BIBLIOGRAPHY

Edited by

Z. KOPAL

University of Manchester, England

M. MOUTSOULAS

University of Athens, Greece

and

F. B. WARANIUS

Lunar and Planetary Institute, Houston, Texas, U.S.A.

(Articles entered into the data base and Lunar and Planetary Institute Library, May – October 1983)

OTHER OBJECTS

1. Asteroids

Baier, G. and Weigelt, G. (Physikalisches Institut der Universität, Erwin-Rommel-Strasse 1, D-8520 Erlangen, F.R.G.): 'Speckle Interferometry Observations of the Asteroids Juno and Amphitrite', *Astron. Astrophys.* **121**, 137–141 (1983)

We have performed digital speckle interferometry of the asteroids Juno and Amphitrite. The speckle interferograms were recorded with the Danish 1.5 m telescope at the European Southern Observatory. The measurements show that both asteroids have elliptical shapes. The diameters of Juno were measured to be 230 km ± 20 km ($0\overset{''}{.}26$) and 288 km ± 20 km ($0\overset{''}{.}32$) (24 December 1979, 6^h10^mUT), the diameters of Amphitrite were 160 km ± 30 km ($0\overset{''}{.}11$) and 255 km ± 30 km ($0\overset{''}{.}17$) (4 April 1981), 8^h30^mUT).

Birch, P. V., Tedesco, E. F., Taylor, R. C., Binzel, R. P., Blanco, C., Catalano, S., Hartigan, P., Scaltriti, F., Tholen, D. J., and Zappala, V. (Perth Observatory, Bickley, Western Australia): 'Lightcurves and Phase Function of Asteroid 44 Nysa During its 1979 Apparition', *Icarus* **54**, 1–12 (1983)

Light curves of asteroid 44 Nysa obtained during 20 nights in 1979 as part of a global campaign are presented. The synodic period was $6^h25\overset{m}{.}3$. The phase coefficient of the primary maximum was 0.026 mag/deg and the absolute *V* magnitude 7.05. The phase function is linear from 2° to 25°; no opposition effect is present.

Burchi, R. and Milano, L. (Astronomical Observatory of Collurania, Teramo, Italy): '2 Pallas Pole Revisited', *The Moon and the Planets* **28**, 17–21 (1983)

2 Pallas pole was revisited and using a set of old and new photoelectric observations of zero amplitudes the pole coordinates were determined. The synodic period of Schroll *et al.* (1976) was checked,

Earth, Moon, and Planets **32** (1985) 193–237.

and a good agreement found for both coordinates of the pole and synodic period with those determined by Schroll *et al.* (1976).

Carlsson, M. and Lagerkvist, C.-I. (Astronomiska Observatoriet, Box 515, 75120 Uppsala, Sweden): 'Physical Studies of Asteroids. XI. Photoelectric Observations of the Asteroids 2, 161, 216 and 276', *Astron. Astrophys. Suppl.* **53**, 157–159 (1983)

Light curves and *UBV*-colours are presented for the asteroids 2 Pallas, 161 Athor, 216 Kleopatra and 276 Adelheid. For asteroid 216 a light curve amplitude $1\overset{\mathrm{m}}{.}1$ was observed.

Erdi, B. (Dept. of Astronomy, Eotvos Univ., Budapest, Hungary): 'A Note on the Normalized Period of Libration of Trojan Asteroids', *Celest. Mech.* **30**, 3–6 (1983)

A comparison is made between Garfinkel's and Erdi's theory of Trojan asteroids concerning the normalized period of libration near L_4. An exact agreement is shown up to the fourth order of the parameter α_0 of Garfinkel's solution.

Harris, A. W. and Young, J. W. (Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA 91109); 'Asteroid Rotation IV. 1979 Observations', *Icarus* **54**, 59–109 (1983)

Results of photoelectric lightcurve observations made during 1979 are reported. Of a total of 53 asteroids observed, reliable rotation periods are reported for 22 asteroids for which no previous values are known, 7 periods are reported which are revisions of previously reported values, and for 12 other asteroids periods are suggested which are admittedly of low reliability and those objects should be reobserved. In addition, phase relations are presented for many of the asteroids, fitted to the theoretical phase function of Lumme and Bowell. Adopting their formalism, mean absolute magnitudes at zero phase angle, $\bar{V}(0°)$, for 52 asteroids, and values of the multiple scattering parameter, Q, for 22 asteroids are reported. For comparison purposes, the absolute magnitude, $V(1,0)$ and the linear phase coefficient, β_V, in the traditional system are computed. In the appendixes (1) the methods of observation and data reduction are discussed, which are recommended to other lightcurve observers in the hope of standardizing reporting practices as much as possible; and (2) a cumulative index of all asteroid rotation data of which the authors are aware is presented.

Hartmann, W. K. (Planetary Science Inst., Tucson, AZ 85719): 'Vesta; A World of its Own', *Astronomy* **11**(2) 6–13 (1983)

Battered by impacts, flooded with lava, and internally differentiated, Vesta may be one of the strangest asteroids known.

Henrard, J. and Lemaître, A. (Dept. of Mathematics, Facultés Universitaires de Namur, Rempart de la Vierge, B-5000 Namur, Belgium): 'A Mechanism of Formation for the Kirkwood Gaps', *Icarus* **55**, 482–494 (1983)

In this paper an analytical model describing the effect of a displacement of the Jovian resonances in the asteroid belt is analyzed. It is found that a small displacement can transform a truncated uniform density distribution of asteroids into a gap. As a possible explanation for the displacement, the effect of the removal of an accretion disk in the early stage of the solar system is investigated. It is found that removal of a disk containing a few percent of the solar mass between the orbit of the asteroids and the orbit of Jupiter is sufficient to account for the observed Hecuba gap.

Ip, W.-H. and Herbert, F. (Max-Planck-Institut für Aeronomie, Katlenburg-Lindau, F.R.G.): 'On the Asteroidal Conductivities as Inferred from Meteorites', *The Moon and the Planets* **28**, 43–47 (1983)

Solar wind interactions with planetary bodies without intrinsic magnetic fields depend to a large extent on the electrical conductivities of the objects in question. If the combined (i.e., ionospheric and interior) electrical conductivities are large, as in the case of Venus, the solar wind interaction is strong due to the generation of a large electrical current flow. It is suggested here that a similar interaction may occur at some asteroids, if their interior conductivity can be approximated by the conductivities of carbonaceous or iron bearing meteorites. This interaction, in turn, can be used as a tool for remote sensing of the asteroidal interior properties in a spacecraft mission to asteroids.

Ostro, S. J., Campbell, D. B., and Shapiro, I. I. (Dept. of Astronomy, Cornell Univ., Ithaca, NY 14853): 'Radar Observations of Asteroid 1685 Toro', *Astron. J.* **88**, 565–575 (1983)

We report results of 13-cm-wavelength radar observations of 1685 Toro conducted in July 1980 at the Arecibo Observatory. Our data yield detections of radar echoes in the same sense of circular polarization as transmitted (i.e., the SC sense) as well as in the opposite (OC) sense. The radar spectra reveal correlated, approximately twofold variations in radar cross section and spectral bandwidth as functions of rotational phase, with two maxima and two minima per rotation cycle. Our estimate of the ratio of SC to OC echo power, $\mu_c = 0.18 \pm 0.04$, suggests that most, but certainly not all, of the backscattering is due to single reflections from surface elements that are fairly smooth at decimeter scales. However, the total absence of the sharply peaked spectral signature of quasi-specular scattering requires substantial roughness at some much larger scale(s). When combined with photopolarimetric results of Dunlap *et al.* (1973), our observations provide constraints on Toro's size, shape and surface properties. The maximum distance of any part of Toro's surface from the spin axis is between 2.4 and 3.4 km. The ratio of Toro's longest to shortest equatorial widths is between 1.4 and 2.2. Modeling Toro as a homogeneously scattering ellipsoid yields weighted-least-squares estimates for the lengths of the equatorial semiaxes: $a = 2.60 \pm 0.10$ km and $b = 1.68 \pm 0.17$ km, and a nearly Lambertian scattering law. The magnitude of the post-fit residuals suggests systematic departures of Toro from this simplified model, including a possible surface feature with enhanced radar reflectivity and depolarization. The length, $2c$, of the rotation axis cannot be estimated from our data, as it is highly anticorrelated with the radar reflectivity. If we assume that $c \leqslant b$, our ellipsoid provides $\pi ab = 13.7 \pm 1.8\ \mathrm{km}^2$ as an estimate for an upper limit on Toro's projected area. Using this result, we derive approximate lower limits on Toro's λ 13-cm and B-filter geometric albedoes (0.04 and 0.23, respectively) which constrain the composition and porosity of Toro's surface. Our lower bound on Toro's B-filter albedo is substantially higher than the value (0.14) reported by Dunlap *et al.*

Schober, H. J. (Institut für Astronomie, Universitätsplatz 5, A-8010 Graz, Austria): 'The Large C-Type Asteroids 146 Lucina and 410 Chloris, and the Small S-Type Asteroids 152 Atala and 631 Philippina: Rotation Periods and Lightcurves', *Astron. Astrophys. Suppl.* **53**, 71–75 (1983)

Photoelectric observations are presented for four asteroids. 146 Lucina and 410 Chloris (larger C-type asteroids) were observed in Sep. 1979 at CTIO, the rotation periods are $P = 18^{\mathrm{h}}.54$ and $P = 32^{\mathrm{h}}.50$, respectively, both derived by Harris and Young (1982), using my observations prior to publication.

152 Atala was observed in Nov. 1981 at OHP, a rotation period of $P = 5^{\mathrm{h}}.282 \pm 0^{\mathrm{h}}.004$ was derived with a lightcurve amplitude of $0^{\mathrm{m}}.50$. 631 Philippina was observed in Feb. 1981 at ESO, and a period of $P = 5^{\mathrm{h}}.92 \pm 0^{\mathrm{h}}.01$ could be derived with a maximum lightcurve amplitude of $0^{\mathrm{m}}.20$. 152 Atala and 631 Philippina are both small-sized S-type asteroids and rotate much faster.

Colors and magnitudes were measured for the asteroids, excluding 152 Atala; for 631 Philippina colors were obtained frequently over all rotational cycles with no variation exceeding the scatter.

Schober, H. J. and Schroll, A. (Institut für Astronomie, Universitätsplatz 5, A-8010 Graz, Austria): 'Rotation Properties of the High-Numbered Asteroids 1236 Thais and 1317 Silvretta', *Astron. Astrophys.* **120**, 106–108 (1983)

The high-numbered asteroids 1236 Thais and 1317 Silvretta were observed photoelectrically in *UBV*, each during three nights in September 1980, using the 0.6 m Bochum telescope during ESO-time, at the European Southern Observatory, La Silla, Chile.

For 1317 Silvretta we derived a rotation period of $P = 7^{\mathrm{h}}.0.48 \pm 0^{\mathrm{h}}.0.006$ ($\mathrel{\hat{=}} 0^{\mathrm{d}}.2937 \pm 0^{\mathrm{d}}.0003$) and a lightcurve amplitude of $0^{\mathrm{m}}.40$ with primary and secondary extrema.

For 1236 Thais an increase in brightness was detected during three consecutive nights (72 h) with $\Delta V = 0^{\mathrm{m}}.08$, indicating that 1236 Thais might be a lowly spinning asteroid with a very long rotation period, as found also for other small sized asteroids (10–30 km) in Schober et al. (1982) and Harris (1982).

For both asteroids frequently *UBV*-colors were measured and no variation exceeding the scatter was remarked.

Schrol, A. and Schober, H. J. (Institut für Astronomie der Universität Graz, Sonnenobservatorium Kanzelhohe, A-9520 Sattendorf, Austria): 'Lightcurves and Rotation Periods for the Asteroids 70 Panopaea and 235 Carolina', *Astron. Astrophys. Suppl.* **53**, 77–79 (1983)

The asteroids 70 Panopaea and 235 Carolina were observed photoelectrically in *UBV*, both during four nights in September 1980, using the 0.6 m Bochum telescope during ESO-time, at the European Southern Observatory ESO, La Silla, Chile.

For 70 Panopaea we derived a rotation period of $P = 15^{\mathrm{h}}.87 \pm 0^{\mathrm{h}}.04$ (= $0^{\mathrm{d}}.661 \pm 0^{\mathrm{d}}.002$) and a lightcurve amplitude of $0^{\mathrm{m}}.12$, with primary and secondary extrema in the lightcurve.

For 235 Carolina we found $P = 17^{\mathrm{h}}.56 \pm 0^{\mathrm{h}}.03$ (= $0^{\mathrm{d}}.732 \pm 0^{\mathrm{d}}.001$), with an amplitude of at least $0^{\mathrm{m}}.35$, also showing a double wave lightcurve characteristic.

For both asteroids frequently *UBV*-colors were measured and no variation exceeding the scatter was found.

Surdej, J., Surdej, A. and Louis, B. (Institut d'Astrophysique, Université de Liège, Avenue de Cointe 5, B-4200 Ougree-Liège, Belgium): 'U.B.V. Photometry of the Minor Planets 86 Semele, 521 Brixia, 53 Kalypso and 113 Amalthea', *Astron. Astrophys. Suppl.* **52**, 203–211 (1983)

Asteroids 86 Semele, 521 Brixia and 53 Kalypso, 113 Amalthea were observed photometrically during the 1980 and 1981 oppositions, respectively. The *V* lightcurve of 86 Semele displays two asymmetric maxima and minima with a total amplitude $\Delta V = 0.18$ mag. The derived synodic rotation period for this minor planet is $P_s = 16^{\mathrm{h}}38^{\mathrm{m}}02^{\mathrm{s}} \pm 16^{\mathrm{s}}$ and the color indices are found to be $B\text{-}V = 0.690 \pm 0.011$ 0.008 and 0.320 ± 0.015 mag. For 521 Brixia, we can just state that this asteroid is a slow rotator ($P_s > 24^{\mathrm{h}}$) showing light variations greater than $\Delta V \simeq 0.09$ mag and with color indices $B\text{-}V = 0.714 \pm 0.008$ and $U\text{-}B = \pm\ 0.011$ mag. It is very likely that 53 Kalypso rotates with a period $P_s = 26^{\mathrm{h}}33^{\mathrm{m}} \pm 4^{\mathrm{m}}$ with a total light amplitude $\Delta V > 0.10$ mag and color indices $B\text{-}V = 0.692 \pm 0.015$ and $U\text{-}B = 0.341 \pm 0.022$ mag. The lightcurve of 113 Amalthea shows large amplitude variations ($\Delta V > 0.26$ mag) with a noticeable broad minimum. However, only part of the rotation cycle was covered by our observations and we can just ascertain that the rotation period of 113 Amalthea is greater than 12^{h} with measured color indices equal to $B\text{-}V = 0.888 \pm 0.012$ and $U\text{-}B = 0.487 \pm 0.019$ mag. Let us finally mention that the *B-V* and *U-B* color indices of these four minor planets do not present any variation exceeding the mean scatter over the observed rotation cycles.

Taylor, R. C. and Tedesco, E. F. (Lunar and Planetary Lab., Univ. of Arizona, Tucson, AZ 85721): 'Pole Orientation of Asteroid 44 Nysa Via Photometric Astronomy, Including a Discussion of the Method's Application and its Limitations', *Icarus* **54**, 13–22 (1983)

The results of photometric astrometry, a method of determining the orientation of a rotation axis, as applied to asteroid 44 Nysa are presented. The pole orientation of Nysa was found to be $\lambda_0 = 100°$, $\beta_0 = +60°$ with an uncertainty of 10°. The sidereal period is $0^{\mathrm{d}}.267\,559\,02 \pm 0.000\,000\,06$, and the rotation prograde. Refinements to, and limitations of, the application of the method of photometric astrometry are discussed. In light of the results presented herein, we believe that all photometric astrometry pole determinations of the past should be redone.

Tedesco, E. F., Taylor, R. C., Drummond, J., Harwood, D., Nickoloff, I. Scaltriti, F., Schober, H. J. and Zappala, V. (Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA 91109): 'World-wide Photometry and Lightcurve Observations of 1 Ceres During the 1975–1976 Apparition', *Icarus* **54**, 23–29 (1983)

We present 19 lightcurves of asteroid 1 Ceres obtained during a global campaign in 1975–1976. The synodic period is 0.37812 ± 0.000 04 day. The mean absolute V magnitude is 3.61 ± 0.03 and the phase coefficient is 0.040 ± 0.001 mag/deg. The *U-B* and *B-V* phase coefficients are + 0.0015 ± 0.0007 and + 0.0006 ± 0.0003 mag/deg, respectively. The colors at zero phase are $B\text{-}V = +0.70 \pm 0.01$ and $U\text{-}B = +0.41 \pm 0.01$.

Tedesco, E. F., Taylor, R. C., Drummond, J., Harwood, D., Nickoloff, I., Scaltriti, F., and Zappala, V. (Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA 91109): 'Worldwide Photometry and Lightcurve Observations of 16 Psyche During the 1975–1976 Apparition', *Icarus* **54**, 30–37 (1983)

We present 26 lightcurves of 16 Psyche from 1975 and 1976. The synodic period during this apparition was $4^h.1958$. Combining photometric data from this opposition with those from previous apparitions allowed us to derive a mean phase coefficient in V of 0.026 ± 0.002 mag/deg and to establish that Psyche's absolute V_0 magnitude and rotational amplitude vary with aspect; at 90° aspect, $V_0(1, 0) = 6.27 \pm 0.05$ and the lightcurve amplitude is 0.30 mag, while at 0° or 180° aspect, $V_0(1, 0) = 6.02 \pm 0.02$ and the amplitude is $\lesssim$ 0.03 mag. This behavior is accounted for if, to first order, Psyche's shape is that of a triaxial ellipsoid with axial ratios near 5:4:3. Colors at zero phase are $U\text{-}B = 0.26 \pm 0.01$ and $B\text{-}V = 0.71 \pm 0.01$. Color phase coefficients are < 0.001 mag/deg in $U\text{-}B$ and 0.0010 ± 0.0004 mag/deg in $B\text{-}V$.

Veeder, G. J., Matson, D. L., Hoover, G., and Kowal, C. (Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA 91109): 'Infrared (JHK) Photometry of Asteroids. 11.', *Astron. J.* **88**, 1060–1063 (1983)

We report *JHK* (1.2, 1.6, and 2.2 μ) photometry for 38 asteroids of various spectral classifications. M asteroids tend to have infrared colors intermediate between the color domains of E and P asteroids. A few D asteroids have redder *J–H* colours than most C asteroids. The unusually red *J–H* color of 246 Asporina indicates it is a member of the A class.

Veeder, G. J., Marson, D. L., and Tedesco, E. F. (Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA 91109): 'The R Asteroids Reconsidered', *Icarus* **55**, 177–180 (1983)

JHK infrared photometry shows that R asteroids have two distinct infrared color domains. Most R asteroids have JHK and visual colors and albedos that fall amongst those observed for S asteroids, but a small subset is clearly different. These are designated as a new A class of asteroids.

Veillet, C. (Centre D'etudes et de Recherches Geodynamiques et Astronomiques, AV. Copernic, F-06130 Grasse, France): '1980–81 Observations of Miranda: New Orbit and Mass of Ariel and Umbriel', *Astron. Astrophys.* **118**, 211–216 (1983)

112 positions of Miranda relative to Uranus are given: 30 in 1980 from Pic-du-Midi 1-m and Danish-ESO 1.5-m reflectors and 82 on eight quasi-consecutive nights on 1981 April 6–14 with the Danish-ESO 1.5-m reflector. The 1981 series permits a determination of osculating elements: Inclination is confirmed, in agreement with Whitaker and Greenberg's 1948–72 positions, but the eccentricity is found at a very low value. Deriving the 1948–49 data from Van Biesbroeck's measurements, and gathering all published positions of Miranda (300 points) confirm all the orbital parameters except for those linked to the eccentricity found as 0.0021 ± 0.0005. Ariel and Umbriel mass product, $(1.37 \pm 0.15)\ 10^{-10}$, and Miranda nodal precession period, 17.97 ± 0.14 yr, joined to recent J_2 and J_4 determination from apsidal precession of the rings, yield the mass of Ariel, $(3.2 \pm 0.5)\ 10^{-5}$, and Umbriel $(0.4 \pm 0.1)\ 10^{-5}$ (masses in units of mass of the planet). Recent determinations of the diameter of the satellites by Brown et al. give Ariel a denisty 2.2 ± 0.8 and Umbriel 0.48 ± 0.20.

Zappala, V., Di Martino, M., Scaltriti, F., Djurasevic, G., and Kneževič, Z. (Astronomical Observatory of Torino, 10025 Pino Torinese, Italy): 'Photoelectric Analysis of Asteroid 216 Kleopatra: Implications for its Shape', *Icarus* **53**, 458–464 (1983)

In some recent theoretical papers it has been suggested that gravitationally bound "rubble piles" in hydrostatic equilibrium possibly exist among the asteroids. For a higher-than-critical value of the angular momentum acquired by such a body, the instability phenomena can produce fission into a binary system. S. J. Weidenschilling suggested that 216 Kleopatra may represent a binary asteroid, since it has a large light curve amplitude (1.3–1.4 mag). In this paper new observations of Kleopatra are presented, suggesting the equal plausibility of the single triaxial ellipsoid model. Namely, when phase and aspect effects are taken into account, the actual maximum amplitude is reduced to about 0.9 mag at 90° of aspect which is close to the value predicted by theory for the instability limit.

Moreover, multiple-scattering effects [M. Poutanen, E. Bowell, and K. Lumme, *Bull. Amer. Astron. Soc.* **13**, 725 (1981)] can reduce the axial ratio a/b even more. If the single-body model is adopted, the density of Keopatra should be on the order of $1.7\,g/cm^3$. This low value seems reasonable for "rubble pile" models.

Zappla V., Martino, M. Di., Scaltritti, F., Burchi, R., Milano, L., Young, J. W., Wahlgren, G., and Pavlovski, K. (Osservatorio Astronomico di Torino, I-10025 Pino Torinese, Italy): 'Remarkable Modification of Light Curves for Shadowing Effects on Irregular Surfaces: The Case of the Asteroid 37 Fides', *Astron. Astrophys.* **123**, 326–330 (1983)

This paper presents photoelectric observations of the asteroid 37 Fides carried out at four Observatories: Torino Astronomical Observatory, Teramo Astronomical Observatory, Table Mountain Observatory, and Hvar Observatory. The observations were made between November 1980 and February 1981 and cover a large interval of phase angles (~ 2° to ~ 23°).

Our light curves have been compared with runs obtained during the 1979 apparition by Schober (1982) who derived a period $P_{syn} = 14^{h}.66$ with four maxima and four minima per cycle. Analysis of our observations, combined with the variations in the shape of a light curve as the phase angle changes and at different oppositions, led us to check the possibility that $P_{syn} = 7^{h}.33$ could satisfy our observations.

The multiple scattering factor $Q = 0.179$ and the absolute magnitude at zero degrees phase angle $V_0(0°) = 7.27$ mag were derived.

The need for extensive observations at different apparitions and at different phase angles in order to derive reliable values of the rotational periods of asteroids are emphasized.

2. Comets

Arduini, M., Bibring, J. P., Cazes, S., Combes, M., Coron, N., Crifo, J. F., Encrenaz, T., Gispert, R., Harduin, D., Lamarre, J. M., and Malaise, D. (Laboratoire de Physique Stellaire et Planetaire, P. O. Box 10, 91370 Verrières-le-Buisson, France): 'The Comet Halley Flyby I. R. Sounder "I.K.S."', *Adv. Space Res.* **2**(4) 113–122 (1983)

An infrared sounder is being developed in France to observe in 1986 Comet Halley from the Soviet 'Vega' flyby probes. The instrument, called 'I.K.S.', has three measuring channels. Two of these channels will provide the spectrum of the comet emission in the spectral intervals 2.5–5.0 μ, at a constant resolution $\lambda/\Delta\lambda = 50$.

