee, Moscow, U.S.S.R.), Yeroshenko, Y. G., Lugovenko, V. N., Okulesskii, B. A., Popov, A. G., and Kharitonov, A. L.: 'A Comparison of the Magentic Field Anomalies For the Moon and Earth', *The Moon* **16**, 289–294. (1977)

A comparative analysis of the anomalous magnetic field of the Moon, information about which was obtained by the Apollo 15 subsatellite, and the anomalous magnetic field of the Earth, involving data provided from surveys at various altitudes (up to 500 km) is given. As a result of spectral analysis of these fields it is shown that the main difference of the spectra is in the lower intensity of long period lunar anomalies and the increased rate of their damping with height, which is probably connected with the absence of any kind of magnetization by induction.

Weiss, H. (Dept. of Geophysics & Space Physics and Institute of Geophysics & Planetary Physics, University of California, Los Angeles, CA 90024) and Coleman, P. J., Jr.: 'The Moon's Permanent Magnetic Field: A Cratered-Shell Model', *The Moon* **16**, 311–315. (1977)

As part of our study of the larger-scale remanent magnetic field of the Moon, we have examined the effects of cratering in an otherwise spherically symmetrical shell magnetized by a concentric dipolar magnetic field H_0 to an intensity of magnetization cH_0, where c is a constant. In our initial model, we assume that the material excavated from the craters is distributed with random orientation and thus does not contribute to the remanent dipole moment $\mathbf{M}_g$. We further assume that the mare fill does not contribute significantly to $\mathbf{M}_g$. We choose the magnetizing dipole moment $\mathbf{M}_0$ and the constant c such that the magnitude of the product $cH_0 \simeq 3 \times 10^{-4}$ Γ at the outer surface of the shell in the equatorial plane of the dipole. This value of the intensity of remanent magnetization was chosen to be within the range 10^{-7}–10^{-3} Γ; the intensities of thermo-remanent magnetization exhibited by Apollo samples. Finally, we use the locations and diameters of the 10 largest craters on the Moon and the depth-to-diameter ratios of Pike's formulation to model approximately the excavation of the magnetized shell.

The remanent dipole moment $\mathbf{M}_g$ was calculated for each of three orthogonal orientations of the magnetizing dipole $\mathbf{M}_0$. The three magnitudes of $\mathbf{M}_g$ fall in the range 4×10^{18}–1×10^{19} Γ cm^3 which is close to the upper limit of 10^{19} Γ cm^3 estimated for M_g from the field measurements obtained with the Apollo subsatellites. Further, the distribution of the craters is such as to produce a significant transverse component of $\mathbf{M}_g$ with acute angles between the spin axis and $\mathbf{M}_g$ in the range 51°–77°.

6. Radiation of the Moon; Optical and Thermal Properties of the Lunar Surface

Andre, C. G. (Chemistry Dept., University of Maryland, College Park, MD 20742), Bielefeld, M. J., Eliason, E., Soderblom, L. A., Adler, I., and Philpotts, J. A.: 'Lunar Surface Chemistry: A New Imaging Technique', *Science* **197**, 986–989. (1977)

Detailed chemical maps of the lunar surface have been constructed by applying a new weighted-filter imaging technique to Apollo 15 and Apollo 16 X-ray fluorescence data. The data quality improvement is amply demonstrated by (i) modes in the frequency distribution, representing highland and mare soil suites, which are not evident before data filtering and (ii) numerous examples of chemical variations which are correlated with small-scale (about 15 km) lunar topographic features.

Durrani, S. A. (Dept. of Physics., University of Birmingham, Birmingham, England) and Bull, R. K.: 'Etchable Ranges of Fossil and Fresh Heavy-Ion Tracks in Lunar and Analogous Crystals', *Nuclear Instr. Methods* **140**, 553–556. (1977)

In using the etchable lengths of charged particles in meteoritical and lunar crystals as a means of assigning atomic numbers to cosmic-ray primaries, it is necessary to have reliable calibration data with known heavy ions. Results of a systematic study of etchable lengths of both fresh and fossil heavy-ion tracks in terrestrial as well as extraterrestrial crystals are reported in this paper, using a number of polishing, etching and observational procedures. Fossil tracks in lunar, but not in meteoritical, crystals are found to be shorter but more temperature-resistent than their simulated counterparts. This difference is attributed to the hotter and more radiation-filled environment on the Moon.

