Table 2. Spectroscopic analysis of whitlockite in chondrites. In the third column heading, M stands for the metal indicated at the left of the various values.

Metal	Micrograms*	Moles M_xO in $3 M_xO \cdot P_2O_5$
	Allegan	
Mg	0.06	0.2
Fe	.08	.2
Ca	.8	2.5
Na	.04	.1
	Waconda	
Mg	0.025	0.3
Fe	.02	.1
Ca	.35	2.5
Na	.012	.1
	Holbrook	
Mg	0.07	0.4
Fe	.05	.1
Ca	.7	2.4
Na	.028	.1

* 0.01 μg of silicon was reported in this analysis and is believed to represent a silicate contamination. The silicon, together with amounts of Mg and Fe corresponding to an olivine composition of forsterite$_{75}$, are omitted.

with a calcium content of 0.8 μg, successfully detected, was also below the limit of detection for phosphorus. Assuming the sum of the metal oxides exist in the ratio of 3 moles per mole of P_2O_5, as in isostructural β $Ca_3(PO_4)_2$, an approximate formula for whitlockite in these meteorites is $0.3\ MgO \cdot 2.5\ CaO \cdot 0.1\ FeO \cdot 0.1\ Na_2O \cdot P_2O_5$. The formula agrees fairly well for that of terrestrial whitlockite from Palermo quarry, except for the Na_2O reported by Frondel, and is consistent with some studies of binary phosphate systems made by Ando. He found that a maximum of about 0.4 mole MgO could substitute for CaO in β $Ca_3(PO_4)_2$ in the system $3\ MgO \cdot P_2O_5 - 3\ CaO \cdot P_2O_5$. The amount of MgO in substitution depends on the temperature of formation and the rate of cooling in a relatively insensitive manner. In the system $Ca_3(PO_4)_2 - CaNaPO_4$, Ando found that the β $Ca_3(PO_4)_2$ structure can accommodate 0.1 mole of Na_2O but that samples with 0.3 or 0.2 moles of Na_2O per mole of P_2O_5 yield x-ray diffraction patterns of β $CaNaPO_4$ and β $Ca_3(PO_4)_2$. The latter structure does not form when Na_2O is equal to or exceeds 0.4 mole.

In the chondrites studied, whitlockite occurs as xenomorphic grains 0.1 to 0.6 mm in diameter, and is generally found in the silicate matrix of the meteorite. It adjoins the grain edges of silicates, iron-nickel, troilite, ilmenite, magnetite, and chromite. Inclusions of these minerals are common. Only in the Plainview chondrite, was whitlockite observed inside a chondrule. Since the formation of chondrules is not well understood, the significance of this observation is not readily apparent. The optical properties for meteoritic whitlockite are similar to those found by Frondel but generally have slightly smaller refractive indices: $N = 1.624 \pm 0.002$. The birefringence is very weak, about 0.002. The grains are clear and colorless with a vitreous luster. Preliminary surveys made on etched polished sections indicate the mineral occupies from 0.1 to 0.2 percent of the volume of the stone. Harrisonville contains the highest concentration, about 1 percent of the volume.

In those chondrites where whitlockite and chlorapatite coexist, they occur as monomineralic grains dispersed throughout the matrix of the stone. This mutual association is consistent with the phase diagram of the binary system $CaCl_2$–$Ca_3(PO_4)_2$ (*7*). The separation suggests slow cooling of a melt accompanied by crystal fractionation. On the other hand, both phosphate minerals appear as interstitial fillings in the silicate matrix, are without crystal form, and contain inclusions of most of the other minerals present in the stone.

The evidence presented here suggests that the previously recognized meteoritic mineral merrillite is actually whitlockite. In addition, the formula for merrillite ($3\ CaO \cdot Na_2O \cdot P_2O_5$) is in disagreement with the findings of Franck, Bredig, and Frank (*8*), who report that the only ternary compound found in the system CaO-Na_2O-P_2O_5 is $2\ CaO \cdot Na_2O \cdot P_2O_5$, which is stable up to 1450°C even in the presence of free CaO.

