BIBLIOGRAPHY

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(Articles in journals received in LSI Library January 1, 1976 to April 30, 1976)

1. Motion of the Moon and Dynamics of the Earth-Moon Systems; Shape and Gravity Field of the Moon

Moesgaard, K. P. (History of Science Dept., Univ. of Aarhus, Ny Munkegade, DK-8000 Arhus C, Denmark): 'Elements of Planetary, Lunar, and Solar Orbits, 1900 B.C. to A.D. 1900, Tabulated for Historical Use', *Centaurus* **19**, 157–181. (1975)

Ashbrook, J.: 'November's Lunar Eclipse: An Analysis', *Sky Telescope* **51**, 76–90. (1976)

A summary of special observations performed during the November 1975 lunar eclipse is presented.

Bender, P. L. (National Bureau of Standards and Univ. of Colorado, Boulder, Colo. 80302) and Silverberg, E. C.: 'Present Tectonic-Plate Motions from Lunar Ranging', *Tectonophysics* **29**, 1–7. (1975)

Measurements to determine the motion of the Pacific Plate with respect to North America are planned to start within a few months. The University of Hawaii Lunar Ranging Station on Maui is expected to begin operating, and to achieve an accuracy of 2 or 3 cm soon for a single run. The University of Texas McDonald Observatory has been achieving an accuracy of 8–15 cm on a routine basis since late 1971. Work on further improving the McDonald accuracy is planned. Using data from many runs, an accuracy of 1 cm/yr is expected for the relative motion within the first few years.

A transportable lunar-ranging station has been proposed which could be constructed in about eighteen months. The station could observe for 3–6 weeks at a chosen site, and determine the location of the site with respect to the fixed lunar-ranging stations. The accuracy expected as 1–3 cm in each coordinate. If approved, a possible initial itinerary for the station might be as follows: (a) two or three sites in California, including Goldstone, plus one site in Utah; (b) sites in Baja California and Mexico, plus several others in the U.S.; (c) several sites in Central America, the Caribbean, and South America; (d) repeat measurements in California, Utah, and Baja California, plus initial measurements at sites in Africa, India, and the Pacific. It is expected that data on plate motions also will become available from satellite range measurements and VLBI.

Bowin, C. (Woods Hole Oceanographic Institution, Woods Hole, Mass. 02543), Simon, B., and Wollenhaupt, W. R.: 'Mascons: A Two-Body Solution', *J. Geophys. Res.* **80**, 4947–4955. (1975)

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Almost all of the mass distributions that have been proposed to account for the large positive gravity anomalies associated with lunar mascons have assumed single-body sources of a mass excess. In the case of mare fill with a reasonable density contrast ($+0.5$ g/cm^{-3}) with crustal material, a fill thickness of about 16 km for Mare Serenitatis is thus required to account for the observed gravity values at 100-km height. Such a great thickness would require a 16-km-deep hole prior to filling, and such a topographic depression is inconsistent with the depths of the topography of the Mare Nectaris and Mare Oriental basins, which have little fill, and with estimates of mare thicknesses based on buried crater dimensions. A two-body mascon solution, however, requires only about a 2-km thickness of fill and a 12-km rise of a lunar Moho beneath Mare Serenitatis to account for observed gravity anomalies. The mantle dome results from an uprising of mantle material beneath the mare basin, bringing the impact crater to near isostatic equilibrium. Two kilometers of fill is inferred to have accumulated later, when the crust became rigid enough to sustain the load. Together the fill and the dome account (at about 20% and 80%, respectively) for the magnitude of the observed mascon anomalies. This type of two-body solution can account for greater magnitude mascon gravity anomalies by proportional increases in the fill thickness. The top of the mantle dome or plug is placed at 60-km depth to match observed seismic velocity structure. This mascon structure has an anomalous gravity field that is in agreement with the maximum magnitude of anomalies observed at several heights above Mare Serenitatis. The thickness of fill would be greater if the basin floor had subsided under the load of early fill material.

Burša, M. (Astronomical Institute of the Czechoslovak Academy of Sciences, Praha): 'Deflections of the Vertical at Lunar Mascons', *Bull. Astron. Inst. Czech.* **26**, 346–350. (1975)

The lunar mascons Mare Imbrium, Mare Serenitatis, Mare Orientale (Montes Cordillera) are interpreted masswise on the basis of the deflections of the vertical, using the latest data (Michael and Blackshear, 1972). The theory for determining the depth of the centre of gravity and the mass of the mascons has been elaborated for a spherical Moon. The results are compared with (Burša, 1972), in which data from (Micheal *et al.*, 1969) was used and the elementary theory for a planar field applied.

Calame, O. (Ctr. Etud. Rech. Geodynam. and Astronomiques, 06130 Grasse, France): 'Determination of Moon Free Liberations from Laser Range Measurements', *Compt. Rend. Hebdomadaires Séances Acad. Sci. Ser.* **282**, 133–135. (1976)

Le problème de l'existence d'oscillations «libres», dans le mouvement de rotation de la Lune autour de son centre de masse, a fait l'objet, jusqu'à présent, de nombreuses controverses. Cinq années de mesures de distances lunaires par laser ont désormais rendu possible la mise en évidence de telles librations, avec une détermination quantitative de leurs amplitudes et de leurs phases, pour les trois modes d'oscillation, de période respective 2,9 ans, 27,3 jours et 75 ans, le premier agissant en longitude et les deux autres en latitude.

Forga, R. (Observatoire de Paris, 61, Avenue de l'Observatoire, 75014 Paris): 'Artificial Lunar Satellite', *Astron. Astrophys.* **44**, 25–29. (1975)

In the second part of this paper (Forga, 1973), the system (I) supplies the equations of motion. The components $\partial\Omega_1/\partial s$ and $\partial\Omega_1/\partial u$, second member of these equations, hold z in their expression. z may be replaced by a second approximation value, obtained from the z equation with a second member: this value is substituted in the components $\partial\Omega_1/\partial s$ and $\partial\Omega_1/\partial u$.

Gupta, J. C. (Div. of Geomagnetism, Dept. of Energy, Mines and Resources, Ottawa, Canada): 'Lunar Daily Distance Numbers D and D'', *The Moon* **14**, 247–253. (1975)

In analyses of the effect of variation of the Earth-Moon distance on geophysical phenomena, it is customary to arrange the geophysical data according to the dates of apogee and perigee. However, lunar distances at apogee and especially at perigee vary within wide limits from month to month. A new daily index D' of lunar distance is defined to permit a more precise determination of effects related to lunar distance. It is readily calculated by a computer program.

Hartung, J. B. (Dept. of Earth and Space Sci., State University of New York at Stony Brook, Stony Brook, N.Y. 11794): 'On the Asymmetric Distribution of Lunar Maria', *EOS: Trans. Am. Geophys. Union* **57**, 272. (1976)

The asymmetric distribution of maria over the lunar surface may be the result of the asymmetric character of the gravitational field near the Moon. The gravitational potential field near the Moon's surface due to the masses of the Earth and Moon is obtained from an analysis of the restricted three-body problem. An equipotential surface with approximately the same volume as the Moon is distorted, relative to a presumed spherical Moon, such that the equipotential surface lies outside the Moon on its Earth-facing side and inside the Moon on its back side. The distortion is negligible at the present Earth-Moon distance, but would have been significant earlier in the history of the Earth-Moon system when the two bodies were closer together. Any mare basalt magma forced to the surface would find a slightly easier path on the Earth-facing side than at any other place on the Moon. This advantage would lead to a concentration of more basalt flows onto the surface on the Moon's Earth-facing side.

If sub-surface communication of mare basalt magma existed over long distances horizontally, than a net flow of material from the far to the near side of the Moon could have occurred and thereby caused the earthward offset of the center of mass from the center of figure of the Moon. To explain a 2-km center-of-mass offset requires approximately moving a mass equivalent to the volume of all maria a distance equal to the diameter of the Moon. This would be a difficult task for the mechanism suggested, but would be easier if present estimates of the center-of-mass offset are too high and the maria volumes are too low. This approach avoids the need to explain an asymmetric distribution of lunar crust thicknesses.

Kolaczek, B. (Warsaw Polytechnic University) and Rogowski, E.: 'Determination of Selenographic Coordinates and Rotational Parameters of the Moon by Measuring Zenith Distances from Its Surface', *Soviet Astron.* **19**, 525–529. (1976)

A theoretical analysis is given of possible methods for determining selenographic coordinates and the parameters of the Moon's rotational motion from stellar zenith-distance measurements made directly on the lunar surface. Theories are described for astrometric observations of the zenith distances of stars in the local meridian and for observations at arbitrary azimuths. Although there are several advantages in meridional observations, the clock correction cannot be established. Measurements at arbitrary azimuths are free of this shortcoming; observations of high-declination stars at both elongations would then be of special interest. Appropriate observing programs are recommended.

Kuckes, A. F. (NASA-Goddard Space Flight Center, Lab. for Extraterrestrial Physics, Greenbelt, M.D. 20771): 'Strength and Rigidity of the Lunar Crust and the Implications for Present Day Mantle Convection in the Moon', *EOS: Trans. Am. Geophys. Union* **57**, 272. (1976)

The lunar gravity field is analysed in the context of crustal flexure theory and the results are compared to pertinent terrestrial parameters. Lunar mascon data imply a crustal flexure length of 180–270 km, an elastic lithospheric thickness of 50–90 km and maximum stress of 1 kbar for their support over a plastic lunar interior. Terrestrially such stress magnitudes are maintained for at least 5×10^7 yr. The spatial spectrum of lunar gravity fluctuations indicates a similar flexure length as derived from mascon data. The overall non-equilibrium figure of the Moon can be maintained by stresses of 1 kbar in a 100 km thick elastic shell. The magnitude of the lunar quadrupole moment is in accord with the magnitude of the forces driving mantle convection in the Earth. The membrane stress parameter $\rho g r^2/Et$ (E-Youngs modulus, t crustal thickness) is 250 times larger for the Earth than for the Moon. Thus, the long term structural integrity of the lunar surface vis a vis convectively induced fracture into plates is reasonable.

Lidov, M. L., Lyakhova, V. A., and Solov'iev, A. A.: 'Semianalytical Calculation of the Motion of an Artificial Satellite of the Moon', *Cosmic Res.* **13**, 249–274. (1975)

Perturbation theory is used to develop a semianalytical method of calculating the motion of an artificial satellite of the Moon; it enables one to take into account the influence of arbitrarily many harmonics in the expansion of the Moon's potential in a series in spherical functions. The method is suitable for calculating orbits with almost any parameters. Special procedures which enable one to simplify the evaluation and implementation of such a method of calculations on a computer are described and tested. The algorithm is realized in the form of an Algol program and is tested in practice. Estimates are made of the speed and accuracy in the calculation of the satellite coordinates.

Mulholland, J. D. (McDonald Observatory and Dept. of Astronomy, Univ. of Texas at Austin, Austin, Texas 78712), Shelus, P. J., and Silverberg, E. C.: 'Laser Observations of the Moon: Normal Points for 1973', *Astron. J.* **80**, 1087–1093. (1975)

McDonald Observatory lunar laser ranging observations for 1973 are presented in the form of compressed normal points and amendments for the 1969–1972 data set are given. Observations of the reflector mounted on the Soviet roving vehicle Lunakhod 2 have also been included.

Peale, S. J. (Dept. of Physics, University of California, Santa Barbara, Calif. 93106): 'Dynamical Consequences of Meteorite Impacts on the Moon', *J. Geophys. Res.* **80**, 4939–4946. (1975)

The magnitudes of the excitation of free precession of the lunar spin axis about the position defined by Cassini's laws, free libration in longitude, and free wobble are determined as a function of meteorite angular momentum relative to the lunar center of mass and the position of impact on the lunar surface. Angular momentum conservation suffices for the estimates of precession and libration excitation, but a cratering model for the ejecta distribution is necessary for the estimate of the wobble excitation. The simultaneous excitation of free wobble is always associated with the excitation of precession, and the angular amplitude is at least comparable to but may exceed that of the induced precession by a factor of 3 or 4. It is possible to excite a free libration in longitude with no first-order excitation of free wobble, but generally, all three free motions are excited simultaneously. The induced libration will nearly always have by far the largest amplitude, however. For crater sizes scaled as powers of the impact energy, impacts leaving craters as small as a few kilometers in diameter can excite free motions which will ultimately be observable by the lunar laser ranging experiment.

Shapiro, I. I. (MIT, Cambridge, Mass. 02139), Counselman, C. C., III, and King, R. W.: 'Verification of the Principle of Equivalence for Massive Bodies', *Phys. Rev. Lett.* **36**, 555–558. (1976)

Analysis of 1389 measurements, accumulated between 1970 and 1974, of echo delays of laser signals transmitted from Earth and reflected from cube corners on the Moon shows gravitational binding energy to contribute equally to Earth's inertial and passive gravitational masses to within the estimated uncertainty of 1.5%. The corresponding restriction on the Eddington–Robertson parameters is $4\beta - \gamma - 3 = -0.001 \pm 0.015$. Combination with other results, as if independent, yields $\beta = 1.003 \pm 0.005$ and $\gamma = 1.008 \pm 0.008$, in accord with general relativity.

Smith, J. (Geophysics Dept., Penn. State Univ., College Park, Penn.) and Sjogren, W. L.: 'Lunar Gravity Models: Mare Crisium', *EOS: Trans. Am. Geophys. Union* **57**, 271. (1976)

A newly developed computer program which incorporates many old techniques, is used to estimate much more realistic models than we previously have presented. Such things as (1) curved surface disks that follow the lunar curvature rather than flat slabs normal to the radius at their centers, (2) multi arcs of data at different altitudes rather than one profile, (3) constraints on parameters so very unique distributions can be preserved and (4) complete statistics on solutions have been incorporated. Various density distribution for Mare Crisium have been tested and their parameters optimized to best fit existing gravity profiles. Results show that depth is still a very difficult if not impossible parameter to separate from the mass estimate and that near surface distributions still provide some of the better solutions.

Tapley, B. D. (Dept. of Aerospace Engineering and Engineering Mechanics, The University of Texas at Austin, Austin, Tex. 78712) and Schutz, B. E.: 'Estimation of Unmodeled Forces on a Lunar Satellite', *Celes. Mech.* **12**, 409–424. (1975)

In previous investigations, a procedure for sequentially estimating the state of a lunar orbiting space vehicle acted upon by unmodeled terms in the lunar potential has been developed. Results obtained by processing tracking data from the Apollo 10 and 11 missions indicate that the algorithm provides more precise estimates of the vehicle state than conventional orbit determination procedures and, hence, provides an accurate input for navigation purposes. The question of the agreement of the estimates with the actual unmodeled accelerations has not been established.

This investigation considers the question of the accuracy with which the algorithm can estimate the acceleration due to unmodeled lunar surface mascons. It is shown that an accurate estimate of the time history of the unmodeled acceleration can be obtained. The investigation also considers the effects of the magnitude and location of the mascons, as well as the effect of the observation accuracy.

Williams, J. G. (Jet Propulsion Lab., Pasadena, Calif. 91103), Dicke, R. H., Bender, P. L., Alley, A., Alley, C. O., Carter, W. E., Currie, D. G., Eckhardt, D. H., Faller, J. E., Kaula, W. M., Mulholland, J. D., Plotkin, H. H., Poultney, S. K., Shelus, P. J., Silverberg, E. C., Sinclair, W. S., Slade, M. A., and Wilkinson, D. T.: 'New Test of the Equivalence Principle from Lunar Laser Ranging', *Phys. Rev. Lett.* **36**, 551–554. (1976)

An analysis of six years of lunar-laser-ranging data gives a zero amplitude for the Nordtvedt term in the Earth-Moon distance yielding the Nordtvedt parameter $\eta = 0.00 \pm 0.03$. Thus, Earth's gravitational self-energy contributes equally, $\pm 3\%$, to its inertial mass and passive gravitational mass. At the 70% confidence level this result is only consistent with the Brans-Dicke theory for $\omega > 29$. We obtain $|\beta - 1| \lesssim 0.02$ to 0.05 for five-parameter parametrized post-Newtonian theories of gravitation with energy-momentum conservation, or $|\beta - 1| \lesssim 0.01$ if only β and γ are considered.

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

Dainty, A. M. (Dept. of Earth and Planet. Sci., MIT, Cambridge, Mass. 02139), Goins, N. R., and Toksöz, M. N.: 'Physical State and Structure of the Moon from Seismic Observation', *EOS: Trans. Am. Geophys. Union* **57**, 272. (1976)

Data from the seismometers of the Apollo passive Seismic Experiment are being used to find the Q structure and velocity structure of the Moon. To determine Q, the spectral ratio of short-period records from the same event recorded at two different stations is used, the first minute immediately after P being used. We find that Q is about 5000 for P waves above 500 km depth, indicative of dry subsolidus conditions. Below 600 km to a depth of at least 1200 km, Q is 1000–1500 for P waves, probably due to the presence of a very small amount of partial melt. There is a transition zone from 500 to 600 km depth. To determine velocity structure more accurately than before, we have been using a polarization filter on 3 component long-period records in an attempt to find later phases. Deep reflections have been tentatively identified, and the implications of these and other phases that may be identified will be discussed.

