

17. COMMISSION DE LA LUNE

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Stimulated by the successful missions of several lunar probes, the field of lunar research has developed tremendously since the formation of Commission 17 at the Hamburg Meeting of the IAU. So many papers have appeared that it becomes difficult to organize and impossible in any reasonable time to digest the literature, particularly with the variety of new techniques coming into use. By way of partial compensation we have added to the references identifying numbers (when available) by which an abstract may be found in *Physics Abstracts* (P) and/or one of the NASA Abstract publications (A, N). We also call attention to the NASA continuing bibliography (S). Abstracts for many earlier publications can be found in (U).

We are indebted to Dr E. L. Ruskol for a report on the study of the Moon in the U.S.S.R. from which we insert paragraphs in the appropriate sections below.

A. BOOKS, CONFERENCE PROCEEDINGS

In April 1965, Commission 17 of the IAU joined with NASA to sponsor a symposium on the nature of the lunar surface (8). In May 1966, COSPAR sponsored a symposium in Vienna on the Moon and planets (14). A number of other books have appeared that deal in whole (1, 3, 4, 5, 7, 10) or in part (2, 9, 11) with a variety of problems of lunar research. Many of the articles appearing in the proceedings of the conferences (3, 8, 9) are referenced individually in the appropriate section below. Kopal (6) has published an atlas of lunar photographs from plates taken at the Pic du Midi Observatory.

Scientists of the Central Astronomical Observatory of the Academy of Science of the Ukrainian SSR compiled two books (12, 13) on the shape and motion of the Moon, following an all-Union conference on this topic in Kiev in May 1964.

B. LUNAR PROBES

a. *Hard Landings*

The greatest achievement in lunar research has unquestionably been the successful missions of several Moon probes launched by the United States of America and by the Soviet Union. A preliminary report on the first successful hard-landing probe, Ranger VII on 31 July 1964, was presented at the Hamburg meetings. The data secured by Ranger VII have been published in a series of three photographic atlases (1) and a volume of interpretive analysis (2). The area selected for impact was a relatively smooth mare, known to have several ray systems and ridges and a relatively high crater density, a region since named Mare Cognitum. 'Craters' are the dominant topographic features of the mare surface at all scales down to the smallest

features observed in the last photographs (less than 1 m across) . . . Craters are more abundant in the rays than in the areas between the rays. The number of craters increases . . . rapidly with decreasing crater size . . . Most of the craters smaller than 250 or 300 m in diameter . . . have smoothly rounded rims . . . and a large variation in depth-to-diameter ratio . . . Some of these craters are surrounded by bright halos . . . ' (2).

The lunar maria can be characterized (**Ha 17**) as 'red' or 'blue' on the basis of a slight shift to the red or blue in their reflected solar spectra. Ranger VII impacted a red mare. For Ranger VIII the target of the blue Mare Tranquillitatis was selected, and for Ranger IX the Crater Alphonsus (5). The Ranger VIII and IX missions impacted their selected target areas on 20 February 1965 and 24 March 1966, and returned to earth 7137 and 5814 photographs, respectively. These are published in two atlases (3, 4), with a separate volume of interpretive analysis (5). Most of the chapters of (5) as well as other analyses of the Ranger photographs are referenced separately below; see especially refs. (**D 32; Ha 6, 10, 12, 15, 16; Hb 3, 5, 8, 16, 17, 22, 23, 31, 32, 37, 46, 47; Hc 2, 3, 6, 11, 13; I 15, 34, 39, 49, 52, 53**).

Other general discussions of the Ranger missions are presented in (6, 10, 11, 13), while (7, 8, 9, 12, 14, 15) emphasize the general interpretation of the new high-resolution photographs.

b. Soft Landings

The successful soft landing on the Moon by the Soviet Union's Luna 9 spacecraft on 3 February 1966, enabled earthmen for the first time to see millimeter-sized details of the lunar surface. Luna 9 landed in the western part of Oceanus Procellarum, a region in the immediate neighborhood of the broken ridge that ends southeast of the crater Cavalerius F, so that the photographs cannot with certainty be referred to either a pure mare or a pure mountain surface (7).

Preliminary results from Luna 9 have been published in a book (1) that contains a description of the apparatus, of the photogrammetric methods used for the construction of topographic charts on the landing place, and an illustrated description of its morphological features. The photographs have a resolution of 1–2 mm for the nearest details. On this scale the surface is very rough indeed, but becomes smoother for the larger scale. This conclusion confirms those reached from earth-based observations. No dust was detected. The bearing strength of the surface is sufficient for the soft landing. However the station later slightly shifted its orientation, probably because of some deformation of the lunar soil.

Gold and Hapke (5) interpret the shift of the instrument as evidence that the lunar sub-surface may contain many cavities which are in a precarious state of equilibrium. Lipsky infers (7) a bearing strength of the surface of several kg/cm² from the fact that most of the small rocks have not noticeably depressed the surface under them. He finds 'no fairy castles, no heaps of angular fragments, sand or loose dust or like forms . . . The photographs show that the surface is not the result of fusion of deposited fine dust, for almost all the objects have regular forms, not branched or random ones. Many depressions of various sizes are clearly visible . . . with many rocklike objects' (7).

Davies *et al.* (2) discuss the signals received from Luna 9 at Jodrell Bank. Fielder *et al.* (3) comment on the similarity of the terrain revealed by Luna 9 to the scoriaceous surface of an aa (Hawaii) type lava flow. The resemblance to a lava flow is also noted by Kuiper *et al.* (6) who conclude that the surface shown by Luna 9 is a highly vesicular igneous rock, and clean of dust. Gault *et al.* (4) infer that the lunar surface consists of non-cohesive to weakly cohesive, poorly sorted fragmental material of unknown source and a depth of at least 20 cm, with most of the fragments having sizes less than 1 cm. Shoemaker *et al.* (8) note that the individual fragments could be light and frothy or dense and solid. See also (1 32, 52).

On 2 June 1966, the U.S. Surveyor 1 landed softly inside the Flamsteed ghost ring, about 500 miles from the site of Luna 9. By 5 June Surveyor 1 had sent back 2500 pictures, while the final picture count surpassed 10 000. 'Beautifully clear and sharp, the pictures revealed an eerie, rubble-strewn wasteland stretching level in all directions' (10).

Analysis and evaluation of the data returned during Surveyor's first five days on the Moon (9) indicate that the terrain within 1–2 km of the landing site is 'a gently rolling surface studded with craters, with diameters from a few centimeters to several hundred meters, and littered with fragmental debris ranging in size from less than 1 mm to more than 1 m. The larger craters resemble those seen in the Ranger photographs in shape and distribution . . . The surface is composed of granular material of a very wide size range; coarse blocks of rock and smaller fragments are set in a matrix of fine particles too small to be resolved. This material was disturbed and penetrated by the footpads of the spacecraft to a depth of a few cm . . .' The static bearing capacity of the soil is estimated at about 5 lb/in² (1/3 atm). Counts have been made of rocks as a function of size. The exterior of Surveyor 1 has remained clean and essentially dust free. A tiny nitrogen jet that was fired at the surface near one foot of the spacecraft produced no plume of dust visible to the watching camera (9, 10). Some material disturbed by the footpads was thrown out to form rays . . . darker than the adjacent surface. Photometric and colorimetric observations were obtained. See also (I 21, 52).