The third channel analyzes the comet I. R. image at a spatial frequency of about 1 arc minute^{-1}; two I. R. colours are used in this channel: 7–10 μ and 10–14 μ. From the results expected, it is hoped that (1) most primary simple molecules emitted by the nucleus will be identified; (2) the chemical composition and perhaps crystalline structure of the dust grains and ices released by the comet will be derived; and (3) the diameter of the nucleus and its brightness temperatures will be measured.

Bailey, M. E. (Astronomy Centre, Univ. of Sussex, Brighton BN1 9QH, UK): 'The Structure and Evolution of the Solar System Comet Cloud' *Mon. Not. Roy. Astron. Soc.*, **204**, 603-633 (1983)

The strucutre and evolution of a hypothetical cloud of comets surrounding the Solar System is investigated, with particular reference to showing how the derived results depend on the assumed cometary energy and velocity distribution functions. The mean energy transfer rate by stars and giant molecular clouds is calculated and it is shown that for reasonable values of the parameters the cumulative effect of the clouds is dominant. Thus it is unlikely that the loosely-bound Oort comet cloud could survive for the age of the Solar System.

The equation describing the evolution of the comet cloud between close encounters with nebulae is solved in a good approximation for an initial condition where the energy spectrum is a power law. Formulae are also given which relate the energy spectrum to the velocity distribution function and density distribution, and it is shown how the current energy spectrum can be inferred from observations. Analaytic results for the standard Oort model are presented and we show how this model is just one of a family of hypothetical comet clouds with power-law energy spectra. The spectral index of this standard model does not agree well with that obtained from observations, these indicating a model with flatter spectrum and higher degree of central condensation. More centrrally condensed models may be easier to understand as a by-product of Solar System formation, and are more stable against disruption by encounters with nebulae.

Buffoni, L., Scardia, M., and Manara, A. (Observatorio Astronomico di Milano-Merate, Italy): 'A Study of the Motion of the Periodic Comet Stephan-Oterma (1980G)', *The Moon and the Planets* **28**, 11–16 (1983)

The orbit of *P*/Stephan-Oterma has been determined using 140 observations of the last apparition (1980) and taking into account perturbations by Mercury to Pluto. The evolution of the comet's orbit has been studied over the interval 1976–1984.

Buti, B. (Physical Research Lab., Ahmedabad, India): 'Dynamic Stabilization of Hydromagnetic Surface Waves: Applications to Cometary Plasma Tails', *Astrophys. J.* **268**, 420–427 (1983)

Hydromagnetic waves, at the interface of two superposed magnetofluids, are studied in the presence of electrostatic coherent waves propagating parallel to the surface of discontinuity. Due to nonlinear interaction with the electrostatic waves, hydromagnetic waves, which may be unstable otherwise, can be stabilized. The model developed is applied to study the interaction of the solar wind with the cometary plasma tails.

Crosvisier, J. and Le Bourlot, J. (Observatoire de Meudon, F-92195, France): 'Infrared and Microwave Fluorescence of Carbon Monoxide in Comets', *Astron. Astrophys.* **123**, 61–66 (1983)

We evaluate the excitation of the pure rotation and rotation/vibration lines of the CO molecule in comets. Resonant excitation of the ν(1-0) band by the solar infrared field, with a rate of 2.6 10^{-4} s^{-1} at $r_h = 1$ AU, is the most important excitation mechanism, at least two orders of magnitude greater than UV excitation or excitation of other infrared vibrational bands. For most of the CO molecules, the rotational distribution is governed by infrared fluorescence and spontaneous decay; collisions play a role only in the inner coma. The fluorescence equilibrium population distribution deviates significantly from a Boltzmann distribution.

We derive the expected intensities of the ν(1–0) lines and pure rotation lines. Some ν(1–0) infrared lines, the R2 and R3 millimetre rotational lines and some submillimetre rotational lines might be observable from the ground with existing or future facilities in bright comets. We reanalyse previous unsuccessful observations on the basis of the present excitation model.

Delsemme, A. H. and Combi, M. R. (Dept. of Physics and Astronomy, Univ. of Toledo, OH 43606): 'Neutral Cometary Atmospheres. IV. Brightness Profiles in the Inner Coma of Comet Kohoutek 1973 XII', *Astrophys. J.* **271**, 388–397 (1983)

Several spectrograms of comet Kohoutek taken at Lick Observatory have been analyzed in Toledo. The brightness distribution along the spectrograph slit has been measured for different wavelengths with a high spatial resolving power. The scale lengths for the destruction and for the production of NH_2 are reported here for the first time; they are about the same and both close to 7×10^3 km at a heliocentric distance $r = 0.465$ AU, ruling out NH_3 as parent. The profile of the λ6300 forbidden red line of oxygen indicates that the parent of $O(^1D)$ is produced in a source much smaller than 1000 km radius; so close to the nucleus, the NH_2 (0, 8, 0) contribution to the red line is in the range 5%–15%. The observed center of maximum brightness for the dust (as well as for the NaD line) is shifted sunward by about 900 km with respect to the center of light of the neutral radicals, as well as to that of the ion H_2O^+. The common shift of dust and NaD is interpreted as a confirmation that Na is released by dust, whereas the spatial separation of dust and gas is interpreted by a fountain model acting sunward for the dust trajectories, while the nearly circular isophotes of the gaseous coma remain almost centered on the true nucleus. The model seems to be inconsistent with a dust density outside of the range (2.8 ± 0.3) g cm^{-3}. The present results have important consequences for the astrometric positions used to compute cometary orbits (as well as for cometary missions by spacecraft) because they imply that, when a dusty comet is fully active in the inner solar system, its center of mass may be several arc seconds radially behind its center of brightness.

Fernandez, J. A. and Ip, W.-H. (Max-Planck-Institut für Aeronomie, D-3411 Katlenburg-Lindau, F.R.G.): 'On the Time Evolution of the Cometary Influx in the Region of the Terrestrial Planets', *Icarus* **54**, 377–387 (1983)

It has been argued that Uranus and Neptune could reach their present sizes only at the expense of an initial amount of mass in their accretion zones far exceeding their current masses [e.g., V. S. Safronov, *Evolution of the Protoplanetary Cloud and Formation of the Earth and the Planets* (translated from Russian (1972) by the Israel Program for Scientific Translations, Jerusalem), 1969, and in *The Motion, Evolution of Orbits, and Origin of Comets* (G. A. Chebotarev, E. I. Kazimirchak-Polonskaya, and B. G. Marsden, Eds.), pp. 329–334, IAU Symposium No. 45, 1972]. From a numerical analysis, it is determined that such a scenario would have led to a heavy bombardment of the inner planetary region by cometary bodies as well as the formation of a cometary reservoir (the so-called 'Oort cloud') at very large heliocentric distances. The cometary influx event can be characterized by the arrival of two different populations of stray bodies. At the beginning, the stray population is made up of 'outer planetary region' comets, transferred from the Uranus–Neptune region to the region of the terrestrial planets by gravitational perturbation of the Jovian planets. These comets are characterized for having low-inclination orbits and, once they reach the region of the terrestrial planets, for being mainly under the gravitational influence of Jupiter. Later, 'Oort cloud' comets, driven into the inner planetary region by stellar perturbations, become the dominant component among the incoming comets. The crossover from a outer planetary region comets-dominated regime to a Oort cloud comets-dominated one is found to occur at $t \sim 1.5$–2 AE. Besides the Oort cloud population, a residual population of mass about 10^{-5} times the initial mass is found to remain in the outer planetary region at present. Most of the survivors move on orbits with perihelia in the Uranus–Neptune region and aphelia beyond Neptune's orbit, reaching heliocentric distances up to hundreds or even thousands AU. We thus propose two possible cometary sources: (1) A cometary reservoir – the 'Oort cloud' – of rather spherical structure with a concentration of aphelion points at several times 10^4 AU. Members of the cloud are subjected to the perturbing influence of passing stars. (2) A rather flat system of cometary bodies – the 'cometary belt' – subjected to planetary perturbations but where stellar perturbations have a negligible role due to the larger binding energies of belt comets. Despite their long dynamical time scales, they will be finally ejected or scattered to the region of the terrestrial planets. In the latter case, such belt objects will appear as short-period comets. Therefore, a belt of residual bodies in the outer fringes of the planetary region may be a likely source of the observed family of short-period comets.

Gombosi, T. I., Horanyi, M., Kecskemety, K., Cravens, T. E., and Nagy, A. P. (Space Physics Dept., Central Research Inst. for Physics, Hungarian Academy of Sciences, Budapest, Hungary): 'Charge Exchange in Solar Wind-Cometary Interactions', *Astrophys. J.* **268**, 889–898 (1983)

In this paper we examine the effects of charge exchange between fast solar wind ions and slow cometary neutrals at the contact discontinuity separating the ionosphere of a comet from the solar wind flow. The continuity equations were solved analytically for a water-dominated cometary ionosphere, including both ionization and recombination processes. It was found that this new solution differs significantly from the one obtained by neglecting recombination. The normalized neutral and ion densities in the atmospheres of active comets were shown, using an appropriate dimensionless variable to exhibit an interesting scaling behavior.

Solar wind ions have a significant probability of participating in a charge exchange interaction with a cometary neutral molecule, because the cometary neutral particle density beyond the contact discontinuity is not negligible. In this process, a fast solar wind ion and slow cometary neutral are replaced by a fast neutral particle and a slow heavy ion. The fast neutral particles originating in the solar wind have a much smaller collision frequency with the cometary consituents than the original solar wind ions; hence, they can leave the vicinity of the comet without contributing significantly to the pressure balance between the solar wind and the cometary atmosphere.

Charge exchange can effectively increase the distance of the contact discontinuity from the nucleus by removing a significant portion of the momentum from the solar wind flow. For instance, it is shown that for realistic comet Halley parameters charge exhange can possibly increase the standoff distance from a couple of hundred to a few thousand kilometers.

Hirao, K. and Kaneda, E. (Inst. of Space and Astronautical Science, Tokyo, Japan): 'Scientific Instrumentation of Planet-A VUV Imaging of the Hydrogen Coma of Halley', *Adv. Space Res.* 2(4) 167–169 (1983)

The PLANET-A spacecraft to fly by Comet Halley is equipped with a VUV imaging camera which will take pictures of the hydrogen coma of the comet. The camera is composed of a telescopic mirror lens, a VUV image intensifier, two dimensional CCD, and controlling electronic circuits with a microprocessor. In order to eliminate the blur in the image due to the spinning motion of the spacecraft, a special technique called "spinsynchronized charge swift" is used in the CCD driving.

Hughes, D. W. (Dept. of Physics, Univ. of Sheffield, Hounsfield Road, Sheffield S3 7RH, UK): 'Temporal Variations of the Absolute Magnitude of Halley's Comet', *Mon. Not. Roy. Astron. Soc.* **204**, 1291–1295 (1983)

The variation of the absolute magnitude H_0 of Halley's comet, 1910II, as a function of the apparition number, A, (1910 $\equiv -1$) is given by $H_0 = (6.028 \pm 0.329) + (0.0205 \pm 0.0210)A$. The comet was about 0.5 ± 0.5 mag brighter 2000 yr ago and is losing about $2.3 \pm 2.3\%$ of its mass at each apparition.

Hughes, D. W. and Daniels, P. A. (Dept. of Physics, The University of Sheffield, Hounsfield Road, Sheffield S3 7RH, England): 'The Secular Variation of Cometary Magnitude', *Icarus* **53**, 444–452 (1983)

This paper calculates the mean variation in absolute magnitude per perihelion passage, ΔH_{10}, for short-period comets from the data of Vsekhsvyatskii and finds a value of 0.30 ± 0.06. Other mechanisms used for estimating cometary decay are reviewed and it is concluded that a more probable value for ΔH_{10} is about 0.002. Reasons for the discrepancy between these two values are given.

Johnson, R. E., Lanzerotti, L. J., Brown, W. L., Augustyniak, W. M., and Mussil, C. (Dept. of Nuclear Engineering and Engineering Physics, Univ. of Virginia, Charlottesville, VA 22901): 'Charged Particle Erosion of Frozen Volatiles in ice Grains and Comets', *Astron. Astrophys.* **123**, 343–346 (1983)

Recent laboratory data show that charged particles can effectively erode frozen volatiles, and new molecular species can be produced in some irradiated molecular ice films. Such results have relevance to the competition between collection and loss of volatiles by icy bodies in the solar system and have implications for the nature of the surface composition of these bodies. In CO_2 frost, ion irradiation at 10 K results in a significant increase in volatility when the ice temperature is raised to about 50 K, and CO and O_2 are ejected as well as CO_2. Implications of these results for ice grains and large icy bodies such as comets are discussed.

Klinger, J. (Laboratoire de Glaciologie et de Géophysique de l'Environment du CNRS, Rue Molière B.P. 68, F 38402 – St. Martin d'Heres Cedex, France): 'Classification of Cometary Orbits Based on the Concept of Orbital Mean Temperature', *Icarus* **55**, 169–176 (1983)

The orbital mean temperature (T_m) for periodic cometary orbits has been calculated as a function of eccentricity e for $0 \leqslant e \leqslant 0.97$, the semimajor axis a for $1 \leqslant a \leqslant 100$ AU, and for an albedo $A = 0$. If water ice is the major consituent of comets, it can be concluded from these results that d'Arrest, Encke, Oterma, Schwassmann-Wachmann 2, and Tempel 2 contain crystalline ice. In the past, they must have experienced a short period of high activity due to the phase transition from amorphous to cubic ice. The actual low activity of those comets is not necessarily due to depletion of volatiles. Schwassmann-Wachmann 1 and Halley are expected to contain amorphous ice in the inner part of the nucleus. Schwassmann-Wachmann 1 will conserve its erratic activity for a long time until all its ice is in the cubic state. Halley will have an important activity at small heliocentric distance until final depletion of volatiles as no thick crystalline crust can be built up. The present statements are also valid for albedos $A \leqslant 0.3$. The results are generalized to other periodic orbits.

Krishna Swamy, K. S. (Tata Inst. of Fundamental Research, Bombay, India): 'Fluorescence Excitation of CO in Comets', *Astrophys. J.* **267**, 882–885 (1983)

A complete modeling of the CO molecule based on the resonance fluorescence excitation process shows that the triplet-singlet transitions (Cameron bands) should be observable in comets. The expected intensities of these bands for comet West 1976 VI are consistent with the observations of Smith *et al.* The Ångström bands arising out of the singlet states may also be observable. The expected intensities of vibrational and rotational transitions are also discussed briefly.

Lago, B. and Cazenave, A. (Groupe de Recherches de Geodesie Spatiale, Centre National, d'Etudes Spatiales, 18 Avenue Edouard Belin, 31055 Toulouse Cedex, France): 'Evolution of Cometary Perihelion Distances in Oort Cloud: Another Statistical Approach', *Icarus* **53**, 68–83 (1983)

The evolution of the perihelion distance distribution in the Oort cloud was studied over the age of the solar system, under the gravitational perturbations of random passing stars, using a statistical approach. These perturbations are accounted for through an empirical relation relating the change in cometary perihelion distance to the closest-approach comet-star distance; this relation is deduced from a previous study [H. Scholl, A. Cazenave, and A. Brahic, *Astron. Astrophys.* **112**, 157–166 (1982)]. Two kinds of initial perihelion distances are considered: (a) perihelion distances < 2500 AU, associated with an origin of comets as icy planetesimals in the region of the giant planets, and (b) larger perihelion distances (up to 5×10^4 AU), possibly representative of comet formation as satellite fragments in the accretion disk of the primitive solar nebula. Distant star-comet encounters, as well as rare close encounters, are considered. Several quantities are estimated: (i) number of 'new' comets entering into the planetary region, (ii) number of comets escaping the Sun sphere of influence or lost by hyperbolic ejection, and (iii) percentage of total comet loss over the age of the solar system. From these quantities, the current and original cloud populations are deduced, as well as the corresponding cloud mass, for the two types of formation scenarios.

Lambert, D. L. and Danks, A. C. (McDonald Observatory, Univ. of Texas at Austin, TX 78712): 'High Resolution Spectra of C_2 Swan Bands from Comet West 1976 VI', *Astrophys. J.* **268**, 428–446 (1983)

A 0.3 Å resolution spectrum of the $\Delta v = +1$ sequence in the C_2 Swan system from comet West 1976 VI at a heliocentric distance $r_H = 0.78$AU is found to correspond to a vibrational and rotational temperature of $T_{\text{exc}} = 3500 \pm 400$ K for the upper $d^3\Pi_g$ state. If intercombination transitions are neglected, the predicted temperature for C_2 excited by fluorescence in sunlight is considerably hotter than the observed temperature. The triplet C_2 states may be cooled by intercombination transitions linking the triplet and singlet states. The electronic transition moment $|R_e|^2_{aX}$ of the $a^3\Pi_u - X^1\Sigma_g^+$ transition is estimated by a method previously applied successfully to the Cameron system ($a^3\Pi - X^1\Sigma^+$) of CO. The predicted $|R_e|^2_{aX}$ is shown to be consistent with the estimate based on the relative intensity of the Mulliken (singlet) and Swan systems. It is pointed out that other inter-combination transitions may also play a role.

On high-resolution spectra of selected lines in the Swan 0–0 band, several $^{12}C^{13}C$ lines are identified. Although the quality of the available data is inadequate, a feasibility study shows that, in order to determine the $^{12}C/^{13}C$ ratio, the 0–0 band is probably superior to the 1–0 $^{12}C^{13}C$ 4745 Å band head.

Le Borgne, J. F. (Space Science Dept. of Esa, European Space Research and Technology Center, Noordwijk, The Netherlands): 'Interpretation of the Event in the Plasma Tail of Comet Bradfield 1979 X on 1980 February 6', *Astron. Astrophys.* **123**, 25–28 (1983)

The tail event observed by Brandt *et al.* (1980) in comet Bradfield 1979 X on 1980 February 6 is shown to be due to an interplanetary solar wind disturbance detected aboard Helios 2 and at Earth. Helios 2 was at 0.15 AU from the comet. The tail follows the bulk direction of the solar wind. Acceleration of cometary ions seems to result from small scale hydrodynamic instabilities. Cometary ion density and temperature are deduced.

Moore, M. H., Donn, B., Khanna, R., and A'Hearn, M. F. (Univ. of Maryland, College Park, MD 20740): 'Studies of Proton-Irradiated Cometary-Type Mixtures', *Icarus* **54**, 388–405 (1983)

Radiation synthesis has been proposed as a mechanism for changing the nature of the outer few meters of ice in a comet stored 4.6 billion years in the Oort cloud and may explain some of the differences between new and more evolved comets. Cometary-type ice mixtures were studied in a laboratory experiment designed to approximately simulate the expected temperature, pressure, and radiation environment of the interstellar Oort cloud region. The 2.5- to 15-μm infrared absorption features of thin ice films were analyzed near 20 °K before and after 1 MeV proton irradiation. Various ice mixtures included the molecules H_2O, NH_3, CH_4, N_2, C_3H_8, CO, and CO_2. All experiments confirm the synthesis of new molecular species in solid phase mixtures at 20 °K. The synthesized molecules, identified by their infrared signatures, are C_2H_6, CO_2, CO, N_2O, NO, and CH_4 (weak). Synthesized molecules, identified by gas chromatographic (GC) analysis of the volatile fraction of the warmed irradiated ice mixture, are C_2H_4 or C_2H_6, and C_3H_8. When CH_4 is present in the irradiated ice mixture, long-chained volatile hydrocarbons and CO_2 are synthesized along with high-molecular-weight carbon compounds present in the room temperature residue. Irradiated mixtures containing CO and H_2O synthesize CO_2 and those with CO_2 and H_2O synthesize CO. Due to radiation synthesis, ~ 1% of the ice was converted into a nonvolatile residue containing complicated carbon compounds not present in blank samples. These results suggest that irrespective of the composition of newly accreted comets, initial molecular abundances can be altered and new species created as a result of radiation synthesis. Irradiated mixtures exhibited thermoluminescence and pressure enhancements during warming; these phenomena suggest irradiation synthesis of reactive species. Outbursts in new comets resulting from similar radiation induced exothermic activity would be expected to occur beginning at distances of the order of 100 AU.

Niedner, M. B. Jr., Ershkovich, A. I., and Brandt, J. C. (Lab. for Astronomy and Solar Physics, Nasa/ Goddard Space Flight Center, Greenbelt, MD 20771): 'The Effect of MHD Instabilities on the Flaring of Cometary plasma Tails', *Astrophys. J.* **272**, 362–364 (1983)

Our earlier hypersonic pressure balance model of flaring in cometary plasma tails (Ershkovich, Niedner, and Brandt) has been modified to include the effects of magnetohydrodynamic (MHD) instabilities occurring along the ionopause in the outer-tail regions. The effect of instability is to mix the solar-wind and comet-tail plasmas, increasing the tail magnetic field strength above that calculated from magnetic flux conservation. The earlier model assumed the ionopause to be a tangential discontinuity surface (flux conserving) at all distances, with the result that the magnetic field approached zero in the outer regions of strongly flaring tails. The present model is more realistic and is in better agreement with measurements of cometary plasma tail widths and flaring angles. This agreement leads to an important conclusion that the magnetic flux is not conserved in distant comet tails.

Pirronello, V., Strazzulla, G., and Foti, G. (Osservatorio Astrofisico di Catania, V. Le A. Doria I-95100, Catania, Italy): 'H_2 Production in Comets', *Astron. Astrophys.* **118**, 341–344 (1983)

Recent experimental evidences on the H_2 production by keV ions bombardment of H_2O frozen gas are briefly summarized.

The possibility of H_2 production via such a process in comets as a function of their temperature (or distance to the Sun) is discussed.

Rickmann, H. and Froeschle, Cl. (Astronomiska Observatoriet, Uppsala, Sweden): 'A Keplerian Method to Estimate Perturbations in the Restricted Three-Body Problem', *The Moon and the Planets* **28**, 69–86 (1983)

We develop a new and fast method to estimate perturbations by a planet on cometary orbits. This method allows us to identify accurately the cases of large perturbations in a set of fictitious orbits. Hence, it can be used in constructing perturbation samples for Monte Carlo simulations in order to maximize the amount of information. Furthermore, the estimated perturbations are found to yield a good approximation to the real perturbation sample. This is shown by a comparison of the perturbations obtained by the new estimator with the results of numerical integration of regularized equations of motion for the same orbits in the same dynamical model: the three-dimensional elliptic restricted three-body problem (Sun–Hupiter–comet).

Sicardy, B., Guerin, J., Lecacheux, J., Baudrand, J., Combes, M., Picat, J. P., Lelievre, G., and Lemonnier, J. P., (Observatorire de Paris-Meudon, Section d'Astrophysique, F-92190 Meudon, France): 'Astrometry and Photometry of Comet P/Halley in October and November 1982', *Astron. Astrophys.* **121**, L4–L6 (1983)

Comet P/Halley (1982i) has been observed at the Canada-France-Hawaii 3.6-m Telescope (C.F.H.T.) on October 17th, November 15th and 16th, 1982, using an electronographic camera. Positions were measured with an accuracy of ± 1.5 arc sec. the B-magnitude was 24.6 ± 0.4 in November 1982. Data reduction procedures are presented.

A value of the nuclear radius is derived: $\rho = 3.1^{+3.4}_{-1.6}$ km for an albedo ranging between 0.05 and 0.5.

