BIBLIOGRAPHY OF THE MOON AND PLANETS

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(Compiled from Journals received in the Lunar and Planetary Institute Library May–August 1978)

[**Editorial Note**: Because of the extensive nature of this bibliography it is to appear in two parts. The concluding part, dealing with Uranus, Venus, Other Objects, and Meteorites, will appear in the next issue of *The Moon and the Planets*.]

MOON

1. Motion of the Moon and Dynamics of the Earth–Moon System; Shape and Gravity Field of the Moon

Cok, D. R. (Dept. of Physics, Harvard University, Cambridge, Mass. 02139): 'On the Perturbations of a Close-Earth Satellite Due to Lunar Inequalities', *Celes. Mech.* 16, 459–479. (1978)

The lunar disturbing function for a close-Earth satellite is expressed as a sum of products of harmonics of the satellite's position and harmonics of the Moon's position, and the latter are expanded about a rotating and precessing elliptic orbit inclined to the ecliptic. The deviations of the Moon from this approximate orbit are computed from Brown's lunar theory and the perturbations in satellite orbital elements due to these inequalities are derived. Numerical calculations indicate that several perturbations in the position of the satellite's node and perigee have magnitudes on the order of one meter.

Dimitrijevich, V. (4400 Lindell Blvd., St. Louis, Missouri 63108): 'A Contribution for Estimating the Moon's Physical Libration Parameters α, β and γ Using the Moment of Inertia $A < B < C$ Values, Determined by Zhongolovich Triaxial Formulas', *EOS: Trans. Amer. Geophys. Union* 59, 315. (1978)

This study describes a procedure for estimating the Moon's physical libration parameters α, β and γ, using the assumption that the Moon has a triaxial shape. For the procedure, six Moon parameters were adopted: mean radius, gravitational constant, three potential coefficients (C_{20}, C_{22} and S_{22}) and the lunar moment of inertia ratio $C/M_m a_m^2$. By application of the Zhongolovich triaxial formulas, the moment of inertia values, A, B and C, were estimated. The physical libration parameters were then determined from the formulas

$$\alpha = \frac{C-B}{A}, \quad \beta = \frac{C-A}{B}, \quad \gamma = \frac{B-A}{C}.$$

The estimated parameters β, γ, C_{20}, C_{22} and $C/M_m a_m^2$, so obtained, coincide closely to the values published by Blackshear and Gapcynski (1977).

The Moon and the Planets 21 (1979) 199–254. 0165–0807/79/0212–0199$08.40.
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Dvorak, J. (Div. of Geological and Planetary Sciences, Calif. Inst. of Tech., Pasadena, Calif. 91125) and Phillips, R. J.: 'Grimaldi: Lunar Bouguer Gravity' *EOS: Trans. Amer. Geophys. Union* 59, 313. (1978)

Grimaldi is a small multiringed basin located on the western limb of the Moon. Spacecraft gravity data reveals a mascon associated with the inner ring of this structure. Topographic data for this feature (made available by S. Zisk) show that the mare material within the inner ring lies at a level ~ 1 km below the level of nearby Oceanus Procellarum. Preliminary estimates for the topographic contributes to the gravity field indicates a maximum Bouguer anomaly of 90 mgal. Approximately 20% of this positive anomaly can be accounted for by the mare material lying within the inner ring. The remaining positive anomaly is represented by a plug of high density material ~ 120 km in diameter and at least 20 km thick.

The association of these high density regions with multiringed basins and the lack of their association with large lunar craters, comparable in size to Grimaldi (e.g., Petavius and Humboldt) including a large crater partially filled with mare material (Neper), suggests that the major component of these positive anomalies were produced in connection with the formation of the outer rings. Currently, we are of the opinion that these positive anomalies are due to higher density lunar mantle material centrally uplifted by the inward collapse of material which formed the concentric outer rings.

King, R. W. (Dept. of Earth and Planetary Sciences, MIT, Cambridge, Mass. 02139), Counselman, C. C. III, and Shapiro, I. I.: 'Universal Time: Results from Lunar Laser Ranging', *J. Geophys. Res.* 83, 3377–3381. (1978)

Lunar laser ranging observations from the McDonald Observatory have been analyzed by least squares to estimate universal time (UT) simultaneously with parameters representing the locations of McDonald and the lunar retroreflectors, the orbits of the Earth and the Moon, and the Moon's physical libration. The root-mean-square (r.m.s.) of the postfit range residuals for the 5 year period from October 1970 to November 1975 is 28 cm. The r.m.s. of the differences between our determinations of UT and those of the Bureau International de l'Heure is 2.1 ms, after removal of the mean difference. The differences between our determinations and those of Stolz *et al.* (1976), who analyzed most of the same ranging data with a different approach, have an r.m.s. of 0.8 ms and, in addition to high-frequency 'noise,' exhibit low-frequency variations of $\lesssim$ 1 ms in magnitude which result at least in part from differences in models used for the lunar orbit. Thus problems in modeling the Moon's motions, especially those of long period, make difficult the determination of UT with the accuracy inherent in the ranging observations.

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

Ferrari, A. J. (Jet Propulsion Laboratory, Pasadena, Calif. 91103), Nelson, D. L., Sjorgren, W. L., and Phillips, R. J.: 'The Isostatic State of the Lunar Apennines and Regional Surroundings', *J. Geophys. Res.* 83, 2863–2871. (1978)

High-resolution gravity and topography data taken over the Apennine Mountains have been used to compute their isostatic state. Results show that the Apennines are uncompensated: thus this state implies that the lunar crust and upper mantle have been strong enough over 3.9 b.y. to support the load exerted by this topographic excess. The Apennines produce a maximum shear stress of 60 bar at a depth of 60 km. A lower bound on the lunar crustal viscosity of 1×10^{27} P is calculated on the basis of the assumption of a 10% relaxation over 3.9 b.y. Studies of a broad negative regional anomaly located between Maria Serenitatis and Imbrium necessitate a locally thicker crust to satisfy the observed data. This anomaly may have been produced by a lateral transport of crustal material from beneath the giant impact basins as a result of rebound at the crust–mantle interface.

Goins, N. R. (Dept. of Earth and Planetary Science, MIT, Cambridge, Mass. 02139), Toksöz, M.N., and Dainty, A. M.: 'Seismic Energy Release of the Moon', *EOS: Trans. Amer. Geophys. Union* **59**, 315. (1978)

Previous calculations of the lunar seismic energy release effected by Moonquakes, deep and shallow, have not explicitly corrected for the narrow frequency response of the Apollo seismometers or for the effects of the near-surface strong scattering layer which drastically spreads any seismic arrival. A formula taking these factors into account and giving the source energy in ergs as a function of observed seismic amplitude is

$$E_s = 2\pi^3 \rho c T R^2 \left(\frac{f_c f_0^2}{\Delta f}\right) (5.4 \times 10^{-9})^2 (\bar{u}^2 + \bar{v}^2 + \bar{w}^2)$$

where ρ = density, c = very-near-surface seismic wave velocity, T = duration of seismic signal, R = source-receiver distance, f_c = source cutoff frequency, f_0 = dominant signal frequency, Δf = effective seismometer bandwidth, u, v, w = average (over signal duration) ground motion amplitude in digital units. Using appropriate parameters for long-period seismograms, the source energies for the smallest and largest observed deep Moonquakes are 7×10^{10} erg and 7×10^{12} erg. This method agrees to within a factor of 2 with the energy obtained by using diffusion theory to account for the scattering layer. For shallow Moonquakes, source energies of $1\text{–}2 \times 10^{15}$ erg are obtained for the largest HFT's. The b value of shallow Moonquakes is about 0.5, and, while somewhat uncertain, the b values of deep Moonquakes appear to be about 1.5. Thus the shallow Moonquake annual seismic energy release is about 10^{15} erg year^{-1}, and the deep Moonquake release is about 10^{13} erg year^{-1}. The total lunar seismic energy release is thus about 10 or 11 orders of magnitude less than that of the Earth.

Nakamura, Y. (Univ. of Texas Marine Science Inst., Geophysics Lab., Galveston, Tex. 77550): 'Relative Location of Moonquakes Within a Source Region', *EOS: Trans. Amer. Geophys. Union* **59**, 315. (1978)

A new technique of accurately determining relative locations of a group of deep-focus Moonquakes within a source region has been developed. The technique utilizes cross phase spectra between a pair of Moonquake signals, and is based on an assumption that *P*- and *S*-wave codas are primarily due to scattering near the seismic station. Relative arrival times can be determined with an accuracy that is an order of magnitude greater than the sampling rate of the signals. Applying this technique to a group of Moonquakes from the A_1 source region, the most active of about 80 source regions identified to date inside the Moon, it is found that: (1) the vertical extent of the source region of the repeating Moonquakes is at most 500 m, and the lateral extent is at most 800 m, (2) there is a suggestion that a focal plane that dips downward toward the southwest may exist, and (3) the radiation pattern around the source region rotates as the tidal stress field shifts with time. These results, combined with the variation of the ratios of *P*- and *S*-wave amplitudes lead us to conclude that deep Moonquakes are not caused by tidally triggered release of accumulated tectonic strain, but are mere accumulation and release of tidally induced strain energy within a tectonically inactive lunar interior.

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

Head, J. W. (Dept. of Geological Sciences, Brown Univ., Providence, Rhode Island 02912), Pieters, C., McCord, T., Adams, J., and Zisk, S.: 'Definition and Detailed Characteristics of Lunar Surface Units Using Remote Observations', *Icarus* **33**, 145–172. (1978)

Remote sensing techniques and data may be subdivided into three principal types according to how they are used: (1) *defining techniques* help to define unit boundaries and extent; (2) *characterizing* *techniques* allow classification and characterization of physical features, lithology, or chemical composition; (3) *supporting techniques* provide additional useful information but are not fundamental to the definition or characterization of units. Defined units represent a fundamental subdivision of the rocks in a planetary crust and thus represent processes and sequences of events. The definition and characterization of units provides a framework for the interpretation of planetary processes and history. Detailed consideration of unit definition and characterization is presented using the mare deposits of the Imbrium basin as an example. This example provides guidelines for the utilization of remote sensing techniques in geologic mapping of the Moon and other planets.

Hodges, C. A. (U.S. Geological Survey, Branch of Astrogeologic Studies, Menlo Park, Calif. 94025) and Wilhelms, D. E.: 'Formation of Lunar Basin Rings', *Icarus* 34, 294–323. (1978)

The origin of the multiple concentric rings that characterize lunar impact basins, and the probable depth and diameter of the transient crater have been widely debated. As an alternative to prevailing 'megaterrace' hypotheses, we propose that the outer scarps or mountain rings that delineate the topographic rims of basins – the Cordilleran at Orientale, the Apennine at Imbrium, and the Altai at Nectaris – define the transient cavities, enlarged relatively little by slumping, and thus are analogous to the rim crests of craters like Copernicus; inner rings are uplifted rims of craters nested within the transient cavity. The magnitude of slumping that occurs on all scarps is insufficient to produce major inner rings from the outer. These conclusions are based largely on the observed gradational sequence in lunar central uplifts: from simple peaks through somewhat annular clusters of peaks, peak and ring combinations and double ring basins, culminating in multiring structures that may also include peaks. In contrast, belts of slump terraces are not gradational with inner rings. Terrestrial analogs suggest two possible mechanisms for producing rings. In some cases, peaks may expand into rings as material is ejected from their cores, as apparently occurred at Gosses Bluff, Australia. A second process, differential excavation of lithologically diverse layers, has produced nested experimental craters and is, we suspect, instrumental in the formation of terrestrial ringed impact craters. Peak expansion could produce double-ring structures in homogeneous materials, but differential excavation is probably required to produce multiring and peak-in-ring configurations in large lunar impact structures. Our interpretation of the representative lunar multiring basin Orientale is consistent with formation of three rings in three layers detected seismically in part of the Moon – the Cordillera (basin-bounding) ring in the upper crust, the composite Montes Rook ring in the underlying, more coherent 'healed' crust, and an innermost, 320 km ring at the crust–mantle interface. Depth–diameter ratios of 1/10 to 1/15 are consistent with this interpretation and suggest that volumes of transient cavities and hence of basin ejecta may be considerably greater than commonly assumed.

Koenig, B.: 'Investigations of Primary and Secondary Impact Structures on the Moon and Laboratory Experiments to Study the Ejecta of Secondary Particles. NASA-TM-75023, N77-29042. 1977. pp. 114. Available from NTIS as N77-29042 $6.50. Ph.D. Thesis – Ruprecht Karl Univ., Heidelberg, 1977, translation.

Young lunar impact structures were investigated by using lunar orbiter, Apollo Metric and panorama photographs. Measurements on particularly homogeneous areas low in secondary craters made possible an expansion of primary crater distribution to small diameters. This is now sure for a range between $20\text{ m} \leqslant D \leqslant 20\text{ km}$ and this indicates that the size and velocity distribution of the impacting bodies in the last 3 billion years has been constant. A numerical approximation in the form of a 7th degree polynomial was obtained for the distribution.

Lugmair, G. W. (Chemistry Department, B-017, University of California at San Diego, La Jolla, Calif. 92093) and Marti, K.: 'Lunar Initial $^{143}Nd/^{144}Nd$: Differential Evolution of the Lunar Crust and Mantle', *Earth Planet. Sci. Lett.* 39, 349–357. (1978)

The Sm–Nd evolution of Apollo 15 green glass is discussed. The ICE age (intercept with chondritic evolution) of 3.8 ± 0.4 AE overlaps the range of reported ^{39}Ar–^{40}Ar ages (T_2) and implies a distinct source region for green glass, characterized by very low and unfractionated REE abundances. We present evidence that LINd (lunar initial Nd) is compatible with a "chondritic" type Nd isotopic evolution as observed in the Juvinas meteorite.

Using this normalization we studied the Sm–Nd system of various lunar rock types. The results obtained from a limited number of rocks clearly indicate differential Sm–Nd evolution for the lunar crust and mantle. High-Ti basalts returned by the Apollo 11 and 17 missions were derived from distinct source regions. The ^{143}Nd evolution in KREEP requires a source region of negative $\epsilon(T)$ which is clearly distinct from any mantle reservoir.

Mohan, S. N. (Jet Propulsion Laboratory, Pasadena, Calif. 91103): 'Farside Lunar Topography: New Photogrammetric Solutions Based on Observations from Apollo and Lunar Orbiter Photographs', *EOS: Trans. Amer. Geophys. Union* 59, 315–316. (1978)

Photometeric observations derived from farside Apollo photography has resulted in new topographical solutions in a region north of Mare Marginis. This paper presents photogrammetric solutions in regions defined by the Lunar landmarks Gauss, Maxwell/Vestine in the western longitudes, Belkovich/Mare Humboldtianum in the northern latitude, extending to the features Hilbert, Sklodowska, Curie and Milne in the southern latitudes. The above region represents the total overlap between the Apollo trans Earth phase photographs with the lunar farside and is intended to augment available farside topographical coverage in order to obtain a more uniform global distribution of topographical data of all forms available at the present time. The results of the above described data reduction is used to obtain a 16th degree and order harmonic representation of the lunar surface, which is compared with the currently available lunar gravity field in order to derive a Bouguer gravity anomaly map.

Neukum, G. (Institut für Algemeine und Angewandte Geologie der Universität München, W. Germany and Max-Planck-Institut für Kernphysik, Heidelberg, W. Germany): 'Different Ages of Lunar Light Plains', *The Moon* 17, 383–393. (1977)

The crater populations of 18 lunar light plains (Cayley plains) show a variation in relative ages by a factor of about 4 in crater frequency of regions in the surroundings of the Orientale resp. Imbrium basin, and by a factor of greater than 25 for more distant sites. Thus the idea of a Moonwide synchronism in the emplacement of the lunar light plains with the formation of the basins Imbrium or Orientale cannot be supported.

Some light plains are younger than the youngest basin Orientale. Since these plains cannot have been emplaced by any other basin-forming event and local impact-derived origin can certainly be excluded, an endogenic (magmatic) origin is proposed for these plains.

Age determination data (D_L-values) by Soderblom and Lebofsky (1972) and Soderblom and Boyce (1972) are shown to be correlated with own cumulative crater frequency data (N) for surfaces younger than $\simeq 3.8 \times 10^9$ years; we find $D_L \sim N^{0.6}$, different from the originally proposed relation $D_L \sim N$. For ages $> 3.8 \times 10^9$ years, the D_L data by those authors, especially their light plains data, are incompatible with our crater frequency data.

O'Keefe, J. D. (Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, Calif. 91125) and Ahrens, T. J.: 'Impact Flows and Crater Scaling on the Moon', *Phys. Earth Planet. Interiors* 16, 341–351. (1978)

The axisymmetric distribution of stress, internal energy and particle velocity resulting from the impact of an iron meteoroid with a gabbroic anorthosite lunar crust has been calculated for the regime in which shock-induced melting and vaporization takes place. Comparison of impact flow fields, with phase changes in silicates taken into account, with earlier results demonstrate that in the phase change case when the 15 km s^{-1} projectile has penetrated some two projectile radii into the Moon, the peak stress in the flow is ~ 0.66 Mbar at a depth of 66 km, and the stress has decayed to ~ 66 kbar at a depth of 47 km. Rapid attenuation occurs because of the high rarefaction velocity of the high-pressure phases associated with a 35% (zero-pressure) density increase. This feature of the phase-change flow tends to strongly concentrate the maximum shock pressures along the meteoroid trajectory (axis) and makes the conical zone along which high internal energy deposition occurs, both shallow and narrow. Examination of the gravitational energies required to excavate larger craters on the Moon indicates the importance of gravity forces acting during the excavation of craters having radii in the range greater than ~ 2–~ 140 km. It is observed that the 'hydrodynamic' energy vs. crater radius relation approaches those for various 'gravitational' energy vs. radius relations at the radii values corresponding to the larger mare basins. Cratering energy values in the range of (1.0–9.4) $\times 10^{32}$ erg are inferred on this basis for the Imbrium crater. Using these values and the criteria that all rocks exposed to ~ 100 kbar or greater shock pressures are included in the ejecta (some of which falls back) implies that the maximum depth of sampling expected to be represented within the Apollo collection lies in the range 148–328 km.

Peeples, W. J. (Dept. of Geological Sciences, Southern Methodist Univ., Dallas, Tex. 75275), Sill, W. R., May, T. W., Ward, S. H., Phillips, R. J., Jordan, R. L., Abbott, E. A., and Killpack, T. J.: 'Orbital Radar Evidence for Lunar Subsurface Layering in Maria Serenitatis and Crisium', *J. Geophys. Res.* 83, 3459–3468. (1978)

Data from the lunar-orbiting Apollo 17 radar sounding experiment (60 m wavelength) have been examined in both digital and holographic formats. Surface backscatter (clutter) which masks possible radar returns originating from subsurface changes in lunar electrical properties was reduced by simultaneously comparing radar data from two orbits. Radar returns that correlate from orbit to orbit form two distinct alignments in Mare Serenitatis and one in Mare Crisium. It is proposed that these alignments represent subsurface reflecting horizons. The hypothesis is tested by showing that (1) most of the radar returns fall outside the ambiguity region of the correlation technique, (2) the results are consistent between optically and digitally processed data, (3) the signal levels of the proposed subsurface features are well above the noise floor, (4) the inferred loss tangents appear to be consistent with returned sample measurements, and (5) the discontinuous nature of the reflections most likely arises from interference effects. It is concluded that there are two subsurface radar reflectors with mean apparent depths of 0.9 km and 1.6 km below the surface in Mare Serenitatis and one reflector at a mean depth of 1.4 km below the surface in Mare Crisium. These reflectors represent basin-wide subsurface interfaces.

Strel'tsov, V. A.: 'Optimization of the Process of Gravimetric Surveying on the Lunar Surface', *Cosmic Res.* 15, 686–690. (1977)

Villella, C. J. (Washington, D.C.): 'The Nature and Possible Origin of Lava-like Material Within Chenièr Crater', *The Moon* 17, 343–352. (1977)

This paper considers the origin of certain tongues of lava-like material in Chenièr Crater, a meteorite crater located about 63 km northeast of the major crater, Tsiolkovsky, on the lunar far side. The author contends that the tongues originated from subsurface movement of magma generated as a result of the meteorite impact which created Tsiolkovsky Crater. The impact produced lines of weakness which were further enhanced by the impact forming Chenièr. Magma then moved from Tsiolkovsky through the zones of weakness to Chenièr Crater, extruding on the surface to form the first stringer. Following the extrusion, magnetic movement stopped and a cap formed over the vent. Enough heat was left in place under Chenièr, however, to cause crustal melting and consequently the extrusion of a second and possible third lava-like stringer before the magma chamber under Chenièr cooled and a cap over the vents permanently formed. Confirmation of the theory depends upon whether magma can move through weak zones in the lunar subsurface. Indications of this possibility have been suggested in findings dealing with the floors of Tycho and Aristarchus craters and in a study of the effects of artificial cratering.

Worrall, D. M., Fagin, S. W., and Muehlberger, W. R.: 'Ridge Orientation vs. Position in Circular Lunar Maria', *EOS: Trans. Amer. Geophys. Union* 59, 310–311. (1978)

Mare ridges and arches in circular lunar maria have consistent orientations depending on radial position in the mare basin.

The main outer ring is not circular but consists of linear segments. Many of these segments are parallel to structures in the adjacent highlands and thus may owe their orientations to preexisting structures. The average circular shape is thought to be related to the ring structure of an impact basin. The shapes, post-mare cooling time of formation, and total pattern (NW and NE-trending en echelon systems and N-trending ridges) is consistent with an E–W maximum compression as having caused the mare ridges.

In contrast, mare ridges in the central area (roughly one-half radius of the basin) trend primarily north: Imbrium, N1°E; Crisium, N2°E; Tranquillitatis, N1°W; and Serenitatis, N19°W. Serenitatis is biased westward by the multiple ridges extending southeast from the crater Bessel. Without these, the average trend is nearly north. The consistency of orientation suggests that these ridges (folds) are not affected by edge effects or preexisting underlying structure and thus are decollement folds that give the main regional maximum compressive stress orientation (E–W) which formed the ridges.

Global E–W compression may be due to a reduction of rotational velocity and/or cooling contraction.

Woronow, A. (Lunar and Planetary Laboratory, University of Arizona, Tucson, Ariz. 85721): 'The Expected Frequency of Doublet Craters', *Icarus* 34, 324–330. (1978)

The observed abundances of doublet craters do not necessarily indicate a nonrandom process. Previous studies maintained that planetary surfaces have more doublet craters than would result from randomly located impacts. A new probabilistic calculation and more realistic Monte Carlo simulations demonstrate that the expected and observed number of doublet craters do not differ significantly.

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

Bilson, E. (Center for Radiophysics and Space Research, Cornell Univ., Ithaca, New York 14853): 'Solar Wind Effects on the Surface Chemistry of Lunar Grains', *Geophys. Res. Lett.* 5, 481–484. (1978)

Surface enhancements of iron and magnesium in crystals from lunar rock and soil samples have been measured by ion microprobes and were attributed to solar wind implantation of these elements. In this paper it is shown that these surface enhancements and in particular the Fe/Mg surface concentration ratios can also be explained as resulting from the sputter action of solar wind protons and He ions. Furthermore, since these ions are ten thousand times more abundant in the solar wind than ions of the elements which principally constitute the lunar grains, calculations demonstrate that sputtering by protons and He ions moves approximately a hundred times more Mg atoms, for example, than the number of solar wind Mg ions striking the surface. Ion implantation is unlikely, thus, to have a dominant effect on the major element composition of the surface of lunar grains.

Coish, R. A. (Dept. of Geological Sciences, Univ. of Tennessee, Knoxville, Tenn. 37916), Hu, H. N., and Taylor, L. A.: 'Luna 24 Core Samples from Mare Crisium: Mineralogy and Petrology', *EOS: Trans. Amer. Geophys. Union* 59, 223. (1978)

The Luna 24 soils consist of lithic and mineral fragments, agglutinates, and homogeneous glasses. The rock fragments are principally fine to coarse grained sub-ophitic to ophitic basalts with subordinate amounts of metabasalts and olivine vitrophyres. Chemically, they are very low Ti (VLT) aluminous basalts. Mineral fragments include pyroxene, plag, olivine, with minor amounts of ilmenite, ulvöspinel-chromite, native Fe, troilite, and silica. Pyroxenes trend from augite/sub-calcic augite/pigeonite to ferro-Hd and rarely pyroxferroite compositions. Ti, Ti/Al increase, and Cr decreases with increasing Fe/Fe + Mg in the pyroxenes. Olivines range from Fo75 to Fo3. Fa-rich olivines are more common in the rock fragments than in mono-mineralic grains. Plag compositions are An96 to An78, with a mean of An92.