The high temperature form, α $Ca_3(PO_4)_2$, is not known to occur naturally but can exist as a metastable compound at room temperature owing to the sluggish inversion at 1185°C; however, substitution of 0.1 mole of magnesia for lime prevents the β-α transition even up to 1450°C, as shown by Ando. The presence of whitlockite in meteorites cannot be regarded as conclusive evidence for a temperature of formation of less than 1450°C. Additional studies on synthetic preparations of compositions in the neighborhood of meteoritic whitlockite are needed. The stability of the mineral phosphates in contact with the associated minerals at elevated temperatures may affect our ideas concerning the origin of stony meteorites. Phosphorus can be present in both the oxidized and reduced state; reliable identifications of the phosphates can be made with the techniques employed in this study, which yield information on the distribution and occurrence of the phosphorus present. This work will be extended to include an investigation of an extended group of chondrites as well as the achondrites.

LOUIS H. FUCHS
Argonne National Laboratory, Argonne, Illinois

References and Notes

1. E. V. Shannon and E. S. Larsen, *Am. J. Sci.* (1925), p. 250.
2. Details of this technique are in preparation for publication elsewhere.
3. C. Frondel, *Am. Mineralogist* **26**, 145 (1941).
4. I am indebted to Dr. George Reed for supplying the samples of the meteorites, to John Faris for the spectroscopic data, to Dr. Stanley Siegel and Elizabeth Gebert for the x-ray diffraction results, and to Dr. George Montet for a critical review of the manuscript; all are employees of this laboratory. Special thanks are accorded Prof. Clifford Frondel of Harvard University for supplying a sample of whitlockite from the Palermo pegmatite. While this paper was being revised it was learned from him that studies relating to the identity of merrillite are underway at Harvard. Dr. Brian Mason kindly furnished the sample of the Waconda chondrite. This work was performed under the auspices of the U.S. Atomic Energy Commission.
5. J. Ando, *Bull. Chem. Soc. Japan* **31**, 201 (1958).
6. S. B. Hendricks, M. E. Jefferson, V. M. Mosley, *Z. Krist.* **81**, 355 (1932).
7. R. Nacken, *Zentr. Mineral. Geol.* (1912), p. 545.
8. H. H. Franck, M. A. Bredig, R. Frank, *Z. Anorg. Allgem. Chem.* **230**, 1 (1936).
9. M. A. Bredig, H. H. Franck, H. Füldner, *Z. Elektrochem.* **38**, 160 (1932).

18 April 1962

Electron-Microscope Studies of Braarudosphaera bigelowi and Some Related Coccolithophorids

The Coccolithophoridae are planktonic marine flagellates which produce complex calcite skeletal elements called coccoliths. Fossil coccoliths are currently receiving much study, and have been shown to have great value as index fossils. In many instances the forms are distinctive and large enough to be readily identified in the light microscope. However, study of the smaller species and of detailed structure of the larger forms is best made on carbon replicas of their surfaces in the electron microscope.

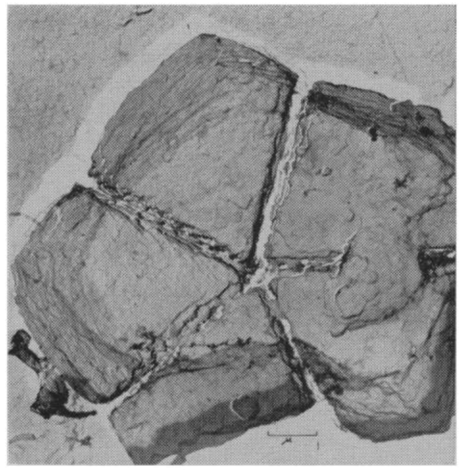
Genera of the family Coccolithophoridae having coccoliths made of five calcite units, each a single crystal, are placed in the subfamily Braarudosphaerinae. Braarudospherids show relatively few distinctive characteristics in the light microscope, but electron micrographs of these forms show that they have complex fine structures.