Snyder, L. E., Palmer, P., and Wade, C. M. (Dept. of Astronomy, Univ. of Illinois, Urbana, IL 61801): 'An Upper Limit to the Microwave Continuum Radiation from Comet Austin (1982G)', *Astrophys. J.* **269**, L21–L23 (1983)

A sensitive search for continuum radiation at 6.1 cm wavelength from Comet Austin (1982g) was made with the VLA at the time of its closest approach, in 1982 August. No signal was detected; the best upper limit for the daily continuum flux density is 1.4×10^{-4} Jy. This is nearly an order of magnitude less than the flux density predicted on the basis of the icy grain halo model.

Strazzulla, G., Pirronello, V., and Foti, G. (Osservatorio Astrofisico, V. le A. Doria, Citta Universitaria, Catania, Italy): 'Physical and Chemical Effects Induced by Energetic Ions on Comets', *Astron. Astrophys.* **123**, 93–97 (1983)

Some experimental results on the modifications induced in condensed gases by bombardment with fast ions are described. These results are interesting for cometary physics because they simulate, to some extent, the effects of the long irradiation of the cometary nucleus by cosmic rays or the effects of solar wind particles flowing onto cometary nuclei, comae and grains. It is shown that at distances greater than 5–6 AU fast ions become the most important agents of erosion and this can contribute to an understanding of the activity of some comets at large distances from the Sun. The production of some molecules (H_2, O_2, H_2O) via such a process is also shown as a function of the solar distance.

Wallis, M. K. and Hassan, M. H. A. (Dept. of Applied Mathematics and Astronomy, University College, Cardiff CF1 1XL, Wales, UK): 'Electrodynamics of Submicron Dust in the Cometary Coma', *Astron. Astrophys.* **121**, 10–14 (1983)

Electromagnetic forces derived from the solar wind fields act strongly on submicron dust grains in the cometary coma. The grain charge and thus the forces are sensitive to composition and cometary plasma conditions, as well as to grain size. For delectric grains of 0.1 μm and conducting grains of 0.3 μm or less, the electromagnetic forces dominate over radiation pressure. The stronger accelerations may produce fan-like structures as sometimes observed. They would also cause grains to circumvent the shields designed to protect the Giotto and Vega spacecrafts speeding through comet Halley's dust coma.

Weissman, P. R. (Earth and Space Sciences Div., Jet Propulsion Lab., 4800 Oak Grove Drive, Pasadena, CA 91109): 'Cometary Impacts with the Sun: Physical and Dynamical Considerations', *Icarus* **55**, 448–454 (1983)

D. J. Michels, N. R. Sheeley, Jr., R. A. Howard, and M. J. Koomen (*Science* **215**, 1097–1102, 1982) observed a comet which appears to have impacted the Sun. Z. Sekanina (*Astron. J.* **87**, 1059–1072, 1982) showed that the comet, 1979XI, was probably a member of the Kreutz group of sungrazing comets. The sungrazers typically have perihelia of 1.2–1.9 solar radii but Sekanina found $q = 0.35\,R_\odot$ for 1979XI. It is interesting to speculate how the perihelion may have been reduced to this small value. The change in perihelion can not be explained by planetary, stellar, or nongravitational perturbations. Tidal splitting of the nucleus on a previous perihelion passage is also ruled out, though a random splitting event near aphelion of the comet's orbit is a remote possibility. The most plausible explanation is collision with another body, most likely a comet, at large heliocentric distance. However, the expected probability of such an event is exceedingly small. Another aspect of the problem is whether the nucleus of 1979XI sublimated completely before impacting the Sun. Assuming a water ice nucleus, it is shown that a surface layer of only 5–15 m thickness would be sublimated prior to impact. Although it is likely that the nucleus tidally disrupted after crossing the solar Roche limit, the ultimate destruction of the nucleus probably resulted from the shock of hitting the denser regions of the solar atmosphere, just above the photosphere.

West, R. M. and Pedersen, H. (European Southern Observatory, Karl-Schwarzschild-Strasse 2, D-8046 Garching bei München, FRG): 'P/Halley: First Signs of Activity?', *Astron. Astrophys.* **121**, L11–12 (1983)

A comparison of two broad-band CCD exposures (3700–7800 A) of P/Halley (1982 i) on 10 December 1982 and 14 January 1983, with the Danish 1.5 m telescope on La Silla, indicates a brightness increase of $1^{\mathrm{m}}.0 \pm 0^{\mathrm{m}}.4$. The January image is broader than the seeing disc, although this may partly be a guiding effect. It is possible that the first signs of nuclear activity have been observed at ~ 10.5 AU. Accurate positions have been measured.

Yeomans, D. K. (Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA 91109): 'Comet Halley and Some Dubious Achievement Awards', Griffith Observer 47(4) 2–10 (1983)

Dr Donald Yeomans is an authority on comets and a previous prize winner in this annual writing contest. (His "The Shaky Beginning of North American Astronomy" appeared in the August, 1981 issue.) He has also been appointed as a Discipline Specialist for Astrometry within the International Halley Watch. *The Comet Halley Handbook – an Observer's Guide,* created for the International Halley Watch – and published by N.A.S.A./J.P.L. – is the product of his hand. With Eric Burgess, Dr Yeomans is currently writing a popular book on comet Halley. If anyone is qualified to hand out Dubious Achievement Awards in connection with Halley's Comet, he is.

3. Meteorites

Arden, J. W. (Dept. of Geology and Mineralogy, Univ. of Oxford, Parks Road, Oxford OX1 3PR, UK): 'Distribution of Lead and Thallium in the Matrix of the Allende Meteorite and the Extent of Terrestrial Lead Contamination in Chrondrites', *Earth Planet. Sci. Lett.* **62**, 395–406 (1983)

Selective chemical dissolution has been used to study the distribution of Pb and Tl in an ultrafine – 20-μm matrix separate of Allende. The matrix was exposed to high-purity reagents ranging from H_2O, then HCI of increasing concentration and finally HF-HCI mixtures. A total of 17 extractions were obtained, each for a minimum period of 10 days. The isotopic compositions of the Pb released during the slow dissolution of the matrix fall into four distinct groups. The first, consisting of four extractions, released a component of terrestrial Pb isotopic composition with a total abundance of about 1 ppb. The next six extractions, which contained the bulk of the indigenous Pb and Tl corresponding to 96% and 94%, respectively, of the total matrix abundance, was of a reasonably homogeneous Pb isotopic composition with mean ratios of $^{206}Pb/^{204}Pb = 10.00$ and $^{207}Pb/^{204}Pb = 10.74$. In the final seven extractions, the released Pb falls into two higher isotopic groupings and probably results from the dissolution of debris from chondrules and inclusions. The apparent age of the internal matrix isochron is 4562 ± 14 My. The release of Pb and Tl shows a reasonable correlation with the matrix dissolution. This indicates that the Pb and Tl reside predominantly within the matrix phases rather than as a localised phase. The Tl isotopic composition of two matrix fractions and whole meteorite were measured and found to be indistinguishable from the terrestrial $^{205}Tl/^{203}Tl$ ratio. Measurement of a terrestrial reagent standard in the range 1–10 ng Tl gave, for 20 analyses, a mean $^{205}Tl/^{203}Tl$ ratio of 2.38907 ± 0.00102 (2σ).

The estimate of terrestrial Pb contamination is considerably lower than the 6–300 ppb assumed in some recent studies in order to explain the phenomenon of apparent excess radiogenic Pb in chondrites. The problem of terrestrial Pb pollution and the evidence which argues against a relatively severe and homogeneous Pb contamination of meteorites, is briefly considered. The apparent initial isotopic composition of the bulk of the indigenous Pb in the Allende matrix was found to be $^{206}Pb/^{204}Pb = 9.57$ and $^{207}Pb/^{204}Pb = 10.47$. This is of a higher composition than the Pb in the Cañon Diablo trilite phase and further indicates that the phenomenon of apparent excess radiogenic Pb in chondrites is real.

Bedgemann, F. and Ott, U. (Max-Planck-Institut für Chemie, D-6500 Mainz, FRG): 'Comment on "The Nature and Origin of Ureilities" by J. L. Berkley *et al.*', *Geochim. Cosmochim. Acta* 47, 975–977 (1983)

The record of primordial noble gases in ureilites imposes serious constraints of models of ureilite petrogenesis. It is argued that the inhomogeneous distribution between different mineral phases and the low $^{40}Ar/^{36}Ar$ ratio in particular can only be satisfied with difficulties in the model proposed by Berkley *et al.*

Berkley, J. L., Taylor, G. J., Keil, K., Harlow, G. E., and Prinz, M. (Dept. of Geology, State Univ. College, Fredonia, NY 14063): 'The Nature and Origin of Ureilites (Reply to a Comment by F. Begemann and U. Ott)', *Geochim. Cosmochim. Acta* 47, 979–980 (1983)

Begemann and Ott (1983) are correct: *in principle,* noble gas data provide constraints on ureilite petrogenesis. Unfortunately, cavernous gaps exist in our knowledge of noble gas geochemistry. Begemann and Ott's objections to our model for the origin of ureilites (Berkley *et al.* 1980) suffer from this lack of quantitative understanding. In this reply we reiterate the petrologic evidence for the carbonaceous material in ureilites being primary (rather than introduced after the silicate assemblage had formed) and address the main points raised by Begemann and Ott.

Bogard, D. D. and Johnson, P. (Nasa Johnson Space Center, Mail Code SN4, Houston, TX 77058): 'Trapped Solar Gases in the ALHA81005 Lunar(?) Meteorite', Lunar and Planetary Science XIV, Abstracts from the Session on Meteorites from Earth's Moon, pp. 1–2 (1983)

We have measured the isotopic abundances of the noble gas elements He, Ne, Ar Kr, and Xe in a primarily matrix sample of Antarctic meteorite ALHA-81005, which may have had an origin from the Moon. This sample contained very large concentrations of what are obviously implanted solar wind gases (Fig. 1). Absolute concentrations and relative abundances of these trapped gases are quite similar to typical solar gas-rich soils and breccias returned from the Moon. Isotopic compositions of the trapped gas in ALHA81005 are also identical to solar gas trapped in lunar samples – e.g., trapped 4-He/-3-He = 2600, 20-Ne/22-Ne = 12.5, 40-Ar/36-Ar = 1.8. Isotopic ratios of Kr and Xe plot on the mass fractionation trends for lunar soils, and there is no obvious evidence of excess radiogenic 129-Xe or fission-produced Xe.

Fayetteville and Pesyanoe are the two regolith-derived meteorites with the largest known concentrations of solar wind gases. Although the 4-He concentrations in Pesyanoe are much lower, and consequently Pesyanoe shows a much less fractionated noble gas abundance pattern compared to ALHA-81005 and to lunar fines and breccias. Meteorites rich in solar gases typically show considerably less mass fractionation of their gases (e.g., much larger 4-He/132-Xe) compared to lunar samples. This fact is probably due to the much higher levels of regolith gardening and ion re-implantation. With accompanying mass-fractionated gas loss, of lunar regolith compared to regoliths on meteorite parent bodies.

A preliminary value for the potassium concentration of the matrix of ALHA81005 (J. C. Laul, Pers. Comm.) indicates that $\sim 1.4 \times 10^{-5}$ cm^3/g of radiogenic 40-Ar should be produced in 4 Gy time. The measured 40-Ar concentration in ALHA81005 is ~ 20 times this value, which strongly suggests the presence of an atmosphere-implanted 40-Ar component such as that which has occurred on the Moon throughout much of its history. Presumably for an asteroid parent body the much shorter gravitational escape time for 40-Ar, the much smaller cross-section of the parent body surface, and the likely weaker solar wind fields would greatly reduce the effectiveness of the atmospheric-implantation process. In fact, the 40-Ar/36-Ar ratios in Pesyanoe and Fayetteville are much larger than in ALHA-81005 and lunar soils and much of the 40-Ar in the first two meteorites is due to *in situ* decay of K.

Even those noble gas isotopes with low relative abundances (e.g., 3-He and 38-Ar) are primarily of solar wind origin in ALHA81005. However, if we adopt a trapped 21-Ne/22-Ne ratio of 0.030, we estimate that about 17% of the measured 21-Ne, or $\sim 26 \times 10^{-8}$ cm^3/g, is cosmic ray produced. For a lunar surface irradiation this value would represent at least 100 MY of cosmic ray exposure.

The presence of large concentrations of solar gases in ALHA81005 clearly indicate that the matrix was finely spread on a surface exposed to the solar wind for a period of time before breccia formation. The large concentrations of solar gases with a mass fractionation pattern like lunar regolith samples, the excess concentrations of radiogenic 40-Ar and the suggestion of an old cosmic ray exposure age are all consistent with an origin of ALHA81005 from the lunar regolith. Such characterisitics are dissimilar to known meteorites and may be hard to reconcile with an origin from the regolith of an asteroid.

Boynton, W. V. and Hill, D. H. (Dept. of Planetary Sciences, Lunar and Planetary Lab., Univ. of Arizona, Tucson, AZ 85721): 'Minor and Trace Elements in Clast and Whole Rock Samples of Allan Hills A81005', Lunar and Planetary Science XIV, Abstracts from the Session on Meteorites from Earth's Moon, pp. 3–4 (1983)

The similarity between Allan Hills A81005 and lunar highlands rocks was noted by Mason, based on a preliminary examination of a thin section. Our data suggest a very strong relationship between ALHA 81005 and highlands rocks from Apollo 16. Based on two different sets of data, we conclude that it is most unlikely that this meteorite originated on a parent body other than the Moon.

Samples. We received two pieces of ALHA 81005 (60 mg. and 20 mg.), which were analyzed separately to check for heterogeneity. Examination under the stereo microscope showed abundant light-colored clasts in a grey matrix. One of the clasts was removed from the larger whole rock sample and analyzed separately. This clast (1 mg.) was among the whitest of the clasts. It had a small pink grain (spinel?) visible on the surface, and a very few dark grains could be seen in the clast.

Experimental. All data were obtained by INAA following a low-flux irradiation at the University of Arizona reactor. Most of the data to be discussed were taken after the samples had decayed to very low activities (the clast sample was counted at 0.25 cps, over 10^4 times weaker than our optimum count rate.). The samples were counted on our new Fast Anti-Compton Specrometer (FACS), which gives a dramatic improvement in signal-to-noise ratio. It is only because of the capabilities of this detector that we were able to get much of this data. We plan to re-irradiate at much higher flux to get our final data.

Evidence for Lunar Origin. The first set of data which suggest a lunar origin is Fe and Mn concentrations in the whole rock and the clast. Laul and Schmitt established that plots of MnO vs. FeO can distinguish lunar material from other known differentiated meteorites. Our data for the whole rock and clast plot in their field of lunar data. The FeO/MnO ratio in the whole rock (65.8) and clast (55) are typical of lunar samples with low abundances of these elements. We feel, however, that these data are necessary but not sufficient to establish lunar origin. A similar FeO/MnO ratio could easily be established in an unsampled parent body. In fact, Laul and Schmitt indicate that FeO/MnO ratios are similar in lunar, meteoritic and terrestrial anorthosites.

More convincing data for a lunar origin of ALHA 81005 is provided by the abundances of incompatible trace elements. Our data for the whole rock and clast are shown in Figure 2. Also plotted are data from Apollo 16 highlands samples 60625 and KREEP. The trace element abundances in 60626 show the characteristic KREEP pattern with a linear decrease in abundances of REE from light to heavy and an increase in Hf, Ta, and Th. This shape pattern is found in a large number of highlands rocks with absolute abundances spanning a range of a factor of 50. These elements have different partition coefficients, which are a strong function of the minerals involved in the fractionation event(s), and hence their final abundance ratios will be dependent on the composition and size of the parent body and on the exact degree of fractionation (partial melting or fractional crystallization). There appears to be no agreement on how the lunar KREEP pattern was established, but it is clear that very extreme fractionations are required. Because it is so difficult to generate this trace element pattern even on the Moon, there appears to be general agreement that this pattern was established only once, and the KREEP pattern was acquired by other rocks such as 60626 by mixing of this KREEP component. It is most unlikely that this pattern could be established on another parent body unless it had a similar bulk composition, size and thermal history as the Moon. Such a parent body clearly does not exist in the Solar System.

Evidence for a Pristine Lunar Clast. The trace element data from the single clast which we analyzed from ALHA 81005 is also plotted in Figure 2. The abundances are about a factor of 400 lower than that observed for pure KREEP. According to Warren and Wasson, all samples with incompatible elements less than 200 times lower than KREEP are pristine. The incompatible element attribute is second in importance only to low siderophile element in establishing the pristinity of samples. It appears then that ALHA 81005 may contain pristine samples of the early lunar crust. Clearly, more work on this interesting meteorite is in order. We are hopeful that investigations of other clasts will provide new insights into the origin of the lunar crust.

Cassidy, W. A. (Dept. of Geology and Planetary Science, Univ. of Pittsburgh, Pittsburgh, PA 15260): 'Prospects for Future Meteorite Recoveries on the Antarctic Ice Sheet', Lunar and Planetary Science XIV, Abstracts from the Session on Meteorites from Earth's Moon, p.5 (1983)

Until recently, there have been only two sites in Antarctica where meteorites have been found in great numbers – the Allan Hills and Yamato sites. Other locations have contained one or a few specimens. Assessment of the Belgica Mountains site is incomplete; over 50 speciments have been recovered there by a Japanese party, and this could be a third major occurrence. During the field season just past a U.S. field party has discovered major new concentrations of meteorites at Pecora Escarpment and at structures associated with the Thiel Mountains. Both areas were visited on a reconnaissance basis only. Fifty specimens were returned, but at least twice that number were seen and left *in situ* for future collection. Because the reconnaissance surveys were incomplete very large areas of exposed ice remain to be traversed, particularly at Pecora Escarpment, and it seems a reasonable speculation that these areas also will be found to bear meteorites. A second U.S. field party, working west and north of the original Allan Hills site, established the occurrence of meteorites over very large areas of blue ice that might be considered to be extensions of the Allan Hills and Elephant Moraine sites. Specimen density in these areas seems lower, but the total added area of known occurrence is very large. The important conclusions for the meteoritical community is that a steady flow of new specimens now seems guaranteed; the rate of return may in fact increase; it should not decrease.

Clayton, D. D. (Dept. of Space Physics and Astronomy, Rice Univ., Houston, TX 77001): Discovery of S-Process Nd in Allende Residue, *Astrophys. J.* **271**, L107–L109 (1983)

New interpretation is given to the isotopic anomalies detected by Lugmair *et al.* in an acid-resistant residue of the Allende meteorite. If the ^{142}Nd excess is due to ^{146}Sm decay, as the discoverers proposed, I argue that the decay has occurred in interstellar grains, so that the conclusion that ^{146}Sm (106×10^8 yr) was alive in the solar system is premature. I show by renormalizing their data that the discovery is likely to be *s*-process Nd, confirming the survival of red-giant stardust in carbonaceous stardust.

De Laeter, J. R. and Cleverly, W. H. (School of Physics and Geosciences, Western Australian Inst. of Technology, Bentley, Western Australia 6102): 'Further Finds from the Mundrabilla Meteorite Shower', *Meteoritics* **18**, 29–34 (1983)

Two new large iron meteorites, weighing 840 kg and 800 kg respectively, have been recovered from the Nullarbor Plain in the vicinity of the original Mundrabilla meteorite site, and are now at the Western Australian Museum in Perth. Numerous small knucklebone-shaped irons were also found at Tookana Rock Hole in the vicinity of Eucla. X-ray fluorescence spectrometry of these meteorites confirms that the additional finds are members of the Mundrabilla meteorite shower.

Delaney, J. S., Takeda, H., Prinz, M., Nehru, C. E., and Harlow, G. E. (Dept. of Mineral Sciences, American Museum of Natural History, New York 10024): 'The Nomenclature of Polymict Basaltic Achondrites', Meteoritics **18**, 103–111 (1983)

The subgroups within the basaltic achondrite site are defined using the structural criterion of Wahl (1952). The 'monomict' meteorites are samples of a single lithology while the polymict meteorites are those containing two or more lithologies. The 'monomict' subgroups; eucrites, cumulate eucrites and diogenites are subdivided into both *brecciated* and *unbrecciated* meteorites. The polymict achondrites sample a petrological-compositional continuum that contains both mafic and ultramafic rock types and may be subdivided into several groups. Two groups of polymict basaltic achondrites, the polymict eucrites and howardites are separated using an arbitrarily defined criterion. The recommended criterion is based on the amount of magnesian orthopyroxite (diogenite) component in the meteorite. Howardites contain more than 10% and polymict eucrites contain less than 10%.

The criteria proposed (perhaps with minor variations), appear to reconcile the ambiguities caused by the polymict eucrites. These meteorites, using earlier structural criteria, are howardites, but using mineralogical-chemical criteria are eucrites. As a subgroup of the polymict achondrites, their relationship with the howardites is clear, and the preservation of the term 'eucrite' in their name highlights their modal affinity to the monomict eucrites.

Easton, J. A. (Dept. of Mineralogy, British Museum (Natural History), London SW7 5BD, UK): 'Grain-Size Distribution and Morphology of Metal in E-Chondrites', *Meteoritics* 18, 19–27 (1983)

The size distribution and morphology of metal grains have been examined in 11 sections of types I and II E-chondrites. The changes in the grain-size distribution and morphology of metal grains correspond with the petrologic types and define a series that reflects increase in thermal metamorphism in the following order: type I, Kota Kota-Indarch-South Oman-St. Mark's; and type II, Jajh deh Kot Lalu-Atlanta-Daniel's Kuil-Hvittis-Pillistfer-Khairpur-Blithfield. Concentrations of metal grains adjacent to the perimeters of chondrules are observable throughout the sequence and delineate relic chondritic structure in six of the seven type II E-chondrites; relic structures are absent from Blithfield.

Ebihara, M. and Honda, M. (Inst. for Solid State Physics, Univ. of Tokyo, Roppongi, Minato-Ku, Tokyo, Japan): 'Rare Earth Abundances in Chondritic Phosphates and their Implications for Early Stage Chronologies', *Earth Planet Sci. Lett.* **63**, 433–445 (1983)

The abundances of nine rare earth elements (REE) in phosphate separates from three ordinary chondrites. Saint Séverin (LL6), Bruderheim (L6) and Richardton (H5), were measured by instrumental neutron activation analysis. All REE except europium are enriched in the phosphate minerals (merrillite and chlorapatite) by factor of 200–300 relative to the chondritic average, whereas Eu is enriched by a factor of 40–50. Electron microprobe analysis showed no significant differences in phosphate mineral composition among the three chondrites studied, though the relative proportions of two minerals varied.

According to our data, REE are enriched by almost the same factor in merrillite and chlorapatite in the Bruderheim and, with less certainty, in the other two chondrites. This behavior of REE contrast with that of the actinoid elements. Th, U and Pu, which are also enriched in phosphate but are fractionated between merrillite and chlorapatite. Since Pu and REE show different fractionation behaviour in chondritic phosphates, it may be difficult to use REE as stand-ins for Pu in ^{244}Pu chronology.

Evans, J. C. and Reeves, J. M. (Geosciences Research and Engineering Dept., Battelle, Pacific Northwest Lab., Richland, WA 99352): Aluminium-26 Content of ALHA81005, Lunar and Planetary Science XIV, Abstracts from the Session on Meteorites from Earth's Moon, p.6–7 (1983)

Since it was determined in preliminary examination that ALHA81005 may be of lunar origin, there has been considerable interest in its recent cosmic ray exposure history. If the meteorite is of achondritic origin it is likely to be saturated in ^{26}Al at 100–130 dpm/kg. Conversely, if the sample was excavated from the moon by a large impact, the exposure age should be very short before recapture in the earth-moon system. As part of the preliminary examination effort, the 23 gm main mass of the sample was hand-carried to Richland, Washington for one week of nondestructive gamma ray analysis at the Battelle Northwest multiparameter gamma ray spectrometry laboratory. One week of counting yielded an ^{26}Al content of 46 3 dpm/kg. This result is intermediate between the two possible cases discussed above and is thus subject to a variety of interpretations. The situation is further complicated by the possibility of long terrestrial age since it is an Antarctic specimen. In order to sort out the full bombardment and decay history of this unique sample, several other isotopic measurements such as ^{36}Cl, ^{10}Be, and ^{53}Mn will be required. The ^{26}Al measurement is consistent with the following interpretations.

