sults of application of the corrections, required by the Smithsonian Standard Earth, to the coordinates obtained from the land survey (*7*). To check possible errors in surveying or modeling we investigated the effects of variation in these coordinates. Since, for the observations under discussion, the effect of change in the station altitude could be almost exactly duplicated by a suitable change in its latitude, only variations in latitude and longitude were considered. The making of a weighted-least-mean-square fit to the raw residuals, for estimation of corrections to the latitude and longitude, led to changes of a few seconds of arc in these coordinates. The root-mean-square values of the after-fit residuals, although of course reduced, were still essentially double the estimated errors. Thus we are left with discrepancies whose absolute values average about 0.3 hz, corresponding to unexplained average variations of nearly 0.6 cm/sec in the radial velocity between the Haystack site and the subradar point on Moon.

Most but by no means all of the sets of data have residuals that appear to vary nearly linearly with time. The implied discrepancies in radial acceleration vary from about 3×10^{-5} to 10^{-4} cm/sec^2. The sets of data are unfortunately too far apart for reliable inference of the periodicities in the residuals; presumably they are of the order of 1 day. Although seemingly very small, such residuals are larger by several orders of magnitude than lunar accelerations attributable to, say, the second harmonic of Earth's gravitational field, or the differential gravitational effect of Venus. Thus it is hard to believe that these residuals are attributable to shortcomings of the lunar ephemeris. Earth's rotation also appears to be known with more than sufficient accuracy for this application. Nonetheless, recent independent evidence from deep space probes (*8*) indicates that the site-Moon ephemeris has similar but substantially smaller errors.

To check the possibility of errors in our computer calculations, we requested independent computation of the Doppler shifts corresponding to a random selection of ten of our data points. The results (*9*) in most instances showed greater disparity when compared with the observed values. The differences between the corresponding theoretical results, varying from 0.05 to 0.2 hz, also remain unresolved.

A sustained series of closely spaced radar observations of Moon, under varying conditions of weather and lunar elevation above the horizon, may provide the clues to enable elimination of these perplexing differences between theory and observation.

CARL R. SMITH*
GORDON H. PETTENGILL
IRWIN I. SHAPIRO†
FRANKLIN S. WEINSTEIN
Lincoln Laboratory, Massachusetts Institute of Technology, Lexington

References and Notes

1. At Lincoln Laboratory's Haystack microwave facility, Massachusetts Institute of Technology.
2. See, for example, J. D. Mulholland and N. Block, *Jet Propulsion Laboratory Tech. Mem. 33–346* (Aug. 1967).
3. P. E. Green, *J. Geophys. Res.* **65**, 1108 (1960).
4. T. W. Thompson and R. B. Dyce, *ibid.* **71**, 4843 (1966); G. H. Pettengill and T. W. Thompson, *Icarus*, in press.
5. Provided on magnetic tape 9314 (DE-19-A) by Jet Propulsion Laboratory.
6. I. I. Shapiro, M. E. Ash, M. J. Tausner, *Phys. Rev. Letters* **17**, 933 (1966).
7. E. M. Gaposchkin, personal communication; *Smithsonian Astrophys. Observ. Spec. Rept. 200* (1967), vol. 3.
8. C. Cary and W. Sjogren, *Science*, this issue.
9. W. Sjogren, personal communication.
10. We thank M. E. Ash, K. Becker, A. Forni, W. Mason, and T. W. Thompson for their contributions in preparation and writing of the computer programs; J. Bauer kindly provided the models of the neutral atmosphere and ionosphere. Lincoln Laboratory is supported by the U.S. Air Force; a portion of this work was aided by NASA contract NSR 22-009-106.

* Present address: Department of Physics, University of Maryland, College Park.

† Present address: Department of Geology and and Geophysics, and Department of Physics, Massachusetts Institute of Technology, Cambridge.

11 December 1967

Denver Meteorite: A New Fall

Abstract. *A meteorite, a single stone weighing 230 grams, was discovered in the roof of a warehouse on 17 July 1967; evidently it fell during the preceding week. The warehouse is on the northeast edge of Denver, Colorado; coordinates, 39°46′57″N, 104°55′50″W. This is the first recovered fresh fall in the United States since the Bells (Texas) meteorite of 9 September 1961. The composition and structure are those of an olivine-hypersthene chondrite.*

Meteorite researchers in the United States have felt frustrated by the few recoveries of meteorites in recent years. Whereas statistics indicate that about ten meteorites probably fall within the United States annually, we now report the first recovery since the Bells (Texas) meteorite of 9 September 1961. A small meteorite penetrated the roof of a Denver, Colorado, warehouse (*1*) in July 1967. A search of the neighborhood for possible additional stones from the same fall was unproductive.