Braarudosphaera bigelowi (Gran and Braarud), originally described from the Recent plankton of the Bay of Fundy, is also common in older beds, having been reported from deposits as old as Cretaceous. A five-sided coccolith (or "pentalith") of this species is shown in Fig. 1. The pentalith consists of five four-sided trapezoidal plates. The sutures along which the plates are joined do not exactly bisect the sides of the pentalith and there is a fivefold axis of symmetry. It is not known exactly what holds the plates of the pentalith together, but there may be some sort of chitinous film joining them. In the living organism, 12 pentaliths are joined together to form a dodecahedral coccosphere within the protoplasm. The coccospheres disintegrate readily, but the individual pentaliths are relatively durable. The edges of the pentaliths show a distinct lamination, while the upper and lower faces are smooth.

An Upper Cretaceous pentalith of uncertain affinites (Fig. 2) superficially resembles *Braarudosphaera bigelowi* so closely that it might easily be confused with it in the light microscope. However, the five plates which form this pentalith have a distinctive arrangement. Four of the plates overlap each other in a regular fashion, but the fifth lies beneath all the other plates. The hole in the center of the pentalith is much larger than is the case with *B. bigelowi*. Some of the Upper Cretaceous references to *B. bigelowi* may refer to these indeterminate pentaliths.

Braarudosphaera undata Stradner (Fig. 3), originally described from the Paleocene of Austria, differs from *B. bigelowi* in having sutures which terminate at the points of the pentalith and in having undulate edges. The laminar structure shows up clearly in the electron micrograph. The outlines of calcite rhombs may be distinctly seen on the surface.

The genus *Pemma* differs from *Braarudosphaera* in having pentaliths with more nearly circular outline, and by the presence of a "pore" in each of the five plates. The electron micrograph of a specimen of *Pemma rotundum* (Figs. 4 and 5), the type species of the genus, reveals that the "pore" is not an actual perforation of the plate, but is a deep



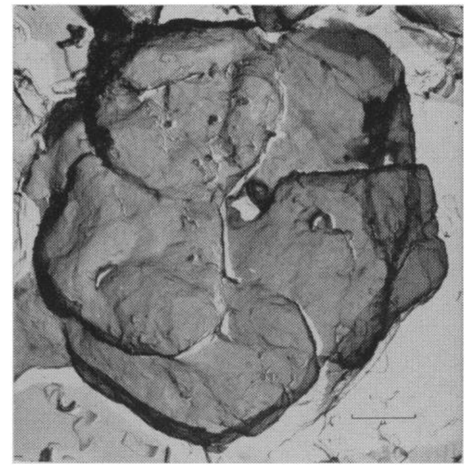
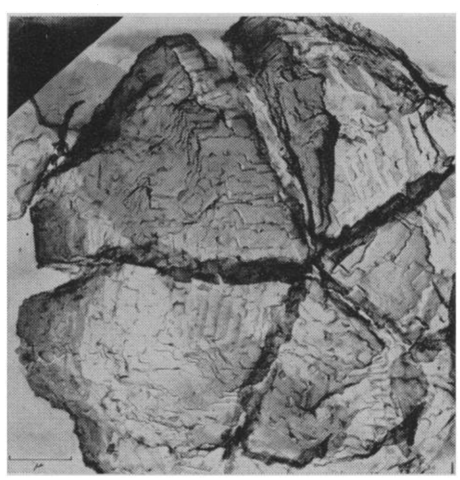


Fig. 1 (left). *Braarudosphaera bigelowi*; (Gran and Braarud); Lutetian; Donzacq, Landes, France. [University of Illinois, Electron Microscope Laboratory (E.M.L. No. 2091)]. Fig. 2 (right). Undetermined coccolithophorid; Campanian; Folx-Les-Caves, Belgium. [E.M.L. No. 2041].