(1) *Achondritic origin.*
In this case the sample either has a relatively short cosmic ray exposure age (500 000 yr) or a very long terrestrial age (1.1 m.y). The latter is a bit unlikely since the longest terrestrial age seen to date is only 700 000 yr. Obviously some combination of the two is also possible.

(2) *Lunar origin.*
Several possibilities exist for a lunar origin. The sample could simply have been saturated at shallow depth on the moon and spent a short time in space and in the ice. That situation is illustrated. The sample would be excavated in that case from a depth of only one meter which is rather shallow for an impact large enough to throw it into space. If excavated from a significantly greater depth then the situation becomes essentially the same as for the achondritic case, i.e., a time in space of at least 500 000 yr which does appear a bit long for a spatial residence time of lunar ejecta.

The ^{26}Al content measured in this sample is thus a bit improbable for either a lunar or achondritic origin. Additional measurements of other isotopes should therefore prove extremely interesting.

Futrell, D. S. and Fredriksson, K. (6222 Haviland Ave., Whittier, CA 90601): 'Brecciated Muong Nong-Type Tektites', *Meteoritics* 18, 15–17 (1983)

Welded breccias and faults in Muong Nong-type indochinite tektites from Thailand are illustrated. Electron probe analyses of these tektites show somewhat higher Al and alkalies in light-colored layers, and somewhat higher Si and Ca in dark-colored layers.

Gault, D. E. (Murphys Center of Planetology, Murphys, CA 95247): 'The Terrestrial Accretion of Lunar Material', Lunar and Planetary Science XIV, Abstracts from the Session on Meteorites from Earth's Moon, pp. 8–9 (1983)

It is well established by both experiment and computer modeling that an impact of a meteoritic projectile on the lunar surface will eject lunar material free of the Moon's gravitation into cis-lunar and heliocentric space. In order to assess the amount of lunar material arriving on Earth and its probable origin on the Moon, two series of ejecta-trajectory calculations have been performed: (1) three-body calculations to determine the conditions for direct (i.e., first perigee) encounter with Earth, and (2) four-body calculations to determine the mass and equilibrium conditions (i.e., life times) of lunar material ejected into geocentric orbits. All calculations assume the Moon is in a circular orbit about Earth at its mean distance (384 405 km) with an orbital period of 27.32 days (0.22997 radians/day). Co-planar orbits were used for the four-body series with starting conditions corresponding to a full-Moon phase. Capture radius of Earth was included a 100 km deep atmosphere and taken to be 6478 km. With these assumptions there remain five independent variables: latitude β and longitude δ of the point of impact, ejection angle with respect to surface θ and azimuth ejection angle λ, and the ejection velocity V_e. The latter was restricted to values less than 5 km/s as the physical limit for ejection of material in the vaporous state.

With $\theta = 45°$, a good representative value for ejection angle, direct Moon–Earth trajectories can originate from almost 2/3 of the lunar surface, an area extending from 34° W. along the equator in an easterly direction past the sub-terrestrial and anti-terrestrial points to 160° W. and extending to the 80° latitudes. Ejection velocities of $V_e = 2.55$ to $2.7\ \mathrm{km\,s^{-1}}$ make the greatest contribution for direct trajectories; lower velocities produce mostly geocentric orbits and higher velocities lead to mostly heliocentric orbits. Steeper ejection angles move the area for direct trajectories eastward and in the limit for vertical ejection reduce the area to about 2% of the near-side surface. Conversely, more shallow ejection angles move the area westward and in the limit for tangential trajectories encompasses the entire lunar surface.

For the four-body calculations the northern hemisphere was divided into 12 equal areas (effectively 24 for the entire Moon with the mirror symetry of the co-planar orbits) with a centered point for ejection. Eight trajectories spaced 45° apart in azimuth were calculated for each point for eight ejection velocities $V_e = 2.4$ to $3.2\,km\,s^{-1}$. The trajectories were traced until either impact occurred on the Earth or Moon, until the trajectories were modified into heliocentric orbits, or until the time exceeded 30 yr. Of the original 768 starting trajectories, 523 made direct entry into heliocentric orbits, 9 made direct impact on Earth, and the remainder (236) entered geocentric orbits that were subsequently modified to produce 55 Earth impacts, 7 lunar impacts, and 172 injected into heliocentric space. Only two of the trajectories remained in geocentric orbits at the end of 30 years.

These four-body results, together with a model of the mass-velocity distribution of high-velocity ejecta derived from experimental results, indicate that with an isotropic flux of impactors approximately 0.5% of the mass escaping the Moon arrives at Earth on direct trajectories. The bulk of the ejected mass lost from the Moon, 85%, passes directly into heliocentric space, 13% enters geocentric orbits, and the remaining 1% is returned to the Moon. The subsequent modification of the geocentric orbits brings the final mass distribution to 94% into heliocentric space, 4% Earth accretion, and 2% swept back up by the Moon. It is interesting to note that the geocentric population of orbits appears to consist of two families of trajectories having 3- and 5-yr half-lifes. Despite their relatively short life times in geocentric orbits, in the real environment of a steady, isotropic flux of impactors a small concentration or 'cloud' of lunar material must be accumulated around Earth, and it is from this 'cloud' that Earth accretes most of its lunar material.

With the present meteoritic influx rate on the Moon taken to be of the order of 10^8–$10^9\,g\,yr^{-1}$ for masses greater than a few milligrams, which are capable of producing fusion material larger than a few microns, it is estimated that the Moon is currently losing 10^9–$10^{10}\,g\,yr^{-1}$. Of this total mass loss, it appears that no more than 10^7–$10^8\,g\,yr^{-1}$ are accreted by Earth, the total derived from both direct trajectories and the 'cloud' in geocentric orbits (estimated to be of the order of 10^{10}–10^{11} g).

Although this estimated mass of lunar material arriving on Earth is small in comparison to other sources of extra-terrestrial matter (0.1–1.0%?), it is an inescapable conclusion that lunar material is ejected from the Moon and that some of that material ultimately arrives on Earth. Composition of the material favors a source from the large areas of highland units (anorthositic?) relative to the smaller areas of mare units (basic?). It is a tantalizing challenge for the geosciences for

Goswami, J. N. and Nishiizumi, K. (Physical Research Lab., Ahmedabad 380 009, India): Cosmogenic Records in Antarctic Meteorites *Earth Planet Sci. Lett.* **64**, 1–8 (1983)

Aliquot samples of twenty-nine Antarctic L and H chondrites were analyzed for their nuclear track records and ^{53}Mn activities. Track density in the analyzed samples range from 10^4 to $\sim 6 \times 10^6\,cm^{-2}$. An important finding is the observation of track-rich grains in a set of four L3 chondrites ALHA 77215, 77216, 77217 and 77252, suspected to belong to the same fall based on petrographic observations. An additional sample, ALHA 78105, a L6 chondrite, also contains track-rich grains. ^{53}Mn activity is at near saturation level in $\sim$ 65% of the analyzed samples indicating exposure ages $>$ 10 m.y. in these cases. Very few H chondrites from the 7-m.y. exposure age peak are apparently sampled among the ones analyzed in this study. About 6% and 4% respectively of the Antarctic H and L chondrites, analyzed so far for their cosmogenic records, have precompaction irradiation features. Combined analysis of ^{53}Mn and nuclear track data allowed us to confirm or rule out the proposed pairing of several sets of Antarctic meteorites, and also to estimate the preatmospheric sizes of some of these meteorites. The results indicate that most of the small Antarctic meteorites ($<$ 1 kg) have suffered high ($>$ 95%) ablation mass-loss.

Graham, A. L. (Dept. of Mineralogy, British Museum (Natural History), London, UK): 'An Unequilibrated Inclusion in the Romero (H3–4) Chondrite', *Meteoritics* **18**, 51-61 (1983)

Within the chondritic matrix of Romero (H3–4) is a metal-poor inclusion consisting largely of olivines showing quench textures, minor low-Ca pyroxene and rare metal and sulphide. The olivines within this inclusion have the dominant composition Fa_8 with a range $Fa_{7.5-17}$. The matrix (Romero host) olivines are, in the main, equilibrated with an average composition of Fa_{18}, but are lower in CaO and Cr_2O_3 than the inclusion olivines. The high chromium content of the inclusion olivines suggests that they formed under conditions different from those represented by the other olivines in Romero.

Grossman, J. N. and Wasson, J. T. (Inst. of Geophysics and Planetary Physics, Univ. of California, Los Angeles, CA 90024): 'Refractory Precursor Components of Semarkona Chondrules and the Fractionation of Refractory Elements Among Chondrites', *Geochim. Cosmochim. Acta* **47**, 759–771 (1983)

Chondrules from the Semarkona (LL3.0) chondrite show refractory and common lithophile fractionation trends similar to those observed among the chondrite groups. It appears that chondrules are mixtures of a small number of pre-existing solid components, and we infer that chondrule precursor materials were related to the nebular components involved in the lithophile element fractionations recognized in ordinary chondrites. Compositional trends among the chondrules can be used to deduce the compositions of these components.

We use instrumental neutron activiation analysis to measure many (~ 20) of the lithophile elements in 30 chondrules. The amounts of oxidized iron were calculated from other compositional parameters: concentrations of Si were estimated using mass-balance considerations. The data were corrected for the diluting effects of non-lithophile constituents. Plots of lithophile elements *versus* a reference refractory element such as Al show that there were two major chondrule silicate precursor components: a refractory, olivine-rich, FeO-free one, and a non-refractory, SiO_2-, FeO-rich one.

The refractory component probably forms from olivine-enriched condensates formed above the condensation temperature of enstatite. The non-refractory component must have formed from fine-grained materials that were able to equilibrate down to lower nebular temperatures. Chondrite matrix may have had an origin similar to that of the non-refractory material, and constitutes a third lithophile-bearing component that took part in chondrite fractionation processes. The low abundance of refractories and Mg in ordinary and enstatite chondrites was produced by the loss of materials having a higher refractory-element/Mg ratio than that in the refractory component of chondrules.

Hamano, Y. and Matsui, T. (Geophysical Inst., Univ. of Tokyo, Bunkyo-Ku, Tokyo 113, Japan): 'Natural Remanent Magnetization of the Wellman Meteorite', *Geophysical Research Letters* **10**, 861–864 (1983)

Magnetic measurements revealed that the NRM of the Wellman meteorite (H5) varies with the position within the meteorite. In the outer part with a thickness of about a few cm, the intensity of the NRM is high (~ $100 \, Am^{-1}$) and the remanence consists of almost a single component. On the other hand the NRM intensity in the internal part is as low as $10 \, Am^{-1}$ and consists of three components. The directions of these three components are coherent among multiple samples. The two components with the lower coercivities are magnetically very soft, and must have been acquired on the earth's surface. The magnetic stabilities of the surface magnetization and that of the hard component of the internal remanences are high and similar to each other. The stable direction of the internal magnetization is almost antipodal to the surface magnetization. These observations suggest that all the remanences of the Wellman meteorite have been acquired during the fall through the earth's atmosphere and on the earth's surface.

Huneke, J. C., Armstrong, J. T., and Wasserburg, G. J. (Lunatic Asylum of the Charles Arms Lab., Div. of Geological and Planetary Sciences, California Inst. of Tech., Pasadena, CA 91125): 'Fun with Panurge: High Mass Resolution Ion Microprobe Measurements of Mg in Allende Inclusions', *Geochim. Cosmochim. Acta* **47**, 1635–1650 (1983)

The performance characteristics of PANURGE, a modified CAMECA IMS3F ion microprobe, have been studied at a mass resolving power of 5000 for the purpose of determining isotopic ratios at a precision level approaching that of counting statistics using beam switching. The techniques used for this type of measurement are described. Using this approach, the isotopic composition of Mg and Si and the atomic ratio of Al/Mg in minerals from the Allende inclusion WA and the Allende FUN inclusion Cl have been measured with the ion microprobe at high mass resolving power. Enrichments in ^{26}Mg of up to 260% have been found. Mg and Al/Mg measurements on cogenetic spinel inclusions and host plagioclase crystals yield Mg-Al isochrons in excellent agreement with precise mineral isochrons determined by thermal emission mass spectrometry. The measurements confirm the presence of substantial excess ^{26}Mg in WA ($^{26}Mg^*/^{27}Al = 5 \times 10^{-5}$) and its near absence in Cl ($^{26}Mg^*/^{27}Al <$

4×10^{-6}). In WA plagioclase, data for which $^{27}Al/^{24}Mg = 300$ to 1000 define a linear array with $^{26}Mg^*/^{27}Al = 3 \times 10^{-5}$ and with initial $^{26}Mg/^{24}Mg$ composition 30% greater than in high Mg phases. This suggests a metamorphic reequilibrium of Mg in Allende plagioclase at least 0.6 my after WA formation. There were no variations in detected $^{26}Mg^*/^{27}Al$ in WA plagioclase associated with concentration of $^{26}Mg^*$ into isolated clusters. We have confirmed by ion probe measurements that the Mg composition in Allende Cl is highly fractionated and is uniform among pyroxene, melilite, plagioclase, spinel crystals and spinel included in melilite and plagioclase crystals. Likewise, the Si composition is mass fractionated and is the same in pyroxene, melilite and plagioclase.

Jones, J. H. and Drake, M. J. (Lunar and Planetary Lab., Univ. of Arizona, Tucson, AZ 85721): 'Experimental Investigations of Trace Element Fractionation in Iron Meteorites, II: The Influence of Sulfur', *Geochim. Cosmochim. Acta* **47**, 1199–1209 (1983)

We have investigated the partitioning of Ir, Ge, Ga, W, Cr, Au, P, and Ni between solid metal and metallic liquid as a function of temperature and S-concentration of the metallic liquid. Partition coefficients for siderophile elements such as Ir, W, Ga and Ge increase by factors of 10–100 as the S-concentration of the metallic liquid increases from 0–30 wt%. Partition coefficients for other siderophile elements such as Ni, Au and P increase by only factors of 2–3. In contrast, partition coefficients for the more chalcophile element Cr decrease. These experimentally-determined partition coefficients have been used in conjunction with a fractional crystallization model to reproduce the geochemical behavior of Ni, P, Au and Ir during the magmatic evolution of groups IIAB, IIIAB, IVA and IVB iron meteorites. The mean S-concentration for each group increases in the order IBV, IVA, IIIAB, IIAB, in accord with cosmochemical prediction. However, we are unable to reproduce the geochemical behavior of Ge, Ga, W and Cr in an internally consistent way. We conclude that the magmatic histories of these iron meteorite groups are more complex than has been generally assumed.

Kallemeyn, G. W. (Inst. of Geophysics and Planetary Physics, Univ. of California, Los Angeles, CA 90024): 'Alha81005: A new Sample from the Lunar Highlands?', Lunar and Planetary Science XIV, Abstracts from the Session on Meteorites from Earth's Moon, pp. 10–11 (1983)

Evidence is mounting that the Antarctic meteorite find, ALHA81005, represents the first lunar sample recovered without the expenditure of a significant portion of a nation's GNP. This would make it the first meteorite whose actual parent body can be deduced with hard evidence – although this hard evidence *required* the technological recovery of lunar samples.

Petrographically, ALHA81005 appears to be a regolith breccia, notably low in metal, with troctolitic clasts and a matrix containing swirly glass (Warren *et al.*,). Our 113 mg sample contains an estimated 40% clast material and is currently being studied by instrumental neutron activation analysis.

Several points can be made from our preliminary compositional data. The Fe ($45\,mg\,g^{-1}$) and Mn ($0.58\,mg\,g^{-1}$) contents of our sample are similar to those of Apollo-16 soils and rocks, and the bulk Fe/Mn ratio of 77 is near the mean lunar value of ~ 80. This Fe/Mn ratio is distinct from those of known chondritic and achondritic meteorites and from the Earth's mantle; it provides strong evidence for a lunar origin. The bulk Mg/(Mg + Fe) (0.71) vs. Ca/(Ca + Na + K) (0.96) of the sample plots just above the region defined by lunar ferroan anorthosites. Incompatible elements are low, 0.01–0.02× those in incompatible-rich lunar KREEP. the REE pattern (3–5× CI) is typical of anorthosities, with a small light/heavy enrichment and a strong positive Eu anomaly. Siderophile element concentrations are very low (which correlates with the low observed metal contents), and the meteoritic fraction is $< 1\%$. The Ir/Au ratio is near the CI value, somewhat higher than typical values in mature Apollo-16 soils; this suggests that the sample is from a younger, less-mature regolith.

The petrographic and compositional data for ALHA81005 suggest a lunar highlands origin, so a comparison to the bulk chemistry of the Apollo-16 and Luna-20 sites seems appropriate. We plot lithophile, siderophile and incompatible elements normalized to mean Apollo-16 and Luna-20 soils. The Na content of ALHA81005 (2.2 mg/g) is notably low relative to both locations, especially Apollo16. Since the variation of Na among Apollo-16 sampling sites is quite small, the difference seems significant. The difference with Na at the Luna-20 locations is much smaller and may not be significant as the lowest Luna-20 values are near ALHA81005. There seems to be a general trend of decreasing Na and increasing Mg in highlands samples from the center to east limb of the nearside;

the high Sc/Sm and Ti/Sm ratios for ALHA81005 also suggest a closer relationship to Luna-20, and a provenance well-away from the center of the nearside. Unfortunately, nothing is known regarding the nearside far west or the entire farside, but it seems likely that they are similar to the Luna-20 site. Titanium is also quite low in ALHA81005 relative to both Apollo-16 and Luna-20, although this element shows a greater range of variation than Na among the different Apollo-16 sampling stations. It has been previously noted that the Apollo-16 locations appears to have a high-Ti component, possibly from KREEP having a higher local Ti concentration. Scandium is also depleted along with Ti in ALHA81005 relative to the Luna-20 site, perhaps reflecting a lower SCCRV component in the sample.

All compositional data are consistent with a lunar origin for ALHA81005. Its lunar location was probably well-away from the center of the nearside. Its composition is nearer that of the Luna 20 location than the Apollo-16 location, although there are sufficient differences to suggest a provenance remote from both of these locations, including especially the far-eastern limb and the farside.

Kerridge, J. F. (Inst. of Geophysics, Univ. of California, Los Angeles, CA 90024): 'Isotopic Composition of Carbonaceous-Chondrite Kerogen: Evidence for an Interstellar Origin of Organic Matter in Meteorites', *Earth Planet. Sci. Lett.* **64**, 186–200 (1983)

Stepwise combustion has revealed systematic patterns of isotopic heterogeneity for C, H and N in the insoluble organic fraction (m-kerogen) from the Orgueil and Murray carbonaceous chondrites. Those patterns are essentially identical for both meteorites, indicating a common source of m-kerogen. The data cannot be reconciled with a single mass-fractionation process acting upon a single precursor composition. This indicates either a multi-path history of mass-dependent processing or a significant nucleogenetic contribution, or both. If mass-fractionation were the dominant process, the magnitude of the observed isotopic variability strongly suggests that ion-molecule reactions at very low temperatures, probably in interstellar clouds, were responsible. In any case, an interstellar, rather than solar nebular, origin for at least some of the meteoritic organic matter is indicated. This has interesting implications for the origin of prebiotic molecules, temperatures in the early solar system, and the isotopic compositions of volatiles accreted by the terrestrial planets.

Kitamura, M., Yasuda, M., Watanabe, S., and Morimoto, N. (Dept. of Geology and Mineralogy, Faculty of Science, Kyoto Univ., Sakyo 606, Japan): 'Cooling History of Pyroxene Chondrules in the Yamato-74191 Chondrite (L3) – An Electron Microscopic Study', *Earth Planet. Sci. Lett.* **63**, 189–201 (1983)

Fine textures of clinopyroxene in an excentroradial pyroxene chondrule (EPC) and a comb-like pyroxene chondrule (CPC) in the Yamato-74191 chondrite (L3) have been studied by analytical electron microscopy. Both pyroxenes consist of three regions different in composition and texture; core, mantle and marginal regions, though the pyroxenes of the CPC are more Fe-rich than those of the EPC. The core region is the most Mg-rich with no Ca component and commonly shows polysynthetic (100) twins. The mantle region is slightly calcic, and the marginal region shows a rapid increase of Ca outward.

The polysynthetic twins, cracks and subgrain boundaries in the core in the EPC and CPC must have formed during the transition from proto-type to clino-type pyroxenes. The exsolution textures in the mantle and marginal regions indicate initial crystallization of pigeonite-*C* followed by decomposition into pigeonite-*P* and augite. The decomposition must have taken place by nucleation growth in the mantle region and by spinodal decomposition in the marginal region. The periodicity of 15–20 nm in the spinodal decomposition textures indicates that the cooling rate of the pyroxenes, when passing through about 1000 °C, was of the order of a few tens to several degrees centigrade per hour. The cooling history of the chondrules has been explained by a monotonous cooling controlled by the cooling rate of the surrounding medium.

Korotev, R. L., Haskin, L. A., and Lindstrom, M. M. (Dept. of Earth and Planetary Sciences Washington Univ., St. Louis, MO 63130): 'Lunar Highlands Breccia 81005 (ALHA): So Apollo 18 Flew, but Where did it Sample?', Lunar and Planetary Science XIV, Abstracts from the Session on Meteorites from Earth's Moon, pp. 12–13 (1983)

Seven subsamples of meteorite ALHA81005 totaling 78 mg were analyzed by INAA for 33 elements (Table 1). Two are primarily (> 80%) white lithology (samples 1A, 3A), four primarily (> 90%) dark (samples 2M1, 2M2, 3M1, 3M2), and one is residue (3R). Compositions of all seven are similar, with subtle differences between dark and light lithologies. ALHA81005 has a characteristic lunar highlands composition including high concentrations of Al and Ca and, relatively, Cr; low concentrations of Na and K; and interelement ratios and relative REE abundances unlike those of other meteorites and typical terrestrial rocks.

In bulk composition ALHA81005 resembles many lunar breccias and soils of anorthositic norite composition, but is slightly less rich in Na, much less in Ti, and very much less in K and the large ion lithophile elements (LILE) associated with KREEP. The closest matches for the major elements (ME) are certain Apollo 16 VHA impact melts (e.g., 60018, 60335, and 61016 and some "anorthositic gabbro" clasts from Apollo 17 breccias (e.g., 72235,36, 77017,57, and 76315,62). However, ALHA-81005 has lower concentrations of Na (0.7 ± 0.3×), Ti (~ 0.35×), and LILE (Sm, 0.07–0.6×). In ME composition, ALHA81005 also resembles soils from Apollo 16 station 5 and 6, but has less Na, Ti, K, and LILE, slightly less Al, and 1.4× more Mg. Polymict highlands rocks with comparable LILE concentrations are more anorthositic (e.g , 64435 and 67455). The pristine samples closest in ME composition to ALHA81005 are anorthositic norites 67215 and 15565,113 and troctolites 73235,127 and 76255,58. All but 76255 also have low LILE concentrations.

Relative LILE concentrations in ALHA81005 resemble those of many lunar highlands samples that have little or no KREEP. The magnitude of the Eu anomaly is in the narrow range characteristic of highlands samples with similar REE concentrations, a strong geochemical argument for a lunar origin. Among meteorites, only the Moore Co. eucrite has similar overall REE concentrations and Eu anomaly, but the chondrite normalized concentrations increase slightly with atomic number unlike most lunar patterns, Moore Co. ME are unlike those of ALHA81005.

