BIBLIOGRAPHY

As was already mentioned in the Preface, an integral part of each issue of our journal should be a current critical bibliography of the entire field of lunar studies – an essential and truly indispensable service for a rapidly growing interdisciplinary domain of our science – containing titles, abstracts, or critical comments, on work published concurrently in all other journals or more informal sources.

This bibliography, which will appear quarterly (and thus much more rapidly than in any existing standard source) will cover our entire subject under the following more specific headings:

(1) Motion of the Moon in space, and dynamics of the Earth–Moon system; lunar astronautics.
(2) Motion of the Moon about its centre of gravity (librations).
(3) Shape and gravitational field of the Moon.
(4) Internal structure of the Moon.
(5) Thermal and stress history of the Moon.
(6) Chemical composition of the Moon.
(7) Lunar exosphere.
(8) Lunar coordinates and mapping of the Moon.
(9) Morphology of the lunar surface.
(10) Origin and stratigraphy of lunar formations.
(11) Physical structure of the lunar surface.
(12) Photometry of the Moon.
(13) Thermal emission of the lunar surface.
(14) Electromagnetic properties of the Moon.
(15) Exploration of the Moon by spacecraft.

Needless to say, the individual headings may sometimes overlap; and the reader will do well to consult the adjacent headings in quest of his sources.

The authors of papers or reports published currently in other sources are invited to send reprints (or preprints) of their contributions to the Editorial Office of our journal, to ensure that abstracts of their papers can be included promptly in our bibliography. When no indication to the contrary is given, the abstracts are due to the authors of the respective communication. Critical remarks – if any – will usually bear the initials of the respective editor.

The Editors express their appreciation to Dr. John W. Salisbury for supplying a part of the bibliographical material presented in this section.

1. Motion of the the Moon in Space

Bruman, J. R.: 'A Lunar Libration Point Experiment', *Icarus* **10** (March 1969), 197–200.

Photographs of the lunar libration point L4 were made during the lunar eclipse of 6 October 1968, using the 48-inch Schmidt telescope at Palomar Mountain, California. An area about 6.6° square was covered. Neither discrete objects nor clouds, associated with the L4 point, were found. The detection limit for discrete objects was at least 15th magnitude and probably 17th magnitude; for clouds, the limit was determined by short-term variations in the local pattern of night sky-glow.

Lazarev, R. G. and Shakhov, V. A.: 'On the Modulating Influence of the Moon on the Mass Distributions of Meteoroids', *Astronomical Circulars of the U.S.S.R. Academy of Sciences*, No. 501, 1969.

Link, F.: 'Occultations d'étoiles par la terre observées de la lune', *Icarus* **10** (January 1969), 105–108.

L'installation temporaire des observateurs sur la Lune, qui aura lieu dans le proche avenir, rendra possible la photométrie des étoiles pendant leurs occultations par la Terre. Le phénomène peut rendre de grands services dans l'exploration de la structure atmosphérique vers 100 km d'altitude où l'on est limité aux recherches par les fusées. La théorie photométrique des occultations est donnée dans un cas général ainsi que quelques applications numériques.

Lyttleton, R. A.: 'The Origin of the Moon', *Science Journal (London)* **5** (May 1969), 53–58.

Morrison, L. V. and Sadler, Flora McB.: 'An Analysis of Lunar Occultations 1960–66', *Monthly Notices Roy. Astron. Soc.* **144** (1969), 129–141.

About 10 000 observations of occultations of stars by the Moon have been reduced using the lunar ephemeris $j = 1$ with corrections for limb profile irregularities. The resulting observed minus tabulated positions of the Moon have been analysed and the following conclusions drawn:

(1) There is no significant difference between the duration of the E.T.1 second and the S.I. second. On this assumption the relation between the ephemeris and atomic time scales is

$$\text{E.T.1 (Newcomb)} = \text{A3} + 32^{\text{s}}.24 \pm 0^{\text{s}}.02 \text{ (s.e.)}.$$

(2) The following periodic terms are present in the observed minus tabulated positions of the Moon,

(i) in longitude $(+0''.173 \pm 0''.008) \sin l$
$(+0''.172 \pm 0''.008) \cos l$
(ii) in latitude $(-0''.207 \pm 0''.018) \cos F$
$(-0''.096 \pm 0''.014) \sin l$
$(+0''.355 \pm 0''.021) \cos L$

The first three terms can be interpreted as corrections to Brown's values of the eccentricity, longitude of perigee and longitude of node of the Moon's orbit.

(3) These values confirm that no significant corrections to the adopted values of the motions of the node and perigee are required.

(4) The observations reflect the small error $-0''\cdot 034 \sin(F-2D)$ in the Improved Lunar Ephemeris.

Mullins, L.: 'Viewing the Earth-Moon Lagrangian Points L4 and L5 from an Observation Balloon and from the ARM Using S-052', NASA STAR 7, No. 11, N69-23205, June 8, 1969.

O'Keefe, John A.: 'Origin of the Moon', *J. Geophys. Res.* **74** (May 1969), 2758–2767.

Recent geological discoveries suggest that the Moon originated during a catastrophic event, at a date near -3.5 b.y. It is here suggested that the event was the fission of the proto-Earth to form the Moon. It is shown that fission would be expected to lead, not to a pair of corotating bodies, as generally assumed, but to two bodies each rotating with approximately the angular velocity of the critical Jacobi ellipsoid, and revolving in a period about double the period of rotation. This fission process would conserve angular momentum and would approximately conserve energy and vorticity. It would be followed immediately by a period of severe energy dissipation, in which the two bodies would be brought to corotation. During this period, both bodies would be subjected to heating sufficient to volatilize their constituents. During this period, it is suggested that the system would resemble a contact binary. In particular, it is suggested that there would be a large loss of matter and of angular momentum from the proto-Moon. In this way is explained the small mass of the Moon relative to the mass of the Earth, the deficiency of the total angular momentum of the present Earth–Moon system, and the evidence of differential volatilization in the early history of the Earth.

Vanýsek, V.: 'Detectability of Lunar Libration Clouds at Small Phase Angles', *Nature* **221** (1969), 47–48.

Lunar libration clouds (LLC) have been observed visually and photographically as very faint nebulosities near the predicted positions of the Lagrangian points L4 and L5. All observations were made at relatively large phase angles $\theta \geqslant 140°$, mostly $\theta \sim 170°$, however, unless the particle diameters are very large, the phase function of lunar libration clouds will not follow the Lambert law or the lunar phase curve. The phase function has been computed for different models of polydisperse clouds of dielectric or absorbing spherical particles, for various size parameters and the size distribution function $\varphi(a) = a^{-4}$. From these results it is evident that successful observation of LLC4 and LLC5 may be expected at elongations of 15° and 30°, if the particles are not extremely large and if the refractive index is close to 1 for pure dielectric particles ($[n'/n-1] \leqslant 0.1$). The detectability of pure dielectric silicate or limonite grains at smaller phase angles is much less that that of ice, iron-like, or slightly absorbing spherical particles. The detection of intensity excesses in zodiacal light at the predicted points of L4 and L5 would be at least some indication of the dominant size of interplanetary grains in the lunar libration clouds. In regard to the twilight phenomena, extra-atmospheric observations in the visual spectral region are desirable. Ground-based observations in the near infrared should be successful, especially if the cloud contains slightly larger particles than considered in the set of models.