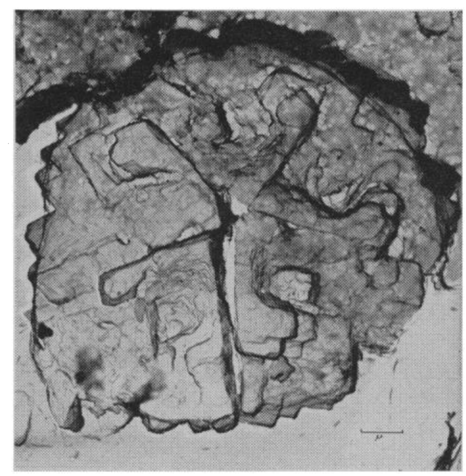
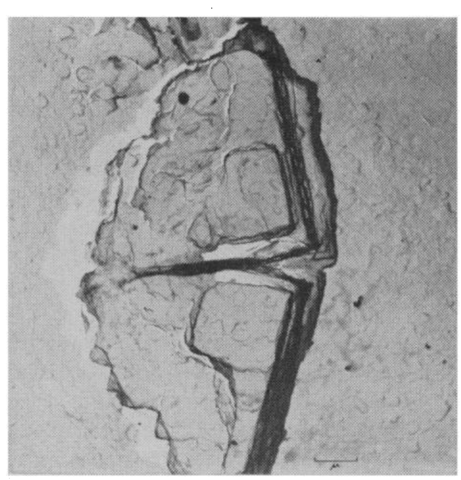


Fig. 3 (left). *Braarudosphaera undata* Stradner; Lutetian; Donzacq, Landes, France. [E.M.L. No. 1934]. Fig. 4 (right). *Pemma rotundum*; Lutetian; Donzacq, Landes, France. [E.M.L. No. 2099].



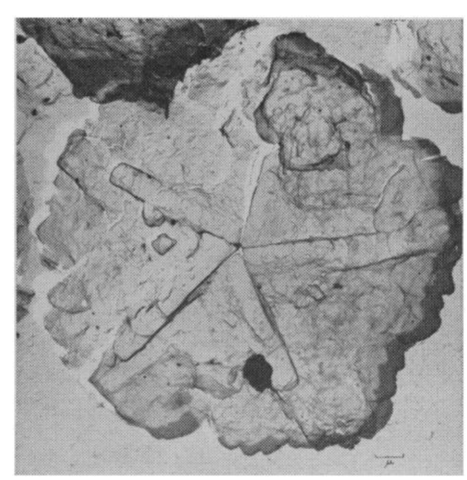


Fig. 5 (left). *Pemma rotundum*; Lutetian; Donzacq, Landes, France. [E.M.L. No. 2092]. Fig. 6 (right). *Micrantholithus flos*; Lutetian; Donzacq, Landes, France. [E.M.L. No. 2098].

depression on one face, probably the facies distalis of Stradner (*1*) (Fig. 4). The other face, probably the facies proximalis of Stradner, possesses a rhomboidal raised area instead of a depression (Fig. 5). The "pores" are bordered by a raised area extending from the center of the pentalith along the right suture of each plate, then curving halfway around each "pore." The edge of the pentalith is clearly serrate, with about six serrations per plate. The edges of the serrations correspond to the edges of calcite rhombs, and all rhombs in one plate have the same orientation.

The members of the genus *Micrantholithus* are usually five-pointed star-shaped pentaliths. The type species of the genus, *Micrantholithus flos*, is composed of five triangular plates with raised edges along the sutures (Fig. 6). The specimen shown in the electron micrograph is badly corroded in places, so that the symmetry is no longer perfect. However, the raised areas bordering the upper right suture can be seen to have almost exactly the same width, and the species, when viewed in the light microscope, appears to be absolutely symmetrical.

The coccoliths with the pentameral symmetry discussed above appear to be quite distinctive but the electron micrographs reveal that they are made of the same structural elements. The differences between them are differences chiefly of ornamentation; their structural similarity implies a close genetic relationship.

W. W. HAY
KENNETH M. TOWE
Department of Geology and
Electron Microscope Laboratory,
University of Illinois, Urbana

Reference

1. H. Stradner, *Erdoelzeitschrift* **75**, 487 (1959).

12 February 1962

Acute Radiosensitivity in Mice of Differing W Genotype

Table 1. Thirty-day mortality, after whole-body x-irradiation of mice differing in *W*-series genotype and in genetic background.

