The Twelfth Plenary Meeting of COSPAR, Prague, May 11–24, 1969

Many interesting papers were presented to this year's COSPAR Meetings. We include the abstracts of those which refer to the Moon.

Symposium on Dynamics of Satellites:

Michael, W. H., Jr., Blackshear, W. T. and Gapcynski, J. P.: 'Results on the Mass and the Gravitational Field of the Moon as Determined from Dynamics of Lunar Satellites'.

This paper presents a review of procedures and a summary of recent results on the mass and gravitational field of the Moon. Gravitational field solutions as represented by spherical harmonic expansions of the potential through various degrees and order are available, and typical solutions obtained by the different procedures are presented. The relative and absolute precisions of the solutions in fitting the data are illustrated by residual plots and other considerations. Lunar surface elevation plots, based on the gravitational coefficients (assuming homogeneity), illustrate the distribution and magnitude of mass anomalies over the lunar sphere. For a 13th-order field, the contour plots show considerable correlation with published mascon results in regions where such results are applied to determination of the moments of inertia of the Moon, which correspond very closely to overall homogeneous density distribution in the Moon, and to determination of other properties related to mass distribution.

Roy, A. E.: 'The Use of Brown's Lunar Theory in Lunar Satellite Perturbations by Sun and Earth'.

In order to compute the lunar potential's effect on the orbit of an artificial lunar satellite it is necessary to calculate and subtract perturbations by Earth and Sun to a high degree of accuracy. The present paper describes how the first- and second-order Earth-solar changes in the elements of the selenocentric Keplerian satellite orbit are obtained by making use of Brown's lunar theory. Values are given of the accuracy obtained by comparing changes in the orbital elements of a typical lunar satellite (of semi-major axis 1.25 times the Moon's radius, eccentricity 0.17 and orbital inclination 30°) calculated from the first-order analytical theory and from numerical integration of the Gauss-Lagrange planetary equations. It is found for example that during two full orbits, the maximum errors in the semi-major axis and periselenium distance are of order 7 cm at most, while angular accuracy is equally satisfactory.

Open Meeting of Working Group I:

Lundquist, C. A.: 'Photometry from Apollo Tracking.'

During near-Earth phases of Apollo missions, Baker-Nunn cameras track the space-

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craft, rocket hardware, and clouds associated with various mission events. For example, after translunar injection of Apollo 8, residual propellants released from the separated Saturn SIV-B rocket produced a spectacular cloud of ice that was photographed for nearly two hours as the cloud proceeded Moon-wards. The relative positions of the Command Module, SIV-B, and cloud are recorded on photographs from the Spain Baker-Nunn when the spacecraft was about 50 megameters from the Earth. Analysis of such observations use densitometer measurements of the photographic image. The photometric results include the stellar magnitude of major Apollo components. The analyses also yield the brightness, dynamics, and duration of Apollo rocket exhausts and venting clouds.

Alley, C. O.: 'The Apollo 11 Laser Ranging Retro-Reflector Experiment: Opportunity for New Precision in the Study of the Earth-Moon System'.

It is expected that astronauts will deploy a compact array of high quality solid fused silica optical corner reflectors on the lunar surface during the first U.S. manned landing. The array is intended to serve as a fiducual mark for precise laser ranging from Earth stations. Continued measurements of such point to point distances to the expected uncertainty of ± 15 cm would increase our knowledge of the following scientific areas: the fundamental physics of gravitation (test for secular change of G); geophysics (rotation of the Earth, motion of the pole, and intercontinental drift rates); selenophysics (physical librations, size and shape, cartography); as well as the lunar orbital motion. The characteristics of the array will be described along with the laser ranging techniques required.

Open Meeting of Working Group II:

Alexander, W. M., Arthur, C. W., Hohn, J. L., and Corbin, J. D.: 'Lunar Explorer 35: 1967–1968 Measurements of Picogram Dust Particle Flux in Selenocentric Space'.

Measurements from experiments in interplanetary and cislunar space were found to be consistent with data from Lunar Orbiter, the Lunar Explorer 35 100 pg sensor and the Lunar Explorer 35 5 pg sensor during non-shower periods. It should be emphasized that data from the large particle sensors of Lunar Explorer 35 and Lunar Orbiter evidenced no difference between shower and non-shower periods. The Lunar Explorer 35 5 pg sensor is the only sensor showing enhancement during shower activity. It must be further emphasized that the data from this sensor is consistent with all other measurements during non-shower times. In addition, data for five shower periods show not only consistency between time of occurrence of showers but also repetition during two years.