Vondrák, J.: 'Results of Measuring the Positions of the Moon by the Method of Equal Altitudes', *Bull. Astron. Inst. Czech.* **20**, No. 4 (1969), 223–226.

The paper gives a survey of the differences in observed and calculated zenith distances of the bright lunar limb. The measurements were performed at the Geodetical Observatory Pecný with a small circumzenithal in 1965–68. On the basis of these measurements a relation is derived between the Atomic Time *A3* and the Ephemeris Time and also a relation between the *TU2* time and the Ephemeris Time. The mean deviation of the Moon in latitude and the correction of the ephemeris radius of the Moon together with the personal error of the observer were calculated for each year as secondary quantities.

Результаты измерений положений Луны методом одинаковых высот. В статье приводится обзор разностей наблюдаемых и вычисленных зенитных расстояний освещенного края диска Луны. Измерения проводились на Геодетической обсерватории Пецны малым циркумзениталом в 1965–68 г. На основании этих измерений выводится соотвошение между атомным временем *A3* и эфемеридным временем и соотношение между равномерным временем *TU2* и эфемеридным временем. Как второстепенные величины были для каждого года получены среднее отклонение Луны в широте и поправка эфемеридного радиуса Луны вместе с личной ошибкой наблюдателя.

2. Motion of the Moon about its Centre of Gravity

Holland, R. L. and Sperling, H. J.: 'A First-Order Theory for the Rotational Motion of a Triaxial Rigid Body Orbiting an Oblate Primary', *Astron. J.* **74** (April 1969), 490–496.

New results are derived which predict the principal effect of the gravitational and magnetic torques on the rotational motion of an asymmetrical rigid body in a regressing orbit about an oblate primary mass. Using the method of averages, a first-order theory is developed and three integrals, which determine the motion of the angular-momentum vector, are derived. The solutions are periodic in a rotating coordinate system defined by the orbit plane and line of nodes. The results may be applied to astronomical problems of precession and the astronautical problems of artificial satellites.

Peale, S. J.: 'Generalized Cassini's Laws', *Astron. J.* **74** (April 1969), 483–489.

All of the possible stable, coplanar configurations of a planet's or satellite's spin vector, orbit normal, and the vector designating the precession of the orbit are shown to represent extremes in the energy associated with the body's orientation. It is shown that such a stable configuration yields a relation between the moment differences $(C-A)/C$ and $(B-A)/C$, and bounds on their magnitudes if the spin angular velocity is commensurate with the orbital mean motion. Only a value of $(C-A)/C$ is determined by a stable configuration for noncommensurate rotation. The effect of $(B-A)/C$ on the value of $(C-A)/C$ for the observed lunar configuration is less then the uncertainty introduced by observational error. Mercury is likely to be in one of two possible stable configurations. The value of $(C-A)/C$ as a function of the obliquity of the equator plane to the orbit plane is derived for both configurations, and the effects of axial asymmetry, although small for the likely values of $(C-A)/C$ for Mercury, are explicitly displayed for the entire range of $(C-A)/C$.

3. Shape and Gravitational Field of the Moon

Carlson, A. E., Jr. and Helmsen, M.: 'Validity of Topography Representation by Truncated Series of Surface Harmonics', *Icarus* **10** (1969), 57–65.

In a series of papers published in Icarus, Dr. C. L. Goudas has reported on the harmonic analysis of lunar topography. In his studies, the lunar topography was represented by a finite uneven distribution of elevations. For each sample of elevations he applied the unweighted least-squares method in estimating the best-fitting coefficients for a truncated series of surface spherical harmonics. This paper is concerned with the ambiguities of such estimates. The effects of changing the evenness and density of the sample of points on the estimated coefficients are shown by analyzing the correlations among the estimated coefficients, the degree of fit of the derived function, and the results of the orthogonality test.

Gavrilov, I. V.: 'Figure and Dimensions of the Moon on the Basis of Astrometric Observations', (in Russian), Ukrainian Academy of Sciences, Kiev, 1969, 1–150.

Характеристики фигуры Луны играют важную роль при решении многих теоретических и практических задач, связанных с всесторонним ее изучением как ближайшей цели межпланетных полетов.

Монография посвящена теории и практике современных астрономических измерений Луны и определению из них наиболее достоверных величин, характеризующих ее фигуру и размеры. Выведенные из наблюдений параметры фигуры сопоставляются с соответствующими теоретическими данными. Обсуждаются также некоторые вопросы физической интерпретации полученных результатов.

В книге впервые собраны воедино, проанализированы и систематизированы полученные до настоящего времени основные результаты измерений Луны и их обработки, опубликованные в разных работах. Существенную часть их составляют оригинальные исследования, выполненные в Главной астрономической обсерватории АН УССР.

Рассчитана на астрономов, геофизиков и научных работников смежных специальностей, занимающихся космическими исследованиями; будет полезна также аспирантам и студентам старших курсов соответствующих специальностей.

4. Internal Structure of the Moon

Urey, H. C.: 'The Contending Moons', *Astronaut. Aeronaut.* **7** (January 1969), 34–41.

Urey, H. C. and MacDonald, G. J. F.: 'Geophysics of the Moon', *Science Journal (London)* **5** (May 1969), 60–64.

6. Chemical Composition of the Moon

Armstrong, T. W. and Alsmiller, R. G., Jr.: 'An Estimate of the Prompt Photon Spectrum Arising from Cosmic-Ray Bombardment of the Moon', *Astronaut. Acta* **14** (1969), 143–149.

An estimate has been made of the photon leakage spectrum from the Moon due to photons arising from the capture and inelastic scattering of neutrons produced by galactic cosmic rays. The method of calculation consisted of estimating the energy and spatial distribution of the neutron flux in the Moon and then using Monte Carlo methods to obtain the photon source and to perform the photon transport. While the photon production and transport are carried out with some exactitude, the results must be considered very approximate because of the approximate neutron-flux distribution that is used. In particular, no attempt is made to account for the important effect which hydrogen in the lunar composition would have on the neutron-flux distribution.

Gilvarry, J. J.: 'Nature of the Lunar Mascons', *Nature* **221** (Feb. 22, 1969), 732–736.

The hypothesis that there was once water on the Moon can account for the lunar mass concentrations – mascons – recently deduced to be present beneath the circular maria.

Haymes, R. C.: 'Feasibility Study of Lunar Neutron Albedo Experiment', *NASA STAR* **7**, No. 8, N69-19320, April 23, 1969.

A feasibility study is made on the effect of the slow and fast neutron counting rates due to increases in water content. A lunar neutron simulator, consisting of neutron detectors and a fast neutron source, measures the effect of water concentration on the ratio using a basaltic material like that found on the Moon by the Surveyors. A sand-water mixture was also used in order to demonstrate the effects of differing elemental compositions in the sample. Data obtained using a 0.3% water content (by weight) in basalt indicate an increase of about 4% in the ratio over the 0.2% water content level. As expected from theory, the variation in ratio with water concentration is quite linear, for both samples tested. The only effect of variations in the elemental composition is to alter the slope of the line.