Agglutinates constitute up to 40% of the soil samples and tend to decrease with depth in the core. Because the composition of agglutinitic glass is approximately the same as that of the bulk soil, EMP analyses of large representative portions of the glass from 6 horizons were performed. The Avg. composition is: SiO_2 44.5%, TiO_2 0.9%, Al_2O_3 14.7%, FeO 16.9%, MgO 9.1%, CaO 12.0%, Na_2O 0.4%, K_2O 0.05%. However, the compositions of the glass display bimodality (e.g., 24 149), a minor mode with highland composition, in contrast to the VLT, high Al, low Mg basalt mode. An unusual type of agglutinate was found which does not contain the typical myriad of native Fe grains. It contains well over 20% FeO and may represent an agglutinate which did not incorporate appreciable solar-wind H_2 into its melt – hence, little FeO reduction resulted.

Evsyukov, N. N. (Kharkov State Univ.) and Shestopalov, D. I.: 'Mineral Composition of Lunar Soils', *Solar System Res.* 12, 15–20. (1978)

Normative mineral composition schemes for various groups of lunar soils are presented. A comparison of 0.95 μ absorption-band intensity with pyroxene content, as calculated from optical data, is presented for 50 lunar regions. The effect of soil glass content on absorption band intensity is considered, and the accuracy of mineral content determination from this intensity is evaluated.

Grove, T. L. (Dept. of Earth and Space Sciences, State Univ. of New York, Stony Brook, New York 11794): 'Experimentally Determined FeO–MgO–CaO Partitioning Between Pyroxene and Liquid in Lunar Basalts', *EOS: Trans. Amer. Geophys. Union* 59, 401. (1978)

Pyroxene–liquid pairs have been analyzed in 15 equilibrium and 25 controlled cooling rate experiments on low Ti-mare basalt compositions. The experiments (performed in Fe capsules sealed in silica tubes) are on 3 basalt compositions whose residual liquids span a wide range of molar Fe/Fe + Mg) (0.54 to 0.88), CaO/Al_2O_3 (1.87 to 2.18) and TiO_2 (0.5 to 3.2) values. The results yield molar bulk D's ($= X^{pyx}_{oxide}/X^{liq}_{oxide}$) and $K_D^{Fe-Mg} = (X^{pyx}_{FeO}X^{liq}_{MgO}/X^{pyx}_{MgO}X^{liq}_{FeO})$ for low Ca clinopyroxene (Wo contents less than 20%), and augite. The equilibrium data and cooling rate data span the temperature ranges 1200° to 1070°C and 1190° to 970°C, respectively. Bulk D's are identical in equilibrium and cooling rate experiments, despite the large variations in minor elements found in pyroxenes produced during dynamic crystallization. Bulk D's for the 40 low Ca pyroxene–liquid pairs are: $\log_{10}D_{MgO} = 3.52(T') - 1.98$, $\log_{10}D_{FeO} = 1.35(T') - 1.03$, yielding a temperature dependent K_D; $\log_{10} K_D^{Fe-Mg} = -2.17(T') + 0.95$. K_D^{Fe-Mg} for high Ca pyroxene is nearly temperature independent (0.23 at 1200°C and 0.22 at 975°C). D_{CaO} is extremely temperature sensitive for low Ca pyroxene coexisting with ol ± spinel; $\log_{10}D_{CaO} = 8.05(T') - 6.13$, and become nearly constant when coexisting with augite and/or plagioclase; $\log_{10}D_{CaO} = 2.08(T') - 1.72$. D_{CaO} for high Ca pyroxene is nearly temperature independent; $\log_{10}D_{CaO} = 0.27(T') - 0.15$. The partitioning data for CaO are useful in determining the bulk liquid chemistry and appearance temperature for pyroxene during basalt crystallization. Surprisingly, partitioning of Fe and Mg between low Ca pyroxene and liquid follows the simple exchange relation and is insensitive to substantial variations in both liquid composition and pyroxene Ca and minor element contents.

Ivanov, A. V. (Vernadskiy Institute of Geochemistry and Analytical Chemistry, Academy of Sciences of the USSR, Moscow): 'Sodium Loss in the Production of Lunar Maria Regolith', *Geochem. Int.* **14**, 165–168. (1977)

A quantitative evaluation of the sodium loss during lunar regolith formation is given.

Kerridge, J. F. (Institute of Geophysics, University of California, Los Angeles, Calif. 90024), Kaplan, I. R., Kung, C. C., Winter, D. A., Friedman, D. L., and Desmarais, D. J.: 'Light Element Geochemistry of the Apollo 12 Site', *Geochim. Cosmochim. Acta* **42**, 391–402. (1978)

Analytical techniques of improved sensitivity have revealed details of the concentrations and isotopic compositions of light elements for a comprehensive suite of samples from the Apollo 12 regolith. These samples show a wide spread in maturity, although maximum contents observed for solar wind elements are less than observed at other sites, possibly reflecting relative recency of craters at the Apollo 12 site. Isotopic composition of nitrogen is consistent with the idea that $^{15}N/^{14}N$ in the solar wind has increased with time, at least a major part of this increase having occurred in the past 3.1 Gyr. Sulfur isotope systematics support a model in which sulfur is both added to the regolith, by meteoritic influx, and lost, by an isotopically selective process. Most soils from this site are heavily contaminated with terrestrial carbon.

Khisina, N. R. (V. I. Vernadsky Institute of Geochemistry and Analytical Chemistry, USSR Academy of Sciences, Moscow), Mokeeva, V. I., Volkova, A. Ya., Sletova, T. V., Burkin, V. I., Tobelko, K. I., and Makarov, E. S.: 'X-Ray Diffraction Study of Particles of Lunar Soil Returned by Luna 24 Probe', *Geokhimiya* 1978, 323–332. (1978) (in Russian)

Using X-ray powder and single-crystal diffractometry as well as X-ray diffraction in Gandolfy cameras the fines of Luna 24 regolith sample and a number of single-crystal grains from fraction 4–5 taken from the depths 92, 118, 170 and 184 cm have been studied. An identification of single-crystal grains has been prepared. The iron content in olivines has been estimated and the data are compared with olivines sampled by Luna 16 and Luna 20. Based on the X-ray diffraction characteristics of the clinopyroxene exsolution and diffusivity degree of *c*-type reflexes the preliminary conclusion on the cooling history of the studied samples has been made.

Norman, M. (Dept. of Geological Sciences, Univ. of Tennessee, Knoxville, Tenn. 37916), Coish, R. A., and Taylor, L. A.: 'Luna-24 Core Samples from Mare Crisium: Glass Chemistry and Magma Evolution', *EOS: Trans. Amer. Geophys. Union* **59**, 223. (1978)

Luna-24 soil samples contain 4–10% glass beads and fragments. These glasses are distinguished from agglutinitic glass based on their rounded to sub-rounded forms, lack of vesicles and native Fe droplets, and chemical homogeneity. On the assumption that some of these glasses represent frozen samples of various igneous melts, it is possible to obtain valuable information on magma evolution on the Moon, in general, and in Mare Crisium, in particular.

Green, brown, clear, and devitrified glass particles were classified chemically into mare and non-mare components. The mare components, represented by green and brown glasses, predominate. These glass have very low Ti, high Al, low Mg basaltic compositions, similar to that of rock fragments from this core. The green glass is distinguished from the brown glass by its higher normative olivine content. Within the non-mare component (i.e., clear glass), anorthosites, anorthositic gabbros (Highland

Basalts), and minor amounts of Fra Mauro Basalts are represented. The devitrified glasses have chemistries which span the entire range of mare and non-mare compositions.

It is speculated that the primary magma for the Mare Crisium had the approximate composition of the Apollo-15 green glass. The brown glass represents a simple fractional crystallization of olivine, whereas, the Luna-24 green glass is derivable from a melt with a composition of the Apollo-15 glass by a more complicated fractionation scheme involving both olivine and pyroxene.

Papike, J. J. (Dept. of Earth and Space Sciences, State University of New York, Stony Brook, New York 11794) and Vaniman, D. T.: 'The Lunar Mare Basalt Suite', *Geophys. Res. Lett.* 5, 433–436. (1978)

Recent studies have greatly expanded our knowledge of lunar mare basalts. Since 1976 there has been a revision of the Apollo 12 low-Ti mare basalt suite and the discovery of a new very low-Ti (VLT: $< 1\%$ TiO_2) basalt suite at Apollo 17 and in the new Soviet samples from Mare Crisium (LUNA 24). Current studies suggest that the VLT basalts may be in some way related to the enigmatic "green glasses" which are found in the soils from every lunar landing site. Telescopic studies of spectral reflectance and crater systematics show that basalts of varying Ti content were extruded throughout the history of mare volcanism. These new discoveries indicate that mare basalts can no longer be classified into the two simple groups of older, high-Ti basalts and younger, low-Ti basalts.

Papike, J. J. (Dept. of Earth and Space Sciences, State Univ. of New York, Stony Brook, New York 11794) and Bence, A. E.: 'Lunar Mare Basalts and Terrestrial Mid-Ocean Ridge Basalts: Comparative Chemistry, Mineralogy and Petrology', *EOS: Trans. Amer. Geophys. Union* 59, 311. (1978)

Lunar mare basalts and terrestrial mid-ocean ridge basalts (MORB) have several characteristics in common: both cover significant planetary surface area (mare basalts $\sim 17\%$ and deep sea basalts $\sim 50\%$); both result from fissure-type eruptions, and both occupy planetary topographic lows. There are also striking differences; the span of mare basalt volcanism is ~ 3.1–3.9 b.y., compared to 0–200 m.y. for MORB's. MORB's (relative to mare basalts) are enriched in SiO_2, Al_2O_3, Na_2O and depleted in 'Cr_2O_3', TiO_2, 'FeO'. In addition MORB natural glasses have higher Mg/Mg + Fe ratios.

Feldspars from MORB's range from An_{90} to An_5 with most in the range An_{80}–An_{40}. In contrast feldspars from mare basalts range from An_{98} to An_{75} reflecting the alkali depletion of the Moon. Olivines from MORB's range from Fo_{91} to Fo_{15} with most in the range Fo_{60}–Fo_{88}; $Cr_2O_3 = 0$ to 0.16 wt.%. Mare basalt olivines range from Fo_{80} to Fo_0 similar to MORB's but are significantly enriched in 'Cr_2O_3' = 0–0.50 wt.%. Pyroxenes in MORB's are diopsidic augites. Mare basalt pyroxenes are depleted in Ca and Mg relative to MORB pyroxenes and show more extensive Fe zonation. In addition the low fO_2 eliminates ${}^{VI}Fe^{3+}$–${}^{IV}Al$ as a substitution couple.

The low and high Ti mare basalt source regions must have been mineralogically distinct. Low-Ti basalts could have been derived from an olivine–pyroxene source (200–500 km) while the high-Ti basalts could have been derived from an olivine–pyroxene–ilmenite cumulate source in the outer 150 km of the Moon. MORB tholeiites most likely originated by 20–30% partial melting of a source region dominated by olivine with some opx + cpx, Melt separation occurred at depths < 100 km.

Roedder, E. (959 National Center, USGS, Reston, Virginia 22092) and Weiblen, P. W.: 'High-silica Glass Inclusions in Olivine of Luna-24 Samples', *EOS: Trans. Amer. Geophys. Union* 59, 225. (1978)

Optical examination of eight polished grain mounts of Luna-24 drill core material (0.25–0.50 mm) revealed several inclusions in olivine crystals that consist of clean glass with exceptionally high silica, yet they contain no visible silicate daughter minerals and no reaction effects from the olivine walls.

One has glass with the composition SiO_2 87.2, Al_2O_3 6.84, FeO 1.27, MgO 0.95, CaO 1.76, Na_2O 0.9, K_2O 0.02, TiO_2 0.36, MnO 0.15, Cr_2O_3 0.01, total 99.46, and shows no other phase except a shrinkage bubble; the other has glass with the composition SiO_2 93.8, Al_2O_3 1.51, FeO 2.32, MgO 1.61, CaO 0.06, $Na_2O < 0.1$, K_2O 0.11, total 99.41, and contains a shrinkage bubble and a globule of immiscible sulfide melt. Both compositions are unique and quite unlike the high-silica, high-potassia melt of granitic composition that is found as inclusions in late-stage minerals in these (and the Apollo) samples – the result of silicate liquid immiscibility. Although most Luna-24 olivine (and pyroxene) is iron rich, the host olivine for the first of the two inclusions is among the most magnesian olivines found (Fo_{73}). The origin of these inclusions and the lack of reaction effects are perplexing unresolved problems.

Vaniman, D. T. (Dept. of Earth and Space Sciences, State University of New York, Stony Brook, New York 11794) and Papike, J. J.: 'The Lunar Highland Melt-Rock Suite', *Geophys. Res. Lett.* 5, 429–432. (1978)

Size can be used as a criterion to select 18 large (> 1 cm) samples from among 148 melt-rock fragments of all sizes. This selection provides a suite of large samples which represent the important chemical variants among highland melt rocks; each large sample has enough material for a number of sample-destructive studies, as well as for future reference. Cluster analysis of the total data base of 148 highland melt rocks shows six distinct groups: anorthosite, gabbroic anorthosite, anorthositic gabbro ('highland basalt'), low-K Fra Mauro, intermediate-K Fra Mauro, and high-K. Large samples are available for four of the melt-rock groups (gabbroic anorthosite, anorthositic gabbro, low-K Fra Mauro, and intermediate-K Fra Mauro). This sample selection reveals two sub-groups of anorthositic gabbro (one anorthite-poor with negative Eu anomaly and one anorthite-rich without Eu anomaly). There is a sharp distinction between those Apollo-16 melt rocks and glasses which have both been classified as 'gabbroic anorthosite'.

5. Electromagnetic Properties of the Moon

Berg, O. E. (Max-Planck-Institut für Kernphysik, 6900 Heidelberg, Federal Republic of Germany): 'A Lunar Terminator Configuration', *Earth Planet. Sci. Lett.* 39, 377–81. (1978)

Although introduced more than two decades ago, electrostatic soil transport on the lunar surface remains a controversial subject due, primarily, to insufficiently high surface fields and particle charges to initiate and sustain the phenomenon. This paper introduces a realistic geometrical configuration for the terminators which plausibly provides adequate fields and charges. Myriads of miniature sunlit islands and dark valleys are formed in the vicinity of a zig-zag terminator line as it moves. The islands and valleys are surrounded by areas of opposite electrical polarity, providing local field regions up to thousands of volts per centimeter. The result is random directional movement of electrostatically charged lunar fines. It is shown that the mechanism can readily account for the denuding of certain asteroids while others exhibit a layer of dust on their surface.

Daily, W. D. (Eyring Research Institute, Provo, Utah 84601) and Dyal, P.: 'Scale Size Measurements of Lunar Remanent Magnetism', *EOS: Trans. Amer. Geophys. Union* 59, 315. (1978)

The scale lengths characteristic of lunar remanent magnetic fields have been measured by studying the interaction of the fields with the solar wind planes. This interaction, theoretically described by diffusion of the remanent field into the plasma, results in a distortion of the field by plasma currents just above the lunar surface. The remanent field components are modeled by $B \propto e^{-qx} \cos my$ where the horizontal (y) scale size $L = 2\pi/m$ and the vertical (x) scale size is q^{-1}. Field distortion is expected to be a function of $L\sqrt{N}$ where N is the plasma density. The predicted interaction has been compared with that measured by the Apollo surface magnetometers and the solar wind spectrometers. Both the vertical and horizontal components of the remanent field distortion were compared to solar wind plasma density at the Apollos 12, 15, and 16 landing sites. At Apollo 15 the surface fields are of such small magnitude and/or scale size that interaction with the solar wind plasma is negligible. Analysis of Apollo 12 data indicates a field scale size of about 12 km at this site. At Apollo 16 the analysis indicates a similar scale size of approximately 4 km. These results imply that the scale lengths characteristic of the lunar remanent magnetic fields and remanent magnetism are as small as a few kilometers over much of the Moon and are further evidence that the processes responsible for the magnetization were local and not global in extent.

Hobbs, B. A. (Dept. of Geophysics, Univ. of Edinburgh, Edinburgh, Scotland) and Parker, R. L.: 'Limitations on the Parameters of the Solar Wind in Modelling Lunar Electromagnetic Induction', *Geophys. J. Roy. Astron. Soc.* 52, 433–439. (1978)

A striking feature of the day-side response of the Moon to periodic fluctuations in the solar wind is the rapid rise, and subsequent fall, in the amplitude of the transfer function as the inducing field frequency increases. This behaviour can be characterized by the amplitude values at the two frequencies 24 and 40 mHz. Before the response of a conductivity model representing the Moon can be calculated at a given frequency, the parameters (v, θ) (where v is the solar wind speed and θ is the angle between the solar wind velocity and the magnetic field propagation direction) have to be specified. By applying some results due to Parker (1972) to the above two data points, we have determined constraints on the parameter space (v, θ). In particular, we determine the region of the (v, θ) space in which conductivity models may be found that satisfy our data pair. Outside this region, there are no conductivity models satisfying the data pair, and hence many (v, θ) values are inconsistent with the original data and the model assumptions.

La Torraca, G. A. (Dept. of EPS, MIT, Cambridge, Mass. 02139) and Madden, T. R.: 'The Diffraction of Alfvén Waves by the Moon', *EOS: Trans. Amer. Geophys. Union* 59, 367. (1978)

Electrical conductivity models of the Moon have been inferred from lunar surface magnetic field measurements obtained while the Moon was in the bulk plasma flow of the solar wind. To minimize data noise due to plasma flow interactions with surface remanent magnetic fields, we study lunar induction fields obtained while the Moon was in the middle of the geotail lobes. In this region, plasma flow is minimal and the measured induction fields can be assumed to be due to Alfvén wave diffraction by the Moon. We model the Moon as an inhomogeneous conducting sphere immersed in a cold plasma where the static magnetic field is constant in magnitude and direction. For this model, two cylindrical modes of Alfvén waves are diffracted, the guided and unguided modes. The diffracted guided mode is confined to a cylinder delineated by the direction of the Earth's magnetic field and the diameter of the Moon. A combination of spherical and cylindrical field representations are used to match the lunar surface boundary conditions and confine the guided Alfvén wave mode. We assume an initial conductivity structure, calculate the lunar surface fields, compare these predictions with the published data of Schubert *et al., Geophys. Res. Lett.* 2, 277 (1975), and apply generalized inverse techniques to get a best fit to their data. Additionally, we infer that the source of the incident Alfvén waves is in the distant geotail.

Sanders, G. D. (Dept. of Space Physics and Astronomy, Rice Univ., Houston, Tex 77001), Hills, H. K., and Freeman, J. W.: 'Two Temperature Structure of the Magnetosheath at Lunar Distance', *EOS: Trans. Amer. Geophys. Union* 59, 364. (1978)

Recent analysis of magnetosheath data returned by the Apollo suprathermal ion detector experiments has shown that the magnetosheath at lunar distances consists of two proton populations having different temperatures. There is evidence that the colder component ($KT \sim 10$ eV) is unshocked solar wind. The hotter component ($KT \sim 100$ eV) is characteristic of shocked solar wind. This two temperature structure is observed across the entire magnetosheath at lunar distances.

Weiss, H. (Dept. of Earth and Space Sciences, Univ. of California, Los Angeles, Calif.), Russell, C. T., Lichenstein, B. R., and Coleman, P. J., Jr.: 'Solar Wind Interaction With the Moon: Enhanced Magnetic Field Fluctuations at Low Altitudes', *Geophys. Res. Lett.* 5, 592–594. (1978)

Evidence of a magnetically turbulent region above the lunar dayside is presented. This region apparently exists when the Moon is in the solar wind and is approximately 100 km s^{-1} thick. Possible explanations for the presence of a dayside turbulent sheath are investigated and, to within the accuracy of the data, none can satisfactorily explain its presence.

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

England, A. W. (U.S.G.S., Reston, Virginia) and Johnson, G. R.: 'Spectral Gradient of Lunar Radiobrightness – Heat Flow or Volume Scattering?', *J. Res. U.S. Geological Survey* 6, 505–509. (1978)

Lunar heat flow cannot be derived unambiguously from the spectral gradient of the radiobrightness. Volume scattering of microwaves by rock clasts within the lunar regolith results in a spectral component in the 5 to 30 centimeter range of wavelengths that is a significant fraction of that resulting from lunar heat flow.

Florenskii, P. V. (Geological Institute, Academy of Sciences of the USSR) and Chernov, V. M.: 'Observations of Transient Lunar Phenomena (Third List)', *Solar System Res.* **12**, 47–55. (1978)

More than 100 reports found in the literature or published for the first time to 800 earlier cataloged observations of transient lunar phenomena have been added. The accuracy of the observations are also discussed.

Hirth, W. (Radioastronomisches Institut der Universität Bonn, Germany), Butz, M., Velden, L., and Furst, E.: 'The Centre-to-limb Variation of the Moon's Brightness at 2 and 6 cm Wavelength', *The Moon* **17**, 395–400. (1977)

A map of the Moon at 2 cm wavelength is presented. The angular ($\simeq 1'$ arc) and temperature resolution (< 0.1 K) is sufficient to study systematic details of the brightness distribution. In particular, the centre-to-limb variation is considered. An estimate of the dielectric constant ϵ is possible ($1.4 \leqslant \epsilon \leqslant 2.5$). The existence of a temperature gradient in the lunar surface layers is used to derive the depth of penetration of electromagnetic waves (L_e), which is $L_e \simeq 8$ m for 2 cm wavelength. The parameters derived from the 2 cm map are found to be compatible with those obtained from a former observation at 6 cm wavelength.

Wildey, R. L. (Dept. of Astronomy and Physics, Northern Arizona University, Flagstaff, Ariz. 86001): 'The Moon in Heiligenschein', *Science* **200**, 1265–1267. (1978)

An analysis of 25 photometric digital images of the Moon has been carried out to obtain a single image in a new mapping parameter, the Heiligenschein exponent. The data necessarily represent a range of lunar phases, but all are within 10 hours of full Moon. The new parameter characterizes the rate at which lunar features brighten as their local phase angles approach zero. Although considerable contrast is present in this parameter, there is only a small correlation with normal albedo. In particular, the large albedo difference between maria and highlands is not simply reflected in Heiligenschein differences, which are larger within each category of terrain than the difference between the Heiligenschein averages of each. A correlation with age may be present in both the maria and the highlands, but its determination will require separation into distinct geochemical provinces.

7. Lunar Environment

Bulgher, D. (Dept. of Space Physics and Astronomy, Rice Univ., Houston, 77001), Benson, J., and Manka, R. H.: 'Lunar Nightside Ions: Relation to Surface Potential', *EOS: Trans. Amer. Geophys. Union* 59, 349. (1978)

The Apollo Suprathermal Ion Detector Experiments observe bursts of ions with energies nominally in the 250 eV/q to 1250 eV/q range throughout the lunar night. Evidence exists that the source of these events is the dayside lunar atmosphere. The solar wind $\mathbf{v} \times \mathbf{B}$ electric field serves as a mechanism for transporting dayside ions to the nightside. We are working on calculations of ion trajectories from the dayside lunar atmosphere to the nightside. These, combined with ion energies observed at the lunar surface, determine the surface potential. Calculations indicate that the nightside surface potential varies as a function of position on the lunar surface, becoming more negative deeper into the nightside, with the potential generally several hundred volts negative. An extreme lower limit of the nightside lunar surface potential is $-$ 1500 V.

Chernyak, Y. B. (Zatonnaya str. 10-1 fl. 178, Moscow 115407, USSR): 'On Recent Lunar Atmosphere', *Nature* 273, 497–501. (1978)

Two independent kinds of lunar expedition data are considered which put forward some strong theoretical evidence of the existence of a considerable atmosphere on the Moon during the greater part of its history. The transformation of a meteoritic flux when passing through an arbitary atmosphere has been analysed and tentative estimates of the lunar atmospheric power presented.

Hughes, D. W. (Dept. of Physics, University of Sheffield): 'Lunar Atmosphere Past and Present', *Nature* 273, 489–490. (1978)

8. Lunar Colonization and Space Utilization

Arnold, J. R. and Duke, M. B.: 'Summer Workshop on Near-Earth Resources; Workshop Held at La Jolla, Calif., 6–13 Aug 1977'. NASA CP 2031; S-482; JSC-13139. 107 pp., Jan 1978. Available as N78-16973 NTIS HC A06/MF A01.