The fact that the 5 pg sensor data shows enhancement during shower times, while the 100 pg sensor does not, indicates that if these particles are lunar ejecta, the nature of the hypervelocity phenomenon on the lunar surface is such that only particles in the picogram range have velocities sufficient to escape the Moon's sphere of influence. If these picogram particles are not lunar ejecta, but primary particles in a meteor stream, they are of recent origin since the perturbing forces due to solar radiation pressure and drag succeed in removing picogram-sized particles from the original orbits in very short time spans. However, for the 100 pg particles not to show an enhancement if the particles are from the streams would mean a flux-mass distribution in the stream considerably different from that of sporadic interplanetary dust particle distributions. Present analysis of the data cannot differentiate between lunar ejecta and primary particles of streams. A detailed analysis of the data, with emphasis on the exact location of the spacecraft in its orbit at the time of high event rates, is presently in progress in an attempt to determine the effects of shielding – in reference to showers – and the possible existence of any type of focusing forces of lunar ejecta due to hypervelocity impacts. It is possible that this analysis will yield more information concerning this question. However, at this time, a flux enhancement of picogram-sized particles in selenocentric space related in some manner to major shower activity consistently occurs. It must be noted that this enhancement is only slightly more than an order of magnitude above the non-shower flux rate for selenocentric space. Consequently, it would not be expected that this enhancement would be significant in cislunar space unless there are focusing forces which are at present unknown.

Open Meeting of Working Group VII:

Masursky, H.: 'Photography from Apollo 8 and Lunar Orbiter Missions'.

Jaffe, L. D.: 'Lunar Surface: Recent Spacecraft Observations'*.

Recent lunar-orbiting and landing spacecraft of the Luna, Lunar Orbiter, Explorer, Surveyor, and Apollo series have supplied many measurements of lunar characteristics. These show that both maria and highlands are covered with a layer of particles, of sizes predominantly 2–60 μ. The layer has a strong vertical gradient of physical properties, and a depth, in the maria, of a few meters. It was evidently produced from underlying more cohesive material, primarily by meteorite impact. The content of major elements in this material is similar to that of high-iron basalt in the maria and probably to low-iron basalt in the highlands. A variety of rocks, up to tens of meters in diameter, lie on and in the fine matrix. Rock shapes, fractures, and burial demonstrate erosion. Craters of sizes down to a few centimeters are visible; many craters are clearly of impact origin and many others clearly volcanic. Downhill transport of material is visible on scales of centimeters to kilometers. Mass concentrations on a scale of hundreds of kilometers are present, but there is considerable evidence of past large-scale melting and flow.

* A more complete discussion of many of the points presented in this paper is available elsewhere (1).

Troitski, V. S.: 'Comparison of the Chemical Composition of Lunar Surface Material Determined by Radio Astronomical Observations with the Results of Chemical Analysis obtained by Surveyor'.

As a result of the investigations of electrical properties of the Earth's rocks at superhigh frequencies, it is shown that the value of the specific loss angle tangent $b = \mathrm{tg}\,\Delta/\varrho$ and the value of $a = (\sqrt{\varepsilon} - 1)/\varrho$ where ϱ is the volume weight of the material, depends essentially on the chemical composition and to a lesser degree on the crystalline structure of rocks (effusive and intrusive rocks). The value 'b' varies for the different rocks by 20–30 times (from acid rocks to ultrabasic ones) and the value 'a' by a factor of 2. According to the results of measurements the corresponding dependences are determined, associating the typical mean chemical composition of the rocks with values of 'b' and 'a'. There arises the possibility of determining the chemical composition of the Earth's rocks according to the value of 'b' and in a less precise degree according to the value of 'a'. An experimental check shows a rather good coincidence of the true composition determined by the chemical analysis and the method proposed. It makes it possible to determine the chemical composition of material of the upper cover of the Moon and Planets, assuming their cover consists of silicates and the corresponding values of 'b' and 'a' are measured for it. For the Moon the value 'b' is estimated more precisely. By using the dependence of 'b' on the chemical composition one may determine the mean chemical composition of material of the upper surface of the Moon.

It should be noted that the comparison of the data of the chemical composition obtained by the 'Surveyor' program and by radio astronomical estimations reveals a good agreement with each other.

Leikin, G. A., Shvidkovskaya, T. E., and Krasnopolsky, V. A.: 'Some Data on Lunar Surface Microstructure Deduced from Studies on the Moon's Infrared and Ultraviolet Radiation Obtained from 'Zond-3' Space Probe'.