Goins, N. R. (Dept. of Earth and Planet. Sci., MIT, Cambridge, Mass. 02139), Cheng, C. H., and Toksöz, M. N.: 'Deep Moonquake Polarity Reversals and Tidal Stress in the Moon', *EOS: Trans. Am. Geophys. Union* **57**, 272. (1976)

We have found that several recent A1 moonquakes are reverse polarized with respect to the earlier events. In each case, this reversal is seen on the records from all available stations. At least 2 stations were available for each event. At each station, both the *P* and *S* wave trains on all available components are consistently reversed, and the *P* to *S* amplitude ratios are nearly the same as in the unreversed case. These reversals have been confirmed both by eye and by cross-correlation functions, where the maximum negative cross-correlation coefficient reaches −0.75. All of these reversed events have occurred since the A1 focus reached a minimum of activity, in both number of events and event magnitude, during 1972. To date, no A1 events occurring after this activity minimum have been observed to be normally polarized. This indicates that there is a correlation between the polarity of the events and the activity of the A1 focus. The activity minimum itself has been previously interpreted as being part of a six-year cycle related to the slight difference between the lengths of the anomalistic and nodical months. The reversal itself indicates some sort of shift in moonquake source, either a rotation of the focal mechanism or a complete reversal of the focal motion. This in turn suggests a change in the stress pattern causing the moonquakes. Because of the correlation between these reversals and the orbital periods, it is most likely that the tidal stress field is shifting. If the tidal stress acts as a trigger for the moonquakes, a shift in this triggering force could permit the ambient stress field to release in a different manner at the A1 focus, producing the reversal. Thus, the polarity reversals seen at the A1 focus are an important constraint on moonquake focus processes and lunar stress patterns.

Hsui, A. T. (Dept. of Earth and Planet. Sci., MIT, Cambridge, Mass. 02139), Toksöz, M. N., and Johnston, D. H.: 'Thermal Evolutions of the Moon, Mercury and Mars', *EOS: Trans. Am. Geophys. Union* **57**, 271. (1976)

The evolution of planetary interiors and surface features is strongly dependent on the thermal regime of the planet. Theoretical thermal models may be constructed from solutions of the heat conduction equation or with simulated convection. In this paper, the effects of actual convection (in both the partially molten and solid states) upon thermal evolutions of planetary bodies are studied. Since the mode and strength of convection are controlled by the size of the body, only the small planets (the Moon, Mercury and Mars) are being investigated. Effects of core separation and heat source differentiation are incorporated. All thermal models presented satisfy known geological and geophysical constraints. The results indicate that differentiation is completed very early in the planetary histories. At the present, the Moon has a thick lithosphere (~500 km). The interior of the Moon is at about 1200°C. A thermal convective region exists at about 700 km depth and extends to the center. Because of the high magnetic field around Mercury detected by the Mariner 10 mission, many models have been proposed to maintain a presently molten iron core within that planet. Our model favors a solid mantle at the present. Mars is relatively young geologically. Its lithosphere is thinner than that of Mercury and the Moon and partial melt regions may exist in the upper mantle. Since all the planets are formed hot or heated early in their history, there are more convective cells to transport the heat. As a planet cools in time, the convective region shrinks towards the center.

Jarosch, H. (Lunar Science Inst., 3303 Nasa Rd. 1, Houston, Tex. 77058): 'A New Look at the Lunar Seismic Data', *EOS: Trans. Am. Geophys. Union* **57**, 282. (1976)

After making a survey of what has been achieved from the lunar seismic data, a suite of interactive computer programs was prepared for the L.S.I. PDP 11/45 in order to make a new attack on the seismic data. As a start, the body-wave data was chosen. The method tried was to use a non-linear filter to produce product motion seismograms since this was already used successfully by Rolf Meissner and his colleagues. Care was taken in order to produce sharper late arrivals. This approach has been applied to date only to the man-made impacts. The analysis was carried out on long-period components and this meant that the LM impacts at distances of 770 kms and over were not detected. Assuming that the scattering of the data is mainly due to Rayleigh-wave scattering which is elliptically polarized, this method which depends on linear polarization of the signal has a better chance of succeeding. Having obtained a set of arrival times for the different events, it was necessary to collect up arrival times belonging to the same phase. Since some of the noise is also linearly polarized, it is possible to produce false alarms which must then be eliminated.

Mark, N. (Hawaii Institute of Geophysics, University of Hawaii, Honolulu 96822) and Sutton, G. H.: 'Lunar Shear Velocity Structure at Apollo Sites 12, 14, and 15', *J. Geophys. Res.* **80**, 4932–4938. (1975)

Spectral amplitude ratios of horizontal-to-vertical motion produced on seismographs of Apollo 12, 14, and 15 lunar impacts of meteoroids, the Apollo 14 and 15 lunar modules, and the Apollo 15 S4B, show consistent differences among the recording sites. On the assumption that the motion in the portions of the records chosen for analysis (near maximum amplitude) represents predominantly fundamental mode Rayleigh waves and that the compressional wave velocity structure is similar to that derived in other investigations involving the Apollo active and passive seismic experiments and in view of estimates of elastic properties of the surface derived from Surveyor spacecraft landings, estimates are made of the shear wave velocity structure under the three sites. Near-surface velocities are about 35 m s^{-1} at the three sites. The results for site 14 indicate an increase to about 100 m s^{-1} near 8-m depth and to 200 m s^{-1} at 38-m depth. Results for sites 12 and 15, although they differ in detail, show a smoother gradient and generally a greater velocity at a given depth than that indicated at site 14, reaching velocities of about 400 m s^{-1} near 120-m depth. If the assumed *P* velocity structures are correct and if changes in *S* velocity coincide with changes in *P* velocity, then V_p/V_s decreases from 2.9 to 2.0 in the upper 19 m at site 12, in the upper 38 m at site 14, and in the upper 21 m at site 15.

Morgeli, M., Eberhardt, P., Eugster, O., Geiss, J., and Grogler, N.: 'Analysis of Fission Xenon in Lunar Rocks to Determine Early History of Moon', (Abstract), *Helvetica Phys. Acta* **48**, 493–494. (1975)

Informationen über die Frühgeschichte des Mondes in der Zeitspanne zwischen dem Ende der Kernsynthese und der Verfestigung der Mondkruste können durch das Studium der Edelgastochterprodukte von heute zerfallenen radioaktiven Isotopen (Pu^{244}, I^{129}) erhalten werden. Wir haben in der Apollo-14-Breckzie 14305 eine Fission-komponente nachgewiesen, die vermutlich dem Zerfall von Pu^{244} (Halbwertszeit 82 Millionen Jahre) zugeschrieben werden muss. Die Breckzie wurde in mehrere Strukturelemente aufgeteilt, um festzustellen, ob ein Teil des Gesteinsmaterials zur Zeit der Bildung des Mondes entstand und somit das Fission Xe 'in situ' speichern konnte, ober ob andere Einbaumechanismen für das Fission Xe verantwortlich waren. Die Ergebnisse der ersten Analysen sollen diskutiert werden.

(Forschung unterstützt durch den Schweizerischen Nationalfonds.)

Nakamura, Y. (Univ. of Texas, Marine Sci. Inst., Geophysics Lab., Galveston, Tex. 77550), Latham, G. V., and Dorman, H. J.: 'Structure and State of the Lunar Interior Inferred from Seismic Data', *EOS: Trans. Am. Geophys. Union* **57**, 272. (1976)

The interior of the Moon derived from travel times and amplitude variations of seismic waves and relative arrival times of *P* and *S* waves from artificial and natural sources has the following characteristics: (1) The uppermost 300 km zone is well below the solidus, as indicated by a normal Poisson's ratio of 0.250 ± 0.025 and a high *Q* of about 4000. This zone is divided into two layers of distinct velocity contrast, the crust and the upper mantle, probably because of early differentiation. Possible shallow moonquakes occur in the upper part of this zone, indicating release of accumulated strain energy. This activity is very weak compared with the Earth and is not concentrated in narrow belts like earth-quake belts. A negative shear-velocity gradient of 0.0013 (km s^{-1}) km^{-1} in the upper mantle is inferred, suggesting a relatively high temperature gradient. (2) The zone between 300 and 900 km depths is rather unusual. Shear-wave velocity decreases rapidly near the top of this zone, reaching the critical gradient at about 400 km depth. The lower part of this zone shows an unusually high Poisson's ratio of 0.36 ± 0.02. This zone transmits shear waves, but only of low frequencies; thus, a solid with temperature approaching the solidus may be indicated. Deep moonquakes occur near the lower boundary of this zone, strongly controlled by tides. (3) The zone below about 900 km depth shows high attenuation of shear waves, probably because of partial melting. Deep moonquakes immediately above this zone probably reflect the high tidal-strain accumulation expected at the boundary between solid and partially molten zones. A core of radius between 170 and 350 km and of greatly reduced *P* velocity is tentatively identified.

Phinney, R. A. (Dept. of Geological and Geophysical Sciences, Princeton Univ., Princeton, N.J. 08540) and Malin, P. E.: 'Monte Carlo Elastic Wave Modeling of Lunar Seismograms', *EOS: Trans. Am. Geophys. Union* **57**, 282. (1976)

Modeling of the Apollo seismograms by a Monte Carlo method was first done by Gold and Soter, for the scalar wave case. We have developed the needed expressions for the scattering cross sections for elastic waves, and used these to recompute the power envelopes for models of the lunar crust. Contributions from the different scattering orders may be separately assessed. The results permit a quantitative check of the method used to pick S phases from surface sources from the power envelope. The relative importance of attenuation and scattering losses may be seen. These results are compared with calculations based on the theory for mode to mode scattering in a waveguide. The adequacy of a two-dimensional (surface) scattering model for the lunar case is considered.

O'Keefe, J. D. (Dept. of Geophysics and Planet. Physics, UCLA, Los Angeles, Calif. 90024) and Ahrens, T. J.: 'The High Speed Ejecta from a Meteorite Impact and Planetary Accretion', *EOS: Trans. Am. Geophys. Union* **57**, 274. (1976)

Eulerian finite difference calculation of the high speed flow associated with the impact of an iron meteorite with a gabbroic surface at 15 km s^{-1} has permitted us to examine the mass and energy distribution in the initial high speed ejecta exceeding various escape velocities. Gabbro exceeding velocities of ~ 1 km s^{-1} is primarily in the solid-state whereas, in the ejecta exceeding the escape velocity of the Moon, some 0.2% of the meteoroid mass is in a vaporized state. The escaping gabbro ejecta, comprising some 18% of the meteoroid mass, is largely molten. After impact, the amount of mass exceeding the escape velocity of the Moon, reaches its final value at a time corresponding to ~ 2 transit-times of the impact shock through the meteorite. Our results demonstrate that for impact of objects at ~ 15 km s^{-1}, the Moon and larger planets are efficient accretors. Moreover for impacts on planets having escape velocities greater than 1 km s^{-1}, the fraction of energy lost is less than 5%. Post-impact, initial ejecta, areal densities are calculated for a spherical Moon and result in thicknesses which decrease with increasing radius (r) as $r^{-2.93}$. At $r = 7000$ km, the ratio of meteorite to rock ejecta is $\sim 1/300$.

Stiller, H. (Central Inst. Physics of the Earth, Academy of Sciences, Potsdam, Germany), Wagner, F. C., and Vollstadt, H.: 'A model for the V_p-Pressure Function of Cracked Lunar Rocks and Some Possible Seismological Consequences', *Tectonophysics* **31**, 129–137. (1976)

Changes in wave velocity in rocks are mainly caused by pressure and depend on porosity and pore filling. For terrestrial and lunar rocks two formulae can be stated which are comparable with each other and the coefficients of which can be determined from wave velocity and uniaxial stress measurements. The behaviour of rocks may be compared with dynamic phenomena in the Earth's crust, and in particular with pre-rupture phenomena (shocks, etc.) in seismic regions. The coefficient K_0 of imperfect bonds in rock increase with the number of shocks and brings about a decrease in wave velocity in seismic regions. The variations in wave velocity are connected with changes in electrical and thermal conductivity and with magnetic variations.

Winters, R. R. (Dept. of Physics and Astronomy, Denison Univ., Granville, Ohio 43023), Malcuit, R. J., and Mickelson, M. E.: 'The Lunar Capture Hypothesis: A Post-Apollo Evaluation', *EOS: Trans. Am. Geophys. Union* **57**, 272. (1976)

The capture of a lunar-sized body by Earth depends primarily on the physical properties of the smaller body at the time of capture. Gerstenkorn (1969), in a pre-Apollo analysis of the capture hypothesis, concluded that if the Moon is a captured body, then it must have been warm and therefore deformable at the time of capture. Subsequently, using estimates of physical parameters of the *present* (rigid) Moon, Kaula and Harris (1973) concluded that capture is implausible because only about 5×10^{32} ergs could be dissipated in the Moon per close encounter. This value is about 2.5 orders of magnitude lower than that needed for capture of a lunar-sized body with $v_\infty \sim 0.5$ km s^{-1}. However, it is more reasonable to use estimates of the physical parameters of the *ancient* Moon for such calculations. Estimates can now be made in light of the Apollo results. Petrological evidence suggests that the Moon was very warm early in its history. Most lunar scientists agree that the lunar anorthositic crust was differentiated from a global magma chamber generated by the heat released during lunar accretion. In addition, the presence of a large volume of mare material apparently emplaced between 3 and 4 b.y. ago implies that the Moon's interior was at least partially molten at that time. Using estimates of the physical parameters expected to describe a warm Moon, it can be shown using the approach of Kaula and Harris that the energy dissipated during a close encounter *is sufficient* to allow capture. A possible capture scenario features accretion of the Moon in a heliocentric orbit beyond that of Mars. Gravitational perturbations by Jupiter then force the Moon into an Earth-crossing orbit. A series of non-capture encounters ensues with the Moon's orbit evolving into a near Earth-coincident orbit from which the Moon is captured.

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

Casella, C. J. (Dept. of Geology, Northern Illinois Univ., DeKalb, Ill. 60115): 'Evolution of the Lunar Fracture Network', *Geolog. Soc. Am. Bull.* **87**, 226–234. (1976)

A statistical study of the directions of structural lineaments on parts of the Moon shows three significant preferred orientations that trend generally northwest, northeast, and north. Locally, many preferred directions are radial to large lunar impact basins, indicating that their formation influenced the direction of some fractures.

A systematic fracture pattern exists down to the smallest observable scale on both the near and far sides. The existence of such a pattern at the polar regions is less clear. Geometric regularity of preferred orientations of fractures of pre-Imbrian age indicates that a systematic set of fractures was formed over the lunar surface during the very earliest episode of lunar history, probably before the formation of many large lunar basins. The presence of these same fracture patterns on materials of younger age indicates that this initial fracture pattern was rejuvenated repeatedly through time.

Cintala, M. J. (Dept. of Geological Sciences, Brown University, Providence, R.I. 02912), Head, J. W., and Mutch, T. A.: 'Characteristics of Fresh Martian Craters as a Function of Diameter: Comparison with the Moon and Mercury', *Geophys. Res. Lett.* **3**, 117–120. (1976)

Martian craters defined as fresh on the basis of morphologic parameters have been analyzed for the presence and abundance of various morphologic features as a function of size. Bowl-shaped craters dominate the fresh crater population below about 15 km. The onset of central peaks occurs at about 5 km. Craters above about 15 km often have terraced walls, central peaks, and hummocky floors; at diameters of 40 km and greater, these features dominate fresh martian crater morphology. Central peak onset occurs at smaller diameters on Mars and the Moon than on Mercury, and terrace onset at similar diameters on the Moon and Mars, but at larger diameters than on Mercury. Since Mars and Mercury have a similar surface gravitational acceleration (greater than twice that of the Moon), gravity-controlled crater features should appear at similar diameters on the two planets. However, the differences in onset and abundances of central peaks and terraces on Mars and Mercury indicate that processes other than gravitational effects may also be important.

Cintala, M. J. (Dept. of Geol. Sciences, Brown University, Providence, R.I. 02912), Head, J. W., and Mutch, T. A.: 'Characteristics of Fresh Martian Craters as a Function of Diameter: Comparison with the Moon and Mercury', *EOS: Trans. Am. Geophys. Union* **57**, 274. (1976)

Martian craters defined as fresh on the basis of morphologic parameters have been analyzed for the presence and abundance of various morphologic features as a function of size. Bowl-shaped craters dominate the fresh crater population below about 15 km, while the majority of fresh craters at larger diameters have flat floors. The onset of central peaks occurs at about 5 km. Craters above about 15 km often have terraced walls, central peaks, and hummocky floors. Decreases in the relative occurrences of hummocky floors and central peaks at larger diameters (>50 km) may be caused by small amounts of eolian infilling. Comparisons with the Moon and Mercury show that central peak onset occurs at smaller diameters on Mars than on the Moon or Mercury; terrace onset occurs at similar diameters on the Moon and Mars, but at larger diameters than on Mercury. Since Mars and Mercury have a similar surface gravitational acceleration (greater than twice that of the Moon), gravity-controlled crater features should appear at similar diameters on the two planets. However, the differences in onset and abundances of central peaks and terraces on Mars and Mercury indicate that processes other than gravitational effects may also be important. Among these nongravitational factors are varying impact velocities at different distances from the Sun and dissimilar target and substrate characteristics.