Fisher, A. D. (Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, MA 02139) and Staelin, D. H.: 'Possible Effect of Subsurface Inhomogeneities on the Lunar Microwave Spectrum', *Icarus* **32**, 98–105. (1977)

Inhomogeneities beneath the lunar surface could alter the average microwave emission spectrum of the Moon in a fashion generally consistent with observations, even in the absence of an average heat flux or density gradients with depth. The lunar subsurface was modeled as an inhomogeneous lossy dielectric with three-dimensional refractive index fluctuations characterized by independent horizontal and vertical correlation lengths. The model suggests that attempts to infer the physical properties of the Moon from the lunar microwave spectrum could be significantly inaccurate if subsurface scattering were neglected.

Gold, T. (Center for Radiophysics and Space Research, Cornell University, Ithaca, NY 14853), Bilson,

E., and Baron, R. L.: 'The Search for the Cause of the Low Albedo of the Moon', *J. Geophys. Res.* **82**, 4899–4908. (1977)

The effects of different weathering processes on the albedo of the lunar surface cover is discussed. The surface chemical composition of numerous lunar soil and pulverised rock samples was determined by auger electron spectroscopy. The optical albedo of these samples was also measured. The chemical concentration of iron and titanium is greater on the surface of soil samples than it is on the surface of crushed rock samples with similar bulk composition, whereas the albedo of soil samples is lower than that of the crushed rock samples. A correlation is presented between the surface iron + titanium content and the albedo. Results of solar wind simulation experiments show that irradiation of crushed lunar rock samples with a small dose (corresponding to 3000 years of solar wind) of 2 keV energy protons changed the surface chemistry of the rock to that of the soil. A much larger dose of protons (corresponding to 30 000 years of solar wind) was needed to darken crushed rock to the albedo of the soil of similar bulk chemical composition. The mechanism of darkening by solar wind is discussed, and its effectiveness is compared to that of other darkening processes.

Hapke, B. (Department of Earth and Planetary Sciences, University of Pittsburgh, Pittsburgh, PA 15260): 'Interpretations of Optical Observations of Mercury and the Moon', *Phys. Earth Planet. Interiors* **15**, 264–274. (1977)

Optical, thermal and radar remote-sensing measurements indicate that Mercury is covered with a relatively thick layer of soil similar in texture and thickness to lunar regolith. Photometric limb profiles measured by Mariner 10 imply that the small-scale slopes on Mercury are about half those on the Moon, probably because of differing gravity. The differential photometric functions of Mercury and the Moon have a latitudinal dependence which can be completely accounted for by shadowing in craters. The lack of polar darkening on Mercury in spite of the presence of a magnetic field implies that the dominant soil-darkening process on Mercury, and by extension, on the Moon is not dependent on the solar wind, but probably is deposition of material evaporated by meteorite impacts. Recent measurements of Mercury's spectral reflectivity in the IR and vacuum UV are both consistent with the surface rocks of Mercury being lower in FeO than those of the Moon. Based on laboratory experiments the average FeO content on the surface of Mercury is estimated to be between 3 and 6%.

Hubbard, N. J. (NASA Johnson Space Center, Houston, TX 77058) and Woloszyn, D.: 'Orbital Gamma-Ray Data and Large-Scale Lunar Problems', *Phys. Earth Planet. Interiors* **15**, 287–302. (1977)

The orbital gamma-ray data obtained during Apollo 15 and 16 have been used to infer new information about the Moon and to generalize some of the information provided by the study of lunar samples. These orbital data show that Mg, and to a lesser extent Fe, are major variables in the chemical composition of the early lunar crust. However, Fe does not attain high enrichments until the genesis of mare basalts later in lunar history. The orbital data show that the lunar highlands are not composed of a homogeneous material of anorthositic chemical composition. Rather, the petrogenetic processes associated with the lunar highlands have produced a wide range in Mg/Fe ratios. The variations in Mg/Fe ratios between large regions of the non-mare and highland areas of the lunar surface are nearly equal in magnitude to those seen in the non-mare and highland lunar samples. The chemical variations in lunar samples require extensive chemical differentiation to produce. Thus regional variations in the mode and/or extent of chemical differentiation exist and the early intense bombardment of the lunar surface has not destroyed this record. The central highlands and the high-Th regions immediately to the west (Lalande and Fra Mauro) differ markedly from other pre-mare and highland regions by having very high Mg/Fe ratios. Only Mendeleev has an equally high ratio but it has much lower Mg and Fe concentrations. The central highlands also differ from the farside highlands by having higher Mg concentrations and lower K/Th ratios. Some of the Apollo samples with high Mg/Fe ratios may be representative of the predominant materials in those areas that show the highest Mg/Fe ratios.