Studies of the infrared spectrum of the Moon's continental region within the 3.5–3.9 μ range show that the effective sizes of inhomogeneities are considerably larger than the wavelength, being equal to about tens of microns.

For this spectral range the photometric function is quite well represented by the Hapke function with parameter $g \simeq 0.3$. The studies of ultraviolet radiation (2100–2700 Å range) show that in this spectral range the photometric function cannot be represented by the Hapke function at any value of the parameter g. According to the Hapke function a dependence on phase angle is conserved, this dependence being different for various wavelengths. The features of the ultraviolet spectrum can well be explained on the assumption that apart from inhomogeneities of the order of tens of microns, there are inhomogeneities smaller than infrared wavelengths but comparable to the ultraviolet wavelengths. This theory enables the order of these inhomogeneities to be estimated as $\sim 0.5\ \mu$. Thus, the photometric function for the Moon has to include not only the effects of geometric optics but also diffraction over small inhomogeneities. Differences in values of the parameter g for measurements in the infrared and visual spectral ranges are possibly associated with the fact that the inhomogeneities of the order of $\sim 0.5\ \mu$ are insignificant for $\lambda = 4\ \mu$ but are significant for $\lambda = 5000$ Å.

Hayakawa, S., Matsumoto, T., and Nishimura, T.: 'Structure of the Lunar Surface'.

As observed with lunar landing probes, the lunar surface is covered by small grains. This was predicted by optical observation that the lunar brightness shows little limb darkening and the brightness depends sharply on the lunar phase. The lunar probes give an upper limit of the grain size, whereas the optical observation tells us that the grain size is significantly greater than the optical wavelength. We have observed the lunar brightness in the infrared region. The phase dependence of the infrared albedo indicates that the average grain size is several tens of microns. The longitude dependence of thermal radiation is found to be consistent with the lunar surface model as obtained from the infrared albedo.

Krupenio, N. N.: 'The Measurement of Scattering Characteristics of Local Lunar Regions from Space Vehicles'.

Results of the 3-cm radioband measurements of the specific effective scattering area of the lunar surface carried out in the landing regions of 'Luna-9' and 'Luna-13' automatic stations are presented in this paper. The measurement results are compared with the results of the specific effective scattering area determination carried out in the landing regions of the automatic stations 'Surveyor-1', 'Surveyor-3' and 'Surveyor-7', as well as with the results of the lunar surface specific effective scattering area determination using Earth-based radar measurement data.

Comparison of the measurements showed that the electromagnetic properties of the substance in the mare regions of the Moon differ insignificantly from those averaged over lunar disk.

Urey, H. C.: 'Mascons on the Moon'.

It has been well known for the last 50 years that the moments of inertia of the Moon do not agree with the assumption that the Moon was ever in equilibrium with the orbital, rotational and gravitational forces of the Earth–Moon System. Recent data from the orbiters agree with these conclusions, and, in fact, indicate that inhomogeneities exist below the surface of the Moon at considerable depths. Possibly variation of density with angular position would eliminate considerable stress at the center of the Moon. The recent observations of Muller and Sjogren on the mascons in the near surface of the Moon indicate gravitational anomalies on the order of a few hundred kilometers in dimension, and are due to high density of materials at moderate depth in six circular maria of the Moon, and also in a central region of the near hemisphere. These gravitational anomalies can be explained by masses in the neighbourhood of 10^{21} or 10^{22} g. It is also evident that smaller anomalies exist in other regions due to excess masses near the lunar surface.

Several explanations for these anomalies have been advanced. Muller and Sjogren suggested that these were due to the remnants of colliding objects which produced the circular maria, and this appears to be the most obvious explanation that has been advanced. The hypothesis that these masses are remnants of such colliding objects requires that they arrived at the Moon with low velocity, as was suggested by Gilbert many years ago. The masses calculated from the estimates of the energies required to produce the maria, assuming low velocities agree closely with those masses indicated form the gravitational anomalies.

