Luogufengite: A new nano-mineral of Fe\textsubscript{2}O\textsubscript{3} polymorph with giant coercive field

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**Abstract**

Luogufengite, Al-bearing $\varepsilon$-Fe\textsubscript{2}O\textsubscript{3}, is a new member of Fe\textsubscript{2}O\textsubscript{3} polymorphs discovered in late Pleistocene basaltic scoria from the Menan Volcanic Complex nearby Rexburg, Idaho. It is an oxidation product of Fe-bearing basaltic glass at high temperature and is associated with maghemite and hematite. Luogufengite is an euhedral or semi-euhedral nano-mineral with its crystal size ranging from ~20 to ~120 nm. The mineral has a space group of $Pnma_2_1$; its unit-cell parameters refined from synchrotron X-ray powder diffraction pattern are $a = 5.0647(3)$, $b = 8.7131(6)$, $c = 9.3842(5)$ Å, and $Z = 4$ (calculated density = 4.905 g/cm$^3$) with the doubled hexagonal (ABAC) packing of oxygen atoms. The eight strongest lines of the measured X-ray diffraction pattern \{d(Å)/I/(hkl)\} are: 3.197(27.3)/(022); 2.945(29.1) (013); 2.708(100)/(122); 2.437(35.8)/(131); 1.716(24.4)/(204); 1.507(40.7)/(135); and 1.458(37.2)/(330). The empirical formula is $\text{Fe}_{1.71}\text{Al}_{0.23}\text{Mg}_{0.02}\text{Ti}_{0.03}\text{O}_3$. The crystals display (110) twins with twin boundaries of (110), (100), and (130) due to their pseudo-hexagonal symmetry. Luogufengite is an important mineral that records paleomagnetism of volcanic rocks because of its large magnetic coercivity. This unique magnetic property of the mineral may explain the observed unusually high-remanent magnetization in some igneous and metamorphic rocks and even martian rocks with high-remanent magnetization.

**Keywords:** Luogufengite, hematite, maghemite, scoria, nano-mineral, remanent magnetization, coercive field, lodestone

**Introduction**

The new mineral luogufengite, a Fe\textsubscript{2}O\textsubscript{3} polymorph analogous to the synthetic $\varepsilon$-Fe\textsubscript{2}O\textsubscript{3}, was discovered in late Pleistocene basaltic scoria from the Menan Volcanic Complex nearby Rexburg, Idaho. Powder X-ray diffraction (XRD) and high-resolution transmission electron microscopy (HRTEM) were used to determine its crystal structure and chemical composition. There are five known crystalline polymorphs of Fe\textsubscript{2}O\textsubscript{3} to date: hematite (\(\alpha\)-Fe\textsubscript{2}O\textsubscript{3}), maghemite (\(\gamma\)-Fe\textsubscript{2}O\textsubscript{3}), luogufengite (\(\varepsilon\)-Fe\textsubscript{2}O\textsubscript{3}) (synthetic) (Zboril et al. 1999), and \(\zeta\)-Fe\textsubscript{2}O\textsubscript{3} (synthetic) (Tucek et al. 2015). Luogufengite is a dark brown nano-mineral—an intermediate polymorph between maghemite and hematite (Tronc et al. 1998; Machala et al. 2011; Lee and Xu 2016). Synthetic $\varepsilon$-Fe\textsubscript{2}O\textsubscript{3} phase has a broad range of applications due to its unusual magnetic properties (e.g., giant coercive field, ferromagnetic resonance, and coupled magneto-electrics) (Jin et al. 2004; Gich et al. 2005; Tucek et al. 2010). The coercive field ($H_c = 2.0$ T) of $\varepsilon$-Fe\textsubscript{2}O\textsubscript{3} nano-crystals is much larger than those of oxide-based commercial magnets of BaFe\textsubscript{12}O\textsubscript{19} ($H_c = 0.64$ T) and Co-ferrites ($H_c = 0.74$ T) (Jin et al. 2004; Kohout et al. 2015).

In this paper, the crystal structure, composition, and mineral association of luogufengite are presented. There is a previous study on the mixture of $\varepsilon$-Fe\textsubscript{2}O\textsubscript{3} and magneto nano-crystals in subcellular phytoferritin of a plant (McCLean et al. 2001). However, the published electron diffraction pattern (Fig. 2d in the paper) does not support the presence of $\varepsilon$-Fe\textsubscript{2}O\textsubscript{3}. Herein, we describe a natural $\varepsilon$-Fe\textsubscript{2}O\textsubscript{3} (luogufengite) that occurs in basaltic scoria. The name has been approved by Commission on New Minerals, Nomenclature and Classification (CNMNC) of the International Mineralogical Association (IMA 2016-005) (Xu and Lee 2016). The mineral was named after a Chinese mineralogist, Professor Luo Gufeng (born in 1933), who has passionately taught crystallography and mineralogy at Nanjing University of China for more than 50 years. Luogufengite has been deposited in the collection of the Geology Museum of the Department of Geoscience, University of Wisconsin-Madison, with specimen numbers UWGM 2341, UWGM 2342, and UWGM 2343.

**Samples and Methods**

Scoria samples containing luogufengite were collected from the Menan Volcanic Complex, Rexburg, Idaho. The Menan Volcanic Complex consists of broad, flat volcanoes, formed by low-viscosity eruptions, with tholeiitic basalts dominating the surface exposures (Hackett and Morgan 1988; Russell and Brisbin 1990). The formation of scoria was related to the interaction of external water with the late-stage (late Pleistocene) eruption in the center of the Menan complex (Hackett and Morgan 1988; Russell and Brisbin 1990). The scoria generally resulted from rapid vesicula-