Beals, C. S. (Manotick and Ottawa, Ontario) and Tanner, R. W.: 'On the Age of Mare-Orientale', *J. Roy. Astron. Soc. Canada* **69**, 299–306. (1975)

The age of Mare Orientale is reviewed and there is reasonable accord between the results of previous observers and those of the present authors. The catastrophic event producing the basin of Mare Orientale definitely occurred later than that producing the well-known Imbrium basin, making it probably the most recent of the large maria. The age of the central lava flow is comparable with that of the present surface of Mare Imbrium and definitely younger than the rough surfaces of the other parts of the mare basin. It is suggested that the filling of this and other mare basins is due to a succession of lava flows of which only the most recent can be observed. On this basis it seems likely that the relative immaturity of the Orientale basin is a consequence of the relatively short time available between the time of impact and the failure of the heat sources responsible for lava flows.

Cordell, B. M. (Dept. of Planet. Sciences, Univ. of Arizona, Tucson, Ariz. 85721): 'Orientale Basin Ejecta: Radial Thickness Variations from Crater Statistics', *EOS: Trans. Am. Geophys. Union* **57**, 274. (1976)

Crater statistics and 'filled-crater' assumptions are utilized to derive a radial ejecta thickness function characteristic of ejecta surrounding the lunar Orientale basin. Predicted ejecta thicknesses are 3.4 km at the Cordillera ring ($\equiv 1R_B$), decaying gently to 2.0 km at $1.7R_B$ where a slope discontinuity results in 750 m at $1.82R_B$. The corresponding ejecta volume (between R_B and $1.82R_B$) is 3.68×10^6 km^3.

A geometric ejecta model assuming ejecta thickness decreases monotonically away from the basin, circular symmetry, and a recent crater depth-diameter relation, is used to obtain an approximate radial thickness function. The function is modified to allow for realistic depth variations for craters of the same diameter; thickness predictions are systematically larger ($\simeq 2\times$) than models based on terrestrial crater extrapolations but are consistent with estimates from individual pre-basin craters.

This radial ejecta thickness function is of interest because (1) it does not suffer from large extrapolations and unknown gravity effects inherent in terrestrial crater extrapolation models, (2) it includes the effects of non-zero crater depth dispersion, and (3) the thickness function is tailored specifically to the basin in question.

Frey, H. (Geophysics Branch, NASA/Goddard Space Flight Center, Greenbelt, M.D. 20771) and Lowman, P. D., Jr.: 'Terrestrial Crust and Crustal Evolution: Lunar and Martian Analogs', *EOS: Trans. Am. Geophys. Union* **57**, 272. (1976)

Lunar and martian evolutionary patterns are examined for data relevant to the early evolution of the Earth. Basin-forming impacts on all the terrestrial planets are largely responsible for initiation of the crustal dichotomies observed, and seem capable of producing a high ratio of ocean-highland type surface from an originally global, thin, andesitic crust on the Earth. Basins on the Earth were only 10–20% larger than their lunar counterparts, and were some 20% more numerous per unit area than on the Moon. The relative thicknesses of the terrestrial and lunar crusts 4 billion years ago accounts for the increased magnitude of highland-crust destruction on the Earth. Martian mega-tectonic features associated with incipient plate formation are larger than those on the contemporaneous Earth, both in absolute dimensions and relative to the planetary radius. This is a consequence of the absence of horizontal transport of the martian lithosphere; the resulting long residence time over asthenospheric structures (mantle plumes?) allows extended vertical and horizontal development of epeirogenic uplifts and their associated features. This situation is similar to that which probably existed on the Earth 3.5–3 billion years ago, and to that on the Arabian-African shield in the early Cenozoic, just before the beginning of the seafloor spreading. The early terrestrial crust 3 billion years ago consisted of relatively few plates of large size.

Hawke, B. R. (Dept. of Geol. Sciences, Brown Univ., Providence, R.I. 02912): 'Ponded Material on the North Rim of King Crater: Influence of Pre-Event Topography on the Distribution of Impact Melt', *EOS: Trans. Am. Geophys. Union* **57**, 275. (1976)

King (71 km) is a fresh lunar farside crater that has a large pool of lavalike material on its northern rim. This pool is generally interpreted to be impact melt associated with crater formation as are nearby flows and veneer deposits. The size and localization of this deposit on one segment of the rim are anomalous. The main pond is 15–20 km in diameter, covers an area of 241 km^2 and has an estimated average depth of 100 m. Volume calculations indicate that at least 30 km^3 of lavalike material may be present in the large pond and several smaller pools in the area. If the pond were formed by runoff of impact melt from the surrounding terrain, as is suggested by flow features, the drainage area of the pond (~ 1370 km^2) would have been initially covered to an average depth of 22 m. This compares favorably to a veneer thickness of 10–40 m in areas where the material solidified before drainage was complete. Apollo photography reveals the presence of two large pre-King craters (117 km and 40 km in diameter) north of the King target site. These craters produced a topographic low which was apparently interested by the King transient cavity, allowing shock-melted material to eject preferentially through the breach during the terminal stages of the event. Much of King's northern rim stands only 1–2 km above the floor as opposed to 4–5 km for the remainder. An additional effect of the smaller crater was to provide a basin in which molten material could collect. The intersection of preexisting topographic lows by impact crater cavities may be important in producing asymmetries in the distribution of impact melt on crater rims.

Head, J. W. (Dept. of Geol. Sciences, Brown Univ., Providence, R.I. 02912): 'The Significance of Substrate Characteristics in Determining Morphology and Morphometry of Lunar Craters', *EOS: Trans. Am. Geophys. Union* **57**, 274–275. (1976)

Variations in strength, geometry and characteristics of target materials may affect the characteristics of large lunar craters. Information on the outer portion of the lunar crust comes from geological and geophysical studies: extensive cratering has produced a megaregolith 2–3 km thick with an extremely irregular lower contact, overlying a basement layer. The basement layer consists of an upper zone of intensely fractured and brecciated bedrock formed by in situ deformation associated with cratering. This grades down through increasingly less severe levels of impact effects (microfractures, etc.) until relatively undisturbed (or annealed) crystalline bedrock is reached at about 25 km. The major discontinuity in terms of gross physical properties is the boundary at about 2–3 km which separates the fragmental layer (*P*-wave velocities < 3 km s^{-1}) from the fractured crystalline substrate 3–6 km s^{-1}. Major changes in fresh lunar crater morphology and morphometry are seen at diameters of 10–20 km, and include onset of terraces, central peaks, polygonal shape, flat floors, and depth/diameter variations. Fresh crater diameters of 10–20 km correspond to crater depths of 2–3 km, the approximate thickness of the megaregolith layer. Many of the observed changes in crater morphology and morphometry appear to be due to changes in the characteristics of the growing crater cavity as it passes from the low-strength megaregolith into the more coherent crustal substrate. This basic change in crater growth is accompanied by changes in the modification stage of the event.

Kislyuk, V. S.: 'Refinement of the Coordinate Zeta of Craters of the Moon's Visible Hemisphere Based on Data of Zond 8 Photographs', *Cosmic Res.* **13**, 369–376. (1975)

The positions along the direction toward the Earth and the absolute heights of 78 craters in the western part of the Moon's visible hemisphere are refined on the basis of measurements of three photographs of the Moon obtained by the Zond 8 spacecraft. The method of analyzing the measurements is presented.

Lowman, P. D., Jr. (Geophysics Branch, Goddard Space Flight Center, Greenbelt, Md. 20771): 'Crustal Evolution in Silicate Planets: Implications for the Origin of Continents', *J. Geology* **84**, 1–26. (1976)

Evidence from comparative planetology is combined with independent evidence from terrestrial geology to produce a general theory for the origin of continents. The Moon, Mercury, Mars, and possibly Venus each had a similar sequence of early crustal evolution: (1) a first differentiation, forming a global igneous crust; (2) major impact fracturing of this crust, probably peaking about 4 b.y. ago; and (3) a long period of basic magmatism. Mare evolved beyond this stage to initial tectonic fracturing of the early crust and construction of volcanic massifs. Since the Earth has far more internal energy and a greater volatile content than the smaller planets, it must have undergone differentiation at least as rapid and as extensive as theirs. It must also have had a comparable cratering history. The following sequence of events is therefore proposed for the Earth's internal crustal evolution: Stage I (4.7 b.y. ago)—Origin by rapid, high-temperature process; Stage II (4.7–4.0 b.y. ago)—First differentiation, producing a global igneous crust of dominantly andesitic composition, with subordinate amounts of basaltic and anorthositic rocks, and concurrent impact peaking at about 4 b.y. ago with formation of mare-like basins and impact fracturing of crust; Stage III (4.0–ca. 3 b.y. ago)—Second differentiation, by regional basic and ultrabasic magmatism, producing primitive ensialic ocean basins analogous to Oceanus Procellarum and the northern plains of Mars, concurrent with continuing generation of sialic magma from mantle, crustal deformation, and redifferentiation of initial crust by partial melting and remobilization; Stage IV (3 b.y. ago to present)—Initial tectonic fracturing by crustal foundering under basic lavas, and beginning of plate tectonic processes. Ensialic ocean basins were converted to the present type of basins by sea-floor spreading and subduction. Fundamentally modern crustal evolution by plate-tectonic processes began about 2.5 b.y. ago, in Stage IV. The original andesitic crust underwent repeated redifferentiation by partial melting and other processes, producing mantled gneiss domes—now intrusive into greenstone belts (remnants of Stage III basic volcanics)—and Proterozoic massif anorthosites, and—by interaction at plate boundaries—orogenic batholiths. Some enlargement of the ocean basins and formation of new basins (oceanization) has occurred through Stage IV by various processes, but constancy of continental freeboard suggests that the volume of continental crust has not changed greatly in the last 3 b.y. The Earth's continents in this theory are the greatly altered remnants of an originally global crust, rather than aggregations of orogenic belts or sialic nuclei.

Peterfreund, A. R. (Dept. of Geol. Sciences, Brown Univ., Providence, R.I. 02912): 'Alphonsus Dark-Haloed Craters: Examples of Isolated Dark Mantle Sources', *EOS: Trans. Am. Geophys. Union* **57**, 275. (1976)

The dark-haloed craters of Alphonsus represent energetic volcanic eruptions on the lunar surface. The deposits around the source craters contain a low, broad rim structure and consist of a thin veneer of unconsolidated material void of boulders in the meter range. The depth of deposited material is a maximum at the rim crest (<40 m), and thins rapidly with distance from the source crater, to where it is indistinguishable from background material. The diameters of the craters and deposits range from 1.1–3.0 km and 3.5–10.0 km, respectively. Volumes of the craters range from 0.15–0.96 km^3 and for the deposits estimates range from 0.2–1.4 km^3.

The observed morphologic features and physical perimeters of the dark-haloed craters fit a model of a lunar cinder cone eruption. On the basis of ballistic particle trajectories, ejection velocities exceeding 100 m s^{-1} and an initial ejection angle $\sim 70°$ are necessary to account for ejected material at a range of

5 km from the source crater. A minimum of 90 m s^{-1} is required to explain material ejected to that distance assuming a maximum angle of 45°. These ejecta velocities and deposit volumes are within the upper range of similar properties for terrestrial cinder cones.

The dark-haloed deposits of Alphonsus are unique as dark mantle deposits as they represent isolated examples of explosive events in an area void of mare deposition. The energetic conditions of eruption suggest either the presence of a localized volatile source or high dynamic pressure related to depth of origin.

Settle, M. (Dept. of Geol. Sci., Brown Univ., Providence, R.I. 02912) and Head, J. W.: 'Impact Cratering: Models of the Growing Crater Cavity', *EOS: Trans. Am. Geophys. Union* **57**, 274. (1976)

A series of models describing the growth of the initial crater cavity formed during an impact cratering event has been constructed assuming: (a) parabolic cavity shape (Dence, 1973) (b) power law model for the distribution of primary ejecta, (c) constant rate of cavity radius growth, and (d) power law relationship between the depth and radius of the transient cavity such that

$$\left(\frac{d}{d_f}\right) = \left(\frac{R}{R_f}\right)^c,$$

where d and R are depth and radius of the transient cavity at a specific time and the subscript f refers to the final values of these parameters, also assumed. The angle formed by a line tangent to the model cavity at the original ground surface is considered to approximate the ejection angle of material exiting the growing cavity.

Values of $c < 1.0$ physically represent cavities in which the percentage increase in cavity depth is much greater than the percentage increase in cavity radius during the early phases of excavation. For $c < 1.0$ ejection angle and velocity decrease rapidly in the early phases of excavation when less than 10% of the final cavity volume has been excavated; the bulk of the ejecta generally exists at angles of 34°–50° in agreement with small scale experiments (e.g. Oberbeck, 1971). These models indicate that the ejection range of deep material increases as c decreases (i.e. for cases in which cavity depth approaches its final value rapidly in the early phases of excavation).

Srnka, L. J. (Lunar Science Institute, Houston, Texas 77058), Criswell, D. R., and Wollenhaupt, W. R.: 'Lunar Topography and the Limb Compression Source Regions', *The Moon* **14**, 59–69. (1975)

Data from the Apollo 15, 16, and 17 laser altimeters has been used to study slopes, elevations and roughness in the identifiable regions on the Moon which sporadically produce plasma compressions and magnetic field enhancements in the solar wind/lunar void boundary, when those regions are at a flow limb. It is found that occurrence rates for such 'limb compressions' derived from Explorer 35 satellite measurements are significantly correlated with peak, average and rms slopes in the source regions, whereas rates derived from Apollo 15 and 16 subsatellite data are not correlated with topography. This suggests that two or more mechanisms operate in the source regions to produce limb compressions. Together with the nown correlation between limb compressions and local surface remanent magnetic fields, the results indicate that lunar magnetization is not strongly related to surface features.

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

Adams, J. B. (Dept. of Geological Sciences, Univ. of Washington, Seattle, Wash. 98195) and Charette, M. P.: 'Spectral Reflectance of Highland Rock Types at Apollo 17: Evidence from Boulder 1, Station 2', *The Moon* **14**, 483–489. (1975)

Many of the non-mare rock types at Apollo 17 can be identified uniquely by their spectral reflectance properties. Mineralogical and textural information is present in the spectral curves of samples from Boulder 1, Station 2. It should be possible to determine the regional extent of rocks similar to the boulder using reflectance spectra from a spacecraft in lunar orbit.

Ahrens, T. J. (Seismological Lab., California Institute of Technology, Pasadena, Calif. 91125): 'Compaction by Impact of Unconsolidated Lunar Fines', *The Moon* **14**, 291–299. (1975)

New Hugoniot and release adiabate data for 1.8 g cm^{-3} lunar fines (sample, 70051) in the ~2 to ~70 kbar range demonstrate that upon shock compression intrinsic crystal density (~3.1 g cm^{-3}) is achieved under *shock stresses* of 15 to 20 kbar. Release adiabate determinations indicate that measurable irreversible compaction occurs upon achieving shock pressures above ~4 kbar. For shocks in the ~7 to 15 kbar range, the inferred, *post-shock*, specific volumes decrease nearly linearly with increasing peak shock pressures. Upon shocking to ~15 kbar the post-shock density is approximately that of the intrinsic minerals. If the present data for sample 70051 are taken to be representative of the response to impact of unconsolidated regolith material on the Moon, it is inferred that the formation of appreciable quantities of soil breccia can be associated with the impact of meteoroids or ejecta at speeds of as low as ~1 km s^{-1}.

Basu, A. (Dept. of Geology, Indiana University, Bloomington, Ind. 47401), DesMarais, D. J., Hayes, J. M., and Meinschein, W. G.: 'Integrated Investigation of the Mixed Origin of Lunar Sample 72161,11', *The Moon* **14**, 129–138. (1975)

Sample 72161,11 (dark mantle at LRV-3) has a graphic mean grain size (M_z) of 3.88 ø, inclusive graphic standard deviation (σ_I) of 1.29, and a total carbon content of 204 μg C g^{-1} sample, and is, therefore, quite mature. However, the agglutinate content is only 30% in the 90–177 μm particles, indicating an apparent departure from steady state. Analyses of C, CH_4, and H_2 concentrations in size fractions larger than 149 μm show that the volume correlated component of these species increases with increasing grain size. In a homogeneous agglutinate population the volume correlated component is expected to be independent of grain size. The observed increase can be interpreted in terms of the mixing of a dominant local population of coarser agglutinates, with high carbon and hydrogen, with an imported population of finer agglutinates relatively poor in carbon and hydrogen. When analyses of size-fractions from the bulk sample are considered, these effects are apparently obliterated by the admixture of coarse-grained material low in aglutinates. It seems likely that this low agglutinate content is a consequence of the breakdown of the fragile, large agglutinates in the imported material during their movement to the sample site.