The large depression on the lunar farside (Big Backside Basin) contains at least a two-component mixture of rock types; one type is probably the local highland material and the other is a basaltic material whose bulk composition approaches that of the frontside mare regions. The surface elevation in the Big Backside Basin is similar to that of the frontside mare and the high-Th regions. The high-Th areas and the mare areas (Cognitum and Imbrium) that are colinear on Fe vs. Th and K vs. Th plots all have about the same surface elevations. This suggests that the high-Th material ('KREEP') was emplaced as lava flows on a pre-existing low surface. Mare Serenitatis has the lowest surface elevation of any mare included in this study and the chemical composition of its surface is nearer to that of pure mare basalts than that of other maria studied. Taken together with the thicker fill in Mare Serenitatis, this suggests that the thicker fill has resulted in a larger mare-basalt component in the regolith, i.e., vertical mixing has been the major means of mixing non-mare material with mare basalts to produce the mare regoliths.

Priboeva, N. V.: 'Investigation of Differences in Color in Selected Areas on the Lunar Surface II. The Areas of Tycho and the Alpine Valley', *Solar System Res.* **11**, 23–30. (1977)

The previous work in this series was the first experiment to obtain the distribution of color characteristics in a selected area of the lunar surface by means of photographic photometry. In the course of the work, we improved the technique of deriving colorimetry schemes. We present here the results of photocolorimetry investigations using the new technique in three regions of the spectrum. We have investigated mountainous continental surface in the region of the crater Tycho, and the region around the Alpine valley, where there is both mountainous and mare-type surface.

Surkov, Y. A., Moskaleva, L. P., Kharyukova, V. P., Manvelyan, O. S., and Shcheglov, O. P.: 'Experimental Simulation of the Gamma Radiation Produced by Nuclear Interactions of High-Energy Particles with the Material of the Moon and Planets', *Cosmic Res.* **15**, 118–124. (1977)

This article examines the processes leading to the emission of γ quanta by the material of the Moon and planets, describes the procedure and the results of experimental simulation with an accelerator, gives determinations of the γ quanta's emission cross sections when rocklike elements and compounds are bombarded with high-energy protons, and also examines the possibility of using the experimental-simulation data for interpreting the results obtained by automatic interplanetary stations.

Zaitsev, A. L., Kayevitser, V. I., Kuteryavkov, A. I., Matyugov, S. S., Pavelyev, A. G., Petrov, G. M., and Yakovlev, O. I.: 'Bistatic Radar Moon Observation Using a Modulated Signal' (in Russian), *Radiotekhnikai Elektronika* **22**, 2097–2104. (1977)

Zook, H. A. (NASA(Johnson Space Center, Houston, TX 77058), Hartung, J. B., and Storzer, D.: 'Solar Flare Activity: Evidence for Large-Scale Changes in the Past', *Icarus* **32**, 106–126. (1977)

An analysis of radar and photographic meteor data and of spacecraft meteoroid penetration data indicates that there probably has not been a large increase in meteoroid impact rates in the last 10^4 yr. The solar flare tracks observed in the glass linings of meteoroid impact pits on lunar rock 15205 are therefore reanalyzed assuming a meteoroid flux that is constant in time. Based on this assumption, the data suggest that the production rate of Fe-group solar flare tracks may have varied by as much as a factor of 50 on a time scale of about 10^4 yr. No independenly obtained data are known to require conflict with this interpretation. Confidence in this conclusion is somewhat qualified by the experimental and analytical uncertainties involved, but the conclusion nevertheless remains the present 'best' explanation for the observed data trends.

