22. COMMISSION DES MÉTÉORES ET MÉTÉORITES

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INTRODUCTION

In the preparation of this report, the following members of Commission 22 assisted by sending me summaries of research carried out, and bibliographies of papers published in the field of meteoritics:—Astapovich, Babadjanov, Ceplecha, Cook, Elford, Ellyett, Halliday, Hirose, Hoppe, Kizilirmak, Kresák, Lindblad, McCrosky, Nielsen, Oleak. I wish to thank all these for their help. I would like also to thank a number of other scientists who have kept me supplied with relevant papers, and pre-prints in advance of publication.

Since the last report of this Commission was completed during the second half of 1964, I have omitted all 1963 references here. For references from 1964 on there will be some omissions in borderline fields such as space, lunar surface studies and geology, and also in the papers of those countries from which I did not receive a complete bibliography.

Research on meteorites, tektites, and the dust collected from polar snows and deep-sea sediments, is covered in the accompanying report for our Committee on Meteorites, by E. L. Fireman. I include here a general treatment of meteor crater research, and the detection of cosmic dust by satellites and spacecraft.

GENERAL

During the last three years there has been considerable activity in the field of meteoritics. New monographs have been published by Hawkins (1964*a*), 'Meteors, Comets, and Meteorites', and by Astapovich (1966*c*), 'Meteors and Meteorites'. Russian editions have been published of 'Meteor Science and Engineering' by D. W. R. McKinley, 'Meteorites' by B. H. Mason, and 'Tektites' by J. A. O'Keefe, while an English edition of 'The Giant Meteorites' by E. L. Krinov has appeared. The third, and completely revised, edition of the Prior-Hey 'Catalogue of Meteorites' became available late in 1966 at the British Museum (Natural History) London. A new catalogue of bright fireballs by A. V. Nielsen (1967) will appear shortly. E. O'Connell (1965) has prepared a very useful catalogue of meteorite craters on the earth's surface, both confirmed and suspected features.

An international symposium on the subject 'Meteor Orbits and Dust', was held at the Smithsonian Astrophysical Observatory, Cambridge, Mass., U.S.A. in August, 1965. The proceedings of this symposium will appear in *Smithsonian Contributions to Astrophysics*, vol. 11. The Committee on Comets and Meteors in the U.S.S.R. held a session in Kazan in 1965, under the chairmanship of V. V. Fedynsky. The Committee on Meteorites in the U.S.S.R. organized the 11th Conference on Meteorites in Moscow in May 1964, (Yavnel, 1964) and the 12th Conference on Meteorites in Novosibirsk in May 1966. The latter dealt mainly with the problems of the Tunguska event of 1908. A conference on luminous night clouds was held in Tallin, Estonia, in March 1966. The Meteoritical Society held Annual meetings at Tempe, Arizona, October, 1964; Odessa, Texas, October, 1965; and Washington, D.C., November, 1966. The Working Group on Meteorites, organized by UNESCO, held three meetings in Paris, the first in February, 1964, the second in October, 1965, and the third (final meeting) in October, 1966. An international workshop on methods of obtaining winds and densities from radar meteor trails was held at Waltham, Mass., in August, 1966, under the auspices of the Air Force Cambridge Research Laboratories. Meetings of the Organizing Committees of Commission 22 and of the 1967 Symposium on the Physics and Dynamics of Meteors, were held at Cambridge, Mass., August, 1965, and at Smolenice, Czechoslovakia, October, 1966.

Papers in the field of meteoritics now appear in a continually growing list of publications. The following current periodicals are devoted specifically to this subject:—*Meteoritika* and *The Meteoritical Bulletin*, published in Moscow; *Bulletin of the Committee on Comets and Meteors*, published in Dušhanbe; and *Meteoritics*, published by the Meteoritical Society.

One of the trends noticed during the last three years has been a new awareness of the importance of the rapid recovery of meteorites and the study of these objects before the short-lived radio isotopes have dropped below detectable levels. To aid in tracking fireballs bright enough to drop meteorites multiple camera networks have been set up in the mid-western United States (McCrosky and Boeschenstein, 1965) and in Czechoslovakia (Ceplecha and Rajchl, 1965*a*, 1965*b*). The latter is now being extended into the territory of Germany. Tentative plans have been made for a network similar to the above in Ukrainian SSR and in western Canada. The Canadian national committee on meteorites has for some time had an organized system for reporting bright fireballs and recovering newly fallen meteorites (Folinsbee and Bayrock, 1964). The chief subjects dealt with by the UNESCO Working Group on Meteorites have been the facilities for the rapid international exchange of new meteorites, and the legal status of such specimens. The study and identification of terrestrial meteorite craters has been actively pursued.

Manned space flights beyond the immediate environment of the Earth will take place in the near future. As a result of this, interest in the conditions found in interplanetary space has accelerated rapidly, and numerous experiments for the recording of the impacts of space dust have been mounted on satellites and spacecraft. A great deal of work has also been carried out in the field of a quantitative study of the influx of meteorite particles on the Earth, and the distribution of the orbits of these particles in the solar system.

A number of reports appeared summarizing the results of cooperative efforts in various countries. Babadjanov *et al.* (1964) described the IGY meteor observations in the U.S.S.R., and Keay (1965) meteor research in New Zealand. Baldet (1965) wrote a general note on meteor observing. Šimek (1964*a*) has published a convenient table for the calculation of meteor velocities, and the same author (1965*b*) has dealt with the automatic registration of fast random phenomena.

VISUAL AND TELESCOPIC OBSERVATIONS

Visual observations of meteors and fireball reports were collected by the American Meteor Society as in previous years (Olivier, 1964*a*, 1965*a*, 1966). Based on observations received 1958–63 a second catalogue of visual hourly rates was compiled (Olivier 1965*b*). A catalogue of fireball radiants was also published (Olivier, 1964*b*). The collection of group counts of visual meteors, commenced at Ottawa for the IGY, was continued with the cooperation of selected groups and individuals. Brief summaries have been published in Meteor News (Millman, 1964, 1966). Outstanding bright fireballs have been investigated by Oriti (1965), Pokrzywnicki (1965), and Oleak (1966*a*, *b*). Lamar and Romig (1964) discussed anomalous sound effects connected with fireballs. Various observational effects that must be allowed for in the reduction of visual meteor data were studied by Ivanikov (1965*b*), Znojil (1966), and Kvíz (1965*a*, *b*), and the use of the stereographic projection in meteor reductions was described by McIntosh (1965). A new method of making telescopic meteor velocity observations was described by Porubčan (1966), and the spectral energy distribution for telescopic meteors was studied by Ceplecha *et al.* (1965). Observations of telescopic meteors over base lines of various lengths have been reported by Grygar and Kohoutek (1964) and Znojil (1965). In general heights are in the 80 to 90 km range with an average near 85 km. A comparison of telescopic observations with different types of instruments was also made (Grygar and Kohoutek, 1965). Bakharev (1966) has summarized various characteristics of telescopic meteors, in particular with relation to the IQSY observations in the U.S.S.R.

