detailed information as possible are clearly needed, but unfortunately they are not easily obtainable. Direct spectra have been obtained by Kozyrev (*5*), Spinrad (*6*), Dubois (*7*), and others, and spectrophotometric records have been obtained by Grainger and Ring (*8*). Kozyrev identified carbon bands and H_2^+ in emission, and unidentified emission features were recorded by Spinrad, and Grainger and Ring. Kozyrev has held to an explanation by outgassing or lunar volcanism, and his identification of carbon is of great interest in connection with the presence of dark areas in our second class of sites and in the black-halo craters. Spinrad, and Grainger and Ring tentatively attributed their anomalies to luminescence, although both stated that all external sources of energy (such as solar particles and cosmic rays) are inadequate by orders of magnitude to produce the observed effects. Notably, however, Scarfe's, Spinrad's, and Grainger and Ring's observations, and one of Kozyrev's, were made within 2 days of perigee, at a time when the recorded events have occurred most frequently; this period and a corresponding period around apogee seem to be the most favorable for recording spectra of events. Another Kozyrev observation was made near apogee; two more, at intermediate dates. The lunar sites indicated by their records, where known, consistently fall into the same three classes (ray craters, ring plains, and craters on the borders of the regular maria) as do the historical events.

Table 1 lists sites in order of frequency of events. It is difficult to assess the recovery rate, either total or for any given site, since the rate must be very strongly affected by observational selection and by other factors. For example, the size of the aperture used controlled the size of the field. Instruments with large mirrors of good reflectivity demand high magnification for comfortable viewing, with consequent reduction of the field of view. Thus it is not surprising that very few 20th-century records deal with events on the dark side (about six, compared with more than 40 before 1900 for a comparable number of records); most lunar observers are interested primarily in the details on the illuminated side that are thrown into relief by shadows.

Our catalogue (*1*) lists no events between 1800 and 1821, and only one earlier record outside Europe is known to us (New England, 1668); Europe was then unsettled by the Napoleonic wars. Numbers of events recorded have recently increased considerably; about 24 have been listed during 1965 and 1966. So far as we know, the Gassendi events of April and May 1966 were not seen anywhere in the United States although they were well confirmed in Britain—more probably because American observers then happened to be looking elsewhere on Moon than because no activity occurred in Gassendi while Moon was visible in the United States. A round-the-clock watch, subject to weather conditions, is now possible as observers in Japan, Australia, Europe, and America are interested, and the frequency of recorded events probably will be even higher than the average of two per month during 1965 and 1966.

Only one instance of an event occurring in the uplands has been reported (Hammes, 1878); so many details in the report proved to be false or dubious that we rejected it as a fabrication. Otherwise, the sites recorded visually, and those indicated by the few spectra and other permanent records, fall consistently into the three classes mentioned, and we believe that the results of this analysis are undoubtedly significant. We consider that the topographical distribution of sites that we have discussed supports the conclusion that most lunar transient events result from internal causes — possibly of volcanic nature. Other evidence in favor of internal activity has been presented elsewhere (*9*).

Our finding may be open to some criticism because we used many old records. On the other hand, nearly all of the early observers are known to have been scientists of integrity. Modern reports are coming in with greater frequency as a result of the Moon Blink and other programs, and it will be interesting to see whether the new data support the hypothesis of internal activity.

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10. Aided by NSF grant GP-5940 (administered by the University of Arizona).

3 October 1966

Niningerite: A New Meteoritic Sulfide

Abstract. *Niningerite, a new meteoritic sulfide ranging in composition from* $(Fe_{0.19}Mg_{0.66}Mn_{0.14}Ca_{0.007}Cr_{0.002})S$ *to* $(Fe_{0.52}Mg_{0.33}Mn_{0.06}Ca_{0.06}Cr_{0.03}Zn_{0.004})S$, *from the type-I enstatite chondrites Abee, Saint Sauveur, Adhi-Kot, Indarch, St. Mark's, and Kota-Kota, is described. It is named in honor of H. H. Nininger.*

During a systematic study of the enstatite chondrites (*1*) it was found that the highly recrystallized type-II enstatite chondrites Jajh deh Kot Lalu, Hvittis, Atlanta, Pillistfer, Ufana, Blithfield, Khairpur, and Daniel's Kuil (Fig. 1, 7–14, respectively) contain ferroan alabandite (*2*), whereas the less–extensively metamorphosed type-I enstatite chondrites Abee, Saint Sauveur, Adhi-Kot, Indarch, St. Mark's, and Kota-Kota (Fig. 1, 1–6, respectively) contain a cubic iron-magnesium-manganese sulfide that is compositionally quite distinct

