BIBLIOGRAPHY

1. Motion of the Moon in Space and Dynamics of the Earth-Moon System, Lunar Astronautics

Frachtman, H. E. and Crowther, P. P. (ed.): 'Haystack Pointing System: Moon with Offsets', Contract AF 19(628)-5167, AD 686747 (March 1969).

This report describes the procedure used by the Haystack pointing computer program for obtaining the celestial coordinates of any point on the Moon at any time.

Bschorr, O. *et al.*: 'The Capture and Escape Behavior of Planet/Moon Systems (Das Einfang- und Katapolvermögen von Planet/Mond-Systemen)', NASA Technical Translation, NASA-TT-F-12330, (July 1969).

The flyby technique is an effective means of reducing thrust and time of interplanetary missions. The flyby behavior for planet/moon systems investigated in view of flights to planets. The velocity gains and the conditions for capture and escape are calculated. The maximum capture velocity of a Jupiter/Ganymede flyby is 4.5 km/sec. Probably, the irregular moons of Jupiter, Saturn and Neptune have been captured by a flyby process.

Musen, P.: 'Planetary Effects in the Motion of Natural Satellites', NASA-Technical Note-D-5284 (October 1969).

Addition of the direct and indirect planetary perturbations to the author's 1963 modification of Hansen's theory is proposed. The method described can determine the Saturnian effects upon the motion of the outer Jovian satellites. The expansion of the disturbing function and of its derivatives is reduced to a form convenient for programming.

Orlov, V. P.: 'Particles of the Lunar Origin. 1. The Determination of Elements of Geocentric Orbits of Lunar Particles in the Spatial Case', *Astron. Vestnik* **3** (1969), 76–81.

Elements are deduced of geocentric orbits of particles, ejected from the Moon by shock explosions of meteor bodies, as functions of primary conditions of the ejection: selenocentric longitude λ_0 and latitude φ_0, initial velocity V_0, azimuth A_0 and zenith distance δ_0 of the ejection direction.

It is shown that lines of nodes of geocentric orbits of the lunar origin particles are concentrated near the Moon position at the moment of the ejection of particles.

On the basis of deduced elements of geocentric orbits, the region of the lunar surface, from which a vertical flight of particles, coming to the Earth, is possible, is determined.

3. Shape and Gravitational Field of the Moon

Boyce, W. M.: 'Selenodetic Implications of Mascons', *Science*, **164** (June 6, 1969), 1189–1190.

The author presents the implications of the mascons for the selenodetic data analysis. For methods used in the past, the results are quite discouraging. As application of the method used for Earth satellites to the Moon data was disappointing, most emphasis was given to the 'direct method', in which the orbit parameters and coefficients of a truncated harmonic series are estimated simultaneously by a least-squares fit of the tracking data. With actual data available large systematic patterns remained in the data even after a 10th-degree fit. After the mascon discovery three principal approaches have been suggested. The author's calculations indicate that two of them, considering models up to the 15th degree, are inherently incapable of accurately representing the Moon-with-mascons gravity field close to the surface. The third approach suggests some sort of mixed model by extending the 'direct method' by a set of 'mascon parameters', which have to represent a mascon in agreement with its different interpretations.

J. W. S.

Campbell, M. J., O'Leary, B. T., and Sagan, C:. 'Moon: Two New Mascon Basins', *Science* **164** (June 13, 1969), 1273–1275.

Lunar gravity data and orbital photography indicate that there is a mascon basin approximately 1000 km in diameter on the farside of the Moon and that Mare Marginis is the flooded fraction of a mascon basin approximately 900 km in diameter.

Chujkova, N. A.: 'On the Distribution of Potential and Gravity on the Physical Surface of the Moon', *Astron. Zh.* **46** (1969), 1119–1123.

It is possible to find the distribution of potential and gravity on the lunar surface if both the external gravitational potential and the form of the surface are expansible in terms of spherical harmonics. Harmonics of all orders present in the external potential as well as in the shape of the Moon duly appeared in the expansion for the gravitational acceleration.

Compton, H. R. and Wells, W. R.: 'Determination of Lunar Equatorial Radius using Image-Motion Compensation Sensor Data from Lunar Orbiter 1', NASA-Technical Note-D-5231 (June 1969).

The telemetry data from the image-motion compensation sensor (V/H sensor) on the Lunar Orbiter 1 spacecraft were analysed to determine the radius of the Moon in the equatorial region from about 50° West to about 40° East selenographic longitude. The results indicate that over this region the lunar radii determined from these data vary from a minimum of 1734.6 km to a maximum of 1738.6 km. The arithmetic mean of these radii is 1736.5 km or about 1.5 km smaller than the mission planning value of 1738.09 km prior to the Ranger and Lunar Orbiter series of spacecraft. An asymmetrical bulge toward the Earth was noted in the general area of Sinus Medii. The values of the lunar radii were compared with those determined from a harmonic analysis, Ranger 8 impact analysis, radar measurements, and photogrammetric techniques. Except for the harmonic analysis, these radii are in good agreement with the Lunar Orbiter values.

Giacaglia, G. E. O.: 'A Semi-Analytic Theory for the Motion of a Lunar Satellite', NASA-Technical Note-D-5043 (June 1969).

The theory is developed to third order, where first order is 10^{-2}. Perturbative effects which are considered include those due to the attraction of the Moon, Earth and Sun, the nonsphericity of the Moon's gravitational field, the oblateness of the Earth, coupling of lower-order terms, solar radiation pressure, and physical libration. Short-period terms and those with the period of the Moon's longitude are produced by means of von Zeipel's method; it is proposed to obtain the secular perturbations, and those depending only on the argument of perilune, by numerical integration of the equations of motion.

Jones, R. L.: 'An Analytical Study of Lunar Surface Shape and Size from Lunar Orbiter Mission Photographs', NASA-Technical Note-D-5243 (June 1969).