PHOTOGRAPHY

Various techniques for photographing meteors, and the effects of these techniques and weather conditions on the photometry of meteor trails, have been studied by Volynskaya (1964), Kramer (1965*a*), Izraetskaya (1965), and Ivanikov and Khaimov (1965). Results from a number of systematic programs of meteor photography have appeared. Jacchia *et al.* (1967) discussed selected results from 413 precision-reduced meteors photographed with the Super-Schmidt cameras in New Mexico, U.S.A., during the period 1951–54. Shelton (1965) has made a study of the Quadrantid shower, using all photographic data available. The results of the double-station photographic program, commenced at Ondřejov for the IGY, and since continued, were reported by Ceplecha *et al.* (1964) and by Ceplecha and Ježková (1965). Gulmedova *et al.* (1964) reported results of the photography of meteors in the Turkmen SSR. Detailed photometry of 152 photographed meteors was carried out by Ivanikov (1965*a*). Calibration was made through the use of artificial meteors. It was concluded that, for the 30 meteors with bursts, the normal mass loss in a burst is 10–20% of the mass of the meteoroid.

SPECIAL STUDIES

Experiments in the photoelectric recording of meteors brighter than magnitude + 3 were made by Stepanov (1964, 1965). Hicks *et al.* (1967) used an image orthicon system to photograph meteors. The effects of cosmic rays on meteoroids in space were discussed by Tilles (1966). Konstantinov *et al.* (1966) noted a correlation between gamma ray intensity, as recorded by high-altitude aircraft, and the maxima of prominent meteor showers. They suggest the presence of antimatter in some meteoritic material. The relation between meteors and geomagnetic effects is still controversial. Theoretical aspects of this subject have been treated by Ivanov and Medvedev (1964), Marochnik (1964) and Chapman and Ashour (1965). The general conclusion is that it should be possible to detect magnetic effects from large meteors under certain conditions. The possible electric effects of large meteors have also been computed by Ivanov and Medvedev (1965).

METEOR SPECTRA

Active programs of meteor spectroscopy were continued in Canada at the Meanook, Newbrook, and Springhill Meteor Observatories; in Czechoslovakia at the Ondřejov and Skalnaté Pleso Observatories; and in the U.S.S.R. at the Ashkhabad Observatory. Programs on a smaller scale were also carried out at a number of locations in the U.S.A., U.S.S.R., Great Britain, Japan, the Netherlands and India.

Good dispersion spectra of excellent quality, taken at Ondřejov, have been studied intensively by Ceplecha (1964, 1965*a*, *b*, 1966*b*). Rajchl (1964*a*) has discussed the low dispersion spectra from Ondřejov. Excellent Leonid spectra were secured in Japan during the 1965 return (Tomita, 1966), and these are being studied by H. Hirose, T. Nagasawa and K. Tomita. Meteor spectroscopy, carried out in Scotland from 1958 to 1965, is described by Evans and Evans (1966). They include the detailed study of a Lyrid spectrum. Feibelman and Emmerich (1964) secured an Orionid spectrum at Pittsburgh. The accidental recording of a brilliant fireball on an auroral patrol spectrograph in Alaska is described by Romick, *et al.* (1964). Russell (1964) has discussed the spectra of faint Perseids, photographed in California. Nasyrov and Nasyrova (1966) found from 8 Leonid train spectra, photographed at low dispersion, that the peak of luminous intensity was in the orange-red.

Rajchl (1964*b*, 1965) has summarized some of the general characteristics of meteor spectra as related to the physical theory of meteors. Kramer (1966) has studied the spectrum of a meteor that divided into two parts, and Ivanikov (1966) has determined a panchromatic colour index of + 0·2 from the spectrum of a Perseid meteor.

METEOR TRAINS

The study of meteor trains has recently received considerable attention, especially in the U.S.S.R. Savrukhin and his co-workers have published numerous results based on both visual and photographic observations at Ashkhabad (Savrukhin, 1964*a*, *b*, *c*, *d*, *e*, *f*, 1965*a*, *b*, 1966*a*; Savrukhin and Bezuglova, 1964; Savrukhin and Nasyrova, 1964). Heights of trains were measured in the range 80 to 105 km. Small drift velocities were found below 95 km, higher velocities above 95 km. There was good agreement between meteor train drifts and the drift of the ionosphere in the Es region. Initial diameters of trains were found to average 80 metres. A morphological classification of meteor trains was proposed. Astapovich (1966*a*) has found diurnal, annual, and 11-year periodic variations in 150 meteor trains, recorded during 1500 hours of observation with binoculars. Bakharev and Shodiev (1966) have reported on dual-station photography of meteor trains at Dušhanbe, and Shodiev (1965, 1966) on the characteristics of trains of Perseid and Orionid meteors. Gulmedov (1964), Gulmedov and Yushkevich (1964), and Gulmedov and Nasyrova (1966) have studied atmospheric turbulence and diffusion, using both visual and photographic records of meteor trains at Kazan and Ashkhabad. Truttse (1965) has reported the telescopic observation of a train of a meteor with magnitude + 8. Babadjanov and Kramer (1965) have studied meteor wakes through a system of instantaneous photography. They conclude that wakes, from 300 to 1000 metres long, owe their luminosity primarily to particles fragmented from the meteoroid. Afterglow tails have been studied in the laboratory by Fischer and Rüppel (1964).

RADAR RESEARCH

The radar study of meteors is currently active at a number of locations. Delcourt (1967) has described the French equipment, and Neale (1966*a*, *b*) the two Canadian systems. Šimek (1965*a*, 1966*b*), Hajduk (1965*a*, *b*), and Sládek and Šimek (1965) have discussed features of the meteor radar at Ondřejov, Czechoslovakia, and certain methods of record reduction. Various equipment parameters and numerous results from the Harvard College Observatory, Smithsonian Astrophysical Observatory, Radio Meteor Project have appeared in a series of Research Reports (nos. 1-15) prepared under NASA contract and written by a large number of authors. The physical characteristics of 320 faint radio meteors, selected from over 10 000 reduced on the Harvard-Smithsonian meteor project, have been summarized by Verniani, *et al.* (1966). For these objects, with average mass 10^{-4} g, fragmentation was of common occurrence. Average length of trail was 10 km, average duration 0·3 s, and average height

2·5 km higher than the theoretical value. The maximum electron line-density was found to vary as $m_\infty^{0\cdot7} v_\infty^3$, and was larger than its theoretical value by a factor of 2. Median bulk density was 0·8 g cm^{-3}, confirming the fragile structure of these particles. Radio meteor observations at Millstone Hill, on a wavelength of 68 cm, have been described by Evans (1965). General features of radar meteor work have been covered by Keay (1964), Evans (1967), Kashcheev and Lebedinets (1967) and Millman (1967*b*). The relation of meteor ionization to the ionosphere, and a possible connection with sporadic E formation, was treated by Glazov (1964), Rubtsov (1965), and Ovezgeldyyev and Ostanina (1965). Physical problems of the ionization in meteor trails have been attacked by Fialko (1965*a*, *b*), Fialko, *et al.* (1966), Belkovich (1964), Stepanov and Belkovich (1966), Bayrachenko (1964, 1965), Kruchinenko and Terentjeva (1964) and Rice and Forsyth (1964). Greenhow and Watkins (1964) reported on the characteristics of meteor trails observed at a wavelength of 1 metre. Sugar (1964) has written a general survey of radio propagation by means of meteor trail ionization, and the subject has been further discussed theoretically by Třísková (1964, 1965*a*).

