

the 0.45 μ filter was in colloidal form. However, the uniform results (Table 1) for the coastal cores (Nos. 1 and 2) and for cores 7 and 8 and Morgan's data on the oxidation state of manganese argue against this.

12. A. Nissenbaum and I. R. Kaplan, unpublished data.
13. M. N. A. Peterson, R. R. Brooks, I. R. Kaplan, *Hot Brines and Recent Iron Formations in the Red Sea* (Springer-Verlag, New York, in press).
14. H. Craig, *Science* **154**, 1544 (1967).
15. It is unlikely that this value is due to contamination or evaporation of water, since the sodium value is normal.

16. K. Bostrom and M. N. A. Peterson, *Econ. Geol.* **61**, 1258 (1966).
17. R. Chester, in *Chemical Oceanography*, J. P. Riley and G. Skirrow, Eds. (Academic Press, New York, 1965), vol. 2, p. 23.
18. S. S. Barnes, *Science* **157**, 63 (1967).
19. Supported by U.S. Atomic Energy Commission grant AT(11-1)-34-PA134. We thank Dr. W. R. Riedel, Scripps Institution of Oceanography, and Dr. D. Gorsline, University of Southern California, for the supply of cores. Contribution No. 619 from the Institute of Geophysics and Planetary Physics, University of California, Los Angeles.

27 September 1967

Stanfieldite: A New Phosphate Mineral from Stony-Iron Meteorites

Abstract. A new mineral, stanfieldite, $Ca_4(Mg,Fe)_5(PO_4)_6$, has been found in the Estherville mesosiderite and several pallasites: Santa Rosalia, Albin, Finmarken, Imilac, Mount Vernon, and Newport. The atom ratio Mg:Fe of this mineral varies from 1.5 in Estherville to a constant ratio of about 15 in the pallasites. X-ray, optical, and chemical data for the mineral resemble those for the only intermediate compound in the system $Mg_3(PO_4)_2-Ca_3(PO_4)_2$.

Stanfieldite (I), $Ca_4(Mg,Fe)_5(PO_4)_6$, a mineral unknown in terrestrial rocks, has been discovered in trace amounts (less than 1 percent) as irregular-to-subhedral grains, up to 1 mm in diameter, concentrated along the walls of fracture cracks in two specimens examined of the Estherville mesosiderite. Merrill (2) described this meteorite, a fall, noting the presence of an unidentified calcium phosphate mineral. Since stanfieldite is here associated with whitlockite [ideal formula, $Ca_3(PO_4)_2$], it is not known which was observed by him because both minerals were then unidentified. Stanfieldite also occurs in six pallasites, all of which are finds.

The mineral assemblage in Estherville indicates that nonequilibrium conditions existed during the history of this meteorite. Thus tridymite is present within 0.1 mm of olivine; and the iron and magnesium contents of the orthopyroxene show large variations from grain to grain, although no zoning of these elements was observed within grains that were removed for electron-microprobe analysis. The mole percentage of the ferrosilite molecule ($FeSiO_3$) varies from 14 to 32 in orthopyroxene; that of the fayalite molecule (Fe_2SiO_4) varies from 26 to 34 in olivine. Other minerals present are taenite, kamacite, troilite, schreibersite, ilmenite, chromite, and calcium plagioclase (An_{90}). Lamellae observed in the chromite have been shown to be rutile (3).

Three phosphate minerals were identified in the pallasites studied: stanfieldite, whitlockite, and farringtonite

[ideally $Mg_3(PO_4)_2$]. Stanfieldite was the only phosphate found in Albin, Newport, Finmarken, and Imilac; it occurs with whitlockite in Santa Rosalia and Mount Vernon; only farringtonite was found in Krasnojarsk, Phillips County, and Springwater—the latter was the "type" meteorite in which farringtonite was discovered (4). All identifications were confirmed by x-ray powder photographs. No phosphates were found in Admire, Glorieta Mountain, or Brenham (5).

The phosphate minerals in the pallasites occur as thin veinlets, a fraction of 1 mm in width, penetrating cracks in olivine, or as pockets up to several millimeters in diameter in the olivine matrix. One inclusion of stanfieldite in Newport was practically enclosed by troilite. One should mention that the observed occurrences are limited by the size and nature of the particular specimens available; more suitable samples may reveal findings other than those I report for these particular samples.

However, a special effort was made to find stanfieldite or whitlockite, or both, in meteorites containing farringtonite, with negative results. Wahl (6) has reported farringtonite from Newport and three other pallasites not available to me. If his identifications are correct (his evidence is not reported), Newport contains both stanfieldite and farringtonite. The association of these two minerals is important for fixing of the range of the calcium:magnesium ratio in the phosphatic material prior to crystallization.