Nearly all lunar samples with LILE concentrations as low as ALHA81005 are more anorthositic. Polymict lunar samples with similar ME concentrations are much richer in LILE. KREEP-poor, polymict, anorthositic norites (gabbros) are rare in the lunar collection, but they could be a predominant rock type in areas uncontaminated by KREEP.

ALHA81005 represents a new highlands sampling site. Detailed study will give insight into types and compositions of endogenous highlands rocks and the importance of materials like KREEP and anorthosite. ME concentrations of light and dark lithologies are similar but differences in LILE are substantial, with the light material slightly poorer in Fe, Sc, and Co and much poorer in Ti, K and LILE, but slightly richer in Mg, Na, and Cr and much richer in Br. Ni and Ir concentrations are consistent with a 1–2% chondritic meteorite component, typical of polymict highlands materials. There is no difference in Al concentration between the light and dark samples, yet Fe and Sc differ by 24% and the REE by 200%. Hence the light material is not dark material plus anorthosite. Nor is the dark material simply white material plus KREEP. Only 1% KREEP would be needed to account for the LILE, yet Mg and Cr, which have similar concentrations in KREEP and ALHA81005, are 24% and 12% more enriched in the light samples compared to the dark. The two lithologies represent different but similar mixtures with overall anorthositic norite compositions.

The variety of clasts [2, 20, U. Marvin, pers. comm.] suggests that ALHA81005 was once a soil. ALHA81005 is more similar than sampled soils to typical lunar highlands as estimated from data from the Apollos 15 and 16 orbiting gamma-ray experiments. Its Th concentration is lower (0.5×) and its TiO_2 concentration much lower (0.15×), raising further question about the accuracy of the gamma-ray data for Ti. The gamma-ray experiment indicated that KREEP is principally a lunar nearside phenomenon. KREEP-free ALHA81005 may be our most representative sample of typical lunar highlands surface material and may even have come from Moon's farside!

Kurat, G. and Brandstatter, F. (Naturhistorisches Museum, Postfach 417, A-1014 Vienna, Austria): Meteorite ALHA 81005: A Lunar Highland Breccia, Lunar and Planetary Science XIV, Abstracts from the Session on Meteorites from Earth's Moon, pp. 14–15 (1983)

Thin-section ALHA 81005,8 has been allocated to us for a restricted study period of four weeks starting February 10, 1983. This report necessarily has to be a preliminary one. Here we concentrate on our results on lithic and mineral components in ALHA 81005.

Results: ALHA 81005 is a lunar regolith breccia. Figure 1 shows one of the possible chemical evidences for a lunar origin, the FeO/MnO ratio in olivines. ALHA 81005 is a compacted immature lunar highland soil consisting of a variety of lithic fragments, glass fragments, glass beads, chondrules, and mineral fragments suspended into a glass-rich fine-grained matrix which has been shock-melted in places, probably during compaction. The most common lithic fragments are granulitic metabreccias, followed by 'basaltic' clasts, shocked anorthosites, chondrules, and complex microbreccias.

Igneous lithology: Most igneous rocks present (regardless whether they are real igneous rocks or melt rocks) are metamorphosed and partially equilibrated. Only one fragment (basalt A) of a felspathic basalt composition (low-K Fra Mauro basalt) is apparently not metamorphosed and displays a crystallization sequence of plag, plag + ol, and plag + px. The compositional variation of olivines and pyroxenes are shown and typical analyses are given. The meta-igneous rocks clearly can be divided into two groups: The Mg-suite consists exclusively of fine-grained ophitic rocks which are all olivine bearing and which could be melt rocks. The Fe-suite is coarse to very coarse-grained and apparently of a deeper seated origin. "Metabasalt" H actually is only a large pyroxene fragment with some silica attached to it and we can only infer that it belongs to the basalt suite. The Fe-suite tends to be of noritic composition.

Anorthosites: Two large shocked anorthosite fragments have been encountered. Both belong to the ferroan rock suite, have different pyroxenes and are metamorphically partially equilibrated.

Metabreccias: All granulitic metabreccias are members of the Mg-suite and are of anorthositic noritic-troctolitic composition. Some are Mg-spinel bearing. Metabreccia B is a unique rock fragment consisting mainly of olivine, low-Ca pyroxene, some plagioclas and Cr-Ti spinel. Its real nature is not clear yet.

Chondrules: Three chondrules are present in ALHA 81005,8. All are of the typical ANT composition.

Mineral fragments: Most common is plagioclase followed by low-Ca pyroxenes and olivines. Rare are pink Mg-spinel, chromite, and metal. The mafic minerals belong to both Mg-Fe groups.

Summary: ALHA 81005 is a feldspathic lunar highland breccia. Its composition is dominated by highly magnesian, olivine bearing metabreccias and melt rocks derived thereof. The ferroan rock suite is relatively rare and consists of anorthosites, meta-igneous rocks, one metabreccia, and some mineral fragments. Most glasses compositionally overlap with the melt rocks but not with the magnesian metabreccias. A search for KREEP revealed only one glass and one basalt fragment of low-K composition.

Laul, J. C., Smith, M. R., and Schmitt, R. A. (Radiological Sciences Dept., Battelle Northwest, P.O. Box 999, Richland, WA 99352): ALHA 81005 Meteorite: Chemical Evidence for Lunar Highland Origin, Lunar and Planetary Science XIV, Abstracts from the Session on Meteorites from Earth's Moon, pp. 16–17 (1983)

Summary: Based on the well-established characteristic lunar and meteoritic ratios of FeO/MnO, Cr_2O_3/V and K/La, and REE patterns, ALHA 81005 meteorite is undoubtedly of lunar origin. Our conclusion is confirmed by oxygen isotopic, noble gas, and petrologic studies. The ALHA 81005 meteorite is an anorthositic gabbro (72% Pl) and matches closely in chemical composition to Apollo 15 15418 (5) and Luna 16 21013 highland rocks. The high content of siderophiles Ni, Ir and Au (1–2% meteoritic component) in ALHA 81005 is similar to the siderophiles content in other lunar highland breccias, which strongly suggests that this rock was also subjected to a meteoritic impact on the moon. The terrestrial ages of meteorites collected at the Antarctica including ALHA 81005 are relatively young 0.01–0.7 m.y. Assuming a short space residence time the young terrestrial ages indicate recent excavation of the rock by a cratering event on the Moon This implies that if a recent cratering event by a meteoritic impact can send lunar debris on the earth, then when major lunar basins were formed by planetesimal bodies during early (~ 4 B.y) cataclysmic bombardment, the earth must have received enormous amounts of lunar material which is now mixed in the crust. The finding of a meteorite of lunar origin is the first documented case which further lends credibility to the suggestion that SNC achondrites may come from Mars.

Discussion on the bulk, matrix and clast: The bulk, matrix (dark) and clast (white) were analyzed for 30 elements by INAA. The petrology work on the same sample split was done by Papike's group.

The chemical data are shown. For comparison the data for 15418 and 21013 highland rocks are also included. The chondritic normalized REE patterns of these samples are shown. The clast is low by ~ 20 in REE and other trace elements relative to the matrix and bulk. The chemistry of the bulk is governed by the matrix. The strong element correlations of FeO/MnO and Cr_2O_3/V first noted by Laul et al. and K/La, and later found to be typical ratios for the moon is used to distinguish ALHA 81005 from other Ca-rich achondrite planetary bodies such as Eucrites, Howardites, Shergotittes, Nakhlites and Chasignites. These correlations are shown. ALHA 81005 samples fall on the lunar line, whereas the other achondrites fall distinctly away from the lunar line. The FeO/MnO ratio of 80 provides the strongest evidence in favor of the lunar origin. The rock is reported as a regolith breccia indicating that the observed chemical signatures represent various lithic components similar to 15418 which is also a melt rock.

Levi-Donati, G. R. and Clarke, R. S. Jr. (Instituto Tec. Ind. di Stato "A. Volta", 01600, Pergia, Italy): 'Brianza: An Example of Wrongly Believed Chondrite', *Meteoritics* **18**, 165–166 (1983)

Brianza is neither a 'brecciated chondrite', or an 'iron meteorite'. The specimen may be then *discarded* from the lists of meteoritic falls.

Luck, J.-M. and Allegre, C. J. (Laboratoire de Geochimie et Cosmochimie, Univ. de Paris VI et VII, 4 Place Jussieu, 75230 Paris Cedex 05, France): '187Re–187OS Systematics in Meteorites and Cosmochemical Consequences', *Nature* **302**, 130–132 (1983)

A new technique based on isotope dilution has allowed the reappraisal of ^{187}Re–^{187}Os isotopic tracers. Rhenium and osmium were chemically separated and their isotopic compositions determined by ion-microprobe mass spectrometry. Such an approach led to the absolute dating of meteorites and allowed us to estimate the evolution of the Os isotopic composition in the Earth's mantle. Having improved the analytical procedure and recalibrated our osmium spike, we found that the value we had used previously was too high by a few per cent. We therefore include here our eight previous results on iron meteorites and on St Severin, corrected for this change in spike calibration. Our data now include 11 analyses on irons, and the iron phases of 10 chondrites and of one mesosiderite. From these data we propose a revised and more precise value for the rhenium decay constant, together with a new estimate for the age of the Galaxy.

MacPherson, G. J., Bar-Matthews, M., Tanaka, T., Olsen, E., and Grossman, L. (Dept. of Geophysical Sciences, Univ. of Chicago, 5734 South Ellis Ave., Chicago, Il 60637): 'Refractory Inclusions in the Murchison Meteorite', *Geochim. Cosmochim. Acta* **47**, 823–839 (1983)

Mineralogical and petrographic studies of a wide variety of refractory objects from the Murchison C2 chondrite have revealed for the first time melilite-rich and feldspathoid-bearing inclusions in this meteorite, but none of these is identical to any inclusion yet found in Allende. Blue spinel-hibonite spherules have textures indicating that they were once molten, and thus their SiO_2-poor bulk composition requires that they were exposed to higher temperatures (> 1550 °C) than those deduced so far from any Allende inclusion. Melilite-rich inclusions are similar to Allende compact Type A's, but are more Al-, Ti-rich. One inclusion (MUCH-1) consists of a delicate radial aggregate of hibonite crystals surrounded by alteration products, and probably originated by direct condensation of hibonite from the solar nebular vapor. The sinuous, nodular and layered structures of another group of inclusions, spinel-pyroxene aggregates, suggest that these also originated by direct condensation from the solar nebular gas. Each type of inclusion is characterized by a different suite of alteration products and/or rim layers from all the other types, indicating modification of the inclusions in a wide range of different physico-chemical environments after their primary crystallization. All of these inclusions contain some iron-free rim phases. These could not have formed by reaction of the inclusions with fluids in the Murchison parent body because the latter would presumably have been very rich in oxidized iron. Other rim phases and alteration products could have formed at relatively low temperatures in the parent body, but some inclusions were not in the locations in which they were discovered when this took place. Some of these inclusions are too fragile to have been transported from one region to another in the parent body, indicating that low temperature alteration of these may have occurred in the solar nebula.

Marvin, U. B. (Harvard-Smithsonian Center for Astrophysics, Cambridge, MA 02138): 'Extraterrestrials have Landed on Antarctica', *New Scientist* 97, 710–715 (1983)

The southern icy continent has been yielding a harvest of strange meteorites.

Marvin, U. B. (Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02318): 'Some Petrologic Comparisons Between ALHA81005 and Lunar Highland Soil Breccias', Lunar and Planetary Science XIV, Abstracts from the Session on Meteorites from Earth's Moon, pp. 18–19 (1983)

Specimen ALHA81005 appeared unique when it was discovered on the middle western ice field of the Allan Hills region on the final snowmobile traverse of the 1981–82 season. The field photograph shows a small rounded breccia, about 3 cm across, with conspicuous white clasts under a thin fusion crust. Six other meteorites were found in the same ice field during helicopter reconaissance flights early in the 1979–79 season. None of the other specimens resemble 81005, which remains the only one of its kind found in Antarctica or elsewhere in the world.

Preliminary examination of two thin sections (81005,3 and, 22) show that the rock is a heterogeneous mixture of mineral and rock fragments, colorless glass spherules, and masses of devitrified glass embedded in a dark, glassy matrix. Some portions of the matrix are flow banded and/or crowded with minute (2–4 μm) vesicles. The clast and matrix compositions fall well within the range of lunar highlands materials but differ from those of familiar achondritic meteorites. The glass spherules are reminiscent of those found in lunar soils and regolith breccias.

Plagioclase is by far the most abundant component of the rock. It occurs as mineral fragments and in lithic clasts ranging from cataclastic and granulitic anorthosites to anorthositic gabbros and troctolites with granulitic, ophitic, and cumulate textures. Plagioclase is also an abundant constituent of the colorless glasses, the devitrified glasses, and the brown matrix glasses. Most of the plagioclase is Ca-rich (An 92–98; Av. An 97). Only two small plagioclase clasts among several dozen analyzed ran as low as An 75, Ab 24, Or 0.98. Most of the glasses, both colorless and brown, plot within the plagioclase field of the pseudoternary liquidus diagram of Walker, et al although a few mafic glasses fall within the olivine or spinel fields. The fusion crust is amost pure feldspar glass with a maximum of 2 wt.% each of FeO and MgO.

Pyroxenes and olivines occur as monomineralic clasts up to 0.15 mm across and as mafic components of polymineralic clasts. Lamellae of augite and pigeonite are measureable in numerous grains. The augites range from En 31–50, Fs 15–30, Wo 30–40; the pigeonites from En 43–81, Fs 52–17, Wo 1–10. Sparse ferroaugites are present with compositions averaging En 25, Fs 33, Wo 42. Most olivines range between Fo 60–86, but two grains were found averaging Fo 37. The Wt.% MnO/FeO values measured in the pyroxenes and olivines show an affinity diagnostic of a lunar origin. The pyroxenes follow the line previously determined for the ratios in lunar pyroxes; they plot below the fields determined for achondritic pyroxenes. Within 81005 the pyroxenes and olivines fall (as expected) above and below the trend established for lunar bulk rocks.

Two prominent lithic clasts in section 81005,22 can serve as examples of distinctly lunar materials. The largest clast in the section is a 3 mm gabbroic anothosite in which large plagioclase crystals have been crushed and partially randomized optically. The mode is 87% plagioclase (An 97, Or 0.1) and 13% pyroxenes (En 44, Fs 18, Wo 38 and En 64, Fa 34, Wo 2). Anorthosites of this general character are unknown in achondrites but are common among Apollo highlands samples. The second clast is a 2 mm anothositic gabbro with a relict cumulate texture in which chains of pyroxene and olivine grains lie among plagioclases, most of which have acquired a granulitic texture although the fabric includes two larger-than-average clasts of twinned feldspar. This clast resembles some of the cumulate eucrites, but similar textures and compositions (60% plagioclase, An 96–98; 35% pyroxene En 38–45, Fs 30–44, Wo 32–11; 15% olivine, Fo 38) occur among lunar rocks and the MnO/FeO values are characteristically lunar.

Antarctic meteorite ALHA81005 was propelled to the ice sheet from the surface of the Moon.

Mayeda, T. K. and Clayton, R. N. (Enrico Fermi Inst., Univ. of Chicago, Chicago, Il 60637): 'Oxygen Isotopic Composition of ALHA81005' Lunar and Planetary Science XIV, Abstracts from the Session on Meteorites from Earth's Moon, p. 20 (1983)

The various planetary bodies and meteorite parent bodies have characteristic oxygen isotopic compositions established at the time of their accretion. The differences arise both from mass-dependent fractionation processes and from variable degrees of mixing of components of different nucleosynthetic origins. The major groups of achondritic meteorites form four different groups on the oxygen three-isotope graph: I eucrites, howardites, diogenites, mesosiderites, and pallasites; II shergottites, nakhlites, and chassignites; III aubrites; IV ureilites. All of these except the aubrites lie on mass-fractionation lines either richer or poorer in ^{16}O with respect to the terrestrial fractionation line. The rocks of the Moon are very homogeneous in oxygen isotopes and have a composition lying on the terrestrial fractionation line at a point within the range of terrestrial mantle rocks. Thus, the oxygen isotopic composition of the Moon is distinctly different from that of all meteorites except the aubrites.

Table I shows isotopic data for ALHA 81005 along with data for eucrites and a lunar highlands breccia, analyzed at the same time for comparison. ALHA 81005 is identical in isotopic composition with the Apollo 16 breccia, and is distinctly different from the eucrite samples. Of all the known sources of solar system rocks, only the Earth, the Moon and the aubrite parent body have oxygen compostions compatible with that of ALHA 81005. Chemical data eliminate the Earth and aubrite parent as candidates, leaving the Moon as the likely origin.

Meeker, G. P., Wasserburg, G. J., and Armstrong, J. T. (Lunatic Asylum, Div. of Geological and Planetary Sciences, California Inst. of Tech., Pasadena, CA 91125): 'Replacement Textures in CAI and Implications Regarding Planetary Metamorphism', *Geochim. Cosmochim. Acta* **47**, 707–721 (1983)

Textural and chemical features of five coarse-grained, calcium-aluminum-rich inclusions from the Allende meteorite indicate that some of the melilite in these inclusions was formed by a secondary metamorphic event and not by primary crystallization from a melt or by a sequential nebular condensation process. These inclusions contain embayed pyroxene surrounded by melilite. Physically separated pyroxene crystals are often in optical continuity indicating that they were once part of larger single crystals that have been partly replace by melilite. Other evidences of metamorphism include reaction textures between melilite and spinel, and metamorphic textures such as kink-band-like features, lobate sutured grain boundaries and 120° triple-points. This type of metamorphic process requires the addition of Ca which we propose came from calcite or by introduction of a fluid phase. We believe that the most likely environment for this metamorphic process is on a small planetary body, and not in the solar nebula. The results of this study are compatible with oxygen isotopic heterogeneities within CAI, and provide a mechanism for producing lower temperature alteration phases and the rim phases found in these inclusions. We conclude that planetary processes must thus be considered in the formation history of CAI, and that it is necessary to reconsider the classification system of these objects in light of the replacement process proposed here.

Melosh, H. J. (Lunar and Planetary Lab., Univ. of Arizona, Tucson, AZ 85721): 'Impact Ejection, Spallation and the Origin of Certain Meteorites' Lunar and Planetary Science XIV, Abstracts from the Session on Meteorites from Earth's Moon, pp. 21–22 (1983)

During the course of a major impact event, large quantities of target rock are ejected from the growing crater. Some of this ejecta reaches high velocity: both theory and experiments suggest that significant amounts of ejecta may even exceed the escape velocity of the Moon, Mercury or Mars. Most such high-speed ejecta is strongly shocked and is either melted or crushed into small fragments. However, at least one calculation indicates that some slightly shocked material is accelerated to high velocity.

The recent proposals that the SNC meteorites may have originated on Mars, that Eucrites may have come from Vesta, and the possible discovery of a lunar rock in Antarctica all require high-speed ejection of intact rock fragments from their parent bodies. The estimated fragment size varies – from a few tens of cm for the putative 'lunar meteorite' up to 2 km for the SNC parent bodies. To date, however, there has been little discussion of how large rock fragments might be accelerated to high velocity by an impact.

Study of velocity gauge record data from underground nuclear tests has suggested a model for stress wave propagation subsequent to an impact that promises to yield information on ejecta fragment size, velocity and degree of shock damage. Comparison of the model to data from TNT explosion cratering tests and secondary crater distributions near lunar and Martian crater has yielded satisfactory agreement.

The shock front that propagates away from an impact site shortly after a meteorite strikes attains a nearly spherical form, centered on a point located a distance d below the surface. This 'depth of penetration' d is comparable to the projectile diameter a. The rise time of the stress wave is of order $\tau \simeq a/U$, where U is the impact velocity. The stress wave is asymmetric, falling from its maximum value to near zero after a time $\tau d \simeq d/c_L$, where c_L is the target's P-wave velocity. The peak particle velocity v_P in the wave falls according to a power law:

$$v_P \simeq \frac{U}{2}\left(\frac{a}{r}\right)^{1.87}$$

where r is the distance from the stress wave center at depth d.

This stress wave is reflected at the free surface. The superposition of the direct compressive wave and the reflected tensile wave results in a low stress environment for target material in the vicinity of the surface. Although this material is protected from experiencing high shock pressures by the reflected wave, it nevertheless acquires a large particle velocity (following the 'velocity doubling' rule) which is of order

$$v_e \simeq 2v_P \frac{d}{r}$$

for large r, v_e thus falls as roughly $1/r^3$.

The vertical stress component becomes tensile after reflection. If the target material has a density ρ and dynamic tensile strength σ_t, spalls break off with velocity v_e and thickness

$$1_S \simeq \left(\frac{\sigma_t}{\rho c_L v_P}\right) r$$

beneath the spalls the sudden onset of large tensile stresses breaks the rocks into much smaller pieces

$$1_t \simeq \left(\frac{\sigma_t}{\rho c_L v_P}\right) c_L \tau.$$

These sizes must be understood as *upper limits* – any flaws, joints or inhomogenieties of smaller scale than the 1's above will produce smaller fragments.

These considerations lead to a relation between maximum fragment size and ejection velocity.

$$1_{\max} \simeq \left(\frac{4\sigma_t}{\rho c_L{}^2}\right) \frac{c_L}{v_e} a.$$

For example, if Copernicus was produced by a 5 km radius projectile and $c_L \simeq 5\ \mathrm{km\,s^{-1}}$ (basalt), $\sigma_t \simeq 100$ MPa [14], then debris ejected at $1\ \mathrm{km\,s^{-1}}$ can be no longer than ca. 100 m in diameter. This result agrees reasonably well with the data on Copernican secondaries, although it does no predict the rapid drop-off in the number of secondaries beyond $1.5\ \mathrm{km\,s^{-1}}$. The drop-off is apparently due to crushing of even the spalls when stresses exceed the Hugoniot elastic limit.

A more complex version of this model shows that debris ejected nearly vertically close to the impact site, than at increasingly lower angles at greater distances until the ejection angle reaches an asymototic limit governed by the poisson ratio ν of the target,

$$\Theta_\infty = 2\cos^{-1}\left(\frac{1-2\nu}{2(1-\nu)}\right)^{1/2}.$$

This model is in qualitative and even quantitative agreement with existing data. It indicates that, whereas small (10's of cm) fragments may be ejected to lunar or even Martian escape velocity by large impact, ejection of 100 m size fragments from Mars, if it ever occurs, must proceed by a different mechanism than ballistic flight of spalled fragments.

Morand, P. and Allegre, C. J. (Laboratoire de Geochimie et Cosmochimie (LA 196), Universités de

Paris Vi et Vii, 4 Place Jussieu, 75230 Paris Cedex 05, France): 'Nickel Isotopic Studies in Meteorites', *Earth Planet Sci. Lett.* **63**, 167–176 (1983)

We have analyzed the nickel isotopic composition of meteoritic materials by high-precision mass spectrometry. The samples analyzed include almost all meteorite types for which large isotopic anomalies have been reported for oxygen, silver, magnesium and titanium. These samples are C_1, C_3, L, LL, H and E chondrites, IVB irons, Eagle Station pallasite and inclusion, matrix and "whole rock" samples of the Allende meteorite. The result is that we have not found any anomaly for nickel isotopic compositions within our accuracy of 0.7% for $^{61}Ni/^{60}Ni$, 0.4–0.08% for $^{62}Ni/^{60}Ni$ and 1–1.5% for $^{64}Ni/^{60}Ni$.