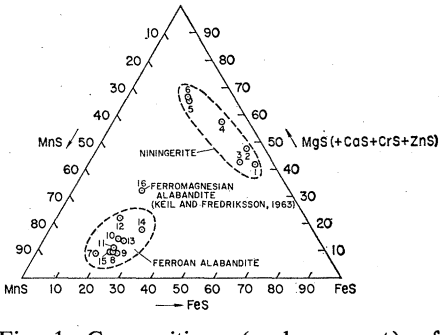

Fig. 1. Compositions (mole percent) of niningerite (points 1–6), ferroan alabandite (points 7–15), and ferromagnesian alabandite (point 16) plotted in a MnS–FeS–MgS (+CaS+CrS+ZnS) concentration triangle. Points 1–6 correspond to type-I enstatite chondrites Abee, Saint Sauveur, Adhi-Kot, Indarch, St. Mark's, and Kota-Kota, respectively; points 7–14 correspond to the type-II enstatite chondrites Jajh deh Kot Lalu, Hvittis, Atlanta, Pillistfer, Ufana, Blithfield, Khairpur, and Daniel's Kuil, respectively; points 15 and 16 correspond to the enstatite achondrites Pesyanoe and Norton County, respectively.

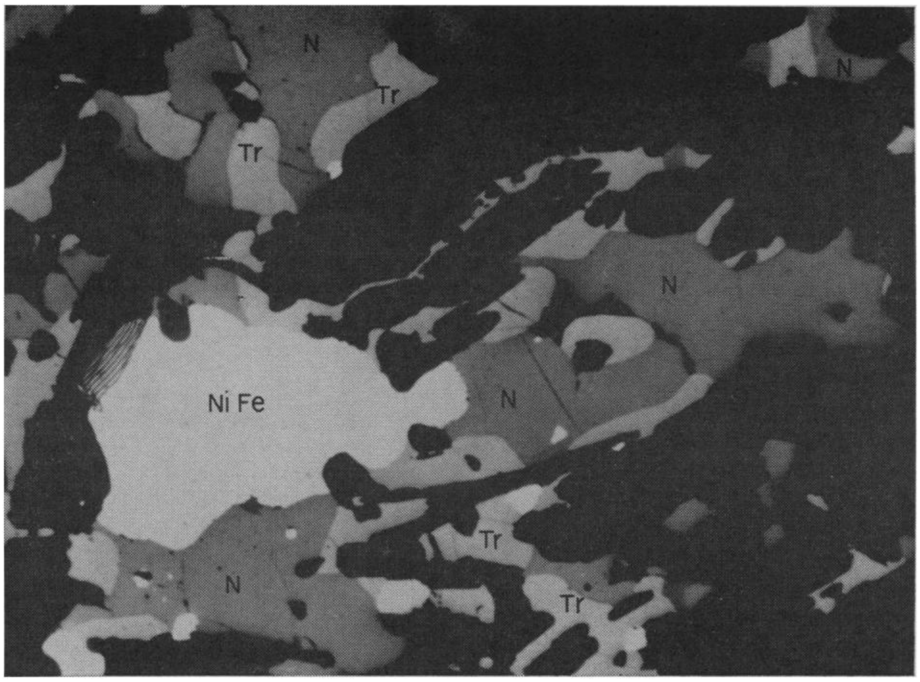

Fig. 2. Niningerite (N) closely intergrown with kamacite (NiFe) and troilite (Tr); matrix is enstatite. Reflected plane polarized light.

from not only ferroan alabandite but also any terrestrial sulfide heretofore described. We propose the new mineral name niningerite (*3*) for this sulfide and now report the results of a compositional study of niningerite in the six type-I enstatite chondrites.

With regard to the identification and composition of meteoritic alabandite-type minerals, some confusion appears to exist in the literature. Such a phase was first reported by Dawson *et al.* (*4*) who claimed to have identified "alabandite" (MnS) in Abee by x-ray diffraction techniques; Ramdohr (*5*) later questioned this determination, pointing out that the mineral is unlike terrestrial alabandite or ferroan alabandite and is probably a new "complex Fe-Mg-Mn-Ca-sulfide with NaCl structure." Our results confirm Ramdohr's findings (*5*) and show that the original identification was incorrect. Furthermore, Dawson *et al.* (*4*) appear to have confused the mineral with oldhamite (CaS), for the mineral labeled oldhamite by them [fig. 5(b)] is most probably not CaS but niningerite. Shortly after the work of Dawson *et al.* (*4*), magnesium sulfide (MgS) was reported by Du Fresne and Anders (*6*) as a new but unnamed mineral from the Pesyanoe enstatite achondrite on the basis of data obtained by x-ray diffraction and optical-emission spectroscopy. Our analyses of their original material (*7*) and of other samples of Pesyanoe (*8*) reveal, however, that the compound is not MgS but an iron-bearing variety of alabandite of the composition $(Mn_{0.68}Fe_{0.23}Mg_{0.08}Ca_{0.009}Cr_{0.007})S$ (Fig. 1, *15*; compare *1*). This finding confirms the earlier work of Yudin and Smishlaev (*9*), and the mineral is therefore properly termed ferroan alabandite. The new mineral we describe was first analyzed by Fredriksson and Wickman; in a footnote in a little-known paper (*10*) they report an approximate composition of the compound from St. Mark's enstatite chondrite; they did not, however, pursue study of this phase.

