Tistarite, Ti₂O₃, a new refractory mineral from the Allende meteorite

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ABSTRACT

Tistarite, ideally Ti₂O₃, is a new member of the corundum-hematite group. It is found as one subhedral crystal in a cluster of micrometer-sized refractory grains along with khamrabaevite (TIC), rutile, and corundum crystals within a chondrule from the Allende meteorite. The mean chemical composition determined by electron microprobe analysis is (wt%): TiO₂ 94.94, MgO 2.06, Al₂O₃ 1.50, ZrO₂ 0.44, FeO 0.24, CaO 0.10, Cr₂O₃ 0.06, sum 99.34. The empirical formula calculated on the basis of 3 O atoms is (Ti₄₀Mg₂₇Al₈₀Zr₃₂O₁₁₀). Tistarite is rhombohedral, R₃c; a = 5.158 Å, c = 13.611 Å, V = 313.61 Å³, and Z = 6. Its electron back-scatter diffraction pattern matches that of synthetic Ti₂O₃ with the R₃c structure. The strongest calculated X-ray powder diffraction lines from the synthetic Ti₂O₃ data are [d spacing in Å (h k l)]: 3.734 (84) (012), 2.707 (88) (104), 2.379 (90) (110), 2.242 (38) (113), 1.867 (33) (024), 1.703 (100) (116), 1.512 (28) (214), 1.489 (46) (300), 1.121 (20) (226), 0.896 (25) (416). The mineral is named after the composition “Ti” and the word “star,” implying that this new refractory mineral is among the first solids formed in the solar system.

Keywords: Tistarite, Ti₂O₃, new refractory mineral, titanium oxide, Allende meteorite

INTRODUCTION

During a nanomineralogy investigation of the Allende meteorite, a new titanium oxide mineral, Ti₂O₃, was discovered in a corundum-rich cluster of refractory grains in situ in an Allende chondrule. Electron microprobe, high-resolution SEM, electron back-scatter diffraction (EBSD), EDS, and Raman analyses have been used to characterize its composition and structure. Synthetic Ti₂O₃ is well known in the field of materials science. We report the first occurrence of Ti₂O₃ in nature.

MINERAL NAME AND TYPE MATERIAL

The mineral and the mineral name have been approved by the Commission on New Minerals, Nomenclature and Classification (CNMNC) of the International Mineralogical Association (IMA 2008-016). The name of the new mineral is derived from the word “star” and the composition “Ti,” implying that this new mineral is likely a condensate among the first solids formed in the solar system at the birth of our star. The thin section containing the holotype material is in the collection of the Smithsonian Institution’s National Museum of Natural History and is catalogued under USNM 3510-6.

OCCURRENCE, ASSOCIATED MINERALS, AND ORIGIN

Tistarite occurs as one isolated grain within a cluster of refractory grains discovered in situ in a ferromagnesian chondrule from the Allende meteorite, along with about 30 corundum (Al₂O₃) grains, one khamrabaevite (TIC) grain, one rutile (TiO₂) grain, and one mullite grain (Al₅Si₃O₁₂) (Figs. 1–2). This cluster is about 130 μm in diameter inside a 1.3 × 1.4 mm chondrule in the section plane. Mg-rich olivine (Fo₉₈–100) occupies the core area of the chondrule with a rim consisting of enstatite and more Fe-rich olivine (Fo₈₃–85), surrounded by matrix of mainly olivine and troilite. The mineral has been found, to date, within only one chondrule in one polished Allende section. The Allende meteorite, which fell at Puebloito de Allende, Chihuahua, Mexico, on February 8, 1969, is a CV3 carbonaceous chondrite.

APPEARANCE, PHYSICAL AND OPTICAL PROPERTIES

One subhedral tistarite crystal was first recognized by its stronger back-scattered electron intensity within a chondrule in the scanning electron microscope (Figs. 1–2). Back-scatter electron (BSE) images were obtained both with a ZEISS 1550VP field-emission SEM and a JEOL 8200 electron microprobe using solid-state BSE detectors. Tistarite occurs as an 5 × 7 μm grain, which is the type specimen. It is gray in reflected light and opaque in transmitted light. Streak, luster, hardness, tenacity, cleavage, fracture, and density were not determined due to the small grain size. It is non-fluorescent under the beams of the electron microprobe and SEM. The calculated density is 4.53 g/cm³, using the empirical formula. Neither crystal forms nor twinning was observed. The a:c ratio calculated from the unit-cell parameters is: 1.26388.

Nano-inclusions have been observed in this tistarite grain by high-resolution BSE imaging (Fig. 3). Their EBSP patterns could not be obtained. Based on the bulk composition of this grain, the platy uniformly distributed inclusions are probably MgTi₂O₄, a new spinel-group mineral. To protect the only type-material grain, TEM is not used to investigate the nano-inclusions through a destructive focused ion beam sample preparation.

CHEMICAL COMPOSITION

Chemical analyses (5) were carried out by means of the JEOL 8200 electron microprobe (WDS mode, operated at 15 kV and