BIBLIOGRAPHY

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4. SATELLITES OF JUPITER

Greenberg, R. (University of Arizona, Tucson, AZ 85721): 'Time-Varying Orbits and Tidal Heating of the Galilean Satellites', NASA Special Publication Series, NASA-SP-494 (1989), 100–115.

The rapid heat loss from Io due to tidal heating would have quickly damped Io's orbital eccentricity were it not for the Laplace resonance with Europa and Ganymede, which continually pumps the eccentricity. Energy for the on-going heat loss must come from Io's orbit, ending to reduce the semimajor axis and accelerate the mean motion n. That orbital evolution is modified by (1) interchange of energy among the resonant satellites and (2) the unknown rate of energy and angular momentum transported from jovian rotation to Io's orbit due to tidal processes in Jupiter. Most physical models of Jupiter suggest the second source of modification would be negligible. In that case, the Io dissipation rate of 7×10^{13} W (McEwen *et al.*, 1985) would correspond to rapid shrinking of Io's orbit at rate $dn/dt \sim (3 \times 10^{-10})\, n\, \mathrm{yr}^{-1}$. Moreover, the system would be evolving, outward from deep resonance, with much greater ideal heating only 10^7 years ago (Greenberg, 1987). In contrast, a model with modification 2 sufficient that the system is a an equilibrium depth in resonance (Yoder, 1979) gives orbital expansion at rate $dn/dt \sim -10^{-10}\, n\, \mathrm{yr}^{-1}$. Either value would shift Io-eclipse times by several minutes over the 300 years of observations. From historical data, Goldstein and Jacobs (1986) found dn/dt near the large positive rate above, but I find that result flawed, due primarily to an incorrect radius assumed for Jupiter as well as aliasing and clock correction problems. Lieske (1987a) finds much slower dn/dt, which implies significant tides on Jupiter, but evolution still outward from resonance, contrary to the equilibrium model. However, Lieske's comparison with Europa's acceleration supports the equilibrium model. This conflict would be resolved, and the equilibrium model preserved, if the typical dissipation rate in Io over the past 300 years were an order of magnitude smaller than the present thermal radiation rate.

Howell, R. R. and Sinton, W. M. (University of Wyoming, Laramie, WY 82071): 'Io and Europa: The Observational Evidence for Variability', NASA Special Publication Series, NASA-SP-494 (1989), 47–62.

Observations of Io show variability over a wide range of wavelengths and time scales. The early reports of posteclipse brightening were largely responsible for focusing attention on this satellite. Alhough no such brightenings have been seen for the past decade, the original reports may have been accurate.

and if so they indicate long-term changes in Io's atmosphere and volcanic activity. The observation of infrared outbursts from Io were direct detections of volcanic activity, although they were not recognized as such until after the Voyager mission. Studies of the infrared flux from Io let us monitor the volcanic activity, and recently developed "high-resolution" techniques let us study individual active regions and eruptions. These techniques show that Loki is still active seven years after the Voyager encounter. However, a recent analysis of eclipse data over that time suggests that its thermal output is declining. Observations have also shown high-temperature, short-lived eruptions taking place in regions that showed no activity during the Voyager encounters. Finally, the discovery that most of the heat flow comes from just one or two active regions on Io suggests that we should expect fluctuations in total output by roughly a factor of two as these active regions die out and new ones are born. The long-term average heat flow may in fact be consistent with the predictions of equilibrium ideal dissipation theories. Europa clearly does not show the level of activity that is present on Io, but some unconfirmed evidence of activity has been reported, and is discussed in this review.

Ingersoll, A. P. (Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125): 'Io Meteorology: How Atmospheric Pressure is Controlled Locally by Volcanoes and Surface Frosts', *Icarus* **81** (1989), 298–313.

The hydrodynamic model of A. P. Ingersoll, M. E. Summers, S. G. Schilpf, 1985, *Icarus* **64**, 375–390 is modified to include the effects of nonuniform surface properties as revealed in recent observational studies. The observations indicate that SO_2 frost is concentrated in a band within 30° latitude of the equator covering 270° of longitude, and that the darker surface at midlatitude is warmer than the frost at times of maximum insolation. The approach to the hydrodynamics has been to make the model simpler and more versatile. Solutions are now obtained in closed analytic form. We calculate atmospheric pressures, horizontal winds, sublimation rates, and condensation rates for a wide variety of surface conditions – patchy and continuous frost cover, volcanic venting (treated as a source of mass distributed over the plume area), discontinuities of surface temperature, subsurface cold trapping, and insolation propagation into the frost. The principal new concept is the horizontal averaging length L, which is equal to $\sqrt{2\pi}H/\alpha$ where H is the atmospheric scale height and α is the sticking coefficient. If frost is present, either on the surface or just below it, then each area of dimension L (of order 100 km) determines its own atmospheric pressure. Away from the volcanic plumes, the pressure follows the local vapor pressure. Inside the plumes the pressure is higher, e.g., a volcanic source of 10^6 kg/sec spread over an area 300 km in radius raises the local pressure by an amount equal to the vapor pressure of a frost at 124 K. The key unknowns for Io are the strength of the volcanic sources and the temperature of frost near the subsolar point. If the frost is cold (below 110 K) then the only substantial atmospheres are beneath the plumes. If the frost is warm (e.g., 125 K) then there is also a substantial atmosphere near the subsolar point. The equatorial frost deposits are then losing net mass at a substantial rate (e.g., 0.1 cm/year for a subsolar frost temperature of 125 K).

Johnson, R. E. (Department of Nuclear Engineering and Engineering Physics University of Virginia VA 22903): 'Plasma Ion Heating of an SO_2 Atmosphere on Io', *Geophys. Res. Letters*, **16** (1989), 1117–1120.

The Jovian plasma ion heating of any atmospheric gas over Io is known to be important for determining the temperature structure and the location of the exobase and for limiting diffusive separation in Io's atmosphere. This is used, along with the plasma supply rate, to estimate an average column of gas over the trailing hemisphere of $\sim 3 \times 10^{16}$ So_2/cm^2 with exobase at $\sim 1.4\ R_{Io}$.

Lunine, J. I. (Lunar and Planetary Laboratory, Tucson, AZ 85721): 'Sulfur Lakes and Silivate Flow: Thermal Emission from Io's Hot Spots', NASA Special Publication Series, NASA-SP-494 (1989), 63–70.

A series of models are constructed to simulate the brightness temperature and size of the Loki hot spots, at several infrared wavelengths, using kinetic temperature distributions for molten sulfur lakes and silicate flows. The physical models for the sulfur and silicate systems have been published; however, the simulations described in this chapter are new. We show that ground-based observations capable of resolving area and brightness temperature at two wavelengths are diagnostic of the physical mechanisms and materials radiating energy away from the Loki region. The mutual events data obtained in 1985 yield a brightness temperature and area for the Loki hot spot at 3.8 μm (Gopuen *et al.*, 1987). For the derived hot-spot area, the brightness temperature agrees with Carr's (1986) silicate-flow model or a sulfur-lake model with lake temperature elevated by 20 K since the Voyager flybys. However, the spot area itself is somewhat larger than either simulation would predict, and is smaller than that predicted by the simple three-temperature fit to the Voyager infrared interferometric spectrometer (IRIS) data of Pearl and Sinton (1982). The effect on the infrared spectrum of changes in thermal output of Loki is explored for the case of the sulfur-lake model.

McEwen, A. S., Lunine, J. I. and Carr, M. H.: (U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff, AZ 86001): 'Dynamic Geophyics of Io', NASA Special Publication Series, NASA-SP-494 (1989), 11–46.

Numerous volcanic eruptions and hot spots show that Io is the most geologically active solid body known in the solar system. The resurfacing rate is remarkably high; as much as 10 cm yr^{-1} is the global average. Surface landforms include calderas, mountains, shield volcanoes, plateaus, flows, grabens, and eroded scarps. The bulk density and topographic relief suggest a dominantly silicate composition, but spectral observations indicate that the surface is covered by SO_2 and other sulfurous materials. The lithosphere is probably more than 302 km thick under regions showing substantial relief. Io's volcanism is most likely powered by tidal heating mechanisms that also differentiated the satellite and drove volatiles to the surface. All recent models place the tidal heating below the lithosphere; disagreement exists, however, as to whether the heating is episodic over geologic time. Active volcanic plumes are of two types. The Prometheus type, concentrated within 30 degrees of the equator, is relatively small (~100 km high) and of long duration (months to years), producing bright halo deposits 200–600 km in diameter. The Pele-type, concentrated in the region from longitude 240° to 360°, is large (~300 km high) and of short duration (days to months), depositing relatively dark and reddish materials over areas of 1000–1500 km diameter. The Prometheus-type plumes are probably driven by SO_2 vapor from reservoirs near 400 K, whereas the Pele-type plumes may be driven by sulfur vapor from reservoirs near 1000 k. The hot spots on Io correspond to low-albedo areas, usually on the floor of calderas. Hot-spot temperatures generally range from 200 to 400 K, and the radiation may be due to convecting sulfur lakes with rapid evaporative outflow or to cooling silicate lavas.

Medina, F., Echevarria, J., Ledezma, E. and Martinez, F. (Instituto de Geofisica, Universidad Nacional Autonoma de Mexico, Apartado Postal 2681, Ensenada, Baja California, 22800 Mexico): 'Infrared Observations of Io during the Mutual Events of 1985: Evidence of Volcanic Activity?', *Astron. Astrophys.* **220**, 313–317.

IR observations of Io were made during the 1985 mutual events. Anomalous flux variations were observed during a partial eclipse of Io by Ganymede and a total eclipse of Io by Callisto; anomalies which are interpreted as occultations of active hot spots on Io. Possible identifications with well known features are discussed. These include active places like Loki Patera, as well as inactive regions at the time of the Voyager encounters but where pyroclastic deposits have been found.

Murchie, S. L. and Head, J. W. (Department of Geological Sciences, Brown University, Providence, Rhode Island 02912): 'Crater Densities and Crater Ages of Different Terrain Types on Ganymede', *Icarus* **81** (1989), 271–297.

Crater densities and size-frequency distributions on Ganymede were measured for separate areas of dark furrowed and dark smooth terrains, reticulate terrain, complex grooved terrain, and groups of grooved polygons and groove lanes having a variety of relative ages. These measurements were used first, together with results of previous studies, to test alternate models of heliocentric and planetocentric crater-forming bombardments of Ganymede and Callisto. The spatial distribution of crater production functions on Ganymede is consistent with a single impactor population having dominated cratering of that satellite's observed surface. In addition, relative crater ages of different Ganymedean material deposits are better reconciled with the deposits' stratigraphic relations if a heliocentric impactor population is assumed. These results are consistent with results of previous studies, interpreted here to indicate that the spatial distributions of most classes of craters on Ganymede and younger craters on Callisto are more consistent with heliocentric than with planetocentric bombardment The measurements were then used to infer the sequence and style of surface modification of Ganymede; bounds on absolute ages depend on the assumption of heliocentric bombardment. Dark terrain was emplaced during a prolonged period of volcanic resurfacing of older, heavily cratered terrain, probably at least 10^8 yrs in duration and at least 3.8–4.0 Gyr ago. Furrows generally formed on blanket-like deposits of dark material, typically hundreds of meters or more in thickness, soon after their emplacement; furrow formation continued globaly throughout the period of dark-material deposition. Next, dark terrain was deformed locally by reticulate terrain formation. Light terrain emplacement subsequently began, at least regionally within "complex grooved terrain." It continued for an extended period (perhaps several times 10^8 yrs) in groove lanes, grooved polygons, and smooth terrain, where a light-material layer averaging several hundred meters or more in thickness was emplaced.

Ojakangas, G. W. and Stevenson, D. J. (Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125): 'Thermal State of an Ice Shell on Europa', *Icarus* **81** (1989), 220–241.

We consider a model of Europa consisting of an ice shell that is decoupled from a silicate core by a layer of liquid water. The thickness of the shell is calculated as a function of colatitude and longitude, assuming that a state of conductive equilibrium exists with the incident annual average solar insolation, tidal dissipation within the shell, and heat flow from the core. Ice thickness profiles are calculated for each of two plausible rheological behaviors for ice: the Maxwell rheology and the generalized flow law rheology. In both cases the strong temperature dependence of the dissipation rate, as well as the temperature dependence of the thermal conductivity of ice, is explicitly included. Because of the strong temperature dependence of the dissipation rate, nearly all of the tidal dissipation is concentrated in the lowermost few kilometers of the shell. Even though the effective Q of the greater part of the shell is $\gg 100$ in our models, average shell thicknesses do not exceed 25 km. Thus, if the total thickness of H_2 which mantles Europa is $\gtrsim 25$ km, none of our models admits the possibility of a completely frozen H_2O layer, although such a state cannot be entirely ruled out, because the rheology of ice at the low tidal frequency has not been directly measured. The total dissipation rates in our models are comparable to those of a constant Q model with $Q \sim 10$. Average thickness profiles are relatively insensitive to heat flow from the core. The second-degree spherical harmonic components of the ice thickness are given and the resulting contributions to the quantities $(B-A)/C$ and $(B-C)/A$ of Europa are estimated. Although the contribution to $(B-A)/C$ is perhaps larger than the permanent value needed to prevent nonsynchronous rotation, its dependence on the shell's orientation relative to synchroneity suggests that very slow nonsynchronous rotation will persist, with reorientation of the shell relative to the satellite-planet direction occurring on a time scale greater than or approximately equal to the thermal diffusion time scale for the shell ($\sim 10^7$ years). The existence of a significant "fossil" bulge on the shell due to long-term elastic behavior of its outer, coldest regions would eliminate nonsynchronous rotation. Since the contribution to $(B-C)/A$ of the thickness variations in most of our models is >0, Europa's shell may experience large-scale polar wander as thermal equilibrium is approached, if the above is the most important permanent contribution to $(B-C)/A$. For some parameter choices, the presence of an insulating regolith that raises the near-surface temperature by more than a few tens of degrees may stabilize the shell against polar wander by reducing thickness variations; yet a modest regolith may enhance the likelihood of polar wander (G. W. Ojakangas and D. J. Stevenson 1989,

Icarus **81**, 242–270) by reducing retarding friction within the shell. The magnitudes of the principal moment differences are insensitive to the details of the parameterization of the tidal dissipation.

Ojakangas, G. W. and Stevenson, D. J. (Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125): 'Polar Wander of an Ice Shell on Europa', *Icarus* **81** (1989), 242–270.

An ice shell on Europa that is decoupled from the silicate core by a layer of liquid water has a thermal-equilibrium thickness profile that varies with position over its surface because of spatial variations in the surface temperature and tidal dissipation within the ice (G. W. Ojakangas and D. J. Stevenson (1989), *Icarus* **81**, 220–241). The second spherical harmonic degree components of these thickness variations and of any fossil rotational and tidal bulges present on the shell contribute to the inertia tensor of the body. The problem is that of a planetary elastic lithosphere that is topographically loaded from below. Following R. J. Willemann and D. L. Turcotte (1981, *Proc. Lunar Planet. Sci. B* **12**, 837–851), we develop equations describing the variatious in the inertia tensor of a body when second harmonic degree topography is added to the base of the crust. For an ice shell on Europa, it is found that a state of thermal equilibrium may involve an unusual orientation of the principal axes of inertia (when hydrostatic bulges are ignored) in which the intermediate and maximum principal moments are interchanged. To reach the preferred orientation for synchronous satellites, a thermal-equilibrium shell must execute a net reorientation of 90° about the satellite-planet direction. We present a simple model of a rigid, synchronously rotating satellite in a circular orbit for which the principal moment difference $B - C$ increases with time, becoming positive for $t > 0$. The model demonstrates that the expected reorientation is indeed dynamically favored.

We then consider a more realistic model in which Europa's shell and ocean are assumed to reorient as a single entity, independently of the core, hindered only by viscous dissipation within the shell. Such coupling of the shell with the ocean, and lack of coupling with the core, is suggested by G. W. Ojakangas (1988, *Coupled Thermal and Dynamical Evolution of Planetary Bodies*, Ph.D. thesis, California Institute of Technology). The model suggests that friction in the shell eliminates the possibility of polar wander unless a low-conductivity regolith increases the near-surface temperature by a few tens of degrees, so the ice just below the regolith behaves viscously on the polar wander time scale. However, if the equator-to-pole near-surface temperature difference is decreased by more than a critical, model-dependent amount, the shell's inertia tensor no longer has an unstable form in thermal equilibrium. Alternatively, polar wander may occur if preexisting surface fractures (e.g., due to tidal stresses) extend to a depth where the ice behaves viscously. These fractures must be lubricated (perhaps by liquid water from below). If the temperature T_f at the base of the regolith or the surface fractures is >125 °K, the model suggests that polar wander occurs on a time scale $\leqslant 2 \times 10^6$ years (decreasing as T_f increases), after $B - C$ becomes positive. In the absence of dissipation, polar wander would occur in $\sim$few $\times\ 10^3$ years. Large-scale polar wander may occur episodically, separated by periods on the order of the thermal diffusion time for the shell ($\sim 10^7$ years), although a state of slow, continuous drifting of the pole is also possible. The time scale of viscous flow of topography at the base of the ice is also near 10^7 years. Polar wander is a very effective means for fracturing the ice and may have contributed to the observed global fracture systems in Europa's ice.

Schneider. N. M. Smyth, W. H. and McGrath, M. A. (University of Arizona, Tucson, AZ 85721): 'Io's Atmosphere and Neutral Clouds', NASA Special Publication Series, NASA-SP-494 (1989), 71–74.

Much of our basic understanding of the Io atmosphere, neutral clouds, and plasma torus has come from the study of variations in their morpholoy, density, and energy distribution. This chapter discusses the time variabilities inherent in the physical processes that govern the behavior of the system, and their relative importance in proposed models of the Io atmosphere. Observations are discussed and compared to model predictions, and new constraints are placed on these models. The variations are then examined in the context of the complete neutral-cloud/plasma torus system, and the unsolved problem of overall system stability is discussed. Several possible mechanisms responsible for the stability are described and evaluated. Future observations of time variable phenomena show real promise for probing the nature of the atmosphere and its complex interaction with the plasma torus.

Simonelli, D. P. and Veverka, J. (NASA/Ames Research Center, Moffett Field, CA 94035), 'Search for Temperature Effects in the Photometry of the Ionian Dayside', NASA Special Publication Series, NASA-SP-494 (1989), 183–195.

Strobel, D. F. (The Johns Hopkins University, Baltimore, MD 21218): 'Energetics, Luminosity, and Spectroscopy of Io's Torus', NASA Special Publication Series, NASA-SP-494 (1989), 183–195.

This chapter gives a review of the Io torus on the following topics: composition, temperature, luminosity, energetics, interaction of Io's atmosphere corona with the plasma torus, time constants, and variability. Convergence is finally being reached on the steady-state composition and temperature of the plasma torus. The luminosity of the torus during the Voyager encounters was larger (0.4–0.8 eV cm^{-3} s^{-1}) than originally inferred as a consequence of improved atomic physics. The energy crisis may have been finally resolved by including heating of the thermal plasma by inflowing energetic (~1–20 keV) ions from the outer magnetosphere, but more quantitative calculations and direct measurement of these ions are needed. There is significant variability in torus plasma properties with the extreme conditions being represented bv the periods of the Pioneer and Voyager encounters when the average electron density may have differed by as much as a factor of 25.

5. MARS

Burnham, R.: 'New Views of Mars and Phobos', *Astronomy* **17**(9) (1989), 28–32.

The Soviet Union's short-lived Phobos mission has given scientists their first close-up look at Mars in seven years.

Friedmann, E. I. and Koriem, A. M. (Polar Desert Research Center and Department of Biological Science, Florida State University, Tallahassee, FL 32306): 'Life on Mars: How it Disappeared (IF it was ever there)', *Adv. Space Res.* **9** (1989), (6)167–(6)172.

The cryptoendolithic microbial community in the Ross Desert (McMurdo Dry Valleys) of Antarctica exists at temperatures significantly below the temperature optima of the primary producers. Surviving near the limit of their physiological adaptability, the organisms are under severe environmental stress, so further deterioration in the environment results in cell damage and death. The sequence of events leading to extinction is considered to be a terrestrial analog for disappearance of possible life on early Mars. Progressive stages of cell damage and death in the Ross Desert material are documented with transmission electron microscopy.

Graham, D.: 'Your Views of Mars', *Popular Astronomy* **36**(3) (1989), 17–19.

The 1988 perihelic opposition of Mars.

Klinger, J. M., Mancinelli, R. L. and White, M. R. (NASA-Ames Research Center Solar System Exploration, MS 239-12, Moffett Field CA 94035): 'Biological Nitrogen Fixation under Primordial Martial Partial Pressures of Dinitrogen', *Adv. Space Res.* **9** (1989), (6)173–(6)176.

Early Earth and early Mars were similar enough such that past geochemical and climatic conditions on Mars may have also been favorable for the origin of life. However, one of the most striking differences between the two planets was the low partial pressure of dinitrogen (pN_2) on early Mars (18 mb). On Earth, nitrogen is a key biological element and in many ecosystems the low availability of fixed nitrogen compounds is the main factor limiting growth. Biological fixation of dinitrogen on Earth is a crucial source of fixed nitrogen. Could the low availability of dinitrogen in the primordial Martian atmosphere have prevented the existence, or evolution of Martian microbiota? *Azotobacter vinelandii* and *Azomonas agilis* were grown in nitrogen free synthetic medium under various partial pressures of dinitrogen ranging from 780–0 mb (total atmospheres = 1 bar). Below 400 mb the biomass, cell number and growth rate decreased with decreasing pN_2. Both microorganisms were capable of growth at a pN_2 as low as 5 mb, but no growth was observed at a $pN_2 \leq 1$ mb. The data appear to indicate that biological nitrogen fixation could have occurred on primordial Mars ($pN_2 = 18$ mb) making it possible for a biotic system to have played a role in the Martian nitrogen cycle. It is possible that nitrogen may have played a key role in the early evolution of life on Mars, and that later a lack of available nitrogen on that planet (currently, $pN_2 = 0.2$ mb) may have been involved in its subsequent extinction.

Mancinelli, R. L. (Solar System Exploration Branch, MS 39–12, NASA-Ames Research Center, Moffett Field, CA 94035): 'Peroxides and the Survivability of Microorganisms on the Surface of Mars', *Adv. Space Res.* **9** (1989), (6)191–(6)195.

Results of the Viking mission seem to indicate that there is a ubiquitous layer of highly oxidizing aeolian material covering the Martian surface. This layer is thought to oxidize organic material that may settle on it, and is therefore responsible for the lack of detection of organic matter on the planet surface by Viking. The mechanism that creates the oxidizing condition is not well understood, nor is the extent of the oxidation potential of this material. It has been suggested that the oxidizing nature of the soil is due to photochemical reactions which create hydrogen peroxide and superoxides in the surface soil. One question of importance to planetary protection regarding this material is, what is its potential for destroying terrestrial microorganisms, thus making the surface of Mars "self-sterilizing"? Using data obtained by the gas exchange experiment on Viking, and for simplicity assuming that all of the O_2 released came from H_2O, the concentration range for H_2O_2 on the surface of Mars can be calculated to be 25–250 ppm. The microbial disinfection rate by H_2O_2 is concentration dependent, and is highly variable within the microbial community. Data from our laboratory indicate that certain soil bacteria survive and grow to stationary phase in 30,000 ppm H_2O_2. However, the total number of organisms decreases in the presence of H_2O_2. These results indicate that it is doubtful that the presence of H_2O_2 alone on Mars would make the surface "self-sterilizing".

McKay, C. P. and Stoker, C. R. (Space Science Division, NASA Ames Research Center, Moffett Field CA 94035): 'The Early Environment and Its Evolution on Mars: Implications for Life', *Reviews of Geophysics* **27** (1989), 189–214.

There is considerable evidence that the early climate of Mars was very different from the inhospitable conditions there today. This early climate was characterized by liquid water on the surface and a dense atmosphere composed predominantly of CO_2. The duration of these warm initial conditions on the surface of Mars is uncertain, but theoretical models suggest that they could have persisted for hundreds of millions up to a billion years. From studies of the Earth's earliest biosphere we know that by 3.5 Gyr ago, life had originated on Earth and reached a fair degree of biological sophistication. Surface activity and erosion on Earth make it difficult to trace the history of life before the 3.5-Gyr time frame. If Mars did maintain a clement environment for longer than it took for life to originate on Earth, then the question of the origin of life on Mars follows naturally. The fossil evidence of early life on Earth provides clues as to what form fossils on Mars might take. Of particular interest are stromatolites, macroscopic, layered structures that result from the anchoring of sediments by microorganisms living in the photic zone. Since over two thirds of the Martian surface is more than 3.5 Gyr old, the possibility exists that Mars may hold the best record of the events that led to the origin of life, even though there may be no life there today.

Moore, H. J. and Jakosky, B . M. (U.S. Geological Survey, Menlo Park, CA 9402): 'Viking Landing Sites, Remote-Sensing Observations, and Physical Properties of Martian Surface Materials', *Icarus* **81** (1989), 164–184.

Important problems that confront future scientific exploration of Mars include the physical properties of Martian surface materials and the geologic processes that formed the materials. The design of landing spacecraft, roving vehicles and sampling devices and the selection of landing sites, vehicle traverses, and sample sites will be, in part, guided by the physical properties of the materials. Four materials occur in the sample fields of the Viking landers: (1) drift, (2) crusty to cloddy, (3) blocky, and (4) rock. The first three are soillike. Drift material is weak, loose, and porous. We estimate that it has a dielectric constant near 2.4 and a thermal inertia near 1×10^{-3} to 3×10^{-3} cal cm^{-2} sec$^{-1/2}$ K^{-1}) because of its low bulk density, fine grain size, and small cohesion. Crusty to cloddy material is expected to have a dielectric constant near 2.8 and a thermal inertia near 4×10^{-3} to 7×10^{-3} because of its moderate bulk density and cementation of grains. Blocky material should have a dielectric constant near 3.3 and a thermal inertia near 7×10^{-3} to 9×10^{-3} because of its moderate bulk density and cementation. Common basaltic rocks have dielectric constants near 8 and thermal inertias near 30×10^{-3} to 60×10^{-3}. Comparisons of estimated dielectric constants and thermal inertias of the materials at the landing sites with those obtained remotely by Earth-based radars and Viking Orbiter thermal sensors suggest that the materials at the landing sites are good analogs for materials elsewhere on Mars. Correlation of remotely estimated dielectric constants and thermal inertias indicates two modal values for paired values of dielectric constants and thermal inertias near (A) 2 and 2×10^{-3} and (B) 3 and 6×10^{-3}, respectively. These two modes are comparable to the dielectric constants and thermal inertias for drift and crusty to cloddy material, respectively. Dielectric constants and thermal inertias for blocky material are larger but consistent with values in the northern plains. Our interpretations are compatible with an aeolian origin for drift and similar materials elsewhere on Mars. The postulate that moderate dielectric constants and thermal inertias larger than 3 or 4×10^{-3} are produced by cementation of soillike materials is partly consistent with the data. The average dielectric constant and thermal inertia and their correlation with one another suggest that most of the surface of Mars should present few difficulties to future surface exploration, but some surfaces may present difficulties for spacecraft that are not suitably designed.

Raitala, J . (Department of Astronomy, University of Oulu, Oulu, Finland): 'Development of the Alba Patera Volcano on Mars', *Adv. Space Res.* **9** (1989), (6)143–(6)146.

The Alba Patera volcano is located in the middle of an almost 3000 km long fossae grabe zone radial to the Tharsis bulge. Alba Patera construction is wide, but only 7 km high. It has the appearance of a large, central-vent shield volcano with very low slope angle. Huge volumes of lavas have erupted from its center and flank vents to build it. The viscosity of the lavas must have been relatively low allowing them to flow hundreds of kilometers along the gentle downslopes. Lava tubes and flows radiate from central Alba Patera, where complex calderas can be seen. The composition of the lava flows may be indicative to the Martian internal development. A deep magma generation has to be considered as a possible cause for low-viscous lavas.

Raitala, J. and Kauhanen, K. (Department of Astronomy, University of Oulu, Oulu, Finland): 'Magma Chamber-Related Development of Alba Patera on Mars', *Earth, Moon and Planets* **45** (1989), 187–204.

The formation of the central calderas of the Alba Patera summit area is proposed to have been caused by collapse(s) into relatively shallow and wide magma chamber(s). The subduction or collapse of the whole central Alba Patera area and the formation of peripheral circular fossae grabens around it were caused by a deeper, wider and more primary magmatic process which was more directly connected to the ascending hot mantle.

Robinson, M. S .: 'Surveying the Scars of Ancient Martian Floods', *Astronomy* **17**(10) (1989), 38–45.

With computer-generated images of Mars' Kasei Valley, planetary scientists can take an aerial tour of a slice of the planet's geologic past.

Rothschild, L. J. and DesMarais, D. (NASA-Ames Research Center, MS 239–12, Moffett Field, CA 94035): 'Stable Carbon Isotope Fractionation in the Search for Life on Early Mars', *Adv. Space Res.* **9** (1989), (6)159–(6)165.

