Decagonite, Al$_{71}$Ni$_{24}$Fe$_5$, a quasicrystal with decagonal symmetry from the Khatyrka CV3 carbonaceous chondrite

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ABSTRACT

Decagonite is the second natural quasicrystal, after icosahedrite (Al$_{68}$Cu$_{34}$Fe$_7$), and the first to exhibit the crystallographically forbidden decagonal symmetry. It was found as rare fragments up to ~60 µm across in one of the grains (labeled number 126) of the Khatyrka meteorite, a CV3 carbonaceous chondrite. The meteoritic grain contains evidence of a heterogeneous distribution of pressures and temperatures that occurred during impact shock, in which some portions of the meteorite reached at least 5 GPa and 1200 °C. Decagonite is associated with Al-bearing trevorite, diopside, forsterite, ahrensite, clinoenstatite, nepheline, coesite, pentlandite, Cu-bearing troilite, icosahedrite, khatyrkite, taenite, Al-bearing taenite, and steinhardtite. Given the exceedingly small size of decagonite, it was not possible to determine most of the physical properties for the mineral. A mean of seven electron microprobe analyses (obtained from three different fragments) gave the formula Al$_{71}$Ni$_{24}$Fe$_5$ on the basis of 100 atoms. A combined TEM and single-crystal X-ray diffraction study revealed the unmistakable signature of a decagonal quasicrystal: a pattern of sharp peaks arranged in straight lines with 10-fold symmetry together with periodic patterns taken perpendicular to the 10-fold direction. For quasicrystals, by definition, the structure is not reducible to a single three-dimensional unit cell, so neither cell parameters nor Z can be given. The likely space group is P10$_5$/mmc, as is the case for synthetic Al$_{71}$Ni$_{24}$Fe$_5$. The five strongest powder-diffraction lines [d in Å (hkl)] are: 2.024 (100), 3.765 (50), 2.051 (45), 3.405 (40), 1.9799 (40). The new mineral has been approved by the IMA-NMNC Commission (IMA2015-017) and named decagonite for the 10-fold symmetry of its structure. The finding of a second natural quasicrystal informs the longstanding debate about the stability and robustness of quasicrystals among condensed matter physicists and demonstrates that mineralogy can continue to surprise us and have a strong impact on other disciplines.

Keywords: Quasicrystal, aluminum, meteorite, chemical composition, TEM, X-ray diffraction, new mineral, decagonite

INTRODUCTION

Quasicrystals, solids with quasiperiodic atomic arrangements that violate the mathematical constraints of conventional crystallography, exhibit rotational symmetry forbidden to crystals, such as fivefold, sevenfold, and higher-order symmetry axes (Levine and Steinhardt 1984; Shechtman et al. 1984). The first occurrence of a quasicrystalline phase in nature, icosahedrite Al$_{68}$Cu$_{34}$Fe$_7$ (Bindi et al. 2009, 2011), displayed a fivefold symmetry in two dimensions and icosahedral symmetry in three dimensions and was found in the Khatyrka meteorite, a CV3 carbonaceous chondrite (Steinhardt and Bindi 2012; MacPherson et al. 2013; Bindi and Steinhardt 2014). The discovery represents a breakthrough in mineralogy and in condensed matter physics. The intriguing discovery in Grain 126 of the Khatyrka meteorite (Bindi et al. 2014, 2015) of steinhardtite grains with composition Al$_{58.50}$Ni$_{32.50}$Fe$_{10.50}$ and the fact that decagonal quasicrystals have been reported in the Al–Ni–Fe system (Tsai et al. 1989), stimulated us to continue the search for other quasicrystals.

Here we report the description of the second natural quasicrystal and the first with decagonal symmetry, which is named