Lowman, Jr., P. D.: 'Composition of the Lunar Highlands – Possible Implications for Evolution of the Earth's Crust', *J. Geophys. Res.* **74** (January 1969), 495–504.

This paper is a theoretical investigation of the implications for the origin of the Earth's continents and ocean basins of three possible chemical compositions for the lunar highlands: ultrabasic, basic, and intermediate to acidic. Ultrabasic or basic lunar highlands would imply that the existence of sialic crust on the Earth is due to some major difference between the Earth and the Moon; the three most likely differences are presence of an atmosphere, presence of a core, and size. The theory that continents are essentially geosynclinal accretions is shown by recent geological investigations to have numerous weaknesses and may imply an age for the Earth of over 5 b.y. A proposed alternative is that large, thick primordial continents were formed by high-pressure magmatic processes caused by early segregation of the core, with later continental evolution being essentially subordinate accretion to and reworking of these protocontinents. A basic composition for the lunar highlands would imply that the basic crustal layers of the Earth are the remnants of a primordial basaltic crust. Sialic lunar highlands would imply that the Earth's continents are essentially igneous, and were derived from the mantle early in geologic time. Furthermore, the nearly global extent of the lunar highlands suggests that the Earth's crust has evolved by the growth of ocean basins rather than the growth of continents, perhaps by foundering of continental segments under flood basalts as proposed by Beloussov. A geochemical probe of Venus is recommended as an approach to further study of continent formation, because the nearly identical size and density of Venus would eliminate the variables of mass and core formation complicating the Earth-Moon comparison.

O'Keefe, J. A.: 'Water on the Moon and a New Nondimensional Number', *Science* **163** (Febr. 1969), 669–670.

A nondimensional number called the Jeffreys number, which represents the ratio of the Reynolds number to the Froude number, is useful in geophysical problems related to the motion of viscous masses under gravity. The Jeffreys number is used to show that it is impossible for the lunar maria to be underlain by a layer of material 1 kilometer thick having the plastic properties of ice.

Orowan, E.: 'Density of the Moon and Nucleation of Planets', Letter to *Nature* **222** (May 31, 1969), 867.

8. Lunar Coordinates and Mapping

Classen, J.: 'The First Maps of the Moon', *Sky and Telescope* **37** (February 1969), 82–83.

Goudas, C. L. and Higgins, T. P.: 'The DOD Selenodetic Control System and the Force Function of the Moon', *Astrophys. Space Sci.* **3** (April 1969), 490–517.

The figure of the Moon as defined by the DOD-66 Selenodetic Control System is first studied. Then, using the derived equation for the surface and adopting the density law $\delta = \delta_c + \alpha \varrho^p$, we have evaluated the volume integrals relating the form of the surface to the gravity harmonics.

Kopal, Z.: 'La Photographie de la lune à l'observatoire du Pic-du-Midi', *L'Astronomie* **83**, 115–129.

9. Morphology of the Lunar Surface

Baldwin, R. B.: 'Ancient Giant Craters and the Age of the Lunar Surface', *Astron. J.* **74** (May 1969), 570–571.

Several extremely large, very ancient lunar craters not previously described are pointed out. The conclusion is drawn that the surface of the Moon is in a steady state. Even the largest craters do not last indefinitely. Probably no portion of the lunar surface dates back as far as 4.5 billion years.

Fryer, R. and Titulaer, C.: 'Crater Statistics Near the Flamsteed P Ring', Communications of the Lunar and Planetary Laboratory, University of Arizona **8**, pt. 2, No. 133 (1969), 51–61.

Previous work on the population curves and crater distribution in the vicinity of Surveyor I is reviewed and extended. A total-population curve is derived for craters ranging in size from centimeters to kilometers. Comparison is made with Ranger data covering an equivalent diameter range. The floor of the low ring Flamsteed P is found to be usually young, younger than the surrounding mare; this is consistent with the recent hypotheses of O'Keefe and Fielder which regard the ring as a recent extrusive structure.

Hartmann, W. K. and Yale, F. G.: 'Mare Orientale and its Intriguing Basin', *Sky and Telescope* **37** (January 1969), 4–7.

Mare Orientale is described and a model for its formation is suggested. The authors propose that an asteroidal impact excavated the central basin, fractured the lunar crust around the structure, and spread the debris blanket. Long after, as radioactivity heated the lunar interior, magma broke out forming the mare areas of the structure; faulting and subsidence occurred until the structure of concentric rings was produced.

Öpik, E. J.: 'Cratering and the Moon's Surface', NASA-CR-99212 Report (January 1969).

Öpik, E. J.: 'The Lunar Environment', *Science Journal (London)* **5** (May 1969), 66–72.

Titulaer, C.: 'Crater Overlap on the Near-Side of the Moon', Communications of the Lunar and Planetary Laboratory, University of Arizona **8**, pt. 2, No. 134 (1969), 63–72.

An investigation of the overlap of craters on the front side of the Moon shows a well-defined anomalous area around Tycho. This Tycho Association of craters may have originated as a result of the collision of a cometary shower, the nucleus of which formed Tycho itself. Alternative explanations are also considered. No full explanation is possible without additional research.

10. Origin and Stratigraphy of Lunar Formations

Barricelli, N. Aa. and Metcalfe, R.: 'The Lunar Surface and the Early History of the Earth's Satellite System', *Icarus* **10** (January 1969), 144–163.

The hypothesis that most lunar craters and some of the maria are the result of impacts by meteors and larger celestial bodies colliding with the Moon has long been a favorite interpretation of these features.

If this hypothesis is correct, many of the structures visible on the lunar surface may be the result of early collisions with other Earth satellites. A method to discriminate between surface structures due to satellite impacts and other impacts is proposed, and several implications concerning the early history of the Moon and the satellite system of Earth are presented.

An interpretation of the predominance of maria on the side of the Moon which presently faces towards the Earth and their absence on the far side is obtained by considering that the Moon's distance from the Earth has been steadily increasing in the last few billion years. Under these conditions collisions with Earth satellites moving in orbits external to the Moon's own orbit are likely. The effect this may have on the distribution of maria, and the way in which our results can be used to interpret their present distributions are discussed in Appendices 1 and 2.

Donaldson, J. R.: 'The Lunar Crater Dawes', *Photogram. Eng.* **35** (March 1969), 239–245.

Many of the lunar craters probably were formed by meteoritic impact and many volcanic craters may have been stimulated by such an action. In addition, there are those such as Dawes that appear to be volcanic in origin, although this is not to say that a meteoritic impact could not possibly have started the chain of events leading to its present state of existence. But, in the absence of features associated with an impact, the crater Dawes is an outstanding example of endogenous origin. This hypothesis however, is not compatible with contemporary geologic interpretation, that lends itself more to an impact theory. Based on a geologic analysis of the area on a detailed basis relative to origin, a geologic map of the crater is suggested. Although this approach to the presentation of Dawes has its implicit ambiguities, it nevertheless stresses a map relating more to origin rather than to a fixed system correlating all craters with one theoretical approach.

Gilvarry, J. J.: 'Geometric and Physical Scaling of River Dimensions on the Earth and Moon', *Nature* **221** (Feb. 8, 1969), 533–537.

The absence of indications of mature lunar river systems is predicted by the scaling of river dimensions from the Earth to the Moon.