On 24 December 1966, the Soviet Union's Luna 13 made a successful soft landing on the Moon, and is sending back pictures of good quality. A probe rod, to test the firmness of the lunar ground, was reported unable to penetrate far into the rocky ground. Luna 13 is reported to carry also a special apparatus for measuring the density of lunar rocks.

c. Far Side of the Moon

In July 1965 the Soviet space probe Zond-3 photographed most of the area of the far side of the Moon not previously recorded by Lunik 3. The new pictures, with a resolution of about 3 km, fully confirm the earlier conclusion that the far side of the Moon has far fewer maria than the near side, and is in general lighter, more mountainous and more densely cratered. Two features not seen on the earthward side are of particular interest: chains of large (10–30 km) craters extending up to 1500 km in length; and numerous large (~500 km) depressions, named thalassoids, in size and shape similar to maria, but different in having crater-scattered floors and lacking the dark color of maria (1, 4, 5).

Measurements of the UV spectrum by a spectrophotometer (1900 to 2750 Å) and by a spectrograph (2700–3550 Å) gave a decrease in albedo from 5% at 3550 Å to 3.5% at 3400–3100 Å and to 1% at 2850 Å. The albedo increases to 2% at 2400 Å and decreases again to 1% at 2000 Å (2). Infrared spectra at 3–4 μ were also obtained by Zond-3.

Hartmann (3) discusses the origin of lunar basins and thalassoids, the history of huge concentric structures, and the origin of radial and grid systems of lineaments on the lunar surface, with reference to the structures of the far side.

d. Orbiters

On 3 April 1966 the Soviet probe Luna 10 became the first artificial satellite of the Moon, with the orbit inclined 71° 54' to the lunar equator, with a periselenium distance of 350 km and aposelenium of 1017 km from the surface, and a period of 2^h 58^m 15^s (1). After 460 revolutions, on 30 May 1966, the orbital elements were 72° 2', 378.7 km, 985.3 km, and 2^h 58^m 3^s. A preliminary analysis of the orbital evolution indicated that gravitational anomalies of the Moon are small (3).

Preliminary results of measurements by Luna 10 gave the following magnetic field intensities (in 10⁻⁵ gauss)

3 April
145 April
248 April
18-369 April
17

The increase in intensity in the period 5-6 April was possibly caused by the passage of the Moon through the magnetic tail of the Earth. Perhaps also as a result of that passage, the registered densities of electrons with energies of the order of 10^4 eV exceeded the interplanetary background by a factor of 70-100. The density of micrometeoroids measured by acoustic counters was nearly 100 times higher than that in the interplanetary space (2).

The total γ -radiation intensity of the lunar surface measured by a γ -spectrometer is 1.5-2.0 times that measured over granite rocks. But only 10% of it can originate from the decay of radioactive elements U, Th, K^{40} , and 90% must be attributed to the radioactivity induced by cosmic rays. The abundance of radioactive elements in rocks on maria is similar to that in basalts. On the continents this abundance is lower and corresponds to that in ultra-basic rocks. Local variations in the total intensity of the lunar γ -radiation (induced + natural) do not exceed 40% (4, 5, 6).

On 14 August 1966 the United States' Orbiter 1 became an artificial satellite of the Moon in an orbit inclined 12.16° to the equator, a period of $3^h 37^m 45^s$, and periselenium and aposelenium distances of 189 and 1865 km; these figures were changed to $3^h 20^m$, 58 km and 1848 km on 21 August. Orbiter 1 was equipped to monitor meteoroids and radiation, and to photograph the lunar surface, particularly nine possible landing sites for Program Apollo. Orbiter 1 secured over 200 photographs, many of excellent quality (8, 9), before it was caused to crash on 29 October.

Tracking data have been obtained to permit detailed study of the Moon's shape and gravitational field. Preliminary indications, from data of Orbiter's first few days, are that the Moon has a 'relatively large pear-shaped component and that the gravitational properties will be of considerable scientific interest' (10). See also (M 13).

The Moon's third satellite, Luna 11, was placed in an orbit inclined 27° to the lunar equator on 28 August 1966, at a height ranging between 159 and 1200 km. We have no information on its mission. Luna 12 was placed in orbit on 25 October 1966, and has sent back pictures.

On 10 November 1966 Orbiter 2 attained a circumlunar orbit ranging between 1850 and 210 km above the surface, where it served for five days as a passive probe of the lunar gravitational field. On 15 November the low point of the orbit was reduced to 50 km for the primary mission of photographing 13 potential landing sites. Orbiter 2 fell silent on 6 December, after transmitting 95% of its scheduled 211 photographs. To date NASA has released a set of spectacular pictures of the region of the crater Copernicus, seen obliquely from a distance of 240 km and a height of 46 km above the Moon with the crater Fauth in the foreground (11).

C. CARTOGRAPHY

Arthur and Kuiper report completion of the scheme of lunar nomenclature for the Moon's visible hemisphere, which was proposed and approved by the IAU at its 1964 Hamburg meeting. This nomenclature is embodied in the catalog, *The System of Lunar Craters* (1), which is in four parts and gives positions and dimensions for 17 000 craters, and in a two color map in four sheets (2). The compilation of this nomenclature has been a task of some magnitude, and it is hoped that the work will be rewarded by wide acceptance of the new scheme.

Other cartographic work by scientists of the Lunar and Planetary Laboratory include selenodetic measures on three Yerkes photographs by Arthur (6, 12, 13), drawings of areas of the northwest (19) and southeast (20) lunar limbs by Herring. Strom (32) has mapped in detail lineaments within 60° of the center of the Moon's face, and delineated four global lineament systems and radial systems associated with four circular maria.

Since the Hamburg meetings, scientists of the U.S. Geological Survey have accelerated their program of geologically mapping the Moon by telescopic means. Thirty-five maps at a scale of 1:1 000 000 are now published (3) or available in preliminary form (A 7a) out of a planned 44 which will cover most of the earthside hemisphere. Aspects of the geology of selected regions have been discussed (26, 27, 30, 34, 37, 38, 39). The geological mapping aims to express the structure, history, and formative processes of near-surface materials, and maps class into units those materials believed to have formed simultaneously in about the same way. The units appear in order of relative age. In addition the scientists have employed photographs taken by Ranger VIII for geologic (24, 33, Hc 13) and topographic (25) mapping of a region of Mare Tranquillitatis; and by Ranger IX for the floor of Alphonsus (Hb 8, 13). See also refs. (Ha 11, 12, 15, 149).