Other minerals in the pallasites are

given by Mason (7) as kamacite, taenite, troilite, schreibersite, olivine, chromite, and lawrencite; they do not include plagioclase, orthopyroxene, or tridymite. I have found copper metal in Newport and Mount Vernon. Mason reports that the olivine is of uniform composition within each pallasite; thus, unlike the Estherville occurrence, stanfieldite in the pallasites probably crystallized in an equilibrium environment.

Under the microscope, stanfieldite is generally clear and transparent but has a reddish-to-amber tint when viewed in a specimen. Pockets of the mineral in Finmarken and Mount Vernon are bluish-white because of weathering (8). No discernible cleavage was noted for any of the occurrences. The optical properties for the mineral in Estherville follow: biaxial positive; refractive indices for sodium light are $\gamma = 1.631$, $\beta = 1.622$, $\alpha = 1.619$ (all ± 0.002); $2V$, $50^\circ \pm 2^\circ$. The indices for the mineral in Santa Rosalia are lower: $\gamma = 1.604$ and $\alpha = 1.594$ —probably because of its lower FeO content. The mineral in Albin had the largest $2V$, 55° to 60° ; otherwise the indices equal those in Santa Rosalia.

Stanfieldite is monoclinic; x-ray powder data appear in Table 1. Cell constants, determined from Weissenberg photographs of the Estherville material, are: a , 17.16 ± 0.03 Å; b ,

Table 1. X-ray powder diffraction data for stanfieldite from the Estherville meteorite. Norelco powder camera (diameter, 11.45 cm); CoK_{α_1, α_2} Fe filter. Diamond powder used as an internal standard. There were 49 additional lines of intensity 2 or less below 1.847 Å.

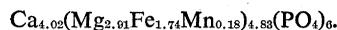
Relative intensity	dÅ observed	Relative intensity	dÅ observed
5	8.31	10	2.817
5	6.01	2	2.734
½	5.412	3	2.695
3	5.006	½	2.651
½	4.810	½	2.603
½	4.603	8	2.505
1	4.340	1	2.414
½	4.209	½	2.348
½	4.110	2	2.294
½	3.941	1	2.264
6	3.845	1	2.210
8	3.747	2	2.170
½	3.596	2	2.130
3	3.256	1	2.080
½	3.196	2	2.014
1	3.098	1	1.961
3	3.048	½	1.917
1	2.959	½	1.888
		4	1.870
		1	1.847

Table 2. Compositions of stanfieldite (10) in percentages by weight. The six pallasites were Santa Rosalia, Albin, Finmarken, Imilac, Mount Vernon, and Newport. In parentheses are ranges in values for all pallasites; Na₂O was not above background.

Component	Estherville	Average from six pallasites
CaO	24.6	26.6 (26.2-27.2)
MgO	12.9	21.0 (20.1-21.6)
FeO	13.8	2.5 (2.2- 2.7)
MnO	1.4	0.4 (0.4- 0.5)
P ₂ O ₅	46.6	50.4 (50.3-50.5)
<i>Totals</i>		
	99.3	100.9

10.00 ± 0.02 Å; *c*, 22.88 ± 0.04 Å; β, 100° 15' ± 10'. The powder data are not indexed because of the multiplicity of possible reflections for each line, which reflects the large cell size. Two possible space groups are *Pc* and *P2/c*. The space group *P2₁/c* is eliminated by the presence of a weak 050 reflection on the single-crystal photographs. The powder patterns for the mineral from Estherville and from all pallasites are identical, corresponding closely with those listed for the synthetic compound Ca₄Mg₅(PO₄)₆ on ASTM card 11-231. The calculated x-ray density for the molecule Ca₄Mg₃Fe₂(PO₄)₆ is 3.15 g/cm³ for *Z* = 8; the density by the sink-or-float method is 3.15 ± 0.01 g/cm³. The hardness is greater than 4 and slightly less than or equal to 5.

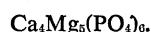
The chemical composition (Table 2) was determined by electron-microprobe methods. Greater substitution of iron for magnesium is observed in the Estherville occurrence; this finding is also characteristic of the associated olivine and orthopyroxene. Analysis of Estherville stanfieldite yields the formula



If one takes into consideration the analytical error of 2 percent of the amount present and adds manganese to iron, this formula may be written Ca₄Mg₃Fe₂(PO₄)₆. The average composition for stanfieldite from all pallasites gives the formula



or ideally,



The iron-free mineral has been synthesized by heating a mix, prepared according to the last formula, at 800°C for several days in a platinum crucible in air. The optical properties and x-ray

powder pattern of the single-phased product are identical with those for the mineral in the Santa Rosalia meteorite.