Guest, J. E. and Murray, J. B.: 'Nature and Origin of the Tsiolkovsky Crater on the Lunar Far Side', *Planetary Space Sci.* **17** (January 1969), 121–141.

The principal geological units which make up the Tsiolkovsky structure are defined and described, and their age relations and origin established wherever possible. From this evidence it is concluded that an impact origin is most likely for the main structure, but that later volcanic outbursts occurred. The most compelling evidence in favour of impact is the presence of a ring of high crater density at about one crater diameter from the rim; most craters in this ring are considered to be secondary impact craters. The strong circularity of the crater does not favour a caldera origin.

Some features of Tsiolkovsky are compared with other large lunar craters.

Novikov, V. V.: 'Stratovolcanos in the Lunar Mesorelief', *Soviet Astron.* **12** (1969), 891–894.

A partial statistical survey of cone-shaped formations on the lunar surface identifiable with terrestrial stratovolcanos has been made on large-scale photographs of the Moon. The locations where these structures occur are mentioned. Selected analogs among the stratovolcanos in Kamchatka are exhibited.

Ronca, L. B. and Green, R. C.: 'Large-Scale Evolution of the Lunar Surface', *Astrophys. Space Sci.* **3** (April 1969), 564–578.

The first part of the paper describes the relationship between the erosional stage of craters and the crater areal density. It is shown that class-2 and -3 craters are progressively more abundant as the crater areal density increases, while craters of class 4 and 5 are more abundant with decreasing crater areal densities. A geological model is proposed, in which the class of a newly formed crater is 1. As time progresses, erosional agents will increase the class of the crater to class 2, then 3, and, in some cases, to 4. The length of time between classification steps is not known in terms of years, but is equivalent to the time necessary for the crater density to increase by 2 to 8 craters per unit area for craters larger than 10 km, and by 10 to 20 for craters larger than 3.5 km. Craters of class 5 and some of class 4 are not formed by the same erosional agents, but are catastrophic, caused either by a mare-producing impact or by 'flooding' of mare material.

The second part of the paper presents a method for relatively dating large lunar areas. The method uses the model previously developed. A relative time sequence is constructed using the density of craters of classes 1, 2, and 3 and the percentage of these which is of class 1. As an example, 18 large areas are defined on the lunar near side and are put in temporal order. Mare Serenitatis appears to have the youngest terrain, and an area southwest of the Rupes Altai appears to have the oldest.

In the final part of the paper a geological model is developed in order to explain age differences in the terrae. The model calls for 'rejuvenation' of lunar terrains, caused by the seismic waves and ballistic sedimentation resulting from large impacts. The area surrounding Mare Orientale is cited as an example of a terrain so affected. A similar effect on the terrae of the near side could explain the apparent age relationships measured.

Wells, R. A.: 'An Introduction to the Martian Grid System', *Geophys. J. Roy. Astron. Soc.* **17** (1969), 209–224.

The linear features on Mars, commonly referred to as canals, have been mapped into two overlapping grid patterns – one oriented approximately NW-SE, NE-SW, and the other N-S, E-W. The tectonic aspects of the lineaments are discussed and comparisons of the grid patterns are made with the lunar grid system. These lineaments have been deduced to be tectonic zones of weakness. The grid patterns on Mars can be mapped through 360° of longitude. Similarities in the lunar and Martian diagonal grids suggest a similar origin for both systems. The presence of a N-S, E-W grid for Mars and the absence of one for the Moon indicates differences in tectonic activity between the lunar and Martian crusts.

11. Physical Structure of the Lunar Surface

Conel, J. E.: 'Infrared Emissivities of Silicates: Experimental Results and a Cloudy Atmosphere Model of Spectral Emission from Condensed Particulate Mediums', *J. Geophys. Res.* **74** (1969), 1614–1634.

Infrared emissivities of powered silicates are shown by experiment to contain new maxima and

minima that are representative of both composition and particle size. A cloudy atmosphere model for radiative transfer in a condensed powder is developed in which the scatter is considered to be both nonconservative and linearly anisotropic. The scattering parameters are computed as functions of frequency from the Mie diffraction theory. Detailed calculations of the spectral emissivity of quartz are presented. The model is shown to account for many features observed experimentally in the spectra of quartz powders and sand. Changes in the spectrum with particle size can be understood in terms of changes in the albedo for single scattering and the degree of forward scatter with particle size. The principal Christiansen frequencies of silicate powder films obtained from transmission measurements are shown to be diagnostic of mineralogy and to be frequencies of maximum emissivity for powders. The relationship is discussed in detail for quartz.

Conel, J. E.: 'What the Rangers revealed about Lunar Geology', *Astronaut. Aeronaut.* **7** (January 1969), 64–68.

Halajian, J. D. and Reichman, J.: 'Correlation of Mechanical and Thermal Properties of the Lunar Surface', *Icarus* **10** (March 1969), 179–196.

The infrared lunar nighttime temperature and bearing strength of postulated lunar materials, ranging from dust to porous rock, are correlated by means of common parameters such as porosity, particle of pore size, and degree of consolidation. The analysis is based on theoretical expressions of thermal conductivity and bearing strength of porous media in vacuo. Particular emphasis is given to the temperature dependence if thermal conductivity and to the relative contribution of its radiative and conductive components.

We found that there is a definite trend of increasing bearing strength with increasing lunar midnight temperature (T_m). Values of T_m less than 100K correlate with soft loose powders, while values of T_m more than 130K correlate with hard porous rocks. The correlation is ambiguous at intermediate T_m values (100–130K) because they correspond to a 'transition region' where the bearing strength of consolidated and unconsolidated media overlap. Surveyor 1 appears to have landed in such an area.

Some of the ambiguities in the correlation could be resolved by laboratory measurements of the thermal conductivity and bearing strength of porous media and by extending the analysis to include microwave thermal emission of the lunar surface. A crude but convenient method of 'mapping' the bearing strength of the lunar surface by remote means would appear to be the correlation of new and better-resolved thermal emission data for the dark side of the Moon with in situ thermal and mechanical measurements.

Hartmann, W. K.: 'Terrestrial, Lunar and Interplanetary Rock Fragmentation', *Icarus* **10** (March 1969), 201–213. Also in Communications of the Lunar and Planetary Laboratory, University of Arizona **8**, pt. 2, No. 136 (1969), 75–79.

Collected data are presented on mass distributions of fragmented rocks. These can be used to interpret extraterrestrial rock samples. Lunar surface material disturbed by Surveyors is broken in a way characteristic of low-energy, mechanical breakage, as expected. Debris around decameter-scale lunar craters with strewn rock fields also exhibits this property, suggesting that many such craters are secondary impacts. Centimeter-scale debris on the lunar maria shows evidence of extensive regrinding, probably due to repeated primary and secondary impacts, but such debris near Tycho appears not to have been so extensively ground; evidently this results from Tycho's young age. Telescopic asteroids have evidently been fragmented by attenuated shock waves in sporadic collisions, while meteorites are apparently the debris from repeated and/or hypervelocity collisions.

Hörz, F.: 'Structural and Mineralogical Evaluation of an Experimentally Produced Impact Crater in Granite', *Contr. Mineral. Petrol.* **21** (1969), 365–377.