A study of the Lunar Orbiter photographs is being conducted in order to yield a precise estimate of the lunar size and shape and contribute to the establishment of an accurate selenodetic system. A preliminary report on results obtained from mission I photography is presented, in addition to a discussion of the photogrammetric reduction techniques being utilised and the established film reading practices. Selenographic coordinates of many distinct lunar features were calculated with an expected uncertainty of ± 200 m by a digital computer program using film readings as input and are represented by computer-produced contour charts of the lunar sites. These machine-produced charts are found to be in agreement with isolated radii obtained independently with the use of the Lunar Orbiter V/H sensor (which had an expected uncertainty of $\pm$ 700 m). From a qualitative point of view, they are found to agree with Ranger tracking data. The arithmetic mean of approximately 2000 radii distributed between $\pm$ 45° longitude and $\pm$ 5° latitude was found to be 1735.7 km, whereas the two equatorial semiaxes were found to be 1736.6 km and 1734.2 km at 0° and 90° longitude, respectively. The results of the study suggest that the currently accepted value of the mean lunar radius of 1738 km is in error.

Makarenko, N. L.: 'A Geometrical Figure of the Marginal Zone of the Moon from Measurements of its Apparent Diameter in Greenwich', *Astron. Vestnik* **3** (1969), 135–141.

Parameters and orientation of an ellipsoid, representing a geometrical figure of the marginal belt of the Moon, are deduced from the reduction of Greenwich meridional measurements of apparent vertical and horizontal diameters of the Moon. The lunar ellipsoid obtained can be used for the reduction of observations of edges of the lunar disc in the case of various librations to the centre of a geometrical figure, i.e. to the centre of this ellipsoid.

O'Leary, B. T., Campbell, M. J., and Sagan, C.: 'Lunar and Planetary Mass Concentrations', *Science* **165** (August 15, 1969), 651–657.

Mascons beneath large circular basins may explain dynamical asymmetries in the Moon, Mars and Mercury.

4. Internal Structure of the Moon

McCrea, W. H.: 'Densities of the Terrestrial Planets', *Nature* **224** (October 4th, 1969), 28–29.

Recent determinations of the masses and radii of the planets may be interpreted as showing that the systems Earth-Moon-Mars and Mercury-Venus could have resulted from the break-up of two unstable planetary bodies of identical chemical composition. Thereby various features of planetary evolution would be elucidated.

6. Chemical Composition of the Moon

Classen, J.: 'Mondvulkanismus und Perlstein als Ursachen der Tektiteschauer', *Veröffent. Sternwarte Pulsnitz* (1969), No. 6.

Until now all theories have explained only partially the phenomena of tektike generation. All results gathered by observations may be explained by considering the tektites to be pearlstone-type meteorites arising from the interior of the Moon, and breaking into balls like Earth-borne pearlstone when entering the terrestrial atmosphere. Then the balls fall to the Earth in a dense bulk and can be found in the form of tektites.

Duke, M. B.: 'Surveyor α-Scattering Data: Consistency with Lunar Origin of Encrites and Hoardites', *Science* **165** (August 1st, 1969), 515–517.

Lunar Sample Preliminary Examination Team: 'Preliminary Examination of Lunar Samples from Apollo-11', *Science* **165** (Sept. 19th, 1969), 1211–1227.

A physical, chemical, minerological and biological analysis of 22 kg of lunar rocks and fines.

Nakamura, Y. and Latham, G. V.: 'Internal Constitution of the Moon: Is the Lunar Interior Chemically Homogeneous?' *J. Geophys. Res.* **74** (July 15, 1969), 3771–3780.

A procedure for constructing lunar models has been developed in which pressure, temperature, and compositional effects are taken into account. Pertinent lattice-dynamical relations are also incorporated. By using this procedure, a series of lunar models have been constructed based on the latest measurements on the physical properties of rock-forming minerals. Chemically homogeneous models thus constructed are found to have too high a density at the surface and probably too large a moment of inertia. We conclude that (1) there must be a concentration of lighter material near the surface of the Moon, and (2) the deep interior of the Moon is more likely to be chemically heterogeneous than to be homogeneous throughout although the possibility of chemical homogeneity cannot be ruled out judging from the current range of uncertainty of the moment of inertia of the Moon.

Reynolds, R. T. and Summers, A. L.: 'Calculations on the Composition of the Terrestrial Planets', *J. Geophys. Res.* **74** (May 15, 1969), 2494–2511.

Calculations based on mathematical models are performed to provide improved estimates of the major element chemical abundances within the Earth, Venus, Mars, Mercury, and the Moon. Approximate equations of state at high pressure for the important constituents of the terrestrial planets are constructed from experimental data and theoretical relations. Bounds on the amounts of these materials present within detailed self-consistent models of the terrestrial planets are calculated, subject to the assumption of additive partial molar volumes, and the sensitivity of the abundance calculations to variations in the primary assumptions is indicated. Representative models give calculated total Iron mass fractions of 0.38 for the Earth, 0.35 for Venus, 0.26 for Mars, 0.68 for Mercury and 0.13 for the Moon.

Turkevich, A., Franzgrote, E. J., and Patterson, J. H.: 'Chemical Composition of the Lunar Surface in Mare Tranquillitatis', *Science* **165** (July 18, 1969), 277–279.

More precise and comprehensive analytical results have been derived for lunar material at the Surveyor V landing site from α-scattering data. The composition is, in general, basaltic; the low sodium and high titanium contents, however, are distinctly different from the abundances in meteorites or common terrestrial rocks.

8. Lunar Coordinates and Mapping of the Moon

Lipsky, Yu. N. and Chikmachev, V. I.: 'A Cartographic Gridding of Photographs Received with the Automatic Interplanetary Station 'Zond-3' by the Method of Rectification by Orientating Points', *Astron. Zh.* **46** (1969), 643–651.

With a view to control the available maps of the far side of the Moon in the Sternberg Astronomical Institute Department of Physics of the Moon and Planets, a cartographic gridding of the Moon photographs Nos. 14, 18, 28 received with the automatic interplanetary station 'Zond-3' (1965) was carried out by the method of rectification on a spherical screen. Simultaneously with the receiving of correct images in which perspective distortions are practically eliminated, this method provides their cartographic gridding, i.e. plotting of a graticule of selenographic co-ordinates on a corrected image (a receiving of photomaps). The estimation of precision is carried out from values of the lack of matchings of images of a slide orienting points and appropriate points of a screen. The mean quadratic error of the position of objects of the photomaps obtained does not exceed 0.5°.