Murty, S. V. S., Goel, P. S., Minh, D. Vu., and Shukilyukov, Yu. A. (Dept. of Chemistry, Indian Inst. of Tech., Kanpur 208016, India): 'Nitrogen and Xenon in Acid Residues of Iron Meteorites', *Geochim. Cosmochim. Acta* **47**, 1060–1068 (1983)

Total nitrogen, measured by neutron activation analysis, is highly enriched in residues from iron meteorites obtained by dissolution of the metal in dilute H_2SO_4, relative to the bulk value. On the average, the residues, representing 3% mass, contain 22% of total N. Group IA has more dissolved N than IIIA. Lithium and Ir show a distribution pattern parallel to N. Total Xe has been measured in several residues and its isotopic composition is, similar to atmospheric Xe for mass numbers 131 to 136 but not for ^{124}Xe and ^{126}Xe which are strongly depleted in the non-magnetic residues. It is suggested that iron meteorites have trapped in their micro-inclusions, some pre-solar nebular matter which is isotopically heterogeneous.

Murty, S. V. S., Shukla, P. N., and Goel, P. S. (Dept. of Chemistry, Indian Inst. of Technology, Kanpur, Kanpur 2080 16, India): 'Lithium in Stone Meteorites and Stony Irons', *Meteoritics* **18**, 123–136 (1983)

Lithium contents have been determined by neutron activation analysis in 54 meteorites distributed as: C(9), H(13), L(10), LL(3), E(2), achondrites (11), and stony irons (6). Among the undifferentiated meteorites Li contents range from 1 to 3 ppm. Li contents are higher in Ca-rich achondrites and pallasites respectively. Among achondrites Li correlates positively with Ca and Al and inversely with Mg. A minor Li-rich phase might be associated with the plagioclase component of achondrites. In several meteorites Li concentration is determined in magnetic and nonmagnetic fractions, chondrules, and light and dark components (for the gas-rich meteorites).

Niemeyer, S. (Physics Dept., Univ. of California, Berkeley, CA 94720): 'I-Xe and ^{40}Ar-^{39}Ar Analyses of Silicate from the Eagle Station Pallasite and the Anomalous Iron Meteorite Enon', *Geochim. Cosmochim. Acta* **47**, 1007–1012 (1983)

Silicate from two unusual iron-rich meteorites were analyzed by the I-Xe and ^{40}Ar-^{39}Ar techniques. Enon, an anomalous iron meteorite with chondritic silicate, shows no loss of radiogenic ^{40}Ar at low temperature, and gives a plateau age of 4.59 ± 0.03 Ga. Although the Xe data fail to define an I-Xe correlation (possibly due to a very low iodine content), the inferred Pu/U ratio is more than 2σ above the chondritic value, and the Pu abundance derived from the concentration of Pu-fission Xe is 6 times greater than the abundance inferred for Cl meteorites. These findings for Enon, coupled with data for IAB iron meteorites, suggest that presence of chondritic silicate in an iron-rich meteorite is diagnostic of an old radiometric age with little subsequent thermal disturbance. The Eagle Station pallasite, the most ^{16}O-rich meteorite known, gives a complex ^{40}Ar-^{39}Ar age pattern which suggests a recent ($\lesssim$ 0.85 Ga severe thermal disturbance. The absence of excess ^{129}Xe and the low trapped Ar and Xe contents, are consistent with this interpretation. The similarity between ^{40}Ar-^{39}Ar data for Eagle Station and for the olivine-rich meteorite Chassigny lends credence to the previous suggestion of a connection between Chassigny and pallasites, in the sense that similar processes operating at similar times on different parent bodies may have been involved in the formation of olivine in both types of meteorites.

Nishiizumi, K., Arnold, J. R., Elmore, D., Ma, X., Newman, D., and Gove, H. E. (Dept. of Chemistry,

B-017, Univ. of California at San Diego, La Jolla, CA 92093): '^{36}Cl and ^{53}Mn in Antarctic Meteorites and ^{10}Be-^{36}Cl Dating of Antarctic Ice', *Earth Planet Sci. Lett.* **62**, 407–417 (1983)

Cosmic-ray-produced ^{53}Mn ($t_{1/2}$ = 3.7 × 10^6 yr) has been measured in twenty Antarctic meteorites by neutron activation analysis. ^{36}Cl ($t_{1/2}$ = 3.0 × 10^5 yr) has been measured in fourteen of these objects by tandem accelerator mass spectrometry. Cosmic ray exposure ages and terrestrial ages of the meteorites are calculated from these results and from rare gases. ^{14}C ($t_{1/2}$ = 5740 yr) and ^{26}Al ($t_{1/2}$ = 7.2 × 10^5 yr) data. The terrestrial ages range from 3 × 10^4 to 5 × 10^5 yr. Many of the L3 Allan Hills chondrites seem to be a single fall based on these results. In addition, ^{10}Be ($t_{1/2}$ = 1.6 × 10^6 yr) and ^{36}Cl have been measured in six Antarctic ice samples. The first measurements of ^{10}Be/^{36}Cl ratios in the ice core samples demonstrate a new dating method for ice.

Ostertag, R. and Ryder, G. (Institut für Mineralogie, Corrensstrasse 24, 4400 Munster, F.R.G.): 'ALHA81005: Petrography, Shock, Moon, Mars, Giordano Bruno, and Composition', Lunar and Planetary Science XIV, Abstracts from the Session on Meteorites from Earth's Moon, pp. 23–25 (1983)

ALHA81005,8 is a glassy, olivine-rich regolith breccia, beyond any reasonable doubt of lunar origin. It is dominated by feldspathic granulitic impactites, contains some cataclastic ferroan anorthosites and minor mare basalt components, but lacks detectable KREEP. Its bulk composition (25.1% Al_2O_3; 8.9% MgO; 5.6% FeO) has a higher Mg and is poorer in Na and Ti than other lunar soils, a reflection of its large plutonic troctolitic component (olivine fragments) and the poverty of KREEP. We contend that the sample is far more likely to be ejecta from Giordano Bruno than any other lunar crater, hence ALHA81005 provides information about the Moon's NE limb. The sample was not detectably shocked during ejection from the Moon, although most of its components had already been shocked during regolith formation. Evidently escape of material from planets following impacts does occur without melting, and without the requirements for high indigenous volatiles. If Giordano Bruno *is* the source, then neither are oblique impacts necessary. The implications for meteorites of possible Martian origin are obvious.

Reynolds, J. H. (Dept. of Physics, Univ. of California, Berkeley, CA 94720): Isotopic Anomalies in Meteorites Explained?, *Nature* **302**, 213–214 (1983)

Palme, H., Spettel, B., Weckwerth, G., and Wanke, H. (Max-Planck-Institut für Chemie, 6500 Mainz, FRG): 'Antarctic Meteorite ALHA 81005, A Piece of the Ancient Lunar Highland Crust', Lunar and Planetary Science XIV, Abstracts from the Session on Meteorites from Earth's Moon, pp. 25–26 (1983)

In 1660, an Italian physicist, P. M. Terzago maintained that meteorites are of lunar origin. Since then the idea has been repeatedly taken up by scientists, until lunar samples were found to be different from all known types of meteorites. However, it now appears that the old hypothesis was justified, at least with respect to the dynamical problem of transferring material from the Moon to the Earth. The results of our chemical analysis (instrumental neutron activation techniques, Table 1) of Antarctic meteorite ALHA 81005 undoubtedly show that it is a lunar highland breccia, confirming the original suspicion by Mason.

(1) Contents of Mn and Fe are in the range of lunar highland rocks, Fe/Sc, Mg/Cr, and Sc/V ratios are identical to the ratios in highland rocks. The latter three ratios are characteristic for highland rocks with a meteoritic component. "Pristine" rocks have different ratios.

(2) The chemical composition of ALHA 81005 fits into the multi-element lunar highland mixing diagram of Wänke *et al.*

(3) The major element composition of ALHA 81005 is very similar to that of a group of lunar highland rocks, called feldspathic granulitic impactites (FGI) by Warner *et al.* The composition of these FGI-rocks (e.g. 78155) and chemically related materials with about 25% Al_2O_3 (e.g. anorthositic gabbros comes very close to the proposed composition of the average lunar highlands.

(4) Like FGI-rocks, ALHA 81005 has no KREEP-type pattern of incompatible elements. It has e.g. a flat heavy REE pattern. Incompatible elements are in general less fractionated than those in KREEP. The absolute content of incompatible elements is lower than in FGI-rocks.

(5) ALHA 81005 has, similar to FGI-rocks, a significant meteoritic compoment with an essentially chondritic pattern of siderophiles (1.5% Cl-equivalent).

(6) The abundances of 'plagioclase trace elements' Sr, Eu, Na, Ga are similar to those of the most primitive cataclastic anorthosites, early crystallisation products of the lunar magma ocean. The composition of the mafic component of ALHA 81005 (assuming it is representative for a major crustal unit) may also be relatively primitive. Its mg-number (0.73) is similar to that for Ringwood's parental lunar crust magma (0.07), which represents the composition of the magma ocean, when plagioclase saturation is reached.

Conclusions; ALHA 81005 has the average lunar highland composition, far away from the KREEP-rich (high U) areas of the front sider around the great basins. The K and Th content of ALHA 81005 is even below the estimates for the farside, deduced from the X-ray experiments. This could indicate that a significant fraction of the farside may be lower in K and other incompatible elements than previously thought. Because of the absence of KREEP, ALHA 81005 was formed from a KREEP-free soil. Since the soils at the Apollo landing sites are inevitably contaiminated with KREEP, ALHA-81005 may originate from the far side of the Moon, far away from the great basins or it may have formed before the ejection of KREEP. 3.8 to 4 by ago, or more likely both, since soil breccias on the front side do not appear to have survived the great bombardment of the great basin forming bodies.

Highland rocks on the front side have in most cases ages between 3.85 – 4 by. Only some KREEP-free highland rocks have higher ages. The FGI-rock 78155 has a crystallization age of 4.22 ± 0.04. Other granulitic impactite clasts are also older than 4 by. This may indicate an age of more than 4 by for ALHA 81005.

Highland rocks formed around 3.9–4 by have almost without exception lower than chondritic Ir/Au ratios. Older rocks or clasts in rocks have higher Ir/Au ratios. Since ALHA 81005 has a chondritic Ir/Au ratio, it may be older than 4 by. This is an independent piece of evidence pointing to a high age for ALHA 81005.

Because of the brecciated nature of ALHA 81005 the age estimates are valid for its essential ingredients such as for example granulitic and anorthositic clasts. The compaction age could be much younger.

Pieters, C. M. (Dept. of Geological Science, Brown Univ., Providence, RI 02912): 'If ALHA81005 came from the Moon, can we tell from where?', Lunar and Planetary Science XIV, Abstracts from the Session on Meteorites from Earth's Moon, pp. 27–28 (1983)

Careful documentation of lunar sample locations has been essential for understanding the geologic context of such valuable materials. Samples have been returned from nine locations on the nearside, and each mission has brought new unsuspected surprises. Lunar scientists now seem to have acquired a sample from a 10th location, but without the desired supporting documentation.

Identification of possible source regions on the moon for meteorite ALHA81005 is difficult, but not impossible if enough clues can be obtained. Presented here are preliminary results of laboratory and telescopic spectral reflectance measurements that are used to identify compositional information to link the mineral assemblages observed in the meteorite with those for unsampled areas on the nearside lunar surface. When combined with other data and the photogeologic evidence, this information could narrow the number of possible source regions considerably. If ALHA81005 is representative of a regional rock type, these first results suggest the source region for the meteorite is not a common surface unit for the lunar nearside and as such has not previously been extensively sampled by U.S. and Soviet missions. However, the general spectral character of ALHA81005 indicates a bulk mineralogy comparable to some specific lunar samples.

Results for Telescopic Reflectance measurements of the lunar nearside. Near-infrared (.7–2.5 μm) spectral reflectance measurements have been obtained for about 150 small lunar areas (3–20 km in diameter) using earthbased telescopes. Compositional implications of data for highland craters are presented in Pieters and are only summarized here. Most highland spectra indicate regional rock types with a mineral assemblage of feldspathic material containing orthopyroxene as the dominent mafic component. A few small fresh craters reveal rock types with a greater abundance of more calcium-rich pyroxenes as well. The large, usually older, craters with central peaks have apparently exposed a somewhat different suite of rock types with both mafic components (olivine and calcium-rich clinopyroxenes) and more complete anorthositic rock types being observed.

Laboratory reflectance measurements of ALHA81005. A potted butt sample ALHA81005,2 was made available for laboratory spectral reflectance measurements prior to preparation of additional thin sections from the sample. Seventeen measurements were obtained using the Reflectance Experiment Laboratory (RELAB) over a period of two days: two visible spectra (0.4 to 0.9 μm) for 13 near-infrared (0.7–1.8 μm), and 2 continued near-infrared (1.7–2.7 μm). Data for 12/21/82 were obtained for a smooth flat surface with $i=0°$, $e=30°$. The sample was roughened slightly with a coarse grit for the measurements made on 12/22/82. A monochromatic incident beam covered a sample area of about 10 mm in length; the detector viewed a sample area of about 2 mm in diameter within this beam, the precise location of which was undetermined. The near-infrared data were averaged to obtain a spectrum of the bulk properties of the sample. As is commonly observed for rock or slab spectra the near-infrared continuum was generally flat or negatively sloped. In order to allow direct comparison of absorption features with lunar telescopic data the spectra were divided by an estimated contiuum and the residual absorptions examined.

An average for the 13 near-infrared measurements obtained on both days is shown. This spectrum would be comparable to a whole rock spectrum and is the current best estimate of the overall spectral character for this sample of ALHA81005. Since the sample was moved slightly between individual measurements, the location of each measurement and the resulting spectra varied.

Data Interpretation for ALHA81005. Specific mineral components can be identified in the spectra of this meteorite. The band minimum between .9 and 1.0 μm in all the average spectra as well as a second absorption observed near 2 μm implies a pyroxene component. The broad multiple band with a center near 1.05 μm in individual spectrum 2d is characteristic of olivine. The spectrum average for the second day contains these olivine measurements; its spectral character (broad band widening towards longer wavelengths) is typical of olivine and pyroxene mixtures. The superimposed feature near 1.3 μm seen in spectrum 2a is commonly interpreted as Fe-bearing feldspar, although a feature this strong usually requires a fairly Fe-rich (> .1%) plagioclase. Further laboratory measurements are required to determine relative contributions to the 1.3 μm feature from Fe-bearing feldspar and from olivine in the whole rock spectrum average of Figure 1.

Discussion. Comparisons of the spectral characterisitics of ALHA81005 were made with laboratory measurements of lunar highland samples of Adams, and telescope measurements of highland areas of Pieters. Some returned lunar anorthositic troctolites and gabbros exhibit the same characteristics as ALHA81005: a broad absorption band centered between 0.95 and 1.0 μm with a strong 1.3 μm feature or inflection. The average of ALHA81005 data however, is unlike any specific lunar area measured telescopically although it does resemble a minor group of nearside craters that exhibit more majic mineral assemblages than most of the highlands. (The band center for most observed highland areas is at a much shorter wavelength, implying low-Ca orthopyroxenes as the major mafic component.) Of all the nearside lunar large craters with central peaks measured telescopically, only Tycho and Aristarchus would merit further study as possible source regions; both exhibit an absorption between 0.96 and 1.0 μm and a strong 1.3 μm feature or inflection.

Ryder, G. and Ostertag, R. (Inst. für Mineralogie, Corresnsstrasse 24, 4400 Münster, FRG): 'ALHA-81005: Petrographic Components of the Target', Lunar and Planetary Science XIV, Abstracts from the Session on Meteorites from Earth's Moon, pp. 29–30 (1983)

Introduction: Our petrographic and microprobe study of ALHA81005 had the intention of determining the provenance of the component material e.g. plutonic or extrusive, and to compare them with other, known lunar rock types. Unfortunately we had less than one month to carry out the work, thus it is incomplete and some interesting observations and analysis could not be followed up and checked. We concentrated on single mineral analysis for mafic mineral fragments (major and minor elements), and in lithic clasts (granulites, anorthosites, and others, but not inlcuding crystalline impact melts), and on analysis of glasses – beads, blebs, and shards, nearly all clear and colorless, but also some brown matrix glass. Routine, 10-element analysis were the rule, but for Ca and Ni in olivines, and N, K, P, and Ti in some glasses, more precise analysis were made using manually-determined peaks and backgrounds and 100-second counts. Some of the latter analysis were performed at the Naturhistorisches Museum in Vienna.

Mafic mineral grains were studied optically and with the microprobe. Of those analyzed (about 50 larger than 100 μ, about 60% were olivines.

Pyroxene fragments: Under the microscope pyroxenes are a diverse group, ranging from colorless to brown; from clear to inclusion-rich; and from unexsolved to finely-exsolved (less than $1\,\mu$ to $5\,\mu$) to less common, coarsely-exsolved varieties. Major element analyses show a corresponding diversity. Attempts were made to resolve lamellae, but inadequate time produced inadequate results. Almost invariably the browner pyroxenes and nearly all those which contain inclusions (Ti-oxide, sulfides) are Fe-rich. Some are more Fe-rich than known lunar ferroan anorthosites, and some are too Ti, Cr, and/or Al-rich to be from such samples. Several have compositions similar to pyroxenes from very-low Ti and low Ti mare basalts – these are Ca rich and either unexsolved or finely exsolved. The pigeonite at $En_{68}Wo_8$ is unexsolved, and has minor elements consistent with a low-Ti mare basalt source. Other pyroxenes are similar to those in ferroan anorthosites, with low Ti, Cr and Al abundances and either no or coarse ($> 10\,\mu$) exsolution. Mg-rich pyroxenes (Mg'~ 80) are colorless, and either unexsolved or coarsely exsolved, and similar to lunar front-side plutonic norites. They are much coarser than pyroxenes in the granulites in the sample. Several grains, both Mg and Fe-rich, are dominantly high-Ca pyroxenes; all show some exsolution. Pyroxenes appear to come from three major sources: Mg-rich plutonic norites, ferroan anorthosites and extrusive or shallow-intrusive Fe-rich rocks, probably mare basalts.

Olivine fragments: Olivines are generally inclusion-free, and colorless to pale green. They are dominantly Mg-rich (Mg' > 77), and although they cluster strongly around the compositions of olivines in the granulites, many of them are coarser ($> 200\,\mu$) than olivines in the granulites (rarely $100\,\mu$), suggesting a different source. A few are iron-rich. Routine analysis showed no olivines with CaO above our detectability limit of ~ 0.15%, and more precise analysis (detectably better than 0.01%) for 9 grains confirms the very low CaO far below the 0.2 to 0.5% for olivines in mare basalts and highland impact melts. Most are similar to known plutonic rock samples. Ni in the 9 olivines ranged from 100 (± 30) ppm in the Fo_{94} grain to less than the usual detectability limit of ~ 50 ppm. These Ni abundances are typical of lunar pristine rocks, and are lower than phenocryst olivines in low-Ti mare basalts.

Lithic fragments. We analyzed mafic minerals and plagioclases in clasts which were dominantly plagioclase (cataclastic anorthosites), in feldspathic granulite impactites similar to front-side granulites, and in 3 small 'cumulate'-looking samples, as well as some other minor types (Figures 3 and 1 of accompanying abstract). The anorthosites are *all* ferroan, and have pyroxenes with low minor element contents; a few contain iron-rich olivine. In general the compositions are clearly distinct from the granulites, but some granulites are also ferroan. The granulites are all olivine-rich, and are almost exclusively granulite rather than poikiloblastic. One of the 'cumulates' is magnesium (Mg'84), similar to granulites except that it is coarser-grained (px $> 200\,\mu$, rather than a few tens of microns), and lacks olivine. The other two 'cumulates' are ferroan; both have pyroxenes and plagioclase $500\,\mu$ across, and one is poikilitic with exsolved pyroxene. All plagioclases are calcic (Ab < 5). One lithic fragment consists of angular, coarse, very calcic plagioclase fragments embedded in a mafic glass (M in Table) whose dominant component appears to be amafic troctolite. Several small clasts contain the assemblage $Fo_{80} - En_{80} - An_{97}$, unknown among lunar frontside plutonic rocks. Although this assemblage is similar to granulites, their grain size is coarser, and they may represent a plutonic igneous rock suite. One fragment consisting mainly of pyroxene may be a mare basalt. The pyroxene, mainly one grain is about $500\,\mu$. across, and is not, under the microscope, visibly exsolved. Within the clast are two blebs of silica (~ $50\,\mu$.) and minor plagioclase and troilite. The pyroxene is iron-rich and its analyses form two clusters, one high-Ca and one low-Ca, but these are not separate grains. Instead they represent either zoning or a tendency toward exsolution. Ti, Cr, and Al are inconclusive as to provenance, but are *compatible* with a slowly-cooled, very low-Ti mare basalt.

Glasses: Ou glass analyses were concentrated on clear, near-colorless impact glass, the fusion crust, some brown matrix glass, and the glassy matrix of a plagioclase-rich breccia. A range of analyses is shown in the Table, and all glass averages are plotted on Figures 4 and 5. We believe that the fusion crust provides the best estimate of the bulk rock composition, and analyzed 6 points in the vesicular, clear-glass portion at the edge, far removed from interferences from partly digested clasts. This analysis is close to being an average of all the other clear glasses, except for the extreme compositions. One of the beads is nearly identical in composition to the fusion crust except for even lower Na (B3). Three analyses of brown matrix glass are more dispersed. Phosphorous is extremely low, consistent with a lack of KREEP. Some of the more extreme glasses show some evidence of a mare component in their elevated Ti/K and Ti/P ratios: among known lunar rock types mare basalts have Ti/K of 30–50, all others less than 6; mare basalts have Ti/P 60, all others less than 20, mainly less than 10. The high Ti-glass may have Ti contributed dominantly by a mare component, and certainly not from a KREEP component, the other known major source of Ti in lunar samples.

Components of ALHA81005: The fusion crust and main cluster of glass compositions are less aluminous than A 16 soils and have a higher Mg/Fe ratio, and lower TiO_2 and Na_2O (both $< 0.3\%$) than any other lunar soils, consistent with the dominance of troctolitic and granulitic components and the absence of KREEP. The 'troctolitic' component is not well defined, except that, according to glass norms and the mafic mineral fragments in the rock, it is plutonic, magnesium, low in Ni, has a high al/px ratio, and, if it contains plagioclase, the plagioclase is very calcic. It could be similar to lunar front-side, Mg-suite troctolitic and/or similar to the olivine-rich component in L 20 soils. Several lines of evidence suggest the presence of a small mare basalt component.

Rubin, A. E. (Dept. of Mineral Sciences, National Museum of Natural History, Smithsonian Insitution, Washington, DC 20560): 'The Adhi Kot Breccia and Implications for the Origin of Chondrules and Silica-Rich Clasts in Enstatite Chondrites', *Earth Planet Sci. Lett.* **64**, 201–212 (1983)

The Adhi Kot EH4 enstatite chondrite breccia consists of silica-rich clasts (12 ± 5 vol.%), chondrule-rich clasts (55 ± 10 vol.%) and matrix (35 ± 10 vol.%) The silica-rich clasts are a new kind of enstatite chondritic material, which contains more cristobalite (18–20 wt.%) than enstatite (12–14 wt.%), as well as abundant niningerite and troilite. The bulk atomic Mg/Si ratios of the clasts (0.22–0.40) are much lower than the average for enstatite chondrites (0.79. Kamacite and martensite (with 8–11 wt.% Ni and a martensitic structure) occur in all three breccia components. The clasts have kamacite-rich rims, and kamacite-rich aggregates occur in the matrix.