The problem of the relation between the meteor echo duration and the corresponding meteoroid mass has claimed the attention of a number of workers. Underdense trails have been studied by Třísková (1965*b*) and Poole (1967*b*), the Geminid shower by Plavcová (1965), and the problem generally by McIntosh (1966). It appears difficult to go from a given echo duration distribution to a unique solution of the mass distribution. In a series of papers Fialko (1965*c*, *d*, *e*, 1966*a*, *b*) and Fialko and Romanyuk (1966), using radar observations from a number of stations in the U.S.S.R., attacked both the problem of the mass distribution and the kinetic energy distribution of meteoroids.

A monumental study of the drift of radio meteor trails was carried out at Kharkov by Kashcheev (1965) and Kashcheev and Tsesevich (1965). Some 500 000 drifts were measured during the IQSY in 1964–65, and the chief periodicity found was one of 12 hours. The initial radius of overdense trails was estimated as 1 metre at 95 km height (Bibarsov, 1966), the drifts of radio trails and visual trains were compared (Bibarsov, 1964), and parameters of turbulent motion were found for the Kharkov radio trails (Delov, 1965). Watkins (1965) discussed the influence of the Earth's magnetic field on radio meteor trails.

PHYSICAL THEORY

A general note on the physics of meteor entry has been published by Romig (1965). The ionizing efficiency of meteors has been discussed by Verniani and Hawkins (1964) who conclude, based on Ottawa radio results, that a meteor of absolute visual magnitude 0, velocity 40 km s^{-1}, and radiant elevation 30°, has an original mass, m_∞, of 0·8 g. Verniani (1965) found that the photographic luminous efficiency coefficient $\tau_{op} = 10^{-19}$, which means that, for a velocity of 40 km s^{-1}, 0·002 of the kinetic energy appears as photographed luminosity. Theoretical luminous efficiencies, based on atomic collisional cross sections, have been given by Derbeneva (1966). Oleak (1966*c*) has published a note on temperature radiation from fireballs.

Dalton (1967), using Öpik's theory, Hawkins and Southworth's 285 sporadic Super-Schmidt meteors, and a five-variate statistical analysis, finds the mass of a meteor of absolute visual magnitude 0, velocity 30 km s^{-1}, as 2·2 g. Verniani (1964) finds densities for faint photographic meteoroids in the range 0·1 to 1·0 g cm^{-3}, with the density for Giacobinid meteoroids possibly as low as 0·001. Markina (1965) has also studied the densities and masses of photographic meteors. Ceplecha (1966*c*) has called attention to the necessity of separating meteors into major groups based on orbital characteristics, before finding mean densities for the corresponding meteoroids. The way in which a meteoroid looses mass has been discussed by Bibarsov (1964) and Sandakova and Sherbaum (1966), and the physical details of fragmentation of a meteoroid by Kruchinenko (1965), Kramer (1965*b*), Vorobjeva and Kramer (1965), Levin and Simonenko (1966), and Lebedinets and Portniagin (1966). The effects of the structure of the meteoroid on the physics of meteor entry have been studied by Jones and Kaiser (1966), and Kolomiets (1966). The determination of atmospheric parameters from meteor theory is the subject of papers by Babadjanov (1965), and Shiryaeva (1965).

METEOR FLUX

In discussing meteor rates, from which we can determine the flux of meteoroids on the Earth, one of the basic problems is the mass distribution. Kalinkov (1964) has studied this on the basis of over 300 000 visual and telescopic meteor observations taken from the literature for the period 1900–61. He found an average value of 2·5 for the ratio between numbers of meteors in successive magnitude intervals from magnitude − 4 to + 9, after eliminating the doubtful area from magnitude + 3 to + 6 where naked-eye observations overlap the telescopic. The magnitude distribution in various meteor streams has been investigated by Kresáková (1966), and for sporadic meteors by Lindblad (1967). The latter finds a ratio over 4 between successive magnitudes in the magnitude range − 3 to + 2. The size distribution of the very much smaller zodiacal particles was discussed by Southworth (1964).

Systematic observations of meteor rates determined by radar have been published for the northern hemisphere by Millman and McIntosh (1964, 1966), Lazarev (1965*a*), and Baldwin and Kaiser (1965). Millman (1965) has listed a simplified radar meteor index, based on the Ottawa meteor patrol. Elford (1967) has compared the published radar rates for the northern and southern hemispheres respectively, and has estimated the incidence of meteors on the Earth. Kresák and Kresáková (1965) have studied the frequency of bright photographic meteors, and the geographic latitude variations in rates have been discussed by Kresák (1964*a*) for meteor showers, and by Halliday (1964) for meteorite falls. The use of the diurnal and seasonal variations in meteor rates to determine meteor velocities has been dealt with by Kohoutek (1964*a*, *b*) and by Kresák and Kresáková (1964).

Pushnoj (1964) has published the details of 1565 telescopic meteors observed in the Crimea during the IGY, over a total observing period of 250 hours. Kresák and Kresáková (1966) have determined the density distribution of telescopic meteors around the Earth's orbit.

Unusually high radar meteor rates in 1963 have been reported for both the northern and southern hemispheres (Ellyett and Keay, 1964*a*; McIntosh and Millman, 1964; McIntosh, 1967). Meteor rates have been further studied in relation to unusual periodicities (Keay *et al.*, 1966), lunar phases (Ellyet and Keay, 1964*b*), and Indian rainfall (Duncan *et al.*, 1965). Non-random aspects of the times of meteorite falls have been investigated by Brown and Goddard (1964), and the past history of the flux of large meteorites by Hartmann (1965*a*, *b*).

METEOR SHOWERS

Special studies have been made of the returns of a number of showers. The most outstanding event for many years past was the 1966 Leonid return. The maximum, near 12 hours U.T. 1966 November 17 was very sharp and well recorded by radar at Ottawa, Ontario, by a visual team at Kitt Peak, Arizona and by arctic stations in the U.S.S.R. It is possible that the shower in 1966 reached a higher peak than that for the 1833 Leonid return. In addition to numerous shower observations published in papers already referenced the following reports on various recognized showers have appeared: Perseids—Abdylov (1965), Poole (1965), Kaiser *et al.* (1966), Kopecký (1966), Kramer and Rudenko (1965); Geminids – Webster *et al.* (1966); Leonids – Martynenko (1965), Nazarenko and Lazarev (1966), Šimek (1966*a*); Lyrids – Bagrov *et al.* (1964), Savrukhin (1966*b*), Šimek (1964*b*); δ Arietids – Terentjeva (1965*a*, *b*); δ Aquarids – Terentjeva (1965*c*); Sextanids – Nilsson (1964*a*); Vela-Puppids – Ellyett and Roth (1964); and minor showers – Terentjeva (1964*a*, 1965*d*), Bakharev (1965). General characteristics of some of the major meteor showers were summarized by Millman (1967*a*).

