of this conclusion by observation from Earth is problematical since the average daily advance of 45 kilometers about equals the resolution limit under best seeing conditions and since microhills might form because of only partially absorbed H_2O deposit; that is, they might be covered by ice when freshly formed. The rate of advance as a function of Martian time of day could be established by photography from a Martian orbiter programmed to take observations of the same selected areas two or three times daily over a sufficiently long period. A highly suitable opportunity to accomplish this will occur in 1973.

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References and Notes

1. C. Troll, *Structure Soils, Solifluction and Frost Climates of the Earth*, Translation 43 by H. E. Wright, Jr. (U.S. Army Snow Ice and Permafrost Research Establishment, Wilmette, Illinois, October 1958).
2. E. C. Slipher, *The Photographic Story of Mars* (Northland Press, Flagstaff, Ariz., 1962).
3. B. Hapke and H. Van Horn, *J. Geophys. Res.* **68**, 4545 (1963).
4. V. G. W. Harrison, *Proc. Phys. Soc. London* **58**, 403 (1946).
5. F. L. Bartman, L. W. Chaney, M. T. Surh, "Reflectance of Kodak White Paper," *Univ. of Michigan, High Altitude Eng. Lab. Tech. Rep. 05863-5-T* (1964).
6. N. N. Sytinskaya, "Determination of the degree of smoothness of planets by photometric methods," NASA No. N63-81360, transl. from *Leningrad Univ. Sci. Rec. No. 116* (1949).
7. V. V. Sharonov, "The Nature of the Planets," *NASA TTF-77, OTS 63-11177* (Israel Program for Sci. Transl., Jerusalem, 1964).
8. A. Dollfus, in North American Aviation Co. *Proceedings of Lunar and Planetary Exploration Colloquium* (1961), vol. 2, No. 3, p. 30.
9. J. H. Focas, "Observations of Mars Made in 1961 at the Pic du Midi Observatory," *Jet Propulsion Lab. Tech. Rep. No. 32-151* (1962).
10. G. P. Kuiper, in North American Aviation Co. *Proceedings of Lunar and Planetary Exploration Colloquium* (1961), vol. 2, No. 3, p. 34.
11. W. Mohaupt, "Observations on soil mixing and needle-ice formation in the Stubai and Grödener Valley," dissertation in German, Univ. of Hamburg (1932).
12. G. de Vaucouleurs, *Physics of the Planet Mars* (Faber, London, 1954).
13. N. N. Sytinskaya, "Recent investigations of the atmosphere and surface of Mars," NASA No. N63-20654, transl. from *Priroda* (*Nature*), **45**, No. 6, 33–41 (1956).
14. To a limited extent this would result if the integration of solar heating is started earlier than 260° heliocentric longitude. Additional amounts of water at this point can be derived from the polar clouds (Gérard de Vaucouleurs, private communication).
15. N. A. Weil, *Lunar and Planetary Surface Conditions* (Academic Press, New York, 1965), p. 159.
16. G. P. Schilling, "Parametric comparison of the atmospheres of Earth and Mars," *Rand Corp. Rep. No. RM-2817-JPL* (1961).
17. N. P. Barabashov and I. K. Koval, "Photographic photometry of Mars with filters," in *Results of Observations of Mars in the USSR during the Great Opposition of 1956* (NASA translation TTF-93, 1962), pp. 18–21.
18. C. Tombaugh, in North American Aviation Co. *Proceedings of Lunar and Planetary Exploration Colloquium* (1959), vol. 1, No. 4, p. 40.
19. L. D. Kaplan, G. Münch, H. Spinrad, *Astrophys. J.* **139**, 1 (1964).
20. W. M. Sinton, in *Advances in the Astronautical Sciences*, G. W. Morgenthaler, Ed. (Western Periodicals, North Hollywood, Calif., 1964), vol. 15, pp. 543–551.
21. Y. Mintz, in North American Aviation Co. *Proceedings of Lunar and Planetary Colloquium* (1962), vol. 3, No. 1, p. 12.
22. The possibility of liquid water in ground capillaries has been mentioned in "The Atmospheres of Mars and Venus," *Nat. Acad. Sci.-Nat. Res. Counc. Publ. 944*, prepared by W. W. Kellogg and Carl Sagan (Washington, D.C., 1961), p. 24.
23. E. J. Öpik, in *Progress in the Astronautical Sciences*, S. F. Singer, Ed. (Interscience, New York, 1962), vol. 1, pp. 278–279.
24. J. A. Adamcik, *Planetary Space Sci.* **11**, 355 (1963).