Lipsky, Yu. N.: 'Atlas of the Reverse Side of the Moon, Part 2'. Transl. into English of the Publ. *Aylas Obratnoy Storony Luny, Chast 2,* Nauka Press, Moscow, 1967, NASA-Technical Translation-F-514 (April 1969).

An atlas has been compiled of photographs and data derived from Zond-3 observations of the reverse side of the Moon. Discussed in the report are: (1) a description of the satellite and its flight to the

Moon: (2) details of the on-board phototelevision system: (3) extension of a single system of selenographic coordinates to the eastern section of the reverse side of the Moon: (4) analysis of photographs, compilation of a map, and catalog of formations discovered: (5) object identification in overlapping regions of photographs obtained by Luna-3 and Zond-3: (6) distribution density, size and shape of craters: (7) topographic features of selected objects: (8) photometric characteristics of selected objects; and (9) a brief global survey of the lunar surface. Also included are lists of names proposed for formations discovered on the reverse side of the Moon.

9. Morphology of the Lunar Surface

Carrière, G.: 'The Lunar Craters, Actual Magnetic Fossils (Les Cratères Lunaires, Veritables Fossiles Magnétiques)', NASA-Technical Translation-F-12460 (June 1969).

Mukhamedzhanov, A. K. and Stanyukovich, K. P.: 'Analysis of Statistical Data on Distribution of Craters and Stones on the Lunar Surface', *Astron. Vestnik* **3** (1969), 7–13.

The relationship between distribution of the smaller craters and distribution of stones on the lunar surface is investigated. From this analysis, is developed a method to determine the dynamic characteristics of the splinters covering the lunar surface now as a wreckage material when these splinters were thrown out on impact during the craters' formation. This method is used to study the firmness of the Moon's cover. Estimations given in the paper show that firmness of the Moon's cover already at several meters in depth (not more than 10 m) is approximately two orders higher than the tolerable static charge on the lunar surface which was confirmed by automatic interplanetary stations 'Luna-9' and 'Surveyor-I'.

Pohn, H. A. and Offield, T. W.: 'Astrogeology 13: Lunar Crater Morphology and Relative Age Determination of Lunar Geologic Units', Interagency Report, NASA-Contractors Report-101685 (January 1969).

Shemyakin, M. M.: 'On the Regularity in the Disposition and Sizes of Craters in Crater-Chains on the Moon', *Astron. Vestnik* **3** (1969), 65-75.

About 20 crater-chains on the visible part of the Moon were investigated by the author in 1960–1966. The following regularities are true for these chains: (1) centres of all craters in a chain lie on an arc of a circle or on a curve, very close to it; (2) diameters of craters change regularly, here there are three cases: (*a*) diameters decrease in the ratio $d_n/d_{n+1} = \sqrt{2}$ (in certain cases $d_n/d_{n+1} = 2$), (*b*) a part of craters submits to the same regularity, another part has an equal size, (*c*) all craters are equal; (3) distances between centres of craters change, for the most part, analogously to the variation of the diameter of craters. About 30 chains were investigated in regional zones and on the reverse side of the Moon. The same regularities were found here.

Symmetrical crater-chains are discovered: in the form of a necklace (near the walled plain Hipparchus), and in the form of a bird (on the reverse side of the Moon), where sizes of craters decrease regularly from the centre of a chain to the edges, as well as groups of chains.

The irregularity of size distributions of craters is noted for the investigated chains.

10. Origin and Stratigraphy of Lunar Formations

Adler, J. E. M. and Salisbury, J. W.: 'Behavior of Water in Vacuum: Implications for Lunar Rivers', *Science* **164** (May 2, 1969), 589.

The authors attempt to model in a vacuum chamber the process of aqueous erosion producing sinuous rills on the lunar surface under an ice blanket, as suggested by Lingenfelter *et al.* Their results show that ice will readily form in a vacuum to a sufficient thickness to allow liquid water to exist beneath it, as predicted. The model streams produced in vacuum did not, however, erode rille-like channels. The soil surface invariably displayed a hummocky appearance.

J. W. S.

Dorn, W. G. Van: 'Lunar Maria: Structure and Evolution', *Science* **165** (August 15, 1969), 693–695.

The Lunar maria are considered to have evolved as homologous, transient, gravity-wave systems from large impact craters on a crustal layer 50 km thick, fluidized from beneath by prompt, shock-induced melting inside an initially hot Moon.

Fisher, R.V. and Waters, A. C.: 'Red Forms in Base-Surge Deposits: Lunar Implications', *Science* **165** (Sept. 26th, 1969), 1349–1352.

Undulating dunelike deposits of surface debris, widespread over parts of the lunar landscape, are similar in form, but greater in size than base-surge deposits found in many mare volcanoes and tuff rings on Earth. The bed forms of base-surge deposits develop by the interaction of the bed materials with those in the current passing overhead. Therefore the 'patterned ground' produced differs from that formed by ballistic fallout.

Kane, J., Carucci, G., Turner, B., and McEntee, J.: 'Origin of Mascons, Maria and Sinuous Rilles' (letter to the Editor), *Nature* **224** (October 11th, 1969), 164.

An explanation of the origin of mascons, the location of which is correlated to that of sinuous rilles, is attempted.

M. D. M.

Mackin, J. H.: 'Origin of Lunar Maria', *Bull. Geol. Soc. Am.*, **80**, 735–748.