Basu, A. (Center for Astrophysics, 60 Garden Street, Cambridge, Mass. 02138) and Bower, J.: 'Major Element Chemistry of Lunar Agglutinitic Glass', *EOS: Trans. Am. Geophys. Union* **57**, 273. (1976)

Compositions of lunar agglutinitic *glass* and not whole agglutinates have been obtained from 351 focused beam microprobe analyses. Predictably, agglutinitic glass from highland and mare areas are different in composition and reflect the relative local distribution of mafic and felsic minerals. Averages of 115 Apollo 12 and 58 Apollo 16 agglutinitic *glass* analyses are:

	Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	Cr_2O_3	MnO	FeO
A12	0.46	8.9	15.0	47.6	0.69	10.5	2.5	0.34	0.24	13.9
A16	0.51	7.1	24.8	44.2	0.13	14.3	1.1	0.16	0.14	6.9

The FeO/FeO + MgO ratios of most glass analyses lie in the range 0.40–0.70 and there is a strong negative correlation between Al_2O_3 (<1%–37%) and FeO (<1%–27%). A random count of surviving silicate-mineral clasts from Apollo 15 and Apollo 17 agglutinates gives 51% pyroxene, 40% plagioclase

(~An_{92}) and 9% olivine (~Fo_{75}). The FeO/FeO + MgO ratios in clastic pyroxenes are usually *less* than 0.40.

The contrast in values of FeO/FeO + MgO in agglutinitic glass and pyroxenes, and the nature and abundance of plagioclases and olivines generally confirm the differential assimilation hypothesis for the production of agglutinitic glass. However, except for Si there is a very high variability ($\bar{x}/\sigma \sim .33$) in the major composition of agglutinitic glass. Though rare, maskelynite compositions are also encountered. Further, in comparison to the bulk composition of the soil 72501, for example, the agglutinitic glass therein (42 analyses) is depleted in SiO_2 and is enriched in CaO and Al_2O_3 but not in FeO or MgO. This implies that processes including (1) preferential vitrification of plagioclase and (2) loss of volatiles (e.g. Si, Na) upon micrometeoritic impaction also played a major role in determining the fate of lunar agglutinitic glass.

Blanchard, D. P. (NASA/Johnson Space Center, Houston, Tex. 77058), Haskin, L. A., Jacobs, J. W., Brannon, J. C., and Korotev, R. L.: 'Major and Trace Element Chemistry of Boulder 1 at Station 2, Apollo 17', *The Moon* **14**, 359–371. (1975)

Twenty-seven samples of matrix and clast materials from Boulder 1 at Station 2, Apollo 17 have been analyzed for major and trace elements as part of the study of this boulder by Consortium Indomitabile. Both unusual and common types of material have been characterized.

Gray and black competent breccia (GCBx and BCBx) and anorthositic breccia (AnBx) have compositions which are common at the Apollo 17 site and were common at the site of boulder formation. Light friable breccias (LFBx) have compositions which are not found at the Apollo 17 site other than in the boulder. Pigeonite basalt is a new type of lunar rock and has characteristics that would be expected of a highland volcanic rock. It is associated with LFBx material, and like LFBx material it is exotic to the Apollo 17 site. Coarse norite is an old primitive rock which is no longer (if ever) found as millimeter fragments at the Apollo 17 site. It was, however, present as millimeter fragments associated with GCBx and BCBx materials at the site and time of boulder formation. Therefore the boulder-forming process combined materials from at least two different localities or vertical strata; at least one of these (LFBx) has not been previously sampled and analyzed.

Boynton, W. V. (Institute of Geophysics and Planet. Physics, Dept. of Chemistry and Geophysics and Space Physics, Univ. of Calif., Los Angeles, Calif. 90024), Chou, C.-L., Bild, R. W., Baedecker, P. A., and Wasson, J. T.: 'Element Distribution in Size Fractions of Apollo-16 Soils: Evidence for Element Mobility During Regolith Processes', *Earth Planet. Sci. Lett.* **29**, 21–33. (1976)

Three Apollo-16 soils, 61220, 63500 and 65500, having diverse properties were separated into six size fractions and analyzed for 8 volatiles and siderophiles. Relative concentrations of an additional 20 elements were determined in 61220 and 63500. The volatile elements Cd, Zn, In and Ga increase in concentration with decreasing grain size; in the finest fractions the increase is roughly parallel to the increase in specific surface area, and a surface correlation is inferred. The total increase from coarsest (177–500 μm) to finest (<5 μm) fraction is by factors of 10–20 for Zn and Cd in soils 61220 and 63500. Concentrations of elements that are good indicators of KREEP (Sm), mare basalts (Fe) and anorthosites (Ca) show nearly no dependence on size. The preservation of the observed surface correlation throughout regolith evolution suggests that the volatile elements are labile on the lunar surface.

Concentration-size distributions of siderophiles show peaks in the 80–300 μm range for each soil, independent of whether they are dominantly extralunar (Ni, Ge, Au, Ir) or lunar (Co) in origin. If this peak results from agglutinate formation, a viable mechanism must allow for incorporation of the extralunar siderophiles. Alternatively, the peak may result from a continuous growth of metal grain size during the evolution of the regolith.

Bruno, E. (Instituto di Mineralogia, Cristallografia e Geochimica dell'Universita di Torino, Italie) and Facchinelli, A.: 'Crystal-Chemical Interpretation of Crystallographic Anomalies in Lunar Plagioclases', *Bull. Soc. Francaise Mineralog. Cristallograph.* **98**, 113–117. (1975)

Unit-cell dimensions of lunar plagioclases, γ in particular, notably differ from those of terrestrial plagioclases with the same An-content inferred from Ca/Ca + Na + K or Ca/8O.

It is shown that this crystallographic anomaly is a consequence of the chemical anomalies affecting lunar plagioclases.

In particular it is a consequence of the presence of $\square[Si_4O_8]$ in solid solution. This molecule influences the composition of the framework, to which the γ angle is strongly related.

On the basis of these results some data on the thermal state of lunar plagioclases are briefly discussed.

Chou, C.-L. (Dept. of Geology and Erindale College, University of Toronto, Canada M5S 1A1) and Pearce, G. W.: 'Correlations of Magnetic Properties with Nickel Content and Origin of Metallic Iron in Lunar Soils', *EOS: Trans. Am. Geophys. Union* **57**, 274. (1976)

We have determined room-temperature magnetic properties for six Apollo 17 soils and 66041. These same soils are also analyzed for Ni and other trace elements by neutron activation techniques. The Fe^0 and Fe^{++} contents are calculated based on their saturation magnetization and paramagnetic susceptibility. The Fe^0 content varies from 4.6–7.5 mg g^{-1} in Apollo 17 soils and is 5.5 mg g^{-1} in 66041; the Fe^{++} content varies from 9.27–18.1% in Apollo 17 soils and is 5.1% in 66041. The Fe^{++} results are in good agreement with those obtained by chemical methods. Nagata *et al.* (1975) suggest that the intensity of room-temperature saturation magnetization is possibly related to the bulk Ni content of lunar samples. Our data of Fe^0 and Ni contents of soils show that the Ni/Fe^0 ratio of soils from highlands sites (0.054–0.08 g g^{-1}) is distinctly higher than that of mare soils (0.022–0.052 g g^{-1}), indicating the metal particles of mare and highland soils are formed by different processes. The ratio of highlands soils is close to that of meteoritic materials (0.056–0.35 g g^{-1}), suggesting that most of metal particles in highlands soils originated as disseminated meteoritic iron. Metallic iron in mare soils consists mostly of fine-grained particles and is too abundant to be accounted for by meteoritic material. Mare soils must be enriched in Fe^0 by indigenous reduction processes. Using all magnetic data of Apollo 16 soils obtained in this lab, we found that metallic iron and Ni are strongly correlated. Since the lowest content is found in the North Ray soil 67601, this trend may be explained by a mixing model, i.e., mature highland regolith is diluted by young, immature North Ray ejecta. Positive correlation between Fe^0 and Ni among Apollo 17 soils are also observed if mare soils 71501 and 75081 are disregarded.

Compston, W. (Research School of Earth Sciences, Australian National University, Canberra, Australia), Foster, J. J., and Gray, C. M.: 'Rb–Sr Ages of Clasts from within Boulder 1, Station 2, Apollo 17', *The Moon* **14**, 445–462. (1975)

Rb, Sr and $^{87}Sr/^{86}Sr$ have been determined for fragments of matrix and clasts from three of the hand-specimens of Boulder 1, 72275, 72255, and 72215. Total-rock and certain plagioclase samples from a crushed norite clast (Civet Cat) define an age of 4.17 ± 0.05 *AE* (2σ) for the pre-Serenitatis igneous differentiation of the norite. Pyroxene and other mineral separates were affected by a later event at about 3.9 ± 0.1 *AE*. An unshocked clast of pigeonite basalt has a well-fitted mineral isochron of 4.01 ± 0.04 *AE*. Samples of the competent breccia matrix comparatively rich in small clasts of highly radiogenic micro-granite define a mixing line equivalent to 4.03 ± 0.03 *AE*, which denotes the age of the microgranite. Other samples of the matrix dominated by small anorthosite clasts define a 4.4 *AE* mixing-line and demonstrate that Sr isotope equilibration between plagioclase and matrix did not occur during the high-temperature event that indurated the matrix.

Duennebier, F. (Marine Science Inst., Univ. of Texas, Galveston, Tex. 77550): 'Thermal Movement of the Lunar Regolith', *EOS: Trans. Am. Geophys. Union* **57**, 274. (1976)

Diurnal temperature variations of 280 K at the lunar surface generate stresses in the lunar regolith that are relieved by small moonquakes. These events are detected by the short period seismometers deployed by the astronauts as part of the Passive Seismic Experiment and the Lunar Surface Profiling

Experiment (LSPE). Most of these thermal moonquakes occur during the lunar daytime although activity continues throughout the lunar night. Sources of these events located near the LSPE appear to correlate with crater fields and with the location of a rock near the center of the array. It is suggested that lateral diurnal stress variations in the regolith, rather than gravitational slumping, are the main energy source for these moonquakes. Gradual filling of craters would be an expected consequence of this activity.

Gehrke, C. W. (Dept. of Biochemistry, University of Missouri, Columbia, MO. 65201), Zumwalt, R. W., Kuo, K., Ponnamperuma, C., and Shimoyama, A.: 'Search for Amino Acids in Apollo Returned Lunar Soil', *Origins of Life* **6**, 541–550. (1975)

The lunar samples from Apollo flights 11 through 17 provided the students of chemical evolution with an opportunity of examining extraterrestrial materials for evidence of early prebiological chemistry in the solar system. Our search was directed to water-extractable compounds with emphasis on amino acids. Gas chromatography, ion-exchange chromatography and gas chromatography combined with mass spectrometry were used for the analysis. It is our conclusion that amino acids are not present in the lunar regolith above the background levels of our investigations.

Geisler, M. (Zentralinstitut fur Isotopen- und Strahlenforschung der Akademie der Wissenschaften der DDR, Leipzig (DDR): 'Instrumentelle Aktivierungsanalyse an Lunarem Material', *J. Radioanalytical Chemistry* **28**, 209–219. (1975)

Lunar soil samples of the Luna 16 and Luna 20 missions were analysed by neutron activation in a generator and a nuclear reactor, respectively, and following gamma-spectrometry by Na I(Tl) and Ge(Li) detectors. By 14 MeV neutron activation there were determined the abundances of 5 major elements (O, Mg, Al, Si, Fe) and by reactor activation the abundances of 18 major and trace elements (Na, K, Sc, Cr, Mn, Fe, Co, Mo, La, Ce, Sm, Eu, Tb, Yb, Lu, Hf, W, Th) and the detection limits of 4 additional elements (As, Rb, Sb, Cs). The standard rocks BM and GM of the ZGI were used as standards in the reactor activation analysis.

Goldstein, J. I. (Dept. of Metallurgy and Materials Science, Lehigh Univ., Bethlehem, Pa. 18015), Axon, H. J., and Agrell, S. O.: 'The Grape Cluster, Metal Particle 63344,1', *Earth Planet. Sci. Lett.* **28**, 217–224. (1975)

Metal particle 63344,1 consists of hundreds of metallic globules welded together to form a structure somewhat like a bunch of grapes. It is the largest lunar metal sample found to date, over 5 mm in its longest dimension. Silicate material is attached to the outside of the sample and consists mainly of glass and fragments of An-rich plagioclase derived from a regolith composed of fragments of highland-type rocks.

The globules are all of the same composition (6.25 wt.% Ni, 0.35 wt.% Co, 0.8 wt.% P and Fe) and were produced at the same time and from the same source. No primary solidification structure was observed in the globules. A Widmanstätten pattern of kamacite in taenite and a precipitation pattern of phosphides, which were equilibrated to a temperature of ≤ 600°C, also developed in the metal. The metallographic evidence indicates that the particle was slow cooled from the solidification temperature (~ 1300°C) taking days to possibly months to reach 600°C.

Two possible mechanisms are proposed for the formation of the globules of 63344,1. One mechanism involves the primary impact of an iron meteorite which produces a metallic liquid and vapor phase. The second mechanism involves the formation of a liquid pool of metal after impact of an iron meteorite projectile followed by a secondary impact in the liquid metal pool. Both mechanisms call for special conditions and sequences of events in order to form a chemically coherent cluster of metal globules uncontaminated by silicates. These globules may adhere after partial solidification and the particle may be slow cooled by burial 0.5–5 m deep in the original ejecta blanket.

Goswami, J. N. (Dept. of Physics, University of California, Berkeley, Calif. 94720) and Hutcheon, I. D.: 'Cosmic Ray Exposure History and Compaction Age of Boulder 1 from Station 2', *The Moon* **14**, 395–405. (1975)

Fossil track analyses of a ~3 cm section of boulder fragment 72255, collected at the base of the South Massif, yield a surface exposure age for this boulder in its present location of ~40 m.y. This age is in good agreement with the ^{81}Kr–Kr exposure age (Leich *et al.*, 1975), suggesting that the boulder was either never exposed to cosmic radiation prior to its emplacement at the foot of the South Massif or that it was heavily shielded during any previous irradiation. High-voltage electron microscope observations reveal no evidence of solar flare irradiation prior to breccia compaction, indicating that the breccia components were never part of a pre-Serenitatis near-surface regolith. The fission track record of a whitlockite crystal from 72255 yields a fission track age of $3.96^{+0.04}_{-0.07}$ g.y. Comparison with the ^{40}Ar–^{39}Ar age of 4.00 ± 0.03 g.y. suggests that this age represents the compaction age of the parent boulder.

Johnson, D. (Univ. of Texas at Dallas, P. O. Box 688, Richardson, Tex. 75080), Frisillo, A. L., Dorman, J., Latham, G. V., and Strangway, D. W.: 'Elastic Properties of a Lunar Regolith Sample', *EOS: Trans. Am. Geophys. Union* **57**, 274. (1976)

Seismic compressional wave velocities have been measured in the laboratory for an Apollo 15 lunar soil sample (15301,38) under low uniaxial pressures corresponding to burial down to about 70 m. The velocities measured are consistent with those found in situ. The presence of a large gradient in the surficial zone of the Moon, implying the presence of an efficient wave guide, is inferred from the experimental results. The enhancement of horizontal ground motion relative to vertical motion, observed in lunar seismograms, is consistent with surface wave properties derived from the experimental model. The increase in compressional wave velocity from about 100 m s^{-1} to 300 m s^{-1} at depth ranging from 4 to 12 meters, inferred from lunar seismic data, cannot be explained by simple compaction alone. Attempts to measure the bulk modulus of the sample were not successful. The strain threshold at which elastic properties give way to inelastic behavior was below the capability of the available apparatus.

Jovanovic, S. (Chemistry Div., Argonne National Lab., Argonne, Ill. 60439) and Reed, G. W., Jr.: 'History of Boulder 1 at Station 2, Apollo 17 Based on Trace Element Interrelationships', *The Moon* **14**, 385–393. (1975)

Correlations among the trace and minor element pairs Cl and Br, Cl and P_2O_5, and Ru and Os, present in parent igneous rocks, generally survived the processes of boulder breccia formation.

Fractions of the Cl, Br, and Hg that are mobilized by water leaching and/or volatilization at moderate temperatures ($\leq$450°C) place constraints on the thermal history of Boulder 1 and its component breccias. Since, and possibly during, consolidation, the boulder has probably not been subjected to temperatures of $\geq$450°C.

The parent rocks of the Apollo 17 boulder and breccia samples studied could have been derived from two initial magmas. Boulder 1, Station 2 gray competent breccias 72255 and 72275 Clast #2 appear to be genetically unrelated to gray competent breccia and anorthositic material 72215, or to light friable breccia 72275; they do appear to be related to samples 72395 (Boulder 2) and 76315 (Station 6 boulder).