The U.S. Air Force, Aeronautical Chart and Information Center has used the Ranger photographs to refine its shaded relief maps of the Moon (4). Their previous maps at a scale of 1:1 000 000 were the largest-scale maps previously available for the impact areas of the Rangers. Their new series (4) possesses scales of 1:500 000, 1:100 000, 1:10 000, and 1:1000. These maps 'provide in a condensed, but qualitative, form much of the new topographic data acquired by the Ranger Block III missions' (Ba 5). References (15, 17, 23) discuss various aspects of the ACIC mapping program.

A number of papers discuss various procedures and problems in lunar cartography and selenodesy (5, 7-11, 14, 18, 21, 22, 31, 35, 36). Papers (16, 28, 29) are concerned with the problem of determining elevations on the Moon. See also (Ha 5, 8).

Lisina and Shevchenko developed van Diggelen's photometric method for the study of relief and applied it to maria regions (40) and the surroundings of the crater Kepler (41). Markov (42) found the diameter-depth relation: $\log D = 1.0662 \log d + 0.6200$, for craters seen on Ranger VII photographs. Mukhamedzhanov and Stanjukovich (43) studied the distribution of primary and secondary ejecta of the crater-forming impact which can explain the double rims of certain craters.

Towards an investigation of the geometrical shape of the Moon, Gavrilov (44) developed a method of photography of the Moon and of compiling catalogs of selenocentric positions of details of the lunar surface. After analyzing existing catalogs and adding new measures, he constructed a net of basic points. From measures of 16 photographs of the Moon, with the Schrutka-Rechtenstamm and Baldwin Catalogs as reference, Gavrilov *et al.* (45) compiled a catalog of space coordinates of 160 basic points. This was extended to a similar catalog of 500 basic points (46). Gavrilov (47) has compared different systems of position.

Lunar Nomenclature

The enormous amount of new data related to the mapping of lunar craters, obtained from the space programs of the U.S.A. and the U.S.S.R. necessitates a complete review of the problem of nomenclature of various lunar features. Recommendations made by special committees of the National Academies of the U.S.A. and U.S.S.R. furnish a starting point for consideration of the problem by the Sub-committee on Lunar Nomenclature of Commission 17 of the IAU under the chairmanship of Z. Kopal. As the result of correspondence undertaken prior to and meetings held during the General Assembly of the IAU in Prague, recommendations will be made to the General Assembly concerning nomenclature for features of the reverse side of the Moon and also of special features on the visible surface.

A poll of the membership of Commission 17, undertaken by its president, indicates that the majority favors extension of the present system of nomenclature to the reverse side of the Moon, with craters named for deceased scientists, with special attention to astronomers.

D. PHOTOMETRY OF THE MOON

Barabashov and Ezersky studied the microrelief of different lunar regions (30, 31) on the basis of V. A. Fedoretz's photometric catalog of 1952. The same authors and Ezerskaya (Fedoretz) (32) studied the reflective properties of 31 areas in Mare Nubium and Mare Cognitum using the Ranger VII photographs, and found that their microrelief does not differ considerably from that of the average lunar surface.

Akimov (33) deduced a complicated empiric formula for the brightness distribution at different phase angles, and found it in fairly good agreement with his observations. Hämeen-Anttila *et al.* (8) studied the shadow effect of surface irregularities, which they found insufficient to explain the observed phase curves, the theoretical curves being more linear and less steep at small phase angles than the observed curves. Hapke (12) modified his earlier (11) theoretical lunar photometric function, by wrinkling the porous, open surface of the previous model into a series of steep-sided depressions. Oetking (19) found that many terrestrial substances, when observed with an instrument of small aperture, show a prominent rise in reflectivity if the direction of observation is within $\pm 5^\circ$ of the direction of the incident light. Hapke (20) has commented on this conclusion. Wildey (29) made photoelectric measurements in *U*, *B*, and *V* of a number of lunar features extending over a range of morphological types and selenographic coordinates; deviations from the average photometric function have been correlated with stratigraphic class.

Ashby (1) determined the average energy reflected by the lunar surface. Rydgren (21) used the coronagraph at Anacapri to measure the earthshine on the Moon. Opriatova (34) discovered a decrease in albedo towards the ultraviolet in the region 4200–3200 Å.

Coyne (4) determined differential colors for 36 areas on the Moon, with respect to a standard area in Mare Serenitatis. He found no dependence of the differential colors on phase angle, a result confirmed by Scott (22). Mironova (38) studied the spectral distribution of light reflected from 30 small regions of the lunar surface.

Mironova (17) and Sergeeva (23), from spectrophotometric studies, found signs of luminescence at 4250 Å and 5050 Å in the crater Aristarchus. Petrova (35) obtained almost identical spectrophotometric curves for four lunar maria: Tranquillitatis, Crisium, Serenitatis, Sinus Iridum. In the southwest part of Sinus Iridum she found (36) a violet emission band ($\lambda_{\max} = 4250 \text{ Å}$) similar to that in Aristarchus. Near craters Kepler and Le Monnier a green ($\lambda_{\max} = 5350 \text{ Å}$) emission band was observed. She found that some volcanic sublimates containing rock-salt and exposed to ultraviolet illumination showed a luminescence with two maxima, at 4260 Å and 4100 Å, resembling that in Aristarchus. See also (I 45).

Sharonov and Sytinskaya (37, 24, 25, 27) found that the reflective properties of fresh volcanic crusts studied in field conditions at Kamchatka are similar to those of the Moon, but the roughness of the lunar surface should be much greater. See also (10, 14).

Van Diggelen (5) studied the radiance of lunar objects at small phase angles on plates taken during the eclipse of 18 November 1956. The photometric and color properties of several lunar eclipses have been observed (3, 6, 13, 2, 16, 18). Hansen and Matsushima (9) have sought to explain the exceptional darkness and non-reddening of the eclipse of 30 December 1963 by an unusually large extinction in the Earth's upper atmosphere, while Link (15) invokes lunar luminescence to explain the difference in brightness of various eclipses. Bell and Wolbach (39) call attention to the relation originally found by Danjon between eclipse brightness and color and phase of the sunspot cycle. Matsushima (40, 41) finds some correlation between the brightness of the eclipsed Moon and the geomagnetic index K_p .

See Section I and (J 4, 5) for additional material on the interpretation of photometric observations.

E. POLARIMETRY

Kokhan (10) published a catalog of the polarization and position angles of the polarization plane of light reflected by 35 areas of the lunar surface at phase angles from -140° to $+140^\circ$. Lipsky and Bondarenko (11) found that for many lunar objects at phase angles $>30^\circ$ the polarization decreases with increasing wavelength; at $\pm 90^\circ$ it is 10–15% higher in the blue than in the red. On the other hand, at angles $<30^\circ$ the polarization in the red exceeds that in the blue, especially for maria and ray systems.