Isotopic measurements and, more specifically, ratios of ^{13}C to ^{12}C in organic relative to inorganic deposits, are useful in reconstructing past biological activity on Earth. Organic matter has a lower ratio of ^{13}C to ^{12}C due largely to the preferential fixation of ^{12}C over the heavier isotope by the major carbon-fixation enzyme, ribulose-1,5-bisphosphate carboxylase/oxygenase, although other factors (e.g., availability of source carbon, fixation by other carboxylating enzymes and diagenesis of organic material) also contribute to fractionation. Would carbon isotope discrepancies between inorganic and organic carbon indicate past biological activity on Mars? In order to answer this question, we analyse what is known about terrestrial biological and abiologic carbon fixation and its preservation in the fossil record, and suggest what the isotope discrimination during possible biologic and abiologic carbon fixation on Mars might have been like. Primarily because isotopic signatures of abiotically fixed carbon overlap with those of biotic fixation, but also because heterotrophy does not significantly alter the isotopic signature of ingested carbon, fractionation alone would not be definitive evidence for life. However, a narrow range of fractionation, including no fractionation, would suggest biotic processes. Never-the-less, isotopic ratios in organic deposits on Mars would be extremely useful in analysing prebiotic, if not biotic, carbon transformations on Mars.

Schultz, R. A. (Geodynamics Branch, NASA Goddard Space Flight Center, Greenbelt, MD 20771): 'Strike-slip Faulting of Ridged Plains near Valles Marineris, Mars', *Nature* **341** (1989), 424–426.

The surface of Mars shows abundant evidence of extensional and contractional deformation in the form of normal faults, grabens and wrinkle ridges. In contrast, strike-slip faults have been considered to be extremely rare or absent on Mars. This view is based on the lack of significant lateral offset of pre-existing markers such as craters across suspected faults. Thus, Mars is believed to have evolved without plate tectonics or other large-scale lateral motions of the lithosphere. However, careful study of Viking Orbiter images is revealing that strike-slip faults may be present on Mars. Here I identify and document several well preserved examples of martian strike-slip faults and examine their relationships to wrinkle-ridges. The strike-slip faulting predates or overlaps periods of wrinkle-ridge growth south-east of Valles Marineris, and some wrinkle ridges may have nucleated and grown as a result of strike-slip displacements along the echelon fault arrays. Lateral displacements of several kilometres inferred along these arrays may be related to tectonism in Tharsis.

Schwartz, D. E. and Mancinelli, R. L. (NASA-Ames Research Center, Solar System Exploration Branch, MS 239-12, Moffett Field, CA 94035): 'Bio-Markers and the Search for Extinct Life on Mars', *Adv. Space Res.* **9** (1989), (6)155–(6)158.

Geologic and climatologic studies suggest that conditions on early Mars were similar to early Earth. Because life on Earth is believed to have originated during this early period (3.5 billion years ago), the Martian environment could have also been conducive to the origin of life. To investigate this possibility we must first define the attributes of an early Martian biota. Then, specific geographic locations on Mars must be chosen where life may have occurred (i.e. areas which had long standing water), and within these distinct locations search for key signatures or bio-markers of a possible extinct Martian biota. Some of the key signatures or bio-markers indicative of past biological activity on Earth may be applicable to Mars including: reduced carbon and nitrogen compounds, CO_3^{2-}, SO_4^{2-}, NO_3^-, NO_2^2, Mg, Mn, Fe, and certain other metals, and the isotopic ratios of C, N and S. However, we must also be able to distinguish abiotic from biologic origins for these bio-markers. For example, abiotically fixed N_2 would form deposits of NO_3^- and NO_2^-, whereas biological processes would have reduced these to ammonium containing compounds, N_2O, or N_2, which would then be released to the atmosphere. A fully equipped Mars Rover might be able to perform analyses to measure most of these biomarkers while on the Martian surface.

Sinclair, A. T. (Royal Greenwich Observatory, Herstmonceux Castle, Hailsham, East Sussex BN27 1RP, England): 'The Orbits of the Satellites of Mars Determined from Earth-Based and Spacecraft Observations', *Astron. Astrophys.* **220** (1989), 321–328.

All available positional observations of the satellites of Mars, both Earth-based and from the Mariner 9 and Viking spacecraft, have been used for a re-determination of the orbits of the satellites. The method used makes a direct solution for various physical parameters of Mars: the mass, low-order gravity field coefficients and precession rate. Reasonably well-determined values are obtained for these parameters. The secular acceleration of Phobos is well-determined from these data, and implies a future lifetime of about 40 million years.

Thomas, P. and Weit, C. (Center for Radiophysics and Space Research, Cornell University, Ithaca, NY 14853): 'Sand Dune Materials and Polar Layered Deposits on Mars', *Icarus* **81** (1989), 185–215.

The relationship of dark sand dunes to the polar layered deposits of Mars is investigated by mapping the colors and morphologic settings of the dunes in and near the polar deposits. In the north polar region the dunes have restricted sources in the layered deposits that are associated with arcuate scarps 10–50 km in length and <500 m in height. Most dune sources are in the more eroded parts of the layered deposits and are probably in the stratigraphically older deposits. In the southern polar region dune material appears to have sources in erosional reentrants and erosional "windows" in the layered deposits. Colors and albedos or the layered deposits range from values close to "bright dust" to values that are much darker and less red. The polar dune materials have approximately the same colors and albedos as major dune fields at all other latitudes on Mars. These results suggest that no exotic polar mechanisms are needed to explain the polar dunes and that sand (saltating material) was carried into the polar regions during at least part of the formation of the layered deposits.

Wharton, R. A., Jr., McKay, C. P., Mancinelli, R. L. and Simmons, G. M., Jr. (Biological Sciences Center, Desert Research Institute and University of Nevada, Reno, NV 89506): 'Early Martian Environments: The Antarctic and Other Terrestrial Analogs', *Adv. Space Res.* **9** (1989), (6)147–(6)153.

The comparability of the early environments of Mars and Earth, and the biological evolution which occurred on early earth, motivates serious consideration of the possibility of an early martian biota. Environments which could have contained this early martian life and which may presently contain evidence of this former life include aquatic, ice, soil, and rock habitats. Several analogs of these potential early martian environments. which can provide useful information in searching for extinct life on Mars, are currently available for study on Earth. These terrestrial analogs include the perennially ice-covered lakes and sandstone rocks in the Polar Deserts of Antarctica, surface of snowfields and glaciers, desert soils, geothermal springs, and deep subsurface environments.

Zaitsev, Y. (Institute of Space Research, USSR Academy of Sciences, Moscow, USSR): 'The Red Planet in a New Light', *New Scientist* **123** (1989), 52–56.

Photos of Phobos, the first heat images of Mars and traces of the planet's leaking atmosphere have all come from a Soviet space mission that, earlier this year, some said was a failure.

6. SATELLITES OF MARS

Anderson, J. D., Borderies, N. H., Campbell, J. K., Dunne, J. A., Ellis, J., Hellings, R. W., Lau, E. L., Preston, R. A., Traxler, M. R., Williams, J. G., Yoder, C. F., Chandler, J. F., Resenberg, R. D., Shapiro, I. I., Berthias, J. P., Blamont, J., Linkin, V. M. Kerzhanovich, V. V., Akim, E. L. and Ivanov, N. M. (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109): 'Testing General Relativity with Landers on the Martin Satellite Phobos', *Adv. Space Res.* **9**(9) (1989), 71–74.

We describe a planned experiment to obtain range and Doppler data with the Phobos 2 Lander on the surface of the Martian satellite Phobos. With the successful insertion on 29 January 1989 of Phobos 2 into Mars orbit, we anticipate that the Lander will be placed on the surface of Phobos in April 1989. Depending on the longevity of the Lander, we expect to obtain range and Doppler data for a period of from one to several years. Because these data are of value in performing solar-system tests of general relativity, we review the current accuracy of the relevant relativity tests using Deep Space Network data from the Mariner-9 orbiter of Mars in 1971 and from the Viking Landers in 1976–1982. We also discuss the expected improvement from data anticipated during the Phobos 2 Lander Mission; most important will be an improved sensitivity to any time variation in the gravitational "constant" as measured in atomic units.

Horstman, K. C. and Melosh, H. J. (Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721): 'Drainage Pits in Cohesionless Materials: Implications for the Surface of Phobos', *Journ. Geophys. Res.* **94** (1989), 12433–12441.

Viking orbiter images show grooves and chains of pits crossing the surface of Phobos, many of which converge toward the large crater Stickney or its antipode. Although it has been proposed that the pits and grooves are chains of secondary craters, their morphology and geometric relations suggest that they are the surface traces of fractures in the underlying solid body of Phobos. Several models have been proposed to explain the pits, of which the most plausible are gas venting and drainage of regolith into open fractures. The latter mechanism is best supported by the image data and is the mechanism studied in this investigation. Drainage pits and fissures are modeled experimentally by using two rigid substrate plates placed edge to edge and covered by uniform thicknesses of dry fragmental debris (simulated regolith). Fracture extension is simulated by drawing the plates apart, allowing drainage of regolith into the newly created void. A typical drainage experiment begins with a shallow depression on the surface of the regolith, above the open fissure. Increased drainage causes local drainage pits to form; continued drainage causes the pits to coalesce, forming a cuspate groove. The resulting experimental patterns of pits and grooves have pronounced similarities to those observed on Phobos. Characteristics such as lack of raised rims, linearity of grooves and chains of pits, uniform spacing of pits, and progression from discrete pits to cuspate grooves are the same in the experiments and on Phobos. In contrast, gas-venting pits occur in irregular chains and have raised rims. These experiments thus indicate that the Phobos grooves and pits formed as drainage structures. The pit spacing in an experiment is measured at the time that the maximum number of pits forms, prior to groove development. The average pit spacing is compared to the regolith thickness for each material. Regression line fits indicate that the average spacing of drainage pits in unconsolidated, noncohesive regolith is nearly equal to the thickness of regolith and appears to be independent of the angle of repose, within the resolution of our experiments. This provides a simple means of estimating regolith thickness where drainage pits are present. On Phobos, two locations differing by 90° in longitude have average pit spacings that suggest regolith thicknesses of 290 and 300 m, suggesting that large areas of Phobos have a nearly uniform regolith thickness of approximately 300 m.

Kührt, E. and Giese, B. (Institut für Kosmosforschung, Akademie der Wissenschaften, DDR-1199 Berlin, Rudower Chaussee 5, German Democratic Republic): 'A Thermal Model of the Martian Satellites', *Icarus* **81** (1989), 102–112.

A thermal model of the Martian satellites is developed that takes into account their ellipsoidal shape, eclipse effects, the temperature dependence of the heat conduction coefficient, and the reflected and thermal radiation of Mars. Results for the diurnal temperature behavior of Phobos and Deimos for different latitudes, longitudes, and seasons are presented.

8. NEPTUNE

Beatty, J. K.: 'Welcome to Neptune', *Sky and Telescope* **78** (1989), 350–359.

Voyager 2 has done it again. This enduring interplanetary exlorer – arguably the most productive spacecraft ever built by NASA – dashed past distant Neptune in late August. The long-awaited encounter completes Voyager 2's reconnaissance of the solar system's four largest planets, a trek that had little chance of success when the spacecraft was launched more than 12 years ago.

Begley, S. and Hager, M: 'A Fantastic Voyage to Neptune', *Newsweek*, Sept 4, (1989), 50–56.

It's blue, beautiful and on the edge of the solar system.

Berry, R.: 'The Colors of Neptune', *Astronomy* **17**(9) (1989), 34–35.

With its powerful telephoto cameras, Voyager 2 photographed several distinct features in the Neptunian atmosphere.

Berry, R.: 'First Discoveries at Neptune', *Astronomy* **17**(10) (1989), 32–34.

A "Great Dark Spot," bands of clouds, and a new satellite were revealed by Voyager 2 as it approached Neptune.

Berry, R.: 'Triumph at Neptune', *Astronomy* **17**(11) (1989), 20–28.

We have now traveled nearly to the edge of our solar system, thanks to that intrepid explorer, Voyager 2.

Chaikin, A.: 'Farewell Voyager: A Photo Finish at Neptune', *Final Frontier* **2**(6) (1989), 24–27, 52–54.

The show from Neptune was everything you would expect from one of history's great explorers.

Chyba, C. F., Jankowski, D. G. and Nicholson, P. D. (Center for Radiophysics and Space Research,

Cornell University, Ithaca, NY 14853–6801): 'Tidal Evolution in the Neptune-Triton System', *Astron. Astrophys.* **219** (1989), L23–L26.

Neptune's moon Triton is spiralling in towards the planet due to tides raised on both Neptune and Triton. Dissipation from tides on Triton will arise when either its orbital eccentricity or spin-axis obliquity is nonzero. Triton's current obliquity may lie close to either 0° (state 1) or 100° (state 2), corresponding to the two stable Cassini extrema of its rotational Hamiltonian. The Kaula tidal formalism is used to model the past and future evolution of the system in both states. For nominal parameters ($Q_N = 10^4$, $Q_T = 10^2$) in state 1, Triton will reach Neptune's Roche limit in ~3.6 Gyr with a decrease in its orbital inclination from the present 159° to ~145°. In state 2 substantial heating due to obliquity tides leads to significantly different orbital evolution. In this case, Triton's inclination will increase to an end-point of 180° in 10^7–10^8 yr, at which time the satellite will make a transition to state 1. Triton will then evolve in to Neptune's Roche limit in ~1.4 Gyr. Extrapolation into the past suggests that Triton's orbit has always been retrograde, with an inclination of at least ~125°. For $Q_T = 100$, any initial eccentricity would have damped to the present upper limit of 5×10^{-4} in ~200 Myr. If Triton was captured at an earlier epoch, then any measurable current eccentricity is most probably due to cometary impacts, rather than representing a tidal "relic".

David, L.: 'Voyager 2: Miles to Go', *Ad Astra* **1**(9) (1989), 24–27.

Dobrovolskis, A. R., Borderies, N. J. and Steiman-Cameron, T. Y. (NASA Ames Research Center, Moffett Field, CA 94035); 'Stability of Polar Rings around Neptune', *Icarus* **81** (1989), 132–144.

Perturbations from Neptune's highly inclined satellite Triton can maintain stationary rings passing nearly over Neptune's poles. These hypothetical polar rings are nearly perpendicular to Triton's orbit as well, and lie within several degrees of the plane of Voyager II's trajectory through the Neptunian system. Polar rings can coexist with equatorial rings at different radii. This paper offers an analytic proof that polar rings of Neptune can be stable despite dissipation of energy by collisions between particles. It also includes a computer simulation of a Neptunian ring settling into a polar orientation.

Davies, J. (Royal Observatory, Edinburgh, U.K.): 'Encounter at the Edge of the Solar System', *New Scientist* **123** (1989), 45–49.

This month the NASA spacecraft Voyager 2 will visit Neptune and its unusual moons. Then, after its last planetary encounter, it will head off into deep space.

Eberhart, J.: 'Envisioning Arcs of Moondust at Neptune', *Science News* **136** (1989), 87.

Goldreich, P., Murray, N., Longaretti, P. Y. and Banfield, D. (California Institute of Technology, Pasadena, CA 91125): 'Neptune's Story', *Science* **245** (1989), 500–504.

It is conjectured that Triton was captured from a heliocentric orbit as the result of a collision with what was then one of Neptune's regular satellites. The immediate postcapture orbit was highly eccentric with a semimajor axis $a \sim 10^3 R_N$ and a periapse distance r_p that oscillated periodically above a minimum value of about $5R_N$. Dissipation due to tides raised by Neptune in Triton caused Triton's orbit to evolve to its present state in $\lesssim 10^9$ years. For much of this time Triton was almost entirely molten. While its orbit was evolving, Triton cannibalized most of the regular satellites of Neptune and also perturbed Nereid, thus accounting for that satellite's highly eccentric and inclined orbit. The only regular satellites of Neptune that survived were those that formed well within $5R_N$ and they move on inclined orbits as the result of chaotic perturbations forced by Triton. Neptune's arcs are confined around the corotation resonances of one of these inner satellites. The widths and lengths of the arcs imply that the satellite's radius is at least $30/(\sin i)^{2/3}$ kilometers for $i \leq 1$, where i is the angle of inclination.

Hammel, H. B., Baines, K. H. and Bergstralh, J. T. (Institute for Astronomy, University of Hawaii, Honolulu, Hawaii 96822): 'Vertical Aerosol Structure of Neptune: Constraints from Center-to-Limb Profiles', *Icarus* **80** (1989), 416–438.

We present and analyze center-to-limb (CTL) profiles of the equatorial region of Neptune, extracted from images with good spatial resolution. Models of the quiescent atmosphere of Neptune are consistent with at least two distinct cloud layers, a thin stratosphere haze and a deep cloud. The 8900-Å CTL profile requires the presence of some material above the 5-mbar level. Assuming isotropic scattering, the optical depth of the material is less than 0.15 for hazes with single scattering albedos larger than 0.6. CTL profiles at three methane bands could not be fitted simultaneously with a single scattering layer, implying that there may be multiple haze layers. The methane-band data tolerate thin scattering hazes in the pressure level from 0.4 to 1.5 bars, but the optical depths must be less than 0.5 (again, assuming isotropic scattering). Such a thin haze does not provide sufficient reflected flux at 6340 Å (a continuum region), indicating the presence of another scattering layer deeper than 1.5 bars. A bright cloud layer (single scattering albedo near 1) with optical depth 3.0 at 2.6 bars provides a good fit to 6340-Å reflectivity. Superposed on the quiescent atmosphere are discrete bright features. The lack of detectable disk-integrated variability at shorter wavelengths helps constrain the vertical aerosol structure of these bright regions. Specifically, the difference of the bright feature from its surroundings in 1986 was probably caused by an increase in optical depth or height of a stratospheric haze layer.

Hammel, H. B., Beebe, R. F., De Jong, E. M., Hansen, C. J., Howell, C. D., Ingersoll, A. P., Johnson, T. V., Limaye, S. S., Magalháes, J. A., Pollack, J. B., Sromovsky, L. A., Suomi, V. E. and Swift, C. E. (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109); 'Neptune's Wind Speeds Obtained by Tracking Clouds in Voyager Images', *Science* **245** (1989), 1367–1369.

Images of Neptune obtained by the narrow-angle camera of the Voyager 2 spacecraft reveal large-scale cloud features that persist for several months or longer. The features' periods of rotation about the planetary axis range from 15.8 to 18.4 hours. The atmosphere equatorward of −53° rotates with periods longer than the 16.05-hour period deduced from Voyager's planetary radio astronomy experiment (presumably the planet's internal rotation period). The wind speeds computed with respect to this radio period range from 20 meters per second eastward to 325 meters per second westward. Thus, the cloud-top wind speeds are roughly the same for all the planets ranging from Venus to Neptune, even though the solar energy inputs to the atmospheres vary by a factor of 1000.

Henbest, N.: 'Neptune: Voyager's Last Picture Show', *New Scientist* **123** (1989), 45–48.

The spacecraft Voyager 2 is leaving the Solar System 12 years after its launch. Its last close encounter showed us clouds on blue and stormy Neptune, and surprises on Triton, the moon with an icecap of methane, volcanoes powered by nitrogen and a very odd surface indeed.

Kerr, R. A.: 'The Neptune System in Voyager's Afterglow', *Science* **245** (1989), 588–589.

Any time the view of a planet leaps from a fuzzy dot accompanied by two pinpoints of light to the riveting details of swirling clouds, rings, cratered moonlets, and even individual dust particles, planetary science is going to be in for some upheaval. Voyager 2's encounter with Neptune was no exception. Something as seemingly innocuous as an hour or two shift in the new length of a Neptunian day is giving meteorologists and physicists fits. And Neptune's canted, complex magnetic field found by

Voyager knocks into a cocked hat most ideas about why a similar field at Uranus was unique. But there were more reassuring discoveries as well. Here are samplings of both sorts of findings.

Kinoshita, J.: 'Neptune', *Scientific American* **261**(5) (1989), 82–91.

Voyager 2's cameras unveil a stormy world and a frozen moon molded by volcanism.

Kerr, R. A.: 'Facing a Final Exam at Neptune', *Science* **245** (1989), 1450–1451.

Jupiter, Saturn, and Uranus have taught many lessons about the outer planets; but will they apply to Voyager 2's last port-of-call, the still mysterious planet Neptune?

Lindley, D.: 'Voyager's Final Solar System Rendezvous', *Nature* **340** (1989), 95.

High clouds and hurricanes on Neptune. Triton marked by glaciers and ice volcanoes.

Lindley, D.: 'Considered View of Neptune', *Nature* **341** (1989), 95.

Voyager 2 pictures of Neptune taken as the spacecraft retreated from the planet.

McLaughlin, W. (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109): 'Journey to Neptune', *Spaceflight* **31** (1989), 340–346.

In the year of 1846, when Neptune was discovered at the Berlin Observatory, the Smithsonian Institution in Washington and the Carl Zeiss optical factory in Jena were founded, Hector Berlioz's *Damnation of Faust* was first performed, in Paris, and Iowa was admitted as the twenty-ninth state of the Union. Time has been kind, on the whole, to these enterprises, except that Neptune has languished on the edges of scientific knowledge due to its great distance from Earth. In Pasadena in the year of 1989, this lapse was rectified as the flight team at JPL guided inquisitive Voyager 2 through the Neptunian system.

Moore, P.: 'The Discovery of Neptune', *Mercury* **18** (1989), 98–107.

The story of the search for Neptune has been told many times, but even today after the lapse of almost a century and a half there are still discrepancies in the various accounts, as well as all manner of conflicting opinions. The author attempts a totally unbiased summary.

Ratcliffe, M.: 'Giant Spots Reveal Neptune's Tempests', *New Scientist* **123** (1989), 21.

Rosenberg, D: 'The Final Frontier', *Computer Graphics World* **12**(11) (1989), 58–60, 63, 65–66.

Image processing and visualization techniques help Voyager 2 zoom in on Neptune.

Smith, B. A.: 'Voyager's Discoveries Mount On Final Rush to Neptune', *Aviation Week and Space Technology* **131**(9) (1989), 16–20.

Little was known about Neptune prior to Voyager' s arrival due to the great distance from Earth.

Smith, B. A.: 'Voyager Ends Neptune Flyby, Yielding Historic Triton Data', *Aviation Week and Space Technology*, **131**(10) (1989), 18–21.

'Voyager's Last Picture Show', *Sky and Telescope* **78** (1989), 463–470.

The final weeks of August were filled with wondrous pictures from a place many humans had difficulty imagining. Some 4.4 billion kilometers away there was a blue planet that the inhabitants of Earth were seeing close up for the first time. When Voyager 2 was launched 12 years ago, who could have imagined Neptune's dynamic deep blue atmosphere, white clouds of methane, a system of tenuous rings, and pink, frigid Triton? The following pages contain a sampling of the 8,000 Voyager images received at the Jet Propulsion Laboratory – pictures that planetary scientists have only begun to sift through. More than 10 million kilometers from Voyager's August 25th closest approach, Neptune's disk nearly filled the probe's narrow-angle camera in the photograph here. From this distance, cloud features could be seen changing in only a few hours.

9. SATELLITES OF NEPTUNE

Henbest, N.: 'Triton Steals the Show from Neptune', *New Scientist* **123** (1989), 22.

Henbest, N. and Morgan, C.: 'Mathematician Predicts a Multitude of Moons', *New Scientist* **123** (1989), 29.

Kerr, R. A. (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109): 'Triton Steals Voyager's Last Show', *Science* **245** (1989), 928–930.

Even after 7 billion miles of exploration Voyager 2 observations of Neptune, its rings, and its moons can still stir controversy about the giant outer planets.

Maddox, J.: 'Neptune's Satellites Predicted?', *Nature* **340** (1989), 673.

A theory believed to be successful in predicting the satellites of Uranus is not widely accepted. Much will hang on whether it has been successfully applied to Neptune.

10. PLUTO

Eshleman, V. R. (Center for Radar Astronomy, Stanford University, Stanford, CA 94305–4055): 'Pluto's Atmosphere: Models Based on Refraction, Inversion, and Vapor-Pressure Equilibrium', *Icarus* **80** (1989), 439–443.

It is suggested that the distinctive "bites" out of observed stellar occultation signatures of the atmosphere of Pluto are due to refraction associated with a temperature inversion in near-surface boundary layer. Based on radio occultation measurements with Viking, it appears that despite major differences, Pluto and polar ice-cap regions on Mars have similar inversions and may share the characteristics of vapor-pressure equilibrium at the surface.

McKinnon, W. B. (Department of Earth and Planetary Sciences and McDonnell Center for the Space Sciences, Washington University, St. Louis, MO 63130): 'On the Origin of the Pluto-Charon Binary', *Astrophys. J.* **344** (1989), L41–L44.

The normalized angular momentum density J of Pluto-Charon, assuming equal densities for both components and that Pluto's mutual occulation radius is close to correct, is 0.45. This exceeds the critical J, 0.39, above which no stably rotating single object exists. A collisional origin for the binary is strongly implied. J exceeds 0.39 for Charon densities ρ_C above $1.8\ \mathrm{g\,cm^{-3}}$ and is significantly greater than that of the Earth–Moon system for any plausible ρ_C. Moreover, for $\rho_C \gtrsim 2.3\ \mathrm{g\,cm^{-3}}$, a tidally evolved Charon starting at the appropriate Roche limit implies a Pluto with $J > 0.39$ alone. This is not a possible initial configuration, so $2.3\ \mathrm{g\,cm^{-3}}$ is a dynamical upper limit to Charon's density. If Charon forms outside the Roche limit, the upper limit is raised; the effect of viscosity on Pluto's rotational stability and the ρ_C upper limit is also discussed. The dynamical lower limit to ρ_C is too low to be meaningful, so a plausible cosmochemical lower limit of $1.0\ \mathrm{g\,cm^{-3}}$ is assumed. These density limits hint that Charon is less dense than Pluto, but both a more or less dense Charon would be consistent with a collisional origin if one (the least massive) or both proto-objects were differentiated. The angular momentum of the system requires that the proto-objects be comparably (if not equally) sized, if off-center impact velocities vary between escape ($\sim 1.3\ \mathrm{km\,s^{-1}}$) and somewhat greater values ($\sim 2.5\ \mathrm{km\,s^{-1}}$) appropriate to Pluto's eccentric and inclined solar orbit. The average temperature increase, post-Charon formation, could be as great as 100 K (for a 3/1 rock/ice mass ratio), triggering differentiation. This formation scenario differs from some lunar formation scenarios in that the comparable mass ratios of the impactors allow non-Keplerian gravitation and viscous coupling to move Charon's mass to Roche altitude. The impact velocities are too low for vaporization of water ice except during jetting. Loss of material during the jetting phase may be substantial, though, affecting the final system ice/rock ratio in the case of differentiated proto-objects.

Stern, S. A. (Laboratory for Atmospheric and Space Physics, and Department of Astrophysical, Planetary and Atmospheric Sciences, University of Colorado, Boulder, CO 80309): 'Pluto: Comments on Crustal Composition, Evidence for Global Differentiation', *Icarus* **81** (1989), 14–23.

The implications of rapid atmospheric escape and the established presence of methane on Pluto's surface leads to the conclusion that unless Pluto's crust is young, it cannot contain more than a few percent by volume nonvolatile material (e.g., water ice, rock). Were this not the case, the escape of volatiles would cause a deepening lag deposit to form and eventually halt the resupply of CH_4 to Pluto's surface. Unless Pluto's surface methane has been recently deposited, it is therefore possible to conclude that Pluto has likely differentiated. The consequences of differentiation are explored as they relate to Pluto's bulk composition, surface topography, and atmospheric composition. Several relevant observational tests of the differentiation hypothesis are suggested.

12. SATURN

Di Cicco, D. and Robinson, L. J.: 'Saturn and 28 Sgr Highlights', *Sky and Telescope* **78** (1989), 360–365.

So much data was gathered as Saturn and Titan passed in front of 5th-magnitude 28 Sagittarii last July 3rd that it will be months or years before all the scientific fruits are extracted and published. Yet many of the observations are fascinating in themselves not only for what was seen but for how both amateurs and professionals accomplished what they did.

Grossman, A. W., Mugleman, D. O. and Berge, G. L. (Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125): 'High-Resolution Microwave Images of Saturn', *Science* **245** (1989), 1211–1215.

An analysis of high-resolution microwave images of Saturn and Saturn's individual rings is presented. Radio interferometric observations of Saturn taken at the Very Large Array in New Mexico at wavelengths of 2 and 6 centimeters reveal interesting new features in both the atmosphere and rings. The resulting maps show an increase in brightness temperature of about 3 K from equator to pole at both wavelengths, while the 6-centimeter map shows a bright band at northern mid-latitudes. The data are consistent with a radiative transfer model of the atmosphere that constrains the well-mixed, fully saturated, NH_3 mixing ratio to be 1.2×10^{-4} in a region just below the NH_3 clouds, while the observed bright band indicates a 25 percent relative decrease of NH_3 in northern mid-latitudes. Brightness temperatures for the classical rings are presented. Ring brightness shows a variation with azimuth and is linearly polarized at an average value of about 5 percent. The variations in ring polarization suggest that at least 20 percent of the ring brightness is the result of a single scattering process.

Irion, R. (Public Information Office, University of California, Santa Cruz, CA 95064): 'Probing Saturn and Titan by Starlight', *Astronomy* **17**(11) (1989), 50–54.

Observers turned a rare alignment of Saturn with a bright star into new insights about the planet's rings and the atmosphere of its largest moon.

Longaretti, P.-Y. (California Institute of Technology, Pasadena, CA 91125): 'Saturn's Main Ring Particle Size Distribution: An Analytic Approach', *Icarus* **81** (1989), 51–73.