Vapor clouds from apparently external sources permeated the source regions of the boulders.

Leich, D. A. (Dept. of Physics, University of California, Berkeley, Calif. 94720), Kahl, S. B., Kirschbaum, A. R., Niemeyer, S., and Phinney, D.: 'Rare Gas Constraints on the History of Boulder 1, Station 2, Apollo 17', *The Moon* **14**, 407–444. (1975)

Rare gas isotopic analyses have been performed on both pile-irradiated and unirradiated samples from Boulder 1, Station 2. Two samples from rock 72255, the Civet Cat clast and a sample of adjacent breccia, have concordant ^{40}Ar–^{39}Ar ages of 3.99 ± 0.03 b.y. and 4.01 ± 0.03 b.y., respectively. Several samples from rock 72275 have complex thermal release patterns with no datable features, but an intermediate-temperature plateau from the dark rim material of the Marble Cake clast yields an age of 3.99 ± 0.03 b.y. – indistinguishable from the age of rock 72255. We regard these ages as upper limits on the time of the Serenitatis basin-forming event.

The absence of fossil solar-wind trapped gases in the breccia samples implies that a prior existence for the boulder as near-surface regolith material can be regarded as extremely unlikely. Instead, the small trapped rare-gas components have isotopic and elemental compositions diagnostic of the terrestrial-type trapped component which has previously been identified in several Apollo 16 breccias and in rock 14321. Excess fission Xe is found in all Boulder 1 samples in approximately 1 : 1 proportions with Xe from spontaneous fission of ^{238}U. This excess fission Xe is attributed to spontaneous fission of ^{244}Pu *in situ*.

Cosmic-ray exposure ages for samples from rocks 72215 and 72225 are concordant, with mean ^{81}Kr–Kr exposure ages of 41.4 ± 1.4 m.y. and 44.1 ± 3.3 m.y., respectively. However a distinctly different ^{81}Kr–Kr exposure age 52.5 ± 1.4 m.y. is obtained for samples from rock 72275. A two-stage exposure model is developed to account for this discordance and for the remaining cosmogenic rare-gas data. The first stage was initiated at least 55 m.y. ago, probably as a result of the excavation of the boulder source-crop. A discrete change in shielding depths ~35 m.y. ago probably corresponds to the dislodgement of Boulder 1 from the South Massif and emplacement in its present position.

Levskii, L. K.: 'Ar^{40} in Regolith', *Geokhimiya* **1975** (11), 1653–1659. (1975)

Обсуждается справедливость предположений, положенных в основу гипотезы о происхождении Ar^{40} в лунном реголите за счет сорбции ионов Ar^{40} из лунной атмосферы. Экспериментальные данные по изотопам аргона для реголита из мест посадки «Аполона-11» и «Луны-16», а также оценка баланса содержания Ar^{40} в лунной атмосфере не поддерживают гипотезу. Часть реголита содержит Ar^{40}, который либо произошел за счет распада K^{40} in situ, либо за счет другого неизвестного процесса.

Marvin, U. B. (Center for Astrophysics, Cambridge, Mass. 02138): 'The Boulder', *The Moon* **14**, 315–326. (1975)

The external morphologies of Boulder 1, Station 2, and of the four samples taken from it by the Apollo 17 crew, are briefly described. The boulder is a polymict breccia, containing the following principal materials as clasts: gray competent breccias (GCBx), black competent breccias (BCBx), anorthositic breccias (AnBx), pigeonite basalt (PB), coarse norite (CN). All are enclosed in a matrix of light-colored friable breccia (LFBx).

Marvin, U. B. (Center for Astrophysics, Cambridge, Mass. 02138): 'Apollo 16 Rock 61224,6: A Lunar or Meteoritic Eucrite?', *EOS: Trans. Am. Geophys. Union* **57**, 277–278. (1976)

Specimen 61224,6 occurred in the 4–10 mm fraction of a white soil layer at a depth of 30–35 cm in a trench in the rim of Plum Crater. When viewed macroscopically, the rock appeared to be a coarse, friable, pyroxene-plagioclase gabbro with no visible opagues or other accessory minerals. Its most unusual feature was a delicate shell of colorless glass on each freshly broken surface. Thin sections confirmed the simple mineralogy: 45% plagioclase, 55% pyroxenes with a coarse-grained (0.5–3 mm) cumulate texture. The sections also revealed sparse globules and veinlets of metallic Ni-Fe and troilite. The plagioclase ($An_{81}Ab_{18}Or_{0.2}$) ranks among the most Na-rich of feldspars in the lunar samples. The pyroxenes form two clusters centered upon pigeonite ($En_{66}Fs_{32}Wo_{3}$) and augite ($En_{45}Fs_{15}Wo_{40}$).

The plutonic texture bears an overprint of shock effects. Some patches of plagioclase still show evidence of twinning but most of it has been transformed to a leafy intergrowth of glass and crystals, with colonnade structure along some former grain boundaries. Every pyroxene grain is rimmed by a selvage of mafic glass, which accounts for the fragile glassy coatings on the specimen's fractured surfaces. Shock-melting has occurred in situ without destroying the original plutonic fabric.

This eucritic rock bears at least as strong a resemblance to certain basaltic achondrites as it does to any other lunar rock. Analyses designed to test a lunar vs meteoritic origin are scheduled for the near future. If 61224,6 proves to be lunar, it will provide interesting comparisons between igneous processes in the highlands crust and in meteorite parent bodies.

McSween, H. Y., Jr. (Dept. of Geological Sciences, Harvard University, Cambridge, Mass. 02138): 'A New Type of Chondritic Meteorite Found in Lunar Soil', *EOS: Trans. Am. Geophys. Union* **57**, 277. (1976)

A fragment found in soil from the Apollo 12 site (12037, from the N rim of Bench Crater) appears to be a unique type of carbonaceous chondrite, petrologically and chemically distinctive from other chondrites and lunar rocks. Chondrules consisting of shocked pyroxene (bronzite) rimmed by euhedral troilite crystals are set in a dark aphanitic matrix. Abundant magnetite in the matrix exhibits microscopic morphologies (spherules and platelets) characteristic of Type I carbonaceous chondrites. The bulk composition of this sample has high Mg/Fe relative to other chondrites, and P and S are strongly enriched. Microprobe defocused beam analysis of 62 points gives the following average wt % oxides: Na-0.90, Mg-27.82, Al-2.98, Si-37.79, P-1.05, K-0.13, Ca-1.39, Ti-0.12, Cr-0.56, Mn-0.14, Fe-19.68, Ni-1.67, S (as the element)-5.29. Most compositional differences between this meteorite and other chondrites may be explained by fractionation of Fe phases (magnetite and troilite). Low refractory element contents preclude mixing with lunar materials. This sample may be a preserved fragment of the Cl meteoritic component present in the lunar regolith. Its characteristics suggest that ancient meteoritic debris samples by the Moon may be significantly different from that captured by the present-day Earth.

Meyer, H. O. A. (Dept. of Geosciences, Purdue University, West Lafayette, Ind. 47907) and Tsai, H.-M.: 'Lunar Glass Compositions: Apollo 16 Core Sections 60002 and 60004', *Earth Planet. Sci. Lett.* **28**, 234–240.

Approximately 500 glasses between 1 mm and 125 μm in size have been analyzed from fourteen samples from the Apollo 16 core sections 60002 and 60004. The majority of glasses have compositions comparable to those found in previous studies of lunar surface soils; however, two new and distinct glass compositions that are probably derived in part from mare material occur in the core samples. The major glass composition in all samples is that of Highland Basalt glass, but it also appears that high-K Fra Mauro Basalt (KREEP) glass is more common at the Apollo 16 site than was previously thought. The relative abundance of glasses within the core samples is random in distribution: each sample is characterized by a particular assemblage and distribution of the constituent glass compositions.

Mints, R. I., Petukhova, T. M., Grokhovskii, V. I., and Shaldybin, V. P.: 'Metallography of a Fragment of Relic Iron Carried Out by the Soviet Automatic Station 'Luna-20', *Metallovedenie i Termicheskaia Obrabotka Metallov* **1**, 2–5. (1975)

Study of the structure of metallic fragments in lunar substance makes it possible to determine the effect of thermal, mechanical, and radiation factors on their formation. This is important in explaining the nature of iron–nickel alloys.

Mokeeva, V. I. (Geochem. and Anal. Chemistry Institute, Moscow, U.S.S.R.), Simonov, M. A., Belokoneva, E. L., Makarov, E. S., Ivanov, V. I., and Rannev, N. V.: 'X-Ray Study of Details of Structure and Distribution of Magnesium and Iron Atoms in Lunar and Terrestrial Olivines', *Geokhimiya* **1976** (1), 84–92. (1976)

Приведены новые данные прецизионного рентгеноструктурного анализа для четырех лунных оливинов из Моря Изобилия, лежащих по составу в пределах от 27,0 до 48,0 мол. % *Fa*.

Сделано сопоставление собственных и литературных данных по прецизионным рентгеновским исследованиям кристаллической структруы лунных и земных оливинов. Не наблюдается каких-либо характерных отличительных особенностей в деталях атомной структуры у лунных и земных оливинов. Существует явная тенденция к очень небольшому преимущественному вхождению атомов железа в структурные позиции M1. Коэффициент K_D, характеризующий распределение атомов магния и железа в позициях M1 и M2, колеблется в пределах $\pm 0{,}10$ от прямой $K_D = 1{,}10$ для всех составов и, по нашим данным, не зависит от железистости оливинов.

Morgan, J. W. (Enrico Fermi Institute and Dept. of Chemistry, University of Chicago, Chicago, Ill. 60637), Higuchi, H., and Anders, E.: 'Meteoritic Material in a Boulder from the Apollo 17 Site: Implications for Its Origin', *The Moon* **14**, 373–383. (1975)

Sixteen samples of Boulder 1 from Station 2 at the Apollo 17 site were analyzed by radio-chemical neutron activation analysis for Ag, Au, Bi, Br, Cd, Cs, Ge, Ir, Ni, Rb, Re, Sb, Te, Tl, U, and Zn. Two clast samples contain no meteoritic material and appear to consist of relatively pristine igneous rocks: an unusual, KREEP-rich pigeonite basalt of very high Ge content, and an alkali-poor coarse norite. Nine grey or black breccia samples contain a unique, Group 3 meteoritic component of Ir/Au ratio 0.65–0.82, which appears to separate into subgroups 3H and 3L on the basis of Ni, Ge, and Re content. It is quite distinct from the Group 2 component (Ir/Au – 0.46–0.54) that dominates at the Apollo 17 site.

The unique black-rimmed clasts from this boulder show striking compositional zoning. The cores of anorthositic breccia are very low in Rb, Cs, and U, and have a distinctive 5L meteoritic component (Ir/Au $\approx$ 1.1). The black rinds are 5- to 10-fold richer in Rb, Cs, and U and have a Group 3 meteoritic component. The cores may represent breccias formed in an earlier impact that became coated with alkali-rich ejecta during the event that produced the boulder.

Because of the rarity of the Group 3 meteoritic component at the Apollo 17 site, this boulder cannot represent ordinary Serenitatis ejecta, with their characteristic admixture of the Group 2 Serenitatis projectile. It may represent pre-Serenitatis material excavated from the fringes of the crater during late stages of the Serenitatis impact, but only lightly shocked and hence uncontaminated by the Serenitatis projectile.

Nunes, P. D. (U.S. Geological Survey, Denver, Colo. 80225) and Tatsumoto, M.: 'U–Th–Pb Systematics of Selected Samples from Apollo 17, Boulder 1, Station 2', *The Moon* **14**, 463–471. (1975)

Nine U–Th–Pb whole-rock analyses of selected brecciated materials from sample 72215 and one analysis of a pigeonite basalt clast from 72275 are presented. Both samples are from Boulder 1, Apollo 17. These data supplement previous Boulder 1 U–Th–Pb analyses of samples 72275 and 72255. U and Th concentrations indicate that most of the samples contain a moderate to large KREEP component. Samples containing the least KREEP are a noritic clast (72255,49; Civet Cat clast) and an anorthositic clast (72275,117). Evidence for the migration of Pb from Pb-rich matrix material into relatively Pb-poor clasts is presented for two clasts.

Most of the Boulder 1 data define a linear trend that intersects concordia at $\sim$3.9 and 4.4 b.y. when plotted on a U–Pb concordia diagram. The presence of one anorthositic clast distinctly off this trend indicates that a simple two-stage U–Pb evolution history is inadequate to explain all the data. Accordingly physical significance is only attached to the lower concordia intercept age of 3.9–4.0 b.y. The older concordia intercept age of $\sim$4.4 b.y. is interpreted to reflect an averaging of events both older and younger than 4.4 b.y.

The data sugest that significant differentiation and/or metamorphism occurred $\sim$4.2 b.y. ago. The age of this event, however, is not accurately defined by these data.

Ryder, G. (Center for Astrophysics, Cambridge, Mass. 02138): 'Lunar Sample 15405: Remnant of A Kreep Basalt–Granite Differentiated Pluton', *Earth Planet. Sci. Lett.* **29**, 255–268. (1976)

Large, coarse-grained fragments of granite, containing plagioclase, a silica polymorph, potash feldspar, and exsolved pyroxene, with minor ilmenite, a phosphate, Fe-metal, and troilite, occur in sample 15405. A similar coarse-grained clast type (KREEP-rich quartz-monzodiorite) has a similar mineralogy but contains more ilmenite, large phosphates, less silica, and lacks troilite. One unusual KREEPy olivine vitrophyre fragment is also present. All the other fragments in 15405 are of Apollo 15-type KREEP basalt; ANT-suite and breccia fragments are conspicuously absent. The groundmass of 15405, of a KREEP basalt composition, is vesicular with a variolitic texture and is interpreted as an impact melt. Except for the olivine vitrophyre, the fragments are believed to be the remnants of a shallow-level KREEP basalt–granite differentiated pluton, in which granite was produced as the residual liquid without involvement of immiscibility effects.

The large amount of melt required to produce the pluton, and the retention of the pluton's integrity from crystallization until the formation of the source boulder of 15405 suggest that KREEP basalt magma is not ancient ($\sim$4.3 b.y.), but was produced by the partial melting of the interior of the moon at around 3.90–3.95 b.y.; this conclusion is supported by the presence of KREEP basalt in soil breccia 15205, to the exclusion of other highland rock types. If this interpretation is correct, the source of Apollo 15-type KREEP basalt had a Rb/Sr ratio higher than anorthositic norite, commonly proposed as the source rock.

Ryder, G. (Center for Astrophysics, Cambridge, Mass. 02138), Stoeser, D. B., Marvin, U. B., Bower, J. F., and Wood, J. A.: 'Boulder 1, Station 2, Apollo 17: Petrology and Petrogenesis', *The Moon* **14**, 327–357. (1975)

Boulder 1, Station 2, Apollo 17 is a stratified boulder containing dark clasts and dark-rimmed light clasts set in a light-gray friable matrix. The gray to black clasts (GCBx and BCBx) are multigenerational, competent, high-grade metamorphic, and partially melted breccias. They contain a diverse suite of lithic clasts which are mainly ANT varieties, but include granites, basaltic-textured olivine basalts, troctolitic and spinel troctolitic basalts, and unusual lithologies such as KREEP norite, ilmenite (KREEP) microgabbro, and the Civet Cat norite, which is believed to be a plutonic differentiate. The GCBxs and BCBxs are variable in composition, averaging a moderately KREEPy olivine norite. The matrix consists of mineral fragments derived from the observed lithologies plus variable amounts of a component, unobserved as a clast-type, that approximates a KREEP basalt in composition, as well as mineral fragments of unknown derivation. The high-temperature GCBxs cooled substantially before incorporation into the friable matrix of Boulder 1.

The light friable matrix (LFBx) is texturally distinct from the competent breccia clasts and, apart from the abundant ANT clasts, contains clasts of a KREEPy basalt that is not observed in the competent breccias. The LFBx lacks such lithologies as the granites and the Civet Cat norite observed in the competent breccias and in detail is a distinct chemical as well as textural entity. We interpret the LFBx matrix as Serenitatis ejecta deposited in the South Massif, and the GCBx clasts as remnants of an ejecta blanket produced by an earlier impact. The source terrain for the Serenitatis impact consisted of the competent breccias, crustal ANT lithologies, and the KREEPy basalts, attesting to substantial lunar activity prior to the impact. The age of the older breccias suggests that the Serenitatis event is younger that 4.01 ± 0.03 b.y.