Avramchuk (1) studied the polarization of several lunar areas with color filters and discussed the discrepancies between the data by different authors. Morozhenko (12) measured the polarization of light reflected by different terrestrial rocks. Dzapiashvili and Xanfomaliti (13) used a new electronic polarovisor to obtain lunar images showing the distribution of position angles of the plane of polarization over the disk. Pospergelis (14) designed a new electronic polarimeter for planetary research, which permits the determination of all Stokes' parameters.

Clarke (2) has discussed previous data and added new observations on the wavelength dependence of the polarization. Hopfield (7) presented a theoretical interpretation for the negative polarization of moonlight at small phase angles. Marin (8) made polarization measurements of the Moon and planets in the spectral region from 0.8 to 1μ .

Gehrels, Coffeen and Owings (6) made photoelectric measurements of brightness and polarization on various lunar regions at *UBV* and 0.94μ wavelengths. Coffeen (3) studied five laboratory samples, three of porous dust layers of ground volcanic cinder particles in 'fairy castle' structures, and two of porous but solid lava fragments. He found the wavelength and phase dependence of the lunar polarization most closely matched by the fairy castle structures; the solid fragment was more highly polarized than the Moon and had essentially no wavelength dependence.

Dollfus has presented (5) preliminary results of an extensive study of the polarization of 14 selected regions of the lunar surface at Meudon and Pic du Midi. Complete curves of polarization have been obtained at the wavelengths 1.10, 0.95, 0.83, 0.60, and 0.55μ ; measures at 0.40, 0.37, 0.35, and 0.325μ are in progress. From these data and laboratory study of the polarimetric properties of various substances, Dollfus (4, 5) concludes that the Moon's surface is completely covered in all areas by a layer of small uncompact, highly absorbing dust particles, whose absorptivity has been increased by the action of the solar wind on the lunar surface.

The U.S. Geological Survey has made polarimetric measurements to provide data for the description of lunar geologic units, with emphasis on determination of maximum positive polarization for each unit (9); in general the maximum polarization of a geologic unit is inversely related to its albedo, although occasional exceptions occur.

F. THERMAL PROPERTIES AND INFRARED STUDIES

Radiometric and photometric mapping of the Moon at various phases by Shorthill and Saari (22, 18) and by Ingrao *et al.* (5) has led to the discovery of many thermal anomalies on the surface of the Moon. While detectable at various phases, particularly around the sunset limb, the lunar hot spots are especially striking during total eclipses of the Moon, where they have been extensively studied by Shorthill and Saari (16, 17, 18, 19, 20, 21, 23) at the wavelength region 10–12 μ . They report (18) that more than 400 hot spots have been identified and cataloged. 'Most of them are craters that appear visually bright at full Moon; some have ray systems, some bright interiors, and some bright rims' (18). A substantial percentage were not associated with major ray craters (16), with a marked concentration in Mare Tranquillitatis (21). Some substantial anomalies are identified with quite small craters (18). It is suggested that the thermal anomalies have the properties of bare rock, without an insulating layer of

dust. Other scientists (1, 26, 29) suggest that the thermal anomalies may arise from lunar roughness on a centimeter scale rather than from special thermal composition or the presence of local thermal sources.

Markov and Khokhlova (8) measured the emission near 3.6μ and $8-13\mu$ during the eclipse of 7 July 1963, and obtained a relatively high albedo at 3.6μ of 0.3. They found the maria remained warmer by several degrees than the highlands during the eclipse. They detected (9) also a difference in the heating rate of the east and west limbs of the Moon during this eclipse, an anomaly they attribute to differences in the physical parameters.

Several scientists studied the lunar surface in the near infrared. Moroz (10) measured spectra of selected regions at full Moon and found an increase in albedo with wavelength out to 2.2μ , which was very similar for a variety of lunar structures—maria, highlands, and bright craters—that differ considerably in absolute albedo. Binder *et al.* (2) found the color of the Moon to be very uniform in the region $1.0-2.2\mu$, with a few exceptions. From observations made on the second flight of Stratoscope II, Wattson and Danielson (28) also find that the lunar albedo is substantially higher in the infrared out to about 2.5μ than in the visual. Moroz (10) found that volcanic ash and slag display a variation in albedo with wavelength similar to that of the lunar surface.

Wattson and Hapke (27) and Binder *et al.* (2) investigated the infrared characteristics of terrestrial rocks and simulated lunar surface materials. Terrestrial rock samples were generally much less red than the lunar surface in the $1.0-2.2\mu$ region. However samples of volcanic rock, irradiated with 2.0 keV H^+ ions, corresponding to an equivalent irradiation of the lunar surface for about 2.5×10^5 years, simulated the intensity ratios for the lunar infrared. This experiment supports Hapke's hypothesis that solar irradiation can produce the unusual spectral curve and low albedo of the lunar surface.

Burns and Lyon (3) studied the errors introduced into temperature determinations when one assumes that the emissivity of the lunar surface is independent of wavelength. Their calculations for a variety of substances which might reasonably be expected on the surface of the Moon indicates that the emissivity varies significantly. The deviations from blackbody behavior would give calculated lunar temperatures too low by 3.5 to 5.5%. Murcay (11) found that the observed radiance of the lunar surface in the 8 to 10.4μ region was not compatible with gray or blackbody radiation at any temperature. He concluded that the emissivity varied from roughly unity at 8.5μ to about 0.9 at 10μ .

In a study of the lunar spectrum in the region $8-11\mu$, Moroz (10) showed that the absorption band of SiO_2 at 9μ is absent, probably because of the pulverized nature of the surface layer. Bolometric measurements by Chistjakov (32) with a resolution of 45×15 km² did not reveal any thermal anomalies for the crater Alphonsus. Ryadov *et al.* (14) discuss their measurements in the $8-13.5\mu$ region of the integrated thermal radiation from the Moon over various phase angles, and derive an average disk temperature of the full Moon. Observing the Moon in the $16-24\mu$ window, Hunt and Salisbury (4) found anomalies that suggested differences in chemical composition among several features of the lunar surface.

Linsky (6) developed models with temperature-dependent thermal properties to analyze the observations at both the infrared and the radio wavelengths. Troitsky (24) developed a mathematical analysis of the thermal and radio emission data from the surfaces of the Moon and planets. Murray (13) points out some inconsistencies between the radio-derived temperature of 207 °K used in the foregoing (24) model, and infrared data which give a temperature of about 100 °K—as determined independently by Saari (15) and Troitsky (25)—for the antisolar point of the lunar surface.

