Carletonmooreite, Ni$_3$Si, a new silicide from the Norton County aubrite meteorite

LAURENCE A.J. GARVIE$^{1,2, *}$, CHI MA$^3$,†, SOUMYA RAY$^2$, KENNETH DOMANIK$^4$, AXEL WITTMANN$^5$, AND MEENAKSHI WADHWA$^2$

$^1$Center for Meteorite Studies, Arizona State University, 781 East Terrace Road, Tempe, Arizona 85287-6004, U.S.A.
$^2$School of Earth and Space Exploration, Arizona State University, 781 East Terrace Road, Tempe, Arizona 85287-6004, U.S.A.
$^3$Division of Geological and Planetary Sciences, California Institute of Technology, 1200 East California Boulevard, Pasadena, California 91125, U.S.A.
$^4$Lunar and Planetary Laboratory, University of Arizona, 1415 N 6th Avenue, Tucson, Arizona 85705, U.S.A.
$^5$Eyring Materials Center, Arizona State University, Tempe, Arizona 85287, U.S.A.

**Abstract**

Carletonmooreite (IMA 2018-68), Ni$_3$Si, is a new nickel silicide mineral that occurs in metal nodules from the Norton County aubrite meteorite. These nodules are dominated by low-Ni iron (kamacite), with accessory schreibersite, nickelphosphide, perryite, and minor daubréelite, tetrataenite, taenite, and graphite. The chemical composition of the holotype carletonmooreite determined by wavelength-dispersive electron-microprobe analysis is (wt%) Ni 82.8 ± 0.4, Fe 4.92 ± 0.09, and Si 13.08 ± 0.08 (n = 6, total = 100.81) giving an empirical formula of (Ni$_{2.13}$Fe$_{0.10}$)$_{2.13}$Si$_{0.85}$, with an end-member formula of Ni$_3$Si. Further grains discovered in the specimen after the new mineral submission extend the composition, i.e., (wt%) Ni 81.44 ± 0.82, Fe 5.92 ± 0.93, Cu 0.13 ± 0.02, and Si 13.01 ± 0.1 (n = 11, total = 100.51 ± 0.4). The backscattered electron-diffraction patterns were indexed by the $Pm3m$ auricupride (AuCu$_3$)-type structure and give a best fit to synthetic Ni$_3$Si, with $a = 3.51(1)$ Å, $V = 43.2(4)$ Å$^3$, Z = 1, and calculated density of 7.89 g/cm$^3$. Carletonmooreite is silver colored with an orange tinge, isotropic, with a metallic luster and occurs as euhedral to subhedral crystals 1 × 5 μm to 5 × 14 μm growing on tetrataenite into kamacite. The dominant silicide in the Norton County aubrite metal nodules is perryte (Ni,Fe)$_2$(Si,P)$_3$, with carletonmooreite restricted to localized growth on rare plessite fields. The isolated nature of small euhedral carletonmooreite single crystals suggests low-temperature growth via solid-state diffusion from the surrounding kamacite and epitaxial growth on the tetrataenite. This new mineral is named in honor of Carleton B. Moore, chemist and geologist, and founding director of the Center for Meteorite Studies at Arizona State University, for his many contributions to cosmochemistry and meteoritics.

**Keywords:** Carletonmooreite, silicide, meteorite, aubrite

**Introduction**

Aubrites are achondrite meteorites that are mostly pyroxenites dominated by nearly Fe-O-free enstatite with lesser amounts of plagioclase, diopside, forsterite, and accessory metals, sulfides, phosphides, and other phases (Keil 2010). Most aubrites are regolith impact brecciated pyroxenites that formed under highly reducing conditions. They have igneous origins and underwent fractional differentiation under highly reducing conditions (e.g., Keil 2010 and references therein). The Norton County aubrite is arguably the most studied meteorite of this class, in part because of the large 1 ton mass that was recovered from the February 18, 1948, fall over Kansas and Nebraska (La Paz 1948; Leonard 1948). To date, 25 minerals have been recorded from the Norton County meteorite and it is the type locality for caswellsilverite, cronustite Ca$_{2}$Cr$_{2}$S$_{3}$·2H$_{2}$O, and schöllhornite N$_{8}$H$_{2}$Cr$_{2}$S$_{3}$·H$_{2}$O.

Metallic Fe-Ni is a minor component in the aubrites and occurs in a range of petrographic relationships from sub-micrometer grains to centimeter-sized nodules (Casanova et al. 1993). Possible origins for the metal include formation through in situ reduction, incorporation via impacts, fragments of fractionally crystallized core, or trapped metal from a silicate + metal + sulfide magma (Casanova et al. 1993). Based in part on elemental and isotopic data, Ray et al. (2021) concluded that the Si-bearing metal likely represents an incompletely segregated metal fraction formed during partial melting on the aubrite parent body. The Norton County metals have received scientific attention, in part because of their unusual chemical composition and because they host perryte, an Fe-Ni silicide phosphide (Wai 1970; Wasson and Wai 1970; Okada et al. 1991). Other minerals in the metal nodules include schreibersite, daubréelite, caswellsilverite, and graphite (Garvie et al. 2018). Unlike many meteoritic metals, a typical Widmanstätten pattern of kamacite and taenite is not present. Instead, many of the metal nodules show a prominent pseudo-Widmanstätten pattern delineated by