Ryder, G. (Smithsonian Astrophysical Obs., 60 Garden Street, Cambridge, Mass. 02138) and Basu, A.: 'Apollo 15 KREEP Basalt', *EOS: Trans. Am. Geophys. Union* **57**, 278. (1976)

Defocussed beam analyses of KREEP basalts from the Apollo 15 soil, drill core, and rock 15405 indicate that considerable variation in chemistry exists over and above that due to analytical errors or the non-representative character of fragments. In the Soil and drill core KREEP basalts, K_2O (wt.%) ranges from 0.48 to 1.97 (mean, $\bar{x} = 0.83$; standard deviation, $\sigma = 0.41$) and is positively correlated with an increase in Fe/Mg. SiO_2 ($\bar{x} = 51.4$, $\sigma = 1.4$), Al_2O_3 ($\bar{x} = 17.73$, $\sigma = 2.8$), FeO($\bar{x} = 7.2$, $\sigma = 1.3$) show less variation. KREEP basalts from rock 15405 have less chemical variation: K_2O ranges from 0.51 to 0.78, and is not strongly correlated with Fe/Mg. The KREEP basalts, especially those in 15405, have a considerable range of textures and grain size, including subophitic and variolitic varieties, and pyroxene grain lengths varying between fragments from means of ~1 mm to ~100 μ. No obvious relationship between texture and chemistry exists other than that K-rich varieties are mesostasis-rich. The large variation of K_2O but only moderate variation of FeO is at variance with a model in which near-surface crystal fractionation produces the different basaltic liquids, except perhaps for the case of the 15405 basalts. The chemical relationships instead support an origin by variable degrees of partial melting of a uniform source region, although a rigorous analysis is not yet possible. Therefore we do not support models for the origin of Apollo 15 KREEP basalt via crystallization in lava lakes produced by impact melting of older KREEP basalts, but interpret the observed compositions as direct extrusions from subsurface partial melting that occurred 3.95–4.0 b.y. ago. Some of the KREEP basalts may have been extruded into Mare Imbrium, and therefore later than the Imbrium event. There is no reason to believe that Apollo 15-type KREEP basalt is either pre-Imbrium or post-Imbrium; it is probably both, and bears no direct relation to the Imbrium event.

Schmitt, H. H. (Office of Energy Programs, National Aeronautics and Space Admin., Washington, D.C. 20546): 'Geological Model for Boulder 1 at Station 2, South Massif, Valley of Taurus-Littrow', *The Moon* **14**, 491–504. (1975)

It appears possible to establish a preliminary geological model for the origin and evolution of the breccias of Boulder 1 at Station 2 in the Valley of Taurus-Littrow based on firm and probable geological constraints. The crystallization of plagioclase and other ANT-suite phases now present as clasts appears to have occurred in the lunar crust about 4.5 b.y. ago during the 'melted shell stage' of lunar history as that history is presently modeled. The original rocks containing these phases, which now make up the gray competant breccias of Boulder 1, were greatly modified by impact processes during the 'cratered highland stage' and the early part of the 'large basin stage', up to about 4.0 b.y. ago. About 4.0 b.y. ago, pigeonite basalts with KREEP affinities appear to have been intruded into the pre-Serenitatis crust from which the light friable breccias of Boulder 1 were later derived.

During the large basin stage, three major dynamic events profoundly influenced the present character of the Boulder 1 materials. These events probably occurred as follows: (1) formation of gray competent breccia containing ANT-suite clasts in the hot ejecta blanket of an old large basin event, such as Tranquillitatis, that took place about 4.0 b.y. ago; (2) rebrecciation and redeposition of the gray competent breccia, mixed with light friable breccia and pigeonite basalt, in a relatively cool ejecta deposit, possibly produced by the northern Serenitatis event; (3) uplift and exposure of the Boulder 1 materials in the South Massif by the southern Serenitatis event about 3.90 b.y. ago.

Schultz, L. (Max-Planck-Institut fur Chemie, Mainz, Germany) and Signer, P.: 'Spallogenic and Trapped Noble Gases in Meteoritic and Lunar Breccias', *EOS: Trans. Am. Geophys. Union* **57**, 152. (1976)

Meteorites and lunar surface materials are exposed to high energetic particles which produce spallogenic nuclides in these rocks. The dependence of spallogenic production rates on shielding and target chemistry has been studied on meteorites and it is possible to deduce exposure ages of different clasts or xenoliths from their concentrations of spallogenic noble gas isotopes. We have measured He, Ne, and Ar in xenoliths from 4 gas-rich meteoritic breccias: Cangas de Onis (3 different xenoliths), Djermaia (9), St. Mesmin (12), and Weston (7). Both, in Weston and in St. Mesmin one xenolith of each was detected to have an exposure age higher than that of the other xenoliths. This is strong evidence that individual xenoliths have had a pre-exposure to galactic cosmic rays before compaction of the material to the breccia. Furthermore, lunar breccias containing solar gases have been studied (14301, 14307, 15015, 60016). In 15015 and 60016 two clasts have been found to differ in their spallogenic gas contents. Shielding or target chemistry variations cannot be account for these differences. Thus for meteoritic and lunar breccias the conclusion can be drawn that besides the irradiation of the compacted rock parts were preirradiated by galactic cosmic rays and the solar irradiation.

Soldatenkov, A. T. (P Lumumba University, Org. Chem. Dept., Moscow, U.S.S.R.) and Sytinskii, I. A.: 'Pre-Biological Synthesis of Amino-Acids and Their Search in Meteorites and Moon-Rocks', (Review or Biblio.) *Uspekhi Khimii* **45**, 329–353. (1976)

Дан обзор новых данных о различных способах предбиологического синтеза аминокислот и обнаружении очень малых количеств аминокислот в метеоритах и лунных породах. Представлен материал о возможных предшественниках этих аминокислот. Рассмотрен малоизвестный пока вопрос о вероятных механизмах образования аминокислот в условиях предбиологического синтеза.

Steele, I. M. (Dept. of Geophysical Sciences, The University of Chicago, Chicago, Ill. 60637): 'Mineralogy of Lunar Norite 78235; Second Lunar Occurrence of $P2_1$ ca Pyroxene from Apollo 17 Soils', *Am. Mineralog.* **60**, 1086–1091. (1975)

Thin section 78235,40 is a coarse (1–2 mm), highly-shocked norite composed of ~30 percent low-Ca pyroxene (En 78 Fs 19 Wo 3), ~55 percent Ca-rich plagioclase ($An_{93}Ab_6$, mol %; Fe = 0.04–0.09, Mg = 0.05–0.08, K = 0.08 wt %), 15 percent glass and traces of an SiO_2 mineral, Ca-rich pyroxene (En 50, Fs 7, Wo 43), Fe-metal (Co ~ 1.6, Ni ~ 1.7 wt%), troilite, Cl-apatite, REE-whitlockite, baddeleyite, chromite, and Nb-rutile (Nb-10.7 wt %). The numerous glass veins with vesicles result from shock melting of the norite. Layering is apparent and may result from a cumulate origin, and/or shock deformation. Re-examination of low-Ca pyroxene from coarse pyroxene-plagioclase fragments from Station 8 soils shows the second lunar occurrence of $P2_1ca$ symmetry, and it is inferred that 78235 pyroxene has this symmetry based on similarities between the two samples. This and the coarse grain size indicate a plutonic origin for 78235.

The 78235 pyroxene is the most magnesian of noritic pyroxenes from the moon, implying that it may result from early lunar differentiation. Noritic breccias are considered to be mixtures because they do not correspond to mineralogies of inferred plutonic norites such as 78235.

Stettler, A., Eberhardt, P., Geiss, J., Grogler, N., Maurer, P.: 'Distribution of K and Cl in Apollo 17 Orange Soil', (Abstract) *Helv. Phys. Acta* **48**, 493. (1975)

Die Anwendung der Ar^{39}–Ar^{40}-Methode auf Korngrössenfraktionen der exotischen Apollo-17-Probe 'orange soil' ermöglichte es, den Zeitpunkt der Abkühlung (3,70 × 10^9 a) und das Strahlungsalter (30 × 10^6 a) der Glaskugeln zu bestimmen. Gleichzeitig ergab das Ausgasungsverhalten der im Reaktor durch die Reaktionen $K^{39}(n,p)Ar^{39}$ und $Cl^{37}(n,\gamma\beta)Ar^{38}$ erzeugten Isotope Hinweise darauf, dass die flüchtigen Elemente K und Cl in den äussersten Schichten der Körner deutlich angereichert sind. Eine mögliche Interpretation hierfür ist, dass diese Elemente aus einer heissen Atmosphäre stammen, welche an den bereits abgekühlten Glaskugeln kondensierte. Als Quelle dieser Atmosphäre kommen vulkanische Aktivität oder Verdampfungsprozesse bei Meteoriteneinschlägen in Frage. Die stufenweise Extraktion ergab ferner für Ar^{39} und Ar^{37} Aktivierungsenergien von 44 und .57 kcal/Mol im Temperaturbereich 700–1000°C. Das Glas verhält sich somit gegenüber thermischer Diffusion im Kristall ebenso retentiv wie lunarer Anorthosit und irdischer Anorthit.

Vdovykina, V. G. (Acad. Sci. UKSSR, Gecchem. and Anal. Chem. Inst., Kiev., UKSSR) Vdovykin, G. P., and Turkina, L. F.: 'Origin of Moon Regolith', *Dopovidi Akademii Nauk Ukrainskoi RSR*, Seriya B. *Geologiya, Geofizika, Khimiyia ta Biologiya* **1975** (12), 1059–1062. (1975)

On the basis of the already published 30 chemical analyses of typical glasses of the Moon regolith samples brought by Luna-16, Luna-20 and the expeditions of Apollo, their main petrochemical peculiarities are considered in connection with the regolith origin. The petrochemical peculiarities evidence for a similar mechanism of the regolite formation in different regions of the Moon. The petrochemical data do not contradict a supposition on the regolith formation resulted from spraying and quick cooling of the substance drops during eruption. The processing of regolith is determined by explosions at meteorites impacts.

Wahlen, M., Niederer, F., and Geiss, J.: 'Solar Tritium in Samples of Lunar Rocks', (Abstract) *Helv. Phys. Acta* **48**, 493. (1975)

An einem von der Apollo-15 Mission zurückgebrachten Mondstein wurden mit einem speziell entwickelten Verfahren einige Schichten von *ca.* 1 mm Dicke von der Oberfläche abgetragen, und darin die Tritiumaktivität und der Edelgasgehalt gemessen. Aus den Messungen dieser Tiefenprofile kann ein Wert, bzw. eine obere Grenze für den Fluss energiereicher Tritonen abgeschätzt werden (kinetische Energie 10–100 MeV), die in Sonnenflecken produziert werden. Die Resultate werden mit früheren Tritiummessungen an Mondmaterial und mit den auf Satelliten gemessenen Flüssen energetischer ^{3}H- und ^{3}He-Teilchen verglichen.

Walker, D. (Hoffman Lab., Harvard University, Cambridge, Mass. (02138) Kirkpatrick, R. J., Longhi, J., and Hays, J. F.: 'Crystallization History of Lunar Picritic Basalt Sample 12002: Phase-Equilibria and Cooling-Rate Studies', *Geol. Soc. Am. Bull.* **87**, 646–656. (1976)

Experimental crystallization of a lunar picrite composition (sample 12002) at controlled linear cooling rates produces systematic changes in the temperature at which crystalline phases appear, in the texture, and in crystal morphology as a function of cooling rate. Phases crystallize in the order olivine, chromium spinel, pyroxene, plagioclase, and ilmenite during equilibrium crystallization, but ilmenite and plagioclase reverse their order of appearance and silica crystallizes in the groundmass during controlled cooling experiments. The partition of iron and magnesium between olivine and liquid ($K_D = 0.33$) is independent of cooling rate (0.5° to 2000°C/hr), temperature (1325° to 600°C), and pressure (0 to 12 kb). Comparison of the olivine nucleation densities in the lunar sample and in the experiments indicates that the sample began cooling at about 1°C/hr. Pyroxene size, chemistry, and growth instability spacings ('swallowtails'), as well as groundmass coarseness, all suggest that the cooling rate subsequently decreased by as much as a factor of 10 or more. The porphyritic texture of this sample, then, is produced at a *decreasing*, rather than a discontinuously increasing, cooling rate.

Wasilewski, P. J. (Astrochemistry Branch, Lab. for Extraterrestrial Physics, Goddard Space Flight Center, Greenbelt, MD. 20771) and Fuller, M. D.: 'Magnetochemistry of the Apollo Landing Sites', *The Moon* **14**, 79–101. (1975)

The magnetochemical synthesis, as presented, derives from an integration of the magnetic property systematics developed with corresponding bulk chemistry and petrology, and the results of mixing and reduction responses which feature in the production of the lunar regolith. Magnetochemical properties of the lunar soils are correlated with the Al/Si ratio and telescope spectral reflectivity curves. Magnetochemical diagrams utilizing χ_p (paramagnetic susceptibility $\simeq$ FeO) and I_S (saturation magnetization $\simeq$ Fe metal) serve to classify lunar samples, indicate the extent of mixing, and demonstrate that although reduction does take place in production of the regolith, the role of mixing is quite significant. The relative metal size distribution and magnetic stability for various rock types and soils of varying Al/Si values are reflected in the R_I (ratio of saturation isothermal remanence – I_R, to saturation magnetization – I_S) vs R_H (ratio of remanent coercive force – H_R, to coercive force – H_c) plot. All magnetic hysteresis loop parameters considered vary systematically according to the Al/Si values. All Apollo landing sites have distinct telescope curves correlated with petrology, chemistry, Al/Si values, and magnetic properties. Magnetic properties of sites not visited can now be reasonably estimated based on telescope reflectivity curves and orbital geochemical experiments.

Wechsler, B. A. (Dept. of Earth and Space Sciences, State University of New York, Stony Brook, New York 11790), Prewitt, C. T., and Papike, J. J.: 'Chemistry and Structure of Lunar and Synthetic Armalcolite', *Earth Planet. Sci. Lett.* **29**, 91–103. (1976)

A study of the chemical trends displayed by lunar armalcolites has been made in conjunction with single-crystal X-ray structure refinements of lunar and synthetic armalcolite in order to assess the possible importance of Ti^{3+} in lunar armalcolite and to characterize the effects of cation substitutions on the structure. The apparent cation deficiencies found in lunar armalcolites analyzed with the electron microprobe most likely reflect the presence of Ti^{3+}, although the existence of vacancies cannot be ruled out. Structure refinements of an Apollo 17 armalcolite are consistent with either interpretation. These results support experimental evidence suggesting the presence of Ti^{3+} in armalcolite and indicate that virtually all lunar armalcolites probably contain ~4–11 mol.% $Ti_2^{3+}Ti^{4+}O_5$ component in solid solution. The cation distribution in lunar armalcolite is essentially completely ordered. However, synthetic crystals quenched from near 1200°C have been found to retain significant cation disorder.

Wolfe, E. W. (U.S. Geological Survey, Flagstaff, Ariz. 86001): 'Geologic Setting of Boulder 1, Station 2, Apollo 17 Landing Site', *The Moon* **14**, 307–314. (1975)

Boulder 1 at Station 2 is one of three boulders sampled by Apollo 17 at the base of the South Massif, which rises 2.3 km above the floor of a linear valley interpreted as a graben formed by deformation related to the southern Serenitatis impact. The boulders probably rolled from the upper part of the massif after emplacement of the light mantle. Orbital gravity data and photogeologic reinterpretation suggest that the Apollo 17 area is located approximately on the third ring of the southern Serenitatis basin, approximately 1.25 times larger than the analogous but fresher Orientale basin structure. The massif exposures are interpreted to represent the upper part of thick ejecta deposited by the southern Serenitatis impact near the rim of the transient cavity. Basin ring structure and the radial grabens that give the massifs definition were imposed on this ejecta at a slightly later stage in the basin-forming process. There is no clear-cut compositional, textural, or photogeologic evidence that Imbrium ejecta was collected at the Apollo 17 site.

Wood, J. A. (Center for Astrophysics, Cambridge, Mass. 02138): 'The Nature and Origin of Boulder 1, Station 2, Apollo 17', *The Moon* **14**, 505–517. (1975)

The Boulder 1 breccias are similar in composition to other Taurus-Littrow massif samples and therefore probably derived from the same source, undoubtedly the Serenitatis basin. However, they are substantially different in texture from other Apollo 17 massif rocks, indeed are very nearly unique among the rocks returned by all Apollo missions. The boulder is set apart by its content of dark, rounded inclusions or bombs, up to several tens of centimeters in dimension, consisting largely of very fine, angular, mineral debris, welded together by a lesser amount of extremely fine-grained material that appears to be devitrified glass.

To account for these uncommon structures, a phase of the basinforming impact event is sought that would produce relatively small amounts of debris and deposit them on or near the basin rim. It is suggested that the components of the boulder might represent very early, high angle ejecta from the Serenitatis event, and that the dark breccia inclusions are accretional structures formed from a cloud of hot mineral debris, melt droplets, and vapor that was ejected at high angles from the impact point soon after penetration of the Serenitatis meteoroid. This small amount of early high-angle ejecta would have remained in ballistic trajectories while the main phase of crater excavation deposited much larger amounts of deeper-derived debris and melt-rock on the rim of the basin, after which the early ejecta was deposited as a cooler (~450°C) stratum on top. The matrix of this breccia gained its modest degree of coherency by thermal sintering as the capping stratum cooled. The boulder is a fragment of this layer, broken out and rolled to the foot of the South Massif ≤55 m.y. ago.