Measures of the surface temperature during the lunar night were carried out also by Low (7) and by Murray and Wildey (12). The latter used especially sensitive infrared detectors

to measure the radiance of the shaded lunar surface, and consider the observed pattern of sunset cooling to be inconsistent with the presence of a thick homogeneous layer of dust. They report a number of thermal anomalies, but no systematic nighttime temperature differences between maria and uplands. The presence of thermal anomalies also suggested the existence of regions completely free from strongly insulating dust.

G. RADIO STUDIES

This section deals with two major fields of investigation: thermal radiation from the Moon at radio (mm and cm) wavelengths, reviewed in (26, 39, 40); and the reflection of man-made radar waves by the Moon, reviewed in (18, 30). The distance to the Moon has been measured by radar (11, 24, 42), and by laser (29); reflected light signals were registered by a group of scientists of Lebedev Physical Institute (45). Kokurin *et al.* (46) discuss methods of determining orbital parameters and the shape of the Moon by optical location.

Thermal. A number of papers (1, 20, 22, 27, 31, 41, 48) report observations of thermal radiation at mm wavelengths from the eclipsed Moon. Troitsky (38) elaborated a theory for the radioemission of the eclipsed Moon, which he compares with observations of the 1963 and 1964 eclipses at 1.20 mm. He concludes that the average thickness of the porous surface layer is 6 ± 3 meters, and that the density doubles its value at 2–3 cm below the surface, with a decrease by a factor 2 in the absorption coefficient for cm wavelengths.

Observations of thermal radiation from the center of the uneclipsed Moon yielded determinations of the brightness temperature (27, 35, 47). Papers (8, 14, 22, 34) investigate the relative brightness temperatures of selected regions of the Moon. Gary *et al.* (14) have determined contours of 3 mm brightness over the lunar disk at 14 phases of the Moon, and derived phase curves for a number of latitudes. The average phase lag of 22° indicates that the lunar surface has a very low thermal conductivity (8, 14). In addition Drake (8) reports preliminary evidence for a correlation between 3 mm and infrared thermal anomalies, and stresses that the 3 mm observations require for interpretation at least a two-component model and 1-mm structures all over the surface. In a related study, King *et al.* (22) determined relative brightness temperatures and cooling rates of selected lunar regions during the eclipse of 1963 December 30.

Gary *et al.* (14) found the brightness temperature of the maria to exceed that of the neighbouring highlands by $2.6 \pm 0.2^\circ$ K, at 3 mm. Salomonovich (34, 43) found that at 8 mm the brightness temperature of the maria exceeded that of the continental regions by $1.5 \pm 0.5\%$ (averaged over a lunation); for the midnight temperature this excess was 8° K. The corresponding variation in γ is no more than 25%. From a study of the polarization of the lunar radioemission at 6.3 cm and comparison with previous data at 3.2 cm, Gol'nev and Soboleva (44) conclude that the surface is rough on the mm scale.

Troitsky and his collaborators at Gorki Radiophysical Institute continued to develop the 'artificial Moon' method for temperature measurements at different radio wavelengths. The temperature gradient with depth was found to be $2\text{--}5^\circ/\text{meter}$, the thermal heat flow from the interior, 1×10^6 cal cm^{-2} s^{-1} (assuming temperature-independent thermal properties of the porous surface layer). The full list of papers published by this group can be found in reviews (26, 39).

Radar. In a study of lunar radar echoes by a delay-frequency analysis, Thompson (37) derived radar scattering maps of the Moon. He finds that mountainous regions reflect 1.5 to 2 times as much power as maria regions, while certain craters reflect up to 10–20 times the average.

From a review of radar observations Hagfors (18) concludes that the lunar surface is covered by a material having an effective dielectric constant of 2.6 and that the surface undulations

on the Moon have a mean slope of $11-12^\circ$ on the scale of about 1 meter. He suggests that the enhanced reflectivity found for young rayed craters is caused by both a higher intrinsic reflectivity and a greater roughness in these features. The results of a study of polarization in radar echoes agree with a model consisting of a tenuous top layer at least 10 cm thick, supported by a denser underlying layer (17).

A number of other papers discuss the analysis of radar echoes from the Moon, with emphasis on the laws of geometrical optics in (32, 33) and on a distribution of structure sizes in (2, 3, 23, 4, 5, 19). Values for the mean slope are derived in (2, 4, 18, 32), while (11, 18, 30, 32) provide values of the dielectric constant. Katz (21) compares the wavelength dependence of the lunar reflectivity with that of various terrestrial surfaces. Taylor (36) investigates anomalies in the Faraday rotation of lunar echoes and the possibility of a relationship to the geomagnetic index K_p .

Hagfors (16) establishes the relationship between the geometric-optic approach and the autocorrelation approach to the analysis of lunar radar echoes for a Gaussian autocorrelation function when the surface has Gaussian height statistics and introduces deep phase modulation on the incident wave. He finds that, if an appreciable amount of small-scale structure is present, the range of scales responsible for the scattering will include an increasing amount of small-scale structure with increasing angle of incidence. A similar conclusion is reached by Fung and Moore (12), who show that large-scale features determine the return at near-normal incidence and small-scale features determine that from near grazing incidence. Evans (11) reports measurements at 1130, 68, 23, 10, 3.6 and 0.86 cm. At all six wavelengths it appears that part of the echo arises from a highlight located at the center of the Moon's visible disk. A second component comes almost equally from the remaining parts of the surface. The division of power in the two components changes markedly as the wavelength is reduced. At 68 cm, 80% of the power is returned from the highlight, while at 8.6 mm only 15% can be associated with this component. The angular power spectrum observed for the power from the highlight also changes with wavelength, indicating that the r. m. s. slope of the surface increases as the wavelength is reduced. These observations are interpreted as evidence of a wide range of structure sizes on the Moon. The measurements at decameter wavelengths by Davis *et al.* (6, 7) provide additional evidence that at radio frequencies the Moon displays a central highlight that contracts and brightens with increasing wavelength.

H. SURFACE FORMATIONS

a. General

O'Keefe (13) has reviewed the present understanding of the structure and origin of the Moon. Fielder (4) has reviewed the present state of lunar geology. Kopal (8) reviews the definition of lunar coordinates, methods for determining the exact shape of the Moon, the origin of lunar formations, and other problems of lunar topography. McCauley (11) discusses the nature of the lunar surface as determined by geologic mapping.

From a theoretical comparison of lunar and terrestrial surfaces on globes of equal size, Brock (1) concludes that the coarser tectonic patterns of the Earth and Moon are similar. Dietz (2) suggests that there may be structures on Earth that are analogous to both lunar craters and maria. Geyer and Lopik (5) discuss application of methods of geophysical analysis to study of the lunar surface. Khodak (7) discusses the chief structural elements of both sides of the Moon, including walled plains, craters, maria, valleys and fissures. Krejci-Graf (9) discusses primarily rays and crater shapes.