An analytic theory for Saturn's ring particle size distribution is developed using the so-called "dynamic ephemeral bodies" (or DEBs) model of ring particles (S. J. Weidenschilling, C. R. Chapman, D. R. Davis, and R. Greenberg, 1984, in *Planetary Rings*, pp. 367–416, Univ. of Arizona Press, Tucson). Accretion and erosion criteria are defined, and the fundamental integrodifferential equation describing the collisional evolution of the mass distribution function of ring particles is derived in the approximation that the ring velocity dispersion is independent of the particle size. A simple stationary solution of this equation is developed, which reproduces all the main features of the distributions determined from the Voyager I radio data (H. A. Zebker, E. A. Marouf, and G. L. Tyler, 1985, *Icarus* **64**, 531–568). The main results of this work are the following: (i) the upper cutoff of the distribution can be explained by a relative enhancement of the erosion of the large particles; (ii) the power-law index of the distribution can be related to parameters characterizing the particle collisional properties; (iii) the model yields estimates for the particle life times and for the dispersion velocity in various unperturbed regions of the rings; (iv) "hard-sphere" ring particle models are most probably ruled out, because they lead to stationary distribution functions in disagreement with the Voyager results.

Robinson, L. J.: 'Saturn and a Winking Star', *Sky and Telescope* **78** (1989), 259.

Rucker, H. O., Rabl, G. K. F. and Desch, M. D. (Space Research Institute, Austrian Academy of Sciences, Lustbuhel Observatory, A-8042 Graz, Austria): 'External Control of the Saturn Kilometric Radiation by the Solar Wind: Comparison between Voyager 1 and 2 Observations', *Annales Geophysicae* **7** (1989), 341–354.

Relatively long periods of observation of Saturn's non-thermal radio emission (SKR) in the kilometric wavelength range by Voyagers I and 2 (V1, V2) allowed a detailed investigation of the long-term modulation of SKR to be made. Previous studies have shown that the solar wind quantities momentum, ram pressure and kinetic energy flux are the dominant drivers of SKR. On the basis of these earlier investigations the present study includes several important improvements in order to derive a consistent view of the external control of SKR. A comparison of ballistic and hydrodynamic propagation of solar wind features from the spacecraft to Saturn allows the uncertainty inherent in the projection to be checked. In addition, the V1 and V2 SKR time profiles are calculated with equal detection thresholds. In order to check the statistical relationship we apply the same statistical methods, superposed epochs and linear prediction filtering, to both V1 and V2 data sets. The present study also includes the complete set of the solar wind time derivative profiles in order to check the response of SKR to the onset of any external influence. The main outcome of this study is consistent with results found in previous studies and confirms that momentum, ram pressure, and kinetic energy flux are the primary solar wind parameters in stimulating SKR. There are indications that, under certain conditions and for limited periods of time, magnetic properties and time derivatives of the solar wind have increased importance.

13. SATELLITES OF SATURN

Dourneau, G., Le Campion, J. F. and Dulou, M. R. (Observatoire de l'Université de Bordeaux I, 33270 Floirac, France): 'Astrometric Observations and Comparison with Theory of Saturn's Satellites from Bordeaux Observatory, 1984', *Astron. J.* **98** (1989), 716–722.

The astrometric observations of Saturn's satellites reported in this paper have been reduced from the SAO catalog. Observed positions of the satellites are given both in absolute topocentric astrometric coordinates and in differential coordinates by using a reference satellite. Residuals derived from comparison between observed and computed positions of the satellites are also reported. A discussion shows that Iapetus, which presents the highest residuals, needs, more than all other observed satellites, an improvement of its theory of motion.

Harper, D., Taylor, D. B. and Sinclair, A. T. (Computer Laboratory, The University, P.O. Box 147, Liverpool L69 3BX, England): 'Analysis of the Orbits of Titan, Hyperion, and Iapetus by Numerical Integration', *Astron. Astrophys.* **221** (1989), 359–363.

The orbits of Titan, Hyperion and Iapetus have been generated by numerical integration and fitted to micrometric observations made in the period 1874–1923. The least-squares fitting process yields a good determination of the mass ratio Titan/Saturn $(2.36651 \pm 0.00028)10^{-4}$. The numerical integration has an accurate scale, determined by the value adopted for the mass of Saturn, and so it is a useful means of showing scale errors of the observations. The observations of the angular separation from Saturn were found to be particularly prone to error, being systematically large by about $0\farcs5$.

Lunine, J. I. and Rik, B. (Lunar and Planetary Laboratory, University of Arizona, Tucson, Arizona 85721): 'Thermal Evolution of Titan's Atmosphere', *Icarus* **80** (1989), 370–389.

A semianalytical model is constructed of the evolution of Titan's atmosphere and surface. The model assumes the presence of a massive (kilometer-deep) ethane-methane ocean at the surface, which serves as a reservoir for atmospheric gases important in determining the thermal balance of the troposphere. As stratospheric photolysis irreversibly converts methane to higher hydrocarbons with time, the ocean becomes progressively enriched in ethane and depleted in methane. The resulting change in the abundance of gases drives the evolution of the atmospheric thermal structure. The solubility in the ocean of nitrogen, argon, and hydrogen is quantified as a function of methane content, which permits the atmospheric composition to be calculated as a function of ocean composition. The surface temperature as a function of atmospheric composition and surface pressure is calculated using a grey atmosphere, two-stream approximation with infrared opacities supplied by collisions among nitrogen, methane, and hydrogen molecules. A suite of evolution models is presented corresponding to different present day ocean compositions, various atmospheric hydrogen abundances, and different schemes for frequency-averaging the gas opacity for use in the grey atmosphere formalism. Over a plausible range of parameters characterizing present-day ocean and atmospheric compositions, slow evolution over several billion years is obtained. This result is consistent with the original motivation for postulating an ethane-methane ocean, namely, that it provides a means for maintaining the atmosphere observed by Voyager over a reasonable fraction of geologic time. Models of atmospheric evolution in the absence of an ocean are briefly discussed; these are driven by stochastic resupply of methane to the atmosphere by volcanism or impacts. Variation of solar radiation at the surface due to changes in haze column abundance and tropospheric clouds are not considered in the present effort. The results show that methane photolysis connects the properties and time history of Titan's atmosphere and possible ocean, not only by the prodnction of ethane from methane, but equally importantly through the formation of molecular hydrogen.

Raulin, F., Dubouloz, N. and Frère, C. (Laboratoire de Physico-Chimie de l'Environnement, Université de Paris 12, 94000 Créteil, France): 'Prebiotic-Like Organic Syntheses in Extraterrestrial Environments: The Case of Titan', *Adv. Space Res.* **9** (1989), (6)35–(6)47.

On Titan, the largest satellite of Saturn, several of the organic molecules of terrestrial prebiotic importance are formed in its reduced nitrogen-methane atmosphere poor in hydrogen. However, because of the cold temperatures of Titan's environment, liquid water is absent from its surface, likely to be covered by an ocean of liquid ethane and methane. In addition, most of the atmospheric organics must condense in the low stratosphere, giving clouds of organic aerosols. Microphysical modeling of these processes shows that in the low atmosphere the aerosols would be constituted of a nucleus of several 10 microns mean diameter, mainly composed of nitriles, and covered by a thick layer of propane, ethane and methane. After precipitation of these aerosols down to the surface, a fraction of their organic material must dissolve in Titan's ocean. Thermodynamic modeling of the ocean indicates that this low temperature liquid milieu should include high concentrations of various organics. Thus, prebiotic chemistry on Titan appears to be governed by atmospheric processes in an atmosphere free of oxygen-containing organics, and by organic processes in a cryogenic apolar solvent. It must have followed a way very different from the terrestrial one.

Raulin, F. and Frère, C. (Laboratoire de Physico-Chimie de l'Environment, Université Paris Val de Marne, 94000 Créteil, France): 'Gas Phase Organic Synthesis in Planetary Environments: The Case of Titan', *Journ. British Interplanetary Soc.* **42** (1989), 411–422.

Atmospheric organic synthesis is considered one of the earliest primary steps in chemical evolution which might have led to the emergence of life on Earth. It may have been a source of reactive organics on the primitive Earth and is now a source of organics on most planets of the solar system. What can be the nature and relative abundance of these organics, depending on the main composition of the atmosphere? What are the respective roles of the energy sources and the mechanisms involved? Different approaches to answer these questions include reversible thermodynamics, kinetic modelling and simulation experiments. These approaches and their main results are presented within the frame of examples of atmospheric compositions found on the planets of the solar system. It appears that reduced atmospheres are much more favourable to the reduction of organics than oxidized ones. The best prebiotic atmosphere seems to be a CH_4-N_2–H_2O system.

Comparison between prediction which can be drawn from these approaches and planetary observations shows satisfactory agreement as well as complementarity of theoretical and experimental simulations. In addition, such comparison shows the importance of the largest satellite of Saturn, Titan, to the study of chemical evolution. With a reduced N_2–CH_4 atmosphere, rich in synthesized organics in the gas and aerosol phases and with the likely presence of a CH_4–C_2H_6 ocean, rich in dissolved organics, this moon is one of the next targets of the Cassini space missions.

14. URANUS

Gor'kavyi, N. N., Taidakova, T. A. and Fridman, A. M. (Astronomical Council, USSR Academy of Sciences, Moscow, USSR): 'Statistical Evidence for a Resonance Origin of the Rings of Uranus', *Soviet Astron. Lett.* **14** (1989), 441–443.

The rings of Uranus do not occupy random positions relative to the low-order (1 : 2, 2 : 3, 3 : 4, 4 : 5 and 1 : 3, 3 : 5) resonances of the 10 satellites discovered by *Voyager 2*, but preferentially lie 125–250 km from those strong resonances. This tendency, statistically reliable at the 3.5 σ level, supports the model whereby rings develop at the edge of resonance spiral waves in a Uranian protodisk. The correlation coefficient between the number of rings in successive 1000-km radial intervals and the number of strong resonances is fully 0.84 ± 0.08.

Hofstadter, M. D. and Mugleman, D. O. (Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125): 'Latitudinal Variations of Ammonia in the Atmosphere of Uranus: An Analysis of Microwave Observations', *Icarus* **81** (1989), 396–412.

A radio map of Uranus made with the Very Large Array at a wavelength of 2 cm is analyzed. The main features of the data are that the planet appears strongly limb darkened, and that the image is not symmetric about the sub-Earth point. These features are interpreted as being due to a latitudinally varying ammonia mixing ratio. Assuming NH_3 to be the only parameter that varies, it appears that the south polar region is depleted in ammonia by about a factor of 3 relative to midlatitudes. The change in NH_3 abundance occurs near $-45°$ lat. The calculated NH_3 molar mixing ratios in the 5 to 20 bar region average $4.9 \pm 0.7 \times 10^{-7}$ for latitudes from $-90°$ to $-45°$, and $1.3 \pm 0.4 \times 10^{-6}$ from $-45°$ to $-15°$. Equatorward of this, the model is poorly constrained due to the observing geometry and abundances cannot be accurately estimated. The quoted error bars represent noise in the data. Other sources of error, such as uncertainty in the NH_3 absorption coefficient and in the data calibration, can change the absolute value of calculated ammonia abundances, but are unlikely to affect the relative variations across the disk of the planet. This model is in agreement with previous work that indicated ammonia is depleted relative to a solar abundance and also is consistent with a preliminary analysis of 6-cm observations. The relatively ammonia rich region in our model includes a region where an analysis of Voyager IRIS data indicates there is an upwelling in the atmosphere.

Moses, S. L., Coroniti, F. V., Kennel, C. F., Bagenal, F., Lepping, R. P., Quest, K. B., Kurth, W. S. and Scarf, F. L. (TRW Space and Technology Group, Redondo Beach, CA 90278): 'Electrostatic Waves in the Bow Shock at Uranus', *Journ. Geophys. Res.* **94** (1989), 13, 367–13, 376.

Electrostatic emissions measured by the Voyager 2 plasma wave detector (PWS) during the inbound crossing or the Uranian bow shock are shown to differ in some aspects from the waves measured during bow shock crossings at Jupiter and Saturn. The wave amplitudes in the foot of the bow shock at Uranus are in general much lower than those detected at the other outer planets due to the unusually enhanced solar wind ion temperature during the crossing. This reduces the effectiveness of wave-particle interactions in heating the incoming electrons. Strong wave emissions are observed in the shock ramp that possibly arise from currents producing a Buneman mode instability. Plasma instrument (PLS) and magnetometer (MAG) measurements reveal a complicated shock structure reminiscent of computer simulations of high-Mach number shocks when the effects of anomalous resistivity are reduced, and are consistent with high ion temperatures restricting the growth of electrostatic waves.

12. SATELLITES OF URANUS

Malhotra, R., Fox, K., Murray, C. D. and Nicholson, P. D. (Department of Physics, Clark Hall, Cornell University, Ithaca, NY 14853): 'Secular Perturbations of the Uranian Satellites: Theory and Practice', *Astron. Astrophys.* **221** (1989), 348–358.

The secular solution of Dermott and Nicholson (1986) for the Uranian satellites is compared with a 'synthetic' secular solution derived from the Fourier analysis of a long numerical integration (10^6 orbital periods of Miranda) of the full equations of motion. Although there is excellent agreement between the results for the secular frequencies associated with the inclination and node terms, there are large discrepancies when some eccentricity and pericenter frequencies are compared. The differences are particularly noticeable for the frequencies which are dominated by the satellites Umbriel, Titania and Oberon, and we show that they are primarily due to the 3 : 2 Titania-Oberon and 2 : 1 Umbriel-Titania near-commensurabilities. We derive a simple, revised secular perturbation theory which incorporates the averaged secular effect of first-order near-resonances. With the inclusion of the effects of the above near-resonances, the largest error in the secular frequencies is reduced from 16% to less than 3%. The revised lowest order secular theory provides satisfactory agreement with the results of our numerical integrations, and obviates the need for empirical correction factors to reconcile theoretical values of secular eigenfrequencies with those obtained from numerical integrations (Laskar, 1986). A comparison of our revised eigenfrequencies with the 'corrected' frequencies of Laskar and Jacobson (1987) shows that their determination of the satellite masses is unlikely to be substantially in error.

Thomas, P., Weitz, C. and Veverka, J. (Center for Radiophysics and Space Research, Cornell University, Ithaca, New York, NY 14853): 'Small Satellites of Uranus: Disk-Integrated Photometry and Estimated Radii', *Icarus* **81** (1989), 92–101.

Disk-integrated photometry from Voyager 2 clear-filter images is used to compare properties of the ten small satellites that orbit Uranus interior to Miranda. Two satellites, 1985U1 Puck and 1986U7 Cordelia, are resolved. Observations of Puck cover phase angles of 15 to 33° and yield a phase coefficient of 0.031 ± 0.003 mag/deg. The mean radius of Puck is 77 ± 3 km; its geometric albedo (Voyager clear filter, $\lambda \sim 0.48\ \mu$m) is 0.074 ± 0.008. Cordelia's albedo is found to be similar to that of Puck. This result suggests that all the small satellites may be low-albedo objects with reflectances similar to, but slightly higher than, those of the ring material. Satellite radii calculated with the assumption that they have the same reflectance as Puck range from 13 ± 2 km (1986U7 Cordelia) to 55 ± 6 km (1986U1 Portia). The ϵ-ring shepherds have calculaled radii of 13 ± 2 and 16 ± 2 km; these radii correspond to approximate masses of 1.4 and 2.5×10^{19} g, respectively. No useful constraints on the colors of the small satellites can be obtained given the low signal-to-noise ratio of the color data. We estimate that the opposition magnitudes range from +20.4 for Puck to +23.9 and 24.2 for the two ϵ-ring shepherds.

16. VENUS

Anderson, C. M.: 'Venus: Behind the Veil', *Planetary Report* **9**(5) (1989) 4–5.

Bankwitz, P. and Bankwitz, E. (Akademie der Wissenschaften der DDR, Zentral Institut für Physik der Erde, Telegrafenberg, Potsdam, DDR 16561): 'Venus Surface Features from a Geological Point of View', *Zeits. geol. Wiss. Berlin* **17** (1989), 719–745.

The radar images of the Venus surface made by the Soviet spacecrafts Venera 15 and 16 are impressive because of the contrast richness and quantity of various features which resemble geological features on the Earth. Although the surface temperature is about 460°C, and the physical conditions are very special, the surface of Venus is solid, and there are many structures with geological informations. Due to the pressure on the hot surface, many features will be kept uphold, even brittle ones. Plastic deformations seem to be widespread in the Venus crust.

Bishop, J. (Department of Atmospheric, Oceanic and Space Sciences, University of Michigan, Space Research Building, Ann Arbor, MI 48109): 'Venus Exospheric Structure: The Role of Solar Radiation Pressure', *Planet. Space Sci.* **37** (1989), 1063–1077.

The existence of a 'hot' population of hydrogen atoms in the Venus exosphere is well known. In the outer coronal region where it is dominant ($r \gtrsim 2.0\,R_V$), hydrogen atoms are also subject to a relatively strong radiation pressure exerted by resonant scattering of solar Lyman-α photons. Collisionless models illustrating the consequent structure are discussed, with the nonthermal population mimicked by a dual Maxwellian exobase kinetic distribution. In these models, a considerable fraction of the "hot" atoms outside 2.0 R_V belongs to the quasi-satellite component, this fraction exceeding 1/2 for $4.0\ R_V \lesssim r \lesssim 10.0\,R_V$. Quasi-satellites also raise the kinetic temperature near $2.0 R_V$ by ~150 K. Solar ionization of bound atoms occurs mainly outside the ionopause, yielding a partial escape flux $\geqslant 2 \times 10^6 \text{cm}^{-2} \text{s}^{-1}$ over the dayside exobase for assumed solar conditions. The inclusion of a cold exobase prescribed by *Pioneer Venus* observations has little influence on the outer region (in particular, the quasi-satellite component is unaltered) except that the transition to 'hot' kinetic character occurs closer to the exobase on the nightside due to the colder main exobase temperatures there. Lastly, a 'tail' of bound atoms is formed as in the terrestrial situation.

Campbell, D. B., Head, J. W., Hine, A. A., Harmon, J. K., Senske, D. A. and Fisher, P. C. (National Astronomy and Ionosphere Center, Cornell University, Ithaca, NY 14853): 'Styles of Volcanism on Venus: New Arecibo High Resolution Radar Data', *Science* **246** (1989), 373–377.

Arecibo high-resolution (1.5 to 2 km) radar data of Venus for the area extending from Beta Regio to western Eisila Regio provide strong evidence that the mountains in Beta and Eisila Regiones and plains in and adjacent to Guinevere Planitia are of volcanic origin. Recognized styles of volcanism include large volcanic edifices on the Beta and Eisila rises related to regional structural trends, plains with multiple source vents and a mottled appearance due to the ponding of volcanic flows, and plains with bright features surrounded by extensive quasi-circular radar-dark halos. The high density of volcanic vents in the plains suggests that heat loss by abundant and widely distributed plains volcanism may be more significant than previously recognized. The low density of impact craters greater than 15 km in diameter in this region compared to the average density for the higher northern latitudes suggests that the plains have a younger age.

Clarke, D., Hendry, M. A. and McInnes, C. R. (Glasgow University Observatory, Glasgow G20 0TL, Scotland, U.K.): 'The Contribution of Venus to the Brightness of the Zodiacal Light', *Planetary Space Science* **37** (1989), 1141–1144.

Hong's model (1985) for the brightness behaviour of the Zodiacal Light has been applied to investigate the possibility of detecting an enhancement of intensity on the sunward side of Venus. It is shown that any detectable effect would not be observed beyond a few tenths of an arc minute from Venus, making it unlikely to be seen by the unaided eye.

Dethloff, K. (Academy of Sciences of the GDR, Heinrich Hertz Institut, Observatorium Atmosphärenforschung, Kuhlungsborn, 2565, GDR): 'Barotropic Unstable Planetary Waves in the Middle Atmosphere of Venue', *Zeits. Meteorol.* **39** (1989), 175–178.

The investigations by Elson (1982), Michaelangeli *et al.* (1987) and Dethloff, Zelck (1987) suggested that barotropic instability may be an important process in the middle atmosphere of Venus. Elson (1982) and Michelangeli *et al.* (1987) solved the linearized barotropic vorticity equation by time integration to find the fastest growing, barotropically unstable wave mode. This mode had the zonal wave number 2.

In a similar manner Dethloff, Zelck (1987, later only DZ) solved the linearized barotropic vorticity equation with friction as an eigenvalue problem. DZ investigated the zonal wind profiles of Newman *et al.* (1984) and Walterscheid *et al.* (1985), derived from the Pioneer Venus data in the middle atmosphere for instability. They also found that wavenumber 2 has the greatest instability rates with a phase speed in the range of 4 days. This phase speed is in agreement with satellite radiance data which indicated the presence of planetary-scale waves in the Venus atmosphere.

Now the results of the Venera 15 and Venera 16 missions are available as presented by Oertel *et al.* (1985). On the basis of measurements with the Fourier spectrometer Schäfer *et al.* (1988) determined zonal wind profiles in the middle atmosphere of Venus. The aim of this paper is to investigate these zonal wind profiles for barotropic instability, to compute the meridional structure of barotropic unstable planetary waves in the Venus atmosphere and to compare with data.

Donahue, T. M., Bertaux, J.-L. and Clarke, J. T. (Department of Atmospheric, Oceanic and Space Sciences, Space Physics Research Lab., University of Michigan, Ann Arbor, MI 48109–2143): 'Deuterium on Venus', *Nature* **340** (1989), 513–514.

Grimm, R. E. and Solomon, S. C. (Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02138): 'Tests of Crustal Divergence Models for Aphrodite Terra, Venus', *Journ. Geophys. Res.* **94** (1989), 12103–12131.

Aphrodite Terra, the largest highland region of Venus, is a likely site of mantle upwelling, active volcanism, and extensional tectonics. We examine three alternative kinematic models for the interaction of mantle convection and the surface: one in which little horizontal surface displacement results from mantle flow ("vertical tectonics"), one in which shear strain from large horizontal displacements is accommodated only in narrow zones of deformation ("plate divergence"), and one in which strain from large horizontal motions is broadly accommodated ("distributed deformation"). In support of a divergent plate model for Aphrodite, Head and Crumpler have cited the presence of an organized system of lineaments held to be analogues to oceanic fracture zones; small-scale bilateral symmetry of topographic elements, hypothesized to be rifted and separated relief analogous to some terrestrial oceanic plateaus: and subsidence of topography proportional to the square root of distance consistent with that expected for a divergent thermal boundary layer. We undertake quantitative tests of each of these assertions, and we compare the results with those from similar tests of the Mid-Atlantic Ridge. We find that apart from the long-wavelength symmetry of broadly elevated regions, there is no convincing evidence for regional bilateral symmetry of features several hundred kilometers in size on either planet. The fit of the topography of Aphrodite to that of a thermal boundary layer is in general much poorer than for the Earth, and so other mechanisms such as dynamic uplift or crustal thickness variations must dominate the topography. The broad saddle-shaped region between Thetis and Atla Regiones shows the best fit to the root-distance relation, yielding apparent spreading half rates of a few centimeters per year, but the goodness of fit and apparent spreading rates are quite sensitive to the distance range analyzed. Calculation of a single pole of relative motion for the entire postulated system of transform faults shows that the inferred fracture zone traces are not consistent with a simple two-plate model, regardless of past pole motions. A multiple-plate geometry is therefore called for, and one or more of the lineaments must act as a plate boundary along nearly its full length, if the plate divergence hypothesis is correct. Such a boundary would be distinguishable from other lineaments by geological evidence for recent nontransform motion in forthcoming Magellan radar images. In the absence of such evidence, as long as the existence and distribution of the lineaments are verified, then broad disruption of a thin lithosphere is favored. In such a model, lineaments may be surface manifestations of mantle convective flow. A model dominated by primarily vertical tectonics is tenable only if the lineaments are not confirmed by Magellan.

Khentov, A. A. (Gor'kii State University, USSR): 'Interpretation of the Observed Rotation of Venus', *Soviet Astron* **33** (1989), 105–106.

The possibility of a resonance interpretation of the observed rotation of Venus is ruled out by a joint analysis of current experimental and analytical results.

Kim, J., Nagy, F., Cravens, T. E. and Kliore, A. J. (Space Physics Research Laboratory, Department of Atmospheric, Oceanic and Space Sciences, University of Michigan, Ann Arbor, MI 48109): 'Solar Cycle Variations of the Electron Densities near the Ionospheric Peak of Venus', *Journ. Geophys. Res.* **94** (1989), 11997–12002.

Photochemical equilibrium calculations of electron and ion densities, appropriate for altitudes below about 180 km, were carried out for the Venus dayside ionosphere corresponding to solar cycle maximum and minimum conditions. The results were compared with data from radio occultation measurements. The agreement between the calculations and measurements was in general quite good. These comparisons indicate that the most commonly used neutral atmosphere model of Venus (Hedin *et al.*, 1983) predicts densities which are somewhat low near the electron density peak for solar cycle maximum, but provides surprisingly good predictions for solar cycle minimum conditions.

Kliore, A. J. and Mullen, L. F. (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91102): 'The Long-Term Behavior of the Main Peak of the Dayside Ionosphere of Venus During Solar Cycle 21 and Its Implications on the Effect of the Solar Cycle Upon the Electron Temperature in the Main Peak Region', *Journ. Geophys. Res.* **94** (1989), 13,339–13,351.

One hundred four measurements of the peak electron density in the dayside ionosphere of Venus (solar zenith angle (SZA) $< 80°$), along with 11 Venera 9–10 measurements, were analyzed in order to establish the response of the dayside peak to the varying solar EUV flux over the maximum to minimum phase of solar cycle 21 (December 1979 to December 1986). The relationship of the peak electron density normalized to SZA $= 0°$ and the EUV flux index was found to be $N_m = N_{150}(F_{\mathrm{EUV}}/150°)^{0.376}$, which is in agreement with theoretical predictions based on Chapman theory modified for photochemical processes. The corresponding dependence on solar zenith angle at any given value of F_{EUV} was found to be $N_m(\mathrm{SZA}) = N_0 \cos^{0.511}(\mathrm{SZA})$. The altitude of the peak was found to be independent of either SZA or F_{EUV}. When the CO_2^+ production rate $P_{CO_2^+}$ was computed using the Venus International Reference Atmosphere (VIRA) upper atmosphere model and the EUV flux computed from Hinteregger's (1981) formulae, it was found that the theoretically expected value of 0.5 for $\Delta \log (N_m/T_e^{0.275})/\Delta \log(P_{\mathrm{CO}_2^+})$ was not obtained. Instead, when the assumption was used that $T_e = T_n$ at the altitude of the peak, and the solar cycle corrections given in the VIRA model were applied, a log-log slope of 0.454 ± 0.010 was obtained, and a value of 0.485 ± 0.009 resulted when the VTS3 Venus thermosphere model (Hedin *et al.*, 1983) was used. This suggested that the assumption $T_e = T_n$ is not satisfactory. When the electron temperature T_e^* was extrapolated from the electron temperature probe model (Theis *et al.*, 1980) to $h = 140$ km and a solar cycle variation of $T_e = T_e^* [1 + K(\bar{F}_{10.7} - 190)/190]$ was assumed, the theoretically expected value of 0.500 ± 0.010 was obtained for $\Delta \log (N_m/T_e^{0.275})/\Delta \log (P_{\mathrm{CO}_2^+})$ for $K = 0.30$ when the VIRA model was used and $K = 0.35$ when the VTS3 model was employed. This result implies that the electron temperature at the altitude of the ionosphere main peak on Venus decreases by only about 25% from solar maximum to minimum, in contrast to a decrease of about 50–75% at altitudes of above 200 km.

Marchenkov, K. I. and Zharkov, V. N. (Shmidt Institute of Earth Physics, USSR Academy of Sciences, Moscow, USSR): 'Stresses in the Venus Crust and the Topography of the Mantle Boundary', *Sov. Astron Lett.* **15** (1989), 77–81.

A joint analysis of the interrelated topography and nonequilibrium gravity-field component, based on spherical harmonics $n = 3$–18, yields clues as to the character of the topography of the crust-mantle interface as well as the crustal tension-compression stresses beneath the surface of Venus. Several realistic models are considered, including some with an asthenosphere. Depending on the model, the deflection of the Mohorovičić boundary from its average level ranges from about +80 km (downward) to −20 km (upward), but on the whole it is fairly smooth. The stresses range from about +600 bar (tension) to −700 bar (compression).

Markov, M. S., Smirnov, Ya. B. and Dobrzhinetskaya, L. F. (Geological Institute of the USSR Academy of Sciences, USSR): 'Tectonics of the Venus and the Earth Precambrian', *Earth, Moon and Planets* **45** (1989), 101–113.

Analyzing the tectonics of planets and their satellites we use all the information available from the studies of the Earth and other celestial bodies such as the Moon, Mars and Mercury. An important condition in such analysis is naturally the scale of the phenomena compared. Most surface structures of Venus are known to have no direct analogues on the surface of the present Earth, with its global systems of mid-oceanic ridges, deep trenches and vast lithospheric plates. This might be due to the sharp differences in the present thermal regimes of the Earth and Venus. It has already been suggested in numerous papers that the key to the genesis of the Cytherean surficial structures must be looked for in the geodynamics of the Early Precambrian Earth.