Lunar maria are not simply large lunar craters. Most craters have raised rims; most maria are bordered partly or wholly by broad zones of downwarping. A satisfactory theory for the origin of maria must provide a genetic link between the origin of the depression and the origin of the material which floors it. This paper advances the concept that the maria are the result of giant meteorite impacts with resultant magma formation, circumferential slumping, nuée-ardente eruption, and pooling in topographic low areas. Slumped rims of craters occur on craters with a diameter of 20 ± 5 km or larger. Terrestrial slumps can be shown to be caused by removal of lateral support and movement of the mass initiated by yielding near the base of the free face. Accepting the theory that most lunar craters were formed by impact, then craters over 20 ± 5 km in diameter, but not smaller, penetrated to depths where temperatures were such as to permit the rock to deform rapidly in the lower part of the crater wall. Slumps thus may provide a clue to the thermal gradient in the outer part of the Moon at the time of slumping. Craters 100 km or more in diameter appear to have slumped rims of such magnitude that magma formation and flow is indicated. Frothing of the magma (formation of nuées ardentes) in the low gravity and hard vacuum on the Moon seems likely, as has been demonstrated by laboratory experiments. Mare-scale eruptions indicate ignimbrites of thousands of cubic kilometers (same order of size as the largest terrestrial ignimbrites) and slumping of the St. Lawrence type. This concept implies that the typical mare is floored by a stratigraphic sequence consisting of: (a) the fall-back breccia and partly molten material of the first eruptive phase, (b) an ignimbrite representing the normal nuée-ardente phase of the same eruption, (c) ignimbrites representing younger eruptions elsewhere on the Moon, and (d) minor lava flows. Lunar ignimbrites explain differences in elevation of adjacent flat regions separated by mountains or crater rims; eliminate the necessity of individual feeders to furnish molten material to floor each crater as well as the surrounding plains by the same age and type of material; and allow the preservation, with reduced relief, of pre-existing topography ('ghost craters' and other compaction features common in ignimbrite terrains).

Marcus, A. H.: 'Distribution of Slopes on a Cratered Planetary Surface: Theory and Preliminary Applications', *J. Geophys. Res.* **74** (October 15, 1969), 5253–5267.

The distribution of slopes over any finite span on a surface excavated by primary impact craters is derived from a representation of the surface as a 'moving average' of impact events. The cumulants are always positive, and they are large for typical mare crater densities. In some cases the distribution can be approximated by a rapidly convergent Gram-Charlier type A series. The slope distribution has a much higher peak near zero slope and also has much heavier tails than a Gaussian distribution with the same variance. Under some conditions the slopes have approximately a symmetric stable distribution law with characteristic exponent one unit smaller than the crater diameter population index. Observations of slopes in Mare Cognitum are in good agreement with theory, if the validity of the photoclinometric data and the model can be accepted.

Mason, C. C.: 'Particle Size Distribution of Lunar Surface Material', *Bull. Geol. Soc. Am.* **80**, 587–594.

Previous analysis of the particle size distribution of lunar surface material has assumed a log-log particle size distribution. A distribution of this type means that, with no bounds set on particle size, the total volume of particles goes to infinity. If there are bounds set on particle size, the mode will be the size interval at one of the extremes. The author believes that this is a highly improbable size distribution and that a Gaussian size distribution is more realistic. Using a Gaussian particle size distribution and 50% porosity, plus a surface irregularity correction, the mean particle size at the Surveyor I site is 9.6 μ, and the mean particle size at the Surveyor III site is 54 μ.

Novikov, V. V.: 'The Structure and the Supposed Composition of Rocks of Bottoms of Young Lunar Craters', *Astron. Zh.* **46** (1969), 1115–1118.

Morphological analogies between the Kamchatka volcanic region and some lunar formations are given. The relative brightness distribution over the solar light spectrum in the spectral region up to 2.5 μ for volcanic covering and for some lunar parts is compared on the basis of results, obtained by the author during the Kamchatka expedition of 1967. It is concluded that there is lava covering in the bottom of young craters.

Ronca, L. B. and Green, R. R.: 'Statistical Geomorphology of the Lunar Surface', Boeing Scientific Research Labs. Document D1-82-0866 (May 1969).

When the lunar crater areal density (number of craters per unit area) is contoured on the lunar surface, it is evident that lunar craters are not distributed at random. The terra-mare dichotomy is clearly indicated and also the terrae themselves display nesting and parallelism of the contours. A mathematical 'nesting index' is defined, which varies from zero for a random set of contours to 1 for a perfect bull's eye. For the whole front face of the Moon, the nesting index of all craters of class 1 (fresh craters) is 0.77, class 2 (craters with blurred rims) is 0.87, class 3 (craters with broken rims) is 0.90, class 4 (ruined craters) is 0.85, and class 5 (ghost craters) is 0.72. When only the southern terrae are considered, the nesting index is 0.83 for craters of all classes, 0.71 for craters of classes 1, 2 and 3 combined and 0.26 for craters of class 1.

The relationship between the classes of craters (degree of erosion) is also not random. Craters of class 1 (fresh craters) and craters of class 5 (ghost craters) are common in areas of low crater density. If class 5 and 4 craters are excluded, the proportions of class 1 craters decrease with increasing crater density. This is explained by calling for two independent erosional processes. The first is *continuous* and reduces craters from class 1 to class 2 to finally class 3 and sometimes class 4. The second process is *discontinuous* and produces craters of class 5 and sometimes class 4. Micrometeoritic impacts and space weathering are probably the main causes of the continuous process: ballistic sedimentation, mare flooding, and seismic waves from mare-producing impacts are the main agents of the discontinuous process.

It can be shown that a newly formed crater will remain in class 1 for the length of time necessary for the crater density of that area to increase by a value, k. In practice k ranges from 6 to 24 craters per 58×10^3 km^2. It can be shown that such a process is described by a line of slope -1 when the logarithm of the percentage of class 1 craters is plotted versus the logarithm of the density of craters. Experimental points confirm the theoretical relationship. The position along this line of slope -1 of any lunar area is defined as the *geomorphic index*.

The values of the geomorphic indices on the lunar front face are contoured. The maria, as expected, have a lower value than the terrae and the terrae have nesting contours.

Geologically the phenomenon is explained by calling for two *processes of rejuvenation* of the lunar surface. The first, and most evident, is *mare flooding*, this process is able to bury the majority of craters of an area. The few craters that are left are of class 4 of 5 and, as such, do not enter in the calculations. On the newly formed surface, craters are soon formed and the continuous sequence begins. The geomorphic indices of the front-face maria, including the probable error, are presented. For the case of the maria it is likely that the geomorphologic indices are closely related to time indices, that is, geomorphologically younger maria were the most recent to be formed.

