Panguite, (Ti$^{4+}$,Sc,Al,Mg,Zr,Ca)$_{1.8}$O$_3$, a new ultra-refractory titania mineral from the Allende meteorite: Synchrotron micro-diffraction and EBSD

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ABSTRACT

Panguite (IMA 2010-057), (Ti$^{4+}$,Sc,Al,Mg,Zr,Ca)$_{1.8}$O$_3$, is a new titania, occurring as fine-grained crystals with Ti-rich davsite in an ultra-refractory inclusion within an amoeboid olivine inclusion from the Allende CV3 carbonaceous chondrite. The phase was characterized by SEM, EBSD, synchrotron micro-diffraction, micro-Raman spectroscopy, and EPMA. The mean chemical composition of the type panguite is (wt%) TiO$_2$: 47.97, ZrO$_2$: 14.61, Sc$_2$O$_3$: 10.67, Al$_2$O$_3$: 7.58, MgO: 5.54, Y$_2$O$_3$: 5.38, CaO: 3.34, SiO$_2$: 1.89, FeO: 1.81, V$_2$O$_3$: 0.95, Cr$_2$O$_3$: 0.54, HfO$_2$: 0.28, sum 100.56 with a calculated density of 3.746 g/cm$^3$. Synchrotron micro-Laue diffraction (i.e., an energy scan by a high-flux X-ray monochromatic beam and white beam diffraction) on one type domain at sub-micrometer resolution revealed that panguite is an orthorhombic mineral in space group Phca. The structure is a subgroup of the Ï½3 bixbyite-type. The cell parameters are $a = 9.781(1)$, $b = 9.778(2)$, and $c = 9.815(1)$ Å, yielding $V = 938.7(1)$ Å$^3$, $Z = 16$, and a calculated density of 3.746 g/cm$^3$. Panguite is not only a new mineral, but also a new titania material, likely formed by condensation. It is one of the oldest minerals in the solar system.

Keywords: Panguite, (Ti$^{4+}$,Sc,Al,Mg,Zr,Ca)$_{1.8}$O$_3$, new ultra-refractory mineral, new titania, Allende meteorite, CV3 carbonaceous chondrite, synchrotron micro-diffraction, EBSD

INTRODUCTION

During a nano-mineralogy investigation of the Allende meteorite at Caltech, a new titania mineral (Ti$^{4+}$,Sc,Al,Mg,Zr,Ca)$_{1.8}$O$_3$, named “panguite,” was identified in an ultra-refractory inclusion within an amoeboid olivine inclusion (AOI). Electron probe microanalysis (EPMA), high-resolution scanning electron microscope (SEM), electron backscatter diffraction (EBSD), synchrotron micro-Laue diffraction with subsequent energy scans, and micro-Raman spectroscopic analyses were used to determine its composition, physical properties, and structure and to characterize associated phases. Synthetic (Ti$^{4+}$,Sc,Al,Mg,Zr,Ca)$_{1.8}$O$_3$ is not known. Thus, panguite is not only a new mineral and a new phase to meteoritics, but it is also a new material. In this work, we describe the first occurrence of panguite in nature, as a new ultra-refractory oxide among the oldest solid materials in the solar system. Preliminary results are given in Ma et al. (2011a).

MINERAL NAME AND TYPE MATERIAL

The mineral and the mineral name (panguite) have been approved by the Commission on New Minerals, Nomenclature and Classification (CNMNC) of the International Mineralogical Association (IMA 2010-057). The name panguite is for Pan Gu, the giant in ancient Chinese mythology, who created the world by separating the heaven and earth from chaos in the beginning, in allusion to the mineral with an ultra-refractory origin being among the first solid materials in the solar system. Holotype material (Section MC2Q of Caltech specimen Allende12A) is deposited under catalog USNM 7602 in the Smithsonian Institution’s National Museum of Natural History, Washington, D.C., U.S.A.

OCCURRENCE

The Allende meteorite fell in and near Pueblo de Allende, Chihuahua, Mexico, on February 8, 1969 (Clarke et al. 1971). It is a CV3 carbonaceous chondrite and the study of objects in this meteorite has had a tremendous influence on current thinking about processes, timing, and chemistry in the primitive solar nebula and small planetary bodies. The mineral panguite was found within one irregular ultra-refractory inclusion in one polished section (USNM 7602), prepared from a ~1 cm diameter Allende fragment (Caltech Meteorite Collection No. Allende12A). The host refractory inclusion is about 30 × 20 μm in size in the section plane and resides within an AOI, surrounded by a matrix of mostly fine-grained olivine and troilite. Panguite occurs with Ti-rich davsite and minor Sc-Ti-bearing diopside in the refractory inclusion (Figs. 1–2). Davsite appears to be the common thread for panguite. We have observed this phase in two additional inclusions, one from Allende and the other from the CM chondrite Murchison (Ma et al. 2011b). In both cases, panguite is invariably in contact with davsite. Moreover, Zhang and Hsu (2009) described a phase from the CH chondrite SaU 290, which we have confirmed by EBSD and EPMA at Caltech to be another example of panguite (see their Fig. 6c) and their grains are also in contact with davsite. Given...