Such an approach appears very logical indeed since the rheology of the present Cytherean crust must be closer to that of the Precambrian rigid lithosphere of the Earth which is as if 'floating' in the low-viscous asthenosphere. An attempt has therefore been made to evaluate certain elements in the tectonics of Venus through the rheological properties of its crust comparing structural formation in the low-viscous layers of the Earth crust in the Early Precambrian with data on the morphology of structures on the surface of Venus.

Russell, C. T., von Dornum, M. and Scarf, F. L. (Institute of Geophysics and Planetary Physics, University of California, Los Angeles, CA 90024): 'Source Locations for Impulsive Electric Signals Seen in the Night Ionosphere of Venus', *Icarus* **80** (1989), 390–415.

The rate of occurrence of impulsive bursts of VLF noise in the dark, low altitude, Venus ionosphere increases rapidly with decreasing altitude. Mapping these occurrences as a function of planetary latitude and longitude shows that these signals occur more frequently at some planetary longitudes than others. In each of the three seasons that can be studied there were enhanced occurrence rates over Atla. A stronger correlation is found when the signals are mapped by local time and latitude with a strong enhancement in the occurrence of signals around 2100 LT. It is possible that the signals occur frequently from 2100 LT to dusk and onto the dayside but these signals cannot propagate through the dense ionosphere. In an observing period of 30 sec there are impulsive signals 70% of the time at 160 km in the region of maximum occurrence. The occurrence rates also increase with decreasing latitude. The rate at the equator is 1.6 times the rate at 30° latitude. These properties are consistent with lightning-generated sources for the waves. A rough estimate of the inferred rate of occurrence of lightning on Venus shows it to be equal to or greater than that on Earth.

Tarakanov, Yu. A., Kambarov, N. Sh. and Prikhod'ko, V. A. (O. Yu. Shmidt Institute of Earth Physics, USSR Academy of Sciences, Moscow State University, Moscow, USSR): 'Estimation of the Depth of the Lithosphere of Venus from its Gravitational Field', *Soviet Astron.* **33** (1989), 33–37.

Density inhomogeneities do not disturb the flattening of Venus, but they fully determine the horizontal axes of the geodetic triaxial ellipsoid. The measured flattening of Venus is of ancient origin and is maintained by a very deep lithosphere with a thickness of about 900 km. The lithosphere of Venus may be thicker and more rigid than the Earth's if the mantle of Venus is very dry. The density of the Venusian atmosphere may be very high as a result of outgassing of the mantle.

Taylor, H. A., Jr., Kramer, L., Cloutier, P. A. and Russell, C. T. (Goddard Space Flight Center, Greenbelt, MD 20771): 'Comment on "Distribution of Whistler Mode Bursts at Venus" by F. L. Scarf, K. F. Jordan and C. T. Russell: and Reply', *Journ. Geophys. Res.* **94** (1989), 12087–12093.

18. SPACE UTILIZATION

Alexander, D. B., Zuberer, D. A. and Hubbell, D. H. (Texas A&M University, College Station, TX 77843): 'Microbiological Considerations for Lunar-Derived Soils', *ASA-CSSA-SSSA Special Publication* **52** (1989), 245–255.

Terrestrial soils are composed of inorganic particles, water, air, organic matter, and living organisms

(Alexander, 1977; Brady, 1974). Lunar regolith lacks all but one of these essential components: mineral matter. It contains no living organisms, no water, no organic matter, and only vanishingly small concentrations of the gases that comprise the major portion of the Earth's atmosphere–N_2 and O_2 (Williams and Jadwick, 1980). To produce from this material a 'soil' that will support plant growth, these components must be introduced into the lunar environment. In this chapter we will discuss some of the contributions that will be required of microorganisms to make the development of such a soil possible.

Atzel, A., Schwehm, G., Coradini, M., Hechler, M., De Lafontain, J. and Eiden, M. (Directorate of Scientific Programmes, ESTEC, Noordwijk, The Netherlands): 'Rosetta/CNSR – ESA's Planetary Cornerstone Mission', *ESA Bulletin* **59** (1989), 19–30.

Rosetta – the Comet-Nucleus Sample-Return mission – is one of the four scientific 'Cornerstone' missions to which the Agency has committed itself in its approved Long-Term Programme 'Horizon 2000'. The comet-nucleus samples that it will provide will allow us to study some of the most primitive material in the solar system and the physical and chemical processes that marked the system's beginnings 4.6 billion years ago.

Averner, M. M. (NASA Headquarters, Washington, DC 20546): 'Controlled Ecological Life Support System', *ASA-CSSA-SSSA Special Publication* **52** (1989), 145–154.

The National Aeronautics and Space Administration (NASA) controlled ecological life support system (CELSS) program was initiated in 1978 by the Life Sciences Division, Office of Space Science and Applications (OSSA) with the premise that NASA's goals would eventually include extended-duration missions with sizeable crews requiring capabilities beyond the ability of conventional life support technology. Currently, as mission duration and crew size increase, the mass and volume required for consumable life support supplies also increases linearly. Under these circumstances, the logistics arrangements and associated costs for life support resupply will adversely affect the ability of NASA to conduct long-duration missions. A solution to the problem is to develop technology for the recycling of life support supplies from wastes. The CELSS concept is based upon the integration of biological and physicochemical processes to construct a system that will produce food, potable water, and a breathable atmosphere from metabolic and other wastes, in a stable and reliable manner A central feature of a CELSS is the use of green plant photosynthesis to produce food, with the resulting production of O_2 and potable water, and the removal of CO_2.

Barnes-Svarney, P.: 'Neighbourhood Watch; Hubble's View of the Solar System', *Final Frontier* **2**(6) (1989), 32–33, 60.

NASA's long-awaited space telescope will explore the Solar System without ever leaving Earth orbit.

Baum, R. M.: 'Voyager 2 Answering Scientists' Major Questions about Neptune', *Chemical and Engineering News* **67**(37) (1989), 23–28.

Spacecraft gathers information on planetary satellites, rings, weather patterns, magnetic field, and period of rotation.

Bekey, I.: 'NASA's Plans for Manned Missions to the Moon and Mars', *Spaceflight* **31** (1989), 297–302.

Bender, P. L., Ashby, N., Vincent, M. A. and Wahr, J. M. (Joint Institute for Laboratory Astrophysics, University of Colorado, Boulder, CO 80309): 'Conceptual Design for a Mercury Relativity Satellite', *Adv. Space Res.* **9**(9) (1989), 113–116.

It was shown earlier that 1×10^{-14} Doppler data and 3 cm accuracy range measurements to a small Mercury Relativity Satellite in a polar orbit with 4-hour period can give high-accuracy tests of gravitational theory. A particular conceptual design has been developed for such a satellite, which would take less than 10% of the approach mass for a possible future Mercury Orbiter Mission. The spacecraft is similar to the Pioneer Venus Orbiter, but scaled down by about a factor 4 in linear dimensions. The cylindrical surface of the spin-stabilized spacecraft is highly reflecting to minimize thermal input from the sun. A despun antenna 30 cm in diameter is used for tracking. The transmitted power is roughly 0.2 watts at X-band and 0.5 watts at X-band. The orbit parameters for individual eight-hour arcs and the gravity field of Mercury through degree and order 10 are determined mainly from the Doppler data. A 50 MHz K-band sidetone system provides the basic ranging accuracy. The spacecraft mass is 50 kg or less.

Bents, D. J. (Lewis Research Center, Cleveland, Ohio 44135): 'Preliminary Assessment of Rover Power Systems for the Mars Rover Sample Return Mission', NASA Technical Memorandum Series, NASA-TM-102003 (1989), pp. 26.

Four isotope power system concepts are presented and compared on a common basis for application to on-board electrical prime power for an autonomous planetary rover vehicle. A representative design point corresponding to the Mars Rover Sample Return (MRSR) preliminary mission requirements (500 W) was selected for comparison purposes. All systems concepts utilize the GPHS isotope heat source developed by DOE. Two of the concepts employ thermoelectric (TE) conversion: one using the GPHS RTG used as a reference case, the other using an advanced RTG with improved thermoelectric materials. The other two concepts employed are dynamic isotope power systems (DIPS): one using a closed Brayton cycle (CBC) turboalternator, and the other using a free piston Stirling cycle engine/linear alternator (FPSE) with integrated heat source/heater head. Near term technology levels have been assumed for concept characterization using component technology figure-of-merit values taken from the published literature. For example, the CBC characterization draws from the historical test database accumulated from space Brayton cycle subsystems and components from the NASA 'B' engine through the mini-BRU. TE system performance is estimated from Voyager/MHW-RTG performance estimates considering recent advances in TE materials under the DOD/DOE/NASA SP-100 and NASA CST1 programs. The Stirling DIPS system is characterized from scaled-down Space Power Demonstrator Engine (SPDE) data using the GPHS directly incorporated into the heater head. The characterization/-comparison results presented here differ from previous comparison of isotope power (made for LEO applications) because of the elevated background temperature on the Martian surface compared to LEO, and the higher sensitivity of dynamic systems to elevated sink temperature. Although dynamic systems have historically shown advantages of lower specific mass and reduced isotope inventory per delivered electrical watt, the mass advantage of dynamic systems is significantly reduced for this application due to Mars' elevated background temperature.

Bova, B.: 'To Mars and Beyond', *Air and Space* **4**(4) (1989), 42–47.

When people travel to other planets, what will they have under the hood?

Brooks, R. A. and Flynn, A. M. (MIT Artificial Intelligence Lab., Cambridge, MA 02139): 'Fast, Cheap and Out of Control: A Robot Invasion of the Solar System', *Journ. British Interplanetary Soc.* **42** (1989), 478–485.

Complex systems and complex missions take years of planning and force launches to become incredibly expensive. The longer the planning and the more expensive the mission, the more catastrophic if it fails. The solution has always been to plan better add redundancy, test thoroughly and use high quality components. Based on our experience in building ground based mobile robots (legged and wheeled) we argue here for cheap, fast missions using large numbers of mass produced simple autonomous robots that are small by today's standards (1 to 2 kg). We argue that the time between mission conception and implementation can be radically reduced, that launch mass can be slashed, that totally autonomous robots can be more reliable than ground controlled robots, and that large numbers of robots can change the tradeoff between reliability of individual components and overall mission success. Lastly, we suggest that within a few years it will be possible at modest cost to invade a planet with millions of tiny robots.

Bugbee, B. G. and Salisbury, F. B. (Utah State University, Logan, UT 84322): 'Controlled Environment Crop Production: Hydroponic vs. Lunar Regolith', *ASA-CSSA-SSSA Special Publication* **52** (1989), 107–130.

This chapter discusses two aspects of controlled-environment crop production in a lunar colony. First, we report findings about the effects of optimal aerial and root-zone environments on plant growth. Second, liquid hydroponic systems are compared with lunar regolith as substrates for plant growth.

Burke, J. D. (Jet Propulsion Laboratory, Pasadena, CA 91109): 'Lunar Observatories', *Spaceflight* **31** (1989), 308–309.

Because the Moon's polar axis is inclined at only one and one-half degrees from the normal to the plane of the ecliptic, sunlight is nearly horizontal at the lunar poles. As a consequence, in some polar craters perpetual darkness exists, while on the rims of other craters some portion of the solar disc may always be above the horizon. Although two Lunar Orbiters did photograph the polar regions, our present knowledge of topographic detail is not sufficient to tell whether or not there really are mountains of perpetual light; however, we can be confident that much of the lunar surface around the poles is perennially dark.

Clarke, T. C. and Fanale, F. P.: 'Galileo: The Earth Encounters', *Planetary Report* **9**(5) (1989), 6–10.

With the sensational exploration of Neptune this past August by *Voyager 2*, every planet in the solar system has now been encountered from deep space by Earth-launched spacecraft except Pluto . . . and Earth. When *Galileo* thunders off its Cape Canaveral launch pad, the stage will be set for not only one but two extraordinary Earth encounters.

Compton, W. D.: 'Where No Man Has Gone Before: A History of Apollo Lunar Exploration Missions', *NASA Special Publication Series, NASA-SP-4214* (1989), pp. 420.

Covault, C.: 'NASA Accelerates Lunar Base Planning as Station Changes Draw European Fire', *Aviation Week and Space Technology* **131**(12) (1989), 26–27.

Covault, C.: 'Galileo Launch to Jupiter by Atlantis Culminates Difficult Effort with Shuttle', *Aviation Week & Space Technology* **131**(15) (1989), 58, 63–65, 67.

Launch of the Galileo spacecraft to Jupiter by the space shuttle Atlantis will culminate a tortuous 14-year relationship between the shuttle program and the Jupiter orbiter/probe effort.

Covault, C.: 'Shuttle Launch of Galileo Jupiter Mission Highlights U.S. Space Science Renaissance', *Aviation Week and Space Technology* **131**(17) (1989), 22–24.

Cuzzi, G. (NASA Ames Research Center, Moffet Field, CA 94035): 'Saturn: Jewel of the Solar System', *Planetary Report* **9**(4) (1989), 12–15.

The *Voyager* Saturn encounters in November 1980 and August 1981 can leave little doubt as to the poverty of our collective scientific imagination and the absolute necessity for exploration. Naturally, we had our theories and our consensus wisdom. Based on these, we planned a variety of observation sequences months in advance and eagerly awaited the results. We knew we would get answers to some of our questions, and we knew there would be some surprises. But we had no clue as to the wealth of phenomena that would be revealed when the *Voyagers* entered the Saturn system.

Arriving at JPL (Jet Propulsion Laboratory) late in the evening a week before the *Voyager 1* encounter, I found the entire lab complex ablaze with lights and alive with throngs of people. Colleagues from across the country had gathered to get a little closer look at the new data and toss around ideas, and the international press corps was out in strength. There was a mood of festival in the air. A similar feeling pervaded the *Voyager 2* encounter nine months later.

Discoveries came at a fast and furious clip during both Saturn encounters. Much of the "instant science" that we all did in those hectic weeks has (mercifully) been forgotten, replaced by slower but steadier strides in the years that followed. In this article, there is only enough space for some of the highlights dealing with the rings, the icy satellites and Titan.

DeVincenzi, D. L. and Klein, H. P. (Space Science Division, NASA/Ames Research Center, Moffett Field, CA 94035): 'Planetary Protection Issues for Sample Return Missions', *Adv. Space Res.* **9** (1989), (6)203–(6)206.

Sample return missions from a comet nucleus and the Mars surface are currently under study in the US, USSR, and by ESA. Guidance on Planetary Protection (PP) issues is needed by mission scientists and engineers for incorporation into various elements of mission design studies. Although COSPAR has promulgated international policy on PP for various classes of solar system exploration missions, the applicability of this policy to sample return missions, in particular, remains vague. In this paper, we propose a set of implementing procedures to maintain the scientific integrity of these samples. We also propose that these same procedures will automatically assure that COSPAR-derived PP guidelines are achieved. The recommendations discussed here are the first step toward development of official COSPAR implementation requirements for sample return missions.

Dornheim, M. A.: 'Galileo to Perform First Dedicated Study of Jupiter's Atmosphere and Satellites', *Aviation Week & Space Technology* **131**(15) (1989), 69–70, 75, 77.

Galileo will be the fifth spacecraft to study Jupiter, but will be much more capable than its predecessors.

Drees, L. R. and Wilding, L. P. (Texas A&M University, College Station, TX 77843): 'Pedology, Pedogenesis, and the Lunar Surface', *ASA-CSSA-SSSA Special Publication* **52** (1989), 69–84.

In the waning years of the 20th century and into the 21st century, soil scientists will be faced with new and unique opportunities and challenges. Not all of these challenges will be focused on solving problems in the terrestrial environment. Policy decisions by the U.S. Government point towards increased activity in space exploration, including a manned lunar base. From an agronomic standpoint, lunar materials are not well understood. They need to be investigated, not only to satisfy the scientists basic inquisitiveness, but to explore the feasibility of using in situ or modified lunar materials as a plant growth medium.

Food crops grown in a lunar soil would be an integral component of a bioregenerative life support

system for extended lunar habitation. Lunar materials may provide favorable attributes as a medium for growing plants in a controlled environment: physical support, nutrient reserves, buffering capacity, low maintenance, medium for recycling waste by-products, and nutrient recycling. Live plants also provide a psychological and aesthetic quality of an Earth-like environment.

To better understand how the lunar regolith may be converted or changed to a viable soil material under a human life support environment, the processes and reactions that may occur in an Earth-like environment need to be explored. Although large-scale plot experiments are not feasible for lunar soil research, it is possible to examine analogous processes of soil formation in a terrestrial environment. Our long-term experience with crop production and soil-plant-environmental relationships enables us to better understand processes of soil formation and environmental responses. This basic understanding can then be extrapolated to the processes that would yield a viable lunar soil. In this context, soil concepts will be discussed from a pedological viewpoint.

Duke, M. B., Mendell, W. W. and Roberts, B. B. (NASA Johnson Space Center, Houston, TX 77058): 'Strategies for a Permanent Lunar Base', *ASA-CSSA-SSSA Special Publication* **52** (1989), 23–36.

Planned activities at a manned lunar base can be categorized as supporting one or more of three possible objectives: scientific research, exploitation of lunar resources for use in building a space infrastructure, or attainment of self-sufficiency in the lunar environment as a first step in planetary habitation. Scenarios constructed around each of the three goals have many common elements, particularly in the early phases. The cost and the complexity of the base, as well as the structure of the Space Transportation System, are functions of the chosen long-term strategy. A real lunar base will manifest some combination of characteristics from these idealized end members.

Eberhart, J.: 'Neptune on the Horizon', *Science News* **136** (1989), 111.

Eberhart, J.: 'What a Way to Leave the Solar System', *Science News* **136** (1989), 148, 157.

Voyager 2's journey past distant Neptune and its moons yielded a host of new discoveries and raised just as many new questions. Neptune, long known for its moons Triton and Nereid, now has eight known satellites, and scientists in the Voyager control center at NASA's Jet Propulsion Laboratory in Pasadena, Calif., continued poring over data this week in search of more. In addition, the craft finally detected radio emissions from the planet (evidence that it has a magnetic field), photographed its strange family of rings, and delighted scientists and public alike with its spectacular pictures of Triton.

Eberhart, J.: 'Galileo to Jupiter', *Science News* **136** (1989), 218–219.

Gathering treasures on its loop-the-loop journey.

Ehrlich, H. L. (Rensselaer Polytechnic Institute, Troy, New York, NY 12180): 'Role of Microbes to Condition Lunar Regolith for Plant Cultivation', *ASA-CSSA-SSSA Special Publication* **52** (1989), 139–144.

Fairchild, K. O. and Roberts, B. B. (NASA-Johnson Space Center, Houston, TX 77058): 'Options for the Human Settlement of the Moon and Mars', *ASA-CSSA-SSSA Special Publication* **52** (1989), 1–22.

People have pondered visiting and living on the Moon and Mars since the dawn of civilization. We are only now entering into the era where such dreams are realizable in the foreseeable future. The nation, through the National Aeronautics and Space Administration (NASA), is seriously considering

the steps that would be required to establish permanent habitation on the Moon or Mars. Instead of brief sorties into space, NASA is defining options for evolutionary growth that begins with continuous human presence at a low Earth orbit (LEO) space station and culminates in permanent facilities on the Moon and Mars. How this can best be achieved is a matter of some controversy, subject to technical, economic, political, and cultural pressures.

Finnerty, D. F. (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109): 'The Voyager Interstellar Mission', *Planetary Report*, **9**(4) (1989), 23–25.

While all eyes have been focusing on the upcoming *Voyager 2* flyby of Neptune, *Voyager* Project members have been quietly considering new challenges for the veteran pair of spacecraft. Mission managers are planning to operate these spacecraft well into the next century–by which time they will have left the planets of the solar system far behind–in the *Voyager* Interstellar Mission (VIM).

Just how long are the *Voyagers* likely to survive, and what are they likely to find along the way? How will logistics change when *Voyager* is no longer a priority mission? These are questions that mission planners are seeking to answer on the eve of the last *Voyager* planetary encounter.

Flood, D. J. and Appelbaum, J. (Lewis Research Center, Cleveland, OH 44135): 'Photovoltaic Power System Considerations for Future Lunar Bases', NASA Technical Memorandum Series, NASA-TM-102019 (1989), pp. 8.

The cost of transportation to the lunar surface places a premium on developing ultralightweight power system technology to support the eventual establishment of a lunar base. This paper will describe the photovoltaic technology issues to be addressed by the Surface Power program element of NASA's Project Pathfinder.

Gavaghan, H.: 'A Celestial Odyssey for Galileo', *New Scientist* **124** (1989), 53–57.

Next week, the space shuttle Atlantis should launch the spacecraft Galileo on a six-year journey to Jupiter. It will get there the quickest way it can, by flying once to Venus and twice to Earth.

Gooding, J. L., Carr, M. H. and McKay, C. P. (NASA/Johnson Space Center, Houston, Texas 77058): 'The Case for Planetary Sample Return Missions', EOS: Transactions, *American Geophysical Union* **70**, 745, 754–755.

Principal science goals for exploration of Mars are to establish the chemical, isotopic, and physical state of Martian material, the nature of major surface-forming processes and their time scales, and the past and present biological potential of the planet. Many of those goals can only be met by detailed analyses of atmospheric bases and carefully selected samples of fresh rocks, weathered rocks, soils, sediments, and ices. The high-fidelity mineral separations, complex chemical treatments, and ultrasensitive instrument systems required for key measurements, as well as the need to adapt analytical strategies to unanticipated results, point to Earth-based laboratory analyses on returned Martian samples as the best means for meeting the stated objectives.

Grard, R. J. L. (ESA Space Science Department, ESTEC, Noordwijk, The Netherlands): 'First Results from ESA's Plasma-Wave System aboard Phobos', *ESA Bulletin* **59** (1989), 31–33.

The two Soviet Phobos spacecraft were launched towards Mars, from Baykonur, on 7 and 12 July 1988. Their scientific objectives were to: (i) study the Sun and the interplanetary medium during their transit from Earth to Mars; (ii) explore the magnetosphere of the red planet; and (iii) perform a close flyby of one of the Martian moons, Phobos, after which the mission was named. Both spacecraft carried an experiment developed by ESA's Space Science Department, the so-called 'Plasma-Wave System (PWS)*'.

Helmke, P. A. and Corey, R. B. (University of Wisconsin, Madison, WI53706): 'Physical and Chemical Considerations for the Development of Lunar-Derived Soils', *ASA-CSSA-SSSA Special Publication* **52** (1989), 193–212.

The conversion of pristine geological materials to soils that are capable of supporting growth of higher plants offers exciting opportunities and challenges to scientists. For millions of years, soil-forming processes have been occurring on Earth, but analogous processes have not been active on the Moon because of the absence of water and life. Humankind has long been interested in soils and their ability to support plants, ranging from the ancient Egyptian understanding of the role the annual flooding of the Nile River played in enhancing soil fertility to the latest attempts at altering plant-soil interactions by using techniques of genetic engineering. The relative abundance of food and fiber in the industrialized countries is clear evidence of the success we have had in applying the knowledge of soils and plants accumulated during the last several centuries.

Henderson, B. W.: 'NASA Scientists Hope Mars Rover will be Precursor to Manned Flight', *Aviation Week & Space Technology* **131**(15) (1989), 85–86, 90, 94.

NASA's well-studied Mars Rover Sample Return mission would land a rover on Mars and return soil and rock samples to Earth, but scientists planning the science mission now hope it will serve chiefly as a precursor to manned exploration of the red planet.

Henninger, D. L. (Johnson Space Center, Houston, TX 77058): 'Life Support Systems Research at the Johnson Space Center', *ASA-CSSA-SSSA Special Publication* **52** (1989), 173–192.

Life support systems research involving biological systems is just beginning at the Johnson Space Center and is directed at the development of a lunar-derived agricultural soil capable of supporting plant growth in a manner similar to the way soils support plant growth on Earth. Upcoming research will be directed at a series of experiments directed at the response of lunar regolith to a variety of solvents, environmental conditions, and other induced weathering parameters. Transformation of lunar regolith into other minerals such as zeolites is under investigation. These experiments are directed at developing a long-term productive, resilient soil for plant growth that will be able to supply food to lunar base crews for years.

Other research that has been going on for many years at the Johnson Space Center has centered around what is known as the environmental control/life support systems (ECLSS) program. The goal of the ECLSS work has been to conduct the research and develop the technology to minimize the dependence of the life support systems on expendables that must be resupplied from Earth. These regenerative systems will be the mainstay of Space Station Freedom's life support systems.

Regenerative and the more complex bioregenerative life support systems of the controlled ecological life support system (CELSS) program will be combined to form a hybrid that will then represent a true CELSS. Development of such a life support system is critical to NASA's future long-duration missions. Space Station Freedom crew tours of duty will extend up to 24 wk and perhaps longer. Lunar base crews might spend years on the lunar surface without return to Earth and trips to Mars will involve several years. Life support systems will have to operate for a long time with minimum maintenance.

Hossner, L. R. and Allen, E. R. (Texas A&M University, College Station, TX 77843): 'Nutrient

Availability and Element Toxicity in Lunar-Derived Soils', *ASA-CSSA-SSSA Special Publication* **52** (1989), 85–92.

The cultivation of higher plants on the lunar surface will provide a means of supplying food and recycling O_2 for inhabitants of a lunar base. Ideally, the plants will be grown directly in the lunar regolith or 'soil'; however, as is common on Earth, soil amendments and fertilizers will be required to prevent deficiencies of essential plant nutrients. Further adjustments may be necessary to reduce the level of toxic elements that may occur. This chapter examines the use of lunar soils as a growth medium for higher plants and focuses on nutrient availability and element toxicity problems that may arise due to the chemical properties of the lunar regolith.

Kovtunenko, V. M., Kremnev, R. S., Rogovsky, G. N. and Sukhanov, K. G. (Babakin Engineering Research Centre, GLAVCOSMOS U.S.S.R., 102020 Moscow, USSR): 'Combined Program of Mars Exploration Using Automatic Spacecraft', *Acta Astronautica* **19** (1989), 451–461.

This report contains a retrospective review of results of the Moon, Venus and Mars research programs carried out by Soviet spacecraft during the past 30 years. It briefly outlines some technical characteristics of 'Luna' 'Mars' and 'Venera' spacecraft that provided solution of scientific problems of high priority in space research. Structural continuity in developing different types of spacecraft made it possible to reduce expenditures for the program of planetary studies. Mars research is a challenging direction in planetary studies. Some technological problems in developing spacecraft for the integrated Mars research program incorporating injection of a planet's satellite, landing on its surface and Martian samples return to the Earth are considered here.

Logsdon, J. M. (Space Policy Institute, George Washington University, Washington, DC 20052): 'Evaluating Apollo', *Space Policy* **5** (1989), 188–192.

When President Kennedy initiated Project Apollo he was aware that its value was political and symbolic rather than scientific. As such it was a substantial success, despite subsequent criticism. Its technological and scientific legacy has been far less productive, though it has significantly advanced our understanding of the history of the Moon and Solar System. Hardest to evaluate is the long-term historic impact of the project, but in terms of the centuries-long outward movement of humanity Apollo will certainly be seen as a pioneering step.

MacElroy, R. D., Tremor, J., Bubenheim, D. L. and Gale, J. (NASA Ames Research Center, Moffett Field, CA 94035): 'The CELSS Research Program: A Brief Review of Recent Activities', *ASA-CSSA-SSSA Special Publication* **52** 165–172.

Between 400 and 500 million yr ago, vascular plants began to emerge from the Earth's oceans to colonize the land. This evolutionary change had a marked effect on the subsequent history of the Earth's biosphere because land plants injected large amounts of O_2 into the atmosphere. A relatively rapid evolution of land animals followed, including the appearance of mammals and eventually humans. Today the Earth's biosphere, which includes the surfaces of the land as well as the oceans, is complex and full of activity. Its existence depends on the continuous use and re-use of many chemical elements. The cycling of the major elements is made possible by the contributions of the biological, geological, hydrological, and atmospheric activities of the biosphere.

McKay, C. P. and Davis, W. L. (NASA/Ames Research Center, Moffett Field CA 94035): 'Planetary Protection Issues in Advance of Human Exploration of Mars', *Adv. Space Res.* **9** (1989), (6)197–(6)202.

Current planetary quarantine considerations focus on robotic missions and attempt a policy of no biological contamination. The presence of humans on Mars, however, will inevitably result in biological contamination and physical alteration of the local environment. The focus of planetary quarantine must therefore shift toward defining and minimizing the inevitable contamination associated with humans. This will involve first determining those areas that will be affected by the presence of a human base, then verifying that these environments do not harbor indigenous life nor provide sites for Earth bacteria to grow. Precursor missions can provide salient information that can make more efficient the planning and design of human exploration missions. In particular, a robotic sample return mission can help to eliminate the concern about returning samples with humans or the return of humans themselves from a planetary quarantine perspective. Without a robotic return the cost of quarantine that would have to be added to a human mission may well exceed the cost of a robotic return mission. Even if the preponderance of scientific evidence argues against the presence of indigenous life, it must be considered as part of any serious planetary quarantine analysis for missions to Mars. If there is life on Mars, the question of human exploration assumes an ethical dimension.

McKay, D. S. and Ming, D. W. (NASA Johnson Space Center, Houston, TX 77058): 'Mineralogical and Chemical Properties of the Lunar Regolith', *ASA-CSSA-SSSA Special Publication* **52** (1989), 45–68.