7. Lunar Environment

Daily, W. D. (Eyring Research Institute, Provo, Utah 86401), Barker, W. A., Dyal, P., Parkin, C. W.: 'Ionosphere and Atmosphere of the Moon in the Geomagnetic Tail', *EOS: Trans. Amer. Geophys. Union* **58**, 749. (1977)

In this paper we report on the properties of the lunar ionosphere and atmosphere when the Moon is in the high latitude geomagnetic tail lobes and plasma from external sources is minimal. Under these conditions the principle constituents of the lunar atmosphere are neon and argon with calculated surface concentrations of 3.9×10^3 and 1.7×10^3 atoms cm^{-3} respectively. Ionization of the atmosphere by solar radiation results in electrons of 1.5×10^5 K and ions of 370 K temperatures. A hydrostatic model of this plasma is found to be inadequate because the plasma gravitational potential energy is considerably smaller than its thermal energy. A hydrodynamic model, comparable to that used to describe the solar wind, predicts escape of the plasma away from the sunlit hemisphere and along the geomagnetic field lines forming a cylinder whose base is the lunar sphere. At 100 km altitude the calculated plasma density is 1.2×10^2 electrons cm^{-3} with a flow velocity of 4 to 7 km s^{-1} and a corresponding energy density of $\sim 2.5 \times 10^{-13}$ erg cm^{-3}. These quiescent conditions are sporadically disrupted by the cross-tail electric field which adds a drift velocity component perpendicular to the geomagnetic field and increases the plasma loss rate. In addition, there are occasional time periods when plasma sheet and lobe plasma temporarily dominate the plasma environment during non-quiescent times. The hydrodynamic model of the lunar ionosphere described in this paper is expected to be applicable approximately 30% of the time the Moon is in the geomagnetic tail.

Daily, W. D., Barker, W. A., Clark, M., Dyal, P., and Parkin, C. W.: 'Ionosphere and Atmosphere of the Moon in the Geomagnetic Tail', *J. Geophys. Res.* **82**, 5441–5451. (1977)

During the 4-day period when the Moon is in the geomagnetic tail, the principal constituents of the lunar atmosphere are neon and argon. The surface concentrations of neon and argon are calculated from a theoretical model to be 3.9×10^3 and 1.7×10^3, respectively. The lunar atmosphere is ionized by solar ultraviolet radiation, resulting in electrons at a temperature of about 1.5×10^5 K and ions at about 370 K. We investigated dynamic properties of the lunar ionosphere in the high-latitude tail lobes during quiescent times when plasma energy density from external sources is below the sensitivity threshold of the suprathermal ion detector at the lunar surface. We found that a hydrostatic model of the ionospheric plasma is inadequate because the gravitational potential energy of the plasma is considerably smaller than its thermal energy. A hydrodynamic model, comparable to that used to describe the solar wind, is developed to obtain plasma densities and flow velocities as functions of altitude. The hydrodynamic flow of the ionospheric particles is away from the sunlit hemisphere, in a direction parallel to the magnetic field, and forms a cylinder whose base is the lunar diameter. At 100-km altitude the calculated ionospheric density is 1.2×10^{-2} cm^{-3}, with a flow velocity of 4–7 km s^{-1}. The corresponding energy density is 2.5×10^{-13} erg cm^{-3}. Flow under these quiescent conditions exists approximately one third of the time in the geotail. During other times when cross-tail electric fields are present, the steady flow away from the Moon is disrupted by drift velocity components perpendicular to the geomagnetic field lines; also, sporadic occurrences of plasma sheet or lobe plasma temporarily dominate the plasma environment during nonquiescent times. The electromagnetic properties of the quiescent ionosphere are investigated, and it is concluded that plasma effects on lunar induction studies can be neglected for quiescent conditions in the geomagnetic tail lobes.

Goldstein, B. E. (Jet Propulsion Laboratory, Pasadena, CA 91103): 'Solar Wind Interaction With the Moon: Boundary Conditions and Global Solutions', *EOS: Trans. Amer. Geophys. Union* **58**, 1179. (1977)

The problem of the solar wind interactions with the Moon has been treated using MHD theory; however, the solution in the interior of the Moon and the plasma cavity has not been obtained by matching boundary conditions. The Moon is an absorber of plasma particles; consequently, rare-fraction waves will be attached to the lunar surface forward of the terminator where the Mach cone is tangent to the surface. The rarefraction waves cause a convection of flux into the Moon in the vicinity of the terminators by bending of flow lines toward the Moon. The solution in the lunar interior can then be obtained by matching external conditions through boundary layers. Within an ion gyroradius of the lunar surface and near the terminators, decoupling of proton velocity from magnetic flux convection will create additional fields; solutions using ion inertial terms in Ohm's law are required for this boundary layer. Beneath the ion inertial layer is an electron inertial layer that will contain substantial fields due to electron pressure but with almost no external field leakage. Sonett and Wiskerchen have reported increased east–west magnetic fluctuations for low frequencies at the Apollo 12 site which they attribute to fringing fields; in the model discussed here the fringing field is attributed to currents flowing around the lunar limb. For the case of aligned magnetic field and velocity vectors, an important component of the interior solution will be a quadrupole with similar alignment to match the bending of field lines inward towards the terminator.