ORBITS

Detailed studies of the orbits of bright photographic meteors have appeared in a number of papers (Babadjanov, Suslova, Karaselnikova, 1966; Babadjanov, Getman, Karaselnikova, 1966; Babadjanov and Kramer, 1966, 1967; Sandakova, 1964; Kramer and Markina, 1966). The velocities of faint meteors were determined by Hawkins, Lindblad and Southworth (1964). In 45 orbits determined at Odessa, seven were found to be hyperbolic (Vorobjeva and Rudenko, 1965). Kresák (1964*b*) has discussed the relation between orbits and magnitude distributions, Stohl (1967) certain aspects of sporadic meteor activity, and Kvízová (1964) the relation of meteor and comet orbits to the orbit of Mars. Guth (1967) has proposed a cosmic probe to study retrograde meteors, and Kresák (1966) a probe into the orbit of the Sun-grazing comets.

Terentjeva (1964*b*, *c*, 1965*e*, 1966, 1967) has carried out an exhaustive study of the complex of minor shower orbits, their major characteristics, and their relations to the orbits of comets. Kashcheev *et al.* (1965, 1966) have analysed 12 500 orbits determined by radar observations at Kharkov, and have listed 105 meteor streams and associations. Of these 24 were known previously. Pupyshev (1964, 1965) has studied radiant distribution on the basis of radio observations made at Kazan. Radio surveys of meteor streams have also been carried out, for the northern hemisphere by Poole (1967*a*), and for the southern hemisphere by Nilsson (1964*b*).

Lazarev (1965*b*) has proposed an elliptical model of true-radiant distribution in the ecliptic plane, and from this has calculated rates for meteoric particles encountered in space. Ceplecha (1966*a*, 1967) discussed parameters for the classification of the orbits of sporadic meteors. He found four groups of orbits with some correlation between the orbital elements and the physical characteristics of the meteoroids. In determining average values for the physical and dynamical properties of sporadic meteors the existence of these groups should be recognized. Verniani (1967), in commenting on this, takes issue with some of Ceplecha's conclusions. Kresák (1967) has made a detailed study of the relations among various groups of meteor orbits, comet orbits, and asteroid orbits. He used a graphic coordinate plot of semi-major axis, *a*, against eccentricity, *e*, to illustrate various empirical relations, evolutionary trends, and observational effects. Five distinct classes of meteor orbits were noted, generically related to either comets or asteroids. Using the orbital elements of meteors Dycus and Bradford (1964) discussed their origin, and pointed out the significance of observational boundary conditions in the statistics of meteor orbits, and the importance of noting orbital perturbations produced in a number of different ways. Öpik (1966), in a comprehensive and thought-provoking paper, has dealt with various problems concerning the orbits of small bodies in the solar system. He suggested a basic cometary origin for the meteorites, but it should be noted that among the comets he included certain peculiar objects usually listed as asteroids with abnormal orbits.

INTERPLANETARY DUST

The general properties of interplanetary space were surveyed in a panel discussion held in Ottawa by the Canadian Aeronautics and Space Institute (Millman *et al.*, 1964). Other general papers have been written by Öpik (1964) and Hawkins (1964*b*). Theoretical studies of meteor flux about an attractive centre in space have been carried out by Hale and Wright (1964), and by Shelton *et al.* (1964). The dynamics of dust particles in space have been considered by Shapiro *et al.* (1967), and by Singer (1967), and additional work in the same general area has appeared by McCracken (1967) and by Hoffmeister (1967). The role of the zodiacal light, as an indicator of the nature and distribution of interplanetary dust, was noted by Weinberg (1967), and Roach (1967). Techniques for detecting micrometeoroids from satellites or rockets have been described by Jennison and McDonnell (1964) and by Wlochowicz (1966). Meteoroid bumpers for spacecraft was the subject of a paper by Rolsten *et al.* (1964).

Interplanetary dust in the stratosphere has been discussed by Newkirk (1967), Rosen and Ney (1967) and Grjebine (1967), and in the upper atmosphere by Newkirk and Eddy (1964), Stepanov and Gusakovskaya (1964), Parthasarathy and Rai (1967), and Soberman (1967). The optical laser is still a controversial technique for recording dust in the upper atmosphere (Fiocco and Colombo, 1964; McCormick *et al.*, 1966; Deirmendjian, 1965) but future developments in this field may be of interest.

Results from the detection of micrometeoroid impacts by satellites and space probes have been given by Nazarova (1964*a*, *b*, 1965, 1967) for the U.S.S.R. vehicles, and by D'Aiutolo (1964), D'Aiutolo *et al.* (1967), Nilsson and Alexander (1967), McCracken *et al.* (1967), Alexander *et al.* (1967), and Secretan (1967) for the U.S.A. vehicles. Some previous results have indicated a high concentration of interplanetary dust near the Earth and a possible concentration around the Moon. In this regard Katasev (1964) has noted probable effects of the Earth's atmosphere. The subject has received a very detailed theoretical treatment by Shapiro, Lautman and Colombo (1966), who conclude that it is quite unlikely that the Earth can maintain dust concentration greater than ten times that of interplanetary space. On the experimental side, recent information concerning the behaviour of acoustic detecting crystals (Nilsson, 1966), suggests that the quantitative accuracy of all impact rates determined by the acoustic method must be viewed with suspicion. All this throws grave doubt on the reality of the Earth's dust cloud. Results obtained with a Pegasus-type satellite, where an impact actually shorts a capacitor, are much more reliable. The quantitative data in this case are in the form of penetration rates for known target thicknesses, and the determination of meteoroid masses is still a problem.

I have made no attempt to reference completely the laboratory study of suspected cosmic dust particles. Representative papers were by Wright and Hodge (1964), Hodge and Wright (1964), Hodge, Wright, Langway (1964), Hemenway *et al.* (1964), Crozier (1966). A number of additional papers appear in the *Smithsonian Contributions to Astrophysics*, vol. **11**, 1967.

METEOR CRATERS

Work on the Tungus impact of 1908 in the U.S.S.R. is still very active and has resulted in a number of recent papers. Astapovich (1965, 1966*b*) has made a new study of the trajectory for this object, and Ivanov (1965) has determined a precise time for the event. The atmospheric effects have been summarized by Vasiljev *et al.* (1965) in two papers, the ionization effects by Zolotov (1965), a detailed account of the resulting forest fire has been given by Kurbatskii (1964), and a model for study of the blast effects built by Zotkin and Tsikulin (1966). Shalimov (1964) and Stanjukovich (1964) have made theoretical calculations on the ablation and melting in a hypothetical core of the Tungus object.

The general problems of meteorite crater recognition have been dealt with by Halliday and Griffin (1964), Beals (1965), Beals and Halliday (1965), Shteinberg (1965), Currie (1964*a*), and McCall (1964). Barringer (1964) has published a list of the known meteorite craters on Earth. Hawkins, Meunier and Rosenthal (1964) have discussed some theoretical calculations bearing on the formation of an impact crater. Other features of crater formation have been noted by Tolansky (1964), Ronca (1966), and Short (1966).