A crater 30 cm in diameter and 4.4 cm in depth was produced upon impact of an aluminium sphere

with a homogeneous granite target. The volume excavated was 748 cm^3, the mass ejected 1933 g. The crater geometry is compared with previous laboratory experiments.

Mineralogical investigations revealed that shock induced, microscopic fracturing is lowest in the direction of uniaxial compression, followed by a 45° profile. Due to reflections of stress waves at the free surface, the horizontal profile displayed the highest fracture index.

Kinking of biotite was very common in samples close to the crater walls (≈ 50 kb). However it faded out at a distance which corresponds to approximately 10 kb. This seems to be the lower pressure limit for the formation of kink bands under shock conditions.

Jaffe, L. D.: 'Lunar Surface Material: Spacecraft Measurements of Density and Strength', *Science* **164** (27 June 1969), 1514–1516.

The relation of the density of the lunar surface layer to depth is probably best determined from spacecraft measurements of the bearing capacity as a function of depth. A comparison of these values with laboratory measurements of the bearing capacity of low-cohesion particulate materials as a function of the percentage of solid indicates that the bulk density at the lunar surface is about 1.1 g per cm^3 and that it increases nearly linearly to about 1.6 g per cm^3 at a depth of 5 cm.

Pellicori, S. F.: 'Polarization-Albedo Relationship for Selected Lunar Regions', *Nature* **221** (Jan. 11, 1969), 162. Also in Communications of the Lunar and Planetary Laboratory, University of Arizona **8**, pt. 2, No. 135 (1969), 73–74.

The polarization of several examples of 'pure' maria (dark and light), highlands and mountains has been measured in five passbands from 3360 Å to 5340 Å. Observations of the 30 sec of arc diameter regions were made with the lunar phase angle ($-107° \pm 1.5°$). The darker and lighter maria show approximately twice the polarization of that shown by the mountains and the highlands respectively. Other examples of these topographical types were measured at other phase angles and the same trends were found. These data suggest that there are differences in the mean internal optical pathlength of the particles that cover the different topographies.

Ulrichs, J. and Campbell, M. J.: 'Radiative Heat Transfer in the Lunar and Mercurian Surfaces', Cornell University Center for Radiophysics and Space Research Report No. CRSR 337 (May 1969)

Observations of the Moon and Mercury have shown that a temperature-independent conductivity is not adequate to explain the results; the available laboratory experiments on heat flow in powdered solids lead to the same conclusion and point to the importance of radiative (photon) processes of heat transfer. In this paper the validity of the usual approximate solutions to a simple model of heat transfer in powders by direct comparison with an exact numerical solution is examined. It is found that the approximate solutions can, under some circumstances, adequately describe the planetary observations provided cognizance is taken of the fact that emission is a volume, rather than surface effect; neglect of volume emission may have caused errors of 20K in the interpretation of lunar eclipse observations. It is also found that the usual approximate solutions give very misleading results when applied to certain laboratory measurements.

12. Photometry of the Moon

Classen, J.: 'Veränderungen auf dem Mond', Veröffentlichungen Sternwarte Pulsnitz (Sachsen), No. 5 (1969).

Since 1540, flares can be observed on the Moon. But it is only since 1958 that the opinion gathered way these flares being due to real processes. The flares are assumed to be processes of luminescence or perhaps lunar gas eruptions. The observations of the Moon, promoted recently above all in U.S.A., was limited by preference to the examination of the lighted area of the Moon. Based on a flare the observation of which succeeded in Pulsnitz, the author recommends to observe the ashy moonlight, too. Furthermore, comparison of lightness between Aristarchus and Kepler is proposed by him.

Evsyukov, N. N.: 'Distribution of Colour Index Over the Lunar Surface', *Soviet Astron.* **12** (1969), 876–878.

The dependence of the colour index $C = {}^{m}5700$ Å – ${}^{-m}6700$ Å on the angle i of incidence of sunlight is determined from the data given by Rackham. An analysis of this relation indicates that an additional emission of $0^{m}.2$–$0^{m}.4$ exists in the 6700 Å region. Its maximum falls near the subsolar point. This radiation is most likely produced by luminescence of the lunar surface.

Jones, M. T.: 'A Single Color Investigation into the Uniformity of the Light-Scattering Properties of the Lunar Surface', *Icarus* **10** (January 1969), 66–89.

To satisfy a need for new data from which to evaluate the uniformity of the photometric function over the lunar disc, a catalog is compiled of the relative brightness of 199 lunar features, as observed at phase angles of 2.1°, 17.5°, 32.5°, 46.2°, 59.4°, and 72.1° before full-moon, in the wavelength interval 5500 to 7000 Å. A full description is given of the photographic techniques used in obtaining the photometric data.

McCord, T. B.: 'Time Dependence of Lunar Differential Color', *Astron. J.* **74** (March 1969), 273–278.

Dependence of lunar spectral-reflectivity differences on time has been suggested, and two effects have been discussed: lunar luminescence, or low lunar emission of visible radiation over large lunar regions, and a systematic change of differential color with lunar phase angle. There is some support in the literature for the existence of lunar luminescence but the differential phase effect has not been found previously. An observational study was made by the author to determine the spectral-reflectivity difference (color difference) on the lunar surface in the 0.4 to 0.8 μ spectral region. The differential spectral-reflectivity curves were determined to an accuracy on the order of 0.1% for 83 lunar areas relative to a standard area; some areas were measured many times during several lunations. No luminescence was observed at any time. However, a clear dependence of differential color on phase angle was found with a change of about 2–3% over 90° phase. Color contrast becomes weaker near zero phase. Two possible mechanisms are discussed.

McCord, T. B.: 'Color Differences on the Lunar Surface', *J. Geophys. Res.* **74** (June 1969), 3131–3142.

An observational study was made to determine the spectral reflectivity differences (color differences) on the lunar surface in the extended visible wavelength region. A 21-filter (0.4–0.8 μ), double-beam photoelectric photometer was designed, constructed and used to observe differentially eighty-three areas (some areas being observed many times) to an accuracy of 0.1 to 0.3%. Many color variations were observed up to 10% with some to about 60%. Relative color was dependent on phase angle, but there was no temporally varying luminescence. The broad-band shape on spectral reflectivity curves suggested absorption features and possibly some less broad, low-amplitude (0.2–0.5%) humps. Spectral curve shape appeared dependent on lunar morphology, but there was no universal dependence of color on brightness. These results are interpreted as indicating that color differences are caused mainly by compositional differences and that the shape of spectral reflectivity curves may give some indication of the rock and mineral composition of the lunar surface.

13. Thermal Emission of the Lunar Surface

Alekseev, V. A., Drobova, L. V., and Krotikov, V. D.: 'Thermal Conditions of the Lunar Topsoil and the Integrated Radio Emission of the Eclipsed Moon', *Soviet Astron.* **12** (1969), 872–875.

The thermal conditions in the top surface layer of the Moon during the eclipse of December 30, 1963, are examined theoretically. The data on the thermal conditions are used to calculate the integrated radio emission of the Moon during the eclipse. It is shown that when interpreting experimental data no loss of accuracy will result if the averaging effect of the antenna beam is neglected and the theory developed for the radio emission from the centre of the disk of the eclipsed Moon is used.