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Cohenite in Meteorites: A Proposed Origin

Abstract. *Cohenite [(Fe, Ni)$_3$C] is found almost exclusively in meteorites containing from 6 to 8 percent nickel (by weight). On the basis of iron-nickel-carbon phase diagrams at 1 atmosphere and of kinetic data, the occurrence of cohenite within this narrow composition range as a low-pressure metastable phase and the nonoccurrence of cohenite in meteorites outside the range 6 to 8 percent nickel can be explained. Cohenite formed in meteorites containing less than 6 to 8 percent nickel decomposed to metal and graphite during cooling; it cannot form in meteorites containing more than about 8 percent. The presence of cohenite in meteorites cannot be used as an indicator of pressure of formation. However, the absence of cohenite in meteorites containing the assemblage, metal plus graphite, requires low pressures during cooling.*

Cohenite [(Fe, Ni)$_3$C] is structurally identical to cementite (Fe_3C) and occurs mainly in metallic meteorites. It contains 0.5 to 3 percent (by weight) of Ni (*1*) and is metastable at all temperatures at low pressures (*2*). Thermodynamic calculations suggest that cohenite is stable at high pressures (*3*). Ringwood (*3*) concluded that the presence of cohenite in a meteorite indicates a pressure of formation of at least 25 kb and therefore a parent body of approximately lunar size. Since the appearance of Ringwood's paper, research on cohenite has been active (*1, 4–6*).

Cohenite has been sought in many iron meteorites, but it has been unequivocally identified in only 26 (*7*); of these, 20 meteorites are coarse octahedrites and have nickel contents between 6 and 8 percent. Iron meteorites having this composition make up less than one-third of those analyzed (*8*). Of the remaining six meteorites that contain cohenite, three are nickel-poor ataxites (Ni, 5 to 6 percent) and the rest are medium octahedrites (Ni, 7 to 10 percent). It would therefore seem that the distribution of cohenite in meteorites is not random and that, with certain exceptions, cohenite is restricted to meteorites containing between 6 and 8 percent nickel. Carbon occurrence in iron meteorites is not similarly restricted; the average carbon content is about 0.2 percent (*9*).

The phase-equilibrium relations along the bounding binaries of the ternary system Fe-Ni-C have been investigated in some detail; however, little work has been done in the ternary owing to experimental difficulties. The suggested phase relations in the ternary (Figs. 1 and 2) have been drawn by projection from the existing data along the binaries (*10*). Assemblages involving cohenite in Figs. 1 and 2 decompose in time to

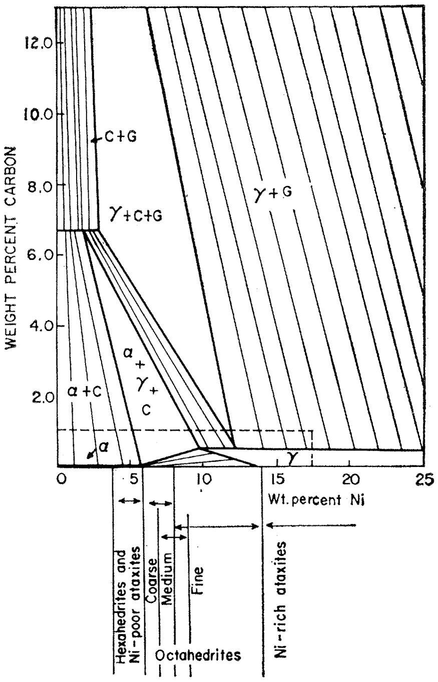

Fig. 1. Isothermal section of portion of the system Fe-Ni-C at 650°C, in which the metastable phase cohenite is included. α, kamacite; γ, taenite; G, graphite; C, cohenite. Dashed line indicates composition range of Fig. 2. Composition ranges of iron meteorites are shown.