The meteorite was discovered on 17 July 1967 when water dripped through the ceiling. Inspection of the roof (flat galvanized-steel sheeting covered with tar and stone chips) revealed a small hole, with the meteorite, a 230-g stone, resting on the inner ceiling about 15 cm below. Heavy rain had fallen on 15 July; the meteorite presumably fell either during or before the rain, but after the preceding rain on 11 July. None of the usual visual and sound effects associated with the fall of a meteorite were observed, but the warehouse is close to the Denver airport and two military airfields, so that loud noises and bright flashes of light do not attract much attention.

The Colorado School of Mines Prospector Service reported that the stone was probably a meteorite and suggested that it be sent to the U.S. National Museum for confirmation. It was received as a rounded stone the size and shape of a small fist; a piece (*2*) had been removed from one end evidently by a diamond saw. The stone had the typical dull-black fusion crust and gray-white interior of a chondritic meteorite. The original weight of the stone was approximately 230 g; density, 3.58.

The mineralogic composition of the meteorite is (percentages by weight) olivine [$(Mg_{0.76}Fe_{0.24})_2SiO_4$], 45; hypersthene [$(Mg_{0.79}Fe_{0.21})SiO_3$], 25; plagioclase [(Na,Ca) $(Al,Si)_4O_8$, (9 mole percent $CaAl_2Si_2O_8$)], 11; nickel-iron, 8; troilite (FeS), 6; diopside [Ca-$(Mg,Fe)Si_2O_6$], 5; chromite ($FeCr_2O_4$), 1; and merrillite [$Ca_3(PO_4)_2$], 1. Such composition is typical of olivine-hypersthene chondrites, the commonest class of meteorites, that comprise about 40 percent of observed falls.

Occasional chondrules as large as 2 cm in diameter are visible on the cut surface of the meteorite. The chondritic structure is not prominent in a thin section under the microscope; the margins of individual chondrules are diffuse and tend to merge with the crystalline groundmass. Interstitial plagioclase is unusually well developed but does not show the polysynthetic twinning characteristic of this mineral in terrestrial rocks. A large grain of merrillite was noted in the thin section. Composition and structure place this chondrite in the L6 type (*3*).

Chemical analysis gave the following percentages by weight: SiO_2, 40.57; TiO_2, 0.14; Al_2O_3, 2.48; Cr_2O_3, 0.47; FeO, 14.16; MnO, 0.33; MgO, 25.30;

CaO, 1.83; Na_2O, 1.01; K_2O, 0.12; P_2O_5, 0.23; H_2O^+, 0.00; H_2O^-, 0.05; C, 0.05; FeS, 5.71; Fe, 6.46; Ni, 1.17; and Co, 0.06.

The history of this meteorite exemplifies the problems of effective recovery. Had the stone fallen a few meters farther east it would have landed in a vacant lot; even if it had been noticed by a casual passerby, probably the inconspicuous black stone would not have been retrieved for scientific study. By fortunate chance it landed on the warehouse roof with sufficient force to punch a hole and cause a leak. Such occurrences are naturally extremely rare: in 1958 LaPaz (*4*) recorded 27 meteorites (from Barbotan, France, in 1790 to Sylacauga, Alabama, in 1954) known to have damaged buildings.

BRIAN MASON
E. JAROSEWICH

U.S. National Museum,
Washington, D.C. 20560

References and Notes

1. Nationwide Papers, Inc., 4800 East 48 Avenue, Denver, Colo.
2. Later recovered from Nationwide Papers, Inc.
3. W. R. Van Schmus and J. A. Wood, *Geochim. Cosmochim. Acta* **31**, 747 (1967).
4. L. LaPaz, *Advan. Geophys.* **4**, 217 (1958).
5. We thank U.S. Plywood–Champion Papers Corp., parent company of Nationwide Papers, Inc., for presenting this meteorite to the U.S. National Museum, and for the cooperation and help of its staff.