The possible large scale use of extraterrestrial resources was addressed, either to construct structures in space or to return to Earth as supplements for terrestrial resources. To that end, various specific recommendations were made by the participants in the summer study on near-Earth resources, held at La Jolla, California, 6 to 13 August, 1977. The Moon and Earth-approaching asteroids were considered. Summaries are included of what is known about their compositions and what needs to be learned, along with recommendations for missions designed to provide the needed data. Tentative schedules for these projects are also offered.

PLANETS

Discussion of Characteristics Pertinent to Several Planets

Akasofu, S. -I. (Geophysical Institute, Univ. of Alaska, Fairbanks, Alaska 99701): 'Interaction Between a Magnetized Plasma Flow and a Magnetized Celestial Body: a Review of Magnetospheric Studies', *Space Sci. Rev.* 21, 489–526. (1978)

Through an intensive study of the magnetospheres of the Earth, Mercury, and Jupiter, we have begun to understand how a magnetized celestial body interacts with a magnetized plasma flow. Some of the important findings are:

(i) The magnetic field of a magnetized celestial body can be superposed, in a collisionless plasma condition, with that of a magnetized plasma flow without the difficulty imposed by the frozen-in-field concept.

(ii) The resulting open magnetosphere is an inevitable consequence of the interaction between a magnetized plasma flow and a magnetized celestial body. The closed magnetosphere may occur only when the flowing plasma is unmagnetized.

(iii) The open structure provides the basis for a magnetosphere and a plasma flow to constitute a dynamo. Most magnetospheric processes are powered by this dynamo process. Thus, a magnetosphere can be considered to be a machine which converts the flow energy of the solar wind into electrical energy which is eventually converted into heat energy in the ionosphere.

(iv) When a magnetized plasma flow is 'turbulent', the efficiency of the dynamo changes and is controlled by the relative orientation of the magnetic field direction of the flowing plasma with respect to that of the celestial body in the vicinity of the equatorial plane of the magnetopause. In particular, when the two fields are antiparallel, the efficiency of the dynamo is considerably increased, and as a result the magnetic energy is accumulated in the magnetosphere.

(v) In such a condition, a magnetosphere enhances the energy dissipation by a series of impulsive processes, called magnetospheric substorms, which are much more efficient in dissipating the accumulated energy than the steady process mentioned in (iii).

(vi) There is no definite evidence that the conversion process of the magnetic energy into substorm energy proceeds in the way predicted by the merging theories.

(vii) A large potential drop of order 10 kV can develop along magnetic field lines even in a collisionless plasma if field-aligned currents of order 10^{-6} A m^{-2} are present.

(viii) A magnetosphere is not an empty 'cavity', carved in a magnetized plasma flow. The latter can flow through a limited region of the magnetosphere, so that it is not a simple matter to define its boundary.

(ix) A magnetosphere tends to develop a circular disk-like structure which extends along the magnetic equator, although its formation mechanism differs considerably for different magnetized celestial bodies.

(x) Most of these conclusions are directly or indirectly related to the fact that the frozen-in-field concept is not necessarily applicable even under a collisionless plasma condition.

Some of these findings may have significant implications in interpreting a variety of astrophysical processes associated with the magnetosphere of magnetic stars, pulsars and head–tail galaxies and also with transient processes, such as solar flares and flarings of particular types of variable stars, etc.

Butler, D. M. (Laboratory for Planetary Atmospheres, NASA Goddard Space Flight Center, Greenbelt, Maryland 20771), Newman, M. J., and Talbot, R. J., Jr.: 'Interstellar Cloud Material: Contribution to Planetary Atmospheres', *Science* 201, 522–525. (1978)

A statistical analysis of the properties of dense interstellar clouds indicates that the solar system has encountered at least a dozen clouds of sufficient density to cause planets to accumulate nonnegligible amounts of some isotopes. The effect is most pronounced for neon. This mechanism could be responsible for much of the neon in Earth's atmosphere. For Mars, the predicted amount of neon added by cloud encounters greatly exceeds the present abundance.

Consolmagno, G. J. (Dept. of Planetary Sciences, Lunar and Planetary Laboratory, University of Arizona, Tucson, Ariz. 85721) and Lewis, J. S.: 'The Evolution of Icy Satellite Interiors and Surfaces', *Icarus* **34**, 280–293. (1978)

The satellites of the outer solar system planets are thought to be mixtures of ices and rocky material, in which decay of radioactive nuclides can lead to internal melting and solid-state convection. Time-dependent models indicate that melting will reach its maximum extent approximately 2.0 GYr after formation; bodies of radius < 500 km will never melt, and those < 750 km in radius will be totally refrozen by present. Surface water flows are not expected for bodies of < 1500 km radius. However, even small (100 km) bodies may be unstable against solid-state convection, and their surfaces may show signs of tectonism. Other processes altering the surfaces include sublimation and photolysis of ices. Sublimation likely explains the absence of CH_4 ices on any Saturnian satellite except Titan; photolysis explains the absence of NH_3 ices on these bodies, and possibly the absence of water ice on the surface of Callisto. The photolysis rate of CH_4 also implies a crustal reservoir of CH_4 on Titan.

Cox, L. P. (Department of Earth and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, Mass. 02139), Lewis, J. S., and Lecar, M.: 'A Model for Close Encounters in the Planetary Problem', *Icarus* **34**, 415–427. (1978)

A model is proposed for single close encounters between two small masses, m_1 and m_2, which orbit a much larger mass, M. The main new feature of the model is the assumption of conic motion of the center of mass of m_1 and m_2 in the gravitational field of M. Comparisons of the model with the three-body equations of motion indicate that the model is a useful approximation for $m_1, m_2 \lesssim 10^{-5} M$. The model is therefore applicable for encounters between bodies of the order of an earth mass or smaller in the presence of the sun. Comparisons are also made of outcomes obtained by the model with outcomes of numerical integration for a large variety of close encounters. The above comparisons reveal that for many purposes the model is an adequate approximation for those encounters with $\epsilon \geqslant 4$, where ϵ is the eccentricity of the hyperbolic orbit of m_1 about m_2.

Dolginov, Sh. Sh.: 'Planetary Magnetism: A Survey', *Geomagnetism and Aeronomy* **17**, 391–406. (1977)

Drobyshevski, E. M. (A. F. Ioffe Physical-Technical Institute, USSR Academy of Sciences, Leningrad, USSR): 'The Origin of the Solar System: Implications for Transneptunian Planets and the Nature of the Long-period Comets', *The Moon and the Planets* **18**, 145–194. (1978)

If the solar system origin is considered within the framework of the author's hypothesis on the binary stars formation as a result of rotational-exchange break-up of the rotating protostar, then difficulties involved in the usual nebular hypotheses are automatically removed (unclear aspects of the possibility of formation of the gas disc proper, the problems of the angular momentum including slow rotation of the Sun and coplanarity of the planetary orbits, of differences in planetary masses and composition, the need for the disc remnants to be swept out, the long time of planetary formation as compared with the possible lifetime of a turbulized disc, etc.).

The major stages of division and evolution of the Jupiter–Sun system are described. Similarities between the massive rotating proto-Jupiter (PJ) and the classical protoplanetary discs are pointed out.

The process of planetoid condensation inside PJ is discussed. The most probable site of the condensation is the region of the first Lagrangian point. The planetoids condensed were lost by PJ as a result of its fast mass decrease. A gas dynamic consideration of the motion of planetoids in PJ yields 1000–3000 y as a time scale for the PJ's mass loss. The number of the moonlike bodies lost (the remaining Galilean satellites fixing their lower mass limit) could reach 10^4.

Evolution of such interacting bodies results in the formation beyond Neptune of a cloud (up to 10^3) of moonlike (and more massive) planets.

The excess concentration of the long-period comets aphelia in this area implies their genetic relation to the planets. A concept of a joint planeto-cometary cloud is introduced. A concrete hydrodynamic mechanism of ice ejection from planets into space, viz. the formation of cumulative (Monroe) jets, is pointed out.

A program of further investigations is outlined and recommendations given for an experimental check on the implications of the new cosmogonic concepts.

Eshleman, V. R. (Center for Radar Astronomy, Stanford University, Stanford, Calif. 94305) and Haugstad, B. S.: 'Effects of Turbulence on Average Refraction Angles in Occultations by Planetary Atmospheres', *Icarus* 34, 396–405. (1978)

Four separable effects of atmospheric turbulence on average refraction angles in occultation experiments are derived from a simplified analysis, and related to more general formulations by B. S. Haugstad. The major contributors are shown to be due to gradients in height of the strength of the turbulence, and the sense of the resulting changes in refraction angles is explained in terms of Fermat's principle. Because the results of analyses of such gradient effects by W. B. Hubbard and J. R. Jokipii are expressed in other ways, a special effort is made to compare all of the predictions on a common basis. We conclude that there are fundamental differences, and use arguments based on energy conservation and Fermat's principle to help characterize the discrepancies.

Farinella, P. (Osservatorio Astronomico di Brera, Merate, Como, Italy) and Paolicchi, P.: 'Conservation Laws and Mass Distribution in the Planet Formation Process', *The Moon* 17, 401–408. (1977)

Within the framework of the nebular theory of the origin of the solar system, conservation laws are applied to the condensation of a ring shaped cloud of orbiting particles. The final configuration is assumed to be a point-like planet in a circular orbit around the Sun. On this ground, it is possible to relate the masses of the planets with the interplanetary distances. This relation is confirmed satisfactorily by the observed masses and orbital radii of several planets and satellites of the solar system.

French, R. G. (Laboratory for Planetary Studies, Center for Radiophysics and Space Research, Cornell University, Ithaca, New York 14853), Elliot, J. L.: and Gierasch, P. J.: 'Analysis of Stellar Occultation Data: Effects of Photon Noise and Initial Conditons', *Icarus* 33, 186–202. (1978)

A new inversion technique for obtaining temperature, pressure, and number density profiles of a planetary atmosphere from an occultation light curve is described. This technique employs an improved boundary condition to begin the numerical inversion and permits the computation of errors in the profiles caused by photon noise in the light curve. We present our assumptions about the atmosphere, optics, and noise and develop the equations for temperature, pressure, and number density and their associated errors. By inverting in equal increments of altitude, Δh, rather than in equal increments of time, Δt, the inversion need not be halted at the first negative point on the light curve as required by previous methods. The importance of the boundary condition is stressed, and a new initial condition is given. Numerical results are presented for the special case of inversion of a noisy isothermal light curve. From these results, simple relations are developed which can be used to predict the noise quality of an occultation. It is found that fractional errors in temperature profiles are comparable to those of pressure and number density profiles. An example of the inversion method is shown. Finally, we discuss the validity of our assumptions. In an appendix we demonstrate that minimum fractional errors in scale height determined from the inversion are comparable to those from an isothermal fit to a noisy isothermal light curve.

Greenberg, R. (Planetary Science Institute, 2030 E. Speedway, Suite 201, Tucson, Ariz. 85719): 'Orbital Resonance in a Dissipative Medium', *Icarus* **33**, 62–73. (1978)

Orbital resonance tend to force bodies into noncircular orbits. If a body is also under the influence of an eccentricity-reducing medium, it will experience a secular change in semimajor axis which may be positive or negative depending on whether its orbit is exterior or interior to that of the perturbing body. Thus a dissipative medium can promote either a loss or a gain in orbital energy. This process may explain the resonant structure of the asteroid belt and of Saturn's rings. For reasonable early solar system parameters, it would clear a gap near the 2:1 resonance with Jupiter on a time scale of a few thousand years; the gap width would be comparable to the Kirkwood gap presently at that location in the asteroid belt. Similarly, a gap comparable in width to Cassini's division would be cleared in Saturn's rings at the 2:1 resonance with Mimas in $\sim 10^6$ y. Most of the material from the gap would be deposited at the outer edge of ring B. The process would also affect the radial distribution of preplanetary material. Moreover, it provides an explanation for the large amplitude of the Titan–Hyperion libration. Consideration of the effects of dissipation on orbits near the stable L_4 and L_5 points of the restricted three-body problem indicates that energy loss causes particles to move away from these points. This result explains the large amplitude of Trojan asteroids about these points and the possible capture of Trojans into orbit about Jupiter.

Haggerty, S. E. (Dept. of Geology, University of Massachusetts, Amherst, 01003): 'The Redox State of Planetary Basalts', *Geophys. Res. Lett.* **5**, 443–446. (1978)

A well established data base exists for the oxidation-reduction (redox) states of basalts on the Earth and on the Moon; the former equilibrate along the fayalite-magnetite-quartz buffer curve, and the latter crystallize in the field of metallic iron stability, below the iron wustite buffer. Preferred accumulation of volatiles and the disproportionation of water into hydrogen and oxygen in thick terrestrial lavas and in ponded lava lakes results in high states of oxidation equivalent to that of hematite stability. At the other extreme, lunar basalts exhibit the effects of sub-solidus reduction and estimates yield $T = 700–1000°C$ and $f_{O_2} = 10^{-16}$ to 10^{-23} atm. Based on a number of cosmogenic properties, models for planetary interiors, and the sequence of condensation with heliocentric distance from the protosun, estimates for the redox states of inner solar system planetary basalts yield the following results: Basalts on Mercury and the Moon crystallize below the iron–wustite buffer curve; Venusian basalts are more oxidized than those on Mercury, less oxidized than those on Earth, and crystallization within the field of wustite stability is suggested; basalts on Earth are dominantly in the field of magnetite stability in close proximity to the fayalite–magnetite–quartz buffer curve; Martian basalts are estimated to crystallize in the upper regions of magnetite stability and well into the hematite field of stability expressed in terms of temperature and oxygen fugacity.

Hartmann, W. K. (Planetary Science Institute, 2030 East Speedway, Suite 201, Tucson, Ariz. 85719): 'Planet Formation: Mechanism of Early Growth', *Icarus* **33**, 50–61. (1978)

Experiments in vacuum (approx. 0.5 to 1 mbar) and in air quantify mechanics of collisions, rebound, and fragmentation at low velocities (1–50 m s^{-1}), under the conditions usually postulated for the preplanetary environment in the primitive solar nebula. Such collisions have been little studied experimentally. Contrary to widespread assumptions, accretionary growth of the largest meteroid- and asteroid-sized bodies in a given swarm results spontaneously from the simple mechanics of these collisions, without other ad hoc sticking mechanisms. The smaller bodies in the swarm are less likely to grow. Granular surfaces form, either by gravitational collapse of dust swarms or by rapid formation of regolith surfaces on solid planetesimals; these surfaces strongly promote further growth by retarding rebound. Growth of large bodies increases modal collision velocities, causing fragmentation of smaller bodies and eventual production of interstellar dust as a by-product of planetesimal interactions.

Hayakawa, S. (Dept. of Physics, Nagoya University, Nagoya, Japan): 'Continual Matter Accretion into the Solar System', *The Moon and the Planets* 18, 321–324. (1978)

Rapid accretion of matter takes place while the solar system resides in a dark cloud of high density. The mass thus accreted may be comparable to the mass of the planetary system. Since the elemental abundances in a dark cloud are considered to be heterogenous due to matter processed inside stars and then ejected, the continual accretion causes elemental heterogeneities in the solar system.

Heppenheimer, T. A. (Center for Space Science, Fountain Valley, Calif.): 'On the Topography of Extrasolar Earthlike Planets', *Icarus* 34, 441–443. (1978)

We consider a class of planets which have experienced early, nearly complete differentiation and outgassing, whose mantles are fully convective, and whose crusts are isostatically compensated. The evolutionary model of Hargraves suggests that in the absence of a runaway greenhouse, such planets may usually possess continent/ocean topographies similar to that of Earth. But if the planet is significantly larger than Earth, and its star of spectral type earlier than G, it may ordinarily be completely water-covered.

Hubbard, W. B. (Department of Planetary Sciences, University of Arizona, Tucson, Ariz. 85721), Jokipii, J. R., and Wilking, B. A.: 'Stellar Occultations by Turbulent Planetary Atmospheres: a Wave-optical Theory Including a Finite Scale Height', *Icarus* 34, 374–395. (1978)

A generalized wave-optical theory of stellar occultations by a turbulent planetary atmosphere is developed. The finite scale height of the atmosphere is retained for the first time. It is found that the finite scale height of the atmosphere affects the scintillations observed during the occultation in a number of ways which are most easily understood in terms of an effective Fresnel scale. We demonstrate the validity of a phase-changing screen approximation for occultation by a turbulent atmosphere in parameter ranges of general interest. Using this approximation various statistical properties of the fluctuating intensity are calculated explicitly. We present expressions for the total scintillation power, correlation function of the intensity, the cross-correlation at two frequencies, and its application to refractivity determinations. All of these expressions are given as a function of occultation depth and of parameters of the mean atmosphere and turbulence.

Jones, G. H. S. (Defence Research Board, Dept. of National Defence, 101 Colonel By Drive, Ottawa, Ontario, Canada K1A 0K2): 'Coherently Overturned Flaps Surrounding Craters', *Nature* 273, 211–213. (1978)

It is suggested that the mechanism of deposition of coherently overturned ejecta blankets may be related to the formation of a hydrodynamic type of wave motion, which breaks in the plunging pattern. This is consistent with the field data and is worthy of further investigation.

Kawata, Y. (Goddard Institute for Space Studies, 2880 Broadway, New York 10025): 'Circular Polarization of Sunlight Reflected by Planetary Atmospheres', *Icarus* 33, 217–232. (1978)

Multiple scattering calculations are performed in order to investigate the nature of the circular polarization of sunlight reflected by planetary atmospheres. Contour diagrams as a function of size parameter and phase angle are made for the integrated light from a spherical but locally plane-parallel atmosphere of spherical particles. To investigate the origin of the circular polarization, results are also computed for second-order scattering and for a simpler semiquantitative model of scattering by two particles. Observations of the circular polarization of the planets are presently too meager for accurate deduction of cloud particle properties. However, certain very broad constraints can be placed on the properties of the dominant cloud particles on Jupiter and Saturn. The cloud particle size and refractive index deduced for the Jupiter clouds by Loskutov, Morozhenko, and Yanovitskii from analyses of the linear polarization are not consistent with the circular polarization. The few available circular polarization observations of Venus are also examined.

Lyttleton, R. A. (Institute of Astronomy, Cambridge, England) and Fitch, J. P.: 'On the Accelerations of the Moon and Sun, the Constant of Gravitation, and the Origin of Mountains', *The Moon and the Planets* **18**, 223–240. (1978)

In a previous paper Lyttleton has shown that the apparent secular accerations of the Sun and Moon, as given by de Sitter, can be largely explained if the Earth is contracting at the rate required by the phase-change hypothesis for the nature of the core. More reliable values for these accelerations have since become available which warrant a redetermination of the various effects concerned on the basis of constant G, and this is first carried out in the present paper. The lunar tidal couple, which is the same whether G is changing or not, is found to be $(4.74 \pm 0.38) \times 10^{23}$ cgs, about three-quarters that yielded by the de Sitter values, while within the theory the Moon would take correspondingly longer to reach close proximity to the Earth at about 1.5×10^9 years ago.

The more accurate values of the accelerations enable examination to be made of the effects that a decreasing G would have, and it is shown that a value $G/G = -3 \times 10^{-11}\ \mathrm{y}^{-1}$ can be weakly satisfied compared with the close agreement found on the basis of constant G, while a value as large numerically as $G/G = -6 \times 10^{-11}\ \mathrm{y}^{-1}$ seems to be definitely ruled out. On the iron-core model, an intrinsic positive component of acceleration of the angular velocity cannot be reconciled at all with the secular accelerations even for constant G, and far less so if G is decreasing at a rate suggested by any recent cosmological theory.

If $G = 0$, the amount of contraction available for mountain-building would correspond to a reduction of surface area of about $49 \times 10^6\ \mathrm{km}^2$ and a volume to be redistributed of $160 \times 10^9\ \mathrm{km}^3$ if the time of collapse were 2.5×10^9 years ago. For earlier times, the values are only slightly reduced. If $\dot{G}/G = -3 \times 10^{-11}\ \mathrm{y}^{-1}$, the corresponding values are $44 \times 10^6\ \mathrm{km}^2$ and $138 \times 10^9\ \mathrm{km}^3$ for collapse at -2.5×10^9 y, and not importantly smaller at $38 \times 10^6\ \mathrm{km}^2$ and $122 \times 10^9\ \mathrm{km}^3$ for collapse at -4.5×10^9 y. Any of these values would suffice to account in order of magnitude for all the eras of mountain-building. An intense brief period of mountain-building on an immense scale would result from the Ramsey-collapse at whatever time past it may have occurred.

Macy, W., Jr. (Inst. for Astronomy, Univ. of Hawaii) and Smith, W. H.: 'Detection of HD on Saturn and Uranus, and the D/H Ratio', *Astrophys. J.* **222**, L73–L75. (1978)

We have observed the HD 5–0 $R(0)$ line on Saturn and Uranus. Values for the D/H abundance ratio computed from models for the atmospheres of these two planets are $5.5 \pm 2.9 \times 10^{-5}$ for Saturn and $3.0 \pm 1.2 \times 10^{-5}$ for Uranus. The D/H ratio for Jupiter of $5.1 \pm 0.7 \times 10^{-5}$ found from a measurement of the HD 4–0 $P(1)$ line is bracketed by the values we find for Saturn and Uranus.

Masursky, H. (U.S. Geological Survey, Flagstaff, Ariz.): 'Terrestrial Evolution – Insights from Moon and Planets', *AAPG Bull. – Amer. Assoc. Petrol. Geologists* **62**, 540. (1978)

During the past 2 decades we have investigated the Moon in great detail, Mars intensively, and Mercury less so. The studies of Venus and the satellite of the outer planets are just beginning. Apparently these bodies all record (1) an early episode of intense bombardment, possibly the end of the accumulation phase; (2) planetwide differentiation and formation of an ancient, heavily cratered crust; (3) redistribution of crustal material, possibly by early convection; (4) emplacement of widespread younger lava flows in the low areas of the planet; and (5) continued sparse cratering, mass wasting, and other geologic processes. Some returned lunar samples are more than 4 b.y. old confirming the preservation of very ancient rocks. These rocks also record strong magnetic fields in the past whereas the field is very weak now. Mars data apparently record former fluvial episodes when the temperature and pressure of the atmosphere and surface must have differed radically from those now observed.

These data and their attendant hypotheses must be based, at least partly, on nonuniformitarian thinking. That is, events are recorded that differ dramatically from those processes operating now. It is possible, however, to infer reasonable scenarios of early planet formation based on, and extended from, processes now observable. Future spacecraft observations of outer-planet satellites will further strain our capability to devise processes that control the evolution of bodies that differ radically in temperature, density, and therefore composition from Earth.

Moroz, V. I., and Mukhin, L. M.: 'Early Evolutionary Stages in the Atmosphere and Climate of the Terrestrial Planets', *Cosmic Res.* 15, 774–791. (1977)

We discuss the early stages in the evolution of the atmosphere and climate of Earth, Mars, and Venus, proceeding on the basis of a unified concept for the initial conditions and basic processes (except for observed differences in the chemical composition and outgasing rate). Our basic conclusions are, first, that liquid water appeared on the Earth's surface during the first few hundred million years. During about the first 2 eons the surface temperature remained close to the melting point. Possibly there were cyclic variations in the temperature near this point, accompanied by variations in the albedo and in the amount of CO_2 in the atmosphere. All during this period there was more CO_2 in the atmosphere than during the present time. For the first 100–500 million years CO_2 was the major constituent of the Earth's atmosphere. Second, much slower outgasing and a lesser amount of heat from the Sun are the reasons why liquid water appeared much later on Mars, only 1 or 2 billion years ago. This was the time of the beginning of the Martian 'paradise' (rivers, a relatively dense atmosphere, warm climate), which ended because of the chemical combination of the CO_2 by the Urey mechanism. Third, present-day physical conditions on Venus are more simply explained if we assume that the primordial material from which it was formed contained little water. Liquid water never occurred on the planet's surface, and in practice there were no processes operating for the chemical combination of the CO_2. The surface temperature of Venus already exceeded 600 K 4 billion years ago.