The second process of rejuvenation operated on the terrae. It can be shown that rejuvenation progressively decreases as one goes from a mare shore toward the center of the terrae. This suggests that the maria are genetically related to the rejuvenation. The hypothesis is presented that mare-producing impacts rejuvenate the environs of the impact locus by seismic waves and ballistic sedimentation. It can be shown that a mare-producing impact caused a moonquake exceeding magnitude 10, sufficient to considerable smooth the surrounding area.

Rejuvenation can also explain the nesting indices of the crater density contours, previously described.

Schumm, S. A. and Simons, D. B.: 'Lunar Rivers or Coalescent Chain Craters?' *Science* **165** (July 11th, 1969), 201.

Comments on a paper by Lingenfelter, Schubert and Peale, published in *Science* **161** (1968) 266, followed by a reply of Lingenfelter, Schubert and Peale.

M. D. M.

Shteinberg, G. S.: Defence Scientific Information Service. 'On the Origin of the Large Lunar Craters and Circular Maria'. Transl. into English from the Russian.

Ulrych, T. J.: 'Lead Isotopes, Lunar Capture and Mantle Evolution', *Nature* **224** (Nov. 22, 1969), 766–768.

Lead isotope data from young mantle derived volcanics suggest that the mantle is a two-stage system. The second stage was formed at the time of the global Anorthosite Event, and both events may have been caused by the capture of the Moon by the Earth.

11. Physical Structure of the Lunar Surface

Gold, T.: 'Apollo-11 Observations of a Remarkable Glazing Phenomenon on the Lunar Surface', *Science* **165** (Sept. 26th, 1969), 1345–1349.

Some glazing is apparently due to radiation heating; it suggests a giant solar outburst in geologically recent times.

Jaffe, L. D.: 'Strength-Density Relations in Particulate Silicates of Complex Shape and Their Possible Lunar Significance', *Science* **165** (September 12, 1969), 1121–1122.

Some terrestrial particulate silicate rocks with complex particle shapes have internal friction angles over 45° and cohesion of about 0.1 N per square centimetre at bulk densities of 0.6 to 0.8 g per cubic centimetre. Mechanical and other properties of the lunar surface layer, observed with spacecraft, may be consistent with a low bulk density and complex reentrant shapes for the fine particles.

Marcus, Allan H.: 'Application of a Statistical Surface Model to Planetary Radar Astronomy', *J. Geophys. Res.* **74** (September 15, 1969), 4958–4962.

A statistical model of the distribution of slopes and elevations on a cratered planetary surface is applied to scattering of radio waves by the Moon and Venus. It is found that the quasi-specular component of backscattered power can be fit by any symmetric stable distribution for elevation differences whose characteristic exponent is between 1 and 2 (crater diameter population index between 2 and 3). The lack of dependence on wavelength of the roughness parameter for decimeter and meter wavelengths, however, suggests that surface elevation differences have nearly a Cauchy distribution, not a Gaussian distribution. The increase of the roughness parameter with wavelength at millimeter and centimeter wavelengths suggests that pebbles and blocks are the major component of small-scale surface roughness.

Matsumoto, T.: 'Geometrical Properties of the Lunar Surface Deduced from Near Infrared Observation', Publ. Dept. of Physics, Nagoya University, Japan.

The phase dependence of lunar brightness observed in the infrared region is interpreted in terms of a fine ragged particle model of the lunar surface. By reference to experimental results on the phase dependences at Mare Serenitatis and at Tycho in the wavelength region from 0.6 μ to 2.2 μ, it is found that the phase dependence is less steep as the wavelength increases. This is explained by the predominance of forward and isotropic scatter at long wavelengths. Taking the Mie scattering of fine particles into account, Hapke's theory is modified. From this analysis it has been concluded that the most probable radius of the particle is 20 μ.

Murcray, D. G.: 'Lunar Surface Studies, Final Report, 17 May 1965–16 Jan 1969', Contract AF 19(628)–4797 (January, 1969).

This report presents the results of a number of investigations, the common goal of which was a better understanding of the lunar surface. These studies have included measuring the infrared emissivity of various areas of the lunar surface in the wavelength region from 7 μ to 14 μ with a balloon-borne system and laboratory studies of the behavior of various materials under simulated lunar environment. The laboratory studies have included the role of sintering in the mechanical properties of lunar surface, techniques for measuring the adhesive properties of fresh surfaces in a high vacuum environment, development of proton beams which can give reasonable proton fluxes in a high vacuum environment for the study of the effect of protons on lunar surface materials and finally the possibility of using X-ray topography as a tool for studying proton damaged surfaces.

Pellicori, S. F.: 'Polarizing Properties of Pulverized Materials; Application to the Lunar Surface', University of Arizona, Optical Sciences Center, Technical Report No. 42, July 25, 1969.

The degree of linear polarization from the Moon as a whole and from individual lunar topographic regions has been measured photoelectrically over the wavelength range 0.32 to 0.55 μ. To contribute to qualitative and quantitative understanding of the lunar surface (and, by comparison, planetary surfaces), a number of laboratory measurements were also made. In the laboratory studies, pulverized samples of volcanic lavas and of pure chemicals were investigated to determine how their polarizing characteristics are affected by particle size distribution, state of surface compaction, composition, wavelength, and phase angle.

It was found that the wavelength dependence of the polarization of the Moon (and of Mercury and Mars) can be explained by the increase in the mean internal optical path length in their particles with decreasing wavelength. With increasing optical path length, the proportion of the light scattered by the particle surfaces (giving high polarization) increases relative to the light scattered by the interiors (giving low polarization). The measurements on laboratory samples indicate that the lunar surface consists of particles of 20 to 35 μ size, which are somewhat translucent, not opaque. Pulverized basalt is a possible material.

Polarimetry provides information about the optical properties of remote surfaces that can be used to help deduce, by empirical comparison, particle size distribution, surface textures, and compositions. It is possible to detect the presence of a specific remote material whose polarizing properties are known. However, unambiguous identification of a mineral species by polarimetry alone is doubtful. Contrary to suggestions of other investigators, Brewster's law (Fresnel's reflection laws) is not applicable to the unambiguous determination of the effective refractive index of a diffusely scattering surface.