10 April 1968

Oxygen-Isotope Ratios in Phosphate from Fossil Marine Organisms

Abstract. *Well-preserved fossil marine organisms generally yield very positive* $\delta^{18}(PO_4^{3-})$ *values which are considered to result from relatively good preservation of the original oxygen-isotope composition of phosphatic material deposited under isotopic equilibrium conditions in oceanic water whose* $O^{18}{:}O^{16}$ *ratio was more positive than that of modern oceans.*

Measurements of oxygen-isotope compositions of phosphate and carbonate from shells and skeletons of living and fossil marine organisms have been reported (*1*, *2*); a tentative equation for the phosphate-water isotopic temperature scale was given, together with the first group of measurements made on some Paleozoic and Mesozoic fossils. Several Jurassic and Cretaceous belemnites showed $\delta O^{18}(PO_4^{3-})$ values (*3*) so positive as to correspond to temperatures even lower than 0°C on the tentative scale established. This fact was considered to result from deposition of phosphatic material under isotopic equilibrium conditions in an oceanic water whose $O^{18}{:}O^{16}$ ratio was more positive than that of modern oceans.

We now report further measurements made on shells and skeletons of fossil marine organisms of Mesozoic and Tertiary ages. The fossils came mainly from North America and Europe (France, England, Germany, Belgium, Netherlands, Italy, Scotland, Denmark, Sweden, and the U.S.S.R.). Belemnites and pelecypods were mainly used, along with some fish teeth, brachiopods, and a few other organisms.

The technique used for purification of the phosphate of the samples, quantitative extraction of the oxygen by fluorination with bromine trifluoride, and its conversion to CO_2 for spectrometric measurements has been described (*1*). The standard deviation of the measurements is ± 0.2 per mille.

We have checked in some living pelecypods, belonging to the same (or similar) genera as some of our fossil specimens, that the phosphate contained in their shells is precipitated under isotopic equilibrium conditions. With regard to fish teeth, our measurements on living specimens confirm that, at least in the case of the species studied, the phosphate is precipitated under equilibrium (or quasi-equilibrium) conditions.

Our samples and results are listed in Table 1; results for samples 1 to 41 have been published (*2*). The $\delta O^{18}(PO_4^{3-})$ values are given versus the SMOW isotopic standard (*3*); they are plotted in Fig. 1 against the geological ages attributed to the fossils.

If one tries to interpret the results in Fig. 1 in terms of paleotemperatures, the temperature results are unreliable. From the most positive isotopic data, and assuming that δ-water is zero, we calculate temperatures that are generally not far from 0°C. On the other hand one cannot calculate both the temperature and the oxygen-isotope composition of ocean water from a phosphate-carbonate isotopic temperature scale (*2*).

We assume that the wide range of isotopic values obtained for each geological level is due only to effects of postdepositional isotopic exchange between the fossils and groundwater. This assumption is confirmed by an evident positive relation between the isotopic values and the degrees of preservation of the fossils. Other evidence of postdepositional exchange processes is the fact that Paleozoic fossils always show very negative and very uniform values in their phosphate-isotope composition. A freshwater fossil (*Antraconauta phillipsii*, sample 32) shows (*2*) the same oxygen-isotope composition as do the sea-water fossils *Obolus* and *Lingula* whose $\delta O^{18}(PO_4^{3-})$ values are close to the δO^{18} value that can be calculated for a phosphate in isotopic equilibrium with rainwater at room temperature.

The isotopic values from belemnites are generally more positive than those from coeval pelecypods or brachiopods as to both carbonate and phosphate. This fact seems quite reasonable if one assumes that (i) isotopic exchange processes for phosphate and carbonate were similar, the only difference being a different rate of exchange; and (ii) the shape of belemnites (very compact structure and relatively small exchange surface) is the best suited for slowing postdepositional exchange processes. The possibility that exchange processes occur normally between fossil shells and groundwater, even rapidly (geologically speaking), is indicated indirectly by the work of Fanale and Schaeffer (*4*); determination of the ages of fossil shells, by the helium-uranium method, led to the conclusion that in the case of Eocene, Oligocene, and Miocene fossils there was evident exchange of uranium between the fossil and local groundwater. It seems quite reasonable that similar exchange processes occur normally in the case of oxygen isotopes. Carbonates should exchange at a much higher rate than do phosphates because of the difference in the activation energies, and the difference in the energy bond between oxygen and C or P atoms.

Let us assume that only the fossils that show very positive $\delta O^{18}(PO_4^{3-})$ values have preserved reasonably well the original isotopic compositions. Starting from such a consideration it seems obvious that we should try to explain our results by assuming that the phosphate of the fossil shells and skeletons was precipitated under isotopic-equilibrium conditions, at unknown temperatures, in oceanic water whose oxygen-isotope composition was more positive than that of modern ocean water.

The oxygen-isotope composition of