American Mineralogist, Volume 105, pages 1704–1711, 2020

Donwilhelmsite, [$CaAl_4Si_2O_{11}$], a new lunar high-pressure Ca-Al-silicate with relevance for subducted terrestrial sediments

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Abstract

We report on the occurrence of a new high-pressure Ca-Al-silicate in localized shock melt pockets found in the feldspatic lunar meteorite Oued Awlitis 001 and discuss the implications of our discovery. The new mineral crystallized as tiny, micrometer-sized, acicular grains in shock melt pockets of roughly anorthitic bulk composition. Transmission electron microscopy based three-dimensional electron diffraction (3D ED) reveals that the $CaAl_4Si_2O_{11}$ crystals are identical to the calcium aluminum silicate (CAS) phase first reported from static pressure experiments. The new mineral has a hexagonal structure, with a space group of $P6_3/mmc$ and lattice parameters of $a = 5.42(1)$ Å; $c = 12.70(3)$ Å; $V = 323(4)$ Å^3; $Z = 2$. This is the first time 3D ED was applied to structure determination of an extraterrestrial mineral. The International Mineralogical Association (IMA) has approved this naturally formed CAS phase as the new mineral "donwilhelmsite" [$CaAl_4Si_2O_{11}$], honoring the U.S. lunar geologist Don E. Wilhelms. On the Moon, donwilhelmsite can form from the primordial feldspathic crust during impact cratering events. In the feldspatic lunar meteorite Oued Awlitis 001, needles of donwilhelmsite crystallized in ~200 μm sized shock melt pockets of anorthositic-like chemical composition. These melt pockets quenched within milliseconds during declining shock pressures. Shock melt pockets in meteorites serve as natural crucibles mimicking the conditions expected in the Earth's mantle. Donwilhelmsite forms in the Earth's mantle during deep recycling of aluminous crustal materials, and is a key host for Al and Ca of subducted sediments in most of the transition zone and the uppermost lower mantle (460–700 km). Donwilhelmsite bridges the gap between kyanite and the Ca-component of clinopyroxene at low pressures and the Al-rich Ca-ferrite phase and Ca-perovskite at high-pressures. In ascending buoyant mantle plumes, at about 460 km depth, donwilhelmsite is expected to break down into minerals such as garnet, kyanite, and clinopyroxene. This process may trigger minor partial melting, releasing a range of incompatible minor and trace elements and contributing to the enriched mantle (EM1 and EM2) components associated with subducted sedimentary lithologies.

Keywords: High-pressure phase, new mineral, donwilhelmsite, Oued Awlitis 001 lunar meteorite, shock metamorphism, subduction, mantle mineral, enriched mantle component