Manka, R. H. (NOAA Space Environment Lab., Boulder, CO & Dept. of Space Physics & Astronomy, Rice University, Houston, TX 77001), Michel, F. C., Freeman, J. W., Benson, J. L., and Reiff, P. H.: 'Non-Magnetospheric Solar Wind Interaction: The Moon', *EOS: Trans. Amer. Geophys. Union* **58**, 756. (1977)

The interaction between the solar wind and a planetary body which does not have a magnetosphere, or relatively dense atmosphere, is illustrated by the case of the Moon where the solar wind plasma and fields can interpenetrate the lunar atmosphere and ionosphere and flow to the surface.

This interaction results in several basic characteristics of the lunar potential, atmosphere, and ionosphere:

– The dynamics of the lunar ionosphere is controlled by fields in the solar wind and at the lunar surface. The ionosphere is not in stationary, thermal equilibrium but is strongly accelerated along the interplanetary electric field.

– These ion trajectories result in escape from the Moon, or impact on the lunar surface and intermixing with solar wind isotopes in the lunar soil grains.

– In contrast with the Earth, the electric surface potential around the body of the Moon is highly asymetric, and varies with time and orbital position.

– Anomalies in the lunar plasma and potential have been observed by the Rice Suprathermal Ion Detector. Recent results imply large screening lengths and possibly heated solar wind in the vicinity of the terminator. Also, numerous night-side lunar ion fluxes are observed which may originate from several possible sources, including acceleration of dayside ions over the lunar poles.

Several of the above characteristics will be discussed.

Shemansky, D. E. (University of Michigan, Ann Arbor, Michigan 48109) and Broadfoot, A. L.: 'Interaction of the Surfaces of the Moon and Mercury with Their Exospheric Atmospheres', *Rev. Geophys. Space Phys.* **15**, 491–499. (1977)

The atmospheres of the Moon and Mercury are controlled entirely by gas atom–surface interaction. Model calculations describing the steady state atmospheres have all been based on the assumption that the atmospheric particle source is a 'saturated' adsorbed surface layer of gas. We suggest that this is in disagreement with what is known of the physics of gas-surface interaction. On the assumption that interaction is with solid atoms bound in a lattice structure, most collisions with the light atmospheric particles are free-free, not free-bound. The observational and theoretical evidence indicates that energy accommodation per collision for He and H on the Moon and Mercury is dominated by first-order interaction terms and is generally less than 0.1 per collision. As a result, estimated thermal escape is drastically reduced for the light atoms on both bodies. We consequently require much reduced solar wind collection efficiencies for protons and α particles. It is suggested that some peculiarities observed in the Mercury He and H atmospheres could be explained by the nature of the gas-surface coupling. The formation of H_2 may not be efficient as a surface or subsurface phenomenon, and the H/H_2 atmospheric ratio may be large.

Switkowski, Z. E. (The Niels Bohr Institute, DK-2100 Copenhagen, Denmark), Haff, P. K., Tombrello, T. A., and Burnett, D. S.: 'Mass Fractionation of the Lunar Surface by Solar Wind Sputtering', *J. Geophys. Res.* **82**, 3797–3804. (1977)

The sputtering of the lunar surface by the solar wind is examined as a possible mechanism of mass fractionation. Simple arguments based on current theories of sputtering and the ballistics of the sputtered atoms suggest that most ejected atoms will have sufficiently high energy to escape lunar gravity. However, the fraction of atoms which falls back to the surface is enriched in the heavier atomic components in relation to the lighter ones. This material is incorporated into the heavily radiation-damaged outer surfaces of grains, where it is subject to resputtering. Calculations predict that an equilibrium surface layer, enriched in heavier atoms, will form with $\delta(^{18}O) \approx +20‰ \approx \delta(^{30}Si)$ and that oxygen will be depleted on the surface layers of grains relative to the bulk composition by about 12.5%. These results are in fair agreement with experiment. The dependence of the calculated results upon the energy spectrum of sputtered particles is investigated. We conclude that mass fractionation by solar wind sputtering is likely to be an important phenomenon on the lunar surface but that the complex isotopic variations observed in lunar soils cannot be completely explained by this mechanism.