Green, R. R.: 'An Analysis of the Distribution of the Major Surface Characteristics and the Thermal Anomalies Observed on the Eclipsed Moon', Boeing Scientific Research Laboratories Document D1.82.0775 (Jan. 1969).

A spherical harmonic method for trend-surface analysis of data distributed on a hemispherical surface is presented. The technique is applied in a study of lunar surficial variability in order to:

(1) Isolate regional from local variations in lunar surface phenomena;
(2) Obtain a mathematical expression for interpretation of map variables between control points;
(3) Quantitatively correlate similarities in configuration between maps of different variables; and
(4) Quantitatively compare regional variability or the same parameter in widely separated regions.

Correspondence between the distribution of lunar thermal anomalies and the (1) lunar albedo, (2) lunar figure, (3) distribution of average crater class, and (4) crater density is established. Contour maps and power spectra of these parameters are presented.

A working hypothesis consistent with the observed relationship is introduced. The hypothesis calls for sudden formation of thermal anomalies by cratering and gradual extinction by ballistic sedimentation and space weathering. The probability of a given crater producing an anomaly is related to the accumulated depth of detrital debris at the locus of formation. A stochastic model based on the hypothesis was constructed. Numerical evaluation of the model provides results which support the hypothesis.

Hunt, G. R. and Salisbury, J. W.: 'Mid-Infrared Spectroscopic Observations of the Moon', *Phil. Trans. Roy. Soc., Series A* **264** (1969), 109–140.

The authors present a detailed theoretical and laboratory experimental background for mid-infrared spectroscopic studies of minerals and rocks. All laboratory work and lunar observations to May 1966 (the date of the meeting, of which this paper was a part) are reviewed. The authors conclude that differences in emissivity of the lunar surface materials are detectable. Sometimes conflicting results of early workers are probably due to differences in technique and wavelength studied.

Murcray, F. H., Murcray, D. G., and Williams, W. J.: 'Infrared Emissivity of Lunar Surface Features, Part I. Balloon Borne Observations',
Salisbury, J. W., Vincent, R. K., Logan, L. M., and Hunt, G. R.: 'Infrared Emissivity of Lunar Surface Features: Part II. Interpretation', Lunar-Planetary Research Branch, Space Physics Laboratory, Air Force Cambridge Research Laboratories, Preprint.

The thermal emission spectra (7.0 μ to 13.5 μ) of 6 selected areas on the lunar surface were measured from an altitude of 31 km and spectral emissivities calculated. All spectra show departures from black or grey body emission. Emissivities in the 8.0–9.0 μ region of the spectrum are significantly higher than those for wavelengths greater than 10 μ. Differences are noted in the wavelengths of peak emissivity particularly between the highland areas and the Maria. The interpretation of the differences in terms of lunar composition is discussed in Part II.

Reber, E. E. and Stacey, J. M.: '1.4-mm and 3.4-mm Observations of the Lunar Eclipse on 18 October 1967', *Icarus* **10** (March 1969), 171–178.

Radiometric measurements of selected lunar areas are reported for the lunar eclipse of 18 October 1967. Observations were made simultaneously at 1.4 and 3.4-mm wavelength on a common largeaperture antenna forming independent half-power antenna beamwidths of 1.78 and 3.3 arc min, respectively. Within the precision of the measurement, as limited by atmospheric variations and radiometer noise, there is no statistically significant difference between the cooling rates of any two lunar areas measured at 1.4 mm. Similarly, there is no statistically significant difference between the cooling rates of any two lunar areas measured at 3.4.-mm.

Temperature changes and cooling rates observed at 3.4 mm are in fair agreement with those measured on the same areas observed at 3.2-mm during the 30 December 1963 lunar eclipse. The lunar areas measured during both eclipse events are Copernicus, Mare Serenitatis, and a mountainous region.

Rusch, W. V. T., Slobin, S. D., Stelzried, C. T., and Sato, T.: 'Observations of the Total Eclipse of October 18, 1967, at a Wavelength of 3.33 millimeters', *Astrophys. J.* **155** (March 1969), 1017–1021.

On October 18, 1967, radiometric observations of a total lunar eclipse were carried out at a wavelength of 3.33 mm from the Goldstone Tracking Station in the Mojave Desert of California. A decrease of 7% in the equivalent black-body disk temperature of the Moon was measured during the eclipse. The 1σ error is estimated to be 0.33% of the Moon temperature. Based on an equivalent black-body disk temperature of the full Moon of 280 K, this 7% decrease amounts to a temperature decrease of $[19.6 \pm 0.9(1\sigma)]$K.

Tikhonova, T. V. and Troitskii, V. S.: 'The Influence of the Heat Flux from the Lunar Interior on Lunar Radio Emission for Non-uniform Material Properties of the Lunar Crust' (in Russian), *Astron. Zh.* **46**, 159–172.

The theory of the constant component of the lunar radio emission in the presence of the heat flux out of the interior is considered for a plane-layer model of the upper surface structure. The calculation of two models is carried out:

(1) Dense rocks of the Moon are covered with a porous layer of the thickness a, within the limits of which the material density and thermal conductivity remain constant. On the lower boundary of the layer the material thermal conductivity changes by a leap of 300–500 times to the value of rock thermal conductivity.

(2) The density of a porous layer changes linearly from the value ϱ_1 on the surface to the value ϱ_2 at the depth a. The thermal conductivity changes linearly only up to the depth of the order $a/3$, and further on the rest part of the layer it increases sharply by 300–500 times to the value of the thermal conductivity of rocks.

The temperature variation into the depth due to the temperature dependence of the thermal conductivity are taken into account for both the models. The integral lunar radiation is found in both cases; the comparison with the experimental spectrum of the constant component is carried out. As a result, estimations for the thickness of the layer a and for the density of the heat flux out of the Moon's interior are obtained.

For the first model:

$$a = 400 \pm 100 \text{ (cm) and } q_s = 0.72 \times 10^{-6} \pm 0.08 \times 10^{-6} \text{ (cal/cm}^2\text{sec)}.$$

For the second one:

$$a = 1000 \pm 300 \text{ (cm) and } q_s = 0.94 \times 10^{-6} \pm^{0.16}_{0.12} \times 10^{-6} \text{ (cal/cm}^2\text{sec)}.$$

The most probable values of the layer thickness and the flux density lie apparently between these two extreme estimations.

Рассмотрена теория постоянной составляющей радиоизлучения Луны при наличии потока тепла из недр для плоскослоистой модели строения верхнего покрова. Проведен расчет двух моделей:

(1) плотные скальные породы Луны покрыты пористым слоем толщиной a, в пределах которого плотность вещества и теплопроводность остаются постоянными. На нижней границе слоя теплопроводность вещества меняется скачком в 300–500 раздо значения теплопроводности скальных пород;

(2) плотность пористого слоя меняется линейно до значения ρ_1 на поверхности до значения ρ_2 на глубине a. Теплопроводность меняется линейно лишь до глубины порядка $a/3$, а далее на остальной части слоя резко возрастает в 300–500 раз дозначения теплопроводности скальных пород.