No author cited: 'From the Moon to Jupiter and Beyond. A Report on the 9th Lunar and Planetary Science Conference, March 1978', *Geotimes* 23(6), 11–28. (1978)

Öpik, E. J. (Armagh Observatory, Northern Ireland): 'The Missing Planet', *The Moon and the Planets* 18, 327–337. (1978)

Ovenden's hypothesis suggesting former existence of a planet of 90 Earth masses which supposedly filled the Titius–Bode gap in the asteroid belt and then suddenly disappeared 16 million years ago, is critically examined by the morphological method. It is shown that an explosive removal, however improbable, could have led to the formation of the asteroids from a non-explosive core (the nuclear charge being placed outside of it), but that life on Earth would have been completely destroyed by three successive blasts – one from the direct impact of the ejecta of the planet, another from the increased radiation suddenly emitted by the Sun when hit by the ejecta, and a third one (arriving, however, first) from the radiation emitted by the nuclear explosion. The geological record of the continuity of life on Earth for the past 10^9 years definitely excludes the possibility of such an explosion in the late Tertiary.

The other mode of removal of the planet – in a gravitational encounter with an intruder either from interstellar space or from the unexplored outskirts of the solar system, under the condition of not having disturbed the existing regularity of planetary orbits – is not only extremely improbable, to be expected once during 100 million times the age of the solar system; but it would leave no asteroids behind, all of the previously existing primaeval asteroids having been rapidly eliminated in encounters with the hypothetical planet.

Whatever the merits of Ovenden's long-range calculations of the secular perturbations of coplanar 'circularized' planetary orbits, the hypothesis of a massive planet to have existed in the asteroidal region and then recently to have suddenly disappeared, belongs to the realm of the impossible. After such a hypothetical event, either we would not be here on Earth, or there would be no asteroids in their present place between Jupiter and Mars.

Prisco, R. A. (Dept. of Space Physics & Astronomy, Rice Univ., Houston, Tex 77001) and Chamberlain, J. W.: 'Spectral Line Profiles in a Planetary Corona: a Collisional Model', *J. Geophys. Res.* 83, 2157–2161. (1978)

The theory of spectral line profiles for a planetary corona is extended to include the effects of $H–H^+$ resonant charge exchange in which satellite particles are omitted. A computational model is detailed, and sample profiles are presented. Observations of Lyman alpha or Balmer alpha profiles would have an important application to an understanding of the distribution of satellite particles and the nonthermal component of escaping hydrogen. The problem of satellites is seen to merit further investigation.

Safronov, V. S. (O. J. Schmidt Institute of the Physics of the Earth of the USSR Academy of Sciences, B. Gruzinskaja 10, Moscow 123242, USSR): 'The Heating of the Earth During its Formation', *Icarus* 33, 3–12. (1978)

The thermal state of the Earth accumulating from solid bodies is investigated. The conductivity equation is deduced for a growing spherically symmetrical planet which takes into account heating by impacts of bodies, by radioactivity, and by compression of its material. The cooling is produced mainly by impact mixing, which is approximately by extrapolating the parameters from known impact craters to larger sizes. The solution of a more simple conductivity equation for a uniformly heated plane parallel layer with moving boundaries is found. It can be considered as an approximate quasi-stationary solution for the temperature distribution in the outer parts of the growing Earth. The result depends substantially on the sizes of impacting bodies but almost not at all on the time scale of the accumulation. The latter only weakly affects the surface temperature and does not affect the temperature distribution in the layer. For bodies of small radii, $r' < r_1$, where the size of the crater is not affected appreciably by gravitation (for the present mass of the Earth $r_1 \sim 1$ km), the heating is small. For bodies with $r' > r_1$, the heating of the layer is roughly proportional to the ratio r'/r_1. Toward the end of the Earth's accumulation the melting point can be reached in the outer layer at $r'_M \gtrsim 60$ km, where r'_M is the radius of the largest body in the power law size spectrum of falling bodies. The estimates of the initial temperature of the Earth can vary within wide limits depending on the mass distribution of large protoplanetary bodies, which at the present time is not known correctly. The initial melting of an upper layer of the Earth a few hundred kilometers thick seems to be possible.

Samokhin, M. V. (Moscow Radiotechnical Institute, USSR Academy of Sciences, Moscow, USSR): 'A One-dimensional Gasdynamical Model of Magnetospheric Convection', *The Moon* 17, 409–423. (1977).

The plasma flow in the equatorial plane of the magnetosphere is examined within the framework of a one-dimensional model in which all quantities are supposed to depend only on the distance along the Sun–Earth axis. The following models are considered: (1) the gasdynamical model in which the Ampère force is ignored, (2) the magnetohydrodynamical model in which the normal component of the Ampère force on the magnetopause is taken into account. The flow regime is calculated in the region including two regions: (1) the layer of the return flow where flow velocity is directed from the Sun, (2) the region of convection where the velocity is directed toward the Sun – on the assumption that the form of the magnetopause and the distribution of the solar wind pressure on the magnetopause are known.

The following physical mechanisms are taken into account: (1) the appearance of a centrifugal force owing to the magnetopause curvature, the centrifugal force partly compensating for the solar wind pressure; (2) the existence of the critical point which is analogous to the point of transition through the local sound velocity in the Laval nozzle or in the Parker model of the solar corona. The thickness of the layer of the return flow and the velocity of convection in the magnetosphere are calculated; and the following peculiarities are found: (1) in the gasdynamical model the convection regime is only possible with high velocities corresponding to the substorm, (2) in the magnetohydrodynamic model the convection velocity and the thickness of the layer of the return flow are reduced; the reduction being connected to the fact that the pressure of the solar wind is partially compensated for by the jump of the magnetic pressure on the magnetopause.

Sato, M: (U.S. Geological Survey, Reston, Virginia 22092): 'Oxygen Fugacity of Basaltic Magmas and the Role of Gas-forming Elements' *Geophys. Res. Lett.* 5, 447–449. (1978)

It is probable that elemental carbon exists in the source region of a basaltic magma and is suspended in the magma during ascent. As carbon has a large redox capacity, it is probably in control of the magmatic f_{O_2} from the source region to the deep crustal environment. Isothermally carbon becomes more reducing with decreasing pressure, and thus reduces the host magma upon ascent. If a magma is anhydrous (e.g., lunar basalts), the reduction by carbon continues through the extrusive phase and the relative f_{O_2} decreases rapidly until buffered by the precipitation of a metallic phase. If a magma is hydrous (e.g., terrestrial basalts), reduction by carbon is eventually superceded by oxidation due to the loss of H_2, which is generated by the reaction of C with H_2O and also by the thermal dissociation of H_2O, and ferric iron is produced. Cumulus crystallization of ferrous silicates also contributes to the oxidation of magma. The relative f_{O_2} of a hydrous magma initially decreases as the magma ascends from the source region, and then increases until magnetite crystallization curbs the rising trend of the relative f_{O_2}.

Sill, G. T. (Lunar and Planetary Laboratory, University of Arizona, Tucson, Ariz. 85721) and Wilkening, L. L.: 'Ice Clathrate as a Possible Source of the Atmospheres of the Terrestrial Planets', *Icarus* 33, 13–22. (1978)

The presence and compositions of atmospheres on the terrestrial planets do not follow directly from condensation models which would have Earth accreting near 500 K. No single mechanism yet proposed adequately accounts for the abundances of noble gases and carbon and nitrogen in the atmospheres. We show that the composition of clathrates forming at low temperatures in cold regions of the nebula can be predicted. Addition of about 1 ppm clathrate material to the Earth can explain observed abundances of Ar, Kr, and Xe. Condensation and adsorption processes occurring at 400–500 K are necessary to explain the observed abundances of Ne, H_2O, C, and N. Possible sources of clathrates could be cometary bodies formed in the outer solar system.

Smith, W. H. (Department of Chemistry and Earth and Planetary Sciences, and McDonnell Center for Space Sciences, Washington University, St. Louis, Missouri 63130): 'On the Ortho-Para Equilibrium of H_2 in the Atmospheres of the Jovian Planets', *Icarus* 33, 210–216. (1978)

The ratio for the equivalent widths for the unsaturated H_2 quadrupole transitions observed in the Jovian planets is calculated and compared with a large number of observations. The comparison indicates that equilibrium hydrogen may be present in Jupiter and Saturn, while Uranus and Neptune exhibit ratios not in accord with equilibrium hydrogen. Observations which can differentiate among the possible states of H_2 are proposed.

Solomon, S. C. (Dept. of Earth and Planetary Sciences, MIT, Cambridge, Mass. 02139): 'On Volcanism and Thermal Tectonics on One-plate Planets', *Geophys. Res. Lett.* 5, 461–464. (1978)

For planets with a single global lithospheric shell or 'plate', the thermal evolution of the interior affects the surface geologic history through volumetric expansion and the resultant thermal stress. Interior warming of such planets gives rise to extensional tectonics and a lithospheric stress system conducive to widespread volcanism. Interior cooling leads to compressional tectonics and lithospheric stresses that act to shut off surface volcanism. On the basis of observed surface tectonics, it is concluded that the age of peak planetary volume, the degree of early heating, and the age of youngest major volcanism on the one-plate terrestrial planets likely decrease in the order Mercury, Moon, Mars.

Stabekis, P. (Exotech Research and Analysis, Inc., Gaithersburg, Maryland) and DeVincenzi, D. L.: 'Planetary Protection Guidelines for Outer Planet Missions', *Life Sciences and Space Research* 16, 39–44. (1978)

Facilities, techniques, and operational procedures used to implement Planetary Protection requirements for the Viking Project are reviewed in order to better define the COSPAR resolution which proposes that Outer Planet spacecraft be assembled using Viking-like clean room technology. It is concluded that, for such missions, PP requirements can be met by adopting Viking clean room standards, personnel and operation procedures, and by establishing PP as an official entity in project management.

Steklov, A. F. (Main Astronomical Observatory, Academy of Sciences of the Ukrainian SSR, Kiev): 'Atmospheres of Planetary Satellites. I. Possible Existence', *Solar System Res.* 11, 179–185. (1978)

We discuss a simplified classification of atmosphere, various criteria for the existence of atmospheres, and their interrelationships. The method we propose for determining the sizes of border line objects which are barely able to possess an atmosphere is applied in analyzing the possible existence of atmospheres for the Galilean satellites of Jupiter. We give upper limits for the gas concentration in the atmosphere of Io, Europa, and Callisto, assuming the absence of significant sources of gas.

Strangway, D. W. (Dept. of Geology and Dept. of Physics, University of Toronto, Toronto, Canada): 'The Record of Magnetic Fields in the Early Solar System', *The Moon and the Planets* 18, 273–279. (1978)

The study of remanent magnetization of lunar samples and of meteorites has opened up the possibility of direct detection of primordial fields in the early history of the solar system. Lunar samples have not yielded a record predating 4.0 b.y. as a result of the intense bombardment on the lunar surface. Meteorites on the other hand can be studied as well as the individual chondrules. These infer the presence of a field as high as 16 Oe when the chondrules within the meteorites formed. This may reflect a primordial field of magnitude inferred for the early solar system. At the same time the magnetic moment of Mars and of Mercury may reflect a magnetization frozen into their crusts during the formation of the crust. These concepts are subject to test by long-range surface magnetic profiles or by satellite studies which would show whether subsequent cratering and volcanic activity has disrupted the crustal pattern. Small objects such as asteroids might also retain a memory of a primordial field.

Toksöz, M. N. (Dept. of Earth and Planetary Sciences, MIT, Cambridge, Mass.), Hsui, A. T., and Johnson, D. H.: 'Thermal Evolutions of the Terrestrial Planets', *The Moon and the Planets* **18**, 281–320. (1978)

The thermal evolution of the Moon, Mercury, Mars, Venus and hypothetical minor planets is calculated theoretically, taking into account conduction, solid-state convection, and differentiation. An assortment of geological, geochemical, and geophysical data is used to constrain both the present day temperatures and thermal histories of the planets' interiors. Such data imply that the planets were heated during or shortly after formation and that all the terrestrial planets started their differentiations early in their history. Initial temperatures and core formation play the most important roles in the early differentiation. The size of the planet is the primary factor in determining its present day thermal state. A planetary body with radius less than 1000 km is unlikely to reach melting given heat source concentrations similar to terrestrial values and in the absence of intensive early heating such as short half-life radioactive heating and inductive heating.

Studies of individual planets are constrained by varying amounts of data. Most data exist for the Earth and Moon. The Moon is a differentiated body with a crust, a thick solid mantle and an interior region which may be partially molten. It is presently cooling rapidly and is relatively inactive tectonically.

Mercury most likely has a large core. Thermal calculations indicate it may have a 500 km thick solid lithosphere, and the core may be partially molten if it contains some heat sources. If this is not the case, the planet's interior temperatures are everywhere below the melting curve for iron. The thermal evolution is dominated by core separation and the high conductivity of iron which makes up the bulk of Mercury.

Mars, intermediate in size among the terrestrial planets, is assumed to have differentiated an Fe–FeS core. Differentiation and formation of an early crust is evident from Mariner and Viking observations. Theoretical models suggest that melting and differentiation of the mantle silicates has occurred at least up until 1 billion years ago. Present day temperature profiles indicate a relatively thick (~ 250 km) lithosphere with a possible asthenosphere below. The core is molten.

Venus is characterized as a planet similar to the Earth in many respects. Core formation probably occurred during the first billion years after the formation. Present day temperatures indicate a partially molten upper mantle overlain by a 100 km thick lithosphere and a molton Fe–Ni core. If temperature models are good indicators, we can expect that today, Venus has tectonic processes similar to the Earth's.

Veverka, J. (Laboratory for Planetary Studies, Cornell University, Ithaca, New York 14853), Goguen, J., Yang, S., and Elliot, J.: 'Scattering of Light from Particulate Surfaces. I. A Laboratory Assessment of Multiple-scattering Effects', *Icarus* 34, 406–414. (1978)

A convenient photometric function for many particulate surfaces is the generalization of the Lommel–Seeliger law derived by Hapke (1963) and Irvine (1966). This generalization accounts for the effects of mutual shadowing among particles, but still assumes that multiple scattering within the surface layer can be neglected – an assumption which is evidently valid for dark surfaces. We describe a series of laboratory measurements which test the range of validity of this basic assumption, and the applicability of the Hapke–Irvine photometric function, for particulate surfaces whose normal reflectances ranges from 0.04 to 1.04. We find that multiple-scattering effects can be neglected, and that the Hapke–Irvine function can be used, for particulate surfaces whose normal reflectance is about 0.3, or less. The function is definitely inapplicable to surfaces whose normal reflectance exceeds 0.4.

Walker, R. L. (U.S. Naval Observatory, Flagstaff, Ariz. 86002), Christy, J. W., and Harrington, R. S.: 'Positions of Planets and Natural Satellites', *Astron. J.* 83, 838–844. (1978)

Positions of the satellites of Uranus and Neptune, relative to their respective planets, are given for the 1975 and 1977 oppositions. In addition, a few astrometric positions of Uranus, Neptune, and some of the satellites of Jupiter, Saturn, and Uranus are also included.

Wesson, P. S. (St. John's College, Cambridge University, England) and Lermann, A.: 'The Formation of Iron, Stone, and Mixed Planetesimals in the Early Solar System', *Icarus* **33**, 74–88. (1978)

The interactions of dust grains with each other in a finite-temperature solar nebula are examined, taking into account the important fact that such grains would carry net steady-state charges like those of grains in interstellar clouds. This charge is given by the well-known Spitzer relation. It provides a screening mechanism that operates during accretion and results in bodies of differing compositions depending on the local temperature in the nebula. In a typical nebula, it is found that planetesimals of $0.1–10^2$ cm size form in a time of order $10^6–10^7$ years. These planetesimals are of iron and stone and mixed composition in the inner solar system, but of mixed composition only in the outer solar system. The predictions of this type of charged-dust accretion can be compared to known data on meteorites and the composition of the planets.

Winters, R. R. (Dept. of Physics and Astronomy, Denison University, Granville, Ohio and Malcuit, R. J.: 'The Lunar Capture Hypothesis Revisited', *The Moon* 17, 353–358. (1977)

Recent work on planetary formation processes have suggested that ancient planetary bodies could have been warmer and, therefore, more easily deformable soon after formation than at present. By use of the estimates for the elastic parameters believed to be appropriate for a warm ancient Moon and Earth, it is shown that the energy of deformation of the planetary bodies during a close gravitational encounter was sufficient to effect capture.

Wyllie, P. J. (Dept. of Geophysical Sciences, University of Chicago, Chicago, Illinois 60637): 'The Effect of H_2O and CO_2 on Planetary Mantles', *Geophys. Res. Lett.* 5, 440–441. (1978)

The solidus for peridotite–H_2O–CO_2 is a divariant surface traversed by univariant lines that locate the intersections of subsolidus divariant surface for carbonate or hydration reactions occurring in the presence of H_2O–CO_2 mixtures. Vapor phase compositions are normally buffered to these lines; the buffering capacity of carbonates is much greater than that of amphibole and phlogopite. Near the buffered curve for the solidus of partly carbonated peridotite, extending to higher pressures and lower temperatures from an invariant point near 26 kbar–1200°C, there is a temperature maximum on the peridotite-vapor solidus. On the CO_2 side of the maximum, above 26 kbar, CO_2/H_2O is greater in liquid than in vapor, and liquids are SiO_2-poor; on the H_2O side of this maximum (including all pressures below 26 kbar), H_2O/CO_2 is greater in liquid than in vapor, and liquids change from forsterite-normative to quartz-normative with increasing H_2O/CO_2 in vapor. Even traces of H_2O and CO_2, in minerals or vapor, lower mantle solidus temperatures through hundreds of degrees compared with the volatile-free solidus.

JUPITER

Atai, A. A. (Shemakha Astrophysical Observatory) and Ibragimov, N. B.: 'Emission Lines in the Spectrum of Io', *Solar System Res.* **12**, 21–26. (1978)

Spectrograms of Io obtained with the 2 m reflector at the Shemakha Astrophysical Observatory, Academy of Sciences of the Azerbaidzhan SSR, at dispersions of 12 and 15 Å mm^{-1} have been used to study profiles of Na I, Fe I, Mg I, and Ca I emission lines. The line profiles were found to be asymmetric. It is shown that variations of the intensity ratio D_2/D_1 in the spectrum of Io do in fact occur, varying within the limits 1.6 ± 0.3. The intensity of the sodium D-line at $\Phi = 90°$ is ≈ 40% higher than at $\Phi = 270°$. The number of radiating neutral sodium atoms and the lower limit of the number of radiating iron, magnesium, and potassium atoms along the line of sight are calculated. In order of magnitude, these quantities comprise 3×10^{11}, 2×10^{12}, 5×10^{11}, 5×10^{10} atoms cm^{-2}, respectively.

Atreya, S. K. (Dept. of Atmospheric and Oceanic Science, Space Physics Research Laboratory, Univ. of Michigan, Ann Arbor 48109), Donahue, T. M., and Kuhn, W. R.: 'Evolution of a Nitrogen Atmosphere on Titan', *Science* **201**, 611–613. (1978)

Photochemical calculations indicate that if NH_3 outgassed from Titan it should have been converted to a dense N_2 atmosphere during the lifetime of the satellite. A crucial step in the process involves a gas phase reaction of N_2H_4 with H. The most favorable conditions for this step would be the intermediate production of a CH_4–H_2 greenhouse capable of raising the gas temperature to 150 K. Subsequently about 20 bar of N_2 could have evolved. The pressure-induced opacity of 20 bar of N_2 should suffice to explain the recently measured 200 K surface temperature. Unlike the situation on Jupiter, NH_3 is not recycled on Titan by reactions involving N_2 or N_2H_4. This may explain the failure of recent attempts to detect NH_3 in the upper atmosphere of Titan.

Beer, R. (Earth and Space Sciences Div., Jet Propulsion Laboratory, Pasadena, Calif.) Taylor, F. W.: 'The Abundance of Carbon Monoxide in Jupiter', *Astrophys. J.* **221**, 1100–1109. (1978)

New spectra of Jupiter in the 5 μm window region have been acquired, from which we deduce that (a) the presence of CO in Jupiter is verified, (b) the column abundance is approximately 1.6×10^{-2} cm amagat ($\equiv 4.3 \times 10^{17}$ mol cm^{-2}), and (c) the CO is probably nonuniformly mixed in the atmosphere, being concentrated into the stratosphere.

Benedict, G. F. (McDonald Observatory and Dept. of Astronomy, Univ. of Texas at Austin, Austin, 78712), Shelus, P. J., and Mulholland, J. D.: 'Astrometric Observations of the Faint Satellites of Jupiter and Minor Planets, 1974–1977', *Astron. J.* **83**, 999–1002. (1978)

Precise positions of the faint satellites VI–XII of Jupiter during the 1974 opposition, and for Jupiter XIII during the 1976–1977 and 1977–1978 oppositions, have been obtained from plates taken with the 2.1 m Otto Struve reflector of the McDonald Observatory by the use of a new quasi-automatic plate measurement and reduction procedure on a PDS microdensitometer. Observations of selected asteroids, including two of 1977 UB (Chiron) are given also.

Browne, G. C. (Astronomy Dept., Univ. of Leicester, Leicester, England) and Meadows, A. J.: 'Light and Dark Spots in the Equatorial Regions of Jupiter', *Planetary and Space Sci.* **26**, 335–338. (1978)

The lifetimes and motions of dark and light spots in the equatorial regions of Jupiter have been studied for the 1972 apparition. The difference in lifetimes of the two types of spot is demonstrated, as are their differing modes of formation and disappearance. The way in which the spots interact is examined in detail, and it is pointed out that this may have implications for the fluid dynamics of the Jovian atmosphere.

Campbell, D. B. (National Astronomy and Ionosphere Center, Arecibo, Puerto Rico 00612), Chandler, J. F., Ostro, S. J., Pettengill, G. H., and Shapiro, I. I.: 'Galilean Satellites: 1976 Radar Results', *Icarus* 34, 254–267. (1978)

Radar observations of the Galilean satellites, made in late 1976 using the 12.6 cm radar system of the Arecibo Observatory, have yielded mean geometric albedos of 0.04 ± 0.01, 0.69 ± 0.17, 0.37 ± 0.09, and 0.15 ± 0.04, for Io, Europa, Ganymede, and Callisto, respectively. The albedo for Io is about 40% smaller than that obtained approximately a year earlier, while the albedos for the outer three satellites average about 70% larger than the values previously reported for late 1975, raising the possibility of temporal variation. Very little dependence on orbital phase is noted; however, some regional scattering inhomogeneities are seen on the outer three satellites. For Europa, Ganymede, and Callisto, the ratios of the echo received in one mode of circular polarization to that received in the other were: 1.61 ± 0.20, 1.48 ± 0.27, and 1.24 ± 0.19, respectively, with the dominant component having the *same* sense of circularity as that transmitted. This behavior has not previously been encountered in radar studies of solar system objects, whereas the corresponding observations with linear polarization are 'normal'. Radii determined from the 1976 radar data for Europa and Ganymede are: 1530 ± 30 and 2670 ± 50 km, in fair agreeement with the results from the 1975 radar observations and the best recent optical determinations. Doppler shifts of the radar echoes, useful for the improvement of the orbits of Jupiter and some of the Galilean satellites, are given for 12 nights in 1976 and 10 nights in 1975.

Cloutier, P. A. (Space Physics and Astronomy Dept., Rice Univ., Houston, Tex.), Daniell, R. E., Jr., Dessler, A. J., and Hill, T. W.: 'A Cometary Ionosphere Model for Io', *Astrophys. Space Sci.* 55, 93–112. (1978)

The ionosphere of Jupiter's satellite Io, discovered by the Pioneer 10 radio-occultation experiment, cannot easily be understood in terms of a model of a gravitationally bound, Earth-like ionosphere. Io's gravitational field is so weak that a gravitationally bound ionosphere would probably be blown away by the ram force of the Jovian 'magnetospheric wind' – i.e., the plasma corotating in the Jovian magnetosphere. We propose here a model in which the material for Io's atmosphere and ionosphere is drawn from the ionosphere of Jupiter through a Birkeland current system that is driven by the potential induced across Io by the Jovian corotation electric field. We argue that the ionization near Io is caused by a comet-like interaction between the corotating plasma and Io's atmosphere. The initial interaction employs the critical velocity phenomenon proposed many years ago by Alfvén. Further ionization is produced by the impact of Jovian trapped energetic electrons, and the ionization thus created is swept out ahead of Io in its orbit. Thus, we suggest that what has been reported as a day–night ionospheric asymmetry is in fact an upstream–downstream asymmetry caused by the Jovian magnetospheric wind.

Cortesi, S. (Specola Solare de l'Observatoire Astronomique Federal, Locarno, Switzerland): 'Determination Quantitative de L'Effect de Phase Dans la Measure des Longitudes sur Jupiter', *Icarus* 33, 410–413. (1978) (in French)

We have quantitatively determined the phase exaggeration effect (Phillips effect) as a function of the planet's phase angle for the correction of the longitude of spots on the Jupiter disk. This was done on the basis of over 1000 visual observations of the longitude of permanent details of Jupiter's surface compared with photographic observations. We also propose the existence of a systematic error (+ $0\overset{\circ}{.}6$ zenographic) in our visual observations. As this error is probably caused by unidirectional motion of the detail over the planetary disk, we named it the 'shift effect'.