An undirectional change in the ambient pS_2/pO_2 ratio in the region of the solar nebula where Adhi Kot agglomerated can explain many of the breccia's petrologic features. If this region initially had a very high pS_2/pO_2 ratio in a gas of non-cosmic composition, surfurization of enstatite and metallic Fe (e.g., $MgSiO_3 + 2Fe + C + 3H_2S = MgS + SiO_2 + 2FeS + H_2O + CH_4$) may have occurred, producing abundant niningerite, free silica and troilite at the expense of enstatite and metallic Fe. The Ni content of the residual metal would have increased, perhaps to $\sim$ 8–10 wt.%. The silica-rich clasts agglomerated under these conditions; a significant fraction of the originally produced niningerite was lost (perhaps by aerodynamic size-sorting processes), lowering the clast's bulk Mg/Si ratios.

The pS_2/pO_2 ratio then decreased (perhaps because of infusion of additional H_2O) and sulfurization of metallic Fe and enstatite ceased. The chondrule-rich clasts agglomerated under these conditions, acquiring little free silica and niningerite. An episode of chondrule formation occurred at this time (by melting millimeter-sized agglomerates of this relatively silica-poor enstatite chondrite material and concomitant fractionation of an immiscible liquid of metallic Fe, Ni and sulfide). The chondrule-rich clasts aggomerated many such chondrules. Subsequently, the matrix agglomerated, acquiring the few remaining chondrules. Kamacite-rich aggregates formed, after the cessation of metal sulfurization, and agglomerated with the matrix. The kamacite-rich clast rims were acquired at this time.

The components of Adhi Kot accreted to the EH chondrite parent body, where the breccia was assembled, buried beneath additional accreting material, and metamorphosed at temperatures of $\gtrsim 700\,^\circ$C. Impact-excavation of the breccia and deposition onto the surface caused the formation of martensite from taenite inside the clasts and the matrix. At the surface, impact-melting produced an albite glass spherule, which was incorporated into the matrix. However, the absence of solar-wind-implanted rare gases in bulk Adhi Kot indicates that the breccia spent little time in a regolith.

Rubin, A. E. (Dept. of Mineral Sciences, National Museum of Natural History, Smithsonian Institution, Washington, DC 20560): 'The Atlanta Enstatite Chondrite Breccia', *Meteoritics* **18**, 113–121 (1983)

Atlanta is the fifth known brecciated enstatite chondrite. It contains a centimeter-sized troilite-rich clast, similar to those that occur in Blithfield. All of these clasts probably formed in the solar nebular under high pS_2/pO_2 conditions in a gas of non-cosmic composition. The absence of ordinary or carbonaceous chondrite clasts in any of the enstatite chondrite breccias and absence of enstatite chondrite clasts or materials formed at high pS_2/pO_2 ratios in ordinary and carbonaceous chondrite breccias support the model that enstatite chondrites were formed at a location distant from those of the other chondritic groups.

Sears, D. W. G. and Ross, M. (Dept. of Chemistry, Univ. of Arkansas, Fayetteville, AR 72701): Classification of the Allan Hills A77307 Meteorite', *Meteoritics* **18**, 1–7 (1983)

The Allan Hills A77307 meteorite has variously been described as a CO, CV, and a unique CO-CM related chondrite. We have found that its thermoluminescence properties are very different from the established members of the CO chondrite class; it has a TL peak at 170 and a suggestion of a peak at 250 °C, while CO chondrites have peaks at 91 ± 7 and 203 ± 11 °C. Either the meteorite has suffered some form of alteration or it is not a normal CO chondrite. The latter is consistent with petrologic and compositional data which we interpret to indicate that although Allan Hills A77307 is related to CO chondrites it is not a normal member of that group.

Shimamura, T. and Lugmair, G. W. (Chemistry Dept., B-017, Univ. of California at San Diego, La Jolla, CA 92093): 'Ni Isotopic Compositions in Allende and Other Meteorites', *Earth Planet. Sci. Lett.* **63**, 177–188 (1983)

A new technique for high-precision isotopic analyses of Ni was developed and applied to terrestrial samples, Allende inclusions and materials from other meteorites. Most of the Allende inclusions analysed here were previously reported to contain isotopically anomalous Ti. In contrast, the Ni isotopic abundances are indistinguishable from normal within presently obtainable precision with only one possible exception. The latter inclusion was shown by others to contain a significantly fractionated magnesium isotopic pattern of 9%/amu. A normal Ni isotopic pattern has also been observed for the chromite/carbon fraction of an Allende acid residue which is known to contain heavy noble gases of highly anomalous isotopic composition. All other meteoritic samples analysed (Khohar matrix and chondrules, Murray matrix, a Tieschitz chondrule and an Orguiel magnetic fraction) also show normal isotopic compositions of Ni; no evidence for effects from now extinct ^{60}Fe could be detected. In spite of ubiquitous isotopic anomalies in Ti from normal Allende inclusions, there is no signature of isotopic variations in Ni from the same samples. Possible constraints for the nucleosynthesis of iron peak elements and for astrophysical and cosmochemical conditions during formation of the solar system are discussed.

Simon, S. B. and Papike, J. J. (Inst. for the Study of Mineral Deposits, South Dakota School of Mines and Tech., Rapid City, SD 57701): 'Petrology of Igneous Lithic Clasts from Polymict Eucrites ALHA76005 and ALHA77302', *Meteoritics* **18**, 35–49 (1983)

A total of seven lithic clasts from the polymict eucrites ALHA76005 and ALHA77032 have been studied pétrographically and analyzed with the electron microprobe. All clasts are composed predominantly of pyroxene and plagioclase, ± ilmenite, troilite, Fe-Ni metal, mesostasis, and silica. Pyroxene compositions in unequilibrated clasts and clast bulk compositions, calculated by model recombination, indicate that the clasts originally crystallized under similar conditions and that they may be genetically related to each other by fractionation of pigeonite and plagioclase.

Simon, S. B. and Papike, J. J., and Shearer, C. K. (Inst. for the Study of Mineral Deposits, South Dakota School of Mines and Technology, Rapid City, SD 57701): Petrology and Mineral Chemistry of ALHA81005, Lunar and Planetary Science XIV, Abstracts from the Session on Meteorites from Earth's Moon, pp. 31–32 (1983)

This unique meteorite, which was originally classified as an anorthositic breccia is better described as a regolith breccia with abundant feldspathic lithic clasts. The breccia has been strongly shocked, which has resulted in the melting of the matrix, destroying most of the debris commonly found in a regolith breccia, and erasing the primary textures of most of the lithic clasts.

We have used our lunar classification system in the determination of the modal petrology of this sample. Norites, troctolites, and gabbros are the most abundant lithic types. Some are shocked and recrystallized whereas others are not. Lithic clasts present in lesser amounts are anorthositic fragments, feldspathic fragmental breccias, RNB/POIK's, and several small fragments that have possible basaltic textures. The largest clast that appears to have retained its original igneous texture is a 0.5 mm spinel troctolite fragment which contains calcic (An_{97}) plagioclase laths, olivine (Fo_{77-80}), and spinel (with 10 wt.% Feo and 5 wt.% Cr_2O_3). Plagioclase dominates the mineral fragment population in the matrix.

In Figure 1, the compositions of plagioclase grains found in the matrix are compared to those from lithic clasts. The ranges and relative abundances are nearly identical, incicating that the matrix grains were derived from lithologies very similar to those that are found in the breccia. This is not the case for polymict eucrites, for which it has been shown that the matrix mineral population could not be completely derived from the lithic clasts. Pyroxenes and olivines exhibit wider compositional ranges than feldspar. Most of the pyroxenes are more Mg-rich than eucritic pyroxens, in agreement with the preliminary analysis. Pyroxene compositions further support a lunar highland origin for this breccia. Figure 4 is a plot of Ti vs. Al in pyroxenes, and the distributions approximates that for highland pyroxene while exhibiting large differences from mare and meteoritic pyroxene. The ALHA81005 pyroxenes clearly define a trend which is non-eucritic and falls within the range for lunar rocks.

In conclusion, the petrographic, modal and mineral chemical data strongly indicate that this meteorite is a breccia from the lunar highlands.

Sipiera, S. P., Olsen, E. J., Eatough, D. L., and Dod, B. D. (Field Museum of Natural History, Chicago, IL 60605): 'Summary of Several Recent Chondrite finds from the Texas Panhandle' *Meteoritics* **18**, 63–75 (1983)

Eleven recent chondrite finds from the Texas Panhandle have been examined and classified according to mineralogical and petrological criteria: five H's, five L's, and one LL chondrite. Five are distinct from nearby finds, while three remain ambiguous and three are related to previously reported chondrites. In addition, data are provided to classify the Muleshoe, Silverton, and Vigo Park chondrites, all of which were previously undescribed in the literature.

Sutton, S. R. and Crozaz, G. (Earth and Planetary Sciences Dept., Washington, Univ., St. Louis, MO 63130): 'Thermoluminescence and Tracks in ALHA-81005: Constraints on the History of This Unusual Meteorite', Lunar and Planetary Science XIV, Abstracts from the Session on Meteorites from Earth's Moon, pp. 33–34 (1983)

Thermoluminescence measurements and a search for nuclear particle tracks were made in 3 fragments of ALHA-81005.

Thermoluminescence: Equivalent does (E.D.) curves determined for 1 mg aliquots of the three fragments are shown in figure 1a along with those of two Antarctic chondrites, ALHA-77003 and ALHA-77272. The ALHA-81005 chips plot well below the chondrites (factor of 10 lower at high flow curve temperatures and up to a factor of 100 lower at low glow curve temperatures). The small, high-temperature E.D. is best explained as the object's "pre-earth" equilibrium dose which is lower than that of chondrites because ALHA-81005 exhibits substantial anomalous fading. (In one week storage at room temperature ALHA-81005 artificial TL decays by 25% compared to $\leqslant$ 5% for chondrites.) Comparing ALHA-77003 (short terrestrial age of 0.04 Ma) with ALHA-77272 (long terrestrial age of 0.54 Ma) demonstrates that, at Antarctic storage temperatures, less than a factor of two thermal decay occurs for glow curve temperatures $\geqslant$ 275 °C. ALHA-81005's TL is actually *more* thermally stable than these chondrites (Artificial TL decayed by a factor of 6 for chondrites stored for 40 minutes at 180 °C while ALHA-81005 TL decayed by only a factor of 3.) Consequently, ALHA-81005's E.D. at 275 °C would be expected to be about the same as its high-temperature E.D. of ~ 10^4 rads. The fact that its E.D. is a factor of about 5 lower indicates the object has been heated above the Antarctic storage temperature (about 0 °C). This interpretation is supported to some extent by the observation that a 15 krad artifical glow curve measured after pre-heating to 290 °C closely reproduces the natural glow curve in both shape and intensity.

The object could have been heated during atmospheric entry, in a near-sun orbit or during a parent-body impact event. Atmospheric entry heating would seem to be ruled out because the high temperature required to explain the TL data (~ 300 °C) occurs only within several mm of the fusion crust (2) and our three chips are random samples of a ~ 1.5 cm diameter fragment with fusion crust removed. A near-sun orbit is possible and a few meteorites show evidence of solar heating. However, such orbits are rare and probably occur for only a few percent of meteorites. Impact heating is the more likely interpretation. In this case, the low E.D. value at 275 °C constrains the object's space exposure to be less than a few thousand years. Such a brief earth transit time lends support to the notion of a lunar origin for ALHA-81005.

Tracks: Feldspar grains from all fragments were mounted, polished and etched in boiling 6.25N NaOH. In this solution, feldspar etching times vary from 30–60 min (revelation of solar flare tracks with densities in excess of 10^8 t cm^{-2} in lunar samples) to 6 h (full revelation of galactic cosmic ray tracks in the Estherville mesosiderite). Most feldspar grains from ALHA-81005 were so highly shocked that they fractured rapidly when etched. However, we succeeded in finding grains which resisted a 6 hr etch. Despite the fact that these samples contain large amounts of solar gases (Bogard, private communication), no nuclear particle track was observed. Whether depth or temperature history is responsible for the lack of solar flare tracks is unclear. However, it should be noted that if the thermoluminescence was mainly acquired on the parent body (our preferred interpretation), the temperature reached by the material during the impact event (~ 300 °C) would be insufficient to erase the tracks. The absence of galactic tracks is compatible with a short transit time between parent body and the earth but could also be explained, because of the rapid decrease of the cosmic ray track production rate with depth, by the shielding of ALHA-81005 in space, or on the parent body, by only ~ 10 cm s of material.

Swart, P. K., Grady, M. M. and Pillinger, C. T. (Planetary Sciences Unit, Dept. of Earth Sciences, Univ. of Cambridge, Cambridge CB2 3EQ, UK): 'A Method for the Identification and Elimination of Contamination during Carbon Isotopic Analyses of Extraterrestrial Samples', *Meteoritics* **18**, 137–154 (1983)

The study of carbon abundance and isotopic composition in extraterrestrial samples is fraught with problems related to contamination in the terrestrial environment and during sample handling. A stepped combustion method is described which demonstrates that progress can be made towards resolving the indigenous species from contamination which for the most part burns at low temperature (< 425 ± 25 °C). The proposed method is not applicable to samples which have indigenous phases burning at low temperatures e.g. the C1 and C2 carbonaceous chondrites. A number of examples where its application is possible are given.

Even meteorites collected immediately after their fall, such as Allende, contain a proportion of extraneous carbon which has deleterious effects on any bulk estimate of isotopic composition. 'Falls' which have spent a considerable time in museum collections and 'finds' (other than Antarctic samples) can be considered as grossly contaminated. Bulk isotope and carbon abundance measurements in the literature for most samples having less than 1 wt% C are thus of questionable value. Antarctic samples have much less contamination of dn organic nature but all seem to contain a weathering component which can be easily recognised and hence disregarded in estimates of bulk composition. Stepped combustion, applied to an Apollo 11 lunar soil which has not been specially stored and which now contains, due to contamination, nearly twice as much carbon as when originally collected, can still afford data closely resembling those obtained from the sample when it was first returned to Earth.

Swart, P. K., Grady, M. M., Pillinger, C. T., Lewis, R. S. and Anders, E.: 'Interstellar Carbon in Meteorites', *Science* **220**, 406–409 (1983)

The Muchison and Allende chondrites contain up to 5 parts per million carbon that is enriched in Carbon-13 by up to + 1100 per mil (the ratio of carbon-12 to carbon-13 is approximately 42, compared to 88 to 93 for terrestrial carbon). This 'heavy' carbon is associated with neon-22 and with anomalous krypton and xenon showing the signature of the *s*-process (neutron capture on a slow time scale). It apparently represents interstellar grains ejected from late-type stars. A second anomalous xenon component ('CCFXe') is associated with a distinctive, light carbon (depleted in carbon-13 by 38 per mil), which, however, falls within the terrestrial range and hence may be of either local or exotic region.

Tera, F. (Dept. of Terrestrial Magnetism, Carnegie Institution of Washington, 5241 Broad Branch Road, N.W., Washington DC 20015): 'U-Th-Pb in Chondrites – Evidence of Elemental Mobilities and the Singularity of Primordial Pb', *Earth Planet. Sci. Lett.* **63**, 147–166 (1983)

A unified graphical approach that emphasizes the strict correllativity in the U-Th-Pb systematics and projects subtle diagnostic deviations from it has been adopted for the evaluation of the existing data base. It has been revealed that:

(1) Excess radiogenic Pb in chondrites is largely an artifact stemming from Pb contamination of some samples and apparent recent U loss from other samples (problems with U analysis?).

(2) Taken at face value, the data indicate that recent U-Th mobility on the chondrule-scale is pervasive in Allende. In contrast, apparent recent U-Th mobility in Barwell is generally consistent with gain of terrestrial Pb.

(3) Allende carries the isotopic imprints of recent *multiple* disturbances in which elemental mobilities were effected but not isotopic homogenization of Pb.

(4) For Allende, the Pb isotope pattern of the matrix samples suggests terrestrial contamination. If this is the case, the systematics indicates for the matrix recent U gain as well. The U-rich chondrules and inclusions, whose discordance is often consistent with U loss, are the probable source. In contrast to the contaminated matrix, the uncontaminated matrix should then be discordant by Pb loss (i.e., U gain).

(5) Canyon Diablo primitive Pb appears to represent the primordial composition from which chondritic Pb evolved. Allegations to the contrary will appear ill-founded.

(6) Identification of variable ancient initial leads by the Pb-Pb method in correlation with as much as 100 m.y. difference in the ages of formations, is not feasible, apparently because of the low U/Pb in the nebula ($\mu \simeq 0.25$).

Treiman, A. H. and Drake, M. J. (Lunar and Planetary Lab., Univ. of Arizona, Tucson, AZ 85721): 'Meteorite from the Moon: Petrology of Terrae Clasts and one Mare Clast in ALHA 81005,9', Lunar and Planetary Science XIV, Abstracts from the Session on Meteorites from Earth's Moon, pp. 35–36 (1983)

Introduction. ALHA 81005 was first noted to be an unusual meteorite during preliminary examination by R. Score (1). Subsequently Mason examined a polished thin section. He noted that the microbreccia contains clasts which are more feldspathic than those in most eucrites and that they resemble anorthositic clasts from lunar terrae rocks. Petrographic and electron microprobe analysis confirm that ALHA 81005,9 originated in the lunar terrae and is the first recognized lunar sample transmitted to Earth by natural processes. A clast of VLT mare basalt in the breccia may restrict the possible source of the meteorite on the lunar surface.

General Description. ALHA 81005,9 is a microbreccia of lithic and vitric clasts set in a fine-grained matrix with pervasive glass. Lithic clasts include anorthosite, troctolite, spinel troctolite, and norite fragments. A majority of clasts retains igneous textures, but few clasts have not been modified thermally and/or mechanically. The remaining lithic fragments have textures varying from cataclastic to granulitic to variolitic with relict plagioclase. The presence of unmodified vitric clasts and matrix glass suggests that most thermal recrystallization preceded formation of the breccia. Deformational features which post dat consolidation of the breccia are not observed.

Confirmation of Lunar Terrae Origin. Pyroxene compositions, particularly molar Mn and Cr contents versus molar Fe/(Fe + Mg) ratios provide sensitive petrochemical criteria for distinguishing between rocks from different planetary bodies. The Mn content of pyroxenes from ALHA 81005,9 (except clast G) all fall within the lunar terrae field (Fig. 1) and indicate that the meteorite is not related to the basaltic achondrites. Similarly the Cr contents of the pyroxenes (except clast G) are inconsistent with a terrestrial or eucritic origin, but are consistent with a lunar terrae source. Thus, pyroxene chemistry confirms the petrographic observation that ALHA 81005,9 is from the lunar terrae.

Terrae Clast Petrology. Compositions of plagioclase and mafic minerals from the anorthositic clasts plot in the field of pristine ferroan anorthosite. In other igneous clasts (except clasts I, U and G) plagioclase is An 96–98, and the molar Mg/(Mg + Fe) ratios of the mafic phases range from 0.52 to 0.84. These compositions extend from the pristine anorthosite field to the pristine Mg-suite field, and imply that the basaltic rocks are impact melts of a source containing anorthositic and Mg-suite protoliths. Anorthositic clasts could represent one protolith; a suitable Mg-suite protolith is not present in ALHA 81005,9 and its composition must be inferred. Plagioclase in the Mg-suite protolith must have been An 96–98 because igneous clasts all contain plagioclase of that composition.

The presence of abundant magnesian pyroxene in the basalts implies that the Mg-suite protolith was noritic, with low-Ca pyroxenes of Mg/(Mg + Fe) > 0.84. Known pristine norites do not contain such magnesian pyroxene and calcic plagioclase, and the Mg-suite protolith may represent an undiscovered lunar rock type.

Two unusual basaltic clasts, I and U, contain plagioclase more sodic than An 96. Clast I is a spinel troctolite with 60% plagioclase laths (An 94), interstitial olivine (Fo 80), and a single crystal of brown spinel ($Mg_{0.64}Fe_{0.37}Al_{1.69}Cr_{0.28}Ti_{0.01}O_4$). Clast U is a norite with plagioclase laths (An 91–An 96) and interstitial low- and high-Ca pyroxene and olivine. Minor phases include troilite, Fe-metal, ilmenite, rutile, and Zr-armalcolite. By mineralogy, clast U is a Mg-norite, but I and U are probably both impact melts.

Clast G: Mare VLT Basalt. Clast G is a unique, small fragment of Fe-rich basalt, consisting of 75% plagioclase laths with interstital high-and low-Ca pyroxene and a silica polymorph (cristobalite?). Mesostasis areas contain pyroxene, ulvospinel, pyroxferroite, silica, troilite and glass (up to 1.9 wt % K_2O). Plagioclase composition is relatively constant at An 95, but pyroxene compositions vary widely. The extreme Fe-enrichment of the clast G pyroxene is consistent with a lunar mare source and rules out a terrae origin. This conclusion is reinforced by the Cr content and Ti/(Ti + Cr) ratios of the pyroxenes. Note that Ti/(Ti + Cr) ratios of the pyroxenes at a given Fe/(Fe + Mg) ratio are very low and are similar to very low titanium (VLT) basalts of Apollo 17 and Luna 24.

Origin of ALHA 81005. There is little doubt that ALHA 81005 originated in the lunar terrae. However, the VLT basalt lithology (clast G) is consistent with a source for this meteorite in a terra region adjacent (within 100 km?) to areas of VLT mare basalt. Luna 24 returned VLT basalt from Mare Crisium, and spectral reflectance study indicates that VLT basalts (some unsampled) also occur in Mare Somniorum, Mare Frigoris, Sinus Roris, northern Mare Imbrium, and western Oceanus Procellarum. The source of ALHA 81005 is probably a young crater in the terrae adjacent to one of these regions if the meteorite is from the Earth-facing hemisphere of the Moon.

Tuniz, C., Pal, D. K., Moniot, R. K., Savin, W., Kruse, T., Herzog, G. F., and Evans, J. C. (Istituto Fisica, Univ. Studi, Trieste, Italy): 'Recent Cosmic Ray Exposure History of ALHA 81005', Lunar and Planetary Science XIV, Abstracts from the Session on Meteorites from Earth's Moon, pp. 37–38 (1983)

Score and Mason note the similarities between certain lunar anorthositic breccias and the Antarctic achondrite, ALHA 81005. The recent history of this interesting object can be illuminated by a consideration of its cosmogenic radionuclide contents. We have measured the ^{10}Be content of a 25 mg sample to be 4.1 ± 0.5 dpm/kg by using the tandem Van de Graaff of the Rutgers Nuclear Physics Laboratory as a high-energy mass spectrometer. Evans and Reeves report an ^{26}Al content of 46 ± 3 dpm/kg for the meteorite.

Table 1 shows the steady-state or saturation values of ^{26}Al and ^{10}Be estimated for four different sets of exposure conditions. It also gives the exposure and terrestrial ages calculated for various one-stage irradiation models, i.e., a single exposure under each of the four sets of conditions specified in Table 1 followed by terrestrial decay. The results are consistent with either a lunar or 'asteroidal' origin with certain restrictions.

(1) ALHA 81005 evidently spent less than 1.1 Myr and probably less than 0.4 Myr in space as a small body. As a rule, the exposure ages of achondrites are considerably older; fewer than 5% of the chondrites have ages under 1 Myr although the fraction is higher among carbonaceous stones.

(2) ALHA 81005 could have accumulated its ^{26}Al and ^{10}Be entirely on the Moon, somewhere within the topmost 100 cm. If so, its time in space was less than 0.1 Myr and its time in the Antarctic less than 0.6 Myr. Both these limits conform to expectations based on other studies. First, Monte Carlo calculations show that roughly 70% of the objects ejected from the Moon and captured by the earth would have ages less than 2 Myr. Second, the average terrestrial age of Antarctic stones appears to be about 2–3 × 10^5 y, consistent with our result of $t_{terr} < 0.6$ Myr.

(3) More complex, n-stage irradiation histories beginning on the Moon could also explain the ^{10}Be and ^{26}Al results subject to restriction (1) above. Measurements of ^{53}Mn and ^{36}Cl may be helful in defining more closely the irradiation and decay history of ALHA 81005.