Research on specific craters throughout the world has been published as listed below:—Campo del Cielo in Argentina by Cassidy *et al.* (1965); Wolf Creek in Australia by McCall (1965); Henbury in Australia by Hodge (1965); Lonar in India by Lafond and Dietz (1964); Ries Kessel in Germany by Johnson *et al.* (1964); Faugères-Cabrerolles in France by Beals (1964); Crestone in U.S.A. by Marvin and Marvin (1966). The greatest activity in the field of crater research has been in Canada during recent years. The current Canadian programme has been summarized by Innes (1964), and additional comments on the origin of the Canadian craters have been published by Dence (1965). Research on specific Canadian craters has been published as follows: – Brent by Beck and Logis (1964); Clearwater Lakes by Dence *et al.* (1965); Deep Bay by Innes *et al.* (1964); Lac Couture by Beals *et al.* (1967); New Quebec by Currie (1964*b*); Nicholson Lake and Pilot Lake by Bunch *et al.* (1967); West Hawk Lake by Halliday and Griffin (1966).

The rapid increase of our knowledge concerning the numerous crater features on the Moon and Mars gives clear indication that craters are one of the most important forms of surface feature on small planetary bodies in the solar system. It is to be hoped that intensive study of all terrestrial crater forms will continue.

PETER M. MILLMAN
President of the Commission

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REPORT OF THE COMMITTEE ON METEORITES

(Prepared by E. L. Fireman, Chairman of the Committee)

Introduction

A number of important advances in the field of meteoritic research have been made during the past three years. Most important is the evidence that the chondrules in meteorites are the most primitive material extant. The silicate spheroids, called chondrules, which are a common textural feature of meteorites, contain the highest Xe 129/Xe 132 ratios. The excess Xe 129 results from the decay of the extinct radioactive isotope I 129, which has a 17 million year half-life. The K–Ar ages of the chondrules are also older than the age of the bulk meteorite. Xe 129 excesses have been found in most stony meteorites; this excess is the most striking of the xenon anomalies reported. Other xenon anomalies have been attributed to cosmic-ray-produced spallations, neutron captures, or a primordial xenon component that differs isotopically from atmospheric xenon. In the case of the calcium-rich achondrite, Pasamonte, the xenon anomalies provide evidence of another extinct radioactivity, Pu 244, which has an 84 million year half-life. This evidence is not nearly as convincing as that for I 129.

Next in importance to the xenon anomalies are the primordial gas contents of meteorites. Primordial gas was first discovered in 1956 by Gerling and Levsky, who found a large amount of helium in the dark fine-grained phase of Pesyanoe. Seven other meteorites, including Kapoeta and Pantar, with dark and light phases, have been shown to resemble Pesyanoe in primordial gas content. Most stony meteorites do not contain dark and light phases; however, they do contain primordial gas of another type that consists mainly of argon, krypton, and xenon.

The rare-gas work resulted from the application of modern mass-spectrometric techniques to meteorites; the application of another modern technique, the electron-probe analyser, has led to important conclusions regarding the temperature history of meteorites. From the nickel contents at taenite-kamacite borders cooling rates of 1 to 10° C per million years were obtained for the metallic meteorites and also for the metallic phase of stony meteorites. This rate range corresponds to that expected at the centre of an asteroid 50 to 300 km in radius. In the electron-probe analyses of stony meteorites, the homogeneity of the olivine was found to be related to the recrystallization or metamorphism that occurred in the meteorite. The degree of metamorphism led to an improved classification of meteorites that is correlated with their primordial gas content.

Of the controversies that engaged the attention of scientists several years ago, the one over 'organized elements' or life in meteorites has subsided for lack of positive evidence.

The controversy over the origin of tektites has also lessened as more evidence for a terrestrial origin is produced; nevertheless, this subject is still being discussed.

The more important dispute regarding the asteroidal, cometary, or lunar origin of meteorites continues. It is generally believed that meteorites are asteroidal.

The study of meteoritics is now so extensive that even the incomplete bibliographies published by the Air Force Cambridge Research Laboratories (AFCRL-66-5, January, 1966), which cover the three years ending in 1964, contain 524 closely typed pages. Rather than reproduce another bibliography of this kind, we shall arrange the meteorite work alphabetically by countries. The reports received from A. G. Massevitch of the U.S.S.R. and W. G. Elford of Australia are given almost in their entirety. We have attempted to summarize the work carried out in other countries. In those where there is a great deal of activity, e.g., the United States and Germany, we have omitted many references for the sake of brevity. In countries such as Tanzania and Turkey, where little work is done, we have listed any reference we could find.

Australia

A study was made of the abundance of the tin isotopes in meteorites in order to test a theory associated with nucleosynthesis, which suggests that the planetesimals were irradiated with a strong proton flux prior to meteorite parent-body formation (Cleverly, 1965*a*, de Laeter and Jeffery, 1965). As a by-product of isotopic analysis, tin has been redetermined for a number of meteorites with a precision that is probably slightly better than that reported previously.

Attention is at present being directed toward the isotopic abundance of elements of high-ionization potential, and the rare-gas content of newly recovered meteorites. Note also papers by Baker (1962, 1963), Baker *et al.* (1964), Binns (in preparation), Binns *et al.* (1966), Brooks *et al.* (1964), Cleverly (1965*b*), Corbett (1964, in press *a*, in press *b*), de Laeter and Jeffery (in preparation), McCall (1965*a*, *b*, *c*, *d*, *e*, in press *a*, in press *b*), McCall and de Laeter (1965), McCall and Jeffery (1964), McCall and Wiik (1966), and Simmonds (1964).

Austria

A study of the extraordinary meteorite collection in Vienna has been initiated (Dorfler *et al.*, 1965, Kurat and Kurzweil, 1965).

Canada

Important meteorite isotope work was carried out at MacMaster University. Krypton anomalies were discovered in meteorites and interpreted in terms of spallation and neutron capture (Clarke and Thode, 1964*a*, *b*). Sulphur isotopes were measured in various phases of meteorites (Hulston and Thode, 1965, Monster *et al.*, 1965). It was found that the sulphate sulphur was slightly depleted and the troilite sulphur was slightly enriched in S 34. In the bulk meteorite samples of sulphur had the same composition as in the Earth. The recently fallen Peace River meteorite (Folinsbee and Bayrock, 1964) was recovered and distributed for extensive analysis.

Czechoslovakia

A number of papers (Fireman, 1965, Fireman and DeFelice, 1964, Kharitonova, 1965*a*, Rost, 1965) have appeared on further studies of the Přibram meteorite. These include isotopic work, chemical analyses, and microscopic investigations. The European programme to obtain photographic records of meteorite-fireballs is discussed by Ceplecha and Rajchl (1965).

Denmark

The museum collection of meteorites as well as the Greenland meteorites have been catalogued and described (Buchwald, 1965, Buchwald and Munk, 1965).

England

The recently fallen Barwell meteorite was recovered and described (Lancaster-Brown, 1966). Electron-prove analyses (Reed, 1965*a*, *b*) of iron meteorites indicate cooling of the iron bodies at low pressure, i.e., a few kilobars or less; on the other hand, the textures of chondrules (Le Bas, 1966) are taken as evidence for their formation in a high-pressure environment, i.e., approximately 50 kb.