Desch, M. D. (Dept. of Physics and Astronomy, Univ. of Florida, Gainesville, Florida 32611) and Carr, T. D.: 'Modulation of the Jovian Emission below 8 MHz', *Astron. J.* 83, 828–837. (1978)

Data gathered from satellite radiometric observations of Jupiter at frequencies between 1310 and 6550 kHz are examined with regard to modulations of the emission in the System III rotation phase, Io phase, and Europa phase coordinates. Following a trend established by groundbased observations at frequencies above 10 MHz, the satellite-detected emission is seen to exhibit little dependence on rotation phase. The occurrence of activity as a function of Io phase, however, is at variance with the trends established by the groundbased studies. Considerable influence by Io is observed over activity recorded at frequencies as low as 2200 kHz, challenging the widely-held belief that Io control is a frequency-dependent phenomenon. We argue that this discrepancy with the higher frequency data is resolved, provided (a) the intensity of the emission relative to radiometer sensitivity is taken into account at each frequency, and (b) Io control is recognized as primarily a flux-dependent phenomenon. In agreement with studies at higher frequencies, we find no evidence for influence by the satellite Europa. The invariance of the observed Io control morphology over a wide frequency range suggests that emission occurs perpendicularly from localized field-aligned plasma-rich regions embedded in an ambient plasma which is too dilute to refract escaping rays strongly.

Fink, U. (Lunar and Planetary Laboratory, University of Arizona, Tucson, Ariz. 85721), Larson, H. P., and Treffers, R. R.: 'Germane in the Atmosphere of Jupiter', *Icarus* **34**, 344–354. (1978)

High-altitude spectra of Jupiter obtained from the Kuiper Airborne Observatory are analyzed for the presence of germane (GeH_4) in Jupiter's atmosphere. Comparison with laboratory spectra shows that the strong Q branch of the ν_3 band of germane at 2111 cm^{-1} is prominent in the Jovian spectra. The abundance of germane in Jupiter's atmosphere is 0.006 (± 0.003) cm-am corresponding to a mixing ratio of 0.6 ppb. This trace amount of germane is consistent with chemical equilibrium calculations if the germane present at ~ 1000 K is carried up by convection to the spectroscopically observable region at ~ 300 K.

Freeman, F. W.: (Dept. of Space Physics and Astronomy, Rice Univ., Houston, Tex.): 'The Galilean Satellites and the Jovian Magnetic Field', *The Moon and the Planets* 18, 325–326. (1978)

Alfvén and Arrhenius have proposed that satellites may form from the condensation of plasma suspended in the dipole magnetic field of a central body. Further, they predict that the condensed material will appear at an orbit distance of two-thirds the distance of the plasma. Recent spacecraft measurements have defined the radial extent of the stable quasi-dipole Jovian magnetic field. In support of the Alfvén and Arrhenius hypothesis, we note that all the Galilean satellites lie within two-thirds of this distance.

Goertz, C. L. (Max-Planck-Institut für Physik und Astrophysik, Institut für Extraterrestrische Physik, 8046 Garching bei München, Fed. Rep. of Germany): 'Energization of Charged Particles in Jupiter's Outer Magnetosphere', *J. Geophys. Res.* **83**, 3145–3150. (1978)

It is shown that corotation of charged particles in the azimuthally asymmetric magnetic field of the Jovian magnetosphere leads to a pitch-angle-dependent energy loss and gain of particles that drift from noon to midnight and midnight to noon, respectively. An isotropic pitch angle distribution at noon would become dumbbell-like at midnight. Nonadiabatic scattering relaxes the dumbbell distribution toward isotropy without changing the particle's energy. This scattering represents an increase of the first adiabatic invariant M. As the particles drift back toward noon at an increased value of M, they gain more energy than they lost during their drift from noon to midnight. The overall energy gain per rotation can be as large as a factor of 2, and in 10 rotations the total energy may be increased by several orders of magnitude. The model can account for the 10-hour modulation of spectral index and makes a number of testable predictions.

Gold, R. E. (APL/JHU, Laurel, Maryland 20810) and Roelof, E. C.: 'A Quantitative Model for Interplanetary Propagation of Jovian Electrons', *EOS: Trans. Amer. Geophys. Union* **59**, 346. (1978)

A quantitative model of Jovian electron propagation has been constructed which reproduces most of the observed features of Jovian electron events between ~ 1 to ~ 10 AU while still remaining consistent with observed propagation characteristics of solar electrons and solar wind stream structure. The model calculations fit the observed relationships between Jovian electron events and solar wind structure as well as their rise times, decay times and interplanetary gradients. The model approximates the electron propagation within the relatively undisturbed cavities of solar wind streams confined between the leading and following stream interaction regions, as scatter-free. The disturbed regions within the solar wind stream interactions are approximated as 2-dimensional scattering mediums with a reflection coefficient at the boundaries that inhibits electron entry from the scatter-free region. Good fits to observations are obtained using: scattering mean free paths along and transverse to the magnetic field within the interaction regions of $\lambda_{\|} \sim 1$ AU and $\lambda_{\perp} \sim 0.2$ AU; boundary reflection coefficients $R \sim 0.5$; injections times ~ 3–5 days (consistent with the interplanetary geometry of Jupiter and the solar wind stream structure 1973–6); and loss times from the interaction region to the outer heliosphere of ~ 6–10 days. The model calculations are in agreement with the Jovian electron seasons at 1 AU and the Pioneer observations out to ~ 10 AU.

Hubbard, W. B. (Dept. of Planetary Sciences, Lunar and Planetary Laboratory, University of Arizona, Tucson, Ariz. 85721) and Anderson, J. D.: 'Possible Flyby Measurements of Galilean Satellite Interior Structure', *Icarus* **33**, 336–341. (1978)

Flyby encounters of the Galilean satellites from a Jupiter orbiter spacecraft could yield information about the second-degree gravity harmonics of these satellites. We have calculated the expected values of these harmonics for a range of plausible interior models in hydrostatic equilibrium. Because the satellites respond to comparable perturbations from rotation and tides, an independent test of hydrostatic equilibrium is feasible. For Io and Ganymede, the expected measurement accuracy from a nominal encounter should make possible an excellent discrimination from the ensemble of interior models. For Europa, a qualitative distinction between near-uniform and centrally condensed models seems feasible. Only for Callisto is the proposed experiment of marginal value.

Johnson, T. V. (Jet Propulsion Laboratory, Calif. Institute of Technology, 4800 Oak Grove Drive, Pasadena, 91103): 'The Galilean Satellites of Jupiter: Four Worlds', *Annual Review of Earth and Planetary Sciences*, Vol. 6 (ed. by Fred A. Donath), pp. 93–125. (1978)

A comprehensive review on the physical properties, the surface characteristics, the atmospheric composition, the origin and evolution of Io, Europa, Ganymede and Callisto is presented.

Maxworthy, T. (Department of Aerospace Engineering, University of Southern California, Los Angeles, Calif. 90007), Redekopp, L. G., and Weidman, P. D.: 'On the Production and Interaction of Planetary Solitary Waves: Applications to the Jovian Atmosphere', *Icarus* **33**, 388–409. (1978)

We present further evidence that strengthens the case for our interpretation of many features in the Jovian atmosphere as solitary Rossby waves (solitons). These include: a mechanism whereby such waves can evolve from the instability of the basic shear flows; further interpretation of the interaction between observed features, and comparison with calculations of the interaction between planetary solitons of a restricted class; and calculations of soliton morphology for a type of shear flow other than the type considered originally by Maxworthy and Redekopp.

McDonough, T. (Jet Propulsion Lab., Pasadena, Calif. 91103), Swartz, W., and Williams, G.: 'The Role of Energetic Particle Precipitation in Jovian Magnetospherics: 1. Secondary Electrons from the Ionosphere', *EOS: Trans. Amer. Geophys. Union* **59**, 351. (1978)

Direct escape of photoelectrons from the Jovian ionosphere has been found to produce only a meager source of thermal plasma for the inflated centrifugally unstable magnetosphere. Since the magnetosphere is known to be well populated with energetic charged particles, it has been hypothesized that the generation of secondary electrons (by the precipitation of some of these particles) and their subsequent escape from the ionosphere might be an important additional source of cooler plasma for the magnetosphere. Estimates of the primary precipitating flux intensities in the range of 1 keV to tens of MeV, required for the generation of escape fluxes comparable to those produced by solar EUV, have been deduced with the use of energetic electron transport codes. Since these flux intensities are the minimum levels that would be considered significant, comparisons with estimates of the losses of energetic electron fluxes, such as those derived from Pioneer data by Thomsen and Sentman determine the relative importance of this mechanism.

Millis, R. L. (Planetary Research Center, Lowell Observatory, Flagstaff, Ariz. 86002): 'Photoelectric Photometry of JV', *Icarus* **33**, 319–321. (1978)

UBV photometry of JV near greatest western elongation shows this satellite to be about one magnitude fainter than previously believed. It is observed to be very red, having a B–V color index near + 1.5 mag. Unlike the Galilean satellites, JV appears to be a low-albedo object.

Nelson, R. M. (Department of Earth and Planetary Sciences, University of Pittsburgh, Pittsburgh, Penn. 15260) and Hapke, B. W.: 'Possible Correlation of Io's Posteclipse Brightening with Major Solar Flares', *Icarus* **33**, 203–209. (1978)

In 6 of the 7 instances where posteclipse brightening of Io has been reported by observers using blue filters, a major solar flare occurred within 10° of the sub-Jovian longitude in the 100 day interval prior to observation. In none of the 18 instances where no posteclipse brightening was observed did such a flare occur. It is proposed that a phenomenon associated with a major solar flare causes an increase in the trapped particle flux at Io's orbit by an order of magnitude. The posteclipse brightening may be caused by thermoluminescence of Io's surface material upon emergence. Alternatively, it is possible that the increase in trapped particle flux would warm the surface, creating a temporary atmosphere which would precipitate during eclipse cooling and vaporize in the period of warming after reemergence.

Naubauer, F. M. (Inst. Geophys., Techn. Univ. Braunschweig, F. R. G.): 'Alfvén Wave Radiation from the Jovian Galilean Satellites', *EOS: Trans. Amer. Geophys. Union* **59**, 352. (1978)

A comparative study of the interaction between the Jovian magnetosphere and the Galilean satellites is presented. *Linear* theory is used as a starting point. The satellite interaction with the magnetospheric plasma is treated including ionizing collisions, charge exchange, photoionization and elastic collisions with neutral atmosphere particles and/or current flow through the conducting interior. The resulting pattern is analyzed in terms of the fast, slow and Alfvén wave modes in the MHD-sense. The Alfvén Mach number varies from 10^{-2} to 0.4 from Io to Callisto. Hence near Io magnetic field disturbances are produced mostly by Alfvén radiation and near Callisto by fast and slow MHD-radiation. Only for Io a strong feed-back with the Jovian ionosphere is expected. Among other interesting results we state the following: Alfvén waves radiated by the satellites and reflected from the Jovian ionosphere lead to a regular sequence of '*images*' of the satellite in the electric fields and flow fields in the wake of the satellite, e.g., generating enhanced diffusion of radiation belt particles.

Ostro, S. J. (Department of Earth and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, Mass. 02139) and Pettengill, G. H.: 'Icy Craters on the Galilean Satellites?', *Icarus* **34**, 268–279. (1978)

A model which possibly accounts for the unusual radar scattering behavior observed for Europa, Ganymede, and Callisto postulates a thick surface layer of ice saturated with nearly hemispherical craters. In the development of this model it is noted that a single reflection at normal incidence reverses the rotational sense of circularly polarized incident radiation, in conflict with the radar observations which show an echo predominantly not reversed. Furthermore, an ensemble of backscattering events, each the result of a large number of successive dielectric reflections, tends to produce a weak and unpolarized echo. However, two coupled reflections can produce the observed backscattering behavior, provided the angles of incidence lie between the Brewster angle and its complement. The effect is maximum when the angles equal 45°, and, for water ice, yields a ratio of 1.9 for components of the echo received in rotational senses the same as, and opposite to, the sense transmitted. Randomly oriented reflecting facets, either of ice on the surface or of rocks in the interior, cannot yield the observed behavior since too few of the total possible backscattering configurations meet the above requirement. Hemispherical surface craters, on the other hand, favor 45° dual reflection. A model consisting of such craters in ice is investigated and found capable of explaining the observed results, not only in respect to polarization, but in respect to albedo and angular scattering law as well.

Piddington, J. H. (National Measurement Laboratory, CSIRO, Sidney, Australia): 'Jupiter–Io Electrodynamic Interaction', *The Moon* **17**, 373–382. (1977)

Strong interaction between Jupiter and its satellite Io is revealed by the control of the decametric radiation, by the distributions of energetic particles, and perhaps by the location of the boundary of Jupiter's plasmasphere near Io's magnetic flux tube. Two opposed theories of this interaction depend on different relative motions of Io and its flux tube. In one case the flux tube is frozen into Io and moves with Io, while in the plasma-sheath model Io moves freely across magnetic field lines. It is shown that the plasma-sheath model is unacceptable, and that Io must drive its flux tube through the magnetosphere. The first error in the sheath theory is in the mechanism of sheath creation by thermal and photoelectric electrons. The second error is in the neglect of electric currents driven through the external plasma by powerful space-charge fields. The third error is in the neglect of hydromagnetic effects of electric currents in Io: the magnetic perturbations, Lorentz forces and power supplied from the kinetic energy of Io. These effects show that Io's force tube is dragged along with Io. This frozen-in model is discussed briefly in connection with energetic electrons, the decametric emission, Io's ionosphere and Jupiter's plasmasphere.

Prather, M. J. (Center for Earth and Planetary Physics, Harvard University), Logan, J. A., and McElroy, M. B.: 'Carbon Monoxide in Jupiter's Upper Atmosphere: an Extraplanetary Source', *Astrophys. J.* **223**, 1072–1081. (1978)

Ablation of meteoroidal material in Jupiter's atmosphere may provide substantial quantities of H_2O. Subsequent photochemistry can convert H_2O and CH_4 to CO and H_2. The associated source of CO could account for the observations by Beer, Larson, Fink, and Treffers, and Beer and Taylor, and would explain the relatively low rotational temperatures inferred by Beer and Taylor. Meteoritic debris might also provide spectroscopically detectable concentrations of SiO.

Ruiz, H. G. V. (Instituto de Investigaciones Fisicas, Universidad Boliviana, LaPaz, Bolivia) and Rowland, F. S.: 'Possible Scavenging Rections of C_2H_2 and C_2H_4 for Phosphorus-containing Radicals in the Jovian Atmosphere', *Geophys. Res. Lett.* **5**, 407–410. (1978)

The ultraviolet photolysis of PH_3 in the laboratory leads to the formation of elemental red phosphorus, and the occurrence of the same reactions in the atmosphere of Jupiter has been suggested as the source of the chromophore of the Great Red Spot. The inclusion of either C_2H_2 or C_2H_4 as scavenger molecule in the laboratory photolysis at 295 K completely suppresses the formation of red phosphorus. Experiments are needed on the activation energies for the reactions of PH_2, PH and P_2 with C_2H_2 and C_2H_4 to determine whether the scavenging processes are also effective at Jovian atmospheric temperature. If the scavenging reactions are effective there, the formation of red phosphorus should occur only in regions with low concentrations of C_2H_2 and C_2H_4.

Schardt, A. W. (NASA/Goddard Space Flight Center, Greenbelt, Maryland 20771) and Birmingham, T. J.: 'Discrepancy in Proton Flux Extrapolation Along Field Lines in the Jovian Mid-magnetosphere', *EOS: Trans. Amer. Geophys. Union* 59, 352. (1978)

The 10-hour intensity modulation of energetic particles in the Jovian magnetosphere is due to the 10.8° dipole tilt which modulates the magnetic latitude of Pioneer-10. According to Liouville's Theorem, the differential particle flux measured at related pitch angles is invariant along a magnetic field line; thus, if the equatorial flux is isotropic, then flux is the same at all points on the field line. The first adiabatic invariant relates the local to the equatorial pitch angle by $\sin\delta = \sqrt{(B/B_0)}\sin\delta_0$ and, in the absence of acceleration or deceleration, the counting rates should be the same. From 30 to 25 R_j, the Pioneer trajectory followed closely along a dipole field line and the 7-fold decrease in the isotropic electron flux (~ 400 keV) away from the magnetic equator can be explained in terms of a radial flux gradient and field lines that are substantially more distended than dipole field lines. A local non-dipolar field model which matches observed magnetic field magnitudes and directions between 15 and 40 R_j gives reasonable agreement with these observations. No such agreement could be obtained for 1.9 MeV protons because their equatorial intensity is almost constant between 34 and 22 R_j. Since proton angular distributions are non-isotropic, comparisons were made at equatorial pitch angles of 20 to 30° and 150 to 160° because these were sampled at all points. A factor of 5 discrepancy in intensity at these angles remains and the angular distribution is also changed markedly. Violation of the first adiabatic invariant is one explanation; other potential explanations will be discussed.

Sentman, D. D. (Dept. of Physics and Astronomy, Univ. of Iowa, Iowa City, Iowa 52242) and Goertz, C. K.: 'Whistler Mode Noise in Jupiter's Inner Magnetosphere', *J. Geophys. Res.* 83, 3151–3165. (1978)

The distinctive 'hat shape' of equatorial pitch angle distributions constructed from Pioneer 10 and 11 Jupiter observations of energetic electrons $E_e > 21$ MeV and $E_e > 31$ MeV at $L = 3$ is examined from the point of view of pitch angle diffusion by resonant interaction with a band-limited spectrum of whistler mode noise. In this picture, the pitch angle profiles are consistent with whistler mode noise limited to frequencies below an upper cutoff frequency $2.8 \lesssim f_c \lesssim 4.6$ kHz. Equatorial linear growth rates of parallel propagating whistlers are evaluated in a fully relativistic manner for the inner region $3 < L < 10$ using previously published models for the spatial distribution of thermal plasma and the energetic electron distributions. The maximum frequency for which wave growth is positive at $L = 3$ is roughly consistent with that implied by the 21 and 31 MeV equatorial pitch angle profiles. Maximum growth rates computed from the respective energetic electron models span the range $0.2 \lesssim \gamma_{max} \lesssim 10\ s^{-1}$ throughout the inner region. The spectral extent of the whistler mode noise, defined by those frequencies for which $\gamma > 0.5\gamma_{max}$, is approximately 2–10 kHz at $L = 3$ and falls smoothly to 0.2–2 kHz at $L = 10$. Raytracing of nonducted whistlers of characteristic frequencies 1–4 kHz generated at the magnetic equator and propagated through a finite temperature (100–400 eV) hydrogen plasma centrifugally confined near the magnetic equatorial plane shows that wave phase speeds decrease to near or below electron thermal speeds before high-latitude reflection can occur. Wave growth in this case is limited to a disc-like region centered about the magnetic equator. The amplitude growth of the most unstable whistlers propagating across the growth region parallel to the magnetic field is ~ exp (3–4). By equating energetic electron radial diffusion injection times to the pitch angle diffusion loss times of electrons in cyclotron resonance with waves of frequencies of maximum unstable growth, the power density of whistler mode noise is estimated to be $10^{-19\pm1}$ G^2 Hz^{-1}. The balance equation for radial diffusive injection and pitch angle diffusive losses occurring in the presence of whistler mode noise of characteristic growths exp (3–4) yields upper limit estimates for the magnitude of fluctuations about the stably trapped limiting intensities in the region $3 < L < 10$. This upper limit is approximately at the 10% level, in reasonable agreement with the smooth radial flux profiles observed during the Pioneer–Jupiter encounters.

Terasawa, T. (Institute of Space and Aeronautical Science, University of Tokyo, Komaba, Meguro-ku, Tokyo 153, Japan), Maezawa, K., and Machida, S.: 'Solar Wind Effect on Jupiter's Non-Io-related Radio Emission', *Nature* 273, 131–132. (1978)

It is shown that Jupiter's non-Io-related radiation shows a good correlation with the dynamic pressure of the solar wind.

Thieman, J. R. (NASA Goddard Space Flight Center, Greenbelt, Maryland 20770) and Smith, A. G.: 'Frequency and Time Dependence of the Jovian Decametric Radio Emissions: a Nineteen-year High-resolution Study', *J. Geophys. Res.* 83, 3303–3309. (1978)

A nineteen-year catalog of observations collected by the Universities of Florida and Texas has permitted detailed comparison of Jovian source characteristics at 10 frequencies from 5.6 to 30 MHz. The spectral morphology of Jupiter's decameter wavelength radio sources was studied by means of high-resolution histograms of occurrence probability for intervals as small as 2° in Jovian system III longitude and the departure of Io from superior geocentric conjunction. Longitude histograms clearly exhibit a substantial shift in the source *A* and source *B* positions between 15 and 10 MHz. Similar diagrams isolate the dependence of each source on the position of Io, illustrating changes with frequency in the structures and sizes of the main probability maxima and in the positions of surrounding secondary peaks. Individual frequency probability histograms for both longitude and Io phase reveal new phenomena, such as a bridge of radiation through source *B* longitudes connecting sources *A* and *C* at 15 MHz and spectral modification of portions of the Io-related source *B* peak.

Thieman, J. R. (Laboratory of Extraterrestrial Physics, Goddard Space Flight Center, Greenbelt, Maryland 20771), Alexander, J. K., and Kaiser, M. L.: 'Short-term Phenomena in Jupiter's Decametric Radio Emissions', *EOS: Trans. Amer. Geophys. Union* 59, 353. (1978)

The non-Io-related decameter-wavelength radio emission from Jupiter have been examined for systematic variations in occurrence probability on a time scale of less than a year. Dependence of the radiation on the Earth–Sun–Jupiter angle has been studied as well as the often-sought correlation of radio storms with solar activity. Such analyses have been hampered in the past by inadequate statistical coverage for the Io-independent data. A new data catalog has been created (now available on magnetic tape) which greatly increases the amount of non-Io-related data by combining twenty years of decameter-wavelength synoptic monitoring results from twelve observing sites scattered world-wide. Catenation of overlapping monitoring times synthesizes long periods of continuous recording and permits analysis of spans of activity which are often interrupted at a single observing site. In the process of merging the data sets the correlation among simultaneous recordings has been reviewed to show the effect of the Earth's ionosphere on the data.

Trafton, L. (McDonald Observatory and Astronomy Department, The University of Texas at Austin,

Austin, Tex. 78712) and Macy, W., Jr.: 'On the Distribution of Sodium in the Vicinity of Io', *Icarus* 33, 322–335. (1978)

We investigate the contribution of scattering in the telescope of our measurements of the size of Io's sodium cloud and to the distribution of emission intensity in the cloud. The brightest regions, within 30″ of Io near opposition and along the equatorial plane, are relatively undistorted but regions further than 45″ away and not close to the equatorial plane are very likely to consist of mainly scattered light. Portions of the cloud in the vicinity of the magnetic equator are also mostly scattered light when Io is near extreme magnetic latitude. The equatorial torus, however, extends up to 20 arcmin from Jupiter. The large size of the cloud is thus confirmed. High-resolution line profile shapes indicate that sodium streams from Io preferentially in the forward direction with velocities distributed up to 18 km s^{-1}. The observed wavelength shifts of the peak intensities from Io's rest frame are compatible with a cloud streaming through a bound atmospheric component but they could also be caused by a velocity distribution peaked at very low velocities.

Treffers, R. R. (Radio Astronomy Laboratory, University of California, Berkeley, Calif. 94720), Larson, H. P., Fink, U., and Gautier, T. N.: 'Upper Limits of Trace Constituents in Jupiter's Atmosphere from an Analysis of its 5 μm Spectrum', *Icarus* 34, 331–343. (1978)

A high-resolution (0.6 cm^{-1}) spectrum of Jupiter at 5 μm recorded at the Kuiper Airborne Observatory is used to determine upper limits to the column density of 19 molecules. The upper limits to the mixing ratios of SiH_4, H_2S, HCN, and simple hydrocarbons are discussed with respect to current models of Jupiter's atmosphere. These upper limits are compared to expectations based upon the solar abundance of the elements. This analysis permits upper limit measurements (SiH_4), or actual detections (GeH_4), of molecules with mixing ratios with hydrogen as low as 10^{-9}. In future observations at 5 μm the sensitivity of remote spectroscopic analyses should permit the study of constituents with mixing ratios as low as 10^{-10}, which would include the hydrides of such elements as Sn and As as well as numerous organic molecules.