Для обеих моделей учитывалось изменение температуры в глубину за счет температурной зависимости теплопроводности. В обоих случаях найдено интегральное излучение Луны и проведено сравнение с экспериментальным спектром постоянной составляющей. В результате получены оценки для толщины слоя a и для плотности потока тепла из недр Луны:

для первой модели

$$a = 400 \pm 100 \text{ см}, \quad q_s = 0.72 \times 10^{-6} \pm 0.08 \times 10^{-6} \text{ кал/см}^2 \text{ сек},$$

для второй модели

$$a = 1000 \pm 300 \text{ см}, \quad q_s = 0.94 \times 10^{-6} \pm^{0.16}_{0.12} \times 10^{-6} \text{ кал/см}^2 \text{ сек}.$$

Истинные значения толщины слоя и плотности потока, скорее всего, находятся между этими, по-видимому, крайними оценками.

Winter, D. F. and Saari, J. M.: 'A Particulate Thermophysical Model of the Lunar Soil', Boeing Sci. Res. Laboratories Document D1-82-0725; Also in *Astrophys. J.* **156** (June 1969), 1135–1151.

Calculations based on several thermophysical models of the lunar soil are compared with recent observations at far infrared wavelengths; none of the models reproduces simultaneously the lunation nighttime and eclipse cooling measurements. A new particulate thermophysical model of the lunar soil is described which utilizes results from the Surveyor spacecraft and from laboratory experiments with evacuated powders. The new model gives good agreement with both lunation and eclipse data in the far infrared and is consistent with measurements of lunar brightness temperatures at millimeter wavelengths. Particulate models are also used to determine the diurnal variation of the infrared surface brightness temperature of the 'hot pole' of Mercury.

14. Electromagnetic Properties of the Moon

Blank, J. L. and Sill, W. R.: 'Response of the Moon to the Time-Varying Interplanetary Magnetic Field', *J. Geophys. Res.* **74** (Febr. 1969), 736–743.

The solar wind plasma on the sunlit side of the Moon is apparently energetic enough to confine any lunar magnetic fields within the lunar surface. Accordingly, the effect of the confining solar wind currents is represented by imposing a surface current at the moon-solar wind boundary, and the induced magnetic field in the lunar interior is calculated as a function of frequency for a simple core-crust model. The solution provides a method for estimating the electrical conductivity, and thus for obtaining information on the temperature, of the lunar interior from magnetic field measurements at the lunar surface.

Griffel, D. H.: 'Induced Fields in the Moon', *Planetary Space Sci.* **17**, 685–691.

The time-dependent magnetic field induced inside a rotating spherical conductor by external sources is calculated. If the sphere spins rapidly, and the applied field is along the spin axis, then the steady-state field inside is uniform, except perhaps in a thin boundary layer at the surface. If the applied field is perpendicular to the spin axis, and uniform, then there is no steady field inside, except in the boundary layer. If it is non-uniform, there is an azimuthal interior field, proportional to the degree of asymmetry of the applied field, and decreasing linearly to zero at the centre. Applications to the Moon are briefly discussed.

Kristoferson, L.: 'Laboratory Simulation Experiment on Solar Wind Interaction with the Moon', *J. Geophys. Res.* **74** (Febr. 1969), 906–908.

Small spheres composed of different materials were subjected to plasma bombardment to simulate solar wind interaction with the Moon. Differences are observed in the vicinity of the spheres, but the wakes are all very much alike.

Ogilvie, K. W. and Ness, N. F.: 'Dependence of the Lunar Wake on Solar Wind Plasma Characteristics', *NASA STAR* **7**, No. 11, N69-22905, June 8, 1969.

Siscoe, G. L., Lyon, E. F., Binsack, J. H., and Bridge, H. S.: 'Experimental Evidence for a Detached Lunar Compression Wave', *J. Geophys. Res.* **74** (Jan. 1969), 59–69.

The behavior of the solar wind flux and direction measured on Explorer 35 in the near lunar wake is presented. The flux near the leading adge of the wake tends to be greater than the free stream value and decreases below detectability near the wake axis. There is probably a small ($\lesssim 3°$) deflection of the wind away from the Moon near the leading edge and a deflection toward the wake axis in the region of reduced flux. These features correlate well with variations in the magnetic field. An interpretation of the observed structure is offered that utilizes the theory of two-dimensional steady simple waves in magnetohydrodynamics. A novel feature of the interpretation is the inference of a deflection of the solar wind from the region of the lunar limb to account for the structure near the leading edge of the wake.

Van Allen, J. A. and Ness, N. F.: 'Particle Shadowing by the Moon', *J. Geophys. Res.* **74** (Jan. 1969), 71–93.

During the period November 10–22, 1967, the Earth–Moon system was bathed in an isotropic, homogeneous beam of solar electrons and protons whose intensities were slowly varying functions of time. Detailed angular distribution and intensity observations of these particles and vector magnetometer observations made simultaneously by the lunar orbiting satellite Explorer 35 are combined to examine particle shadowing effects by the Moon. During the observing period, the Moon and Explorer 35 passed from interplanetary space through the magnetotail. Simultaneous observations were made by the Earth orbiting satellite Explorer 33, which was sunward of the Earth's shock front and at large radial distance from the Earth during most of the observing period. The angular distributions of the intensity of both electrons and protons were accurately isotropic within the magnetotail as well as in interplanetary space. Study of 33 cases of clear *electron* shadowing and two cases of less clear shadowing suggests the following principal conclusions: (a) Magnetic lines of force from external sources thread through the Moon in a rectilinear manner as though it did not exist. The accuracy of this statement is measured by the maximum departure from rectilinear projection that is permitted by the electron shadowing observations. This is approximately 0.1 R_M (lunar radius) in 2 R_M or 3°. (b) Electron shadowing data provide no *direct* information on the region of access of interplanetary electrons into the magnetotail but do provide an upper limit on the trans-B diffusion velocity $v_\perp$ of electrons due to all causes. In the central portion of the magnetotail during magnetically quiet conditions and for radial distances $\lesssim 64 R_E$ (earth radius), $v_\perp \lesssim 100$ km sec^{-1} for 50 keV electrons. This upper limit requires, among other possibilities, that the transverse electric field

$$E_\perp (= Bv_\perp / c) \leqslant 5 \times 10^{-4} \text{ volt meter}^{-1}.$$

Lunar shadowing of protons ($E_P \gtrsim 322$ keV) is also described and discussed but is of much less significance.

15. Exploration of the Moon by Spacecraft

Arnett, J. B. and Hoffman, A. A. J.: 'Problems Associated with the Application of Magnetotellurics to Lunar Exploration', General Dynamics Fort Worth Division Report No. ERR-FW-850, (Feb. 1969).

The application of magnetotelluric methods to lunar exploration is reviewed and problem areas are

outlined. The absence of a lunar magnetic field and an atmosphere, the size of the Moon, and the apparent high resistivity of the lunar surface layer are among the important physical parameters considered.

Berry, Ch. A.: 'Lunar Medicine', *Science Journal (London)* **5** (May 1969), 103–107.

Carpenter, R. B., Jr.: 'A Study of an Extended Lunar Orbital Rendezvous (Elor) Mission, Volume 1: Technical Analysis', *NASA STAR* **7**, No. 7, N69-17728, April 8, 1969.