An automatic polarimeter, designed and built for the integrated moonlight measurements, is described in this report.

'Testing the Lunar Surface', *Nature* **223** (July 12th, 1969), 123.

Our knowledge about the lunar surface material on the eve of the Apollo mission is summarised, with a good outline of the Surveyor experiments.

M. D. M.

12. Photometry of the Moon

Chernov, V. M.: 'The Visibility of the Penumbra of the Earth during Lunar Eclipses', *Astron. Vestnik* **3** (1969), 166–169.

The condition of visibility of the penumbra of the Earth in a telescope corresponds to the average distance between the centres of the Moon and the penumbra equal to $r = 1.01$ of the radius of the latter and for the unnaked eye–when $r = 0.91$.

This distance does not depend on the eclipse brightness, and corresponds to intensity of 2–4 by Danjon's scale. This distance was largest during the lunar eclipse on June 24, 1964, near the middle of which the Moon was invisible.

The cause of the Moon's disappearance during eclipses on December 30, 1963 and June 24, 1964 could be intensive volcanic eruptions with ashes ejections in the regions of ascending flows in the Earth's atmosphere.

Pohn, H. A., Radin, H. W., and Wildey, R. L.: 'The Moon's Photometric Function Near Zero Phase Angle from Apollo 8 Photography', *Astrophys. J. Letters* **157** (September 1969), L193–L195.

A preliminary evaluation of the Moon's photometric function near zero phase has been obtained from Apollo 8 closeup photography.

The results indicate that the lunar reflected brightness is 19% higher at zero phase angle than at $1^\circ.5$ phase angle.

13. Thermal Emission of the Lunar Surface

Allen, D. A. and Ney, E. P.: 'Lunar Thermal Anomalies: Infrared Observations', *Science* **164** (April 25, 1969), 419–421.

The lunar craters Tycho, Copernicus, and Aristarchus have been observed during lunar night at wavelengths between 3 and 14 μ. After an initial fast decrease to a color temperature of 220K, the temperature remains nearly constant through the lunar night. The data suggest that these thermal anomalies (craters) contain hot and cold regions with the hot portions constituting 2 to 10% of the area and probably thermally connected to a subsurface temperature of about 200 K.

Goetz, A. F. H. and Soderblom, L. A.: 'Differences between Proposed Apollo Sites. 3: Far Infrared Emissivity Evidence', *J. Geophys. Res.* **74** (August 15, 1969), 4389–4394.

Infrared emissivity comparison spectra of nine areas on the lunar surface, each 40 km in diameter, indicate that the majority of the lunar surface, including the five Apollo sites, has a constant Si-O ratio so far as present infrared techniques are able to detect. However, an anomaly in the 8.2–9 μ region of the emissivity spectrum of the crater Plato is interpreted as evidence of a significantly different Si-O ratio in the mineral assemblage exposed on that surface.

McCord, Thomas, Johnson, Torrence V., and Kieffer, Hugh H.: 'Differences between Proposed Apollo Sites. 2: Visible and Infrared Reflectivity Evidence', *J. Geophys. Res.* **74** (August 15, 1969), 4385–4388.

The relative spectral reflectivity, 0.40 to 1.10 μ, was measured for 10- to 18-km-diameter lunar areas centered on the five prime Apollo landing sites. Though the spectral reflectivities of the Apollo sites appear typical of the lunar maria in general, significant differences were found among the five sites. The reflectivity differences are attributed to compositional and/or mineralogical differences in the lunar surface materials.

Murray, Bruce, C., Goetz, Alexander F. H., Kieffer, Hugh H., and McCord, Thomas B.: 'Differences between Proposed Apollo Sites', *J. Geophys. Res.* **74** (August 15, 1969), 4382–4384.

Recent observations of the spectral reflectivity and emissivity of the five prime Apollo landing sites are evaluated in the context of similar observations of other localities on the Moon and of data returned from unmanned lunar probes. We conclude that those five sites differ significantly only in minor constituents and/or relative valence states and that those differences are more modest than the differences that characterize mare regions generally. Recommendations of priorities for the five prime Apollo sites are made based on their uniqueness for sample return. Sampling of other lunar localities displaying anomalous emissivities and extreme color differences will be required to ascertain the full range of lithologies that constitute the lunar surface.

Starodubtsev, A. M.: 'Prolonged Measurements of the Lunar Radioradiation at 3.2 cm', *Astron. Zh.* **46** (1969), 652–654.

As a result of measurements of the lunar radioradiation, carried out by the method of 'the artificial Moon' at 3.2 cm during the period from 1964 to 1966 it was found that a constant component of the lunar effective temperature, averaged by the disc, is equal to $213.6° \pm 0.24$. The amplitude of the first harmonics of the lunation frequency is equal to $10.2\ \mathrm{K} \pm 0.37°$, and the phase lag of the radioradiation maximum from the full Moon is equal to $44° \pm 3.5°$.

Winter, D. F.: 'The Infrared Moon: Data, Interpretations, and Implications', Boeing Scientific Research Laboratories Document D1-82-0900 (September 1969).

Measurements of infrared radiation from the Moon are used to estimate the thermophysical properties of the lunar soil and to infer the general nature of small-scale surface relief. Directional emission characteristics of the illuminated surface are probably associated with small craters of recent origin. On the other hand, abnormal populations of exposed rocks are thought to be responsible for many of the localized thermal enhancements observed during an eclipse. Implications of IR measurements regarding the evolution of the surface are described.

14. Electromagnetic Properties of the Moon

Aledseev, V. A. and Krotikov, V. D.: 'Polarization Characteristics of Radio Emission of the Moon allowing for the Averaging Effect of a Knife Type Antenna Pattern', *Izv. Vysshikh. Uchebn. Zavedenii, Radiofiz.* **12** (1969), 5–8.

Blank, J. L. and Grobman, W. D.: 'Electrostatic Potential Distribution of the Sunlit Lunar Surface', NASA-Contractors Report-103636 (April 1969).