Lunar regolith is the layer of loose, incoherent rock material that forms the majority of the Moon's surface. The finer-grained (<1 mm) part of the lunar regolith has been loosely called *soil* and, in most locations, is the result of numerous and repeated bombardment by mostly small meteorites. Unlike terrestrial soils, the regolith lacks the influence of organic matter and the Moon is thought to be completely lacking in water. The regolith holds the most promise as a source of raw materials for use at lunar bases as well as materials for use in building large infrastructures in space. Lunar regolith may also provide rocket propellants and life support consumables (including O_2, H, and manufactured water).

No doubt, the regolith will play an important role in the development of lunar-base agriculture. The regolith may (i) act as a soil and provide a solid support substrate for plant growth, (ii) be a source for essential, plantgrowth elements, and (iii) provide a source of O_2 and H, which may be used to manufacture water – possibly the most important component of an agricultural system.

It has been 20 yr since the first Apollo mission returned samples from the Moon in 1969. Since that time, lunar materials have been thoroughly studied and a wealth of information has been published on their physical, chemical, and mineralogical properties. The study of nonterrestrial surface materials and how they may react as a soil and/or a source of plant nutrients opens up a whole new frontier for researchers in the agricultural community. Because the Moon may be the first stepping stone for the presence of people away from the Earth, the following chapter has been prepared to acquaint agricultural scientists with the mineralogical and chemical properties of the lunar regolith.

McLaughlin, W. I. (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109): 'Putting Voyager Together', *Planetary Report* **9**(4) (1989), 4–7.

Voyager 2 is about to stage another planetary spectacular by flying through the Neptunian system in late August, transforming that distant and dark region from obscure to familiar. Since the flamboyant flybys of Jupiter in 1979, we have come to expect a reliable flow of scientific information from the *Voyager* spacecraft. But the path from the 1960s proposal of a "Grand Tour" to the mature project of the last ten years had many twists. Techniques and technologies had to be developed. Barriers of program definition and funding had to be scaled. And the early phase of flight operations can only be described as "scary."

Mecham, M.: 'Mars Observer Begins New Era Using Proven Spacecraft Design', *Aviation Week & Space Technology* **131**(15) (1989), 79, 81–82.

President Bush's call for a manned mission to Mars has given new prominence to the 1992 launch of the Mars Observer, a mapping satellite that will study the planet's geology and global climate.

Miller, R.: 'Enter Galileo – Back to Jupiter, This Time to Stay', *Final Frontier* **2**(6) (1989), 28–31, 52.

If you think Voyager's quick flyby of Jupiter was spectacular, get ready for a full-fledged expedition.

Miner, E. D. (Jet Propulsion Laboratory, California Institute of Technology Pasadena, CA 91109): 'Voyager 3 Approaches Neptune', *Planetary Report* **9**(4) (1989), 19–21.

Excitement is building rapidly at Caltech's Jet Propulsion Laboratory as *Voyager 2* plummets toward its August 25 closest approach to the solar system's eighth planet. We're closing the gap at the rate of 1,450,000 kilometers (900,000 miles) per day. Images from *Voyager 2*'s high-resolution vidicon camera keep improving in detail (since late 1988 they have exceeded anything obtained from Earth). With all the pre-encounter tests of the spacecraft complete, the *Voyager* Project team at JPL is rehearsed and ready. We will be handling a flood of new data during the four-month Neptune encounter period, from June 5 through October 2, 1989.

At its closest approach to Neptune, *Voyager 2* will sail over the north polar regions of the planet only 29,200 kilometers (18,100 miles) from the planet's center, a scant 5,000 kilometers (3,100 miles) from its polar cloud tops. The moment of closest approach will actually occur on August 24 at 9 p.m. Pacific Daylight Time (PDT), but the radio signals from *Voyager 2*, traversing the 4.5 billion kilometers (2.8 billion miles) to tracking stations near Canberra and Parkes, Australia, and Usuda, Japan, will be received at 1:06 a.m. PDT on August 25. *Voyager 2's* passage behind the planet will be monitored by those stations from 1:12 a.m. through 2:01 a.m. PDT.

Ming, D. W. (NASA Johnson Space Center, Houston, TX 77058): 'Manufactured Soils for Plant Growth at a Lunar Base', *ASA-CSSA-SSSA Special Publication* **52** (1989), 93–106.

The newly created Office of Exploration (OEXP) at the National Aeronautics and Space Administration (NASA) Headquarters is considering several missions that the agency may undertake as a part of the human exploration of our inner solar system. These scenarios include: (i) expeditions to establish the first human presence on another planet (e.g., Mars); (ii) lunar outposts to conduct extraterrestrial science; and (iii) evolutionary expansion to establish self-sufficient human presence beyond low Earth orbit (LEO). Evolutionary expansion is a step-by-step program away from LEO. The first step will probably be the establishment of a lunar outpost that will lead to a self-sufficient lunar base. A self-sufficient lunar base will require the utilization of in situ resources for construction materials, propellants, and lifesupport systems. Plant growth at a lunar base will be essential to sustain a self-sufficient human colony. Several systems exist in which to grow plants, e.g., hydroponics, aeroponics, and solid-support substrates. Most of the plant growth research in controlled ecological life support systems (CELSS) has been aimed toward hydroponic systems. Soils also may be viable plant growth systems; however, our knowledge of how lunar materials will react as soil is virtually unknown.

Lunar materials, as they now exist, may not provide an adequate growth medium for higher plants for several reasons. The poor physical structure of lunar regolith may prevent proper aeration and water movement through the lunar materials. Minerals and materials that comprise the lunar surface may have little nutrient supplying power or retention capacity for plant-essential elements. Also, the toxicity of lunar materials to plants is not well known. For example, high Cr and Ni contents in lunar materials may be toxic to plants. It may be necessary, therefore, to alter lunar materials or prepare "soils" that will be productive for plant growth.

Morrison, D. (Space Science Division, NASA Ames Research Center, Moffett Field, CA 94035): 'Jupiter: First Stop on Voyager's Grand Tour', *Planetary Report* **9**(4) (1989), 8–11.

Jupiter, with its dazzling satellite system, was the first target in the epic journey of the *Voyager* spacecraft. Jupiter is the giant of the planets, with more mass than all of the other eight planets combined. Its powerful gravity has clung to the primordial gases hydrogen and helium, giving Jupiter a composition similar to that of the Sun and stars.

The chemistry of Jupiter is dominated by hydrogen and its compounds, such as water, ammonia and methane. Swirling ammonia clouds float high in its extensive atmosphere. Its interior is primarily liquid hydrogen at a high temperature, with no solid surface.

Although it is immense relative to the other planets, Jupiter's mass doesn't compare with that of a star. In order to sustain a star's internal nuclear reactions, the planet would require nearly 70 times more mass. However, Jupiter does radiate substantial heat in the infrared part of the spectrum. Its interior is still hot as a result of gravitational energy released when the planet formed out of the solar nebula some 4.5 billion years ago.

Even before *Voyager*, we knew the basics of Jupiter's size and composition. Further, radio astronomers had mapped Jupiter's huge magnetosphere of charged particles, trapped in a magnetic field stronger than that of any other planet. Close-up observations of magnetospheric and atmospheric phenomena were prime objectives of the *Voyager* flybys, but we also wanted a good look at the giant planet's array of moons.

Jupiter is at the center of its own miniature "solar system." Among the 13 satellites that we knew about before *Voyager*, the four known as the Galilean satellites are larger than our Moon. The largest, Ganymede, is nearly as big as Mars. From telescopic measurements, astronomers had determined that the outer two Galilean satellites Callisto and Ganymede–are composed in large part of water ice, while the smaller inner satellites–Io and Europa–are primarily silicate in composition, like the terrestrial planets. Little more was known about these worlds until the revelations of the *Voyagers*.

Moura, D. J. P. (CNES, 18 Avenue Edouard Belin, 31055 Toulouse Cedex, France): 'Technical Benefits of Existing Space Systems on Future Scientific Missions: Example of the Vesta Small Bodies Mission', *Space Technol.* **9** No. 3 (1989), 293–304.

This paper illustrates the method and summarizes the results of the CNES phase A studies concerning the spacecraft design of the VESTA Small Bodies mission. Firstly, the main technical constraints of the mission are given. Then, the results obtained on the spacecraft design are presented, highlighting the strong design heritage from existing European space programmes.

Papagiannis, M. D. (Department of Astronomy, Boston University, Boston, MA 02215): 'The Retention by Planets of Liquid Water Over Cosmic Periods: A Critical Factor for the Development of Advanced Civilisations', *Journ. British Interplanetary Soc.* **42** (1989), 401–405.

Life based on carbon and liquid water seems to be the most likely possibility for planets but advanced technology may appear only after a long biological evolution. Consequently, only planets that can retain liquid water over cosmic periods (billions of years) may develop technological civilisations. The retention of liquid water over cosmic periods is a very complex problem, but significant progress has been made in recent years to comprehend its many intricacies.

Pine, D.: 'Good Librations', *Final Frontier* **2**(6) (1989), 32–34, 58–59.

Portree, D. S. F.: 'A Planetary Comeback: Magellan Heads for Venus', *Astronomy* **17**(9) (1989), 38–42.

After a hiatus of twelve years, the United States is back in the planetary exploration business with May' s successful Magellan launch.

Prince, R. P. and Knott, W. M., III (Life Science Research Office, NASA J. F. Kennedy Space Center, FL 32899): 'CELSS Breadboard Project at the Kennedy Space Center', *ASA-CSSA-SSSA Special Publication* **52** (1989), 155–164.

The role plants play in the maintenance of our global environment has been recognized for many years. Undoubtedly, the seasonal changes that occur in many parts of our world contribute to the overall biological and atmospheric stability of planet Earth. Unfortunately, habitats considered for lunar and Mars bases and long-term space missions may not have available all of the natural ecological mechanisms to establish atmospheric equilibrium. Consequently, selected biological, physical, and chemical processes will be assembled into a workable unit that will be controlled by a computer system. An assortment of monitoring and feedback systems will have to be substituted to some extent for a part of the ecological control. Also, because of the size constraints on early missions, compartments for the storage of fresh and waste solids, liquids, and gases will be small, forcing the turn-around time for many processes to be short.

Ravine, M. A. and Soulanille, T. A. (Altadena Instruments Corporation, Catalina Station, Pasadena, CA 91116): 'Cameras for Microspacecraft', *Journ. British Interplanetary Soc.* **42** (1989), 460–467.

Historically, imaging experiments on planetary missions have been massive and have required substantial amounts of power. Such cameras are incompatible with the 'microspacecraft' concept of entire spacecraft that weigh less than 10 kg. We outline an approach for designing a microspacecraft camera, an approach which includes focussing the requirements, clarifying the constraints, and using the highest performance appropriate technologies. This approach was used to design a specific microspacecraft camera: the Small Body Camera (SBC), which would be used to study surface processes on asteroids or comet-nuclei. The study indicates that it would be feasible in the near term to build a camera that weighs of order one kilogram and uses of order five watts of peak power. Other imaging experiments that could benefit from a well designed microspacecraft camera include a high resolution lunar mapper and a Mars weather satellite.

Rea, D. G., Call, M. H. and Craig, M. K. (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109): 'The Case for a Multinational Mars Surveyor Program', *Planetary Report* **9**(5) (1989), 12–15.

To continue the exploration of Mars we need a series of robotic missions, proposed as the Mars Surveyor Program. Elements of this program are being studied not only by the US and USSR but also by other countries and by the European Space Agency. However, these studies have been conducted in isolation from one another. They should be brought together in a coordinated multinational program.

Reichhardt, T.: 'The Drawing Board; Planetary Missions of the 1990s', *Final Frontier* **2**(6) (1989), 18–23, 48–51.

Just when it looked like it was all over, a second "Golden Age" of planetary exploration is about to begin.

Rinnert, K., Lauderdale, R. II, Lanzerotti, L. J., Krider, E. P. and Uman, M. A. (Max-Planck-Institut für Aeronomie, Katlenburg-Lindau, F. R. Germany): 'Characteristics of Magnetic Field

Pulses in Earth Lightning Measured by the Galileo Probe Instrument', *Journ. Geophys. Research* **94** (1989), 13, 229–13, 235.

A lightning-measuring instrument designed for the Galileo Probe mission to Jupiter has monitored the magnetic field signals of Earth lightning for several years. The instrument performs spectral measurements in the narrow-band channels at 3, 15, and 90 kHz (frequency domain) and waveform measurements (time domain) in the band 0.1–100 kHz. In the time domain the instrument accumulates statistical distributions of pulse amplitude, pulse duration, and interpulse interval or gap time during a preset measuring period. The largest amplitude waveform that occurs during the measuring period is also digitized for a window of 1 ms. This paper summarizes the time domain statistics that were made during four storms that exhibited low to moderate lightning rates. Waveforms are presented that appear to be typical cloud discharge waveforms, and their characteristics are presented. For individual pulses or pulse bursts, the mean interpulse gap time and duration time were found to be 74 and 42 μs, respectively. On the average, bipolar pulses were found to be asymmetric, with the ratio of the amplitude of the first half cycle to the second half cycle being 1.4. The evaluation of the waveform statistics shows that the instrument does provide statistics that are representative of terrestrial intracloud and cloud-to-ground discharges. A minimum was found around 100 μs in the gap time distribution of waveform pulses in several studied storms. During one local storm, a periodicity was observed in the lightning pulse rate. The pulse activity was modulated within a broad envelope that peaked every 2–3 min. This modulation may be an indication of the existence of locally active charge regions that have lifetimes of a few minutes.

Rummel, J. D. (Life Sciences Division, NASA Headquarters, Washington, DC 20546) : 'Planetary Protection Policy Overview and Missions', *Adv. Space Res.* **9** (1989), (6)181–(6)184.

The 1967 treaty on the peaceful uses of outer space reflected both concerns associated with the unknown nature of the space environment and the desire of the world scientific community to preserve the pristine nature of celestial objects until such time as they could be studied in an effective manner. Since 1967, NASA has issued policy directives that have adopted the guidelines of COSPAR for protecting the planets from contamination by Earth organisms and for protecting the Earth from the unknown. This paper presents the current status of planetary protection (quarantine) policy within NASA, and a prospectus on how planetary protection and back contamination issues might be addressed in relation to future missions envisioned for development by NASA either independently, or in cooperation with the space agencies of other nations.

Salazar, R. P. and Nock, K. T. (Jet Propulsion Laboratory, Pasadena, CA 91109): 'Lunar Get-Away-Special: Exploring the Moon with a Miniature, Electrically Propelled Spacecraft', *Journ. British Interplanetary Soc.* **42** (1989), 486–490.

A spacecraft and mission concept has been developed to achieve an important lunar science goal. The key elements of this concept are solar-electric propulsion, a miniature spacecraft and a highly focussed science mission.

This mission would carry out a search for water at the lunar poles. Similar missions would incrementally achieve other important goals of a long term lunar science program.

Schwehm, G. H. (Space Science Department of ESA, ESTEC, 2200 AG Noordwijk, The Netherlands): 'Rosetta – Comet Nucleus Sample Return', *Adv. Space Res.* **9** (1989), (6)185–(6) 190.

Rosetta – the Comet Nucleus Sample Return (CNSR) mission is one of the four cornerstone missions to which ESA has committed itself in its approved Long Term Programme "Horizon 2000". Additionally, this mission has been categorised in NASA's Solar System Exploration Committee's Augmented

Programme as a mission of high scientific merit. Since 1985 the mission has been studied jointly by ESA and NASA.

Research on comet nucleus samples will carry the exploration of the solar system to its outer fringes. This mission will begin to provide scientific study of the pre-solar environment and possibly sample materials in the solar system which will allow an experimental approach to chemical and physical processes that marked the beginning of our solar system 4.6 billion years ago.

The Rosetta mission scenario is described with special emphasis on planetary protection issues.

Simpson, R. A. and Miner, E. D.: 'Uranus: Beneath that Bland Exterior', *Planetary Report*, **9**(4) (1989), 16–18.

Voyager 2's third destination on its Grand Tour was the Sun's seventh planet, Uranus. On January 24, 1986, the spacecraft flew within 82,000 kilometers (51,000 miles) of the planet. This was Uranus' first visitor from Earth.

As at Jupiter and Saturn, we discovered much about the planet, its magnetic and radiation fields, its rings and its satellites. Uranus' almost featureless face betrayed few secrets to the spacecraft's cameras, and the thin, extremely dark rings were difficult to image. To penetrate the planet's mysteries required the best efforts of all team members working on *Voyager 2*'s instruments. The radio science investigation in particular became a major contributor to our knowledge of the uranian system.

The radio team used the regular communications link with Earth in several ingenious ways. The extreme stability of the radio's frequency permits *Voyager* navigators to measure the spacecraft's speed to within millimeters per second. By measuring variation in speed resulting from tiny tugs from the planet and its satellites, they could measure the gravitational fields and so derive the masses of the bodies.

As the spacecraft passed behind the planet (and was occulted, or hidden, as seen from Earth), the radio signal passed through Uranus' ionosphere and atmosphere. Just as light passing through water is slowed and bent, so the radio signal changed, enabling scientists to discern structure in the ionosphere and atmosphere, and construct a temperature and pressure profile of this strange world.

Voyager 2's trajectory was carefully chosen so that the radio beam would also pass through the tenuous ring system. Changes in the signal's amplitude and phase told scientists much about the amount of matter in the rings and the size of their component particles.

Smith, B. A.: 'Neptune Rendezvous Will Mark Final Stage of Voyager 2's Mission', *Aviatian Week and Space Technology* **131**(6) (1989), 70–71.

Following the encounter with Neptune, Voyager will be designated the Voyager Interstellar Mission.

Smith, B. A.: 'Missions Mark Resurgence of U.S. Planetary Exploration', *Aviation Week and Space Technology* **131**(15) (1989), 44–45, 47, 51, 53–54.

The United States' first orbiting satellite, Explorer 1, was developed by Jet Propulsion Laboratory (JPL) and launched in 1958. Explorer 1 was the forerunner of a long series of stunning U.S. scientifc and engineering achievements in space exploration over the past three decades. Faced with changing national priorities and severe budget pressures, however, JPL during the 1980s endured a critical period during which there was not a major U.S. planetary launch for more than a decade. The situation now is changing with a series of missions planned for launch which hold out significant prospects for great scientific achievement. A team of *Aviation Week & Space Technology* editors visited NASA and contractor facilities in preparation for this special report.

Stern, S. A. (University of Colorado, Boulder, CO 80309): 'Mars Tethered Sample Return', *Journ. Spacecraft and Rockets* **26** (1989), 294–296.

Stotzy, G. (New York University, New York, NY10012): 'Microorganisms and the Growth of Higher Plants in Lunar-Derived Soils', *ASA-CSSA-SSSA Special Publication* **52** (1989), 131–138.

Life on a lunar base will be affected – in fact, controlled – by microbes, as is life on Earth (e.g., pathogenesis, contamination, spoilage, decay, and biogeochemical cycles, including degradation of wastes). Consequently, the factors that influence the activity, ecology, and population dynamics of microbes on Earth should be similar on the Moon (Table 9–1) (Stotzky, 1974). This, of course, assumes that a lunar base will be an enclosed environment, wherein temperature, pressure, electromagnetic and particulate radiation, atmospheric composition, and other critical environmental factors will be controlled.

Taylor, G. J. (University of New Mexico, Albuquerque, NM 87131): 'The Environment at the Lunar Surface', *ASA-CSSA-SSSA Special Publication* **52** (1989), 37–44

The Moon's geologic environment is dramatically different from Earth's and presents fascinating challenges to engineers designing facilities on the lunar surface. This chapter summarizes the geologic nature of the stark lunar surface and its tenuous atmosphere.

Tibbitts, T. W. (University of Wisconsin, Madison, WI 53706): 'Plant Considerations for Lunar Base Agriculture', *ASA-CSSA-SSSA Special Publication* **52** (1989), 237–244.

A major emphasis is being placed on growth of higher plants for life support in controlled ecological life support systems (CELSS) for lunar and other space bases. The success of CELSS will depend upon using plants with a maximum of efficiency and dependability. Effective plant use in CELSS will require a significant research effort to understand how to maintain production in closed recycling systems under essentially completely automated procedures. The research needs are large and the challenges involve the expertise of a wide variety of plant scientists. For this chapter on plant considerations for lunar bases, research needs have been divided into four general categories to emphasize the unique and different area of research facing scientists working on CELSS. These four categories are (i) plant productivity, (ii) closed environments, (iii) automation and robotics, and (iv) space environment.

Waff, C. B. (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109): 'The Struggle for the Outer Planets', *Astronomy* **17**(9) (1989), 44–52.

In the 1979s, tight budgets and disputes over NASA's program nearly doomed our chance to explore the outer planets.

Waldrop, M. M.: 'Phobos at Mars: A Dramatic View – and Then Failure', *Science* **245** (1989), 1044–1045.

When the Soviet Union's Phobos 2 satellite tumbled out of control at the end of March, researchers' hopes for a close-up view of Mars and its largest moon seemed dashed. But, as Soviet scientists reported at a recent solar system conference held at Caltech in conjunction with the Voyager encounter with Neptune, all was not lost. A good deal of scientific data was returned during the doomed satellite's short life in Mars orbit. One of the most spectacular results was the first temperature map of the Martian surface ever made.

Whitney, G. (US Geological Survey, Denver, CO 80225): 'Geochemistry of Soils for Lunar Base Agriculture: Future Research Needs', *ASA-CSSA-SSSA Special Publication* **52** (1989), 213–236.

The successful use of lunar regolith as a plant growth medium will require a thorough understanding of many geochemical processes. Some of these processes have been studied in Earth soil environments, and several have been investigated experimentally. But lunar regolith differs substantially from Earth soils, and much of our knowledge is not directly transferable. The task at hand is to apply our current understanding of rock-water reactions to the interaction of lunar materials with water in an Earth-like (but artificial) atmosphere, and to expand our understanding of those processes through observation and experimentation. The purpose of this chapter is to outline some of the geochemical research topics that require investigation to develop soils for controlled ecological life support systems (CELSS) on the Moon.

Yin, L. I., Trombka, J. I., Seltzer, S. M., Johnson, R. G. and Philpotts, J. A. (Laboratory for Astronomy and Solar Physics, NASA Goddard Space Flight Center, Greenbelt, MD 20771): 'Possible Use of Pattern Recognition for the Analysis of Mars Rover X Ray Fluorescence Spectra', *Journ. Geophys. Res.* **94** (1989), 13, 611–13,618.

On the Mars rover sample return mission the rover vehicle will collect and select samples from different locations on the Martian surface to be brought back to Earth for laboratory studies. It is anticipated that an in situ energy-dispersive X ray fluorescence (XRF) spectrometer will be on board the rover. On such a mission, sample selection is of higher priority than in situ quantitative chemical analysis. With this in mind we propose pattern recognition as a simple, direct, and speedy alternative to detailed chemical analysis of the XRF spectra. The validity and efficacy of the pattern recognition technique is demonstrated by the analyses of laboratory XRF spectra obtained from a series of geological samples, in the form both of standardized pressed pellets and as unprepared rocks. It is found that pattern recognition techniques applied to the raw XRF spectra can provide for the same discrimination among samples as knowledge of their actual chemical composition.

19. ASTEROIDS

Cellino, A., Di Martino, M., Drummond, J., Farinella, P., Paolicchi, P. and Zappalà, V. (Osservatorio Astronomico di Torino, I – 10025 Pino Torinese, Italy): 'Vesta's Shape, Density and Albedo Features', *Astron. Astrophys.* **219** (1989), 320–321.

The polar axis, gross shape and rough surface albedo distribution of the asteroid 4 Vesta have been recently determined by two distinct and independent sets of observational data, provided by lightcurve photometry and by speckle interferometry. The results are consistent, and show that Vesta is a spheroidal or a quasi-spheroidal object whose surface has a significant albedo variegation. This is the first time that different Earth-based techniques have led to a rough 'map' of an asteroidal object.

Barnes-Svarney, P.: 1989, 'The Near-Earth Asteroids', *Popular Astronomy* **36**(3), 6–8.

The search for near-Earth asteroids.

Harris, A. W. and Young, J. W. (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109): 'Asteroid Lightcurve Observations from 1979–1981', *Icarus* **81** (1989), 314–364.

Results of photoelectric lightcurve observations from Table Mountain Observatory are reported. Most of the observations were made from January 1980 through March 1981. Some earlier observations are included from 1979 which were previously only partially reported (A. W. Harris and J. W. Young, 1983, *Icarus* **54**, 59–109), and some observations of one asteroid in 1984 are included. In addition to the printed paper, we provide (on request to the first author) a machine readable file of the observations.

About 70 different asteroids are reported, in all. Several errors in our 1983 paper are corrected. These include a few preliminary period estimates from the 1980 data, which were listed in Appendix II of that paper, which proved to be in error on careful analysis. In all, about a dozen new or significantly revised periods are reported. All observations were made in the V band, with estimates of the mean and maximum reduced magnitudes given for each object. Sufficient phase angle coverage was obtained for 33 objects to obtain fits of the H–G magnitude relation (E. Bowell *et al.* 1989, in *Asteroids II* (R. Binzel, T. Gehrels, and M. Matthews, Eds.), Univ. of Arizona Press, Tucson (in press) to the data. From these fits, we examine the mean values of the slope parameter, G, for different taxonomic classes. These values are then applied in the analysis of less complete data sets. For the moderate albedo asteroids (classes S and M), the H–C relation appears to fit the available data well. However, for dark asteroids, the relation appears to predict more of an opposition effect than is typically present.

Harris, A. W., Young, J. W., Contreiras, L., Dockweiler, T., Belkra, L., Salo, H., Harris, W. D., Bowell, E., Poutanen, M., Binzel, R. P., Tholen, D. J. and Wang, S. (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91105): 'Phase Relations of High Albedo Asteroids: The Unusual Opposition Brightening of 44 Nysa and 64 Angelina', *Icarus* **81** (1989), 365–374.

Detailed photoelectric lightcurve observations are reported which were made for the purpose of defining the photometric phase relations of high albedo asteroids, particularly at low phase angles. We have observed 44 Nysa at one aspect, and 64 Angelina at both polar aspects, hence we have sampled three different surfaces. All three exhibit a remarkable opposition spike, or brightening, of about 0.25 magnitude, confined to within a few degrees of zero phase angle. Within the scatter of the observations, all three curves are identical, hence the opposition spike cannot be regarded as 'anomalous' or unusual within that class of objects (both asteroids are of taxonomic class E). Since the effect is identical on both hemispheres of Angelina, we can conclude that it is a global characteristic. The observed phase curves are generally similar to those of the Uranian satellites and of Saturn's rings, leading us to suggest that it is a normal property of moderate to high albedo atmosphereless surfaces. In particular it appears that much of the opposition effect of the rings of Saturn may be due to the surface properties of the individual particles, rather than to interparticle shadowing, as has often been suggested.

Hollis, A. J. (Clay Lane, Marton, Cheshire CW7 2GE, England): 'Photometric Properties of the Minor Planets: Observations of (3) Juno in 1983 and 1987', *British Astron. Assoc. Journ.* **99** (1989), 187–189.

From visual observations or (3) Juno in 1983 and 1988 the linear portion of the phase curve can be described by $V(1\alpha) = (5.655 \pm 0.184) + (0.024 \pm 0.018)\ \alpha$ for phase angles, α, between 10° and 25°.

Lagerkvist, C.-I., Magnusson, P., Williams, I. P., Buontempo, M. E., Gibbs, P. and Morrison, L. V. (Astronomiska Observatoriet, S – 751 20 Uppsala, Sweden): 'Physical Studies of Asteroids. XIX. Phase Relations and Composite Lightcurves Obtained with the Carlsberg Meridian Circle', *Astron. Astrophys. Suppl. Ser* **78** (1989), 519–532.

The data on 37 asteroids obtained with the Carlsberg Automatic Meridian Circle at La Palma have been used to obtain the photometric parameters G and H and to draw phase diagrams. His supplements data on 51 asteroids (Lagerkvist and Williams, 1987) and on 31 asteroids (Lagerkvist *et al.*, 1988) using the same techniques. Synodic periods were obtained for 6 asteroids and composite lightcurves drawn. For 10 Hygiea our value of 17.5 h is different from that of Vesely and Taylor (1985) but in agreement with the result reported by Harris and Young (1983). 24 asteroids were of type S and the mean value of 0.19 agrees very well with that of Lagerkvist and Williams (1987) and Lagerkvist *et al.* (1988). For the 6 asteroids of type C we get a mean G value of 0.04 agreeing well with earlier results.

McKinnon, W. B. (Department of Earth and Planetary Sciences, Washington University, St. Louis, MO 63130): *Nature* **340** (1989), 343–344.

Millis, R. L., Wasserman, L. H., Bowell, E., Harris, A. W., Young, J. W., Barucci, M. A., Williamson, R. M., Manly, P. L. Dunham, D. W., Olson, R. W., Baggett, W. E., and Zeigler, K. W. (Lowell Observataory, Flagstaff, AZ 86001): 'The Diameter, Shape, Albedo, and Rotation of 47 Aglaja, *Icarus*, **81** (1989), 375–385.

Observations of the 16 September 1984 occultation of SAO 146599 by 47 Aglaja are reported. Analysis of these observations from 13 sites in the continental United States yields a value of 136.4 ± 1.2 km for the diameter of Aglaja. Based on previouslv published photometry of Aglaja and new observations given in this paper, the rotational period is 13.20 ± 0.01 hr and the zero-phase-angle visual geometric albedo of the face of the asteroid seen at the time of the occultation is 0.071 ± 0.002. While Aglaja is certainly not perfectly spherical, we argue that a signficant portion of the variation with ecliptic longitude of this object's mean brightness must be due to differences in albedo over its surface.