Vdovichenko, V. D. (Astrophysical Institute, Academy of Sciences of the Kazakhstan SSR), Gaisin, A. M., Kuratov, K. S., Salamakhina, T. I., and Sorokina, L. P.: 'Jovian Activity in 1975', *Solar System Res.* 12, 35–39. (1978)

We discuss atmospheric activity on Jupiter during 1975 based on photographic and photoelectric observations in 18 spectral regions spanning λλ 3500–8500 Å. The planet's instability factor in 1975 is higher than for the 1962–1969 period, while its activity factor in 1975 is somewhat lower than for the same period. The activity factor shows time changes of 7–10%.

Vickers, G. T. (Dept. of Applied Mathematics & Computing Science, The Univ. of Sheffield, Sheffield S10 2TN, England): 'A Self-consistent Model of the Jovian Plasma Sheet', *Planet. Space Sci.* 26, 381–385. (1978)

An axially-symmetric, rapidly-rotating magnetosphere containing low-energy plasma is considered. The resulting plasma sheet is presumed isothermal and thin compared with the radius of the sheet. Solutions of the model equations are found which include the effects of centrifugal, pressure and electro-magnetic forces. These solutions show that the sheet has a constant thickness and that the pressure decays exponentially with distance from the equatorial plane. The calculated curves for the magnetic induction field are compared with the observed field of Jupiter.

Williams, G. (School of Electrical Engineering, Cornell, Ithaca, New York 14853), Lovelace, R., Hohlfeld, R., and Kintner, P.: 'Electrostatic Diode and Cyclotron Acceleration of Energetic Electrons and Protons in the Jovian Magnetosphere: Possible Contributors to the Unexplained Particle Fluxes?', *EOS: Trans. Amer. Geophys. Union* 59, 351. (1978)

Some new promising explanations for the presently enigmatic components of the Jovian magnetospheric electron and ion populations are proposed. The effects of these mechanisms upon the energy spectrum of the relativistic electron population are also discussed. The two proposed mechanisms may augment particle-recirculation effects upon the relativistic electron energy spectrum and may explain the high-latitude anomalous fluxes, etc.

MARS

Anderson, D. M. (U.S. Army Cold Regions, Research and Engineering Laboratory, Earth Sciences Branch, Box 282 Hanover, New Hampshire 03755), Schwarz, M. J., and Tice, A. R.: 'Water Vapor Adsorption by Sodium Montmorillonite at $-5°C$', *Icarus* 34, 638–644. (1978)

A large amount of interest has recently been expressed pertaining to the quantity of physically adsorbed water by the Martian regolith. Thermodynamic calculations based on experimentally determined adsorption and desorption isotherms and extrapolated to subzero temperatures indicate that physical adsorption of more than one or two monomolecular layers is highly unlikely under Martian conditions. Any additional water would find ice to be the state of lowest energy and therefore the most stable form. To test the validity of the thermodynamic calculations we have measured adsorption and desorption isotherms of sodium montmorillonite at $-5°C$. To a first approximation it was found to be valid.

Arvidson, R. (McDonnell Center for the Space Sciences, Washington University, St. Louis, Missouri 63130), Carlston, C. E., Guinness, E., Pidek, D., Jones, K., Sagan, C., and Wall, S.: 'Constraints on Aeolian Phenomena on Mars from Analysis of Viking Lander Camera Data', *EOS: Trans. Amer. Geophys. Union* 59, 313. (1978)

The Viking Landers touched-down in the northern hemisphere during the onset of northern summer. The lander cameras have been monitoring the sky and surface on a regular basis since then, providing information on the nature and rate of aeolian processes that extends over nearly a full Martian year. Results that impact our understanding of aeolian dynamics on Mars are: (1) Wind-blown drifts of soil at both landing sites extend from rocks and point in a southerly direction. The southerly direction for the drifts is consistent with the direction of bright streaks seen from orbit at these latitudes and with the wind direction inferred from the Mariner 9 IR measurements near the end of the 1971 dust storm. However, Viking lander meteorology results suggest a much more complex distribution of winds. Two large 'perihelion' dust storms occurred during Viking. Winds did not blow consistently from north to south at either site, during either storm. (2) Viking Lander X-ray fluorescence results and Lander camera multispectral data (0.4–1.1 μm) are consistent with the soils being composed of a mixture of weathering products derived from iron-rich igneous rocks. Similarities in composition and spectra at both landing sites imply that the soil has been homogenized by winds on a global scale. (3) No *obvious* topographic changes have been found in comparing pictures of drifts and other undistrubed areas taken on various days with the lander cameras. Soil material within one of the footpads on VL1 has been significantly scoured by winds. The material in the footpad is loose, and in addition the footpad surface slopes some 30°. Thus, the shear stress needed to entrain material will be lower than that needed to erode material on a flat surface. Soil material dumped onto the lander deck has been considerably shaped by wind and by the action of subsequent dumps of soil, where the soil material impacted onto older deposits and reshaped them. Unfortunately, soil deliveries and dumps have continued throughout the mission, making it very difficult to tell if wind alone has done any of the reshaping. (4) Reference gray patch charts mounted on the lander, used for calibration of multispectral imagery, have obtained a coating of red dust. Some of the dust was blown off the charts at the onset of high winds associated with the two perihelion dust storms. That is not too surprising since the chart surfaces slope at 79° to the horizontal, and the grains must have been held largely by adhesive forces. (5) In sum, the past year on Mars has been a relatively quiet one in terms of aeolian activity at the landing sites. With the exception of some wind induced redistribution of disturbed material, no obvious changes have been detected. Yet, the soil at the landing sites has, in the past, been shaped in a significant way by winds. Either significant aeolian activity at the landing sites is a very rare event, connected to a very occasional storm with high velocity winds, or the deposits at the sites were last altered in a significant way when local climatic conditions were different. One possibility is that aeolian erosion is strongly controlled by the location of the subsolar latitude at perihelion. At present that latitude is below the equator, while both landers are in the northern hemisphere.

Bills, B. C. (Jet Propulsion Lab., Pasadena, Calif. 91103) and Ferrar, A. J.: 'Mars Topography Harmonics and Geophysical Implications', *J. Geophys. Res.* 83, 3497–3508. (1978)

An improved model of Martian global topography has been obtained by fitting a sixteenth-degree harmonic series to occultation, radar, spectral, and photogrammetric measurements. The existing observations have been supplemented in areas without data by empirical elevation estimates based on photographic data. The mean radius is 3389.92 ± 0.04 km. The corresponding mean density is 3.9331 ± 0.0018 g cm^{-3}. The center of figure is displaced from the center of mass by 2.50 ± 0.07 km toward 62° ± 3°S. 272° ± 3°W. The geometric flattening ($f_g = (6.12 \pm 0.04) \times 10^{-3}$) is too great and the dynamic flattening ($f_d = (5.22 \pm 0.03) \times 10^{-3}$) is too small for Mars to be homogeneous and hydrostatic. It is confirmed that the low-degree gravity harmonics are produced primarily by surface height variations and only secondarily by lateral density variations. Maps of the data distribution, global topography, and Bouguer gravity anomaly are presented. These are interpreted in terms of a crustal thickness map which is consistent with gravity, topography, and recent preliminary Viking seismic results. From plausible density contrasts and an assumed zero crustal thickness at Hellas, the inferred minimum mean crustal thickness is 28 ± 4 km.

Blasius, K. R. (Planetary Science Institute, 283 S. Lake Ave., No. 218, Pasadena, Calif. 91101) and Cutts, J. A.: 'Braided Channels Associated with Young Lava Flood Deposits, Tharsis Volcanic Province, Mars', *EOS: Trans. Amer. Geophys. Union* 59, 310. (1978)

Braided channels certainly formed by fluid flow have been identified on some of the youngest volcanic plains on Mars, suggesting either fluvial activity very late in Martian history or the eruption of extremely fluid lavas which mimic water in their erosive characteristics. Channel complexes up to 120 km long and with individual elements up to 1.5 km wide are present on the young volcanic plains which embay Olympus Mons and grooved terrain near 20°N, 124°W and 16°N, 125°W. Apparent source regions are polygonal fractures in plains immediately adjacent to grooved terrain and two troughs about 1 km wide and 6 and 10 km long. Both troughs appear to be truncated by broad lava flows. Larger complexes (up to at least 250 km long) of braided channels (individually up to 8 km wide) occur farther north and east (94 to 101°W, 27 to 36°N). The plains here are older than those associated with Olympus Mons, many flows apparently eroded to low relief hummocky terrain, and the channel complexes appear to represent fragments of more complete systems. Characteristics of these braided channels pose genetic problems similar to those of much larger channels which open onto Chryse Planitia, but they do so more acutely; channeling occurred very late in Martian history arising in relatively small source regions (volcanic vents or springs?), and was intimately related in space and time to flooding by fluid lavas. The small scale braiding and sinuosity of these channels rule out aeolian erosion, but water flows (perhaps due to local melting of ground ice by heat of volcanism) or extremely fluid lava flows which might mimic water flows in their erosive characteristics, both seem to warrant additional investigation.

Booth, M. C. (Dept. of Earth and Space Sciences, Univ. of Calif., Los Angeles, Calif. 90024): 'Carbonate' Formation and the History of CO_2 on Mars', *EOS: Trans. Amer. Geophys. Union* **59**, 313–314. (1978)

The return of Viking data indicating a highly weathered martian surface, and experimental evidence of a nonaqueous process of carbonate formation within Mars-like environments have led to the development of a model for the history of CO_2 on Mars. Using measured rates of carbonate growth from simulated martian environments as upper limits to carbonate growth on Mars, carbonate formation has been found to have potentially played a leading role in the evolution of the martian surface environment with the storage of much of the planet's total outgassed CO_2 inventory in the martian regolith. The withdrawal of CO_2 from the 'free' CO_2 inventory of Mars by both aqueous and nonaqueous carbonate-forming processes is expected to have caused a progressive deterioration in the atmosphere density of the planet over martian geologic time, accompanied by a trend toward a more severe planetary climate. Periods in which an aqueous phase of water may have been in abundance required a high atmospheric abundance of CO_2 and would consequently possess conditions favorable to chemical weathering, and carbonate growth. Clement epochs would therefore accelerate the depletion of the 'free' CO_2 reservoir upon which it depends for atmosphere density. Barring reservoir rejuvenation by late outgassing events, clement epochs are concluded to have been confined to early periods of martian history following largescale planetary outgassing.

From the dependence of nonaqueous carbonate formation upon the atmospheric pressure of CO_2, and temperature, the rate of carbonate growth in a nonaqueous martian environment has been determined to be a gradually slowing process which is reduced further at low temperatures by increases in CO_2 adsorption and condensation at the martian surface. Such a process may still exist at the martian surface although proceeding at a relatively slow rate.

Booth, M. C. (Dept. of Earth & Space Sciences, University of California, Los Angeles, Calif. 90024) and Kieffer, H. H.: 'Carbonate Formation in Mars-like Environments', *J. Geophys. Res.* 83, 1809–1815. (1978)

Carbonate growth was examined within rock powders subjected to Mars-like environmental simulations. Rates of growth under experimental conditions were 10^{12}–10^{13} molecules cm^{-3} s^{-1} with or without an aqueous phase of H_2O present and were found to be proportional to CO_2 pressure. H_2O abundance, and particle surface area. Direct ultraviolet illuminating of powders was found not to affect carbonate growth significantly, but photochemistry of absorbed H_2O was thought to play an important role in chemical alteration activity. Transitory damp periods induced in powders of some experiments by the melting of surface frosts were found to provide only slight assistance to the rate of growth in comparison with experiments in which sublimation of frosts occurred. Liquid water did, however, have a noticeable effect upon the distribution of carbonate material within experimental samples. On the basis of experimental results, carbonate formation is shown to be fully compatible with the low-pressure arid conditions characteristic of the present Mars surface environment. It is further concluded that carbonate formation is likely to be an important aspect of Martian chemical weathering, that carbonate material is likely to represent a major chemical reservoir for the outgassed CO_2 inventory of Mars, and that in the absence of an aqueous phase of H_2O in the environment this carbonate should form as submicron coatings on regolith particle grains.

Chen, R. H. (Space Physics Research Lab., Dept. of Atmospheric and Oceanic Science, Univ. of Michigan, Ann Arbor, Mich. 48108), Cravens, T. E., and Nagy, A. F.: 'Martian Ionosphere in light of the Viking Observations', *J. Geophys. Res.* **83**, 3871–3876. (1978)

A theoretical model has been constructed in which the ion density and the ion and electron temperature distributions are calculated by solving the coupled continuity-momentum equations and the coupled energy equations. The latest experimental results from the Viking 1 and 2 landers are used to vary some of the parameters in the model in order to obtain agreement between the theoretical and experimental results. It is found that solar EUV radiation alone is not able to maintain the observed high ion temperatures. It was also established that the energy coupling between the electron and ion gas is insufficient to account for the measured ion temperatures even in the presence of very large electron temperatures. Direct heat input to the ion gas, probably due to solar wind–ionosphere interactions, can result in ion temperature values in reasonable agreement with the observation. The ion densities calculated with the present model agree well with the Viking observations in the chemically controlled region, but at higher altitudes, dynamic transport processes need to be invoked to achieve consistency among the observed and calculated temperature and density values.

Clark, B. C. (Planetary Sciences Laboratory, Martin Marietta Aerospace, Denver, Colorado 80201): 'Implications of Abundant Hygroscopic Minerals in the Martian Regolith', *Icarus* **34**, 645–665. (1978)

Converging lines of evidence suggest that a significant portion of the Martian surface fines may consist of salts and smectite clays. Salts can form stoichiometric hydrates as well as eutectic solutions with depressed freezing points; clays contain bound water of constitution and adsorb significant quantities of water from the vapor phase. The formation of ice may be suppressed by these minerals in some regions on Mars, and their presence in abundance would imply important consequences for atmospheric and geologic processes and the prospects for exobiology.

Condit, C. D. (U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff, Ariz. 86001): 'Distribution and Relations of 4 to 10 km Diameter Craters to Global Geologic Units of Mars', *Icarus* **34**, 465–478. (1978)

By correlating the 1:25 000 000 geologic map of Mars of Scott and Carr with 4 to 10 km diameter crater density data from Mariner 9 images, the average crater density for 23 of the equatorial geologic–geomorphic units on Mars was computed. The correlation of these two data sets was accomplished by digitizing both the crater density data and geologic map at the same scale and by comparing them in a computer. This technique assigns the crater density value found in the corresponding location on the geologic data set to a discrete computer file assigned each of the 23 geologic units. By averaging the crater density values accumulated in each file, an 'average' crater density for each geologic unit was obtained. Condit believes these average crater density values are accurate indicators of the relative age of the geologic units considered. The statistical validity of these average values is strongest for the geologic units of the largest areal extent. The relative ages as obtained from the average crater density values for the seven largest geologic units, from youngest to oldest, are: Tharsis volcanic material, 21 ± 4 craters/10^6 km^2; smooth plains material, 57 ± 14 craters/10^6 km^2; rolling plains material, 66 ± 16 craters/10^6 km^2; plains materials, 80 ± 17 craters/10^6 km^2; ridged plains material, 128 ± 25 craters/10^6 km^2; hilly and cratered material, 137 ± 38 craters/10^6 km^2; and cratered plateau material, 138 ± 27 craters/10^6 km^2.

Crumpler, L. S. (Dept. of Geology, University of New Mexico, Albuquerque, New Mexico 87131) and Aubele, J. C.: 'Structural Evolution of Arsia Mons, Pavonis Mons, and Ascreus Mons: Tharsis Region of Mars', *Icarus* **34**, 496–511. (1978)

Analysis of Viking Orbiter data suggests that Arsia Mons, Pavonis Mons, and Ascreus Mons, three large shield volcanoes of the Tharsis volcanoes of Mars, have had similar evolutionary trends. Arsia Mons appears to have developed in the following sequence: (1) construction of a main shield volcano, (2) outbreak of parasitic eruption centers on the northeast and southwest flanks, (3) volcano-tectonic subsidence of the summit and formation of concentric fractures and grabens, possibly by evacuation on an underlying magma chamber during eruption of copious lavas from parasitic eruption centers on the northeast and southwest flanks, and (4) continued volcanism along a fissure or rift bisecting the main shield, resulting in flooding of the floor of the volcano-tectonic depression and inundation of the northeast and southwest flanks by voluminous lavas locally forming parasitic shields. In terms of this sequence Pavonis Mons has developed to stage (3) and Ascreus Mons has evolved to stage (2). This interpretation is supported by crater frequency–diameter distributions in the 0.1–3.0 km diameter range.

Cutts, J. A. (Planetary Science Institute, 283 S. Lake Ave., No. 218, Pasadena Calif. 91101), Blasius, K. R., and Pang, K. D.: 'Polar Layered Deposits on Mars: New Evidence on Their Mode of Formation', *EOS: Trans. Amer. Geophys. Union* 59, 313. (1978)

New Viking observations of the north and south polar terrains of Mars provide persuasive evidence that perennial polar frosts control the accumulation of layered deposits.

A number of sites have been found where the margin of the perennial ice caps has formed obliquely to the general topographic grain of a terraced landscape and coincides with the margin of a deposit which is thick enough to entirely obscure terraces with characteristic horizontal and vertical scales of 300 and 30 m respectively. This interpretation of a deposit mantling earlier terracing is confirmed by images acquired to show subtle variations in topography at larger scales. These data indicate that where the terraces are mantled, shallow regional slopes are still preserved and that these subtle topographic features connect together 'islands' of terracing which have excaped the later mantling process. The most straightforward explanation for these observations is that suspended dust generated by planet-wide dust storms is precipitated with the annual ice at the pole but is only retained in areas of perennial ice. The accumulation of annual frosts may also enhance the rate of deposition beyond that occurring elsewhere on the planet. Thus earlier models of the development of the architecture of the polar topography now require updating. We propose that many of the scarps within the polar cap represent the edges of former margins of the perennial polar cap. Thus, most of these scarps should now be considered constructional in nature. The relationship between the climatic cycling which determined the layering and oscillations in cap size which define the positions of scarps remains obscure.

Davies, M. E. (Rand Corp., Santa Monica, Calif. 90406): 'The Control Net of Mars: May 1977' *J. Geophys. Res.* 83, 2311–2312. (1978)

In May 1977 a planet-wide control net of Mars was computed by means of a large single-block analytical triangulation using 17 224 measurements of 3037 control points on 928 Mariner 9 pictures. The direction of the spin axis and the rotation rate as determined by Viking were used. The angle V, measured from Mars' vernal equinox along the equator to the prime meridian (Airy-0), was found to be $V = 148.37° + 350.891\,986°$ (J.D. 2 433 282.5).

Debarbat, S. (Observatoire de Paris, 61, avenue de l'Observatoire, F-75014 Paris, France): 'Observations of Mars Position with the Paris Astrolabe', *Astron. Astrophys. Supplement Series* 32, 335–337. (1978) (in French)

This paper contains results for Mars observed with the Paris astrolabe during the 1975–1976 campaign. Twenty transits have been observed between 1975 October 23 and 1976 January 25. Among them, 14 give 7 double transits for which the corrections to American Ephemeris are given (right ascension and declination). The same quantities calculated for the ephemerides (Kaplan *et al.* 1976) based on Clemence theory and the elements of Mars by Laubscher are also given.

Duxbury, T. C. (Jet Propulsion Lab., California Institute of Technology, Pasadena, Calif. 91103) and Veverka, J.: 'Deimos Encounter by Viking: Preliminary Imaging Results', *Science* **201**, 812–814. (1978)

Recent close flybys of Deimos by Viking revealed a smooth-appearing surface void of grooves. Higher-resolution pictures showed that the surface was actually covered with craters but that a regolith filled the smaller craters, giving the smooth appearance. The surface was also covered with boulders and bright streak-like markings analogous to base-surge or ejecta cloud deposits.

Fanale, F. P. (Space Sciences Division, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, Calif. 91103) and Cannon, W. A.: 'Mars: the Role of the Regolith in Determining Atmospheric Pressure and the Atmosphere's Response to Insulation Changes', *J. Geophys. Res.* **83**, 2321–2325. (1978)

We present a quantitative model for atmosphere-regolith exchange of CO_2 on Mars based on new laboratory measurements of CO_2 adsorption on ground rock at temperatures of 158, 175, 196, and 231 K and CO_2 pressures from 1.0 to 80 mbar. Our model is consistent with Viking observations, whereas models involving a massive residual CO_2 cap and no long-term atmosphere-regolith CO_2 exchange are not. Our model describes the role of the regolith as a CO_2 storehouse, as a long-term buffer of the atmospheric pressure, and as a major factor in determining the response of the atmosphere to postulated changes in surface insolation. We conclude the following: (1) The atmosphere-plus-cap system is buffered on a long-term basis by several hundred grams per square centimeter of exchangeable CO_2 adsorbed in the regolith. (2) If the atmosphere-plus-cap system were arbitrarily removed in its entirety, it would eventually be restored to nearly its former state by reequilibration with the regolith. (3) Exchange with the adsorbed phase in the regolith has greatly restricted ^{18}O enrichment in the atmosphere. (4) The layered terrain primarily represents current periodic pressure increases (of several tens of millibars) caused by exchange of CO_2 between the regolith and the atmosphere-plus-cap system. (5) Pressures of 100–300 mbar might have existed during the early history of the planet.

Favero, M. S. (Hepatitis Laboratories Division, Bureau of Epidemiology, Center for Disease Control, Public Health Service, U.S. Dept. of HEW, 4402 N. 7th St. Phoenix, Arix. 85014): 'Public Health Considerations Associated with a Mars Surface Sample Return Mission', *Life Sciences and Space Research* **16**, 33–37. (1978)

The consensus of scientists is that bringing Martian 'soil' to Earth poses potential health and environmental risks that must be balanced with appropriate safeguards. Some scientists think that the risks are so enormous and contamination technology is so inadequate that the mission should be cancelled. Some think that any sample brought from Mars should be heat sterilized before it enters Earth's atmosphere. On the other hand, some of us believe that the United States has the capability and technology to fully contain a sample from Mars even if it contains viable, highly virulent, and contagious organisms, and to study and manipulate these organisms safely. Those who attach enormous risks to bringing in samples from Mars do so by using analogies to Earth pandemics, latent viruses, and cancer; many of their analogies are misleading and, in fact, have little basis in current scientific experience and modern concepts of epidemiology. Furthermore, they dismiss 'probabilities' of risk and invoke 'possibilities' of risk in their broadest form so that their overriding premise is that all risks, all failures, and all worst case conditions are possible. This view is not rational and if supported most certainly would cause the mission to be cancelled.

Fuller, A. O. (Dept. of Geological and Geophysical Sciences, Princeton University, Princeton, New Jersey 08540) and Hargraves, R. B.: 'Some Consequences of a Liquid Water Saturated Regolith in Early Martian History', *Icarus* **34**, 614–621. (1978)

Flooding of low-lying areas of the Martian regolith may have occurred early in the planet's history when a comparatively dense primitive atmosphere existed. If this model is valid, the following are some pedogenic and mineralogical consequences to be expected. Fluctuation of the water table in response to any seasonal or longer term causes would have resulted in precipitation of ferric oxy-hydroxides with the development of a vesicular duricrust (or hardpan). Disruption of such a crust by scarp undercutting or frost heaving accompanied by wind deflation of fines could account for the boulders visible on Utopia Planitia in the vicinity of the second Viking lander site. Laboratory and field evidence on Earth suggests that under weakly oxidizing conditions lepidocrocite (rather than goethite) would have preferentially formed in the Martian regolith from the weathering of ferrous silicates, accompanied by montmorillonite, nontronite, and cronstedtite. Maghemite may have formed as a low-temperature dehydrate of lepidocrocite or directly from ferrous precursors.

Gault, D. E. (Murphys Center of Planetology, Murphys, Calif. 95247) and Greeley, R.: 'Exploratory Experiments of Impact Craters Formed in Viscous-liquid Targets: Analogs for Martian Rampart Craters?', *Icarus* 34, 486–495. (1978)

Exploratory experimental impact studies have been performed using 'soupy' mud as a target material. Although differing in details, the results appear to support the hypothesis that ejecta deposits around a class of Martian craters recently revealed in high-resolution Viking Oribiter images were emplaced as a flow of fluidized materials.

Goffin, E. (Vereniging voor Sterrenkunde, Belgium) and Meeus, J.: "Mars' Closest Approaches to Earth', *Sky and Telescope* 56, 106–107. (1978)

The dates of all the 1410 oppositions of Mars during the internal of just over 30 centuries, and also the corresponding dates when the distance of Mars from the Earth was minimum are given.