The steady-state lunar surface potential distribution is determined by the condition that the net current to a small surface area vanish, where the dominant currents are due to photoemission of electrons and collection of solar wind particles. The potential determined in this manner is insensitive to the detailed structure of the solar spectrum and depends parametrically on the photoemissive properties of the lunar surface. For a work function of 5.0 V and quantum yield of 0.01, the electrostatic potential during solar minimum decreases from 3.0 V at the subsolar point to less than a volt near the limb. Plausible ranges for the lunar quantum yield and work function are 0.001 to 0.1 and 4 to 6 V, respectively, which correspond to a range of potentials at the subsolar point from 0.6 to 10.2 volts. These values assume a solar wind electron number density and temperature of 5 cm^{-3} and 10^5K respectively. The results indicate that corrections to the ion energies measured by the ALSEP suprathermal ion detector experiment (SIDE) will be unimportant at energies above a few electron volts.

Fuller, B. D. and Ward, S. H.: 'Discussion of Paper by J. L. Blank and W. R. Sill, "Response of the Moon to the Time-Varying Interplanetary Magnetic Field"'.
Reply by J. L. Blank and W. R. Sill: *J. Geophys. Res.* **74** (October 1, 1969), 5173–5177.

Grobman, W. D. and Blank, J. L.: 'Electrostatic Potential Distribution of the Sunlit Lunar Surface', *J. Geophys. Res.* **74** (August 1, 1969), 3943–3951.

The steady-state lunar surface charge and potential distributions are determined by the condition that the net current to a small surface area vanish, where the dominant currents are due to photoemission of electrons and collection of solar wind particles. The lunar crust and photoelectron cloud are too resistive to carry a significant flux. A calculation similar to one used in collisionless electrostatic probe theory shows that the current from the solar wind is predominantly due to the electrons, is independent of potential, and is weakly dependent upon the polar angle θ measured from the moon-sun line. The calculation of the photoelectron current, which takes into account the spread in energies of electrons emitted by monoenergetic photons, determines the surface potential as a function of θ. The solution is insensitive to the detailed structure of the solar spectrum and depends parametrically on the photoemissive properties of the lunar surface. For a work function of 5.0 V and quantum yield of 0.01, the electrostatic potential during solar minimum decreases from 3.0 V at the subsolar point to less than a volt near the limb. Plausible ranges for the lunar quantum yield and work function are 0.001 to 0.1 and 4 to 6 V, respectively, which correspond to a range of potentials at the subsolar point from 0.6 to 10.2 V. These values assume a solar wind electron number density and temperature of 5 cm^{-3} and 10^5 K, respectively.

National Aeronautics and Space Administration: 'Conference on Electromagnetic Exploration of the Moon, 11–13 June 1968, Report of the Program Evaluation Committee', NASA Special Publication-174 (1969).

Rhee, J. W.: 'Lunar Dust Potential', University of Maryland, Dept. of Physics and Astronomy, Technical Report No. 70-015 (August 1969).

The equilibrium potential of a lunar dust particle is determined by the condition that the net current to the surface area vanish. The potential is found to range from +5 to +10 V, depending on the flux of solar wind particles and photoefficiency of the dust particles on the lunar surface.

Strangway, D. W.: 'Moon: Electrical Properties of the Uppermost Layers', *Science* **165** (September 5, 1969), 1012–1013.

Presently available data on the electrical conductivity of the uppermost lunar surface layers are in accord with the presence of dry, powdered rocks in which the dielectric loss tangent is frequency-independent over several decades of frequency. These powders have typical direct-current conductivity values of about 10^{-13} to 10^{-16} mhos per meter and dielectric constants of about 3.0, depending on the packing. Thus the surface layers of the Moon are likely to have an extremely low electrical conductivity. At high frequencies normal dielectric losses lead to much higher apparent conductivities that are frequency-dependent.

15. Exploration of the Moon by Spacecraft

Aganina, M. U. and Krasnopolsky, V. A.: 'Spectral Inhomogeneities of the Lunar Surface in the Middle Ultra-Violet Region from the Data of the Automatic Interplanetary Station "Zond-3"', *Astron. Vestnik* **3** (1969), 14–17.

For the study of colour inhomogeneities the investigated region of the back side of the Moon was divided into 11 parts with sizes of 500 km. For the 'colour' determination of each part in the middle ultra-violet spectrum region, are used the quantities, which are calculated according to formulae (1)–(2) as averages of their values at intervals of wavelengths 2100–2300 Å, 2340–2540 Å, 2560–2720 Å.

The average value of colour contrasts makes up 10%, maximal one is 24%. Apparently, small details of the surface can be distinguished by colour still more.

The investigated region of the Moon breaks up into 3 parts by average brightnesses. For all this the accordance between the brightness of the part in visible and ultra-violet regions is not observed. In particular, the part including Mare Orientale does not show the expected brightness dip in ultra-violet.

Beeler, M. and Michlovitz, K.: 'Lunar Orbiter Photographic Data', *Data User's Note*, NASA-NSSDC 69-05 (June 1969).

The primary purpose of this Data Users' Note is to announce the availability of Lunar Orbiter 1-5 pictorial data and to aid the investigator in the selection of Lunar Orbiter photographs for study. In addition, this Note can give some guidance to the interpretation of the pictures. As background information, the Note includes a brief description of the mission objectives and the photographic subsystem. The National Space Science Data Center (NSSDC) can provide all forms of photographs described in the section on Format of Available Data.

Hillenbrand, R.: 'The First Men on the Moon', *Sky and Telescope* **38** (September 1969), 144–149.

A brief account is presented of the unforgettable moment in which last year men stepped for the first time on another celestial body.

M. D. M.

'The Apollo 11 Experiment', *Sky and Telescope* **38** (September 1969), 149–151.

The four major tasks of the Apollo 11 mission, namely the collection of lunar material, the solar wind experiment, the detection of moonquakes recorded by the seismometers installed on the Moon and the laser experiment are briefly described.

M. D. M.

Jaffe, L. D.: 'Recent Observations of the Moon by Spacecraft', *Space Sci. Rev.* **9** (1969) 491–609.