Heacock (6) reviews pre-Ranger lunar data and presents a general summary of the Ranger results. Kuiper *et al.* (10) discuss particularly the lunar collapse depressions, as well as the structures of maria and craters, and lineaments. Moore (12) compares two lunar crater

morphologies, based on Ranger IX photographs, and concludes that the lunar surface materials are weakly cohesive to noncohesive. Shoemaker (15) discusses the pattern of low ridges and troughs observed on the lunar surface in Ranger photographs, and their relation to the larger lineaments. Urey (16) discusses theories on the evolution and thermal history of the Moon with reference to the Ranger photographs.

Whitaker (17) summarizes conclusions of the Lunar and Planetary Laboratory on the linear grid, rays, craters, and the absence of dust. He presents evidence for a distinction between 'red' and 'blue' maria, and finds evidence that maria are dust-free lava flows from the sharp boundaries between red and blue mare regions. Van Diggelen (3) discusses a statistical method for determining the preferential direction shown by lunar surface formations known as the lunar grid system, and by this method confirms nearly all the systems previously mentioned by Fielder. Rae (14) presents a historical review of work on lunar domes, and a catalog of 113 domes, which he finds normally occur only on maria near the borders or on the floors of lava craters. See also (I 4, 6, 49).

b. Craters

The numerous papers on lunar craters fall into three major categories: discussion of individual craters, statistics of crater size and distribution, and hypotheses of the origin of craters.

The target of Ranger IX, crater Alphonsus, has been mapped and discussed geologically (31). Carr (8) suggests that the alignment of small craters in Alphonsus is strong evidence that many craters were formed by mechanisms originating within the Moon. Ronca (37) concludes that Alphonsus has been deformed by a strike-slip fault of dextral type. The craters Caramuel (1, 33), Dionysius (42), and Aristarchus (D 17, 23) have also received individual attention. The origin of the central peaks of craters has been discussed in terms of faulting and volcanic extrusion (9), and of meteorite impacts (24). Pohn (34) found many crater slopes to have a steepness of at least 37°.

Hartmann (19) finds that the distribution of lunar crater diameters is satisfactorily explained by the impact hypothesis; he attributes a deficiency of small sizes among the oldest craters to a process of erosion. On the other hand, Fielder (13, 14) finds that craters cluster more than could be expected on the impact hypothesis and he concludes that a substantial proportion of craters must be of internal origin, an interpretation criticized by Byron (7).

Ranger photographs have yielded several studies on the distribution (5, 32, 46, 47) and diameter-depth relationship (3, C 42) of craters.

Limitations of space prevent us from discussing individually the various papers dealing with aspects of the meteorite hypothesis (2, 10, 11, 16, 20, 23, 25, 35, 39, 40), the volcanic hypothesis (4, 6, 12, 17, 18, 30, 43, 44) and other problems (15, 26-29, 36, 38, 41, 45) of crater formation, except to note Kopal's suggestion (22) that many smaller craters may be subsidence phenomena, possibly triggered by Moon-quakes following major impacts, rather than due to secondary impacts. See also (I 39-41) and section J.

c. Maria

Shoemaker (11, 12) discusses the fine structure of Mare Cognitum, defining primary and secondary craters on the basis of morphology and distribution, and commenting upon the rarity of small features of positive relief in the Ranger VII photographs. (However a number of small positive-relief features appear on the Orbiter 2 photographs recently released by NASA.) Other discussions of individual maria include Mare Cognitum (2, 3), Mare Tranquillitatis (13), and Mare Humorum (9, 10); see also (D 32). Several papers (1, 4, 6, 7) discuss possible origins of the maria, while (8) considers the possible origin of rilles, ridges, and domes in relation to maria, and (5) compares maria and continental regions with respect to radio emission.

d. Ray Systems

From a study of the faint ray systems around Mare Imbrium by special photographic techniques, Alter (1) finds sufficient resemblance between these faint patterns and the patterns of craters and bright ray systems to conclude that they are of the same genus; he considers the existence of the faint patterns argues against any hypothesis of a deep dust layer, and also against the hypothesis that the craterlets observed along bright rays are direct results of secondary impacts.

Also discussed are the bright rays radiating from certain lunar craters (2), rille complexes (3), ray systems from Ranger VIII photographs (4). In an analysis of radial structures surrounding lunar basins, Hartmann (5) notes that such systems are more developed around presumably younger basins such as Mare Imbrium and Mare Orientale than around older basins, from which he postulates that conditions for producing radial lineaments were optimal during a relatively short period when the basins were flooded.

I. PHYSICAL PROPERTIES AND CHEMICAL COMPOSITION OF THE LUNAR SURFACE

Ruskol (47) reviewed investigations of lunar surface properties carried out in the previous 2–3 years, including results of laboratory simulation of conditions on the lunar surface, and the connection of data on the thermal regime of the Moon's upper layers with the degassing problem of the lunar interior and the history of the lunar atmosphere.

On the basis of photopolarimetric observations (E 6), Gehrels (7) postulates a model of the lunar subsurface that is smooth and firm with little or no dust but with an optically thin layer of ionized micron-sized particles electrostatically suspended over the surface, and accreted from interplanetary space. Objections have been raised (28) concerning the electrostatics of lunar particles and the optical properties of this layer. Gehrels (8) replies that most observations can be explained with a tenuous surface texture with interconnected (rather than freely suspended) scattering elements or particles. Sagan (48) suggests that the photometric properties of the Moon may arise from infall of zodiacal dust particles rather than by proton irradiation of existing dust. Glaser (14) analyzes the implications of the absence of atmospheric pressure for structural, physical, and heat-transfer properties of the lunar surface.

From a review of optical data on the lunar surface and related laboratory studies, Hapke (27) finds strong evidence that the surface of the Moon is covered with a layer of fine dust. From examination of Ranger VII pictures (15), the distinctive thermal and radar properties of the crater Kepler (16), and a review of various data (17), Gold finds evidence for a substantial layer of dust on the lunar surface. Other discussions of lunar dust and its properties include (29, 30, 31, 32, 50, 51, 52): Urey (52) points out that the dust layers postulated by Gold do not necessarily have low physical strength, incapable of supporting a space vehicle. Jaffe (30–32) discusses aspects of the strength of a lunar dust surface. Smoluchowski (51) suggests that sintering by corpuscular radiation may compact the dust and increase its mechanical strength. O'Keefe (43) attributes the softened appearance of the larger craters to a deposit of ash over the lunar surface, or less probably to erosion. Possible mechanisms of erosion on the Moon are treated in (2, 5, 42).

In a study of morphological aspects of the lunar crust, Miyamoto considers such problems as the gas content, viscosity, and differentiation of the original magma (39), the effects on crater formation of decreasing thickness of a silicic crust (41), and suggests that lunar terra is basaltic and maria ultrabasic (40). Paper (46) considers chemical evolution, and (M 28) treats the differentiation of igneous rocks with reference to the Moon.