The phase diagram of the synthetic system Mg₃(PO₄)₂-Ca₃(PO₄)₂ at 1 atm, reported by Ando (9), contains three crystalline phases: the end members have the ideal compositions of the minerals farringtonite and whitlockite, respectively; and a third phase has an intermediate composition close to that of stanfieldite. For comparisons, the mineral compositions are considered to be free of iron and manganese. Ando's diagram for 900°C shows a two-phased region extending from a Mg:Ca atom ratio of 0.08 (corresponding to whitlockite) to one of 0.91 (corresponding to stanfieldite). However, stanfieldite in the pallasites has by analysis a Mg+Fe+Mn:Ca ratio of 1.19, which ratio is apparently independent of the mineral's coexistence with whitlockite and greater than the 0.91 given by the phase diagram. The diagram shows a single-phase region, equivalent to stanfieldite, extending from 0.91 to 1.02; however, since I have synthesized stanfieldite as a single phase at 1.19, it appears that the published phase diagram is not sufficiently accurate to delineate the stability fields of these three phosphate minerals. Although study of the ternary system Fe₃(PO₄)₂-Mg₃(PO₄)₂-Ca₃(PO₄)₂ would be more applicable, Ando's work does suggest that farringtonite and whitlockite will not coexist in a meteorite formed under equilibrium conditions.

LOUIS H. FUCHS

Chemistry Division, Argonne National Laboratory, Argonne, Illinois 60439

- ### References and Notes
- Stanfieldite is named after the late Stanley Field, former chairman of the board of trustees of the Field Museum of Natural History. Together with O. C. Farrington, former curator of geology, he added most of the present meteorite collection of the museum, one of the world's largest. The mineral has been approved by the Commission on New Minerals and Mineral Names of the International Mineralogical Assoc.
 - G. P. Merrill, *Proc. U.S. Nat. Museum* **58**, 363 (1921).
 - P. K. Buseck and K. Keil, *Amer. Mineralogist* **51**, 1511 (1966).
 - E. R. DuFresne and S. K. Roy, *Geochim. Cosmochim. Acta* **24**, 198 (1961).
 - Peter Buseck, Arizona State University, informs me that he has found stanfieldite in four pallasites.
 - W. Wahl, *Geochim. Cosmochim. Acta* **29**, 177 (1965).
 - B. Mason, *Amer. Museum Novitates* **2163** (1963).
 - The x-ray powder pattern of stanfieldite from Mount Vernon contains an impurity line at 6.7 Å; that from Finmarken has extra lines at 6.7 and 7.9 Å. The farringtonite pattern from Phillips County contains three extra lines at 7.9, 6.7, and 2.68 Å. These lines are characteristic of many hydrated phosphate compounds, but no specific identifications were attempted. Microprobe results for some spots on these phosphates were lower than for adjacent spots and were deleted from the analyses reported in Table 2.
 - J. Ando, *Bull. Chem. Soc. Japan* **31**, 201 (1958).
 - The electron-microprobe analyses were performed on carbon-coated, polished, epoxy-resin mounts of from four to six grains of each mineral removed from the meteorite; the instrument was made by Applied Research Labs. Analyzed apatite, olivine, and farringtonite were used as standards. Compositions were corrected for dead time, background, absorption, fluorescence, and atomic number according to Smith (11). Deviation of individual grains was within the analytical error of from 1 to 2 percent of the amount of each calculated oxide.
 - J. V. Smith, *J. Geol.* **73**, 830 (1965).
 - Work performed under the auspices of the AEC. I thank E. Olsen (Field Museum of Natural History, Chicago) and G. Reed (Argonne National Laboratory) for the meteorite samples, E. Olsen for assistance in correction of the microprobe data, S. Siegel and J. Whitaker (Argonne National Laboratory) for the single-crystal x-ray results, G. Montet (Argonne National Laboratory) for critically reviewing the manuscript, and C. Knowles (Department of Geophysical Sciences, University of Chicago) for operation of the electron microprobe.

18 September 1967

Seismic Refraction Profile in Coral Sea Basin

Abstract. *A refraction profile near the south edge of Coral Sea Basin shows sediments, "second layer," and oceanic crust all thicker than normal for an oceanic station; normal mantle lies at a depth of 19 kilometers.*

In October 1960 we made a reversed refraction profile (station MN5) in the southwestern part of Coral Sea Basin, using the R.V. *Argo* and its boat with previously described methods (1). This is the only refraction profile so far reported from the Coral Sea, one of the very few from the southwest Pacific (2).

Lack of previous soundings resulted in location of the profile closer to the

continental slope in the southwest flank of the basin than one would have desired. One end of the line was on the abyssal plain in water 4.45 km deep; the other end was in 3.50 km of water on the continental rise of Queensland Plateau (3), a shoal area, 1 to 2 km deep, resembling in many ways Blake Plateau off the eastern United States (Fig. 1). Because of the large change in depth and the break in slope along the