Lunar flyby, orbiting and landing spacecraft in the last ten years have provided an excellent definition of the nature of the lunar surface, and important information about the lunar interior. Some of the major controversies concerning the Moon appear now to be resolved.

Latham, G., Ewing, M., Press, F. and Sutton, G.: 'The Apollo Passive Seismic Experiment', *Science* **165** (July 18, 1969), 241–250.

The first lunar seismic experiment is described.

Lisina, L. R.: 'The Moon (Luna)', NASA-Technical Translation-F-12309 (July 1969).

Advances in international studies of the Moon, based on abstracts published in the 1964–1965 issue of a Soviet abstracting journal, are reviewed. The review covers the figure, mass, and internal structure of the Moon, lunar cartography, topography, morphology, and radar observations. Lunik satellite observations of the far side of the Moon are noted.

McAllister, B. D., Kerr, J., Zimmer, J., Kovach, R., and Watkins, J.: 'A Seismic Refraction System for Lunar Use', *IEEE Trans. Geosci. Electronics* **GE-7** (July 1969), 164–171.

National Aeronautics and Space Administration: 'Log of Apollo 11', NASA-EP-72 (1969).

National Aeronautics and Space Administration: 'Manned Space Flight Network Reliability for a Lunar Landing Mission', NASA-Technical Memorandum-X-63563, (May 1969).

The reliability analyses are based primarily on failures experienced during flight support status. Previous analyses and predictions of MSFN reliability for supporting the lunar orbiting mission Apollo 8 were reported prior to the mission. This report presents similar predictions about the MSFN reliability for supporting the forthcoming lunar landing, which is scheduled for July 1969. The reliability predictions differ from the previous ones in that these predictions incorporate data from a larger number of missions; and consider the fact that two manned vehicles must be supported simultaneously during the phases when the LWM descends, lands and stays on the lunar surface, ascends, and docks with the CSM. These phases put the MSFN to a more severe use; however, the predictions herein indicate that the MSFN will be able to successfully support the mission.

Ogilvie, K. W. and Ness, N. F.: 'Dependence of the Lunar Wake on Solar Wind Plasma Characteristics', *J. Geophys. Res.* **74** (August 1, 1969), 4123–4128.

Simultaneous measurements in cislunar space of the characteristics of the solar wind plasma as observed by Explorer 34, and the perturbed magnetic field in the lunar wake as detected by Explorer 35, were performed during July–October 1967. The plasma parameter β_i for the ions is found to be more important in determining the magnitude of the umbral positive and penumbral negative anomalies than the direction of the interplanetary magnetic field. A quantitative comparison of these observations with the lunar wake theory of Whang indicates that the solar wind electrons must contribute even more significantly than the ions to the effective β for the plasma. Using the lunar wake as a *solar wind sock* for the electrons yields $\beta_e \sim 2\beta_i$, so that on the average the temperature of the electrons is directly determined to be $T_e/T_i \approx 2$ and the net effective β of the plasma is $\sim 3\beta_i$.

Wortz, E. C., Robertson, W. G., Browne, L. E., and Sanborn, W. G.: 'Man's Capability for Self-Locomotion on the Moon', Vol. II – Summary Report, NASA Contractor Report CR-1403 (September 1969).

This document presents the results of a comprehensive study of man's self-locomotive capabilities in simulated lunar gravity. An inclined-plane and a gimbal-vertical simulator equipped with treadmills were used to simulate lunar gravity. Man's locomotive characteristics and the metabolic costs of walking, running, and loping at velocities from 2 to 12.8 km/h were determined for subjects in pressurized Gemini-4C suits. The results showed that the energy cost of locomotion in simulated lunar gravity is considerably less than that in Earth gravity. Ascending grades caused large increases in metabolic cost over that of level walking where the magnitude of the cost depends on the simulation technique used. Increasing the load carried from 75 to 400 earth-pounds had a small and inconsistent effect on metabolic costs. Changing the smooth, hard walking surface to sandy soil caused a large increase in the metabolic cost at the higher locomotion rates.

'Lunar Timetable', *Nature* **223** (July 12th, 1969), 122.

Timing of the various operations of the anticipated Apollo 11 mission is given.

M. D. M.

'Pictures from Apollo 10', *Sky and Telescope*, **38** (August 1969), 90–94.

Pictures of several lunar features photographed during the Apollo 10 flight are presented with notes.

J.W.S.

'Moon Rocks' – First Results Published, *Nature*, **223** (Sept. 27, 1969), 1305–1306.

Results of the preliminary analysis by the Lunar Receiving Laboratory of the 22 kg of material returned from the Moon are reported and the chief conclusion is that the surface at Tranquillity Base is unlike any known terrestrial rock or meteorite. This is chiefly because of comparatively high concentrations of the elements Ti, Zr, Y and Cr, and because of low amounts of Na, K and Rb. Titanium oxide, for example, makes up roughly 10% by weight of the samples. The age of the samples determined by K/Ar dating indicates that the rocks crystallized some time between 3×10^9 and 4×10^9 years ago. Going by the presence of cosmic ray nuclides, the rocks have been no more than a metre beneath the surface for the past $20-160 \times 10^6$ years. The volcanic rocks contain typical gas cavities and recognizable minerals. One specimen is described as 53% clinopyroxene, 27% plagioclase, 18% opaque material chiefly ilmenite, 2% of other translucent material, and some olivine. Other volcanic rocks in the sample are less fine grained, with grain sizes going up to 3 mm. Typical composition for these medium grained rocks is 46% clinopyroxene, 31% plagioclase, 11% opaque material (again chiefly ilmenite), 5% crystobalite, and 7% of other material including an unidentified yellow mineral and a colourless phase of high refractive index. These rocks do not contain olivine. Many of the rocks have a rounded, eroded upper surface, but are flat or angular on the protected under side. Roughly half the returned material is classified as fine material – the lunar soil – consisting of glasses, plagioclase, clinopyroxene, ilmenite and olivine together with occasional spheres of nickel-iron. The glasses make up about half the fine material. The fine material contained two core samples, one of 10 cm and the other of 13.5 cm. There was no obvious change of particle size with depth in either case.

J.W.S.