Carpenter, R. B.: 'A Study of an Extended Lunar Orbital Rendezvous (Elor) Mission, Volume 2: Supplemental Data', *NASA STAR* **7**, No. 7, N69-17729, April 8, 1969.

Gregory, R. L.: 'Lunar Psychology', *Science Journal (London)* **5** (May 1969), 78–81.

Hamer, H. A. and Johnson, K. G.: 'Effect of Gravitational-Model Selection on Accuracy of Lunar Orbit Determination from Short Data Arcs', *NASA STAR* **7**, No. 10, N69-21018, May 23, 1969.

The purpose of the present report is to give an insight into the accuracy of lunar orbit determination which may be expected with gravitational models having relatively few coefficients. The gravitational models investigated included the spherical harmonics through the fourth order. The results of the analysis were obtained by fitting tracking data from Lunar Orbiter Missions 1 and 3. Relatively short data arcs of a few orbital periods were used in determining the orbit. For the most part, the JPL program was used for the data fits; additional results are presented in which up to 21 coefficients were determined from the Lungfish (lunar gravitational field in spherical harmonics) orbit determination program. The orbit-determination accuracy was analysed by studying the effects of varying the gravitational model and the length of the data arc. In certain cases the gravitational coefficients were solved for and in others the coefficients were held fixed at predetermined values. Various criteria used to compare the cases included results from the fitted data arc as well as data predicted ahead of this arc.

Hustler, J. B. and Lauroesch, T. J.: 'Lunar Photo Study, Phase 4, Final Report 30 Nov 1967–30 Nov 1968'. *NASA STAR* **7**, No. 10, N69-21062, May 23, 1969.

A realistic 10′ × 10′ lunar model was made at a scale of about 1:50 to represent a portion of a potential landing site in Sinus Medii. Construction was based on a contour map of the area furnished by NASA. The visual appearance of the Moon was achieved by dusting with cupric oxide and lighting with a source simulating the Sun. Motion pictures of this model were made to simulate a portion of the view from a LM window during one of the final minutes of a landing. The motion picture sequences showed two basic approaches to landing: a straight-in approach along a 14° incline to a primary site and a dogleg maneuver to a secondary site. A motion picture was made for each trajectory for Sun elevations of 5° and 12°; when projected at 24 frames/sec, these motion pictures show events in real time. Still photographs were made at seven selected positions along the trajectory during the filming of the motion pictures for the straight-in approach. It was concluded that the optimum Sun elevation for a photographic mapping mission depends on the average slope of the terrain being mapped and the accuracy desired. In general, rugged terrain should be mapped at higher Sun elevations.

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.

Jaffe, L. D.: 'The Surveyor Lunar Landings', *Science* **164** (May 1969), 775–788.

Johnson, R. W.: 'The Lunar Colony', *Science Journal (London)* **5** (May 1969), 82–88.

Kopal, Z.: 'Space Astronomy of the Moon', *Scientia* (7) **104**, 3–32 (French translation ibidem, Appendix p. 1–27).

Different types of spacecraft employed for lunar studies since 1964 have provided a wealth of new data which lend themselves for the following conclusions concerning the structure of the lunar surface and its composition: (1) The U.S. Orbiters 1–5 photographed the entire surface of the Moon's near and far side with a resolution of 100–200 m, and some 10^5 km^2 with a resolution of 1–2 m on the Moon. The latter photographs revealed the presence of a large number of boulders, 1–10 m in size, which are apparently being displaced by moonquakes. (2) The Moon does not possess any magnetic field of strength exceeding 10^{-6} that of the Earth; and the electrical conductivity of its mass is so low as to be inconsistent with internal temperatures higher than 1000 °C (Explorer 35). (3) The surface of the Moon is relatively soft and porous down to a depth of several cms. For the upper few mms, the (bulk) soil density is 0.7–1.2 g/cm^3, and increases to about 1.6 g/cm^3 at 5 cms below the surface. The bearing strength of the topmost surface layer is less than 10^4 dynes/cm^2 and increases to 6×10^5 dynes/cm^2 at a depth of 5 cm (Surveyors and Lunas). (4) The chemical composition of lunar surface corresponds (by atomic numbers) to that of basaltic rocks; contains no free iron; and its γ-radioactivity is less than for terrestrial crust rocks. (5) The Moon's gravitational field exhibits anomalies, influencing the motion of the Orbiters, in the regions of several circular maria. These indicate the presence of large massive objects underneath the surface. (6) Measurements of temperatures were performed during the lunar day as well as during two eclipses of the Sun by the Earth witnessed from the lunar surface by the Surveyors on 24 April and 18 October 1967. (7) The intensity and polarization of the light of the solar corona was measured by the Surveyors after sunset up to one-third of the distance of Mercury from the Sun. (8) Terrestrial laser signals were received on the Moon and relayed back by the Surveyor's television cameras.

Kopal, Z.: 'The Moon and Man', *Science Journal (London)* **5** (May 1969), 44–49.

Liemohn, H. B.: 'Optical Tracking of Apollo 8', *Sky and Telescope* **37** (March 1969), 156–160.

Lowman, P. D., Jr.: 'The Moon's Resources', *Science Journal (London)* **5** (May 1969), 90-95.

Malina, F. J.: 'The Lunar Laboratory', *Science Journal (London)* **5** (May 1969), 108–113.

Masurski, H.: 'Lunar Exploration Targets', *Astronaut. Aeronaut.* **7** (January 1969), 42–49.

Meyer, A. J.: 'Exploration of the Moon', *Science Journal (London)* **5** (May 1969), 97–102.

Moyers, W. G.: 'Lunar Orbiter Improved Photo Support Data: Lunar Orbiter 1, Final Report', *NASA STAR* **7**, No. 9, N69-19651, May 8, 1969.

This document is one of five volumes comprising the photo data from Lunar Orbiter missions. This volume contains a description of and tabulates the photo supporting data for all the Lunar Orbiter 1 photos, based on postmission analysis of orbit trajectory and spacecraft performance factors. The two categories of data are; (1) the supporting data information; and (2) supporting and evaluation data. The supporting data information define the parameters contained in the photo evaluation computer program (EVAL); the version of the ephemeris data used; and the sources of input data required for computation of the photographic supporting data. The supporting and evaluation data include output listings of the EVAL computer program for each photo.

Moyers, W. G.: 'Lunar Orbiter Improved Photo Support Data: Lunar Orbiter 2, Final Report', *NASA STAR* 7, No. 9, N69-19652, May 8, 1969.

Moyers, W. G.: 'Lunar Orbiter Improved Photo Support Data: Lunar Orbiter 3, Final Report', *NASA STAR* 7, No. 9, N69-19653, May 8, 1969.

Moyers, W. G.: 'Lunar Orbiter Improved Photo Support Data: Lunar Oribter 4, Final Report', *NASA STAR* 7, No. 9, N69-19654, May 8, 1969.

Moyers, W. G.: 'Lunar Orbiter Improved Photo Support Data: Lunar Orbiter 5, Final Report', *NASA STAR* 7, No. 9, N69-19655, May 8, 1969.

Stewart, H. J.: 'Lunar Exploration – the First Decade raises more Questions than it answers', *Astronaut. Aeronaut.* 7 (January 1969), 32–36.