Finland

Pallasites should be classified into two groups: those with rounded olivine grains, like Brenham, into one group, and those with angular olivine grains, like Eagle Station, into the other group (Wahl, 1965).

France

The Bogou and St Severin meteorites were recovered shortly after fall and were examined for cosmic-ray-induced isotopes (Tobailem and Nordemann, 1965). Studies of spherules of possible cosmic origin gave high accretion rates (Grjebine, 1967) of approximately 10^9 tons per year for the Earth.

Germany

Very extensive isotope and mineralogical work is being carried out at Heidelberg and at Mainz. Research on meteorites is also conducted at Cologne and Tübingen. The overall meteorite research in Germany is so extensive that we can give only the most important results. The fact that chondrules have higher Xe 129/Xe 132 ratios than other phases was confirmed (Auer *et al.*, 1965), and the K–Ar ages of chondrules were found to be higher than those in the other phases. The rare-gas contents in a very large number of meteorites (81 chondrites plus other types) were measured at Heidelberg (Kirsten *et al.*, 1963, Zähringer, 1966*b*. The bronzite chondrites were found to have a different distribution of cosmic-ray exposure ages than the hypersthene chondrites. Both kinds of chondrites were found to have the same distribution of radiogenic ages with the exception that the hypersthene chondrites contain a group with K–Ar and U–He ages of $0{\cdot}5 \times 10^9$ years. K–Ar ages for iron meteorites continue to be high, $6{\cdot}3 \pm 0{\cdot}4 \times 10^9$ years (Müller and Zähringer, 1966). The K–Ar and Rb–Sr ages of the Bosumtwi crater glasses were found to be identical to those of the Ivory Coast tektites

(Gentner *et al.*, 1964, Lippolt and Wasserburg, 1966). Metallic spherules were found in the Bosumtwi crater glass, proving that it was an impact crater (El Goresy, 1966). The German investigators therefore strongly believe that tektites are blobs of glass splashed from impact craters. A mass spectrometer and an electron probe were combined into a single instrument for the first time (Zähringer, 1966*a*). Instruments of this type will probably be useful in future studies of the locations of the primordial and other kinds of gas in meteorites. At Mainz, the primordial helium and neon in Pantar were found by fractional etchings (Hintenberger *et al.*, in press) to be located in the outermost layers of the smallest grains in the dark phase, and could be interpreted as solar-wind implantation before the material accreted. The information on helium and neon obtained for a large number of meteorites (Hintenberger *et al.*, 1964) indicated a difference in the cosmic-ray exposure ages of the high-iron and low-iron groups. About 74% of the high-iron chondrites had cosmic-ray exposure ages below 10^7 years, while only 40% of the low-iron group had ages below 10^7 years.

Holland

Research was carried out on the sputtering of meteorites by positive ions (Heymann, 1964).

India

Extensive radioactivity investigations are being made at the Tata Institute in Bombay. Evidence was found for Al 26 in a Pacific sediment (Lal and Venkatavaradan, 1966). This evidence indicates that these sediments contain an extraterrestrial component irradiated by solar protons.

Japan

Mineralogical studies and radioactivity measurements have been made on meteorites (Honda and Arnold, 1964, Mason, 1963, Miyashiro, 1962). It was found (Miyashiro, 1962) that the plagioclase in chondrites belonged either to a high-temperature form or to a transitional state close to it, thus indicating that chondrites were heated at high temperatures and then cooled sufficiently rapidly to preserve high-temperature optics.

Norway

A carbonaceous chondrite of type 2, the Pollen meteorite, was described (Wolff, 1963). The kamacite was found to exist as spherules of diameter 0·01 mm in the olivine grains, and of diameter 0·1 mm in the matrix.

Poland

The meteorites of Poland are described and chemically analysed. The circumstances surrounding the falls and recoveries with maps of the specific locales are also given. A detailed catalogue of the meteorites in the Polish collections has been prepared (Pokrzywnicki, 1964).

Sweden

In collaboration with U.S. investigators, noctilucent cloud particles were collected in Northern Sweden by rockets and were examined with an electron microscope and an electron microprobe (Hemenway *et al.*, 1964*a*, *b*; Witt *et al.*, 1964). Some insight into the nature and composition of the cloud particles was obtained, but the mechanism of the cloud formation remains uncertain. The minerals and the hydrocarbons in the Orguil meteorite were investigated. It is not determined with sufficient certainty whether or not the material is of biogenic indigenous origin (Nagy, 1966).

Switzerland

A large amount of isotope work was done, and some chemical measurements were made in Switzerland. The rare-gas contents of 30 strong meteorites were measured and the results are in good agreement with the Heidelberg measurements. The same correlation of cosmic-ray exposure ages with meteorite classification (Eberhardt *et al.*, in press) was obtained. The Khor Temiki aubrite was found to contain primordial gas with large amounts of helium (Eberhardt *et al.*, 1965*a*) quite similar to Pesyanoe. This primordial gas was found (Eberhardt *et al.*, 1965*b*) to be in the finest grains of the matrix material and located near the surface of the grains. Anomalies were measured in krypton extracted from meteorites, thus confirming the Canadian results (Marti *et al.*, 1966). Xenon anomalies were measured and they were explained as a combination of spallation, neutron capture, and fission. Bromine and chlorine also were measured in meteorites (von Gunten *et al.*, 1965, Wyttenbach *et al.*, 1965).

Tanzania

A list was compiled (Harpum, 1964) of 25 different types of chondrules in Tanzanian chondrites.

Turkey

The Bursa and Cannakkale chondrites are described. Their rare-gas contents were measured and the following results obtained: the He 4 ages of these meteorites are 3·4 and 3·5 × 10^9 years, the Ar 40 ages are 4·1 and 4·4 × 10^9 years, and the cosmic-ray exposure ages are 2·0 and 9 × 10^6 years, for Bursa and Cannakkale, respectively (Heymann, 1966, Kizilirmak, 1965).

U.S.S.R.

Special committees of the U.S.S.R. Academy of Sciences, and other learned societies have published extensively on the subject of meteorites (Aaloe, 1963; Fesenkov and Krinov, 1964, 1965, 1966; Krinov, 1964*a*, 1965*a*, *b*, 1966*a*, *b*, *c*; Plekhanov, 1963; Vasiliev *et al.*, 1965). Translations of English books have also appeared (Mason, 1962, O'Keefe, 1963).

In the summer of 1964 a stony meteorite (achondrite), Pomozdino, weighing 327 g was discovered in the Komi ASSR. The specific feature of this meteorite is the absence of the unified fusion crust. The numerous solidified spatters seen on its crustless portions were formed by the meteorite matter, which fused in passing through the atmosphere. The meteorite was delivered to the Committee on Meteorites of the U.S.S.R. Academy of Sciences. Another stony meteorite (chondrite), Odessa, weighing 1926 g and having an oriented (bun-shaped) form was also delivered to the Committee on Meteorites (Krinov, 1965*c*).

