Zolenskyite, FeCr\textsubscript{2}S\textsubscript{4}, a new sulfide mineral from the Indarch meteorite

CHI MA\textsuperscript{1,*} AND ALAN E. RUBIN\textsuperscript{2,3}

\textsuperscript{1}Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, California 91125, U.S.A.
\textsuperscript{2}Department of Earth, Planetary, and Space Sciences, University of California, Los Angeles, California 90095-1567, U.S.A.
\textsuperscript{3}Maine Mineral & Gem Museum, 99 Main Street, P.O. Box 500, Bethel, Maine 04217, U.S.A.

Abstract

Zolenskyite (IMA 2020-070), FeCr\textsubscript{2}S\textsubscript{4}, is a new sulfide mineral that occurs within troilite, with clinostatite and tridymite, in the matrix of the Indarch meteorite, an EH4 enstatite chondrite. The mean chemical composition of zolenskyite determined by electron probe microanalysis, is (wt\%): 43.85, Cr 35.53, Fe 18.94, Mn 0.68, Ca 0.13, total 99.13, yielding an empirical formula of Fe\textsubscript{0.99}Mn\textsubscript{0.04}Ca\textsubscript{0.01}Cr\textsubscript{1.99}S\textsubscript{3.98}. The ideal formula is FeCr\textsubscript{2}S\textsubscript{4}. Electron backscatter diffraction shows that zolenskyite has the C\textsubscript{2h}/m CrNb\textsubscript{2}Se\textsubscript{4}-Cr\textsubscript{3}S\textsubscript{4}-type structure of synthetic FeCr\textsubscript{3}S\textsubscript{4}, which has \( a = 12.84(1) \text{Å}, b = 3.44(1) \text{Å}, c = 5.94(1) \text{Å}, \beta = 117.1^\circ \), \( V = 234(6) \text{Å}^3 \), and \( Z = 2 \). The calculated density using the measured composition is 4.09 g/cm\textsuperscript{3}. Zolenskyite is a monoclinic polymorph of daubréelite. It may be a high-pressure phase, formed from daubréelite at high pressures (several gigapascals) and moderate temperatures in highly shocked regions of the EH parent asteroid before becoming incorporated into Indarch via impact mixing. Zolenskyite survived moderate annealing of the Indarch whole-rock. The new mineral is named in honor of Michael E. Zolensky, an esteemed cosmochemist and mineralogist at NASA’s Johnson Space Center, for his contributions to research on extraterrestrial materials, including enstatite chondrites.

Keywords: Zolenskyite, FeCr\textsubscript{2}S\textsubscript{4}, new mineral, sulfide, Indarch meteorite, enstatite chondrite

Introduction

The Indarch meteorite, which fell at Shusha, Azerbaijan on April 7, 1891, is an EH4 enstatite chondrite (Meteoritical Bulletin Database). The meteorite consists of (in wt\%): 72.6% silicates (clinostatite and disordered orthoenstatite, averaging En\textsubscript{98}Fs\textsubscript{1}Wo\textsubscript{0.6}; albite, averaging Ab\textsubscript{97}An\textsubscript{3}Or\textsubscript{5.8}; tridymite); 17.5% Si-bearing low-Ni metallic Fe (kamacite); 7.3% Ti-, Cr-, Mn-, and Zn-bearing troilite; 1.0% niningerite; 0.39% oldhamite; trace amounts of rudashevskvite (Fe,Zn)S; 0.05% FeCr\textsubscript{3}S\textsubscript{4}(listed as daubréelite, but is actually mainly zolenskyite, a porphyritic pyroxene chondrule (Fig. 2). To characterize the chemical composition and structure of zolenskyite (as well as its associated phases), we used field-emission scanning electron microscopy (SEM), electron backscatter diffraction (EBSD), and electron probe microanalysis (EPMA). Synthetic FeCr\textsubscript{3}S\textsubscript{4} and (Fe\textsubscript{10}Cr\textsubscript{6})Cr\textsubscript{2}S\textsubscript{4} with the C\textsubscript{2h}/m CrNb\textsubscript{2}Se\textsubscript{4}-Cr\textsubscript{3}S\textsubscript{4}-type structure have been reported (Tressler et al. 1968; Lutz et al. 1983); presented here is the first natural occurrence of this phase as a new mineral in a chondritic meteorite.

Mineral Name and Type Material

The new mineral and its name have been approved by the Commission on New Minerals, Nomenclature and Classification of the International Mineralogical Association (IMA 2020-070) (Ma 2021). The mineral name is in honor of Michael E. Zolensky (born in 1955), esteemed planetary scientist, cosmochemist, and mineralogist at NASA’s Johnson Space Center for his outstanding contributions to research on extraterrestrial materials, including enstatite chondrites. Caltech sections ICM1, ICM2, ICM3, and ICM6, taken from facing slices of the Indarch meteorite, contain the type material of zolenskyite. Section ICM3, hereafter referred to as USNM 7926, has been deposited in the Smithsonian Institution’s National Museum of Natural History, Washington, D.C., U.S.A., under catalog USNM 7926. USNM 7926 also contains rare grains of joegoldsteinite (MnCr\textsubscript{5}; Isa et al. 2016).

Occurrence and Appearance

Zolenskyite occurs within troilite, associated with clinostatite and tridymite in the Indarch matrix in sections ICM1, ICM2, ICM6, and USNM 7926 (Fig. 1). Zolenskyite occurs as euhedral-subhedral single crystals, ~10–20 \( \mu \text{m} \) in size, with oxidation alteration patches within each grain. Only the brighter clean regions (up to 2 \( \mu \text{m} \) in size) in the backscattered electron images are the type material of zolenskyite, whereas the darker regions are oxidized areas (Fig. 1).

Zolenskyite is opaque. Color, luster, streak, hardness, tenacity, cleavage, fracture, density, and optical properties could not be...