Verkouteren, R. M. and Lipschutz, M. E. (Dept. of Chemistry, Purdue Univ., W. Lafayette in 47907): 'Cumberland Falls Chondritic Inclusions – II. Trace Element Contents of Forsterite Chondrites and Meteorites of Similar Redox State', *Geochim. Cosmochim. Acta* **47**, 1625–1633 (1983)

Mineralogic study of black inclusions in the Cumberland Falls enstatite achondrite revealed that they consitute a highly unequilibrated chondritic suite distinct from other chondrite groups. This highly shocked suite, the forsterite (F) chondrites, exhibits mineralogic trends apparently produced during primary nebular condensation and accretion over abroad redox range. We analyzed these samples and possibly related meteorites for Ag, As, Au, Bi, Cd Co, Cs, Ga, In, Rb, Sb, Se, Te Tl, U and Zn, trace elements known to yield important genetic information. The results demonstrate the compositional coherence and distinctiveness of the F chondrite suite relative to other chondrites. The Antarctic aubrite, ALH A78113, may include more F chondrite material. Trace element contents do not vary with mineral compositions hence do not reflect redox variations during formation of F chondrite parental matter. Trace element mobilization – during secondary heating episodes in the F chondrite parent or during its disruptive collision with the enstatite meteorite parent body – is not detectable. Chemical trends in F chondrites apparently reflect primary nebular processes. Cosmochemical fractionation of lithophiles from siderophiles and chalcophiles occurred at moderately high temperatures certainly higher than those existing during formation of primitive carbonaceous, enstatite and ordinary chondrites of petrologic type $\leqslant 3$.

Verkouteren, R. M., Dennison, J. E., and Lipschutz, M. E. (Dept. of Chemistry, Purdue Univ. W. Lafayette, in 47907): 'Siderophile, Lithophile and Volatile Trace Elements in Allan Hills A81005', Lunar and Planetary Science XIV, Abstracts from the Session on Meteorites from Earth's Moon, pp. 39–40 (1983)

From the time of its discovery in Antarctica, Allan Hills A81005 seemed a likely candidate for the first recognized lunar sample naturally transported to Earth. To study its meteoritic admixture and its geochemical and thermal histories, we requested material from ALH A81005 and were allocated 139 mg of matrix containing 30–40% mm-sized admixed clasts, which were too numerous and small to separate. We divided the sample into two nearly equal-sized portions to assess heterogeneity and analyzed each for 16 trace elements – siderophile As, Au, Co, Ga, Sb; volatile/mobile Ag, Bi, Cd, In Se, Te, Tl, Zn; Lithophile Cs, Rb, U - radiochemical neutron activation analysis. These elements are known to yield important genetic information on lunar and meteoritic materials.

Our duplicate results are entirely satisfactory considering sample heterogeneity and small size and the ppb levels of nearly every element we measured. These data are entirely consistent with a lunar origin for ALH A81005, based on comparison with prior results for similar lunar samples. Siderophile markers of meteoritic admixture (Ag, As, Au and Sb) indicate 0.015 ± 0.005 Cl-equivalent, in accord with the 1–2% admixture found in Apollo samples. Three more volatile (but not siderophile) elements – Se, Cd and Zn – are also in this range, indicating no measurable extraneous volatile admixture. The Cd content and Cd/Zn ratio, 4.0×10^{-3}, are similar to those in numerous lunar samples. The Cs/U ratio, 0.046, is unusually low compared with prior data but Rb/Cs, 30, seems quite normal [4], preliminary Tl results will be presented. Cobalt is slightly high, at 0.044 Cl-equivalents, hinting at admixture by siderophile-rich projectile debris. Part of the Ga excess could be attributable to this but most, if not all of it probably reflects an indigenous component, i.e. anorthosite. Slightly lowered contents of Bi and Te (0.0065–0.0039 Cl-equivalents) are similar to those in lunar highlands samples and may reflect marginal shock-induced mobilization.

In summary, little in the trace element make-up of ALH A81005 distinguishes it from samples returned by the Apollo mission – a remarkable fact considering its unusual history: it is neither unusually rich nor poor in siderophiles and volatiles/mobiles. Thus, the impact that provided $\geqslant 2.4$ km/sec to launch ALH A81005 on its journey to the Antarctic ice sheet left marks no more severe than those found in samples that did not escape the lunar gravitational field. This conclusion is entirely consistent with the 20 GPa shock pressure estimated mineralogically by Warren *et al.* A Martian origin for SNC meteorites, requiring $\geqslant 5.0\,\mathrm{km\,s^{-1}}$, now seems more likely in view of the results for ALH A81005. Just as Apollo had his twin (Artemis/Diana), the Apollo program had its natural twin that launched other lunar samples to Earth, now waiting to be hunted down on the Antarctic ice sheet.

Villa, I. M., Huneke, J. C., and Wasserburg, G. G. (Lunatic Asylum, Div. of Geological and Planetary Sciences, California Inst. of Tech., Pasadena, CA 91125): '^{39}Ar Recoil Losses and Presolar Ages in Allende Inclusion', *Earth Planet. Sci. Lett.* **63**, 1–12 (1983)

Ar analyses are reported for five coarse-grained, Ca-Al-rich inclusions from the Allende meteorite. The samples were neutron-irradiated in individual ampoules, and the Ar gas in the ampoules as well as the samples was analyzed. A large fraction (up to 60%) of the ^{39}Ar from ^{39}K (n.p) reactions was lost out of the inclusions into the ampoules. The ^{39}Ar losses resulted in substantial increases in the apparent ^{40}Ar-^{39}Ar ages of the samples. ^{39}Ar recoil loss during neutron-irradiation is a major effect and must be accounted for in ^{40}Ar-^{39}Ar dating. All of the Allende inclusions studied contained substantial trapped ^{36}Ar. The origin of the trapped ^{36}Ar is unknown, and the possible presence of trapped ^{40}Ar cannot be excluded. Ar measurements on Allende inclusions which have yielded anomalously old ages must be re-examined in the context of ^{39}Ar recoil loss and possible contributions of trapped ^{40}Ar. Allende inclusions appear on both accounts to be poor candidates to search for relicts of presolar materials with well-defined K/Ar ages.

Warren, P. H., Taylor, G. J., and Keil, K. (Inst. of Meteoritics, Dept. of Geology, Univ. of New Mexico, Albuquerque, NM 87131): 'ALHA81005: A Meteorite from the Moon – but can we rule out Mercury?', Lunar and Planetary Science XIV, Abstracts from the Session on Meteorites from Earth's Moon, pp. 41–42 (1983)

There seems to be a clear consensus that ALHA81005 came from the Moon, but before assessing the implications, the remote possibility that it came from some other body should be addressed. Even if it is not lunar, the rock is profoundly important. The parent body would have to be remarkably similar to the Moon. It would have to have the same oxygen isotope ratios, the same FeO/MnO ratios and the same anorthositic type of crust, as the Moon; and it must be atmosphereless, with a regolith containing approximately the same amounts of solar wind rare gases as that of the Moon. It may well be that some planet or asteroid has several of these properties in common with the Moon, but it is extremely unlikely that any other body has all four. The only other plausible source would appear to be Mercury.

Earth, the Moon, and the enstatite chondrite/aubrite parent body, all have oxygen isotope ratios along a single mass fractionation line. Because of their exceedingly low FeO/MgO ratios, it has been suggested that the enstatite chondrites formed in a high-temperature zone $\ll$ 1 AU from the Sun. Thus, it is conceivable that the entire inner solar system was homogenized with respect to oxygen isotopes. Presumably, the Moon became depleted in MnO relative to FeO (compared to similarly FeO-rich chondrites) due to the higher volatility of MnO. Among atmosphereless bodies, this too may be a function of distance from the Sun, for the eucrite parent body (presumably an asteroid) has a higher MnO/FeO than the Moon. But planet size (i.e., escape velocity) and other factors surely must also play a role. A MnO/FeO coincidence between Mercury and the Moon is unlikely, but not impossible.

Anorthositic crusts like that of the Moon probably only form on planets of roughly lunar size. If the planet is too large (i.e., has internal pressures that are too high), its aluminum does not form buoyant plagioclase during the early intense magmatism phase (the magma 'ocean'), but instead forms dense mantle phase(s) such as garnet – this is what probably took place on Earth. Moreover, its early crust is liable to be made over by ongoing geologic activity. If it is too small (i.e., asteroid-sized), it can never form sufficiently large intrusions to lead to global elutriation of plagioclase – this is probably why anorthosites are only a very minor component from the eucrite parent body. Mercury is 4.6 $\times$ more massive than the Moon, but its large core (60–70 wt%) would have displaced all its aluminum towards the surface. The pressure at the base of Mercury's mantle is roughly 100 kb. For comparison, the lunar central pressure is $\sim$ 47 kb, and the pressure at the base of Earth's mantle is $\sim$ 1370 kb. Mercury is probably the right size to have produced an anorthositic crust, provided it was melted extensively like the Moon. Indeed, the visible reflectance spectrum of Mercury is sufficiently similar to spectra from lunar highlands soils to suggest that Mercury's crust is similarly anorthositic, with roughly 5.5 wt% FeO, mainly as orthopyroxene.

Being only 39% as far from the Sun as the Moon, Mercury's surface is exposed to 6.7 $\times$ as much solar wind as the Moon's. A regolith breccia from Mercury will not necessarily have 7 $\times$ higher solar gas contents than one from the Moon, however. Another factor, the mean surface residence time (i.e., reciprocal cratering rate), differs between Mercury and the Moon. The cratering rate on Mercury is most likely ~ 2 ×, but possibly 5 ×, that on the Moon, so an avg. regolith breccia from Mercury probably, but not necessarily, has significantly higher solar gas contents than one from the Moon. ALHA-81005 has noble gas concentrations that are low even for a lunar soil, and most regolith breccias have 2–4 × higher concentrations than soils. If the noble gas data are an obstacle to accepting the lunar origin of ALHA81005, it is because they are too low, not too high. The explanation is probably that ALHA81005 is atypically poor in surficial 'fines' material, for a regolith breccia. We have observed that it appears to contain considerably less of the swirly brown glass associated with such materials, too.

In summary, the possibility should not be completely overlooked that ALHA81005 is from some body other than the Moon; Mercury is the most plausible alternative. But a powerful combination of circumstantial evidence is overwhelmingly in favor of its being from the Moon.

Wlotzka, F., Palme, H., Spettel, B., Wanke, H., Fredriksson, K., and Noonan, A. F. Max-Planck-Institut für Chemie, Mainz, F.R.G.): 'Alkali Differentiation in LL-Chondrites', *Geochim. Cosmochim. Acta* **47**, 743–757 (1983)

The LL-group chondrites Krähenberg (Krbg) and Bhola are heterogeneous agglomerates containing a variety of lithic fragments and chondrules as well as crystal fragments. The Fe/Fe + Mg content of most olivine grains is uniform (Fa_{28}), although a few with distinctly lower Fe contents were found (Fa_{19}). Both meteorites contain large, cm-sized, fragments with high enrichments of K (~ 12×), Rb (~ 45×) and Cs (~ 70×) relative to LL-chondrites, while the REE concentrations are normal (except for a negative Eu anomaly): Na and Sr are depleted (~ 0.5×) and the Na/K weight ratio is 0.33 compared to 11 in the host. However, there is no difference in the sum of Na + K atoms. Also, the major elements, Si, Al, Mg, Ca and Fe, are nearly the same in fragments as in the host material. The K-rich igneous lithic fragments have a microporphyritic texture of euhedral to skeletal olivines in a partly devitrified glass with ~ 4% K_2O. The main parts of both Krbg and Bhola contain mesostasis glasses in porphyritic chondrules and lithic fragments with varying K content (0.1 –8.6% K_2O) and Na/K ratios (0.2–100). Crystalline plagioclase is depleted in K with an average Na/K ratio of 22, *i.e.* higher than that for ordinary chondritic plagioclase, 8.4. Olivines in the large, K-rich fragments and in the host meteorites have the same iron content (Fa_{28}), indicating that both formed under the same oxygen fugacity and probably on the same parent body.

Conceivable mechanisms for the formation of the K-rich rocks from normal LL-chondrite parent materials are: 1. magmatic differentiation: 2. Na-K exchange *via* a vapor phase: 3. silicate liquid immiscibility: 4. volatilization and condensation in impact events. Process 2 appears most feasible for forming a rock enriched only in K and heavier alkalies and depleted in Na without noticeably changing other elements including the REE.

Yasuda, M., Kitamur, M., and Morimoto, N. (Dept. of Geology and Mineralogy, Faculty of Science, Kyoto Univ., Sakyo, Kyoto 606, Japan): 'Electron Microscopy of Clinoenstatite from a Boninite and a Chondrite', *Phys and Chemistry of Minerals* 9, 192–196 (1983)

Clinoenstatite crystals from a boninite and the Yamato-74191 chondrite have been studied with an analytical electron microscope. (100) twins and cracks perpendicular and parallel to the c axis are characteristic of their sub-microscopic textures. The frequency in appearance along the c axis and widths of the cracks have been explained by the dimensional change of the c axis in the direct transformation of protoenstatite to clinoenstatite and by the cooling rate around the transformation temperature. The cracks in the crystals from the boninite are filled with fibrous crystals of talc, while those from the chondrite are open or filled with glass in which fine crystals of plagioclase are common.

4. Cosmic Dust, other Particles, etc.

Ganapathy, R. (Research Lab., J. T. Baker Chemical Co., Phillipsburg, NJ 08865): 'The Tunguzka Explosion of 1908: Discovery of Meteoritic Debris near the Explosion Site and at the South Pole', *Science* **220**, 1158–1161 (1983)

Submillimeter-sized spheres extracted from soil in the Tunguska region of central Siberia contain noble metals in cosmic proportions. The trace element composition and geographical distribution of these spheres suggest that they are from the 30 June 1908 Tunguska explosion and not meteoritic ablation products falling continuously on the earth. Debris from this explosion was also discovered in a South Pole ice core; this discovery indicates that the Tunguska object exploded in the atmosphere with subsequent stratospheric injection and transport of the debris. The celestial body that exploded over Tunguska weighed more than 7 million tons, was more than 0.16 km in diameter, and may well have been a stony meteorite. This discovery offers a new precision time marker in polar ice strata for the year 1909. The steady-state influx of cosmic matter at the South Pole is estimated to be $1.8 \times$ '10^{-8} g cm^2 yr^{-1}, which corresponds to a global influx of 4×10^5 tons yr^{-1}.

Keller, G., D'Hondt, S., and Vallier, T. L. (U.S. Geological Survey, Menlo Park, CA 94025): 'Multiple Microtektite Horizons in Upper Eocene Marine Sediments: No Evidence for Mass Extinctions', Science **221**, 150–152 (1983)

Microtektites have been recovered from three horizons in eight middle Eocene to middle Oligocene marine sediment sequences. Five of these occurrences are coeval and of latest Eocene age (37.5 to 38.0 million years ago); three are coeval and of early late Eocene age (38.5 to 39.5 million years ago); and three are of middle Oligocene age (31 to 32 million years ago). In addition, rare probable microtektites have been found in sediments with ages of about 36.0 to 36.5 million years. The microtektite horizon at 37.5 to 38.0 million years can be correlated with the North American tektite-strewn field, which has a fission track age (minimum) of 34 to 35 million years and a paleomagnetic age of 37.5 to 38.0 million years. There is no evidence for mass faunal extinctions at any of the microtektite horizons. Many of the distinct faunal changes that occurred in the middle Eocene to middle Oligocene can be related to the formation of the Antarctic ice sheet and the associated cooling phenomena and intensification of bottom currents that led to large-scale dissolution of calcium carbonate and erosion, which created areally extensive hiatuses in the deep-sea sediment records. The occurrence of microtektite horizons of several ages and the lack of evidence for faunal extinctions suggest that the effects of extraterrestrial bolide impacts may be unimportant in the biologic realm during middle Eocene to middle Oligocene time.

Leinert, C., Roser, S., and Buitragg, J. (Max-Planck-Institut für Astronomie, Königstuhl, D-6900, Heidelberg, F.R.G.): 'How to Maintain the Spatial Distribution of Interplanetary Dust', *Astron. Astrophys.* **118**, 345–357 (1983)

We discuss two aspects related to the radial dependence of spatial density of interplanetary dust, which was found to be $n(r) \sim r^{-1.3}$ from the Pioneer 10/11 and Helios 1/2 space probes. Obviously, in steady-state a permanent source of dust is necessary to replenish the losses due to Poynting-Robertson effect and mutual collisions.

First, we ask which spatial distribution the dust scource should have to lead to the observed *relative* spatial distribution. Sources limited to a shell at several AU Heliocentric distance are found to be inadequate, while extended ($0.1\ \mathrm{AU} \leqq a \leqq 10\ \mathrm{AU}$ to 20 AU) sources with the semimajor axes distributed $\sim a^{-1.0}$ or $\sim a^{-1.1}$ reproduce the observed density gradient.

Second, we ask whether collisions in interplanetary space would destroy enough of the larger meteoroid particles to create a sufficient supply of dust-sized debris. This is found to be the case. In addition, the extended dust source resulting from these collisions approximately has the spatial distribution required to fit the observed radial dependence of dust density. We therefore consider radio and photographic meteoroids as the mass reservoir from which the interplanetary dust cloud is maintained.

Mukai, T. and Fechtig, H. (Max-Planck-Institut für Kernphysik, D-6900 Heidelberg, F.R.G.): 'Packing Effect of Fluffy Particles', *Planet. Space Sci.* **31**, 655–658 (1983)

Packing forces, produced by an anisotropic sublimation of mantle material of grains located at the surface layer of loosely conglomerated fluffy particles, move the grains towards the center of the fluffy particles. This leads to a reduction of the empty space inside the fluffy particle and consequently to an increase of the mass density of the fluffy particle with time.

As observed by the Helios dust experiment, fluffy particles of low density are ejected by comets with high eccentricity *e* and large semimajor axis *a*. Since *e* and *a* of fluffy particles decrease with time due to the Poynting-Robertson effect, the accompanying increase of the density of fluffy particles seems to explain the existence of normal dense particles in quasi-circular orbits as detected during *in situ* measurements. It also explains that the majority of lunar craters have been produced by normal dense particles rather than by low density particles.

Ray, J. and Völk, H. J. (Max-Planck Institut für Kernphysik, Postfach 10 39 80, 6900 Heidelberg-1, F.R.G.): 'The Retention of Spallation Products in Interstellar Grains', *Icarus* **54**, 406–416 (1983)

Stimulated by recent studies indicating the possible survival of presolar grains in certain meteorites, the importance of recoil loss for the retention of spallation products in submicrometer-sized interstellar dust during irradiation by high-energy cosmic ray protons has been calculated. The model presented incorporates range straggling effects, a realistic distribution of interstellar grain sizes and utilizes an accurate theoretical formalism for the fragmentation recoil momenta. Apart from an only vague understanding of possible grain compositions, the greatest uncertainty concerns the intrinsic material density of interstellar dust which determines the recoil range for any given momentum. It is found that even allowing for a fivefold variation of density values, the retention against recoil is substantial: for example, some 20 to 50% of all ^{38}Ar nuclei resulting from high-energy interactions remain trapped, depending on the target element considered. Retentivities for the various spallation reactions contributing to ^{38}Ar have been calculated and are used to deduce an interstellar spallogenic production rate. The results are then considered in the light of recent discoveries of ^{40}Ar-^{39}Ar apparent ages in excess of 4.53×10^9 yr for some inclusions from the meteorite Allende. Limitations of both the theoretical and experimental efforts presently preclude conclusive statements regarding the question of interstellar grain survival. However, a procedure is outlined whereby this issue might be clarified in future investigations.

Sekanina, Z. (Jet Propulsion Lab., Calif. Inst. of Tech., Pasadena, CA 91109): 'The Tunguzka Event: No Cometary Signature in Evidence', *Astron. J.* **88**, 1382–1414 (1983)

It is argued that existing information on the 1908 Tunguzka fall rules out the possibility that the object was a comet fragment, active or extinct. Evidence on the fireball's enormous terminal explosion several kilometers above the Earth is indicative of the apparent absence of a major breakup in flight before the almost instantaneous mass dissipation of $\sim 10^{12}$ g and invites comparison with a number of the Prairie Network and European Network fireballs displaying prominent terminal flares. It is shown that a fireball of the Tunguska mass is not decelerated very efficiently by the Earth's atmosphere regardless of the assumed ablation rate. As a result, at an entry velocity of ~ 30 km s^{-1} the fireball would have resisted aerodynamic pressures in excess of 10^9 dyn/cm^2 before disintegrating. It is inconceivable that cometary material known for its extreme fragility could survive a load of this magnitude. The data on the Type II fireballs with prominent terminal flares are extrapolated to estimate Tunguzka's critical dynamic pressure at the explosion to be some 2×10^8 dyn/cm^2 and to infer that the fireball's pre-explosion velocity amounted to ~ 10 km s^{-1}, ruling out a comet-like orbit. In order for the Tunguzka object to penetrate deep into the atmosphere, high ablation rates that are characteristics of cometary fireballs should require that Tunguzka's initial mass be orders of magnitude greater than idndicated by evidence. Its association with a short-period comet of Jupiter's family, including P/Encke, is furthermore contradicted by much too large an angle that Tunguzka's line of apsides would then make with Jupiter's orbit plane. The Tunguzka object is described most consistently as a small Apollo-type asteroid, 90–190 m across, having orbited the Sun between $\lesssim 1$ and 1.5 AU before it struck the Earth. The object's common origin with the Farmington meteorite is considered but found to be highly likely.

Shoemaker, E. M. (U. S. Geological Survey, Flagstaff, AZ 86001): 'Asteroid and Comet Bombardment of the Earth', *Ann. Rev. Earth Planet. Sci.* **11**, 461–494 (1983)

Two classes of solid bodies large enough to be detected by telescopes occur in orbits that overlap that of the Earth. These bodies are the Earth-crossing asteroids and comet nuclei. Although their orbits

only rarely intersect the Earth's, the probabilities of their collision with the Earth are nevertheless finite and calculable. Systematic telescopic surveys carried out over the past two decades show that the flux of asteroids and comet nuclei in the Earth's neighborhood is sufficiently high that the effects of occasional collisions should be recognizable in the geological record. During these same two decades, an intensive international search for ancient impact structures has gone forward. The actual rate of bombardment of the Earth during the last half-billion years has been found to be roughly consistent with the present rate predicted from astronomical observations. Within a factor of about two, the average rate of bombardment of the Earth during the last half billion years also appears to be consistent with the average rate of bombardment of the Moon over the last 3.3 billion years.

Spectacular new lines of study have developed in recent years leading to the recognition of rare large impact events that produce geochemical anomalies on a global scale. The possible effects of these large impacts on the Earth's biota have become the subject of vigorous debate. In this paper, I first review the astronomical and geologic evidence concerning the history of bombardment and then discuss the physical effects of large impacts, as they may apply to both the inorganic and organic worlds.

Stauffer, P. H. (Dept. of Geology, Univ. of Malaya, Kuala Lumpur, Malaysia): 'Phantom Tektite Localities of Borneo', *Meteoritics* **18**, 9–13 (1983)

An attempt to find out more about tektite finds at Riam, Indonesian Borneo (Kalimantan), has uncovered a long-standing and complicated confusion about tektite localities in the southern portion of Borneo. It appears that the only authentic localities in the whole of Indonesian Borneo are at Martapura, Pelaihari, and the Sungei (River) Riam Kanan, all within 40 km of each other in the south-eastern corner of the island, and all documented, mainly in Dutch and German works, by the early 20th century. Other localities mentioned and shown on maps in more recent French and English publications are mere phantoms resulting from a succession of misinterpretations of previous literature.