Greeley, R. (Dept. of Geology, Arizona State University, Tempe, Ariz. 85281), Papson, R., and Veverka, J.: 'Crater Streaks in the Chryse Planitia Region of Mars: 'Early Viking Results', *Icarus* 34, 556–567. (1978)

High-resolution images of Chryse Planitia and eastern Lunae Planum from the early revolutions of Viking Orbiter I permit detailed analyses of crater-associated streaks and interpretation of related eolian processes. A total of 614 light and dark streaks were studied and treated stastically in relation to: (1) morphology, morphometry, and orientation, (2) 'parent' crater size and morphology, (3) terrain type in which they occurred, (4) topographic elevation, and (5) meteorological data currently being acquired by Viking Lander I. Three factors are apparent: (1) light streaks predominate, (2) most streaks form in association with fresh bowl-shaped craters, and (3) most light streaks are of the 'parallel' type, whereas dark streaks are approximately evenly divided between convergent and parallel forms; moreover, very few light or dark streaks are divergent or fan-shaped. Light streaks have an average azimuth of 218° (corresponding to winds from the northeast), which approximates the orientation of 197 ± 14° for eolian 'drifts' observed by the Viking Lander imaging team. This lends support to the hypothesis that light streaks are deposits of windblown sediments. Dark streaks are oriented at an azimuth of 42° (approximately opposite that of light streaks) and are nearly in line with the dominant wind direction currently recorded by the Viking meteorology instruments. Although the size of the sample area is not uniform among the various terrain types, the highest frequency of streaks per unit area occurs in the knobby terrain. This is partly explained by the probable production of fine-grained material (weathered from the knobs) to form streaks and other eolian features, and the higher wind turbulence generated around the knobs. The lowest frequency of streaks occurs on the elevated plateaus. The light streaks in Chryse Planitia appear to be relatively stable and to result from deposition of windblown material during times of relatively high velocity northeasterly winds.

Dark streaks are more variable and probably result from erosion by southwesterly winds. Both types will be monitored during the extended Viking mission and the results compared with lander data.

Greeley, R. (Dept. of Geology and Center for Meteorite Studies, Arizona State Univ., Tempe, Ariz. 85281), Spudis, P. D., and Womer, M. B.: 'The Patera of Mars – A Unique Style of Planetary Volcanism', *EOS: Trans. Amer. Geophys. Union* 59, 310. (1978)

The term *patera* was applied to a class of possible volcanic landforms on Mars, observed from Mariner-9, characterized as complex, overlapping depression with scalloped edges. Improved coverage and resolution provided by Viking Orbiters permit reassessment of patera and lead to a tentative *geomorphic* classification: *Class I* patera are similar to Tharsis shield volcanoes, but are smaller and appear to be older, evidenced by degraded surfaces (Apollinaris Patera); others are buried shield volcanoes (Biblis Patera); *Class II* patera have prominent deeply incised channels radial to a central depression (Tyrrhena Patera); the channels may be either erosional or primary structures; *Class III* patera (one member, Orcus Patera) resembles the lunar crater Schiller and is interpreted to be a modified impact crater; *Class IV* patera, represented by Alba Patera, appear to be a distinctive type of shield volcano; these are central volcanoes characterized by their great size (up to 1600 km in diameter), low profile, and radial lava flows of very large volume. Some tube-fed flows on Alba Patera are morphologically similar to those of the Tharsis shields, but are one or two order of magnitude larger, exceeding 7500 km^3 in volume. This implies differences in rate of eruption, vent size and morphology, and possibly lava rheology and chemistry. This class of volcanic construct is unique among the known terrestrial planets and may represent a distinct style of volcanism and eruptive history.

Greeley, R. (Dept. of Geology and Center for Meteorite Studies, Arizona State University, Tempe, Ariz. 85821) and Spudis, P. D.: 'Volcanism in the Cratered Terrain Hemisphere of Mars', *Geophys. Res. Lett.* 5, 453–455. (1978)

Viking Orbiter photography has revealed the importance of volcanism in the geologic evolution of the cratered terrain hemisphere (generally in the southern hemisphere) of Mars. Volcanic units in this region are classified morphologically into four major units: (1) Patera, comprising 2.37×10^5 km^2 (0.3% of the cratered terrain hemisphere), are large, low profile volcanic structures; some appear to be older shield volcanoes, others apparently represent a unique style of volcanism; (2) 'Plains' volcanics occupy 2.3×10^6 km^2 (2.9% of hemisphere) and represent low volume eruptions that formed cones, low shields and other small scale structures; (3) flood volcanics (3.7×10^6 km^2; 4.7% of hemisphere) are produced by high volume eruptions, post-date the older and more degraded plateau plains, and occur mostly as basin-fill materials; and (4) Plateau plains (28.5×10^6 km^2; 36% of hemisphere), the Martian intercrater plains, contain many wrinkle ridges and floor-fractured craters. The results of this study suggest volcanic processes, as well as erosional processes have been important in the obliteration of small (less than 10 km) craters on Mars and that volcanic products may constitute a significant fraction (up to 44%) of the surface rocks in the cratered terrain.

Hartmann, W. K. (Planetary Science Institute, 2030 East Speedway, Suite 201, Tucson, Ariz. 85719): 'Mars: Topographic Control of Clouds, 1907–1973', *Icarus* 33, 380–387. (1978)

Mariner 9 high-resolution photos and topographic information were used to make a topographic analysis of 'blue' and 'red' cloud positions reported over a 66-year period in Lowell Observatory records. A sample of 77 'blue' cloud sites lay preferentially at the highest Martian elevations; 60% centered precisely on the seven major volcanic mountain peaks (unknown when the clouds were observed); another 16% lay on substantial slopes or contacts between cratered terrain and lower plains. The median altitude of blue cloud sites was 2.1 km *above* the global topographic median. These results agree with other evidence that most Earth-detected blue clouds are orographic uplift clouds, composed of condensates. Over half of 131 sporadic yellowish or red clouds were associated with blue clouds or volcanoes, and thus probably did not represent dust storm phenomena, contrary to a commonly held belief. Of 88 'possible dust clouds' (chosen by additional criteria), about two-thirds occur at borders between light and dark areas, in the light regions. These sites may have thin veneers of dust, and current depositional or denudational activity. Median altitude of 'possible dust cloud' sites was 0.5 km *below* the global topographic median. Major dust storms begin in a few 'core areas', two of which associate with major basins Hellas and Isidis, probable reservoirs of mobile dust; but exact topographic control and causes of dust storms are unclear.

Hartmann, W. K. (Planetary Science Institute, 2030 East Speedway, Suite 201, Tucson, Ariz. 85719): 'Martian Cratering V: Toward an Empirical Martian Chronology, and its Implications', *Geophys. Res. Lett.* 5, 450–452. (1978)

This paper estimates ages of Martian features by dividing least-square-fitted crater densities by an estimated Martian crater production rate. This method is more rigorous than methods based purely on assumptions about correspondence of lunar and Martian cratering rates. Results are interpreted as supporting the conclusion of Burns *et al.* (in press) that Mars shifted climatic states due to a change in obliquity caused by buildup of massive volcanics. Prior to a few g.y. ago, conditions favored erosion, deposition, and fluvial channel formation. Recent volcanics post-date this era, and the surfaces of the major shields are fairly well constrained in age to a few hundred my, in agreement with Masursky *et al.*

Howard, A. D. (Dept. of Environmental Sciences, University of Virginia, Charlottesville, Virginia 22903): 'Origin of the Stepped Topography of the Martian Poles', *Icarus* 34, 581–599. (1978)

The circumpolar stepped topography observed within the Martian polar regions can have originated from one of a limited number of processes, including (i) erosion of resistant layers, (ii) erosion rates inversely proportional to slope gradient, (iii) basal sapping, and (iv) bistable rates of erosion and deposition. The last mechanism appears most likely to operate on the polar escarpments, driven by ablation of volatiles on the dark scarps and deposition on the icy flats. Decreasing albedo and a corresponding increase in radiation input caused by dust accumulations on the ablating layered deposits on steeper slopes provides a metastable erosion rate model sufficient to produce a stepped topography. Wind erosion is presumed later to remove the loose excess residual dust which accumulated during ablation of the scarps. The ablation of the scarps contemporaneously with ice accumulation on the flats implies the layered deposits exposed on the scarps have formed beneath overlying flats, and the observed unconformities within these deposits can be due to the exposure of deposits laid down under more than one flat with different gradients. The linearity and mutual parallelism of the scarps is a result of scarp retreat on a regional slope or with a preferred direction of scarp retreat. The spiral arrangement of the scarps is probably due to more rapid retreat of scarps facing slightly west of the equatorward meridian, that is, in the direction of greatest solar and atmospheric warming. The model suggests, but does not prove, that the layered deposits are mostly water ice, with small amounts of codeposited silicate dust and volcanic ash.

Hunt, G. E. (Department of Physics and Astronomy, University College London, London WC1E 6BT, England), Michael, W. H., Jr., Pascu, D., Veverka, J., Wilkins, G. A., and Woolfson, M.: 'The Martian Satellites – 100 Years On', *R. Astron. Soc. Quart. J.* 19, 90–109. (1978)

During 1877 August, using the 26 in. telescope at the United States Naval Observatory in Washington D.C., Asaph Hall discovered the two tiny satellites of Mars. These unique and therefore important observations were the starting point for studies of the smaller bodies of the solar system.

Although the orbital characteristics of both of the satellites were soon established after their discovery, very little information about the physical properties of these two bodies was obtained before the advent of space exploration nearly a century later. Indeed, since the Earth-based measurements provided observations of the integrated disk, the fundamental questions related to the sizes, shapes and surface characteristics of the satellites could not be discussed.

In recent years, pictures of these satellites have been obtained by Mariner 7 in 1969, by Mariner 9 in 1971/72, and by the two Viking spacecraft starting in the Summer of 1976. The observations, together with other supporting measurements, have provided invaluable information on these tiny objects, and clues to their origin.

In order to celebrate the centenary of the discovery of the Martian satellites by Asaph Hall, who was a Gold Medallist of the Royal Astronomical Society in 1879, and to review our current knowledge of these bodies, the Society held a special meeting on 13 May 1977. This written report contains sections provided by the individual contributors who reviewed our current knowledge of these tiny satellites.

Jobson, D. J. (Flight Electronics Div., NASA Langley Research Center, Hampton, Virginia 23665), Tai, M. H., and Katzberg, S. J.: 'Comment on 'Spectrophotometric and Color Estimates of the Viking Lander Sites', by Friedrich O. Huck *et al.*, *J. Geophys. Res.* 83, 3559–3560. (1978)

An estimate of average spectral reflectance for the surface of Mars in six spectral bands is produced and are compared to Hack's estimates.

Klein, H. P. (NASA-Ames Research Center, Moffett Field, Calif. 94035): 'The Viking Biological Experiments on Mars', *Icarus* 34, 666–674. (1978)

The essential findings of the three biological experiments aboard the two Viking Mars landers are reviewed and compared. All three of the experiments yielded significant data in repeated tests of Martian surface samples. Some of the results are consistent with a biological interpretation, although there are serious reservations in accepting this conclusion. Most of the findings, however, are inconsistent with a biological basis. The combined data suggest the presence of several classes of oxidants on Mars and these would account for most of the observations. An explanation for the apparent small synthesis of organic matter in the pyrolytic release experiment remains obscure.

Lambert, R. St. J. (Dept. of Geology, University of Alberta, Edmonton, Alberta T6G 2E3, Canada) and Chamberlain, V. E.: 'CO_2 Permafrost and Martian Topography', *Icarus* 34, 568–580. (1978)

The role of CO_2 permafrost as an erosive agent on Mars is considered. In the CO_2–H_2O system, with a CO_2 triple point at 217 K and 5.1 bar pressure, carbon dioxide solid, liquid, or gas, CO_2 clathrate, and ice are possible stable phases in the range of temperatures and pressures likely to be encountered in the Martian regolith. It is argued that conditions may exist in which CO_2 permafrost is extensive on Mars, provided that adequate CO_2 is available: the maximum ratio of H_2O:CO_2 required in the subsurface pore space system is 17:3. Erosional processes likely to result from such permafrost are block slumping, leading to canyon development; pit chains along faults; chaotic terrain where massive permafrost destruction has occurred; large-scale flows of slurry; and perhaps even the flash floods which create channels.

Levine, J. S. (NASA Langley Research Center, Hampton, Virginia 23665), McDougal, D. S., Anderson, D. E. Jr., Barker, E. S.: 'Atomic Hydrogen on Mars: Measurements at Solar Minimum', *Science* 200, 1048–1051. (1978)

The Copernicus Orbiting Astronomical Observatory was used to obtain measurements of Mars

Lyman-α (1215.671-angstrom) emission at the solar minimum, which has resulted in the first information on atomic hydrogen concentrations in the upper atmosphere of Mars at the solar minimum. The Copernicus measurements, coupled with the Viking in situ measurements of the temperature (170 ± 30 K) of the upper atmosphere of Mars, indicate that the atomic hydrogen number density at the exobase of Mars (250 kilometers) is about 60 times greater than that deduced from Mariner 6 and 7 Lyman-α measurements obtained during a period of high solar activity. The Copernicus results are consistent with Hunten's hypothesis of the diffusion-limited escape of atomic hydrogen from Mars.

McGetchin, T. R. (Lunar and Planetary Institute, Houston, Tex. 77058) and Smyth, J. R.: 'The Mantle of Mars: Some Possible Geological Implications of its High Density', *Icarus* **34**, 512–536. (1978)

The density of the Martian mantle is estimated to be about 3.55 g cm^{-3} (Reasenberg, 1977). Model mineral assemblages for the Martian mantle (at 30 kbar) were calculated using a modified CIPW norm scheme by adding FeO to model terrestrial mantle compositions. The density of the resulting mineral assemblages vary with increasing FeO content. With pyrolite starting compositions for the terrestrial mantle, the resulting model Martian mantle with density of 3.55 g cm^{-3} is not garnet–lherzolite like the Earth; rather it is an assemblage properly called oxide–garnet wehrlite: oxide (periclase–wüstite) 2%; garnet 11%; olivine 73%; clinopyroxene 12%; with *no* orthopyroxene. Partial melting of such an assemblage would yield iron-rich, ultrabasic lavas, with extremely low viscosities. Specifically, model partial melts, assuming production from the quaternary eutectic (inferred to be near: op_7 g_{42} cpx_{43} ox_8) yields an ultrabasic (SiO_2, 41 to 44%) picritic alkali–basaltic melt (norm composition ne 2.5, plag 32, or 2.4, di 20, ol 37, mt 4.4 and ilm, tr, with a computed viscosity of about 12 P at 1200°C. This model for the composition of the Martian surface lavas (derived from geophysical data and petrologic arguments) is in remarkable agreement with a recently published model by Maderazzo and Huguenin (1977) (derived from reflection spectroscopy, experimental and theoretical models for weathering in the Martian environment). The result also appears to be consistent with recent interpretations (Rasool and Le Sergeant, 1977) of Viking atmospheric chemistry results, namely that the Martian crust is potassium poor. There are a number of geological implications which follow, including (1) superfluid lavas may account for some flood and erosional features observed on Mars; (2) the XRF inorganic chemistry experiment on Vikings 1 and 2 (Baird, 1976) indeed may be measuring compositions approaching primary lavas, contrary to current interpretations which favor a rather mature (weathered) soil; (3) ultrabasic (ferrokimberlitic) ash might be a major constituent of the Martian soil, especially if cosmological models concerning the incorporation of a much volatile material within the early accreting Mars are correct – a matter of current debate; (4) a number of mineral assemblages not previously considered are possible in the Martian mantle depending principally on the activity of volatile substances, (S, O, C, H); it is possible that some very unusual magmas are produced on partial melting; and (5) some ferro–granite melts might be produced by liquid immiscibility.

Morris, E. C. (U.S. Geological Survey, Flagstaff, Ariz. 86001), Jones, K. L., and Berger, J. P.: 'Location of Viking-1 Lander on the Surface of Mars', *Icarus* **34**, 548–555. (1978)

A location of the Viking-1 Lander on the surface of Mars has been determined by correlating topographic features in the lander pictures with similar features in the Viking orbiter pictures. Radio tracking data narrowed the area of search for correlating orbiter and lander features and an areas was found on the orbiter pictures in which there is good agreement with topographic features on the lander pictures. This location, when plotted on the 1:250 000 scale photomosaic of the Yorktown Region of Mars (U.S. Geological Survey, 1977) is at 22.487°N latitude and 48.041°W longitude.

Morrison, N. D. (Joint Institute for Laboratory Astrophysics, University of Colorado, Boulder, Colorado) and Morrison, D.: 'The Mysterious Moons of Mars', *Mercury* **7**, 62–63. (1978)

A review of several papers dealing with Viking observations of Phobos and Deimos is presented.

Nadzhip, A. E.: 'Water Vapor in the Martian Atmosphere Based on the Data of Mars 3, Mariner 9, Mars 5, and Viking 1 and 2', *Cosmic Res.* **15**, 815–817. (1977)

Measurements of the water vapor content in the atmosphere of Mars made between 1971 and 1976 by Mars-3, Mariner-9, Mars-5, and Viking 1 and 2 are discussed. It is concluded that: (a) The most common cause of the variations in water vapor content is the variation in the thermal conditions at the surface and in the lower layer of the atmosphere, both seasonal and diurnal. (b) Differences connected by the relief are superposed on the seasonal and diurnal variations. (c) In some cases peculiarities in the H_2O abundance are observed which do not correlate either with temperature variations or with the relief.

Oyama, V. I. (Ames Research Center, NASA, Moffett Field, Calif.), Berdahl, B. J., Woeller, F., and Lehwalt, M.: 'The Chemical Activities of the Viking Biology Experiments and the Arguments for the Presence of Superoxides, Peroxides, Gamma-Fe_2O_3 and Carbon Suboxide Polymer in the Martian Soil', *Life Science and Space Research* **16**, 3–8. (1978)

The evolution of N_2, Ar, O_2, and CO_2 from Martian soil as a function of humidity in the Gas Exchange Experiment are correlated with the mean level of water vapor in the Martian atmosphere. All but O_2 are associated with desorption. The evolution of oxygen is consistent with the presence of alkaline earth and alkali metal superoxides; and their peroxides and the γ-Fe_2O_3 in the soil can account for the generation of radioactive gas in the Labeled Release Experiment. The slower evolution of CO_2 from both the Gas Exchange Experiment and the Labeled Release Experiment are associated with the direct oxidation of organics by γ-Fe_2O_3. The Pyrolytic Release Experiment's second peak may be carbon suboxide as demonstrated by laboratory experiments. A necessary condition is that the polymer exists in the Martian soil.

We ascribe the activity of the surface samples to the reaction of Martian particulates with an anhydrous CO_2 atmosphere activated by u.v. and ionizing radiations. The surface particles are ultimately altered by exposure to small but significant amounts of water at the sites. From the working model, we have predicted the peculiar nature of the chemical entities and demonstrated that the model is justified by laboratory data. The final confirmation of this model will entail a return to Mars, but the nature and implications of this chemistry for the Martian surface is predicted to reveal even more about Mars with further simulations in the laboratory.

Pham-Van, J. (Centre d'Etudes et de Recherches Geodynamiques et Astronomiques (CERGA), France): 'Mars Observations with Algiers Astrolabe (Winter 1973)', *Astron. Astrophys. Supplement Series* **32**, 325–326. (1978) (in French)

The results of Mars observations with Danjon astrolabe during Winter 1973 at Algiers Observatory are given. Tables contain residuals in zenith distance R, calculated with group corrections, for each transit (East or West), corrections φ_1 and φ_2 for defective illumination, Julian Dates (UT) and the observer's name.

Sanchez, M. (Servicio de Rotacion de la Tierra, Instituto y Observatorio de Marina, San Fernando (Cadiz), Spain): 'Observations of Mars with the Danjon Astrolabe of the San Fernando Observatory', *Astron. Astrophys. Supplment Series* **32**, 331–333. (1978) (in French)

This paper contains the results for Mars observed with the Danjon astrolabe (San Fernando Observatory) through two campaigns (Winter 1973–74 and Winter 1975–76). The zenith distance residuals have been published previously (Bol. Obs. San Fernando 1973, 1976). Tables 1 and 2 give the corrections to the adopted coordinates (*American Ephemeris*) as deduced from the double transits of the planet when observed during the same night. Table 3 gives the same corrections for 1975–76 but referred to the ephemeris for Mars of the US Naval Observatory. The observations have been corrected for defective illumination ($\Delta\alpha_1$, $\Delta\delta_1$, and $\Delta\alpha_2$, $\Delta\delta_2$) according to Débarbat and Guinot (1970). Group corrections have been applied.

Schultz, P. H. (Lunar and Planetary Institute, 3303 NASA Road One, Houston, Tex. 77058): 'Martian Intrusions: Possible Sites and Implications', *Geophys. Res. Lett.* 5, 457–460. (1978)

Both the Moon and Mars exhibit volcanic modification of impact craters characterized by subfloor intrusion that either lift the old crater floor or result in extrusions of lava. Endogenic modification of martian craters, however, probably has involved interactions between such intrusive bodies and permafrost, as suggested by differences between lunar and martian floor-fractured craters. Such interactions raise the interesting possibility for hydrothermally concentrating ores in a manner analogous to the Sudbury structure on the Earth that may be consistent with interpretations of Viking lander results.

Scott, D. H. (U.S. Geological Survey, Flagstaff, Ariz. 86001): 'Mars, Highlands–Lowlands: Viking Contributions to Mariner Relative Age Studies', *Icarus* 34, 479–485. (1978)

Stratigraphic relations between lowland plains and highlands, two major types of Martian geologic-terrain units, were not directly distinguishable on Mariner-9 images. Morphologic characteristics and crater densities suggested that the lava plains beneath their eolian cover were younger than adjacent highland rocks, which form a plateau bounded in many places by highly dissected escarpments. Alternatively, the lowland plains could be the older unit and represent a broad erosional surface exhumed by southward retreat of the highlands along their frontal scarp. Viking photos across five areas of the highland–lowland boundary, however, tend to confirm the younger age of the plains-forming lava flows. A time interval of several hundred million years probably occurred between the retreat of the highland scarp and its latest embayment by lava extrusions in the lowlands.

Shingareva, K. B.: 'Martian Surface Feature Nomenclature', *Cosmic Res.* 15, 792–799. (1977)

We give a brief description of the history of Martian surface feature nomenclature. We emphasize the difference in the designation of albedo details revealed by telescopic observations, and relief details of the Martian surface identified in spacecraft surveys. We give a table containing the Latin and Russian versions of the Martian province names and a geomorphological classification of Martian relief features. We also give the Latin spelling and Russian transcription of the designations made by the International Astronomical Union for different Martian surface features, including craters.

Simpson, R. A. (Center for Radar Astronomy, Stanford, Calif. 94305), Tyler, G. L., and Campbell, D. B.: 'Arecibo Radar Observations of Martian Surface Characteristics Near the Equator', *Icarus* 33, 102–115. (1978)

Mars radar observations at 12.6 cm wavelength indicate that many of what were potential Viking landing sites along the planet's equator are rougher than interpretations of Mariner 9 images suggested. Root mean square surface slopes are typically 5° in the region bounded by 160 and 200°W, 0 and 12°S. From Tharsis Montes west to 160°W, radar-scattering characteristics suggest extreme roughness on small scales, perhaps exceeding 10° in r.m.s. magnitude. East of Tharsis and north of Valles Marineris the surface is smooth, with values of r.m.s. slope as low as 1°; the elevation of this plateau was too high for a Viking landing. Study of spectral shapes indicates the Hagfors scattering law remains the best descriptor of quasi-specular surface scattering properties in an average sense; widespread variations in the surface argue against its indiscriminate use, however. Backscattering at moderate (25–40°) incidence angles was studied qualitatively and was found to be significantly above the level predicted by a strictly quasi-specular (e.g., Hagfors) process; it also is variable over the surface.