5. Electromagnetic Properties of the Moon

Banerjee, S. K. (Department of Geology and Geophysics, University of Minnesota, Minneapolis, Minn. 55455) and Mellema, J. P.: 'Early Lunar Magnetism', *Nature* **260**, 230-231. (1976)

A new method for palaeointensity has been applied to three subsamples of a single, 1-m homogeneous clast (72215) from a recrystallised boulder of lunar breccia. Samples from the clast have been dated by ^{40}Ar–^{39}Ar, Rb–Sr and U–Pb methods to yield a date of 4.0×19^9 yr as the age of boulder assembly. The new method has two desirable characteristics; first, its reliance on simulating the natural remanent magnetisation directly with a thermoremanent magnetisation; second, it includes a built-in monitoring device which detects thermally-induced sample degradation (oxidation, sintering and annealing), a common occurrence in lunar samples. We therefore provide here the first credible evidence that the strength of the ambient magnetic field at the Taurus–Littrow region of the Moon must have been about 0.4 oersted, 4.0×10^9 yr BP.

Banerjee, S. K. (Dept. of Geology and Geophysics, University of Minnesota, Minn. 55455) and Swits, G.: 'Natural Remanent Magnetization Studies of a Layered Breccia Boulder from the Lunar Highland Region', *The Moon* **14**, 473–481. (1975)

The average directions of natural remanent magnetization (NRM) of three texturally distinct layers (72215, 72255, and 72275) of a 2 m-sized breccia boulder were found to be the same, while the directions of their stable components of NRM were found to be widely divergent. One clast from 72275 yielded a stable NRM direction which was different from that of the matrix. Approximate paleointensity measurements showed that 72255 and 72275 could have obtained their stable remanence from an ancient magnetic field of the same magnitude. However, 72215 probably was magnetized by a magnetic field of a different intensity. We concluded that the coincident NRM directions owe their origin to a secondary imprint of less stable magnetization imparted during the assembly of the boulder at moderate temperatures (~450°C) on the South Massif. The stable directions, on the other hand, date from the last, higher-temperature (~770°C) magnetizing event experienced by the mineral and lithic components while they were part of the immature pre-Serenitatis regolith.

Brecher, A. (Dept. of Earth and Planet. Sciences, MIT, Cambridge, Mass. 02139): 'Textural Remanence: A New Model of Lunar Rock Magnetism', *Earth Planet. Sci. Lett.* **29**, 131–145. (1976)

In reexamining the accumulated magnetic data on lunar rocks, several common patterns of magnetic behavior are recognized. Their joint occurrence strongly suggests a new model of lunar rock magnetism, which appeals only to partial preferred textural alignment of the spontaneous moments of magnetic grains, without requiring the existence of ancient lunar magnetic fields. This magnetic fabric, mimetic to locally oriented petrofabric, gives rise to an *apparent* 'textural remanent magnetization' (TXRM). In order to account for the observed intensity of 'stable remanence' in lunar rocks, only a minute fraction (10^{-3} to 10^{-5}) of the single-domain iron grains present need be preferentially aligned. Several mechanisms operating on the lunar surface, including shock and diurnal thermal cycling, appear adequate for producing the required type and degree of magnetic alignment in all lunar rock classes. The model is supported by a wide variety of direct and indirect evidence and its predictions (e.g. regarding anisotropic susceptibility and remanence acquisition) can be experimentally tested.

Daily, W. D. (Eyring Research Inst., Provo, Utah 84601), Dyal, P., and Parkin, C. W.: 'Lunar Electrical Conductivity Profile from Magnetometer Network', *EOS: Trans. Am. Geophys. Union* **57**, 271. (1976)

The electrical conductivity of the lunar interior has been determined with a new analytical technique in which simultaneous data are used from a network of the lunar magnetometers: the Apollo 15 lunar surface magnetometer (LSM), the Apollo 16 LSM, and the Apollo 16 subsatellite magnetometer. From this network measurements of induced poloidal fields can be made over the lunar sphere, which are therefore representative of the whole-moon electrical current distribution. Magnetic field measurements were made during times when the Moon was at high latitudes in the geomagnetic tail lobes. Since in the lobes the plasma effects are minimal, the Moon has been modeled as a sphere in a vacuum. In the analysis many individual magnetic events are superimposed to obtain a single large transient with much better signal-to-noise characteristics than single events. The conductivity profile obtained from this 3-magnetometer technique is in close agreement with previous results from our 2-magnetometer analysis using the Apollo 12 LSM and Explorer 35 magnetometers. The conductivity increases rapidly from the surface to about 4×10^{-3} mhos/m at 300 km depth. At greater depths the conductivity increases more slowly to about 2×10^{-2} mhos/m at 800 km depth. A striking feature of the profile is the abrupt transition near 300 km depth where a knee occurs in the conductivity profile. This conductivity transition, the location of which corresponds closely to that of the lunar seismic velocity change reported by Nakamura *et al.* (1974) strongly implies structural or compositional changes at that depth.

Dolginov, S. S. (Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation, Izmiran, USSR Academy of Sciences, U.S.S.R.): 'On the Origin of Ancient Lunar Magnetic Fields', *The Moon* **14**, 255–261. (1975)

The maximum value of possible lunar dynamo-field in our epoch is estimated in the scheme of precession dynamo model. In the light of our notions on the evolution of the Earth-Moon system this scheme may account for the size and character of ancient lunar fields that resulted in magnetization of surface lunar rocks, as well as for the absence of lunar dipole field of paleomagnetic origin in our epoch.

Gold, T. (Center for Radiophysics and Space Res., Space Sciences Bldg., Cornell Univ., Ithaca, New York 14853) and Soter, S.: 'Cometary Impact and the Magnetization of the Moon', *Planet. Space Sci.* **24**, 45–54. (1976)

Collisions of comets with planetary bodies are capable of impressing patterns of magnetization onto them that match those observed for the Moon and possibly for Mercury. The ambient solar wind magnetic field is briefly but strongly enhanced as the large partially ionized cometary atmosphere is compressed against the planetary surface. Just at the time of peak field enhancement, the solid part of the comet collides with the surface and the compressed fields are permanently imprinted by shock magnetization.

Hindin, H. J.: 'Microwaves Help Make Moon Model', *Microwaves* **14**, 16. (1975)

With the help of earth-based radiometer measurements of lunar microwave brightness temperature (a measure of the natural electromagnetic emission at these wavelengths), a model has been made that simulates the upper 50 m of lunar crust.

Knott, K. (Space Science Dept, ESTEC, Noordwijk, The Netherlands): 'A Lunar Signature in the Geomagnetic Ap-Index', *The Moon* **14**, 49–57. (1975)

A study has been performed in an effort to detect a lunar signature in geomagnetic data. Ap-indices available for the period 1932–1972 have been used for this purpose. The data have been divided into some 500 lunar months which were superimposed in synchronism with the phase of the Moon. At or shortly after full Moon a peak appears which exceeds the average value by about 3 standard deviations. Possible explanations for the generation of geomagnetic disturbances by the Moon are given.

McCoy, J. E. (NASA/Johnson Space Center, Houston, Texas 77058), Anderson, K. A., Lin, R. P., Howe, H. C., and McGuire, R. E.: 'Lunar Remnant Magnetic Field Mapping from Orbital Observations of Mirrored Electrons', *The Moon* **14**, 35–47. (1975)

Areas of lunar surface magnetic field are observed to 'mirror' low energy electrons present in the normal lunar space environment. The ambient electrons provide, in effect, a probe along the ambient magnetic field lines down to the lunar surface for remote sensing of the presence of surface fields. This probe, unlike direct measurement by the magnetometer, does not require low altitude or a very stable (magnetotail) ambient field to provide a mapping of regions of occurrence of such fields. Use of the on-board vector magnetometer measurements of the ambient magnetic field orientation allows accurate projection of such mapping onto the lunar surface. Preliminary maps of the lunar surface magnetic areas underlying the orbit of the 'Particles and Fields Satellite deployed from Apollo-16' have been generated, obtaining 40% coverage from partial data to demonstrate feasibility of the technique. As well as providing independent verification of areas such as Van de Graaff already discovered in the magnetometer data. these maps reveal many previously unreported areas of surface magnetism. The method is sensitive to fields of less than 0.1γ at the surface. Application to the full body of available PFS-1 & 2 electron data is expected to provide complete mapping of the lunar surface for areas of magnetization up to latitudes of 35–40 deg. The surface field regions observed are generally due to sources smaller than 10–50 km in size, although many individual regions are often so close together as to give much larger regions of effectively continuous mirroring. Absence of consistent mirroring by any global field places an upper limit on the size of any net lunar dipole moment of less than $10^{10}\gamma$ km^3. Much additional information regarding the magnetic regions can be obtained by correlated analysis of both the electron return and vector magnetometer measurements at orbital altitude, the two techniques providing each other with directly complimentary measurements at the satellite and along the ambient field lines to the surface.

Srnka, L. J. (Lunar Science Inst., 3303 Nasa Rd. 1 Houston, Tex. 77058): 'Global Thermoremanent Magnetization of Planetary Lithospheres', *EOS: Trans. Am. Geophys. Union* **57**, 271. (1976)

The acquisition of thermoremanent magnetization (TRM) in a planetary lithosphere cooling in the field of an internal source dipole has been studied analytically, with the aid of Runcorn's magnetostatics theorem. A general expression is obtained for the global remanent dipole moment, which incorporates the dimensions, coefficient of TRM, magnetic susceptibility, and cooling rate of the crust as well as the strength and sign of the source dipole. For crustal thicknesses less than 0.1 planetary radii, the remanent moment is dominated by TRM components acquired in internal demagnetizing fields due to the finite permeability of the lithosphere, but is independent of the radial cooling rate. Using magnetic characteristics from lunar samples, an upper limit of $\sim 3 \times 10^{18}$ G-cm^3 is obtained for the Moon's remanent dipole moment, in good agreement with Apollo subsatellite observations. In fortuitous cases the global remanent dipole moment may be exactly zero.

Stephenson, A. (Inst. of Lunar and Planetary Sci., School of Physics, Univ. of Newcastle upon Tyne, Newcastle upon Tyne NE1 7 RU, UK): 'Self Reversal of Thermoremanent Magnetisation in Basalts and Global Lunar Magnetism', *Nature* **259**, 101–102. (1976)

By using magnetostatic theory which has already been applied to a simple model of a two-phase titanomagnetite particle – and, on a rather larger scale to the problem of the residual moment of the Moon – it can be shown that a magnetostatic interaction can indeed explain the results of Ryall and Ade-Hall.

Walbridge, E. (Dept. of Systems Engineering, University of Illinois, Chicago, Ill. 60637): 'Lunar Photoelectron Layer Dynamics', *The Moon* **14**, 115–121. (1975)

Possible waves and oscillations in the lunar photoelectron layer (PEL) are investigated. The steady state PEL is reviewed as a basis for discussing PEL motions. Magnetic fields are neglected, so that there are four possible wave modes to consider. The propagation through the PEL of the two electromagnetic modes is discussed. Positive-ion waves, the third mode, are dismissed and plasma waves are considered at length. It is concluded that there are no propagating waves in the PEL other than electromagnetic. However, there is a type of oscillation which appears to be new and which may not be strongly damped. With these oscillations, termed flight-time oscillations, the height of the PEL fluctuates as does the electric field. These oscillations appear to be analogous to the height oscillations of the vertical jet of water in a city park water fountain. If flight-time oscillations are not much damped then it would be simplest to interpret them as plasma oscillations continually driven by the upwelling photoelectron stream. A possible laboratory investigation of these oscillations is discussed. For the surfaces of the Moon and the planet Mercury, the flight-time oscillation frequency, ω_F, is found to be respectively $\sim 4 \times 10^6$ and $\sim 10^7$ rad s^{-1}. The PEL's of those surfaces may be in a state of continual vertical 'quivering' due to flight-time oscillations, or may be quiescent.

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

Binder, A. B. (Science Applications Inc., Tucson, Ariz.): 'On the Heat Flow of a Gravitationally-Differentiated Moon of Fission Origin', *The Moon* **14**, 237–245. (1975)

It is shown that the mean value for the heat flow of a gravitationally-differentiated Moon of fission origin is about 13 erg cm^{-2} s^{-1} and that the heat flow varies regionally from about 3 erg cm^{-2} s^{-1} to more than 45 erg cm^{-2} s^{-1}. These regional variations in the heat flow are caused by a non-uniform distribution of K, U and Th in the KREEP zone at the crust-upper mantle boundary and the redistribution of crustal materials and K, U and Th rich KREEP materials by basin-forming impacts. The scale of these regional variations is hundreds of km. The models presented are in accord with the Apollo 15 and 17 heat flow measurements.

Cameron, W. S. (Goddard Space Flight Center, Greenbelt, M.D. 20771): 'Manifestations and Possible Sources of Lunar Transient Phenomena (LTP)', *The Moon* **14**, 187–199. (1975)

Several different manifestations of lunar transient phenomena (LTP) have been reported. These include: (1) brightenings – both sudden and slow, (2) reddish – both bright and dull, (3) bluish – both bright and dull, (4) fairly abrupt dimmings or darkenings, and (5) obscurations, which may be accompanied by any of the other four manifestations. Approximately 200 lunar features exhibiting such anomalies have been reported at least once, but 80% of all observations are found in less than a dozen sites and 60% are found in about one-half dozen sites.

An observing program is being conducted for the Association of Lunar and Planetary Observers which is designed to monitor the LTP sites, the seismic epicenter sites and non-LTP comparison sites. It addresses the 'brightenings' category of observations and is designed to establish normal brightness of each observed feature for all phases of a lunation. It also seeks to establish a quantified 'seeing' scale. About one-half dozen observers have reported albedo measures (estimated from an albedo scale set up by each observer).

The most extensive new data on albedo versus age (phase of Moon) are for the crater Dawes. Several LTP effects have been discerned in Dawes.

In addition, seeing estimates, based on the behavior of a star's diffraction disk, provided some unexpected results when disk behavior is compared with other subjective estimates of seeing.

Conel, J. E. (Space Sciences Div., Jet Propulsion Lab., California Institute of Technology, Pasadena, Calif. 91125) and Morton, J. B.: 'Interpretation of Lunar Heat Flow Data', *The Moon* **14**, 263–289. (1975)

Lunar heat flow observations at the Apollo 15 and 17 sites can be interpreted to imply bulk U concentrations for the Moon of 5 to 8 times those of normal chondrites and 2 to 4 times terrestrial values inferred from the Earth's heat flow and the assumption of thermal steady state between surface heat flow and heat production. A simple model of nearsurface structure that takes into account the large difference in (highly insulating) regolith thickness between mare and highland provinces is considered. This model predicts atypically high local values of heat flow near the margins of mare regions – possibly a factor of 10 or so higher than the global average. A test of the proposed model using multifrequency microwave techniques appears possible wherein heat flow traverse measurements are made across mare-highland contacts. The theoretical considerations discussed here urge caution in attributing global significance to point heat-flow measurements on the Moon.

Florenskii, P. V. and Chernov, V. M.: 'Observations of Transient Phenomena on the Moon (From Materials of Native Observers). Second List', *Solar System Res.* **9**, 160–164. (1976)

More than 700 published observations of transient phenomena on the Moon have been cataloged. About 40 observations, found in the native literature, as well as published for the first time, are added to the preceding list. The reliability of the observations and the regularity of their distributions in time and in connection with external influences are discussed.

Langseth, M. G. (Lamont-Doherty Geological Obs. of Columbia University, Palisades, N.Y., 10964), Keihm, S. J., and Peters, K.: 'Revisions in the Apollo Heat-Flow Measurements', *EOS: Trans. Am. Geophys. Union* **57**, 271. (1976)

More reliable determinations of the thermal diffusivity of the lunar regolith to depths of two meters have been made using the long temperature histories recorded by the Apollo 15 (3.5 yr) and Apollo 17 (2.0 yr) heat-flow probes. An analysis of the downward attenuation of annual variations, which provides the most reliable indication of diffusivities, yields values in the range 0.73 to $1.0 \times 10^{-4} cm^2 s^{-1}$. Independent determinations of specific heat capacity and regolith density are used to calculate a range of conductivities of 0.9 to 1.3×10^{-4} W cm^{-1} K^{-1}, which is significantly less than the results of *in situ* heater experiments reported earlier. These results require a substantial downward revision in the heat flow values reported earlier to 2.2 μW cm^{-2} (22 mW m^{-2}) at the Apollo 15 landing site and 1.6 μW cm^{-2} (16 mW m^{-2}) at the Apollo 17 site. Analysis of effects of lunar topography on the surface heat flow have been made and shows that corrections due to topography are small compared to measurement errors at Apollo 15. At Apollo 17 a downward correction of about 20% is called for.

Subsurface conductivity contrasts can cause refraction of near surface heat flow. The influence of such refraction on these measurements near the edge of a mascon basin or the Taurus Littrow Valley is estimated, using simple models.