In August and September 1965 the Committee on Meteorites, U.S.S.R. Academy of Sciences, in cooperation with the Commission on Meteorites, Academy of Sciences of Estonia SSR, and the Institute of Geochemistry and Analytical Chemistry, U.S.S.R. Academy of Sciences, conducted an expedition to study the Kaali and Ilumetsa craters. A prospect hole was sunk into the main Kaali crater and the structure of the crater's rim was studied; during these investigations the fragments of the shatter cones caused by the meteorite explosion were found in neighbouring dolomite deposits. A crater 12 m in diameter, the smallest of the group, was fully stripped of the overburden material. The initial form of the crater and the structure of its interior slopes were examined. The dispersed meteoritic matter was extracted from the overburden material. To study the structure of the rims of the Ilumetsa craters, whose meteoritic origin has not yet been definitely established, the researchers made trench-shaped cuttings through the craters' rims. The scientific data gathered by the expedition are now being studied (Krinov, 1966*d*).

The Commission on Meteorites of the Siberian Branch of the U.S.S.R. Academy of Sciences sponsored annual (1964–66) expeditions to the area of the Tunguska fall to collect scientific data. The scientists studied the area of uprooted and flattened forest and observed the character and distribution of the radiation burn, anomalous increment of trees, etc. The data obtained were processed by G. F. Plekhanov, N. V. Vasiliev, and V. G. Fast.

These scientific data, together with material collected earlier, which specified the atmospheric trajectory and orbit of the entering Tunguska substance, indicate that it was a small comet (Ivanov, 1964, Fesenkov, 1966). Experiments carried out with a model and a scaled-down explosion exactly reproduced the actual situation and showed both a blast wave and a ballistic wave effect upon the forest (Zotkin and Tsikulin, 1966).

E. L. Krinov (1964*b*) made a statistical analysis of meteorite falls and finds that occurred in the decade 1953–62.

N. I. Zaslavskaia, I. T. Zotkin, and O. A. Kirova (1964) (the Committee on Meteorites, U.S.S.R. Academy of Sciences) investigated the size distribution of the cosmic globules taken from the Tunguska fallout area and obtained the distribution curve formula.

I. V. Mikheeva and V. D. Kolemensky (1964) (the Leningrad Mining Institute) carried out comparative studies on meteoric and industrial dust by means of X-ray diffraction. For meteoric dust they used the magnetite spherules from the Sikhote-Alin fallout area, and spherules taken from an open-hearth furnace were used for their industrial dust. The data obtained show insignificant differences in the crystal lattice of the magnetite forming the globules.

Kh. A. Viiding (1965) (Tartu University) found meteoric dust (magnetite globules) in the lows of Cambrian sandstones on the territory of Estonia SSR.

V. D. Vilensky (1966) (the Institute of Geochemistry and Analytical Chemistry, U.S.S.R. Academy of Sciences) determined the specific weight of spherical particles collected in the atmosphere.

M. I. D'yakonova and V. Y. Kharitonova carried out systematic chemical analyses of the 15 main components of meteorites. Each new meteorite delivered to the Committee on Meteorites was examined, its chemical composition was determined, and its class and type were determined. They also studied the chemical compositions of both the chondrules and the matrix of meteorites, including the dark and light varieties of some chondrites, and obtained reliable data (D'yakonova, 1964, D'yakonova and Kharitonova, 1964, Kharitonova, 1965*b*).

I. A. Yudin and S. I. Smyshlyaev (the Urals Commission on Meteorites) obtained factual data on the chemical composition and mineragraphic features of opaque minerals of some stony meteorites (Smyshlyaev and Yudin, 1964, Yudin and Smyshlyaev, 1964).

L. G. Kvasha (1965) (the Committee on Meteorites, U.S.S.R. Academy of Sciences) examined the composition of chondrules and obtained results on types of chondrules and on the matrix of meteorites.

A. P. Vinogradov and G. P. Vdovykin (the Institute of Geochemistry and Analytical Chemistry, U.S.S.R. Academy of Sciences) carried out studies on the organic matter of carbonaceous chondrites and arrived at the conclusion that its origin is abiogenic (Vdovykin, 1964*a*, *b*; Vinogradov and Vdovykin, 1964; Vinogradov *et al.*, 1964*a*).

A. A. Yavnel (the Committee on Meteorites, U.S.S.R. Academy of Sciences) studied the distribution of elements in the metal phase of iron meteorites and in chondrites (Yavnel, 1964). He also examined the chemical fractionation in the silicate phase of meteorites (Yavnel, 1966*a*).

Ye. G. Gus'kova (the Leningrad Branch of the Institute of Earth Magnetism, U.S.S.R. Academy of Sciences) studied natural remanent magnetization in iron and stony-iron meteorites (Gus'kova, 1965*a*, *b*).

E. L. Krinov (1965*c*) (the Committee on Meteorites, U.S.S.R. Academy of Sciences) investigated the form, relief, and structure of the fusion crust of some new meteorites. As a result, he found, in particular, that the solidified droplet-globules and little sprays seen spattered out on the crustless meteorite (achondrite), Pomozdino, prove that the crustless portions never had a fusion crust. Hence, the absence of the fusion crust was not due to its peeling off when the meteorite collided with the ground or for any other mechanical reason.

A. P. Vinogradov and I. K. Zadorozhnyi (1964, 1965) measured the cosmogenic, radiogenic, and primary inert gases in stony meteorites.

A. P. Vinogradov and colleagues investigated nuclear reactions in iron meteorites and determined the production rates of radioactive isotopes in chondrites under the influence of cosmic rays (Lavrukhina, 1965*a*, Lavrukhina *et al.*, 1964, Surkov and Nazarkina, 1965, Vinogradov *et al.*, 1964*b*).

G. P. Lovtsus (1964) (the Radium Institute) determined the content and isotopic composition of lead in meteorites.

E. V. Sobotovich (1964) (the Radium Institute) summarized the data on the content of radiogenic and cosmogenic isotopes in meteorites.

A. K. Lavrukhina and colleagues (the Institute of Geochemistry and Analytical Chemistry, U.S.S.R. Academy of Sciences) determined cerium, europium, scandium, barium, and lead contents in the dark and light varieties of the Kunashak and Pervomaiskii Posyoelok chondrites (Lavrukhina *et al.*, 1966).

K. A. Liubarsky (1966*a*, *b*) (the Moscow State University) made a survey of the radiative ages of iron and stony meteorites.

V. G. Fesenkov (1965) (the Committee on Meteorites, U.S.S.R. Academy of Sciences) reviewed the role played by meteorites in the origin of the solar system, and stressed the necessity of taking into account the material composition and structural features of meteorites in connection with the evolution of the solar system.

A. P. Vinogradov (1965) considered the composition of meteorites and their physical and structural features in order to throw light on their origin.

B. J. Levin (1965) (the Institute of Earth Physics, U.S.S.R. Academy of Sciences) reviewed the contemporary information about the conditions of meteorite formations and examined current hypotheses.

I. E. Starik, E. V. Sobotovich, and M. M. Shats (1965) investigated the early history of both terrestrial and cosmic substances according to isotopic dating information.