Standish, E. M., Jr. and Hellings, R. W. (Jet Propulsion Laboratory, Pasadena, CA 91109): 'A Determination of the Masses of Ceres, Pallas, and Vesta from Their Perturbations upon the Orbit of Mars', *Icarus* **80** (1989), 326–333.

Estimates have been made for the masses of the asteroids Ceres. Pallas, and Vesta by measuring their perturbations upon the orbit of Mars. The complete set of planetary ephemeris observational data, including especially the highly accurate ranging data to the Viking landers, is incorporated into a full least-squares adjustment of all ephemeris parameters including the relevant asteroid masses. The results show a mass for Ceres of $5.0 \pm 0.2 \times 10^{-10}$ solar masses (a 15% decrease from Schubart's previous determination), a mass for Pallas of $1.4 \pm 0.2 \times 10^{-10}$ (30% increase), and a mass for Vesta of $1.5 \pm 0.3 \times 10^{-10}$ (9% increase). Chances for future determinations seem to depend upon the Russian Phobos Lander mission and upon future radar-ranging to the asteroids themselves.

Vashkov'yak, M. A.: 'Numerical Averaging Method in the Problem of the Evolution of Resonance Asteroid Orbits', *Cosmic Research* **27** (1989), 6–11.

A numerical method is described for the investigation of the evolution of resonance asteroid orbits over long time intervals. Two successive algorithms for averaging the perturbing function and the right sides of the differential equations in the osculating elements are used to eliminate the fast variables. One of them eliminates the mean longitudes of the asteroid and perturbing planet with the resonance variable held constant. Numerical integration of the averaged equations is used for the next averaging over the period of variation of the semimajor axis of the asteroid orbit. The numerical integration of the twice-averaged equations can be used to investigate the qualitative properties of the evolution over time intervals of 10–100 kyr, which is illustrated by several asteroids having highly elliptical orbits with large inclinations to the plane of the ecliptic.

Zhirnov, V. A. and Lidov, M. L.: 'Problem of Approach to Several Asteroids', *Cosmic Research* **27** (1989), 1–6.

New results are presented for the problem of approach to several asteroids, described in detail in paper [1]. For first asteroid Hestia, models have been constructed of approach to N asteroids for $N =$ 2, 3, 4, 5. Variants are pointed out, in which the expenditures of intrinsic velocity, w_N, in the approach to N asteroids do not exceed: $w_2 = 0.069$, $w_3 = 0.255$ $w_4 = 0.611$, $w_5 = 1.36$ km/sec. The numerical iteration procedure proposed in [1] has been carried out for solving the nonlinear problem of approach, with the help of the linear algorithm of optimal correction. The effectiveness of this procedure is analyzed in numerical samples.

20 COMETS

Altenhoff, W. J., Huchtmeier, W. K., Kreysa, E., Schmidt, J., Schraml, J. B. and Thum, C. (Max-Planck-Institut für Radioastronomie, Auf dem Hugel 69, D-5300 Bonn 1, F. R. Germany): 'Radio Continuum Observations of Comet P/Halley at 250 GHz', *Astron. Astrophys.* **222** (1989), 323–328.

The detection of continuum radio emission from comet Halley has been confirmed using a ^3He cooled bolometer at a frequency of 250 GHz. The radiation, normalized to a geocentric and heliocentric distance of 0.66 and 1.58 AU, respectively, is probably not correlated with the 2.2 or the 7.4 day nucleus rotation periods. The normalized emission is steady with a mean flux density of 51.6 ± 5.2 mJy over the post-perihelion observing period of 8 days (March 1986). This is comparable to the value determined several months earlier (Nov. 1985). The error limits include the uncertainty of the absolute calibration. The derived photometric diameter is 35 km, far in excess of the mean diameter of 11 km determined by the Giotto imaging team. The bulk of the emission seems to come from centimeter-sized particles within a sphere of diameter 3800 km centered on the nucleus. The steady emission over months may indicate that the larger particles remain a long time near the nucleus.

Bar-Nun, A. and Kleinfeld, I. (Department of Geophysics and Planetary Sciences, Raymond and Beverly Sackler Faculty of Exact Sciences, Tel Aviv University, Tel Aviv 69978, Israel): 'On the Temperature and Gas Composition in the Region of Comet Formation', *Icarus* **80** (1989), 243–253.

The findings of the Giotto and Vega spacecrafts on the gas composition of comet Halley, together with an experimental study on the trapping of gas mixtures in amorphous water ice, enable estimation of the gas composition and temperature in the region of comet Halley's formation: If Halley was formed in the solar nebula by condensation of water vapor in the presence of gas, in the region of its formation the CO/CH_4 ratio had to be at least 100 and the temperature about 48 K. The ice particles that formed the comet could not have condensed at a higher temperature and subsequently cool down because then the 7% CO found as a parent molecule could not have been trapped in the ice. A 48 K formation temperature implies that the ice was in amorphous form. This temperature is surprisingly close to the temperatures observed by IRAS for the circumstellar dust shells around α PsA (55 K) and ϵ Eri (45 K) and supports the suggestion that short-period comets were formed outside the region of planet formation. The CO content of comet Halley and the high sensitivity to explosion of irradiated, ice-coated, interstellar grains seem to exclude the possibility of their direct incorporation into comets. Yet, they might have provided the condensed organics – the 'CHON' materials.

Baratta, G. A., Catalano, F. A., Leone, F. and Strazzulla, G. (Osservatorio Astrofisico di Catania, Citta Universitaria, I – 95125 Catania, Italy): 'Post-Perihelion Photometry of Comet Liller (1988a) at Catania (Italy) Observatory', *Astron. Astrophys.* **219** (1989), 322–325.

Photometric observations of comet Liller (1988a) obtained after its passage at perihelion are presented. The standard filters of the International Halley Watch (IHW): C_2, BC, C_3, CN, UC have been used. Gas production rates have been derived. We find these vary as r^{-n} (r being the comet-sun distance) with $n = 3.45$ (C_2), 2.73 (C_3), and 3.21 (CN). Production rates of solids follow the same law as gas with $n = 2.62$. The observations are not incompatible with a nucleus whose sublimation is regulated by an external organic crust.

Bockelée-Morvan, D. (Observatoire de Paris, Section de Meudon, F – 92195 Meudon, France): (FR)

'Chemical Composition of Cores of Comets: Evaluation of More than One Century of Observations, *Ann. Physique* **14** (1989), 89–101.

The 1986 apparition of Halley's comet has been observed by more than one thousand astronomers. Five fly-by missions together with coordinated earth-based observations have led to a quantum leap forward in our knowledge of comets. The view that comets constitute the most pristine material in the Solar System was one of the strongest motivations for cometary observations and *in situ* measurements. One thousand of comets have been observed at that time and all of them belong to the Solar System and did not achieve the high pressures and temperatures which caused the extensive evolutionary alteration that occured in planets. Comets are privileged over meteoritic/asteroidal material because they formed farther from the Sun, as testified by the presence of abundant volatile ices, and because they spent the major part of their life in the distant Oort cloud, at 50000 UA from the Sun, where the temperature and the pressure are typically those of the interstellar medium, i.e. very low. The zone of formation of comets is not known and is situated between 20 UA (in the vicinity of giant planets) and 50000 UA depending upon the models. Since presolar condensates are present in our Solar System, as evidenced by numerous isotopic anomalies in primitive meteorites, it is expected that the study of the composition of cometary nuclei will lead to far-reaching inferences regarding the chemical and physical state of the primordial nebula in which Solar System bodies formed. The composition of comets has been investigated for more than one century through spectroscopic observations of their atmosphere which develops in the inner Solar System under the influence of solar radiation. But conclusive informations on the nature of cometary ices and refractory material have been mostly obtained recently through observations and *in situ* measurements of the atmosphere of Halley's comet.

Boehnhardt, H., Drechsel, H., Vanýsek, V. and Waha, L. (Dr.-Remeis-Sternwarte, Astronomisches Institut der Universität Erlangen-Nürnberg, D-8600 Bamberg, F. R. Germany): 1989, 'Photometric Investigation of Comets Bradfield 1987S and P/Borrelly', *Astron. Astrophys.* **220** (1989), 286, 292.

Photometric observations of comets Bradfield 1987S and P/Borrelly were obtained with the ESO 1 m-telescope in 3 nights between October 18 and 21, 1987, using narrow-band IAU cometary filters and broad-band UBV filters. Absolute production rates of C_2, C_3 and CN as well as relative dust production rates were derived. Both objects exhibit very similar ratios of their gas production rates for the three different molecules. Comet Bradfield 1987S was very dusty compared with P/Borrelly and P/Halley. The dust continua of the objects observed show deviations from a linear relation between continuum flux and projected diaphragm radius. We attribute this effect to the combined influence of the solar radiation pressure and the terminal velocity of the dust, which lead to an asymmetric dust distribution in the coma visible through the diaphragm. The broad-band U magnitudes of P/Borrelly are influenced by the strong CN emission feature, while the B and V fluxes exhibit similar deviations from the linear increase with diaphragm diameter like the narrow-band dust continuum filters.

Buffoni, L., Manara, A. and Scardia, M. (Osservatorio Astronomico di Brera, Via Brera 28, 20121 Milano, Italy): 1989, 'Comet Orbits from Observations during 1984 and Orbital Elements for the Next Perihelion Passage', *Astron. Nachr.* **310** (1989), 243–246.

Corrected orbits of 21 comets from observations published in the Minor Planets Circulars have been calculated. Orbital elements for the next perihelion passages of short period comets are also given.

Campins, H., Lien, J., Decher, R., Telesco, C. M. and Clifton, K. S. (Planetary Science Institute, Science Applications International Corporation, Tucson, Arizona 85719): 'Infrared Imaging of the Coma of Comet Wilson', *Icarus* **80** (1989), 289–302.

Thermal infrared images of Comet Wilson were obtained on three consecutive days starting on 1987 March 13 UT. The brightness of the nuclear condensation did not vary appreciably during the observations, in sharp contrast with the behavior observed in Comet Halley. A dynamical analysis of the structure of the dual coma and tail indicates that the particle size distribution in Comet Wilson is clearly different from that observed in Comet Giacobini-Zinner but closer to that in Comet Halley. The dust ejection was nonisotropic with most of the activity concentrated within about a 60°-wide area east of the subsolar point. This result is interpreted as evidence for prograde rotation of the nucleus. We speculate that Wilson, which is a new comet, has not yet developed a dust mantle. The absence of such a mantle would explain the lack of short time scale (Halley-like) variability and the constant position, with respect to the subsolar point, of the area of maximum dust ejection on all 3 days.

Chirikov, B. V. and Vecheslavov, V. V. (Institute of Nuclear Physics, 630090 Novosibirst, USSR): 'Chaotic Dynamics of Comet Halley', *Astron. Astrophys.* **221** (1989), 146–154.

A simple model of the dynamics of Halley's comet is developed, and its motion is shown to be chaotic due to the perturbations by Jupiter. Estimates for the error growth in the extrapolation of the comet's trajectory are obtained which particularly explain a sharp divergence of different extrapolations of comet Halley's orbit previously obtained. Various mechanisms limiting the full sojourn time of the comet in the solar system are considered. These include the orbit diffusion under the perturbations by Jupiter and by Saturn, the orbit drift due to weak nongravitational forces as well as the prompt ejection of the comet from the solar system upon its very close encounter with Jupiter. The estimated sojourn time of comet Halley in the solar system ($t \sim 10$ Myr) is compared to the period of hypothetical comet showers from the Oort cloud which is about 30 Myr.

Cliver, E. W. (Air Force Geophysics Laboratory, Hanscom AFB, MA 01731): 'Was the Eclipse Comet of 1893 a Disconnected Coronal Mass Ejection?', *Solar Physics* **122** (1989), 319–333.

A re-evaluation of observations of the 16 April, 1893 solar eclipse suggests that the 'comet' photographed during totality was, in fact, a disconnected coronal mass ejection. Like the disconnection event in 1980 reported by Illing and Hundhausen, the outward speed of the convex (toward the Sun) surface for the 1893 event was relatively low ($\sim$90 km s^{-1}). Candidate disconnection events were also observed during solar eclipses in 1860 and 1980.

Combi, M. R. (Atmospheric and Environmental Research, Inc., 840 Memorial Drive, Cambridge MA 02139): 'The Outflow Speed of the Coma of Halley's Comet', *Icarus* **81** (1989), 41–50.

Information regarding the outflow speed of the coma of comet Halley has been inferred from various measurements by a number of investigators using different instruments and techniques. The magnitude of the outflow speed and its variation with radial distance in the coma, with heliocentric distance and with the level of the gas production rate, can be accounted for by a new one-dimensional steady-state model which is described herein. The model includes the effects of the dusty-gas dynamics in the inner coma and the photochemical heating of the outer coma which is in a state of transition from collision-dominated to free molecular flow. More specifically, the model self-consistently and quantitatively accounts for (1) the radial dependence of the outflow speed from the *in situ* Giotto NMS measurements, (2) the asymmetry in the value of the outflow speed determined from the Kuiper Airborne Observatory IR measurements at 1 AU pre- and post-perihelion, and (3) the heliocentric distance dependence of the Doppler line profile widths of the many radio observations of HCN and OH which cover a range from perihelion (0.59 AU) to 2.0 AU.

Cremonese, G. and Fulle, M. (Osservatorio Astronomico, Vicolo dell'Osservatorio 5, I – 35122 Padova, Italy): 'Photometrical Analysis of the Neck-Line Structure of Comet Halley', *Icarus* **80** (1989), 267–279.

In this paper we apply the quantitative analysis of Neck-Line Structures (NLS; Fulle, M. and Sedmak, G.: *Icarus* **74** (1988), 383–398 to the dust streamer and the real antitail which were detected in images of Comet Halley during April, May, and June, 1986 (Sekanina, Z., Larson, S. M., Emerson, G., Helin, E. F. and Schmidt, R. E.: *Astron. Astrophys.* **187** (1987), 645–649 and which were best explained by the NLS model (Fulle, M.: 1987, '*Astron. Astrophys.* **181**, L13–L14). The results concern the dust size distribution at very large sizes, the size-dependent dust ejection velocity from the inner coma, and the anisotropy of dust ejection. All the results are related to the time interval 1986, Jan 10–18. The size distribution which best fits the NLS isophotes is characterized by a power index $u \approx -4.0$ for sizes between 0.2 and 2 mm, and $u \approx -0.4$ for sizes between 2 and 10 mm. Therefore we confirm the strong excess of large dust suggested by McDonnell, J. A. M. *et al.*: 1987, *Astron. Astrophys.* **187**, 719–741, to explain the Giotto data, although these authors obtained a value $u \approx -3.0$ for sizes between 0.2 and 10 mm on 1986, Mar 14. These differences of the u values are in agreement with the results of Fulle, M., Barbieri, C. and Cremonese, G.: 1988, (*Astron. Astrophys.* **201**, 362–372), which showed large variations of the size distribution between January and March. The dust ejection velocity can be expressed by $v = 0.20 \times (1-\mu)^{1/7}(\text{km sec}^{-1})$, where $1-\mu$ is the ratio between the solar radiation pressure force and the gravitational force, in agreement with the results obtained for Comet Bennett (Fulle M. and Sedmak, G.: 1988, *Icarus* **74**, 383–398).

Delsemme, A. H. (Department of Physics and Astronomy, The University of Toledo, Toledo, OH 43066): 'Have Comets Played a Role in the Primary Organic Synthesis?', *Adv. Space Res.* **9** (1989), (6)25–(6)34.

Primary organic syntheses first occurred in interstellar space, where more than sixty different organic molecules have been identified. The most important identifications for prebiotic chemistry probably are HCN, H_2CO, CH_3CN, C_2H_2 and CH_3C_2H, although many others could play important roles. A fraction of these molecules condense, with ubiquitous H_2O and CO_2, on interstellar grains that follow suit when a molecular cloud collapses gravitationally to form a star. An accretion disk surrounds the growing star, and the frosty interstellar grains are more or less heated depending on their distance to the central star. The innermost lose their water and carbon compounds and will form the rocky planets; those at intermediate distances lose most of their water only, and will form the parent bodies of the carbonaceous chondrites. The outermost keep all their frost and will become the comets. Eventually, the orbits of all those minor bodies diffuse into the inner solar system and bombard the inner rocky planets. Their numerous impacts has brought a veneer that explains the atmosphere and the oceans of the Earth, as well as the source of a wealth of organic compounds. Comets and carbonaceous chondrites are the messengers that have brought down to Earth the products of the primary organic syntheses that were ubiquitous in space.

Ershkovich, A. I., McKenzie, J. F. and Axford, W. I. (Max-Planck Institut für Aeronomie, D-3411 Katlenburg-Lindau 3, F. R. Germany): 'Stability of a Cometary Ionosphere/Ionopause Determined by Ion-Neutral Friction', *Astrophys. J.* **344** (1989), 832–939.

The linear MHD stability of the magnetic field structure discovered in the ionosphere of comet Halley during the *Giotto Mission* encounter is analyzed in terms of the hydromagnetic counterpart of the bounce frequency for a stratified atmosphere. The structure resulting from the balance between the Lorentz body force and the ion-neutral friction, as suggested by Cravens and by Ip and Axford turns out to be unstable. If, however, effects of the mass-loading (due to photoionization) and dissociative recombination are taken into account, the ionosphere becomes stabilized except for the Halley ionopause and adjacent ionosphere layer (of thickness ~100 km) which remain unstable.

Gao, H., Chen, P.-S. and Cheng, Y.-K. (Yunnan Observatory, Academia Sinica, China): 'Results and Analysis of Infrared Photometry and Spectrophotometry for Halley's Comet', *Chinese Physics* **9** (1989), 715–718.

From Mar. 25–Apr. 3 of 1986 some observations of Halley's comet in the near infrared region were made at Yunnan Observatory. The instrument used in the observations was an infrared photometer-spectrophotometer with J, H, and K standard filters, and a CVF 1.3–2.6 μm, $\Delta\lambda/\lambda = 2\%$. From results in the J, H, and K bands it is clear that all infrared magnitudes of Halley's comet were going to be faint during the period of observation. Combined with our previous data on the observations of Halley's comet by photoelectric photometry, it could be considered that this was the result of an outburst on the comet perhaps just before the time of infrared observation. From the results of CVF observation in the 1.3–2.6 μm range it is obvious that some emissions at 1.4, 1.9, and beyond 2.6 μm appeared during observations. It seems that the emissions at 1.4 and 1.9 μm came from H_2O, and others possibly came from OH.

Gehrz, R. D., Ney, E. P., Piscitelli, J., Rosenthal, E. and Tokunaga, A. T. (Astronomy Department, School of Physics and Astronomy, University of Minnesota, Minneapolis, Minnesota 55455): 'Infrared Photometry and Spectroscopy of Comet P/Encke 1987', *Icarus* **80** (1989), 280–288.

We present 2.3- to 18.5-μm photometry and 3- to 4-μm spectroscopy of Comet P/Encke that suggest that the comet develops a coma composed primarily of large grains when it is near perihelion. Our data show no evidence for the 3.4-μm hydrocarbon emission feature in P/Encke.

Goraya, P. S., Rautela, B. S., Sanwal, B. B., Gupta, S. K., Duggal, H. K., and Malhi, J. S. (Department of Astronomy and Space Sciences, Punjabi University, Patiala, India): *Earth, Moon and Planets* **45** (1989), 17–27.

Spectral scans of the head of periodic Comet Halley (1982i) have been presented and analysed in detail in the optical region (λλ3200–7000 Å); for ten nights during pre-perihelion period. Emission features due to NH, CN, CH, C_3, and C_2 molecules have been identified. The behaviour of the variation of different emission lines strength as a function of heliocentric distance has been investigated. It is found that the comet exhibits night-to-night variation of brightness. The abundances and production rates of CN and C_2 species have also been derived.

Greenberg, J. May (Laboratory of Astrophysics, University of Leiden P.O. Box 9504, 233 CA Leiden, The Netherlands): 'Synthesis of Organic Compounds in Interstellar Dust and Their Transport to Earth via Comets', *Adv. Space. Res.* **9** (1989), (6)15–(6)23.

It now appears that the chemical evolution of the pre-solar system interstellar dust ensures that a major fraction of comets is in the form of complex organic molecules at least partially of a prebiotic nature and that the submicron interstellar dust preserves its chemical integrity as a result of forming a very tenuous low density comet structure whose solid matter occupies – 1/5 of the total volume. This low density micro structure further provides a physical basis for comets bringing a significant fraction of the original interstellar organic molecules to the earth unmodified by the impact event. Finally, the evidence for a large number of comet collisions with the early earth ensured that the major organic molecular budget on the earth's surface was "continuously" supplied along with water well before 3.8 billion years ago which is the earliest date for life.

Hughes, D. W. (Department of Physics, The University, Sheffield S3 7RH, U.K.): 'Changes in the Extent of the Emission Region on a Cometary Nucleus and its Effect on the Activity Index', *Astron. Astrophys.* **220** (1989), 301–305.

The ability of a comet to reflect and re-radiate sunlight varies as a function of heliocentric distance, r(AU), and is usually found to be proportional to r^{-n}, where n is known as the activity index. When a comet is close to the Sun, the changes that have been observed in the activity index from apparition to apparition, and between the pre- and post-perihelion phases of the orbit, could have a simple physical as well as a chemical cause. It is suggested that the temporal variation in the area of the nucleus that is actively emitting gas and dust is important in this context. For example, the observed post-perihelion activity index of Comet Halley is 3.42 ± 0.13. This value could be due to the fact that both (a) the gas and dust emission is proportional to the incident flux of sunlight, and (b) the percentage, f, of the surface of the nucleus that is potentially active at that time, is varying according to the relationship $f = 14.0\text{–}3.1r^{-2}$.

Ip, W.-H. (Max-Planck-Institut für Aeronomie, D-3411 Katlenburg-Lindau, F.R.G.): 'On Charge Exchange Effect in the Vicinity of the Cometopause of Comet Halley', *Astrophys. J.* **343** (1989), 946–952.

In order to explore the physical nature of the cometopause observed at comet Halley by the *Vega* spacecraft and by the *Giotto* probe, the chemical compositional changes and variations of the thermal energy distributions of the water-group ions are examined adopting a two-dimensional cometary plasma flow field model based on three-dimensional MHD simulations of J. A. Fedder *et al.* The charge exchange loss of hot cometary ions and the solar wind protons could be used to explain the observed number density profiles quantitatively. The resulting exponential depletion of the hot ion populations with a scale length of $\sim 10^4$ km occurs near $6 + 8 \times 10^4$ km along the trajectory of *Giotto* as indicated by both theoretical computations and the ion mass spectrometer measurements. The formation of the cometopause located at $\sim 1.4 \times 10^5$ km is therefore not necessarily as closely related to the charge exchange process as was previously thought. A promising alternative would be the rapid growth of certain plasma instability such that the fast-moving solar wind plasma may be assimilated by the dense, cold cometary plasma lagging behind.

Komitov, B., Shkodrov, V., Ivanova, V., and Stoyanova, S. (Bulgarian Academy of Sciences, Bulgarian Institute of Space Research, Stara Zagora Branch, Astronomy Section, BU-1113 Sofia, Bulgaria): 'Narrow-Band Photometry of Comet Halley, and the λ 3883 CN Emission', *Soviet Astronomy Letters* **14** (1989), 438–440.

The mechanisms responsible for producing cyanogen in Comet Halley are investigated, using narrow-band (3640–4000 Å) Schmidt photographs taken in April–May 1986. The primary source of the λ 3883 CN 0–0 band emission is resonance fluorescence of daughter CN molecules. Several conclusions are drawn as to the parent molecules.

Lamy, P. L., Malburet, P., Liebaria, A., and Koutchmy, S. (Laboratoire d'Astronomie Spatiale, CNRS, Les Trois Lucs, F-13012 Marseille, France); 'Comet P/Halley at a Heliocentric Preperihelion Distance of 2.6 AU: Jet Activity and Properties of the Dust Coma', *Astron. Astrophys.* **222** (1989), 316–322.

We present an in-depth analysis of a high-resolution photograph of comet P/Halley obtained on September 12, 1985 when it was a heliocentric distance of 2.6 AU preperihelion. The coma has a diameter of $1.38\ 10^5$ km and exhibits structures which are interpreted as three jets, one best seen in the outer part of the coma extending to 29000 km and the two others, in the inner part extending to about 7000 km. The integrated magnitude and radial profiles of the coma are given showing that the comet does not follow the simple steady-state, radial outflow model. By combining our photometric result with nearly simultaneous ultraviolet and infrared observations, we find that the strong reddening in the ultraviolet gradually levels off in the visible as the color becomes neutral at 2 μm and blue beyond 3 μm. A geometric albedo at zero phase angle of 0.04 is obtained, as well as a dust production rate of 30 to 120 kg s^{-1}.

Lawler, M. E., Brownlee, D. E., Temple, S., and Wheelock, M. M. (Department of Astronomy, University of Washington, Seattle, Washington 98195): 'Iron, Magnesium, and Silicon in Dust from Comet Halley', *Icarus* **80** (1989), 225–242.

We have used mass spectra from the Vega-1 and Giotto spacecrafts' PUMA-1 and PIA impact mass spectrometers to study the Mg, Si, and Fe composition of Comet Halley's dust grains. Automated and manual methods were developed to select only the highest quality mass spectra, rejecting the many spectra with excessive noise, double peaks, data format errors, or molecular contamination. The rigorous selection algorithms accepted a total of 433 compressed (low resolution) PUMA-1 spectra, 29 of the PUMA-1 uncompressed (high resolution) spectra, and 32 of the PIA uncompressed spectra. This selected data set gives results agreeing in general with results of other authors, but differing in some details such as dispersions of ion ratios. Relative to Si, a fairly constant Mg abundance is found, while Fe varies over a very large range. The majority of Mg appears to be contained in silicates, but the wider range for Fe indicates that it is contained in a range of materials such as metal, magnetite, sulfides, and silicates of varying Fe composition. The lack of sharp clustering in the data reveals that (with the exception of some FeS particles) none of the detected particles are single mineral grains. Halley solids are either composed of mineral grains smaller than the typical particle size, or they contain abundant glass. The distribution of Fe/(Fe + Mg) approximately matches the broad, flat distribution of submicron grains in some types of interplanetary dust particles collected in the stratosphere and is quite different from the narrow distribution found in carbonaceous chondrite matrix. The best match is with interplanetary particles that contain high-temperature, Mg-rich silicates and that are dominated by anhydrous minerals. We tentatively suggest that by analogy Halley is a discordant mixture of ice and high-temperature anhydrous minerals. This contrasts with the carbon-rich carbonaceous chondrites that are dominated by hydrous minerals.

Le, G., Russell, C. T., Gary, S. P., Smith, E. J., Reidler, W., and Schwingenschuh, K. (Department of Earth and Space Sciences and Institute of Geophysics and Planetary Physics, University of California, Los Angeles, CA 90024): 'ULF Waves at Comets Halley and Giacobini-Zinner: Comparison with Simulations', *Journ. Geophys. Res.* **94** (1989), 11989–11995.

This paper compares observations and numerical simulations of magnetic fluctuations near the proton and water group ion cyclotron frequencies as a function of distance from the comets Giacobini-Zinner and Halley. Because the Doppler shift of the ion cyclotron resonance is equal and opposite to that associated with the flow of the solar wind plasma past the observer, one can monitor the amplitude of waves due to different cyclotron resonant instabilities by examining the amplitude of waves near the gyrofrequency of the respective ions as measured in the spacecraft frame. This expectation has been checked by comparison of the data to results of a one-dimensional electromagnetic hybrid simulation of two-ion pickup. Distant from both comets the wave amplitudes are very weak. But as the comet is approached, the wave amplitude grows. These observations are consistent with computer simulations which predict amplitudes that depend on the properties of the injected beams and the local injection rate.

Malara, F., Einaudi, G., and Mangeney, A. (Observatoire de Paris, Meudon, France): 'A Quasi-One-Dimensional Model for the Giacobini-Zinner Plasma Tail', *Journ. Geophys. Res.* **94** (1989), 11805–11811.

An assumption of quasi-one-dimensionality is used to derive a simple set of equations describing the comet Giacobini-Zinner tail configuration. The MHD equations are expanded in terms of a parameter representing the ratio of the length scale in the direction perpendicular to the neutral sheet over the length scale in the direction parallel to the tail. It is shown that in this way it is possible to obtain much information on the structure of the tail and to fit reasonably well the observations made by the ICE spacecraft.

Malara, F., Einaudi, G., and Mangeney, A. (Observatoire de Paris, Meudon, France): 'Stability Properties of a Cometary Plasma Tail', *Journ. Geophys. Res.* **94** (1989), 11813–11819.

The linear stability of the plasma tail of a comet is numerically investigated. The zeroth-order model of the tail plasma configuration is based on the result of a companion paper (Malara *et al.*, this issue), discussing the possible modeling of the data obtained during the ICE encounter with comet Giacobini-Zinner. Effects both of finite resistivity and of velocity shear are taken into account. The tail appears to be unstable against Kelvin–Helmholtz-like modes in which a certain amount of reconnection occurs. Because of the velocity flow shear the perturbation extends far beyond the singular layer and affects in depth the magnetic lobes. The relative importance of the Kelvin–Helmoltz turbulence in the lobes and the level of reconnection, the typical wavelengths, and the growth time of the mode depend on the particular cometary tail considered.