Other explanations have been advanced by various authors. One popular suggestion is that great cavities were produced by very high velocity colliding objects which scattered much lunar material over the surface of the Moon. It is then assumed that lava flow from the interior of the Moon filled these depressions, and that the gravitational anomalies are due to this effect. The difficulty with this suggestion is that lava flows require that the rocky parts of the Moon shall be able to sink, and thus displace liquids from beneath the surface as occurs on Earth. But if sinking of this kind can occur, it appears most probable that the mascons would sink until isostatic conditions existed, and would thus be unobservable. Another suggestion is that water existed on the Moon and supplied sediments which filled the great depressions, and that these sediments supply the gravitational anomaly. A very involved set of events is required in this case to account for the anomalies isostatic adjustment in the early history of the Moon followed by non-isostatic adjustments at later times. The large amounts of sediments that would be required to supply material of this kind are difficult to understand in view of the obvious lack of great river valleys on the surface of the Moon.

The facts are consistent with an hypothesis that the Moon was captured by the Earth early in its history during the terminal stage of the accumulation of the Earth from materials having the approximate uncompressed density of the Earth. These objects were probably part of a cloud of objects about the Earth which fell on the Moon in low velocities during this time. The low average density of the Moon agrees with that expected for an object of solar composition which has lost the volatile elements.

O'Leary, B. T., Campbell, M. J., and Sagan, C.: 'Lunar and Planetary Mass Concentrations'.

Gravity anomalies discovered on the Moon by orbiting spacecraft indicate the presence of subsurface mass concentrations (mascons), the most prominent of which are correlated with circular basins. These mascons in an otherwise equilibrium Moon account for the Moon's triaxial figure. Two of the mascons corresponds to Mare Marginis and to a large basin near the center of the lunar farside, which it is proposed calling 'Occultum'. If large circular features on Mars and Mercury also have mascons beneath them, it is possible to understand, in part, the otherwise puzzling disequilibrium dynamical figures of these planets.

Muller, P. M. and Sjogren, W. L.: 'Lunar Gravimetrics'.

Doppler tracking data accumulated on the five U.S. Lunar Orbiter missions and used ordinarily for navigation purposes, are the sole observations that have produced an abundance of detailed gravity information. Initial reduction of the data revealed large gravity anomalies associated with the circular maria on the lunar front side. In an effort to present the initial data set and other reductions in a more usable and readable form, we have reprocessed the raw data using a slightly different theoretical model, have smoothed the acceleration fits and have plotted the acceleration on the Mercator projection of the lunar surface. Features not visible previously on the original orthographic projection can now be detected and confirmed by the redundant data sets. Quantitative results in the form of a point-mass surface grid are expected in the near future.

Gilvarry, J. J.: 'The Nature of the Lunar Mascons'.
(For abstract see page 118)

Ness, N. F.: 'The Electrical Conductivity and Internal Temperature of the Moon'.

Detailed measurements of the interplanetary magnetic field in the immediate vicinity of the Moon have been performed since July 1967 by Lunar Explorer 35. The magnetic field is found to be only slightly (25%) distorted with no evidence for a bow shock wave. During the interval February to July 1968, periselenium (830 ± 100 km) passed through the solar wind umbral region. A study of the propagation of discontinuities (sudden changes) in the interplanetary magnetic field through the lunar body has been completed. The induction of electrical currents in the lunar interior indicates an effective time constant for eddy current decay of less than 20 sec. This means an electrical conductivity of less than 10^{-4} mhos/m in the lunar interior. The electrical conductivity of silicate rocks depends mainly upon temperature. Thus limitations on possible thermal models of the Moon, consistent with the electrical conductivity measurements, can be obtained. These results are compared with various models of the thermal history to obtain a class of allowed lunar interiors. The conclusion is that the Moon must be a relatively young body (1×10^9 year old) if it possesses a homogeneous heat source composition similar to chondritic meteorites. If differentiation of radiogenic heat sources near to the surface has taken place, the Moon can be old (4×10^9 years).

Feschotte, P.: 'On the Origin of Lunar Relief'.

A new mechanism for explaining the origin of lunar reliefs is proposed on the basis of experiments permitting to recreate the different types of lunar craters by means of pasty projectiles falling from moderate heights onto a surface of similar viscosity and composition.

Thus the present superficial morphology of the Moon could be the result of a rapid magmatic decomposition in intersideral vacuum of an unstable original mantle of the planet. Innumerable fluid spheroids as product of that outgassing process have fallen on the Moon's core in order of decreasing diameter.

The newest results of lunar exploration, including the absence of maria on the reverse side of the Moon, the chronological decreasing size of craters and absence of dust on the surface are taken into account.

Lunar relief suggests a transitory phase of instability in the Moon's history and leads us to consider on the basis of new evidence the possibility of the genesis of our satellite from terrestrial magma as the result of a crucial moment in the evolution of the Earth.