stable assemblages, metal + graphite. Phase diagrams involving cohenite therefore represent metastable equilibria. They can be drawn by analogy with those involving cementite in the system Fe-C, where metastable equilibria involving cementite are reversible. Cohenite is stabilized by pressure (*3*) so that a high pressure section at 50 kb resembles Fig. 1 but represents stable equilibria. Figure 2 shows that Fe-rich taenite [γ-(Fe,Ni)] is stabilized by carbon (*11*) and also that the temperature at which cohenite forms is sensitive to the bulk alloy composition and varies from about 675° to between 600° and 625°C for alloys of the composition of metallic meteorites. At about 610°C, it is postulated that cohenite no longer forms and that graphite forms instead. Because cohenite contains much less Ni than does kamacite [α-(Fe,Ni)] or taenite, the reaction by which it forms (taenite → cohenite + kamacite) should be reversed when the Ni content is high, and no cohenite would form. This is not strictly a change in tie lines, but represents a postulated change in equilibria from metastable to unstable. The 600°C isotherm in Fig. 2 therefore represents stable equilibrium at 600°C.

Decomposition of cohenite takes place by its re-solution and by nucleation of graphite within the surrounding matrix (*12*). Figure 3 shows an experimentally determined rate curve for cohenite decomposition, for which materials and methods were the same as those used by Ringwood and Seabrook (*5*). The rates are more than three orders of magnitude slower than those of synthetic material studied earlier (*6, 13*). The determined rates shown in Fig. 3 are a maximum for natural cohenite, as the starting material was shocked, fractured meteoritic cohenite (Cosby's Creek) which was separated from its metal matrix. Thus it is reasonable to propose that rates are about four orders of magnitude slower in natural decomposition at 650°C (*14*).

Figure 2 shows that cohenite should not form in meteorites containing more than 8 percent Ni unless the C content is exceptionally high. If cohenite formed in meteorites containing as much as 6 percent nickel, it formed at temperatures (675° to 650°C) such that there was sufficient time for it to decompose during the slow cooling of 1° to 10°C per million years (*15*) that occurred in iron meteorites, assuming decomposition rates to be four orders of magnitude slower than the experimentally determined rates. It is only in meteorites containing 6 to 8 percent nickel that cohenite formed at temperatures low enough (650° to 610°C) that cohenite did not totally decompose in the time available in meteoritic cooling. Scalloped cohenite textures and the association of graphite near cohenite concentrations are evidence that cohenite had begun to decompose.