Vanyan, L. L. (Soviet Geophysical Committee, Moscow, U.S.S.R.): 'The Interaction of the Solar Wind with Lunar Magnetic Anomalies', *The Moon* **16**, 321–324. (1977)

A simplified model for the interaction of the cold solar wind with lunar magnetic anomalies is considered. Since on the illuminated side of the Moon the dynamic pressure of the solar wind significantly exceeds the magnetic pressure of the anomalies, upward propagation of the lunar field is possible only by means of diffusion. This process does not depend on the velocity but only on the concentration of the solar wind and the characteristic size of anomalies. Theoretical calculations are compared with the data of Apollo 12 and Explorer 35.

8. Exploration and Utilization of the Moon. (Space Colonization)

Burke, J. D. (Jet Propulsion Laboratory, Pasadena, CA 91103): 'Where Do We Locate the Moon Base', *Spaceflight* **19**, 363–366. (1977)

Because of their local environments, permitting continuous solar energy capture and adjacent cryogenic temperature, the Moon's polar regions may be the preferred sites for early human occupation and use of the Moon. If permafrost exists in the polar shaded regions this preference will become dominant. Though not ideal from the standpoint of all-sky coverage for astrophysical observations, and also possibly subject to terminator-plane particle hazes near the surface, polar sites (and especially the south polar region) may yet offer enough advantages, including constant cryogenic telescope environments and unlimited tracking time, to be preferred sites for the first lunar observatories.

Therefore it is important to investigate these regions, first from orbit and then with automated mobile equipment on the surface, to gain the needed knowledge for decisions as to the best course to take in planning the first human settlements on the Moon.

9. General Reviews on Lunar Studies

Burke, J. D. (Jet Propulsion Laboratory, Pasadena, CA 91103): 'Lunar Polar Orbiter: A Global Survey of the Moon', *Acta Astronautica* **4**, 907–920. (1977)

Lunar data from previous automated and manned exploratory missions have now been analyzed to the point where it is possible to define objectives for new missions to the Moon. The most logical next step is a polar orbiter designed to measure the Moon's gravity field, figure, heat flow, magnetism and surface composition. NASA has commissioned a study of this mission at JPL with participation by lunar scientists from JSC, and also has tentatively selected a group of investigators who constitute a Science Working Team. This paper describes the mission objectives and reports progress in the mission-definition study. As presently, visualized, the orbiter will be launched by a Delta vehicle in 1980. After insertion into an eccentric, polar lunar orbit it will deploy a small, spinning subsatellite whose purpose is to relay precise radio Doppler measurements from the orbiter on the Moon's far side.

After subsatellite delivery, the orbiter will maneuver into a low, circular polar orbit whence the instrument fields of view will be continuously pointed to the nadir for a nominal mission time of one year. Tracking and data acquisition will be via 26 m ground antennas and the JPL Mission Control and Computing Center, with distributed computing elements used in both flight and ground systems to simplify the data interfaces. Significant design advances are intended to include: (1) all systems designed to cost, (2) advanced scientific sensors aboard the spacecraft, (3) ground operations systems designed for largely automated, routine operation, and (4) design and operations concepts applicable to a variety of low-cost orbital missions in the Solar System.

Byers, B. K. (History Office, NASA/Headquarters, Washington, D.C. 20546): 'Destination Moon: A History of the Lunar Orbiter Program', NASA-TM-X-3487, 418 pp. (1977) Available from National Technical Information Service as *N77-23139* $11.00

This publication documents the origins of the Lunar Orbiter Program and records the activities of the missions then in progress. It covers the period 1963–1970 when Lunar Orbiters were providing the Apollo program with photographic and selenodetic data for evaluating proposed astronaut landing sites.

Forbes, G. B. (Millikin University, Decatur, IL 62522) and Lebo, G. R., Jr.: 'Antisocial Behavior and Lunar Activity: A Failure to Validate the Lunacy Myth', *Psychol. Repts* **40**, 1309–1310. (1977)

Police arrest records were studied to determine relationships between lunar activity and arrest rates for various classes of crimes. The data studied represented 7 yr of police activity, and no relationship was found between lunar activity and total arrests, violence against persons, or public intoxication.