Revised values show a higher heat flow at Hadley Rille than at Taurus Littrow. The sense of this difference is the same as that of the surface abundance of heat-generating isotopes mapped by the orbiting gamma-ray experiment, suggesting a feasible correlation for extrapolating the observed values to obtain a global lunar heat flow.

The new analysis indicates only small revisions in the originally reported regolith temperature profiles. Therefore, the revised results remain in accord with Earth-based measurements of radio emissions from the Moon.

Misawa, K.: 'The Effects of the Background Moonlight in the Nightglow Photometry Measured During the Total Lunar Eclipse of 29/30 November, 1974', *Report Ionosphere Space Res. Japan* **29**, 162–166. (1975)

The effect of the background moonlight on the observation of two representative nightglow lines, [O I] 5577 and 6300 Å lines, was studied during the total lunar eclipse of 29/30 November, 1974. It was found that when the distance between the Moon and the direction of the photometer is 30° the measurement of the [O I] 6300 Å line (~45 R) is possible on a night with Moon age less than 4.7 days, and that when the distance is 50° the [O I] 6300 Å (~25 R) is measurable on a night with Moon age less than 5.7 days, and that the measurement of the [O I] 5577 Å line (~300 R) is little affected by the background moonlight for the distance (D) $\geq$ 30° for a night with Moon age less than 4.7 days and for $D \geq 50°$ for that less than 5.7 days.

Taylor, J. W. (Dept. of Chemistry, University of Wisconsin, Madison, Wisc. 53706): 'Spectroscopic Measurements of Surfaces Using Vacuum Ultraviolet Radiation', *The Moon* **14**, 201–207. (1975)

Recent research on surface properties of materials using X-ray and vacuum ultraviolet radiation suggest some relationships in common to lunar research. New and intense sources of vacuum ultraviolet continuum radiation may offer the possibility of probing the surface properties of lunar materials and may permit some experimental demonstrations of the surface phenomena observed on the Moon.

West, E. A. (Space Sciences Lab., NASA-Marshall Space Flight Center, Huntsville, Ala. 35812) and Fountain, J.A.: 'Thermal Diffusivity Measurements of Particulates Using the Differentiated Line Source (Applied to Studies of Lunar, Planetary or Asteroid Surfaces)', *Rev. Scientific Instruments* **46**, 543–546. (1975)

A method is described in which thermal diffusivity measurements can be made on particulate materials using the identical instrumentation as described in previous papers for measuring thermal conductivity. The measurements for the two properties can be made simultaneously, thus eliminating the changes in conditions when they are made separately. This system has particular application for studies of simulated lunar, planetary, or asteroidal surfaces in which laboratory measurements can be correlated with astronomical observations of thermal inertia. A representative set of data is shown which gives thermal diffusivity and thermal conductivity measurements on a particulate basalt in which the values for each temperature were taken simultaneously. A value for specific heat is calculated for measurements taken at each temperature.

7. Lunar Environment

Benson, J. (Dept. of Space Physics and Astronomy, Rice University, Houston, Texas 77001), Freeman, J. W., Jr., and Hills, H. K.: 'Bow Shock Protons in the Lunar Environment', *The Moon* **14**, 19–25. (1975)

Protons from the Earth's bow shock are observed by the Suprathermal Ion detector Experiment (SIDE) in two regions of the lunar orbit. The dawn region begins at the dawn side bow shock crossing and ends ~5 days later and the dusk region begins at ~2 days prior to entering the dusk side magnetosheath and ends at the inbound bow shock crossing. Dusk and dawn refer to a terrestrial coordinate system. The dominant contribution to the ion spectra observed by the SIDE in these regions is from particles with energies between ~750 eV q^{-1} and 3500 eV q^{-1}. 3500 eV q^{-1} is the upper limit of the energy range of the detector. Analysis of simultaneous data from the Explorer 35 magnetometer and the SIDE indicates that the observability of bow shock protons at the lunar distance is dependent on the configuration of the interplanetary magnetic field.

Borg, J. (Laboratoire Rene Bernas, Orsay, France), Comstock, G. M., Langevin, Y., Maurette, M., Jouffrey, B., and Jouret, C.: 'A Monte Carlo Model for the Exposure History of Lunar Dust Grains in the Ancient Solar Wind', *Earth Planet. Sci. Lett.* **29**, 161–174. (1976)

The theoretical motion of individual dust grains in the lunar regolith is analyzed by using a Monte Carlo statistical code where the variables are the mass and speed distribution of meteorites at the lunar surface and the geometrical shape of impact craters. From these computations the detailed irradiation history of the grains in the ancient solar wind is traced back, over a period of 4 billion years, as a function of the grain size. Then by combining this irradiation scheme with the result of solar wind simulation experiments, the time and depth dependent accumulation of solar wind effects in the theoretical grains (solar wind maturation) is inferred. Finally, the validity of these predictions is tentatively checked by discussing a variety of physical and chemical solar wind effects which are registered in the surface layers of lunar dust grains. Therefore these studies give a tentative scenario for the "maturation" of the lunar regolith with respect to solar wind effects, but they also reveal useful guidelines to deduce meaningful information from such effects. In particular, they suggest a "lunar skin" sampling technique for extracting dust grains in lunar core tubes which could help in deciphering the past activity of the ancient solar wind over a time scale of several billion years.

Freeman, J. W., Jr. (Dept. of Space Physics and Astronomy, Rice University, Houston, Tex. 77001) and Ibrahim, M.: 'Lunar Electric Fields, Surface Potential and Associated Plasma Sheaths', *The Moon* **14**, 103–114. (1975)

This paper reviews the electric field environment of the Moon. Lunar surface electric potentials are reported as follows:

Solar Wind – Dayside: ϕ_0 + 10 to + 18 V

Solar Wind – Terminator: $\phi_0 \sim -10$ to -100 V

Electron and ion densities in the plasma sheath adjacent to each surface potential regime are evaluated and the corresponding Debye length estimated. The electric fields are then approximated by the surface potential over the Debye length. The results are:

Solar Wind – Dayside: $E_0 \gtrsim 10$ V m^{-1} outward

Solar Wind – Terminator: $E_0 \sim 1$ to 10 V m^{-1} inward

These fields are all at least 3 orders of magnitude higher than the pervasive solar wind electric field; however they are confined to within a few tens of meters of the lunar surface.

Hodges, R. R., Jr. (The University of Texas at Dallas, Richardson, Tex. 75230): 'Formation of the Lunar Atmosphere', *The Moon* **14**, 139–157. (1975)

Measurements of ^{40}Ar and helium made by the Apollo 17 lunar surface mass-spectrometer are used in the synthesis of atmospheric supply and loss mechanisms. The argon data indicate that about 8% of the ^{40}Ar produced in the Moon due to decay of ^{40}K is released to the atmosphere and subsequently lost. Variability of the atmospheric abundance of argon requires that the source be localized, probably in an unfractionated, partially molten core. If so, the radiogenic helium released with the argon amounts to 10% of the atmospheric helium supply. The total rate of helium escape from the Moon accounts for only 60% of the solar wind α particle influx. This seems to require a nonthermal escape mechanism for trapped solar-wind gases, probably involving weathering of exposed soil grain surfaces by solar wind protons.

Hoffman, J. H. (The University of Texas at Dallas, Richardson, Tex. 75230) and Hodges, R. R., Jr.: 'Molecular Gas Species in the Lunar Atmosphere', *The Moon* **14**, 159–167. (1975)

There is good evidence for the existence of very small amounts of methane, ammonia and carbon dioxide in the very tenuous lunar atmosphere which consists primarily of the rare gases helium, neon and argon. All of these gases, except ^{40}Ar, originate from solar wind particles which impinge on the lunar surface and are imbedded in the surface material. Here they may form molecules before being released into the atmosphere, or may be released directly, as is the case for rare gases. Evidence for the existence of the molecular gas species is based on the pre-dawn enhancement of the mass peaks attributable to these compounds in the data from the Apollo 17 Lunar Mass Spectrometer. Methane is the most abundant molecular gas but its concentration is exceedingly low, 1×10^3 mol cm^{-3}, slightly less than ^{36}Ar, whereas the solar wind flux of carbon is approximately 2000 times that of ^{36}Ar. Several reasons are advanced for the very low concentration of methane in the lunar atmosphere.

Mukherjee, N. R. (Biotechnology and Space Sciences Dept., McDonnell Douglas Astronautics Co., Huntington Beach, Calif.): 'Solar-Wind Interactions: Nature and Composition of Lunar Atmosphere', *The Moon* **14**, 169–186. (1975)

The solar wind interacts directly with the lunar surface material resulting in an essentially complete absorption of the corpuscles producing no upstream bowshock but a cavity downstream from the Moon. The main source of neutral species of the atmosphere, except probably ^{40}Ar, is the solar-wind interaction products. The other sources which appear to be minor contributors to the atmosphere are the interaction products of cosmic rays, planetary degassing, effects of meteorite impacts and radioactive decays. Most of the hydrogen atoms derived from the solar-wind protons contribute to the atmosphere as hydrogen molecules rather than atoms. Only on the basis of the solar-wind protons, alpha particles and ions of oxygen and carbon, the atmospheric species concentration (cm^{-3}) near the lunar surface at 300 K are as follows: H_2 3.3 to 9.9×10^3; He 2.4 to 4.7×10^3; H 3.7; OH 0.25; H_2O 0.24; and O_2, O, CO, CO_2 and CH_4 in concentrations smaller than H_2. Whatever the source, the OH and H_2O concentrations in the atmosphere are about the same. The calculated concentrations are in good agreement with the observations by the Apollo 17 lunar surface mass spectrometer and the Apollo 17 orbital UV spectrometer. At the time of sample collection from the Moon, the hydrogen content in the trapped gas layer of the lunar surface material was partly as hydrogen atoms and partly as hydrogen molecules, but at the time of sample analysis hydrogen was mostly in molecular form. The H_2O content at the time of sample analysis was only a few parts per million by weight.

Prakash, A. (Lab. of Plasma Studies, Cornell University, Ithaca, N.Y. 14850): 'Magnetospheric Protons and Electrons Encountered by the Moon in the Plasma Sheet', *The Moon* **14**, 71–78. (1975)

During its passage through the geomagnetic tail, the Moon encounters the plasma sheet. Properties of plasma sheet electrons and protons, first detected at lunar distances by Explorer 35, are described. The electrons have a rapidly fluctuating non-Maxwellian energy distribution with a mean energy of several hundred electron volts and density ~ 0.2 cm^{-3}. The protons, of energy ~ 1 keV, were usually detected above the instrument background when flowing towards the Earth at ~ 200 km s^{-1}. Implications for migration of grains on the lunar surface are also pointed out and it is suggested that strong terrestrial polar winds in the early history of the Earth-Moon system may have caused some erosion of the Earth-facing side of the Moon, and that gravitational shielding of interplanetary rock flux by the Earth may also be an explanation of the relative smoothness of the front side.

Schneider, H. E. (Dept. of Space Physics and Astronomy, Rice University, Houston, Tex. 77001) and Freeman, J. W., Jr.: 'Energetic Lunar Nighttime Ion Events', *The Moon* **14**, 27–33. (1975)

The Rice University Suprathermal Ion Detector Experiment regularly observes ion events normally ranging from 250 eV q^{-1} to 1000 eV q^{-1} all through the lunar night. These ion events occur most often 2 to 3 days prior to the sunrise terminator. There is also a secondary activity peak 3 to 4 days after local sunset on the Moon. The events are normally of 4 hr or less in duration and the integral flux is 10^6 ions cm^{-2} s^{-1} $ster^{-1}$. This article discusses the character of these events and presents the preliminary findings of a detailed study begun on this subject.

Severny, A. B. (Crimean Astrophysical Observatory, Nauchny, Crimea, U.S.S.R.), Terez, E. I., and Zvereva, A. M.: 'The Measurements of Sky Brightness on Lunokhod-2', *The Moon* **14**, 123–128. (1975)

An astrophotometer was used for measurements of lunar sky brightness in visible and ultraviolet range during day and night. The data obtained showed unexpectedly high values of brightness during the lunar day in the visible region. From measurements during lunar 'twilight' conditions and from the dependence of excessive flux on cos $Z_{\odot}$ we have concluded that the effect is due to scattering of solar radiation by dust particles above the surface of the Moon. Some evidence in favour of dust clouds around the Moon is presented.

Zook, H. A. (NASA/Johnson Space Center, Houston, Tex. 77058): 'Hyperbolic Cosmic Dust: Its Origin and Its Astrophysical Significance', *Planet. Space Sci.* **23**, 1391–1397. (1975)

The heliocentric radial distribution of the flux of hyperbolic cosmic dust particles, as measured by the Pioneer 8 and 9 spacecraft, is closely related to the radial variation of the spatial density of source or "parent" meteoroids. Within the limits of the experimental and theoretical uncertainties the spatial density of parent meteoroids, as deduced from the hyperbolic cosmic dust data, is found to be increasing with increasing heliocentric distance in the neighborhood of one a.u. Other recent experimental evidence confirms this result. The new results also suggest that the ratio of the areal density of submicron sized craters to the areal density of millimeter sized craters will be less on the north–south faces of lunar rocks than on the east–west faces of the same rocks. The change in ratio is not as large as previously thought, however. Finally it is noted that the solar system is not presently contributing significant amounts of dust to the interstellar medium though it may once have done so.

8. General Reviews on Lunar Studies

Asimov, I.: 'The Face of the Moon', *Mercury* **5**, 14–18. (1976)

On no other planet in the solar system would a satellite appear so large as does our Moon when viewed from the Earth. This unique circumstance has profoundly influenced the progress of astronomy and has had a direct impact on the development of other sciences, philosophy and the arts.

Criswell, D. R. (Lunar Science Institute, Houston, Tex. 77058) and Freeman, J. W., Jr.: 'Summary of Conference on Interactions of the Interplanetary Plasma with the Modern and Ancient Moon', *The Moon* **14**, 3–17. (1975)

No Author Cited: 'Rockfest VII: Latest Word on the Early Moon', *Science News* **109**, 196–197. (1976)

A general review of the 7th Lunar Science Conference.

Schmitt, H. H. (Assit. Administrator, Office of Energy Programs, Code N, NASA, Washington, D.C. 20546): 'Evolution of the Moon: The 1974 Model', *Space Sci. Rev.* **18**, 259–279. (1975)

The geology of the decade of Apollo and Luna probably will become one of the fundamental turning points in the history of all science. For the first time, the scientists of the Earth have been presented with the opportunity to interpret their home planet through the direct investigations of another. Mankind can be proud and take heart in this fact.

The interpretive evolution of the Moon can be divided now into seven major stages beginning sometime near the end of the formation of the solar system. These stages and their approximate durations in time are as follows:

1. The Beginning – 4.6 billion years ago.
2. The Melted Shell – 4.6–4.4 billion years ago.
3. The Cratered Highlands – 4.4–4.1 billion years ago.

4. The Large Basins – 4.1–3.9 billion years ago.
5. The Light-colored Plains – 3.9–3.8 billion years ago.
6. The Basaltic Maria – 3.8–3.0(?) billion years ago.
7. The Quiet Crust – 3.0(?) billion years ago to the present.

The Apollo and Luna explorations that permit us to study these stages of evolution each have contributed in progressive and significant ways. Through them we now can look with new insight into the early differentiation of the Earth, the nature of the Earth's protocrust, the influence of the formation of large impact basins in that crust, the effects of early partial melting of the protomantle and possibly the earliest stages of the breakup of the protocrust into continents and ocean basins.

Wegener, A. (The University of Hamburg, Germany): 'The Origin of Lunar Craters', *The Moon* **14**, 211–236. (1975)

This important paper of Wegener's has virtually not been cited or recognized in the current literature, both American and German. It contains many interesting and early ideas on the origin of lunar craters, structure of the lunar surface, accretion of the Moon and Earth, origin of tektites, importance of impacts in early terrestrial history and the comparative tectonics of the Earth and Moon, as well as other topics. As with all translations, considerable freedom has been taken with the actual English words used, but it is hoped that the ideas and technical details are unchanged. In places where the translator was concerned about retaining the specific content, many rather cumbersome sentence structures are preserved. If there are passages of particular importance to the reader, it is recommended that the original text be consulted. Only three of the nine figures of the original text are reproduced in this translation, as the other six are unfortunately very poor quality photographic reproductions which cannot be reproduced any further. The reader who wish to see these figures need to refer to the original text also.

No Author Cited: 'Lunar Ranging Verifies General Relativity', *New Scientist* **70**, 13. (1976)

Six years of measurement of the movements of the Moon to an accuracy of 30 cm (about a foot, one part in a thousand million of the Moon's distance) have provided another confirmation of Einstein's theory of gravity, general relativity. The same measurements have pushed the best-motivated competing theory, Brans and Dicke's "scalar-tensor" theory of gravitation, somewhat nearer oblivion.

Wood, J. A. (Center for Astrophysics, Cambridge, Mass. 02138): 'Consortium Indomitable', *The Moon* **14**, 303–305. (1975)