Soderblom, L. A. (U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff, Ariz. 86001), Edwards, K., Eliason, E. M., Sanchez, E. M., and Charette, M. P.: 'Global Color Variations on the Martian Surface', *Icarus* **34**, 446–464. (1978)

Surface materials exposed throughout the equatorial region of Mars have been classified and mapped on the basis of spectral reflectance properties determined by the Viking II Orbiter vidicon cameras. Frames acquired at each of three wavelengths (0.45 ± 0.03 μm, 0.53 ± 0.05 μm, and 0.59 ± 0.05 μm during the approach of Viking Orbiter II in Martian summer ($L_s = 105°$) were mosaicked by computer. The mosaics cover latitudes 30°N to 63°S for 360° of longitude and have resolutions between 10 and 20 km per line pair. Image processing included Mercator transformation and removal of an average Martian photometric function to produce albedo maps at three wavelengths. The classical dark region between the equator and ~ 30°S in the Martian highlands is composed of two units: (i) an ancient unit consisting of topographic highs (ridges, crater rims, and rugged plateaus riddled with small dendritic channels) which is among the reddest on the planet (0.59/0.45 μm $\simeq$ 3); and (ii) intermediate age, smooth, intercrater volcanic plains displaying numerous mare ridges which are among the least red on Mars (0.59/0.45 μm $\simeq$ 2). The relatively young shield volcanoes are, like the oldest unit, dark and very red. Two probable eolian deposits are recognized in the intermediate and high albedo regions. The stratigraphically lower unit is intermediate in both color (0.59/0.45 μm $\simeq$ 2.5) and albedo. The upper unit has the highest albedo, is very red (0.59/0.45 μm $\simeq$ 3), and is apparently the major constituent of the annual dust storms as its areal extent changes from year to year. The south polar ice cap and condensate clouds dominate the southernmost part of the mosaics.

Soderblom, L. A. (U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff, Ariz. 86001) and Wenner, D. B.: 'Possible Fossil H_2O Liquid–Ice Interfaces in the Martian Crust', *Icarus* **34**, 622–637. (1978)

Throughout the northern equatorial region of Mars, extensive areas have been uniformly stripped, roughly to a constant depth. These terrains vary widely in their relative ages. A model is described here to explain this phenomenon as reflecting the vertical distribution of H_2O liquid and ice in the crust. Under present conditions the Martian equatorial regions are stratified in terms of stability of water ice and liquid water. This arises because the temperature of the upper 1 or 2 km is below the melting point of ice and liquid is stable only at greater depth. It is suggested here that during planetary outgassing earlier in Martian history H_2O was injected into the upper few kilometers of the crust by subsurface and surface volcanic eruption and lateral migration of the liquid and vapor. As a result, a discontinuity in the physical state of materials developed in the Martian crust coincident with the depth of H_2O liquid–ice phase boundary. Material above the boundary remained pristine; material below underwent diagenetic alteration and cementation. Subsequently, sections of the ice-laden zone were erosionally stripped by processes including eolian deflation, gravitational slump and collapse, and fluvial transport due to geothermal heating and melting of the ice. The youngest plains which display this uniform stripping may provide a minimum stratigraphic age for the major period of outgassing of the planet. Viking results suggest that the total amount of H_2O outgassed is less than half that required to fill the ice layer, hence any residual liquid eventually found itself in the upper permafrost zone or stored in the polar regions. Erosion stopped at the old liquid–ice interface due to increased resistance of subjacent material and/or because melting of ice was required to mobilize the debris. Water ice may remain in uneroded regions, the overburden of debris preventing its escape to the atmosphere. Numerous morphological examples shown in Viking and Mariner 9 images suggest interaction of impact, volcanic, and gravitational processes with the ice-laden layer.

Finally, volcanic eruptions into ice produces a highly oxidized friable amorphous rock, palagonite. Based on spectral reflectance properties, these materials may provide the best analog to Martian surface materials. They are easily eroded, providing vast amounts of eolian debris, and have been suggested as possible source rocks for the materials observed at the Viking landing sites.

Squyres, S. W. (Dept. of Geological Sciences and Laboratory for Planetary Studies, Cornell University, Ithaca, New York 14853): 'Martian Fretted Terrain: Flow of Erosional Debris', *Icarus* **34**, 600–613. (1978)

Viking orbital photographs of two regions of Martian fretted terrain have revealed a number of landforms which appear to possess distinct flow lineations. These range from valley floors with lineations which parallel the valley walls to debris aprons with distinctly lobate profiles and lineations which radiate outward from the source area. These features are attributed to the deformation and flow of a mass consisting of erosional particles and ice incorporated from the atmosphere. Such a flow should behave much like a terrestrial rock glacier. A plastic deformation model is presented which is consistent with the known mechanical properties of rock glaciers and with the observed features of the landforms. The valley floor lineations are interpreted as being due to compressional forces resulting from debris flowing inward from the valley walls. Climatic implications of the features are discussed.

Thomas, P. (Laboratory for Planetary Studies and Dept. of Geological Sciences, Cornell University, Ithaca, New York 14853), Veverka, J., and Duxbury, T.: 'Origin of the Grooves on Phobos', *Nature* 273, 282–284. (1978)

It is suggested that the grooves of Phobos are the results of the impact event which formed crater Stickney.

Toksöz, M. N. (Dept. of Earth and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, Mass. 02139) and Hsui, A. T.: 'Thermal History and Evolution of Mars', *Icarus* **34**, 537–547. (1978)

A theoretical thermal evolution model of Mars is constructed, utilizing as constraints the available geophysical and geological data, including those provided by the Viking missions. The calculation includes conduction and subsolidus mantle convection. Calculated models indicate that Martian evolution can be roughly characterized by four different stages. (1) Core formation and crust differentiation: this stage starts from the planet formation to about 1 by thereafter. During this period, Martian core is separated and the initial crust is differentiated. (2) Heating, expansion, and mantle differentiation: this stage begins after the core separation and extends to about 3 by. First, mantle temperatures rise and reach partial melting. Between 2 and 3 by, extensive melting, differentiation, and outgassing occur. Planetary radius increases and extensional features observed at the surface are most likely generated at this stage. (3) Mature phase: after 3 by, the planet reaches maturity. Between 3 and 4 by slow and sustained evolution continues. Lithosphere thickness and partial melt zone deepens. (4) Cooling period: this stage represents the last phase of Martian history. The planet is cooling slowly. The partial melting zone shrinks and volcanic activity tapers off. At present, Martian lithosphere is about 200 km thick and the mantle is convecting slowly. The models suggest that the core is molten, and the calculated surface heat flux is 35 erg cm^{-2} s^{-1}.

Tucker, R. B. (NASA, Langley Research Center, Langley, Virginia): 'Viking Lander Imaging Investigation: Picture Catalog of Primary Mission Experiment Data Record', NASA-RP-1007, N78-20042. 1978. pp. 514. Available National Technical Information Service as N78-20042; paper copy $15.25; microfiche $3.00.

All the images returned by the two Viking landers during the primary phase of the Viking Mission are presented in this report. Listings of supplemental information which describe the conditions under which the images were acquired are included together with skyline drawings which show where the images are positioned in the field of view of the cameras. Subsets of the images are listed in a variety of sequence to aid in locating images of interest. The format and organization of the digital magnetic tape storage of the images are described. A brief description of the mission and the camera system is also included.

Turner, R. J. (Rock Creek Experimental Station, Route 2, Box 167, Sheridan, Oregon 97378): 'A Model of Phobos', *Icarus* **33**, 116–140. (1978)

A model of the Martian satellite Phobos was constructed at a scale of 1:60 000 using 25 Mariner 9 photorecords and a solar-simulation technique. Measurements of the center diameters D, depths d, ratios d/D, longitude and latitude locations of the centers, IAU designations, crater shapes, and rim class are given in a catalog of 260 depressions. An open-ended indexing of the craters is based on their locations by octant and diameter magnitude. Six craters were found with sharply defined rims. At least 28 craters have raised rims. The range of the d/D ratios is from 0.002 to 0.26, with a mean d/D of 0.10. The mean diameter of Stickney is interpreted to be 11.1 km, its minimum 9.6 km, and the diameter of Hall 5.9 km. A 100 m contour-interval topographic map has been drawn from measurements of the model. This is rendered on an elliptical form of a Lambert equal-area polar projection. The topographic map made it possible to estimate vector lengths from the center to Phobos to vertices on a 6-frequency octahedron that fits the satellite. A mean radius of 11.0 km results from averaging the vector lengths to the 146 well-distributed vertices of the polyhedron. A volume of 5620 km^3 is deduced.

Veverka, J. (Cornell University, Ithaca, New York), Thomas, P., and Duxbury, T.: 'The Puzzling Moons of Mars', *Sky and Telescope* **56**, 186–189. (1978)

The surface formations of Phobos and Deimos are discussed.

Yanagita, S. (Cosmic Ray Laboratory, University of Tokyo, Tanashi, Tokyo 188, Japan) and Imamura, M.: 'Excess ^{15}N in the Martian Atmosphere and Cosmic Rays in the Early Solar System', *Nature* **274**, 234–235. (1978)

The necessary cosmic ray flux, required to explain the excess ^{15}N in the Martian atmosphere, is estimated.

Yung, Y. L. (California Institute of Technology, Pasadena, Calif. 91125) and Pinto, J. P.: 'Primitive Atmosphere and Implications for the Formation of Channels on Mars', *Nature* **273**, 730–732. (1978)

The possibility of formation of the martian channels by low viscosity fluids, product of polymerisation of the planet's primitive methane atmosphere by solar ultraviolet radiation, is discussed.

MERCURY

Eberhart, J.: 'Old Bottle, New Wine', (Mercury nomenclature), *Science News* **113**, 330–331. (1978)

Antoniades mapped and named brightness features on Mercury nearly half a century ago. Now his names have been made official – even though his map was wrong.

Melosh, H. J. (Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, Calif. 91125) and Dzurisin, D.: 'Tectonic Implications for the Gravity Structure of Caloris Basin, Mercury'.

Studies of tectonic landforms associated with Caloris Basin on Mercury suggest that isostatic adjustment has occurred in response to basin excavation, and that the smooth plains inside Caloris were emplaced significantly before isostatic equilibrium was attained. Combined with dynamical considerations, this leads us to propose that the Caloris region is characterized by a circular negative or zero free air gravity anomaly centered inside Caloris, and an annular positive anomaly which coincides with extensive tracts of young smooth plains outside the basin. This proposed gravity pattern differs markedly from that associated with mare-filled basins on the Moon.

Ness, N. F. (Laboratory for Extraterrestrial Physics, NASA Goddard Space Flight Center, Greenbelt, Maryland 20771): 'Mercury: Magnetic Field and Interior', *Space Sci. Rev.* **21**, 527–553. (1978)

Between 1965 and 1975, our knowledge of Mercury and its physical characteristics improved dramatically. Radar studies of the planetary orbit and rotation rate and Mariner-10 spacecraft studies of its surface, atmosphere, magnetic field and plasma environment provided startling new results on what had been the least understood member of the terrestrial planets. With a highly cratered surface and a modest magnetic field, Mercury is a differentiated planet with fractionally the largest iron core of all.

Smith, G. R. (Kitt Peak National Observatory, Tucson, Ariz. 85726), Shemansky, D. E., Broadfoot, A. L., and Wallace, L.: 'Monte Carlo Modeling of Exospheric Bodies: Mercury', *J. Geophys. Res.* **83**, 3783–3790. (1978)

Previous model calculations of the helium exospheres of Mercury and the Moon have been based on a regime in which each helium atom impact with the surface results in the selection of a new particle chosen from a given source distribution. The particular velocity space distribution in the source particles was chosen with the implied intent that the resulting atmosphere would be barometric under ideal conditions. In effect, two particle source distributions have been used in the published calculations, which we describe here as Maxwell–Boltzmann (M–B), and Maxwell–Boltzmann flux (M–B–F). In the instances in which the atmospheric distribution has been calculated for regions above the surface, the resulting model atmosphere represents a mixture of the M–B and M–B–F sources. We suggest that none of the published exospheric calculations for the two bodies represent atmospheres produced by a barometric source of particles. Although a barometric source of particles cannot be justified in terms of surface physics, an exosphere produced by such a source is a valuable point of reference for calculations based on more realistic conditions. According to the analysis presented below, the appropriate source distribution should be M–B–F if the particle in the distribution are to be treated as components of flux. Monte Carlo calculations with an M–B–F source are compared with Mariner-10 ultraviolet spectrometer data. The comparison suggests that present models are incapable of fitting the observed Mercury exosphere.

SATURN

Bobrov, M. S. (Astronomical Council, Academy of Sciences USSR): 'Apparent and True Thickness of Saturn's Rings', *Solar System Res.* **12**, 27–34. (1978)

The reader's attention is called to the difference between the apparent thickness of Saturn's rings as seen edge-on $z_{0\text{app}}$ and the true thickness $z_{0\text{tr}}$ in a region small in comparison to the rings' radial width. It is shown that the magnitude of $z_{0\text{app}}$ is determined by the amplitude of wavelike ring deformation, which is produced by long-period gravitational perturbations of the inclinations of the orbits of the ring particles by Saturn's satellites. As for $z_{0\text{tr}}$, compelling evidence of the significant contribution of multiple scattering to the radiation reflected Earthward by the rings in both the visible and radio ranges is indicative of a system many particles thick, i.e., $z_{0\text{tr}} \gg \bar{\rho}$, where $\bar{\rho}$ is the mean particle radius.

Bobrov, M. S. (Astronomical Council, USSR Academy of Sciences, Pyatnitskaya 48, Moscow 109017, USSR): 'Major Satellites Cause Wavy Deformation of Saturn's Rings', *Nature* 273, 284–285. (1978)

It is shown that, allowing for gravitational perturbations of particle orbits by satellites and oblateness of Saturn, one may obtain a model satisfying the observational data, according to which the thickness of Saturn's rings appears to be several orders of magnitudes greater than expected.

Cuzzi, J. N. (Theoretical and Planetary Studies Branch, Space Science Division, Ames Research Center, NASA, Moffett Field, Calif. 94035) and Pollack, J. B.: 'Saturn's Rings: Particle Composition and Size Distribution as Constrained by Microwave Observations 1. Radar Observations', *Icarus* **33**, 233–262. (1978)

We have calculated the radar backscattering characteristics of a variety of compositional and structural models of Saturn's rings and compared them with observations of the absolute value, wavelength dependence, and degree of depolarization of the rings' radar cross-section (reflectivity). In the treatment of particles of size comparable to the wavelength of observation, allowance is made for the nonspherical shape of the particles by use of a new semiempirical theory based on laboratory experiments and simple physical principles to describe the particles single scattering behavior. The doubling method is used to calculate reflectivities for systems that are many particles thick using optical depths derived from observations at visible wavelengths. If the rings are many particles thick, irregular centimeter- to meter-sized particles composed primarily of water ice attain sufficiently high albedos and scattering efficiencies to explain the radar observations. In that case, the wavelength independence of radar reflectivity implies the existence of a broad particle size distribution that is well characterized over the range $1 \text{ cm} \lesssim r \lesssim 1 \text{ m}$ by $n(r)\, dr = n_0 r^{-3}\, dr$. A narrower size distribution with $\bar{a} \sim 6$ cm is also a possibility. Particles of primarily silicate composition are ruled out by the radar observations. Purely metallic particles, either in the above size range and distributed within a many-particle-thick layer or very much larger in size and restricted to a monolayer, may not be ruled out on the basis of existing radar observations. A monolayer of very large ice 'particles' that exhibit multiple internal scattering may not yet be ruled out. Observations of the variation of radar reflectivity with the opening angle of the rings will permit further discrimination between ring models that are many particles thick and ring models that are one 'particle' thick.

Dunham, D. W. (Computer Sciences Corporation, Silver Spring, Maryland 20910) and Elliot, J. L.: 'Lunar Occultation of Saturn. IV. Astrometric Results from Observations of the Satellites', *Icarus* **33**, 311–318. (1978)

The method of determining local lunar limb slopes, and the consequent time scale needed for diameter studies, from accurate occultation timings at two nearby telescopes is described. The results for the photoelectric observations made at Mauna Kea Observatory during the occultation of Saturn's satellites on March 30, 1974, are discussed. Analysis of all observations of occultations of Saturn's satellites during 1974 indicates possible errors in the ephemerides of Saturn and its satellites.

Fink (Lunar and Planetary Laboratory, University of Arizona, Tucson, Ariz. 85721) and Larson, H. P.: 'Deuterated Methane Observed on Saturn', *Science* **201**, 343–345. (1978)

Absorptions for the ν_2 band of deuterated methane (CH_3D) have been observed in the 5 μm spectrum of Saturn, obtained with a Fourier transform spectrometer. Analysis of the band yields a CH_3D abundance of 2.6 ± 0.8 centimeter-amagat and a temperature of 175 ± 30 K for the mean level of spectroscopic line formation. This temperature indicates that a substantial portion of Saturn's flux at 5 μm is due to thermal radiation, and that we are therefore looking fairly deep into its atmosphere, as is the case for the Jupiter 5 μm window. This CH_3D abundance leads to a deuterium/hydrogen ratio of about 2×10^{-5} in Saturn's atmosphere. This ratio is much lower than the terrestrial value but comparable to that determined for Jupiter and may be taken as representative of the deuterium/hydrogen ratio in the solar system at the time of its formation.

Franklin, F. A. (Center for Astrophysics, Harvard College Observatory and Smithsonian Astrophysical Observatory, Cambridge, Mass. 02138) and Colombo, G.: 'On the Azimuthal Brightness Variations of Saturn's Rings', *Icarus* **33**, 279–287. (1978)

We present a simple, semiquantitative explanation that accounts both for the presence of the azimuthal brightness variations in Saturn's ring A and for their absence in ring B. Our explanation avoids any ad hoc reliance on albedo variations and/or synchronous rotation of ring particles. Instead, it requires only some degree of self-gravitation between nearby orbiting bodies. A bias in the particle distribution and corresponding photometric effects are thereby produced – the latter corresponding very closely to the variations observed in ring A. Their absence in ring B is primarily a consequence of the higher optical thickness and decreasing importance of self-gravitation in that ring.

Goldreich, P. (California Institute of Technology, Pasadena, Calif. 91125) and Tremaine, S.: 'The Formation of the Cassini Division in Saturn's Rings', *Icarus* **34**, 240–253. (1978)

The satellite Mimas excites a trailing spiral density wave in Saturn's rings at the position of the 2:1 resonance. The density wave carries negative angular momentum and propagates outward. The wave is damped by a combination of nonlinear and viscous effects, and its negative angular momentum is transferred to the ring particles. Consequently, the particles just outside the 2:1 resonance spiral inward, opening a gap. The inner edge of the gap is close to the resonance position in agreement with the location of the inner edge of the Cassini division. Despite its tiny mass, Mimas is able to clear a gap as wide as the Cassini division. We estimate the ability of Saturn's satellites to open other gaps in the rings. The upper limit to the width of Encke's division implies that the velocity dispersion of the ring particles is $< 10^{-2}$ cm s^{-1}.

Goldreich, P. (California Institute of Technology, Pasadena, Calif. 91125) and Tremaine, S.: 'The Velocity Dispersion in Saturn's Rings', *Icarus* **34**, 227–239. (1978)

The velocity dispersion in a differentially rotating disk of particles such as Saturn's rings is determined by the details of the collision process. Collisions give rise to a viscous stress that converts orbital energy into random motions. Since the collisions are not perfectly elastic, the energy in random motions is dissipated as heat. With increasing velocity dispersion the latter process becomes more important relative to the former because the collisions become less elastic. The velocity dispersion adjusts so that the effects of these two processes balance. The condition for this balance fixes the coefficient of restitution ϵ of the colliding particles as a function of the disk's optical depth τ. We solve the Boltzmann moment equations to determine $\epsilon(\tau)$. If the rings are about as old as the solar system then their radial width implies that the velocity dispersion of the ring particles is less than 0.2 cm s^{-1}. The corresponding vertical thickness is then less than 10 m. We discuss the effects of collisions on the particles in Saturn's rings. If the particles are made of ice they are eroded by collisional debris. The time scale for erosion and accretion is probably shorter than the age of the solar system. Furthermore, for ice particles ϵ is likely to be substantially less than unity even at impact velocities as low as 10^{-3} cm s^{-1}. Thus, a ring of ice particles would be a monolayer thick.

Janssen, M. A. (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, Calif. 91103) and Olsen, E. T.: 'A Measurement of the Brightness Temperature of Saturn's Rings at 8 mm Wavelength', *Icarus* **33**, 263–278. (1978)

We have measured the brightness temperature of Saturn's rings at 8 mm wavelength using the millimeter-wavelength interferometer at the Jet Propulsion Laboratory's Table Mountain Observatory. We obtain for the ring brightness temperature $T_R = 12.7 \pm 2$ K, with the assumption that the rings are of uniform brightness and the region of emission coincides with the visible A and B rings. This result is higher than comparable results obtained at centimeter wavelengths and may indicate a small increase in the thermal emission from the rings at 8 mm. The low brightness temperature places significant constraints on the nature of the ring particles, and implies that they must be either highly metallic or of limited size and composed of a low-loss dielectric material such as water ice.

Lumme, K. (Observatory and Astrophysics Laboratory, University of Helsinki, Helsinki, Finland) and Reitsema, H. J.: 'Five-Color Photometry of Saturn and Its Rings', *Icarus* **33**, 288–300. (1978)

Analysis of 206 high-quality plates from three recent apparitions taken in five colors has yielded several photometric parameters for Saturn and its A and B rings. Phase curves and geometric albedos are derived for two regions on Saturn and for each ring. The phase coefficients of the rings are found to be independent of the ring–plane inclination angle. A comparison of the phase curves shows that the particles of ring A exhibit a larger phase coefficient than do those of ring B. When examined with a multiple-scattering model using Henyey–Greenstein phase functions, the observations of the ring tilt effect indicate that the particles of ring A may also have lower single-scattering and geometric albedos. The color dependence of the geometric albedo of the particles in ring B is shown to be very similar to that of Europa (J II). We find for ring A an optical thickness of 0.50 ($0.45 \leqslant \tau_A \leqslant 0.57$) and for the Cassini division, 0.018 ± 0.004.

Meyer, F. (Centre d'Etudes et de Recherches Géodynamiques et Astronomiques (CERGA), France) and Pham-Van, J.: 'Observations of Saturn with the Astrolabe of the Algiers Observatory During the Years 1969–1974', *Astron. Astrophys. Supplement Series* **32**, 327–330. (1978) (in French)

This paper contains the results of the five campaigns of Saturn at the Algiers Observatory. 66 East and West transits were observed.

Podolak, M. (Department of Geophysics and Planetary Sciences, Tel-Aviv University, Ramat-Aviv, Israel): 'Models of Saturn's Interior: Evidence for Phase Separation', *Icarus* **33**, 342–348. (1978)

Models of Saturn's interior have been constructed based on an accumulation picture of planet formation. It was found that central pressures were ~ 99 Mb, and central temperatures ~ 10^4 K. In sharp contrast to Jupiter, which requires large amounts of heavy material in the envelope to match the observed gravitational quadrupole moment, Saturn requires an almost solar envelope. Indeed, the ratio of enhanced material in the envelope to material in the core is less than ~ 0.1, while the corresponding value for Jupiter is ~ 2.

Smoluchowski, R. (Dept. of Astronomy and Physics, University of Texas, Austin, Tex 78712): 'Width of a Planetary Ring System and the C-ring of Saturn', *Nature* 274, 669–670. (1978)

The structure and dynamics of Saturn's C-ring is discussed.

Veverka, J (Laboratory for Planetary Studies, Cornell University, Ithaca, New York 14853), Burt, J., Elliot, J. L , and Goguen, J.: 'Lunar Occultation of Saturn, III. How Big is Iapetus?', *Icarus* 33, 301–310. (1978)

By considering both the orbital lightcurve of Iapetus and data obtained during the March 30, 1974, occultation of the satellite by the Moon, we obtain information about the brightness distribution on the bright face of Iapetus and derive an accurate value for the satellite's radius. From the observed orbital lightcurve we find that the trailing face of Iapetus must consist predominantly of a single bright material with an effective limb-darkening parameter of $k = 0.62^{+0.10}_{-0.12}$. Given this result the occultation observations imply a radius of 718^{+87}_{-78} km. If the patchy albedo model proposed by Morrison *et al.* represents the surface of Iapetus accurately (as far as the relative albedo distribution is concerned) then the radius of Iapetus is 724 ± 60 km. Both estimates are consistent with the radiometric radius of 835 (+ 50, − 75) km derived by Morrison *et al.* Combining our results with the value of 0.60 ± 0.14 for the normal reflectance (in V) of the material at the center of the bright face derived by Elliot *et al.* we find that the normal reflectance of the dark side material is $0.11^{+0.04}_{-0.03}$. These values are higher than the corresponding values of 0.35 and 0.05 quoted by Morrison *et al.*

[Editorial Note: This bibliography is to be concluded in the next issue of *The Moon and the Planets.*]