The results of our study of niningerite may be summarized as follows: It is opaque in thin sections, gray in reflected light, and intimately intergrown with metallic nickel-iron and troilite; it is isotropic in reflected polarized light. Niningerite occasionally contains oriented exsolution lamellae of troilite, and in a few instances it encloses minute droplets of metallic nickel-iron. All meteorites studied but Abee contain less than 5 percent niningerite by weight; in Abee the concentration varies considerably from section to section; one section contained 14 percent by weight.

For quantitative electron-microprobe analysis, 7 to 20 inclusion-free grains of niningerite were selected microscopically in carbon-coated polished sections; at least ten spot analyses were performed on each grain by moving it in steps of 4 μ under the fixed electron beam, and recording the x-ray intensities after each step. Analyses were carried out by use of wet-chemically analyzed FeS_2, ZnS, $MgSiO_3$, andesine, chromite, and pure Mn standards. Intensity readings were corrected for drift, wavelength shift, detector and amplifier dead-time, background, mass absorption, fluorescence, and atomic number (for details of the method, see *1*). Precision of the measurements was

Table 1. Niningerite: Composition determined by electron-microprobe analysis, calculated density, and lattice parameter; n.d., not determined.

Meteorite, No.	Grains analyzed (No.)	Composition (% by weight)								Lattice parameter (Å)	Calc. density (g/cm³)
		Mg	S	Ca	Cr	Mn	Fe	Zn	Total		
Abee, 1	20	10.1 (8.9–11.6)	41.0 (40.5–41.4)	3.03 (2.34–3.66)	1.84 (1.64–2.04)	4.02 (3.61–4.26)	37.1 (35.6–38.2)	0.31 (0.21–0.40)	97.40	5.17	3.68
Saint Sauveur, 2	15	13.2 (10.9–14.6)	42.7 (41.5–43.3)	2.55 (2.22–2.91)	1.77 (1.69–1.96)	3.93 (3.43–4.54)	35.2 (34.0–36.8)	n.d.	99.35	5.16	3.59
Adhi-Kot, 3	14	11.3 (10.9–12.3)	42.6 (41.7–43.1)	1.96 (1.57–2.28)	1.97 (1.82–2.16)	7.1 (6.3–7.6)	34.2 (33.4–35.4)	n.d.	99.13	n.d.	3.64*
Indarch, 4	7	18.3 (17.5–19.3)	43.4 (41.8–43.5)	1.28 (1.19–1.42)	1.66 (1.44–2.09)	6.5 (6.1–7.0)	27.0 (24.5–28.5)	n.d.	98.14	5.18	3.35
St. Mark's, 5	10	22.7 (21.6–24.9)	47.4 (47.3–49.4)	0.53 (0.42–0.69)	0.40 (0.32–0.51)	11.8 (10.5–12.9)	16.6 (15.5–18.3)	n.d.	99.43	5.17	3.27
Kota-Kota, 6	10	23.5 (18.4–27.1)	46.9 (45.4–47.8)	0.39 (0.28–0.57)	0.14 (0.10–0.17)	11.6 (9.8–12.4)	15.6 (12.8–19.9)	n.d.	98.13	n.d.	3.21*

* A lattice parameter of 5.17 Å was assumed.

Table 2. Niningerite: Metal:sulfur ratios (atomic proportions), and formulas on the basis of one sulfur.

Meteorite, No.	Metal:sulfur	Formula
Abee, 1	0.991	$(Fe_{0.52}Mg_{0.33}Mn_{0.06}Ca_{0.06}Cr_{0.03}Zn_{0.004})S$
Saint Sauveur, 2	1.010	$(Fe_{0.47}Mg_{0.40}Mn_{0.05}Ca_{0.05}Cr_{0.03})S$
Adhi-Kot, 3	0.973	$(Fe_{0.47}Mg_{0.36}Mn_{0.10}Ca_{0.04}Cr_{0.03})S$
Indarch, 4	1.047	$(Fe_{0.34}Mg_{0.53}Mn_{0.08}Ca_{0.02}Cr_{0.02})S$
St. Mark's, 5	0.993	$(Fe_{0.20}Mg_{0.64}Mn_{0.15}Ca_{0.009}Cr_{0.005})S$
Kota-Kota, 6	1.005	$(Fe_{0.19}Mg_{0.66}Mn_{0.14}Ca_{0.007}Cr_{0.002})S$

± 1 percent; accuracy, ± 3 to 5 percent of the amount present, depending on the element and its concentration. Because of such high precision, we considered it worthwhile for comparative purposes to report the data to three significant figures, even though the accuracy may not be better than ± 5 percent.