Marconi, M. L., Korth, A., Mendis, D. A., Lin, R. P., Mitchell, D. L., Réme, H., and D'Uston, C. (Department of Electrical and Computer Engineering, University of California, La Jolla, CA 92093): 'On the Possible Detection of Organic Dust-Borne C_3H^+ Ions in the Coma of Comet Halley', *Astrophys. J.* **343** (1989), L77–L79.

The heavy ion analyzer (PICCA) on board the *Giotto* spacecraft was used to determine the composition of positively charged ions in the environment of comet Halley. Here we argue that a distinct peak at 37 amu, observed in the mass spectrum inside the ionopause, is due to C_3H^+. We further argue that the dominant source of this ion, as well as the earlier identified ion ($C_3H_3^+$ at 39 amu), is not the cometary nucleus but is rather the circum-nuclear halo of the so-called CHON dust particles observed at the comet.

Mason, J.: 'Returning Comet Rockets Past the Earth', *New Scientist* **123** (1989), 29.

Comet Brorsen–Metcalf has already passed its closest position to the Earth. It came within 93 million kilometres.

Matese, J. J., Whitmire, D. P., and Reynolds, R. T. (Department of Physics, The University of Southwestern Louisiana, Lafayette, LA 70504): 'Dust Clouds Around Red Giant Stars: Evidence of Sublimating Comet Disks?', *Icarus* **81** (1989), 24–30.

A growing amount of observational and theoretical evidence suggests that most main sequence stars are surrounded by disks of cometary material within several hundred astronomical units. In this paper we investigate dust production by comets in such disks when the central stars evolve up the red giant and the asymptotic giant branch (AGB) where their luminosities can increase to 10^4–$10^5 L_\odot$. Once released, the dust will undergo collisions, ablation, and be accelerated by the gas outflow, whereupon the smaller fragments ($\geqslant 10$ Å) can become the cores necessary for condensation of the gas. The origin of the requisite cores has presented a well-known problem for classical condensation theory. This explanation is consistent with the dust production observed around red giants and AGB supergiants (which have increasing luminosities) and the fact that earlier supergiants and most WR stars (whose luminosities are unchanging) do not have significant dust clouds even though they have significant stellar winds. Another consequence of the model is that the dust condensation radius is greater than that predicted by conventional theory, in agreement with IR interferometry measurements of α-Ori. A further prediction is that the spatial distribution or the dust (i.e., disk-like) will not, in general, coincide with that of the gas outflow, in contrast to classical condensation theory. The latter test is relevant to the dust shells that condense in classical novae outbursts which we also interpret in terms of disks of cometary material. Verification of these interpretations would provide new evidence that circumstellar disks of cometary material may be ubiquitous.

Mukai, T., Fechtig, H., Grün, E., and Giese, R. H. (Kanazawa Institute of Technology, Nonoichi, Ishikawa 921, Japan): 'Icy Particles from Comets', *Icarus* **80** (1989), 254–266.

The survival probability of the particles leaving a comet is examined based on their orbital changes at the moment of ejection. Considering the repulsive radiation pressure on them plus their emission velocities relative to the cometary nucleus the critical radii s_1 and s_c are defined in a grain radius $s \leqq 10^{-5}$ cm, where the ejected grains with $s_1 \leqq s \leqq s_c$ cannot stay in the Solar System. We have found empirical formulae of s_1 and s_c; e.g., for long-period comets with semimajor axes $a \geqq 10^3$ AU and perihelion distances $q \geqq 3$ AU, $s_c(\text{cm}) = 2.3 \times 10^{-6} a(\text{AU})$ and $s_1(\text{cm}) < 10^{-5}$ in the case of zero emission velocity. Water-ice particles with radii $s \geqq 100\ \mu\text{m}$ contaminated by "dirty" inclusions, which are injected into bound orbits with $q \geqq 7$ AU, are controlled by catastrophic collisions with interplanetary dust, and those with $s \leqq 100\ \mu\text{m}$ are controlled by the Poynting–Robertson drag forces. Contrary to that, almost all dirty water-ice grains on orbits with $q \leqq 7$ AU lose their ice parts due mainly to sublimation.

Mumma, M. J. and Reuter, D. C. (Planetary Systems Branch, NASA Goddard Space Flight Center, Greenbelt, MD 20771): 'On the Identification of Formaldehyde in Halley's Comet', *Astrophys. J.* **344** (1989), 940–948.

The ν_1 and ν_5 infrared bands of formaldehyde in Halley's comet have been synthesized, using a line-by-line model for solar infrared fluorescence from low-temperature H_2CO. Fully resolved spectra were convolved to spectral resolutions comparable with those used on the IKS spectrometer on the *Vega 1* spacecraft. Excellent agreement is obtained between the observed and modeled spectra, permitting a definite identification of H_2CO in Halley's comet. The retrieved production rate is $4.5 \pm 0.5 \times 10^{28}$ molecules s^{-1}, and the rotational temperature is probably less than 150 K, with a best-fit value of about 50 K. We also retrieve production rates (or upper limits) from ground-based spectra of comets Halley and Wilson (1986l), and show that the production rate of H_2CO exhibits significant temporal variability, relative to H_2O, in comet Halley.

Perez-de-Tejada, H. (Instituto de Geofisica, Universidad Nacional Autonoma de Mexico Ensenada, Baja California, Mexico): 'Viscous Flow Interpretation of Comet Halley's Mystery Transition', *Journ. Geophys. Res.* **94** (1989), 10.131.10.136.

A study of the solar wind within comet Halley's ionosheath is presented. It is shown that the plasma changes seen across the intermediate ("mystery") transition, located approximately half way between the bow shock and the cometopause along the Giotto trajectory, are similar to those occurring across an equivalent transition present within the Venus ionosheath. As in Venus, the observed plasma changes are consistent with those expected from the onset of friction phenomena between the shocked solar wind and the main body of ionospheric plasma. It is suggested that the intermediate transition in comet Hally's ionosheath represents the outer boundary of a thick viscous boundary layer that develops from the nose of the cometopause and extends along the flanks of the ionosheath. On the basis of this interpretation it is concluded that the subsolar position of the cometopause may have reached ~3.4 10 km upstream from the nucleus at the time of the Giotto measurements.

Reitsema, H. J., Delamere, W. A., Williams, A. R., Boice, D. C., Huebner, W. F., and Whipple, F. L. (Ball Aerospace Systems Division, Boulder, CO 80306). 'Dust Distribution in the Inner Coma of Comet Halley: Comparison with Models', *Icarus* **81** (1989), 31–40.

The images of the inner coma of comet Halley that were taken with the Giotto camera have been evaluated to obtain information on the near-nucleus dust distribution and its relationship to the nuclear source regions. Over two-thirds of the dust in the inner coma can be modeled remarkably well with only three source regions, each emitting dust into broad jets with opening half-angles of 30 to 50°. The dust in the jets is not sharply bounded but disperses with a Gaussian cross section, consistent with a model in which both gas and dust emissions are confined to finite source regions. Departures from the simple R^{-1} relationship for the radial distribution of dust near the nucleus are reproduced by a model that considers the source region as a composite of adjacent subareas, each emitting dust into cones with opening half-angles of about 10°. Comparison of the azimuthal and radial dust distributions with model predictions gives information on the coma dust, the dust-gas interaction, and the properties of the emitting regions.

Roettger, E. E., Feldman, P. D., Ahearn, M. F., Festou, M. C., McFadden, L. A., and Gilmozzi, R. (Department of Physics and Astronomy, The Johns Hopkins University, Baltimore, Maryland 21218): 'IUE Observations of the Evolution of Comet Wilson (1986I): Comparison with P/Halley', *Icarus* **80** (1989), 303–314.

The ultraviolet spectrum of comet Wilson (1986*l*) was observed with the *International Ultraviolet Explorer* (*IUE*) satellite observatory between September 1986 and November 1987. Observations were made at weekly and biweekly intervals near perihelion, making comet Wilson the first dynamically "new" comet to be observed with the *IUE* through perihelion. This provided the opportunity to compare a "new" comet, Wilson, with a highly evolved comet, P/Halley (1986III), which was observed both preperihelion and postperihelion at about the same heliocentric distances. The derived production rates of several gases, as well as the visual brightness of comet Wilson, were found to decrease monotonically near perihelion, even though the comet remained at approximately the same heliocentric distance. No short term variability of the type seen in P/Halley was observed in comet Wilson. The water production rates, derived from the observed OH emission, were roughly the same for both comets near 1.2 AU, although earlier (near 2.5 AU inbound), comet Wilson showed significantly greater water production than comet Halley. The column densities of several gas species, relative to OH, were about half as high in comet Wilson as in P/Halley preperihelion at comparable heliocentric and geocentric distances. Previously unidentified spectral features were detected near 1474 and 1425 Å; these were identified as Si emissions, with significant fluorescence efficiencies only when the heliocentric velocity of the comet is near zero. However, the intensity of the λ1474 feature, relative to Si λ1814, is inconsistent with atomic data in the literature.

Schulz, R. and Schlosser, W. (Astronomisches Institut, Ruhr-Universität, D-4630 Bochum 1, F. R. Germany): 'CN-Shell Structure and Dynamics of the Nucleus of Comet P/Halley' (Erratum), *Astron Astrophys.* **222** (1989), 367.

Torbett, M. V. (Department of Physics and Astronomy, University of Kentucky, Lexington, Kentucky 40506): 'Chaotic Motion in a Comet Disk beyond Neptune: The Delivery of Short-Period Comets', *Astron. J.* **98** (1989), 1477–1481.

Recent Monte Carlo simulations have demonstrated that a source with a spherical distribution of orbital angular momenta such as the Oort Cloud cannot give rise to the highly flattened distribution of short-period comets. It was also demonstrated that the problem of delivery could be resolved if short-period comets originate in a low inclination disk of comets beyond the orbit of Neptune. Numerical integrations of cometary motion in this disk show that perturbations by the four major planets can result in chaotic motions which, on long timescales, can deliver comets to low inclination Neptune-crossing orbits. Multistage gravitational scattering by the major planets can then, according to theory, supply short-period comets with orbital elements matching observations.

Trotignon, J.-G., Grard, R., and Mogilevsky, M. (Laboratoire de Physique et Chimie de l'Environnement, Centre National de la Recherche Scientifique, F-45071 Orléans Cedex 02, France): 'Electric-Field Measurements in Comet P/Halley's Environment by the High-Frequency Plasma-Wave Analyser', *Annales Geophysicae* **7** (1989), 331–340.

The Vega-1 and Vega-2 spacecraft explored the comet P/Halley's environment in March 1986. Several plasma boundaries were crossed, which result from interaction between solar wind and the comet. Here we report on the observations performed by the plasma-wave analyser APV-V in the vicinity of some of these boundaries: the pick-up region in front of the bow shock, the cometopause, and a region probed by Vega-2 between 0711 and 0714 UT on 9 March 1986. Electric-field spectral measurements are stressed and the interpretations of the data collected by other experiments in these regions are reviewed. The bow shock does not cause any detectable feature in the APV-V electric-field data. A spectral analysis of the electric signal recorded in the 8–14 Hz filter channel near the cometopause, reveals clear oscillations with a period lying between 20 and 60 s. The event observed by Vega-2 in the inner coma, at a distance of about 4000 km from the nucleus, is analysed in every detail. We conclude that the data are strongly influenced by dust impacts.

Yabushita, S. (Department of Applied Mathematics and Physics, Kyoto University, Kyoto 606, Japan): 'On the Discrepancy between Supply and Loss of Observable Long-Period Comets', *Mon. Nat. R. Astr. Soc*, **240** (1989), 69–72.

Long-period comets that are unobservable owing to large perihelion distances are brought to the observable region by the perturbation of the galactic tidal force, while they are lost by planetary as well as galactic perturbations. Both the galactic and planetary perturbations have been calculated for observed long-period comets for which accurate orbital elements are known. It is possible to identify which comets are being newly supplied and which comets are being lost. The supply of new comets is shown to be significantly greater than the loss, so that the present cometary population does not appear to be in a steady state. This strongly suggests that the cometary cloud was disturbed in the recent past and the most likely candidate for the disturbance appears to be a giant molecular cloud.

Yeomans, D. K. (Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109): 'Comets and the Perversity of Nature', *Sky and Telescope* **78** (1989).

Yeomans, D. K. and Chodas, P. W. (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California 91109): *Astron. J.* **98** (1989), 1083–1093.

The standard nongravitational force model, used to represent cometary motions for 16 years now, has been modified to allow the water-vaporization curve to peak a certain number of days (DT) either before or after perihelion. When compared to the standard model, this new, asymmetric model often improves the data fit. The best fit to the astrometric data generally occurs for a value of DT corresponding to the offset in the comet's visual light curve. The asymmetric model, which more accurately mimics the comet's outgassing history, often yields values for the radial and transverse nongravitational parameters that are completely different from corresponding values derived using the standard symmetric model; thus these latter quantities are extremely uncertain and works that have employed them to infer physical properties of comets should be re-examined. Inferred rotation and precession characteristics of cometary nuclei can differ markedly depending upon the model used. For example, the asymmetric model suggests only weakly that the rotation direction of Comet Halley is direct and there is no longer any evidence to suggest that the rotation axis of Comet Kopff passed through its orbit plane in the early twentieth century. Because the asymmetric model relies primarily upon the radial rather than the transverse component to create secular changes in a comet's nongravitational motion, the results with the asymmetric model will generally yield lower thermal lag angles. For Comets Halley and d'Arrest, the approximate lag angles are 4° and 10°, respectively.

21. METEORITES

Brearley, A. J. (Institute of Meteoritics, Department of Geology, University of New Mexico, Albuquerque, NM 87131): 'Nature and Origin of Matrix in the Unique Type 3 Chondrite, Kakangari', *Geochimica et Cosmochimica Acta* **53** (1989), 2395–2411.

The mineralogy and textural characteristics of fine-grained matrix ($<1\ \mu m$) in the unique type 3 chondrite, Kakangari, have been investigated by high resolution and analytical electron microscopy. The matrix contains a diverse primary mineralogy dominated by enstatite and olivine, with lesser amounts of albite, anorthite, Cr-spinel, troilite and Fe, Ni metal. Texturally, the matrix is characterized by irregular clusters or aggregates of crystals which constitute distinct structural units within the matrix, $\sim$2–8 μm in diameter, and frequently have distinct mineralogies. Enstatite in these clusters is an intergrowth of monoclinic and orthorhombic polymorphs, with a microstructure indicative of an origin by high temperature inversion from protopyroxene during rapid cooling. Corroded inclusions of olivine frequently occur within enstatite, suggesting that enstatite formed by reaction of olivine with a silica polymorph at high temperature. The matrix mineralogy of Kakangari formed by high temperature annealing and reaction of fine-grained dust which probably consisted of amorphous or partially crystalline presolar or solar nebula condensates. The constituents of Kakangari matrix cannot, therefore, be considered as pristine, unprocessed solar system material. Annealing probably occurred in a thermal event similar to that which formed the chondrules, but the microstructures and textures of the matrix components suggest that melting did not occur. Chondrules in Kakangari were probably formed from identical precursors to the matrix, but reached temperatures sufficiently high to produce melting. Despite this high temperature processing, the mineralogical clusters in the matrix preserve mineralogical and, hence, chemical heterogeneities in the precursor materials similar to those observed in interplanetary dust particles.

Brearley, A. J., Scott, E. R. D., Keil, K., Clayton, R. N., Mayeda, T. K., Boynton, W. V., and Hill, D. H. (Institute of Meteoritics, Department of Geology, University of New Mexico, Albuquerque, NM 87131): 'Chemical, Isotopic and Mineralogical Evidence for the Origin of Matrix in Ordinary Chondrites', *Geochimica et Cosmochimica Acta* **53** (1989), 2081–2093.

We report the first combined chemical, isotopic and mineralogical study of fine-grained opaque matrix material from a type 3 ordinary chondrite, Allan Hills A77299 (H3.7). Electron microprobe and instrumental neutron activation analysis of a large matrix lump show that it has a major element composition typical of matrix material in type 3 chondrites. Unlike chondrules, it shows no siderophile element depletions and is remarkably unfractionated relative to Cl chondrites, suggesting that it is primitive solar system material. The matrix lump has an unique oxygen isotopic composition which lies below the terrestrial fractionation line and differs markedly from the composition of fine-grained matrix lumps and chondrule rims from Semarkona (Grossman *et al.*, 1987). Transmission electron microscope (TEM) studies of microtomed samples of the fine-grained fraction (<5 m) of the matrix lump show that it consists of rare, angular, clastic grains (>1 m) of pyroxene and olivine, embedded within a groundmass of rounded, fine-grained (<0.5 m) olivines. The mineralogy and textures of the matrix lump are typical of other occurrences of fine-grained matrix studied by TEM in other type 3 ordinary chondrites.

We conclude that the matrix lump in ALHA 77299 consists largely of material that formed by annealing of amorphous presolar dust or nebular condensates and could not have been derived from chondrules by any reasonable mechanism. However, the observed compositional differences between the matrix lump and chondrules in ordinary chondrites are consistent with the idea that some chondrules formed by melting of matrix-like material, accompanied by loss of siderophile and volatile elements.

Chen, Y.-H. and Wang, D.-D. (Guiyang Institute of Geochemistry, Academia Sinica, China): 'Atmospheric Denudation and Ablation Products of Iron Meteorite', *Chinese Science Bulletin* **34** (1989), 843–845.

Cressey, G., Dent, A. J., Dobson, B., Evans, A., Greaves, G. N., Henderson, C. M. B., Hutchinson, R., Jenkin, N., Thompson, S., and Zhu, R. (Department of Mineralogy, British Museum (Natural

History), London SW7 5BD, U.K.): 'Atomic Environment; in Iron Meteorites using EXAFS', *Physica B* **158** (1989), 511–512.

Meteorites are granular, heterogeneous materials, generally crystalline and sometimes displaying fluctuations in composition within individual grains. At face value they break all the rules demanded as prerequisite for EXAFS measurement and analysis: i.e. that systems should be finely dispersed, homogeneous, of uniform composition and that the elements of interest should occupy single sites. Meteorites, however, are natural materials. Details of the phases present, however, and their variation, may provide clues about the nature of the primary agglomeration of the meteorite parent body, to its thermal history and to its break-up in space. Taken in conjunction with what is already known the technique offers unique possibilities for differentiating between phases as well as probing composition and structure with depth. In this paper we report measurements made on Fe–Ni meteorites and demonstrate how the proportions of kamacite (bcc) and taenite (fcc) phases present can be accurately obtained.

Eugster, O. (Physics Institute, University of Bern, 3012 Bern, Switerland): 'History of Meteorites from the Moon Collected in Antarctica', *Science* **245** (1989), 1197–1202.

In large asteroidal or cometary impacts on the moon, lunar surface material can be ejected with escape velocities. A few of these rocks were captured by Earth and were recently collected on the Antarctic ice. The records of noble gas isotopes and of cosmic ray-produced radionuclides in five of these meteorites reveal that they originated from at least two different impact craters on the moon. The chemical composition indicates that the impact sites were probably far from the Apollo and Luna landing sites. The duration of the Moon–Earth transfer for three meteorites, which belong to the same fall event on Earth, lasted 5 to 11 million years, in contrast to a duration of less than 300,000 years for the two other meteorites. From the activities of cosmic ray-produced radionuclides, the date of fall onto the Antarctic ice sheet is calculated as 70,000 to 170,000 years ago.

Fogel, R. A., Hess, P. C., and Rutherford, M. J. (Department of Geological Sciences, Brown University, Providence, RI 02912): 'Intensive Parameters of Enstatite Chondrite Metamorphism', *Geochimica et Cosmochimica Acta* **53** (1989), 2735–2746.

The Enstatite-Oldhamite Geothermometer (EOG) developed by Larimer and Buseck (1974) makes use of the five-phase assemblage kamacite, quartz, enstatite, oldhamite, troilite to determine metamorphic temperatures in enstatite chondrites. A re-evaluation of the thermodynamic foundation of the EOG shows that several of the assumptions and approximations can be significantly improved with new thermodynamic data. The geothermometer has been modified to reflect, among other things, the solution behavior of Si in kamacite, the solution behavior of a calcium silicate component in enstatite, and metal sulfide fusion as a function of temperature and composition.

An analysis of the EOG shows that the activity coefficient of Si in kamacite and the Ca-rich component of enstatite are the model's most important parameters. For Si, the activity coefficient data of Sakao and Elliot (1975) have been used. The activity coefficient of a Ca-rich component of enstatite presents a unique problem since data on this parameter do not exist for one-pyroxene systems and two-pyroxene solution models do not provide unique activity coefficients in the absence of diopside. The model, therefore, has been formulated using $CaMgSi_2O_6$ as the Ca-rich component of enstatite and assumes that it behaves as a symmetric regular Margules solution. The Margules interaction parameter W_G is then used as an adjustable constant and is varied such that the resulting temperatures fall between minimum and maximum temperatures determined independently.

Temperature minima were determined from the enstatite-diopside solvus of Carlson (1986) and indicate that the EL6 chondrites have been metamorphosed to temperatures exceeding 900–1000°C. The temperature of the enstatite-plagioclase-quartz eutectic (1090°C), appropriate for EL6 plagioclase compositions, was used as the metamorphic maxima. With these constraints, a W_G value of 52 kJ/mole was estimated as appropriate (within the context of the model) for EL6 metamorphic conditions. EL6 temperatures determined via this method range from 981°C for Yilmia to 1068°C for Blithfield.

Temperature estimates of greater than 1000°C for the highly equilibrated EL6 chondrites require the formation of a metal-sulfide liquid during metamorphism. Liquid fractionation of this predominantly Fe–FeS liquid could explain the siderophile, chalcophile, and volatile element depletion in the EL6 class relative to Cl and EH chondrites. Liquid fractionation, however, is not required by the model and is consistent with a moderate cooling rate, which is fast enough to lock in high CaO contents in enstatite but slow enough to re-equilibrate troilite and alabandite to low temperatures.

The oxygen fugacity determined in this study shows the enstatite chondrites to have equilibrated at extremely low f_{O_2}. This, as well as the activity of Si that can be extracted from the EOG, indicates that the enstatite chondrites that contain sinoite (Si_2N_2O) equilibrated under high nitrogen fugacities. High f_{N_2} values imply that sinoite-bearing E-chondrites either formed in a nebula of high pressure ($f_{N_2} = 10^{-1}$ at 1050°C) or, more likely, are products of planetary metamorphism.

Halliday, I., Blackwell, A. T., and Griffin, A. A. (Herzberg Institute of Astrophysics, National Research Council of Canada, Ottawa, Ontario K1A 0R6, Canada): 'The Typical Meteorite Event, Based on Photographic Records of 44 Fireballs', *Meteoritics* **24** (1989), 65–72.

We study the observational data relating to 44 events recorded by the Canadian fireball camera network between 1971 and 1984. Each event is believed to have dropped meteorites, with main masses in the range from 0.1 to 11 kg. Median values are given for 20 parameters describing the atmospheric behavior and orbital elements. A typical duration for a meteoritic fireball is 4 seconds, reaching an end height of 31 km and a velocity of 8 km s^{-1} at the end of the luminous path. The peak brightness is typically −9 magnitude but varies from −7 to −15. Meteorites may survive from relatively unspectacular fireballs.

Numerous correlations among parameters are investigated. The strong correlations of brightness with initial mass and of duration with slope of the trajectory could be anticipated. Moderate correlations also exist between: (1) initial mass and end height; (2) initial mass and duration of luminosity; (3) initial velocity and beginning height; (4) initial velocity and the fraction of the mass that survives as the largest fragment; (5) initial velocity and the perihelion distance of the orbit. Ablation limits the survival of small masses while fragmentation is usually severe for masses larger than 10 kg. The fractional survival may peak for entry masses between 1 and 10 kg.

Hughes, D. W. and McBride, N. (Department of Physics University of Sheffield, Sheffield S3 7RH, England): 'The Mass of Meteoroid Streams', *Mon. Not. R. Astr. Soc.* **240** (1989), 73–79.

Meteoroid streams contain the large majority (by mass) of the dust lost by decaying comets and as such provide a clue as to the mass of the parent cometary nuclei. This paper reviews the method used for calculating the mass of a meteoroid stream and presents typical results for some of the major meteoroid streams encountered by Earth. For example the masses of the streams responsible for the Quadrantid, Perseid, Orionid/Eta Aquarid and Geminid meteor showers are found to be 1.3×10^{15}, 3.1×10^{17}, 3.3×10^{16} and 1.6×10^{16} g respectively. These masses are compared with the estimated masses of typical short-period comets.

Jagoutz, E. (Max-Planck-Institut für Chemie, Saarstrasse 23, D-6500 Mainz, F.R. Germany): 'Sr and Nd Isotopic Systematics in ALHA 7705: Age of Shock Metamorphism in Shergottites and Magmatic Differentiation on Mars', *Geochimica et Cosmochimica Acta* **53** (1989), 2429–2441.

The meteorite ALHA 77005 belongs to the group of SNC meteorites which are thought to be fragments of the planet Mars. New Sr and Nd isotopic data are reported for ALHA 77005 whole rock and petrographically distinct mineral separates. Plagioclase crystallized from a plagioclase shock melt fractionating the Rb/Sr ratio at the time of the shock event. A Rb/Sr age of 15 ± 15 Ma for the shock event is measured using this Rb/Sr fractionation. This shock age is, within error, identical to the exposure age of 2.5 Ma.

Using augite and pigeonite a Rb/Sr crystallization age of 154 ± 6 Ma is measured, which is identical to the crystallization age of the Shergotty mesostasis-plagioclase.

Petrographic evidence indicates that the cumulus olivine in ALHA 77005 is derived from a different source than the intercumulus liquid which crystallized the pyroxenes and the plagioclases. Petrographic comparison of all SNC meteorites suggests that most SNC meteorites are orthocumulates in which the cumulus phase comes from a different source than the intercumulus liquid.

The interrelation of the different isotopic systems indicates that the SNC meteorites can be explained by mixing three isotopically distinct sources. These three sources were differentiated early in Martian history. In contrast to the Moon, where plagioclase fractionation is the dominant magmatic process, the major magmatic processes on Mars are mafic magmatism and mixing.

Comparison of Martian and terrestrial isotopic systematics suggests that Mars accreted from a material chemically similar to Cl and ordinary chondrites, whereas the Earth has lower than chondritic Si/Mg and Rb/Pb ratios. A similar feature is observed when comparing C2, C3 and CV chondrites with C1 or ordinary chondrites: C2, C3, CV meteorites and the Earth have less Rb for their apparent Pb inventory.

Jones, W. G., Smith, P. F., Homer, G. J., Lewin, J. D., and Walford, H. E. (Blackett Laboratory, Imperial College, London, SW7 2AZ, U.K.): 'Searches for Fractional Electric Charge in Meteorite Samples', *Zeitschrift für Physik C* **43** (1989), 349–355.

The magnetic levitation technique has been used to test for fractional electric charge on samples of several types of meteorite material, thus providing the first mass-independent search for free quarks or other fractionally-charged particles in natural nonterrestrial materials. The tests were made on diced samples of the Hoba and Forsyth County iron-nickel meteorites, and the Murchison stony meteorite, the latter being plated with iron to allow magnetic levitation. No evidence for fractional charge was found, the quantities tested being 1.3 mg (Hoba), 1.1 mg (Forsyth), and 0.4 mg (Murchison).

Jull, A. J. T., Donahue, D. J., and Linick, T. W. (NSF Accelerator Facility for Radioisotope Analysis, University of Arizona, Tucson, AZ 85721): 'Carbon-14 Activities in Recently Fallen Meteorites and Antarctic Meteorites', *Geochimica et Cosmochimica Acta* **53** (1989), 2095–2100.

This paper reports ^{14}C measurements in meteorites using an extraction method which employs RF melting of samples as small as 0.1 g. A study of extraction of cosmic-ray-produced ^{14}C in samples of Bruderheim gave ^{14}C levels between 38 and 60 dpm/kg for samples which had been preheated in air between 250 and 700°C, with a mean value of 46.8 ± 1.4 dpm/kg. A range of values between 35 and 59 dpm/kg was found for other falls of saturated meteorites preheated to 500°C. The preheating step is shown to be effective in removing terrestrial carbon contamination. A series of samples previously dated by ^{81}Kr as having ages of 120–310 kyr gave ^{14}C levels of between <0.16 and 0.37 ± 0.10 dpm/kg. These levels are consistent with levels of *in situ* production by cosmic rays at the Earth's surface.

Kallemey, G. W., Rubin, A. E., Wang, D., and Wasson, J. T. (Institute of Geophysics and Planetary Physics, University of California, Los Angeles, CA 90024): 'Ordinary Chondrites: Bulk Compositions, Classification, Lithophile-Element Fractionations, and Composition-Petrographic Type Relationships', *Geochimica et Cosmochimica Acta* **53** (1989), 2747–2767.

Concentrations of 26 elements were determined by replicate neutron-activation analysis in 66 ordinary chondrites (22 H, 20 L, 17 LL, 2 intermediate between H and L, and 5 intermediate between L and LL). Olivine and kamacite compositions were determined in adjacent samples about 20% of the chondrites contain kamacite or olivine grains with aberrant compositions >3 s from the mean. The sample set was biased in favor of the reduced, siderophile-rich and oxidized siderophile-poor members of the groups, and in favor of chondrites reported to have unusual compositional features. Several chondrites were reclassified: e.g., the photographed fall, Innisfree, is L, not LL; Albareto is LL, not L; and Xingyang and Zhovtnevyi are H6, not H5.