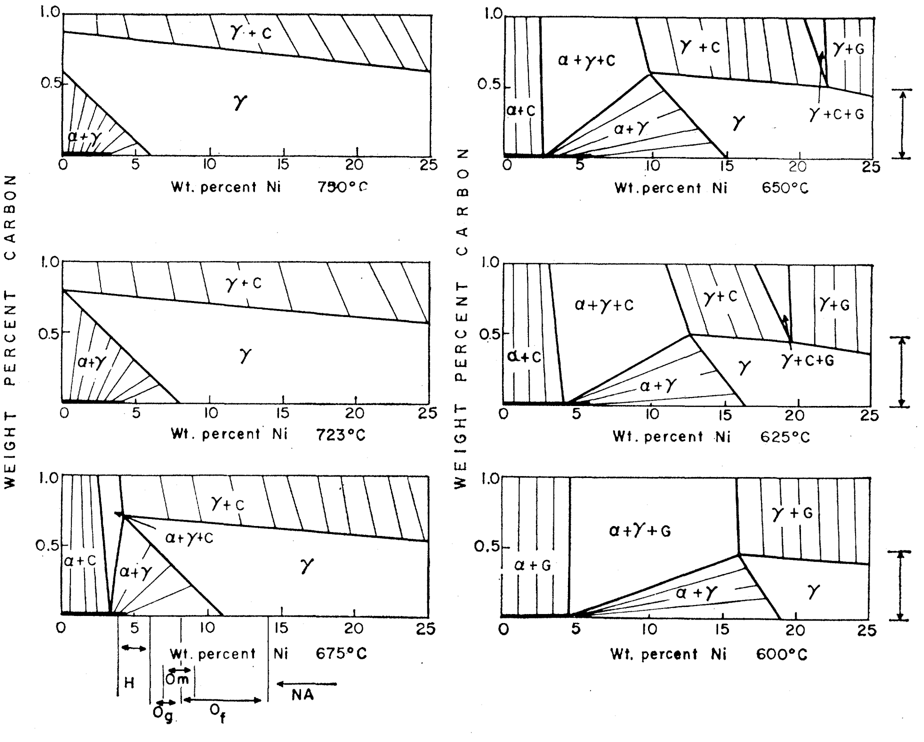

Fig. 2. Isothermal sections of portion of the system Fe-Ni-C in which the metastable phase cohenite is included. Symbols as in Fig. 1. Composition ranges of iron meteorites are shown. H, hexahedrites and nickel-poor ataxites; Og, coarse octahedrites; Om, medium octahedrites; Of, fine octahedrites; NA, nickel-rich ataxites. The arrows from 0 to 0.5 percent C indicate the range of carbon content in iron meteorites.

The relation between the amount of cohenite formed at a given temperature and nickel content as compared to cohenite preservation is summarized in Fig. 4. The total proportion of cohenite precipitated at a given temperature with respect to the calculated total cohenite

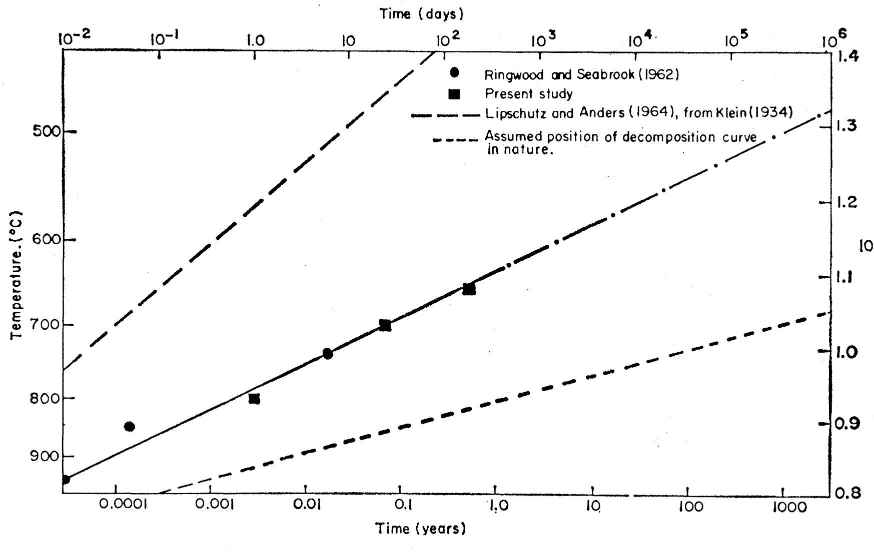

Fig. 3. Temperature plotted against time for total decomposition of Cosby's Creek cohenite, based on present data and those of Ringwood and Seabrook (1962). The curve of Lipschutz and Anders (1964) from the data of Klein (1934) represents 50 percent decomposition. Bottom curve shows decomposition curve which is compatible with the natural occurrence of cohenite.