Gevers, W.: 'Biological Moon-Landing', Abstract. *South African Medical J.* **52**, 209. (1977)

Head, J. W. (Dept. of Geology, Brown University, Providence, Rhode Island 01912): 'Significant Achievements in the Planetary Geology Program 1975–1976', NASA-CR-2827, 36 pp. (1977) Available from National Technical Information Service as *N77-19972*

Recent developments in planetology research as reported at the 1976 NASA Planetology Program Principal Investigators meeting are summarized. Important developments are summarized in topics ranging from solar system evolution, comparative planetology, and geologic processes, to techniques and instrument development for future exploration.

Krugman, H. E.: 'Public Attitudes toward the Apollo Space Program, 1965–1975', *J. Communication* **27**, 87–93. (1977)

The data for this study are based on 31 national telephone surveys conducted between 1965 and 1975. During the ten-year period the public increasingly favored less government activity in the area of space exploration. After the success of the first lunar landing, public opposition to the Apollo program increased because "there was nothing more to be done". In general, it was the opponents rather than the proponents of the Apollo program who were most affected by the success of the program.

Minear, J. W. (NASA/Johnson Space Center, Houston, TX 77058): 'Moon 1977 – Our Geophysical Prospectus', *Geophysics* **42**, 1102. (1977)

Apollo lunar surface experiment packages (ALSEP's) and orbital experiments carried out on Apollo missions 15, 16 and 17 have played a major role in developing our present understanding of the Moon. The first of five ALSEP's was deployed on the lunar surface in November 1969; instruments are still operating and returning useful data at all five ALSEP locations. Twenty-two surface and 13 orbital experiments have been performed. These have included both active and passive seismic investigations of structure and moon quakes, magnetic and gravity field mapping, magnetic sounding, heat-flow measurements, geochemical mapping, laser ranging, radar, altimetry, and solar wind particle interactions with the Moon.

The ALSEP and orbital data form a complimentary set to the moon rock samples and photographic data; each set having a unique and essential input to understanding Earth's Moon. Synthesis of these combined data have yielded a first-order understanding of the Moon as a differentiated planetary object. Elements of this understanding include:

(1) An estimate of the interior structure with a crust and possible iron-rich core. (2) a lithosphere some 600 km thick. (3) a deep interior that may be partially molten, (4) the existence of surface magnetic fields, (5) very low tectonic and igneous activity at present, (6) surface heat flow about half that of Earth, and (7) models of lunar thermal evolution.

The Moon can now be viewed as a representative of a large class of planetary objects that include Mercury, the inter satellites of Jupiter, the larger asteroids and the largest moon in the solar system, Titan. Future lunar missions are presently seen in the context of man's presence on the Moon either as a base for exploration or lunar material utilization.

Mitroff, I. I. (University of Pittsburgh, Pittsburgh, PA 15213) and Fitzgerald, I.: 'On the Psychology of the Apollo Moon Scientists: A Chapter in the Psychology of Science', *Human Relations* **30**, 657–674. (1977)

This paper describes a follow-up study of a 4-year investigation of the scientific attitudes and personalities of a select sample of the Apollo moon scientists. Semantic differentials for the purpose of eliciting the structure of scientific roles and personalities were administered. Also administered were the Leary Adjective Check List and Rotter Incomplete Sentence Blank. The results show not only that there are strong and sharp differences among a small number of different scientific 'types,' but also that scientists are affectively involved with their work to a high degree. The results of the study lend support to some of Abraham Maslow's provocative ideas regarding the psychology of science.

No Author Cited: 'Some Astrophotos to Enjoy', *Sky Telesc.* **54**, 283–287. (1977)

Potentialities of lunar photography with small size telescopes are presented.

Woods, D. R.: 'Lunar mission Cosmos Satellites', *Spaceflight* **19**, 381–388. (1977)

At the IAF Congress in 1963 the late Yuri Gagarin said moonflight techniques being worked out in his country involved the assembly and re-fuelling of spacecraft in orbit. How far did the Russians get with their plans? This article examines the characteristics of four Cosmos spacecraft launched in 1970–71 which could hold vital clues. They are still circling the Earth.

No Author Cited: 'Science Packages on Moon Shut Down', *Science News* **112**, 213. (1977)

The arrays of ALSEPs left on the Moon by Apollo astronauts were shut down in September 1977. Although the scientific instruments have been turned off, the transmitters are being kept on so that scientists from JPL can use the inmodulated carrier waves for geodetic and astrometric studies and spacecraft navigation checks.