A. A. Yavnel studied regularities in the composition and structure of meteorites and considered conditions under which the formation of meteorites occurs. He found that chondrites possess no equilibrium conditions in their compounds and concluded therefore that material crystallization in chondrites proceeds comparatively fast (1965, 1966*b*).

A. K. Lavrukhina (1965*b*) studied the effects of nuclear reactions caused by cosmic rays.

G. P. Vdovykin (1964*c*, 1965) investigated the carbonaceous matter of meteorites in connection with their origin.

K. N. Alexeeva (1964) (the Geology Institute, Academy of Sciences of Ukrainian SSR) studied the physical properties of tektites and obtained quantitative characteristics.

G. G. Vorobiev (1964) (the Committee on Meteorites, U.S.S.R. Academy of Sciences) carried out research on the chemical composition of tektites, and determined the beryllium content in tektites and some other glasses. He also, in collaboration with G. Shkrov (Czechoslovakia), investigated the conditions of falling out and transportation of moldavites (Vorobiev and Shkrov, 1965).

United States

Meteorite work in the United States is extensive and varied. The xenon results are most important. The most striking characteristic of xenon in most meteorites is the Xe 129 excess (Reynolds, 1963). This excess differs not only in different meteorites but also in different phases of a single meteorite. The chondrules have the highest Xe 129/Xe 132 ratio (Merrihue, 1966). Since Xe 129 arises from the decay of extinct radioactivity I 129, which has a 17 million year half-life, chondrules were the earliest to form. There is very little primordial gas in chondrules (Merrihue, 1966), which indicates that they formed under conditions that minimized the entrapment of gas. It was recently suggested (Whipple, 1966) that chondrules formed by lightning in the primitive Laplacian-type nebula. Although the Xe 129 is the most striking xenon anomaly, other anomalies exist (Reynolds, 1963). Xenon of the composition measured in carbonaceous chondrites is called primordial.

Deviations from the primordial composition are ascribed to processes such as spallation, neutron capture, fission, and the decay of extinct radioactivities. The calcium-rich achondrite, Pasamonte (Hohenberg *et al.*, in press, Rowe and Bogard, 1966, Rowe and Kuroda, 1965), has fission-type excesses in the Xe 134 and Xe 136 isotopes, which are ascribed to the extinct radioactivity, Pu 244. This Pu 244 decays mainly by alpha emission with a 76 million year half-life, but in 0·3% of the decays undergoes spontaneous fission; Pu 244 can be produced only by rapid successive neutron captures such as might occur in a super-nova explosion. The Pu 244 evidence indicates that formation of the solar system was preceded by a nearby super-nova explosion. It is puzzling (Rowe *et al.*, 1966), however, that the calcium-rich achondrites Lafayette and Nahkla do not contain Xe 134 and Xe 136 excesses indicative of Pu 244, even though they contain Xe 129 excesses. Since Pu 244 should be enriched in calcium-rich achondrites and since the shorter-lived I 129 was present, the longer-lived Pu 244 should also have been present in Lafayette and Nahkla. Excess fission tracks (Fleischer *et al.*, 1966) were observed in minerals from inclusion in the iron meteorites Toluca and Odessa and were attributed to Pu 244; however, these excess fission tracks follow the uranium contents. It is possible that the excess fission is caused by an excess neutron flux (Fireman, 1966) in the past due either to space erosion or to increased solar activity. Toluca and Odessa are large irons where large fluxes of neutrons would be expected. The case for Pu 244 in Pasamonte rests upon ruling out a host of other possibilities that might produce the excess Xe 134 and Xe 136. Because of its importance to theories regarding the formation of the solar system, a great deal of effort is being put into the study of Pu 244.

Rare gases not ascribed to radioactive decay, cosmic-ray or solar-flare interactions, or extinct radioactivities are called primordial. Extensive measurements of primordial gas have been and are being made. This work has been reviewed in a recent article (Pepin and Signer, 1965). Primordial gas has been classified into two types, a solar type with large helium and neon excesses, and a planetary type with argon, krypton, and xenon excesses. The solar type is in the dark phase of meteorites with dark and light phases and in the carbonaceous chondrites. This type of primordial gas increases with the carbon content and decreases with the degree of metamorphism. The primordial gas contents indicate that the individual grains first solidified and were later compacted together to form the parent bodies of meteorites. The individual grains were altered in the highly metamorphosed meteorites but not in the others.

Radioactivity measurements are quite extensive in the United States but have not led to results as interesting as those of the stable rare-gas measurements. To approximately a factor of two, the radioactivity measurements can be explained by the action of a constant cosmic-ray flux on the meteorite. However, factor-of-two discordances exist and may lead to important developments.

Extensive Monte Carlo calculations of changes in the orbits of small bodies with time have been made (Arnold, 1965), and confirm earlier conclusions obtained analytically by Öpik.

A camera network covering a wide area of central United States (Prairie Network) has been set up and should soon give orbits for a considerable number of meteors that result in meteorites (McCrosky and Boeschenstein, 1965).

Almost as extensive as the isotope studies are the electron-probe studies that bear on the temperature and pressure history of meteorites. The rates of cooling of the meteorite parent bodies in the temperature range of 600 to 400°C were obtained from the gradient in the nickel composition at the borders of the two metal phases, taenite and kamacite. The cooling rates were 1 to 10°C per million years (Goldstein and Ogilvie, 1965*a*, *b*; Goldstein and Short, 1966; Goldstein *et al.*, 1965; Wood, 1964, 1965). These rates are consistent with parent bodies of 300-km radius or smaller.

Electron-probe studies have shown that the degree of homogeneity of the olivine and pyroxene is related to other characteristics of metamorphism in meteorites (Dodd and Van Schmus, 1965, Keil and Fredriksson, 1964, Keil *et al.*, 1964). For example, the carbonaceous chondrites, which are primitive materials with no sign of metamorphism and have high primordial gas contents, contain olivine and pyroxene with inhomogeneous chemical compositions. In ordinary chondrites, such as Bruderheim, which show much evidence for recrystallization or metamorphism in their texture and have little or no primordial gas, the olivine has a homogeneous chemical composition throughout. This metamorphic feature has been incorporated into an improved classification scheme (Van Schmus and Wood, in press) that is very useful for systematizing the primordial gas results.

The data obtained from microphones on satellites that led to the conclusion that a dust belt exists around the Earth were found to be uncertain (Nilsson, 1966). The nature and the quantity of cosmic dust arriving at the Earth are uncertain. Merrihue (1964) found an excess He 3 in the gas released at 600° and 1000°C and an excess Ar 36 and Ar 38 in the gas released at 1400°C from a magnetic fraction of a deep-sea sediment. These results were the first positive isotopic evidence for the presence of cosmic dust widely distributed on Earth. The argon anomaly in sea sediment was confirmed by a number of other scientists. There is also an indication for Al 26 in sea sediments (see Lal and Venkatavaradan, 1966). Dust from the polar ice sheets has given isotopes characteristic of an extraterrestrial component (Fireman, 1967, Tilles, 1967), but no Al 26 (Fireman and Langway, 1965). The discrepancy between sea sediment and polar dust Al 26 is probably due to the dissolution of the Al 26-containing material in the ice.

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