Table 1 lists averages and ranges in the composition of niningerite in each meteorite in order of decreasing iron content. Obviously, composition varies appreciably between meteorites—from $(Fe_{0.52}Mg_{0.33}Mn_{0.06}Ca_{0.06}Cr_{0.03}Zn_{0.004})S$ in Abee to $(Fe_{0.19}Mg_{0.66}Mn_{0.14}Ca_{0.007}Cr_{0.002})S$ in Kota-Kota. The elements Ca and Cr follow Fe, increasing with increase in Fe, while Mn and Mg decrease with increase in Fe. Sulfur content also decreases with increasing Fe because FeS has less S than either MnS or MgS. Furthermore, appreciable differences in composition are sometimes observed between different grains of the mineral in one meteorite (Tables 1 and 2), a situation that markedly contrasts with the homogeneity of the individual mineral grains. Variations in composition within any one grain usually do not exceed the degree of accuracy of the measurements.

Regarding x-ray diffraction, attempts to separate niningerite in the pure state, using heavy media, failed because of the intimate association of the mineral with metallic nickel-iron and troilite (Fig. 2); magnetic separation failed for the same reason. Accordingly the mineral was subjected to x-ray analysis *in situ* by use of the following procedure: The polished, niningerite-bearing, plastic-mounted samples of meteorite used for electron-microprobe analysis were clamped into the sample holder of a Philips-Norelco diffractometer in such a way that the polished surfaces of the meteorites intercepted the x-rays as would smears on glass slides. Finely ground silicon, sprinkled on the surfaces of the meteorites, served as the "internal" standard, and chart and scanning speeds were set, respectively, at 5 cm/min and ¼° 2θ/min.

Within the 28° to 51° 2θ range, the two most intense reflections corresponding to niningerite were weakly developed but distinguishable from peaks due to other minerals: their *d*-spacings (Abee niningerite), together with indices based on assumption of similarity in structure to alabandite, are 2.584 Å (200) and 1.829 Å (220) (*11*). Cell edges, calculated from these reflections, are listed in Table 1; because only the two peaks were available, the lattice parameters are considered no more accurate than ± 0.02 Å. The values do not vary within the assigned range of error of determination, and the average value (5.17 Å) is just less than the cell edge of alabandite (5.22 Å). Calculated densities show an appreciable range, however, because, depending on the extent to which lighter magnesium and heavier iron cations have taken each other's place in the structure, the molecular weights of the six examples of niningerite vary considerably.

The possible origin of this mineral and the complex mineral assemblage present in enstatite chondrites are discussed elsewhere (*1*).

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3. The proposed name honors H. H. Nininger, Sedona, Arizona, for his outstanding contributions to meteoritics; name and definition have been approved by the Commission on New Minerals and Mineral Names, Intern. Mineral. Assoc. Niningerite was first described before the 29th Annual Meeting of the Meteoritical Society, 3–5 Nov. 1966, Washington, D.C.
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8. We thank G. Goles for these samples.
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11. Two meteorites, Kota-Kota and Adhi-Kot, contain niningerite in such small amounts that no peaks corresponding to the mineral were noted.
12. We thank B. Mason and C. B. Moore for providing the samples, J. Erlichman for assistance with the electron-microprobe work, and Sally Craig for the microphotograph of niningerite.

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Digital Model of Evaporite Sedimentation

Abstract. *A deterministic digital model to simulate evaporite sedimentation permits experimentation with depth of water, shape of salt basin, number, position, and strength of the inlets, and rate of evaporation. It provides a reasonable fit to salt thickness and distribution in the Upper Silurian Salina Formation of Michigan.*

Evaporite rocks, salts of the more soluble ions in seawater, are deposited when seawater becomes concentrated by excess evaporation in marginal basins having restricted circulation with the open sea. The simple conceptual model of an evaporite basin (Fig. 1) has a bar or reef near the mouth of its single inlet which restricts circulation with the sea.

As the oceanic water flows from the inlet into the basin it tends to form a thin layer of brine that spreads over the surface of the basinal brine, and, as it does, the salt concentration in the surface layer gradually increases because of the continued evaporation of the water. When the solubility products of the salts in the surface layer are exceeded, the salts precipitate and settle to the bottom of the basin. The order of precipitation of the salts follows the order of least solubility. Normally the carbonates separate first,