On a plot of kamacite Co concentration versus Fa content of olivine, there is a hiatus between H and L, but no hiatus between L and LL. Five chondrites (Bjurböle, Cynthiana, Knyahinya, Qidong, Xi Ujimgin) fall between the main L and LL clusters. Cosmic-ray and U, Th–He outgassing age data do not demonstrate relationships to either group. Our siderophile data support the previous group assignments of unequilibrated chondrites in all cases but two: Bremervörde and Tieschitz have siderophile levels intermediate between H and L.

Our mean group compositions are in good agreement with those previously reported. We confirm that the Co/Ni ratio decreases about 5% through the H–L–LL sequence, and that Na and Mn abundances are about 7% lower in H than in L and LL. Selenium and Zn show similar abundances in the three groups; the very low ($\sim 0.1 \times$ CI) Zn abundance is attributed to condensation as fine, ZnS aerosols that inefficiently settled to the midplane. Abundances of V and Cr decrease by only $\sim 2\%$ between H and LL; thus, only a small fraction was in nebular siderophile components.

With the exception of highly volatile Br, no significant differences in abundance are observed among the petrographic types of each group. This conflicts with earlier conclusions that intertype differences (including a systematic increase in siderophile abundance with increasing type) are present. The small differences we observed are attributable to anomalously low or high contents of one or two phases (generally metal and/or troilite) in a few replicates. The absence of a relationship between composition and petrographic type is consistent with models calling for the progressive therrnal metamorphism of primitive unequilibrated materials to produce the observed spectrum of petrographic grades, and places narrow limits on the relative accretion efficiencies of nebular components in those models calling for the sequential accretion of nebular materials.

Levy, E. H. and Araki, S. (Lunar and Planetary Laboratory, Department of Planetary Sciences, University of Arizona, Tucson, AZ 85721): 'Magnetic Reconnection Flares in the Protoplanetary Nebula and the Possible Origin of Meteorite Chondrules', *Icarus* **81** (1989), 74–91.

Many primitive meteorites are composed largely of chondrules, small once-molten beads of glassy rock. The existence of chondrules poses a basic problem for our understanding of the protoplanetary nebula inasmuch as the chondrules seem to have been melted by very short-lived, transient heating events in otherwise cool nebular surroundings. In this paper, the possibility is investigated that meteorite chondrules formed as a result of melting of protosolar nebula dust balls by the energy released from magnetic flares in the nebula's corona. Analysis of the energy that could be released by magnetic reconnection events in nebular coronal flares shows that previously existing dust balls could be heated transientl to temperatures sufficiently high (above 1700°K) to cause the short-lived melting events that are needed to account for the existence of chondrules. The release of flare energy at rates sufficient to account for chondrule melting requires that the flares occur in the presence of magnetic fields somewhat in excess of 5 G in a lowdensity coronal region of the disk. Nebular magnetic fields of this strength are in accord with magnetizing fields that have been inferred from the measured remanent magnetization of primitive meteorites.

MacPherson, G. J., Croaz, G., and Lundberg, L. L. (Department of Mineral Sciences, National Museum of Natural History, Smithsonian Institution, Washington, DC 20560): 'The Evolution of a Complex Type B Allende Inclusion: An Ion Microprobe Trace Element Study', *Geochimica et Cosmochimica Acta* **53** (1989), 2413–2427.

USNM 5241 is a Type B1 refractory inclusion from Allende, first described by El Goresy *et al.* (1985), that consists of a 1.2 mm-thick melilite-rich and spinel-poor mantle enclosing a 0.6 cm radius spinel-rich core; the inclusion contains xenoliths of spinel-free fassaite ± melilite ± anorthite incorporated within the spinel-rich core. Detailed ion microprobe analyses of individual phases in 5241 show that the rare earth element (REE) concentrations in mantle melilite vary irregularly with increasing distance from the rim of the inclusion, at first decreasing immediately below the rim and then remaining constant between ~0.4 and 1.0 mm. More than 1.0 mm from the rim, the REE concentrations again decrease. Although counterintuitive in the context of *traditional* fractional crystallization models, these REE variations are in fact broadly consistent with such a model in light of recent experimental measurements of $D_{Ree^{3+}(mel)}$ by Beckett *et al.* (1988) that show a strong inverse correlation of D with the åkermanite content of the melilite. Local variations, over distances of <20 m, in the åkermanite content of mantle melilite – as much as 5–10 mol% Åk – with accompanying fluctuations in REE contents, are due to reaction of gehlenitic melilite with tiny inclusions of fassaite, producing narrow zones of more åkermanitic melilite surrounding more fassaitic pyroxene. Spinel-free islands have widely varying bulk compositions, in both major and trace elements, and are probably trapped xenoliths. Measurements of Mg isotopic mass fractionation show that the entire inclusion is enriched in heavy magnesium by 6.1 ± 1.2‰ relative to terrestrial standards, but there are no significant differences between mantle melilite, core melilite + fassaite + spinel, and spinel-free island melilite + fassaite. There is thus no evidence that volatilization played any major role during the formation of the melilite mantle. Significant assimilation of very fassaite-rich spinel-free island material during the post-mantle crystallization of the melt is required to explain the observed decrease of Eu concentration in the core.

We interpret 5241 as having formed largely by fractional crystallization during the first ~40% of its solidification; this was followed by fractional crystallization + xenolith assimilation during the last 60%.

Monod, T: (FR) 'New Data on the Problem of the Chinguetti Giant Meteorite (Adrar, Mauritania)', *Comptes Rendus Acad. Sci. Paris, Ser. II* **309** (1989), 547–552.

The existence of a giant meteorite in the Adrar (Mauritania) largely accepted since 1924, must henceforth be abandoned. An error was made on the identification of the rock of a 40 m hill, that is entirely sedimentary with no trace of metal.

Morgan, J. W. and Walker, R. J. (U.S. Geological Survey, Reston, VA 22092): 'Isotopic Determinations of Rhenium and Osmium in Meteorites by Using Fusion, Distillation and Ion-Exchange Separations', *Analytica Chimica Acta* **222** (1989), 291–300.

A stable isotope-dilution method using resonance ionization mass spectrometry is suitable for the determination of rhenium and osmium abundances and osmium isotopic composition in carbonaceous chondrites and iron meteorites. The chemical procedure involves sodium peroxide fusion, followed by distillation of osmium from sulfuric acid/hydrogen peroxide and subsequent anion-exchange separation of rhenium from the same solution.

Nishiizumi, K., Jull, A. J. T., Bonani, G., Suter, M., Wölfli, W., Elmore, D., Kubik, P. W., and Arnold, J. R. (Department of Chemistry, University of California, San Diego, La Jolla, California 92093): 'Age of Allan Hills 82102, a Meteorite Found Inside the Ice', *Nature* **340** (1989), 550–551.

The recovery of thousands of meteorites in the Antarctic since 1969 has not only greatly increased knowledge of the meteorites themselves but has also provided a new tool for glaciology. Most Antarctic meteorites are found on blue ice areas where old ice is continuously ablated. A measurement of the age of this ice helps us understand meteorite accumulation mechanisms and the dynamics of ice movement. The terrestrial age of a meteorite, the time period since the date of meteorite fall, can be determined from the reduction in concentration of cosmogenic radionuclides during the time the meteorite has been shielded by the Earth's atmosphere. Here we report the terrestrial age of a meteorite that was recovered from below the surface of the ice and argue that this represents a measurement of the age of the ice itself. We measured the cosmogenic radionuclides ^{10}Be (half-life = 1.5 Myr), ^{14}C (5730 yr), ^{26}Al (0.71 Myr), ^{36}Cl (0.30 Myr) and ^{53}Mn (3.7Myr) in the meteorite and

^{10}Be and ^{36}Cl in the ice. We obtained a terrestrial age of 11,000 years for the meteorite which suggests that the snow accumulation area where it fell was only a few tens of kilometres away.

Perelygin, V. P. and Stetsenko, S. G. (Joint Institute for Nuclear Research, Dubna, U.S.S.R.). 'Results of a Calibration of Olivines from Meteorites by Means of ^{238}U Nuclei at the Bevalac Accelerator', *JETP Letters* **49** (1989), 292–296.

The results of a calibration of the sensitivity of olivine crystals from meteorites by means by ^{238}U nuclei at the Bevalac accelerator are reported. The spectra of etchable lengths of the accelerated ^{238}U nuclei and of "ancient" tracks in these olivines show that the group of ancient tracks ~210 μm long found in 1980 in the Nuclear Reactions Laboratory of the Joint Institute for Nuclear Research was caused by galactic cosmic rays of the Th–U group. The possibility of an unambiguous identification of a group of anomalously long cosmic-ray tracks, 340–360μm long, is discussed.

Rasmussen, K. L. (Geophysical Institute, University of Copenhagen, DK-2200 Copenhagen, Denmark): 'Cooling Rate of IIIAB Iron Meteorites', *Icarus* **80** (1989), 315–325.

Metallographic cooling rates have been determined for 12 iron meteorites of group IIIAB using the central taenite Ni content versus laenite width method. Experimentally determined values of local bulk Ni and P are included as input parameters in the calculations as outlined in Rasmussen (1982a, *Icarus* **52**, 444–453). The calculations are based on the recently revised diffusivities and phase diagram recommended by Saikumar and Goldstein (1988, *Geochim. Cosmochim. Acta* **52**, 715–726). The present results show no signs of undercooling in any of the meteorites investigated. The cooling rates are found to be constant through the group, supporting a core origin of group IIIAB. The average cooling rate for the group is found to be 49K/my, corresponding to a parent body radius of 25 ± 7 km. An interpretation of the nucleation history reflecting the early impact history of the parent body is tentatively put forward.

Steele, I. M. (Department of the Geophysical Sciences, The University of Chicago 5734 S. Ellis Ave., Chicago, IL 60637): 'Compositions of Isolated Forsterites in Ornana (C30)', *Geochimica et Cosmochimica Acta* **53** (1989), 2069–2079.

Luminescing forsterite with FeO between 0.25 and 2.0 wt% occurs as cores of isolated grains and within an Fe-rich porphyritic chondrule in the Ornans (C_3O) carbonaceous chondrite. The color variation of the cathodoluminescence depends on the relative intensity of a red emission caused by Cr and a blue emission most intense when transition metal impurities are at the lowest levels. For Ornans forsterite, the blue emission is quenched by Fe at 0.75 wt% and the red at 2.0 wt%. Compositional profiles from core to rim of five isolated forsterites show details of Al, Ca, Sc, Ti, V, Cr, Mn and Fe zoning with respect to position and cathodoluminescence color. FeO shows normal zoning within the core of the five grains, reaching values of 0.75 wt%, at which point rapid enrichment in FeO occurs, reaching FeO values of 20–30 wt% at the grain edge. Titanium and Al are linearly correlated but show erratic changes within each grain; TiO_2 ranges from 500 to 600 ppmw in the core to 100 ppmw in the rim; Al_2O_3 varies from 0.6 wt% in the core to below 0.1 wt% in the rim; CaO is near constant at 0.70 wt% within the blue luminescing core and below 0.4 wt% in the rim; Sc_2O_3 is present in two grains up to 130 ppmw; V_2O_3 shows 500 ppmw at the core and 100 ppmw at the rim. Evidence is presented for growth of euhedral forsterite either from a liquid or gas, subsequent fracturing, precipitation of Fe-metal, and growth of progressively more Fe-rich rims. Diffusion has affected these grains to give halos around metal and diffuse CL boundaries in some crystallographic directions. Some forsterite grains have been incorporated into an Fe-rich assemblage to form chondrules which retain evidence of their origin in the form of these relic grains.

Thiel, K. and Hu, R.-Y. (Nuclear Chemistry Department, University of Köln 5000 Köln 1, F.R.G.): 'The Nuclear Track Depth Profile of the Jilin Meteorite', *Science in China* (*Ser. B*) **32** (1989), 594–603

Using 43 documented drill core samples of the H_5-chondrite "Jilin" the depth profile of GCR-and fission track densities was established. The track profile essentially reflects the GCR-track record of the second (4π-) irradiation stage of "Jilin". Relics of the track record of the first (2π-) exposure are indicated by a deviation from the theoretical depth profile of the 4π-exposure. No Pu-244 fission is observed in the fission track background near the meteorite center. The atmospheric ablation thickness of the two drill cores A and B normal and parallel to the assumed surface of the "Jilin" parent body was found to be 11 ± 4 cm, respectively. A minimum shielding depth of the "top" part of core A during the 2π-exposure is estimated to be ~30 cm. Near surface deviations of the experimental track data from theory are ascribed to a short-term moderate heating event (equivalent to 24 h, ~370°C) no more than 0.4 Ma ago. The resulting partial track annealing in a surface layer of ~15–20 cm thickness of the preatmospheric body can explain the lack of GCR-tracks in Jilin samples from very shallow depths that are based on ^{60}Co measurements.

Trefil, J. (George Mason University, 4400 University Drive, Fairfax, VA 22030): 'Stop to Consider the Stones that Fall from the Sky', *Smithsonian* **20**(9) (1989), 80–93.

More often than we once thought, huge comets and asteroids strike Earth with catastrophic effect – a few months ago, one barely missed us.

Yagi, K., Kimura, M., Kuroda, Y., and Momose, K. (Hokkaido University, Sapporo, Japan): 'Petrology and Magnetic Properties of the Chiang Khan, Thailand, Meteorite', Mineralogy and Petrology **40** (1989), 173–182.

The Chiang Khan meteorite fell on 18th November, 1981 at Chiang Khan, Thailand. It consists of olivine, orthopyroxene, clinopyroxene, Fe–Ni metal, troilite, chromite, plagioclase, glass, and phosphate in order of abundance. Olivine forms barred or porphyritic chondrules, and its composition is uniform (average $Fo_{80.2}$), close-to the average composition of olivine in equilibrated H chondrites. Orthopyroxene and clinopyroxene also have compositions similar to those in equilibrated H chondrites. Both well-defined chondrules and their broken fragments are present in the recrystallized matrix. Microcrystalline plagioclase and clinopyroxene often occur in the groundmass of chondrules, but clear interstitial plagioclase is absent. Chemical composition of chromite plots in the field of chromites in H chondrites. Chiang Khan meteorite is thus classified as an equilibrated H5 type chondrite. The equilibrium temperatures estimated by using mineral pairs are as follows:

Opx-Cpx 800–900°C; Ol-Chromite 510°C.

Water content is 0.24 wt%, and the hydrogen isotopic composition (δD) is -89.5‰.

In the thermal demagnetization experiment magnetization steadily decreased from 0 to 500°C, whereas the remanent magnetization obtained in the A.C. demagnetization experiment is very unstable, probably owing to the large grain size of the Fe–Ni metal.

Yaroshevsky, A. A., Migdisoa, L. F., and Kononkova, N. N.: Mineral Association of Sulfide Nodules of Iron Meteorite Burkhala and Conditions of its Formation' (in Russian), *Geokhimiya* No. 6 (1989), 825–837.

Zanda, B., Malinie, G., and Audouze, J. (Museum National d'Histoire Naturelle, 75005 Paris, France): 'Propagation of High-Energy Partices Inside Solid Matter: Cosmic-Ray-Induced Spallation in Iron Meteorites', Earth and Planetary Science Letters **94** (1989), 171–188.

A model is presented to evaluate the variations with depth of high-energy particle fluxes as they propagate inside spherical solid bodies. This model can be used to calculate the production rates of spallogenic nuclides inside meteorites of various sizes and compositions. The exponential attenuation of the flux, the gradual energy loss due to the Coulombian drag and the production of secondary particles in the spallation reactions are all taken into account in a self consistent way. It is shown that, in the energy range considered (300 MeV to 30 GeV), the particle fluxes are fairly insensitive to the actual angular distribution of the emitted secondary particles, as long as the assumed distribution remains within realistic limits. The propagation equations resulting from these interactions are solved on a spherical mesh consisting in a set of lines of various directions inside the sphere. The computed neutron and proton fluxes are presented in the case of an iron sphere irradiated by galactic cosmic ray (GCR) protons: these results show the critical importance of secondary particles and especially neutrons as depth increases within the sphere. The fluxes are used to calculate the production rates af some cosmogenic nuclides inside iron meteorites. The use of such production rates to gain information on exposure geometry of these meteorites and on the history of the GCR fluxes is discussed through a comparison with experimental data for the iron meteorite Grant. It is shown that the distribution of the different estimated ages within a meteorite could be used to distinguish between a spectral variation and an intensity variation of the GCR flux.

22. MISCELLANEOUS

Bailey, M. E., Wilkinson, D. A., and Wolfendale, A. W. (Department of Astronomy, The University, Manchester M13 9PL, U.K.): 'Periodic Mass Extinctions: Difficulty with Astronomical Explanations', *Adv. Space Res.* **9** (1989), (&)211–(6)217.

Although it is almost certain that comets are shaken free from the Oort cloud by encounters with stars and molecular clouds we have found no process involving these or other perturbers which would give rise to a 30-My periodicity in their arrival at earth.

Bogard, D., Hörz, and Johnson, P. (NASA Johnson Space Center, Houston, TX 77058): 'Shock-Implanted Noble Gases II: Additional Experimental Studies and Recognition in Naturally Shocked Terrestrial Materials' *Meteoritics* **24** (1989), 113–123.

Several experimentally and naturally shocked silicate samples were analyzed for noble gas contents to further characterize the phenomenon by which ambient gases can be strongly implanted into silicates by shock and to evaluate the possible importance of this process in capturing planetary atmospheres in naturally shocked samples. Gas implantation efficiency is apparently mineral independent, as monomineralic powders of oligoclase, labradorite, and diopside and a powdered basalt shocked to 20 GPa show similar efficiencies. The retentivity of shock-implanted gas during stepwise heating in the laboratory is defined in terms of two parameters: activation energy for diffusion as determined from Arrhenius plots, and the extraction temperature at which 50% of the gas is released, both of which correlate with shock pressure. These gas diffusion parameters are essentially identical for radiogenic ^{40}Ar and shock-implanted ^{40}Ar in oligoclase and labradorite shocked to 20 GPa, suggesting that the two ^{40}Ar components occupy analogous lattice sites. Our experiments indicate that gas implantation occurs through an increasing production of microcracks/defects in the lattice with increasing shock pressure. The ease of diffusive loss of implanted gas is controlled by the degree of annealing of these microcracks/defects.

Identification of a shock-implanted component requires relatively large concentrations of implanted gas which is strongly retained (i.e., moderate activation energy) in order to separate implanted gas from surface adsorbed gases. Literature data on shocked terrestrial samples indicate only weak evidence for shock-implanted gases, with an upper limit for ^{40}Ar of $\sim 10^{-6}$ cm^3 STP/g. New analyses of shocked samples from the Wabar Crater indicate the presence of shock-implanted Ar, having concentrations ($\sim 10^{-4}$ cm^3 STP/g) and activation energies for diffusive loss which are essentially that expected from experimental studies. Lack of sufficient target porosity or the presence of ground water may explain the sparse evidence for shock-implanted gas at other terrestrial craters. Although Wabar Crater may represent an unusually favorable environment on Earth for shock-implanting gases, surfaces of other planetary bodies, such as Mars, may frequently provide such environments. Analyses of returned samples from old Martian terraines may document temporal changes in earlier atmospheric composition.

Delano, J. W. and Lindsley, D. H. (Department of Geological Sciences, State University of New York, Albany, NY 12222): 'Chemical Systematics among the Moldavite Tektites: Reply to W. von Engelhardt', *Geochimica et Cosmochimica Acta* **53** (1989), 2447–2448.

Professor von Engelhardt's discussion of two-component mixing is mathematically valid but not definitive with regard to the moldavites. The compositional variations observed among moldavite tektites for the full range of major-, minor-, and trace-elements are explicable only for a minimum of three components. This view was expressed by Delano and Lindsley (1982; p. 2450) and has been strengthened by subsequent work (e.g., Delano *et al.*, 1986, 1987, 1989; Horn *et al.*, 1985; von Engelhardt *et al.*, 1987). We stand by our original statements (Delano and Lindsley, 1982) and will briefly elaborate on them in response to Professor von Engelhardt's comments.

Gostin, V. A., Keays, R. R., and Wallace, M. W. (Department of Geology and Geophysics, University of Adelaide, GPO Box 498, Adelaide, South Australia 5001, Australia): 'Iridium Anomaly from the Acraman Impact Ejecta Horizon: Impacts can Produce Sedimentary Iridium Peaks', *Nature* **340** (1989), 542–544.

The observation of anomalously high iridium concentrations at the Cretaceous/Tertiary K/T) boundary[1] triggered the still unresolved debate concerning the origin of sedimentary Ir anomalies. Several hypotheses have been presented, including meteorite impacts[1,2] and intense volcanism.[3,4] Here we present data from the Acraman impact ejecta horizon, South Australia,[5] which conclusively links high sedimentary iridium concentrations to a major meteoroid-impact structure and its widely dispersed ejecta. An Ir anomaly (up to 2 parts per 10^9 (p.p.b.) Ir as well as Au, Pt, Pd, Ru and Cr anomalies) is present within the ejecta from the Acraman impact event preserved in late Precambrian (~600 Myr BP) shales within the Adelaide Geosyncline. The highest Ir (and Cr) concentrations within the ejecta are associated with the coarser-grained clasts of acid volcanics (boulder to medium-sand size) suggesting that most of the Ir is carried by these fragments. The target rocks at the impact site are comparable acid volcanics that have very low Ir, Au, Pt, Pd, Ru and Cr concentrations, indicating a meteoritic origin for the anomalous Ir levels within the ejecta. To our knowledge, this is the first example in which an accepted, widely dispersed impact-ejecta blanket, itself uniquely linked to a major terrestrial impact structure[5,6] has been shown to be anomalously high in cosmogenic siderophile elements. This finding strongly supports the hypothesis that Ir anomalies in sediments can be produced by terrestrial meteorite impact events.

Greenberg, J. M., Zhao, N., and Hage, J. (Laboratory of Astrophysics, University of Leiden, Leiden, The Netherlands): (FR) 'Chemical Evolution of Interstellar Dust, Comets and the Origins of Life', *Ann. Physique* **14** (1989), 103–131.

Il apparaît maintenant que l'évolution chimique de la poussière interstellaire du système pré-solaire assure que la majeure partie des comètes est formées de molécules organiques complexes au moins en partie de nature "prébiotiques" et que la poussière interstellaire de taille inférieure au micron conserve son intégrité chimique, cela résultant de la formation d'une structure de faible densité dont la partie à l'état solide occupe environ 1/5 du volume total. Cette microstructure de faible densité est la base physique du transport d'une proportion significative des molécules organiques interstellaires originales jusqu'à la terre sans altération par des collisions. Finalement, le grand nombre d'impacts de comètes avec la terre primitive a permis que la majeure partie du capital moléculaire organique à la surface de la terre fût alimenté de façon "continue" accompagné d'eau à une époque bien antérieure 3,8 milliards d'années avant nous, qui représente la date la plus ancienne pour la vie. La structure chimique et morphologique d'un noyau de comète considéré comme un agrégat de poussière interstellaire est confrontée à divers résultats d'observations effectuées sur la comète de Halley: densité du noyau et de la poussière; modèle du nuage de poussière et ses conséquences pour la production de C^+ et de CN dans la coma par des petits grains organiques; l'albedo de surface et la faible conductivité thermique du noyau pour des fortes températures de surface; l'apparition de particules de 10^{-14} g et 10^{-17} g avec des masses plus importantes; les spectres de masse des poussirères et les spectres infrarouges correspondant à des enrobages de nature organique complexes de grains très petits (0.01 μm) de carbone ou de silicates; l'apparition de petits grains résultant de la disruption de grains plus grands. L'irradiation d'un noyau de comète par des rayons cosmiques pendant les 4.5 milliards d'annees passés dans le nuage de Oort paraît être moins intense par plusieurs ordres de grandeur que celle subie par la poussière interstellaire préaglomerée soumise aux photons ultraviolets si ce n'est dans les quelques mètres les plus superficiels du noyau d'une nouvelle comète. La conductivité thermique calculée pour de la poussière aglomérée est certainement inférieure à 10^{-4} fois celle de la glace cristalline. Ceci, combiné a la microstructure de la poussière interstellaire, conduit à penser qu'on a jusqu'ici surestimé le chauffage par le soleil de l'interieur du noyau.

Grieve, R. A. F. (Geophysics Division, Geological Survey of Canada, Ottawa, K1A 0Y3, Canada): 'Manson Structure Implicated', *Nature* **340** (1989) 428–429.

Koeberl, C., Fredriksson, K., Götzinger, M., and Reimold, W. U. (Lunar and Planetary Institute, 3303 NASA Road 1, Houston, TX 77058): 'Anomalous Quartz from the Roter Kamm Impact Crater, Namibia: Evidence for Post-Impact Hydrothermal Activity?', *Geochimica et Cosmochimica Acta* **53** (1989), 2113–2118.

Centimeter-sized quartz pebbles have been found on the rim of the Roter Kamm impact crater. The Roter Kamm crater has a diameter of about 2.5 km and is situated in the Namib Desert, SWA/Namibia. Because of the sand coverage, impact products (breccias, impact melt, shocked rocks) are exposed exclusively in the form of ejecta on the crater rim. The quartz pebbles were found close to the main deposits of the impact breccias and show signs of wind abrasion. Thin sections revealed that the pebbles consist of individual quartz domains that are up to 1 mm in size. Under crossed nicols (polarized light), all individual domains show extinction almost simultaneously within $\pm 2°$, which is a rare phenomenon. Microprobe studies, neutron activation analyses, and X-ray diffractometry confirmed that the material consists of pure quartz. The quartz contains three different types of fluid inclusions: primary inclusions (size about 5–10 μm) that record the formation conditions of the quartz, very small (<1 μm) secondary inclusions associated with the grain boundaries, and late inclusions of irregular size. Freezing point depression measurements of the primary inclusions indicate fluid salinities between 18.3 and 19.6 wt% NaCl. Homogenization temperatures (T_h) for the primary inclusions range from 165 to 250°C. The quartz and the primary inclusions may provide evidence for a post-impact phase of extensive hydrothermal activity, generated by the residual heat from the kinetic energy of the impact.

Love, K. M. and Woronow, A. (Department of Geosciences, University of Houston, Houston, TX 77204): 'Bediasite Source Materials: A Solution to an Endmember Mixing Problem Exploiting Closed Data', *Geochimica et Cosmochimica Acta* **53** (1989), 2449–2450.

Walter (1989) has questioned our conclusion (Love and Woronow, 1988) that selective volatilization of a single, homogeneous source material is a statistically unlikely explanation of bediasite chemistries. We based our conclusion on results of statistical tests involving ratios of "volatile" (Na_2O, K_2O) and "refractory" (Al_2O_3, MgO, CaO) oxides. Walter agrees that under reducing conditions, Na_2O and K_2O exhibit volatile behavior; he states, however, that "under oxidizing conditions, neither Na nor K exhibit particularly volatile behavior", and he suggests such oxidizing conditions for tektite formation. Walter further contends that bediasite chemistries can be explained by high-temperature fractionation of a high-silica melt. We disagree, however, and we will demonstrate that single-source vapor fractionation, whether under oxidizing or reducing conditions, remains an unlikely explanation for the bediasite chemistries.

Lowe, D. R., Byerly, G. R., Asaro, F., and Kyte, F. J. (Department of Geology, Stanford University, Stanford, CA 94305): 'Geological and Geochemical Record of 3400-Million-Year-Old Terrestrial Meteorite Impacts', *Science* **245** (1989), 959–962.

Beds of sand-sized spherules in the 3400-million-year-old Fig Tree Group, Barberton Greenstone belt, South Africa, formed by the fall of quenched liquid silicate droplets into a range of shallow- to deep-water depositional environments. The regional extent of the layers, their compositional complexity, and lack of included volcanic debris suggest that they are not products of volcanic activity. The layers are greatly enriched iridium and other platinum group elements in roughly chondritic proportions. Geochemical modeling based on immobile element abundances suggests that the original average spherule composition can be approximated by a mixture of fractionated tholeiitic basalt, komatiitc, and CI carbonaceous chondrite. The spherules are thought to be the products of large meteorite impacts on the Archean earth.

Von Engelhardt, W. (Mineralogical Institute, University of Tuebingen, Wilhelmstr. 56, D-7400 Tuebingen, F. R. Germany): 'Remarks on "Ratio Plots" and "Mixing Lines" ', *Geochimica et Cosmochimica Acta* **53** (1989), 2443–2444.

Plots of concentration ratios *a/b versus c/d* of four components in a sample of analyses can be interpreted as binary mixture hyperbolas only if mutual linear correlations exist between all components of the sample. Samples of moldavite analyses do not satisfy this condition.

Walter, L. S. (Laboratory for Terrestrial Physics, Goddard Space Flight Center, Greenbelt, MD 20771): 'Volatile Fractionation and Tektite Source Material', *Geochimica et Cosmochimica Acta* **53** (1989), 2445–2446.

In discounting the possibility that vapor fractionation played a part in the origin of bediasites, it has been assumed that Na and K are lost to the vapor phase. Experimental work shows, however, that, under oxidizing conditions, neither Na nor K exhibit particularly volatile behavior. Indeed, the compositional variations exhibited by bediasites are very similar to those obtained dunng experimental high-temperature vapor fractionation of a high-silica melt.