Laboratory studies have been made of the properties—photometric (20, 23, 26, 44, 45; D 10, 14, 17, 19, 20, 24, 25, 27), polarimetric (E 3, 4, 5), thermal (12, 13, 54; F 27), and

miscellaneous (1, 3, 18, 29, 33, 42, 47)—of a variety of substances for comparison with the respective properties of the lunar surface. To match the lunar photometric law, Hapke (23) concludes that a surface must consist of extremely small, rough, nearly opaque objects, arranged into a complex surface of low compaction, such as rock dust, and modified in color and albedo by solar proton bombardment (26).

On the other hand, Halajian (19) finds radiothermal and photometric data to be compatible with a 'homogeneous underdense-cohesive silicate' model, as of rock froth or sintered slag. From thermal data, Glaser *et al.* (13) conclude that the surface is not composed solely of unconsolidated particles, but more likely of sintered materials or highly vesiculated rocks. In a study of 23 samples of terrestrial magmatic rocks, Orlova (44) finds that lunar photometric properties most closely resemble those of volcanic slaggy products. Other Soviet workers (D 14, 24, 25, 27) also find the reflective properties of certain volcanic rocks similar to those of the Moon.

Reference (54) reviews the literature on the thermal conductivity of various substances, while (12) finds that sintered loose perlite has thermal properties similar to the lunar surface. Paper (38) concerns the interpretation of radio and radar data, and (21) considers various properties of the Surveyor 1 landing site.

J. LUNAR VOLCANISM

The last few decades have witnessed a spirited and sometimes acrimonious debate between those who maintain that the lunar craters originated in meteoric impact and those who aver that the craters are of volcanic origin. Data from lunar probes seem about to resolve the question. Although it is still too early to make a definite pronouncement, current evidence suggests that both methods of crater production have been active in producing craters and otherwise molding the lunar surface. Scientists of the U.S. Geological Survey report (Ha 11) their mapping to indicate that the lunar surface probably consists of interbedded and inter-fingering impact and volcanic debris. The observed 'softness' of the high-resolution photographs and the random distribution of crater diameters smaller than 250 meters clearly support the impact theory. On the other hand, the occurrence of large, deep pits with nearly vertical walls, the sharply delineated regions of contrasting color on the surfaces of certain maria, and the scars of field and ghost craters all suggest the action of tectonic forces including extensive lava flows. The observations would appear to rule out the occurrence of extensive transport of dust over the lunar surface. These conclusions are, of course, still tentative. Final decision on the contribution of volcanic processes must await further analysis of existing films and possible exploration of the lunar surface itself by manned or unmanned techniques. In the meanwhile, we should keep an open mind on such questions.

Green (9) reviews the current evidence in support of the hypothesis that volcanic processes have played a major role in the modelling of lunar features. Menzel (24) shows that the Moon, if liquid at any time during its history, would probably have cooled from the outside in. The outgassing processes would have formed a light, foamy lava that would have floated on the heavier magma. Subsequent flows of lava, controlled in part by tides, would account for the appearance of maria and the ghost craters.

Kuiper (11) points out similarities between Liamana Volcano in Hawaii and various lunar features, and suggests that the secondary craters on the slopes of Liamana are probably caused by impact. From a study of the frequency and distribution of crater diameters, Simpson (21, 22) argues that the majority of craters on the Moon and Mars are of volcanic origin. Vonnegut *et al.* (23) suggest that gasses escaping from hot lava may condense to form stable aerosols. O'Keefe (16) interprets a dark stripe seen on certain Ranger VII photographs as evidence for recent lunar volcanism, of intermediate or acid type. On the other hand, Dietz

and Holden (3) express strong doubt that the Moon has either significant internal convection or currently active volcanos. They argue, from the complete or near absence of water, that explosive volcanism is highly unlikely on the Moon. Section H includes additional references on lunar volcanism.

Recent laboratory studies suggest that the absence of a lunar atmosphere must be given more consideration in theorizing on the origin of lunar formations. Dobar (4, 5) finds that a simulated basalt and granite magma, allowed to upwell and solidify in a vacuum, has produced a porous material not found in nature on Earth. The photometric curves of this material resemble closely those from the lunar surface. During the vacuum upwelling, Dobar observed color phenomena similar to those reported around Aristarchus (K 8).

In a report on further observations of the luminous glow in the crater Aristarchus, Kozyrev (10) finds both C_2 and H_2 emission and suggests the latter may be emitted from a fumarole within the crater area. See also (K 4). Middlehurst and Burley (13, K 3) made a complete catalog of observed and recorded lunar events—defined as temporary changes in the appearance of a lunar feature—over the past four centuries. Middlehurst (12) finds no correlation between the occurrence of such events and sunspot numbers, and suggests the events may arise from tidal cracking or crustal deformations, with a release of hot or cold gasses. In a review of evidence for changes on the Moon, Moore (15) doubts the reality of reported structural changes, such as the vanishing of crater Linné, and long-term changes in the reflectivity. But he considers that the transient outbreaks, like those reported in Alphonsus, are probably real. Deák *et al.* (2) postulate a volcanic origin for the reddish spots seen (K 8) in the vicinity of Aristarchus, and calculate the energy liberated from the lunar interior in such an event. See section K for additional references on transient phenomena.

The origin of tektites found on the surface of the Earth has long been debated. These glassy objects appear to be some form of meteorite. In the absence of any clear-cut alternative theory, several scientists have suggested (1, 6, 7, 14, 17) that tektites originated on the Moon, and further, that their study may contribute to understanding the lunar structure (19, 20). O'Keefe and Adams (18) suggest that tektites originated in a lunar ash flow.

K. LUNAR LUMINESCENCE

The problem of whether the lunar surface produces detectable luminescence has two aspects—the possible existence of transient phenomena induced in some way by flare-associated solar activity; and possible longer period variations related to the sunspot cycle and general level of solar activity. Most of the research deals with the former aspect.

A survey of the historical literature turned up 159 dated and seemingly reliable observations of apparent activity on the Moon over the past four centuries (3, J 13). The material was analyzed with respect to solar activity and to tidal action by the Earth (3). The observations of color streaks in the Aristarchus area in late 1963 have been reviewed (8). A search of the literature turned up 16 additional transient events observed between 1783 and 1963 in the vicinity of Aristarchus (6), and negatively correlated with solar activity. A transient increase in brightness around the crater Kepler was observed through a filter centered at 6725\AA , while control plates at 5450\AA showed no effect (10, 9). A subsequent search by similar techniques detected no luminescent phenomena (14). However use of a blink comparator technique has revealed additional color events (20).

By the 'method of line-depths', a variable luminescence reaching as much as 30% of the continuum was observed near 5450\AA , but no luminescence greater than 2% was detected at $H\alpha$ or the Na D-lines (16), nor at around 3900\AA (18). Other observations interpreted as evidence of luminescence at particular wavelengths have been cited above (D 17, 23, 36); see also (I 45).