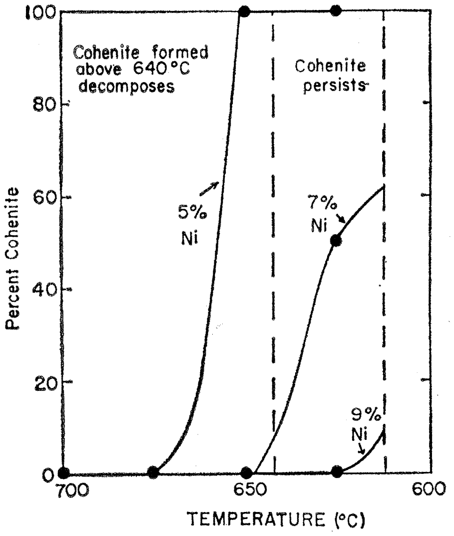

Fig. 4. Cumulative percentage of cohenite formed during cooling plotted against temperature for 3 meteorite compositions, each containing 0.3 percent carbon. Ordinate represents percentage of cohenite present with respect to the total cohenite which would form if all the carbon present were in the form of cohenite. The vertical dashed line at right is 610°, below which cohenite does not form.

in the alloy was plotted as a percentage. Amounts were obtained from the isothermal phase diagrams by the lever law. The diagram is plotted for a bulk carbon content of 0.3 percent and is little changed by alterations in carbon content within the meteoritic range.

The occurrence of cohenite in terrestrial basalts and in meteorites other than those containing 6 to 8 percent Ni may be explained by the fact that these bodies cooled rapidly (from textural evidence), thus preserving the cohenite, or by their very high C contents.

The presence or absence of cohenite in meteorites may be explained in terms of a low pressure origin. The lack of cohenite in iron meteorites other than those containing 6 to 8 percent Ni is strong evidence against a high-pressure origin for these meteorites, because at high pressures cohenite is stabilized. Such meteorites formed in bodies of asteroidal size, or near the surface of larger bodies.

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References and Notes

1. J. F. Lovering, *Geochim. Cosmochim. Acta* **28**, 1745 (1964); J. D. Brown and M. E. Lipschutz, *Icarus* **4**, 436 (1965).
2. All percentages mentioned are by weight.
3. A. E. Ringwood, *Geochim. Cosmochim. Acta* **20**, 155 (1960).
4. M. E. Lipschutz and E. Anders, *ibid.* **24**, 83 (1961); E. Olsen, *ibid.* **28**, 609 (1964); A. E. Ringwood, *ibid.* **29**, 573 (1965).
5. A. E. Ringwood and M. Seabrook, *Geochim. Cosmochim. Acta* **26**, 507 (1962).
6. M. E. Lipschutz and E. Anders, *ibid.* **28**, 699 (1964).
7. S. H. Perry, *U.S. Nat. Museum Bull.* **184** (1944); E. P. Henderson and S. H. Perry, *U.S. Nat. Museum Proc.* **107**, 339 (1958); B. Mason, *Meteorites* (Wiley, New York, 1962); E. P. Henderson, personal communication (1965).
8. A. A. Yavnel, *Int. Geol. Rev.* **2**, 298 (1960).
9. J. D. Buddhue, *Popular Astron.* **54**, 149 (1946).
10. K. W. Andrews, *J. Iron Steel Inst.* **184**, 414 (1956); J. I. Goldstein and R. E. Ogilvie, *Amer. Inst. Mining Met. Eng. Trans.* **233**, 2083 (1965); M. Hansen and K. Anderko, *Constitution of Binary Alloys* (McGraw-Hill, New York, ed. 2, 1958); W. Heller and J. Branner, *Arch. Eisenhuettenw.* **35**, 1105 (1964); L. Kaufman, in *Energetics in Metallurgical Phenomena*, W. Mueller, Ed. (Science Publ., New York, 1966); T. E. Kihlgren and J. T. Eash, *Metals Handbook*, T. Lyman, Ed. (American Society of Metals, Cleveland, 1948); J. J. Lander, H. E. Kern, A. L. Beach, *J. Appl. Phys.* **23**, 1305 (1952); R. F. Mehl and C. Wells, *Am. Inst. Min. Met. Eng. Trans.* **125**, 429 (1937); J. C. Meijering, *Proc. Nat. Phys. Lab. Symp.* No. 9, **2**, paper 5A, 2–20 (1959); A. E. Ringwood and L. Kaufman, *Geochim. Cosmochim. Acta* **26**, 999 (1962).
11. This stabilization causes kamacite nucleation at lower temperatures than in the pure system, which may partly explain the supercooled nucleation of kamacite demanded by recent authors (*15*).
12. R. H. Hickley and A. G. Quarrell, *J. Iron Steel Inst.* **178**, 337 (1954); G. T. Higgins and G. V. Jeminson, *ibid.* **203**, 146 (1965).
13. E. H. Klein, *Stahl Eisen* **54**, 827 (1934).
14. R. Brett, in preparation.
15. J. A. Wood, *Icarus* **3**, 429 (1965); J. M. Short and C. A. Anderson, *J. Geophys. Res.* **70**, 3745 (1965); J. I. Goldstein and R. E. Ogilvie, *Geochim. Cosmochim. Acta* **29**, 893 (1965).

