Krotite, CaAl$_2$O$_4$, a new refractory mineral from the NWA 1934 meteorite

**CHI MA,** 1,* ANTHONY R. KAMPF,** HAROLD C. CONNOLLY JR.,** JOHN R. BECKETT,** GEORGE R. ROSSMAN,** STUART A. SWEENEY SMITH,** and DEVIN L. SCHRADER**

1Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, California 91125, U.S.A.
2Mineral Sciences Department, Natural History Museum of Los Angeles County, Los Angeles, California 90007, U.S.A.
3Department of Physical Sciences, Kingsborough Community College of CUNY, Brooklyn, New York 11235 and Earth and Environmental Sciences, The Graduate Center of CUNY, New York, New York 10024, U.S.A.
5Lunar and Planetary Laboratory, University of Arizona, Tucson, Arizona 85721, U.S.A.
6Department of Geology, Carleton College, Northfield, Minnesota 55057, U.S.A.

**ABSTRACT**

Krotite, CaAl$_2$O$_4$, occurs as the dominant phase in an unusual Ca-,Al-rich refractory inclusion from the NWA 1934 CV3 carbonaceous chondrite. Krotite occupies the central and mantle portions of the inclusion along with minor perovskite, gehlenite, hercynite, and CI-bearing mayenite, and trace hexamolybdenum. A layered rim surrounds the krotite-bearing regions, consisting from inside to outside of grossite, mixed hibonite, and spinel, then gehlenite with an outermost layer composed of Al-rich diopside. Krotite was identified by XRD, SEM-EBSD, micro-Raman, and electron microprobe. The mean chemical composition determined by electron microprobe analysis of krotite is (wt%) Al$_2$O$_3$ 63.50, CaO 35.73, sum 99.23, with an empirical formula calculated on the basis of 4 O atoms of Ca$_2$$_3$$_4$$_6$$_8$O$_4$. Single-crystal XRD reveals that krotite is monoclinic, $P2_1/n$; $a = 8.6996(3)$, $b = 8.0994(3)$, $c = 15.217(1)$ Å, $\beta = 90.188(6)$, and $Z = 12$. It has a stuffed tridymite structure, which was refined from single-crystal data to $R_e = 0.0161$ for 1014 $\sigma F$ reflections. Krotite is colorless and transparent with a vitreous luster and white streak. Mohs hardness is ~6½. The mineral is brittle, with a conchoidal fracture. The calculated density is 2.94 g/cm$^3$. Krotite is biaxial (–), $\alpha = 1.608(2)$, $\beta = 1.629(2)$, $\gamma = 1.635(2)$ (white light), $2V_{\text{meas}} = 54.4(5)^\circ$, and $2V_{\text{calc}} = 55.6^\circ$. No dispersion was observed. The optical orientation is $X = b$; $Y = a$; $Z = c$. Pleochroism is colorless to very pale gray, $X > Y = Z$. Krotite is a low-pressure CaAl$_2$O$_4$ mineral, likely formed by condensation or crystallization from a melt in the solar nebula. This is the first reported occurrence of krotite in nature and it is one of the earliest minerals formed in the solar system.

**Keywords:** Krotite, CaAl$_2$O$_4$, new mineral, refractory inclusion, NWA 1934 meteorite, CV3 carbonaceous chondrite, XRD, EBSD

**INTRODUCTION**

A rare CaAl$_2$O$_4$-dominant Ca-,Al-rich refractory inclusion (CAI), named “Cracked Egg” by Sweeney Smith et al. (2010), is observed in the Northwest Africa (NWA) 1934 meteorite (a CV3 carbonaceous chondrite). During our mineralogy investigation of this CAI, the calcium monoaluminate (CaAl$_2$O$_4$) was identified as a new mineral, named “krotite.” Electron microprobe, high-resolution SEM, electron backscatter diffraction (EBSD), single and powder XRD, and micro-Raman analyses have been used to characterize its composition and structure and the identity and composition of associated phases. Synthetic low-pressure and high-pressure CaAl$_2$O$_4$ phases are well known in the field of materials science (e.g., Rankin 1915; Hörkner and Müller-Buschbaum 1976; Ito et al. 1980). Dmiytriyevanovite was recently reported in a CH3 chondrite and described as the high-pressure mineral form of CaAl$_2$O$_4$ (Mikouchi et al. 2009). Here, we report the first occurrence of the low-pressure polymorph of CaAl$_2$O$_4$ in nature, as a new refractory mineral, krotite.

**MINERAL NAME AND TYPE MATERIAL**

The mineral and the mineral name have been approved by the Commission on New Minerals, Nomenclature and Classification (CMMNC) of the International Mineralogical Association (IMA 2010-038). The name is for Alexander N. Krot (born in 1959), a cosmochemist at the University of Hawaii, in recognition of his significant contributions to the understanding of early Solar System processes. Three thin sections (UA2169TS1, UA2169TS2, UA2169TS3) contain the type material. Section UA2169TS1 is deposited under catalog USNM 7590 in the Smithsonian Institution’s National Museum of Natural History, Washington, D.C., U.S.A. Co-type material (krotite fragments from Section UA2169TS2) is deposited under catalog 63275 in the Natural History Museum of Los Angeles County, California, U.S.A.