Genotype	Mortality (dead/total) of mice exposed to x-ray at levels indicated (r)						$LD_{50/30}$ (r)	95% confidence limits (r)
	540	595	650	715	785	864		
			WC × C57BL/6 females					
WW^v	7/7	13/13	6/6				280*	
W^vw	0/11	3/13	8/21	14/18	16/20	10/10	663	635–692
Ww	0/10	3/12	12/23	17/19	10/17	10/10	665	†
ww	0/8	1/23	1/16	14/28	31/36	9/10	715	690–740
			WC × C57BL/6 males					
WW^v	15/15	9/9	4/4				240*	
W^vw	1/9	6/12	12/16	26/26	25/26	4/4	595	559–634
Ww	2/16	6/12	14/18	18/18	26/27	8/8	600	573–628
ww		3/18	6/21	38/56	14/17	5/5	680	656–704
			WB × C57BL/6 females					
WW^v							350*	
W^vw	0/10	2/10	4/15	6/10	15/20	9/9	692	646–740
Ww	0/11	2/13	3/13	11/14	14/20	8/8	690	651–732
ww	0/10	0/10	0/8	2/10	9/20	11/11	765	735–795
			WB × C57BL/6 males					
WW^v		3/3					340*	
W^vw	0/5	1/7	10/19	12/12	13/13	4/4	635	610–660
Ww	0/9	1/12	6/21	13/14	12/12	5/5	655	625–685
ww	1/15	0/13	3/11	13/20	18/24	13/14	725	696–754

* LD_{50} estimated from mice x-irradiated with 200, 250, 300, 350, or 450 r; six mice exposed per dose. † Not determined because of poor curve fit.

Early in the study of the responses of animals to the effects of ionizing irradiation, the existence of a spectrum of radiosensitivity became apparent. Species differences were noted (*1, 2*), and strain differences were established in mice (*2–4*). Sex differences (*5*) and differences with age (*4, 6*) were reported. In the studies reported here (*7*) it was found that single gene differences can also alter the ability of an organism to survive an exposure to a single large dose of x-rays. This report also presents evidence that the substitution of mutant alleles of the *W*-series for the normal *w* in mice clearly decreases the animal's resistance to radiation.

The *W*-series genes studied in these investigations induce manifold pleiotropic effects. They affect fertility, coat-color pigmentation, and size and number of red blood cells. Consequently, each of the *W*-genotypes studied can be distinguished phenotypically. Hematologically, animals of the WW^v genotype are severely anemic, W^vw animals are slightly anemic, and animals of the Ww and ww genotypes are normal (*8*).

The experiment was designed to minimize other variables which influence radiosensitivity. To this end, intralitter comparisons were made, and animals of two different genetic backgrounds were used for confirmation. The mice used in these experiments were hybrids prepared by crossing animals of inbred strains WB and WC of the genotype Ww with mice of the genotype W^vw made congeneric with mice of strain C57BL/6J by repeated backcrossing (the lowest backcross generation used in these experiments was b.c. 30). Diagrammatically these crosses may be represented thus: WB-Ww × C57BL/6-W^vw, and WC-Ww × C57BL/6-W^vw. It is obvious that the genotypes resulting from these matings would be WW^v, W^vw, Ww, and ww, all segregating in the same litter and, for practical purposes, genetically identical except for the *W*-gene substitution.

The mice were separated at weaning according to sex, housed separately according to litter, maintained on laboratory mouse chows, and given free access to water from the time of weaning to the termination of the experiments 30 days after irradiation. All the animals were 60 to 90 days old at the time of exposure to x-irradiation. All members of a segregating litter were exposed simultaneously so that small variations in x-ray dosage would be equivalent for all categories of genotype, sex, and so forth. Local differences in field density were offset by the use of a motor-driven plywood exposure chamber which revolved horizontally in the x-ray field at the rate of 18 rev/min. X-rays were delivered from a General Electric Maxitron unit operated at 250 kv (peak) and 20 ma with added filtration of ½ mm of Cu plus 1 mm of Al. The distance from target to specimen was 56 cm, and the dose rate was approximately 70 r/min.

Radiosensitivities were calculated as $LD_{50/30}$ values by the method of Litchfield and Wilcoxon (*9*).

The data given in Table 1 clearly indicate that (i) homozygous anemic mice (WW^v) are extremely radiosensitive; (ii) the two heterozygous varieties (W^vw and Ww) are similar to one another in radiosensitivity but less radioresistant than homozygous normal mice