16. I thank E. H. Roseboom, A. E. Ringwood, B. J. Skinner, E. P. Henderson, and H. R Shaw for suggestions. The kinetic study was done during the tenure of a postdoctoral fellowship at the Geophysical Laboratory, Carnegie Institution of Washington. Publication authorized by Director, U.S. Geological Survey.

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Peroxidase and Resistance to Ceratocystis in Sweet Potato Increased by Volatile Materials

Abstract. *Increased peroxidase activity and resistance to black rot was found in sweet potato roots incubated above infected roots in closed containers when compared with similar tissue incubated above uninfected roots. The peroxidase increases were detected in unpurified extracts and in extracts subjected to gel electrophoresis.*

Certain isolates of the fungus *Ceratocystis fimbriata* Ell. and Halst. are pathogens of sweet potato [*Ipomaea batatas* (L.) Lam.] and produce black rot in susceptible sweet potato roots. Activity of peroxidase and polyphenol oxidase is higher in sweet potato tissue inoculated with pathogenic isolates of *C. fimbriata* than it is in uninfected tissue; the increased activity extends into the host tissue beyond the area containing the pathogen (*1*). Recently similar changes in these enzymes were produced by inoculating resistant or susceptible sweet potatoe roots with nonpathogenic strains of *C. fimbriata* (*2, 3*). Normally susceptible tissue which had been inoculated in this way and which exhibited increased enzymic activity was resistant to subsequent infection by pathogenic isolates of *C. fimbriata* (*2, 4*). It appeared from these results that increased peroxidase and polyphenol oxidase activity was associated with resistance to black rot in sweet potato roots.

During the course of this work it was observed that the activity of these enzymes was unexpectedly high in uninoculated, susceptible tissue, used as experimental controls, which was incubated in containers together with tissue infected with pathogenic *C. fimbriata*. This finding suggested that some volatile material from the infected tissue had stimulated the changes in enzymic activity; the material may perhaps have also induced resistance in the uninfected tissue.

To investigate these possibilities, healthy sweet potato tissue was incubated together with either healthy or diseased tissue, and changes in the enzymic activity and susceptibility to black rot were evaluated. Four susceptible varieties (Jersey Orange, Julian, Maryland, and Nemagold) and one resistant variety (Sunnyside) of sweet potato were used (*5*). Roots were surface-sterilized with sodium hypochlorite solution and cut transversely into slices 2 cm thick. Healthy slices or slices infected with *C. fimbriata* (donors) were placed at the bottoms of sterilized glass containers. Healthy (receptor) slices were supported on sterile stainless-steel grids above the other slices in the containers. The containers were sealed and incubated at room temperature for 2 days. The groups of healthy receptor slices were then removed from the containers. Some slices from each container were inoculated with hyphal suspensions of *C.*