The explanation of these transient phenomena remains controversial (1, 6, 7, 12, 13; L 4). A laboratory study found (5) that some materials luminesce strongly in the red when bombarded by 40 keV protons, but this finding was not substantiated by other investigators (17). See also (19).

A different type of transient phenomenon, the C₂ Swan bands observed by Kozyrev around the crater Alphonsus, has been attributed to explosions of acetylene (4).

On the second aspect of the problem, Gehrels *et al.* (E 6) report that luminescence was detected in the photometry of various lunar regions, and independently confirmed by the polarimetry—under the assumption that the luminescent light is not appreciably polarized. They found the lunar surface to be 10–20% brighter (and less polarized) in 1956–59 than in 1963 November–1964 January. The effect was fairly constant from day to day, and thought to vary with the solar cycle. This phenomenon may be related to Danjon's (1922) finding of a relation between phase of the sunspot cycle and brightness and color of the eclipsed Moon (D 15, 39; E 6). Gehrels *et al.* (E 6) note that the eclipse of 1965 November 18 was reddish and bright, and that of 1963 December 30 unusually dim. (See also D 2, 3, 5, 6, 9, 13, 15, 16, 18.) However opinion differs whether the dark eclipses (D 9) or the bright eclipses (D 15) require more 'explanation.'

L. LUNAR ATMOSPHERE AND ENVIRONMENT

Safronov and Ruskol (12) consider the history of the lunar atmosphere formed by gradual degassing of the interior; they conclude that the Moon never had any appreciable atmosphere and that there has been no liquid water on its surface. Gilvarry (I 10) presents evidence in favor of the former presence of water on the Moon. The possibility of detecting a permafrost layer beneath the lunar surface by observations of OH molecules near the Moon has been considered (I 25, 55).

Singer (13) concludes that the only gas in the vicinity of the Moon comes from interplanetary space, and predicts a peculiar type of 'ionosphere' to exist near the Moon, made up of photoelectrons that have insufficient energy to escape and thus are held back by the Moon's electrostatic field. Hinton and Tausch (8) use a simplified model of the lunar atmosphere to calculate average densities of certain neutral and ionized gases near the Moon's surface as a function of the solar corpuscular flux and taking account of sources of gas in the lunar crust. Michel (9) examines the flow of solar wind plasma about the Moon for two limiting cases. Several authors discuss aspects of interaction between the solar wind and the lunar surface (14; I 26, 50, 51) or lunar field (1, 3, 4, 10, 11). See also (J 8).

Observations of γ -radiation and magnetic field intensity by Luna 10 have been cited above (Bd 2, 4, 5, 6). Luna 9 provides data on the γ -radiation from its vicinity (15), much of which is considered a secondary effect of cosmic radiation. Also considered are lunar X-rays (5, 6, 7), radioactivity (I 35), and expected variations in cosmic ray intensity on the Moon (2).

M. INTERNAL STRUCTURE

Levin (23, 24) reviews research on such aspects of internal structure and evolution of the Moon as the origin, thermal history, shape, density distribution, and chemical composition of the Moon. Several of these problems are treated also in (18). From calculations on the thermal history of the Moon, Levin (22) concludes that a period favorable for lava effusions occurred 2.5 to 3.0×10^9 years ago, depending on the content of radioactive elements in the Moon. Papers (18, 27) also treat the thermal history of the Moon.

Fielder (8) considers that Runcorn's theory, in which convection cells keep the Moon's surface buoyed up, provides the only satisfactory explanation for the slight bulge of the Moon

in the direction of the Earth. He further suggests (9) that this convection may also explain the orientation of the two major systems of pan-lunar lineaments. Some theoretical aspects of convection in the Moon's interior are considered in (17, 18). References (4, 15) treat radiative heat transfer within the Moon, while (16, 27) deal with problems of thermal conduction, (7) is a theoretical investigation of the energy balance in the crust, and (28) considers processes of igneous rock differentiation as applied to the Moon.

The shape of the Moon has been reviewed (23, 24), and recently investigated by means of Orbiter 1 (13, Bd 10), and annular eclipses (3, 5). Wildey (29) reviews other methods. From a comparison of observations and new calculations of the motions of the node and perigee, Eckert (6) finds evidence for a large concentration of mass near the surface of the Moon. Koslovskaya (36) considers the density distribution along the radius for some models of the Moon. Shimazu (N 7) analyzes the viscosity distribution within the Moon. Several papers discuss the shape and internal structure (11, 13, 20, 21, 24), the shape and gravity field (2, 12, 26), and the distribution of mass in the Moon (1, 6, 10, 23, 24, 25).

Levin postulates that the oblate shape of the Moon is a direct consequence of the decrease of surface temperature from the equator to the poles, with a corresponding absence of spherical symmetry in the distribution of internal temperature (32, 33, A 13). Safronov (34, A 13) considers some isostatically-compensated models of the Moon with a semi-molten core and solid outer parts, the thickness of the latter being greater along the polar axis due to thermal conditions (Levin's suggestion). He showed that such models can account for the observed 'non-equilibrium' oblateness of the Moon. The necessary difference in thickness of the solid layer is in accordance with the calculations on the thermal history of the Moon performed by Levin and Majeveva (22, 35). Thus, contrary to a widespread opinion, the Soviet scientists find the semi-molten state of the lunar interior, which follows from thermal calculations for the chondritic model of the Moon, does not contradict its non-equilibrium shape.

Zharkov *et al.* (30) review recent trends in studies of the interior structure of the Moon and planets by geophysical methods. They consider (30, 37) the propagation of seismic waves on the Moon for different temperature conditions of its interior. The existence of a very thick layer of low velocities is suggested. Seismic studies are considered also in (1, 19). Zharkov (30) considers quantitatively the relationship between the lunar magnetic field and the conditions in the liquid iron core.

N. ORIGIN AND EVOLUTION OF THE MOON

Scientists of the O. J. Schmidt Institute of Physics of the Earth (5, 6, 11, 12, 13) made new calculations of the effects of tidal friction in the interior of the Earth and Moon on the evolution of the Moon's orbit. They find that the lunar orbit was formerly smaller, less eccentric, and less inclined to the Earth's equator than now, a result they interpret as favoring the formation of the Moon in the Earth's vicinity, and in contradiction to the Alfvén-Gerstenkorn (1) hypothesis on the capture origin of the Moon. The effects of tidal friction are considered also in (4), while (2) presents the hypothesis of origin by capture in a direct orbit at a distance of about 45 Earth radii when the Earth was rotating in about ten hours. Urey (10) reviews, in the light of recent evidence, his 1957 theory that the Moon was one of the primary objects accumulated in primitive gas spheres and is older than the Earth. In (9) he discusses evidence for the contamination of the Moon by terrestrial water. Shoemaker (8) describes the establishment of a geological time scale for major events on the Moon, by using the technique of stratigraphy.

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