Tetrataenite in terrestrial rock

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ABSTRACT

Tetrataenite is an equiatomic and highly ordered, non-cubic Fe-Ni alloy mineral that forms in meteorites from the distortion of fcc taenite due to extremely slow cooling. The mineral has drawn much attention of the scientific community because of its superb magnetic properties, which may make the phase an alternative to the REE-based permanent magnets. Barring only a few passing mentions, the mineral has never been described from any terrestrial rock. Here we report the characteristics of terrestrial tetrataenite from an ophiolite-hosted Ni-bearing magnetite body from the Indo-Myanmar ranges, northeast India. Although the mineral assemblage surrounding it is very similar to that found in the meteorites, the postulated cooling regimes cannot be similar. The mineral is formed as a consequence of hydrothermal alteration of ferromagnesian minerals of the olivine and pyroxene groups. Iron and nickel were released from the silicates and precipitated in the form of Fe-Ni alloy at low temperature in extremely reducing conditions with a lack of sulfur. Our findings suggest a low-temperature hydrothermal origin of tetrataenite warrants a re-examination of the Fe-Ni phase diagram at low temperatures and puts a question mark on the age-old concept of tetrataenite formation as due solely to extremely slow cooling of fcc taenite in meteorites. It also opens up a new vista for adoption of a hydrothermal route to synthesize this rare material.

Keywords: Tetrataenite, Fe-Ni alloy, hydrothermal, terrestrial, Ni-bearing magnetite

INTRODUCTION

Metallic Fe-Ni alloy is ubiquitous in meteorites although its modal abundance is less than 1 vol% (Heiken et al. 1991). The Fe-Ni alloy minerals commonly found in meteorites are kamacite and taenite. Kamacite is characterized by a relatively low Ni-content (<7 wt%) and a body-centered cubic (bcc) structure (the α-phase). Taenite contains up to about 55 wt% Ni and has a face-centered cubic (fcc) structure (the γ-phase). In terrestrial rocks, metallic Fe-Ni is rare and found only in serpentinitized peridotites (Krishnarao 1964; Frost 1985) and volcanic rocks that have assimilated carbonaceous material; both are environments in which there is substantial reducing potential due to the presence of H2 and C (Goodrich and Bird 1985). The compositions of these alloy minerals in terrestrial rocks are predominantly restricted to the awaruite group (NiFe to Ni3Fe) with variable Fe/Ni ratios where Ni concentrations sometimes reach up to 75 wt% (Staples 1962). Tetrataenite, an equiatomic and highly ordered Fe-Ni alloy mineral that generally forms from the distortion of fcc taenite, has been established as a distinct mineral phase in some meteorites (Albertsen et al. 1978a, 1978b; Clarke and Scott 1980). With ~51 wt% Ni, it presents a tetragonal structure (superstructure L1₁, like CuAu), space group P4/mmm; a = 2.533 and c = 3.582 Å (Albertsen et al. 1978a). Tagai et al. (1988, 1995), however, argued that tetrataenite is only metrically tetragonal and its structure has monoclinic symmetry. The mineral is found mainly in extremely slowly cooled meteorites (cooling rate of a few degrees per million years for the temperature interval of 700–350 °C; Wood 1964; Goldstein and Short 1967), and is formed when meteorites cool slowly below 320 °C, which is the order-disorder transition temperature (Zhang et al. 1990). The cooling below 320 °C could be even slower and is important for the ordering of Ni and Fe in the atomic structure. Since below this temperature the auto-diffusion in the Fe–Ni system is insignificant on laboratory timescales, tetrataenite cannot be produced artificially by simple annealing of compositionally equivalent taenite phase with a disordered structure. Therefore, significant amounts of tetrataenite are found only in meteoritic samples that have suffered a slow and very long cooling process (Scorzzelli 1997). Although this ultra-rare Fe-Ni phase can be produced in a small scale synthetically by neutron- or electron-irradiation of Fe-Ni alloys at temperatures below 593 K (Pauleve et al. 1962; Gros and Pauleve 1970; Chamberod et al. 1979), or by hydrogen-reduction of nanometric NiFe2O4 (Lima et al. 2003), its large-scale production has not been achieved as of now. To the best of our knowledge, to date, tetrataenite has never been described from terrestrial rocks barring only a few mentions (Tominaga and Klein 2011; Rajabzadeh and Moosarinasab 2013). In this note we report the identification of tetrataenite in an ophiolite-hosted, Ni-bearing magnetite body from the Indo-Myanmar ranges of northeast India and discuss its characteristics, mode of occurrence, chemistry, and genesis, as well as the possible technological consequences of its occurrence in such an environment.

METHODS OF INVESTIGATION

Five samples from the magnetite body were investigated using a Leica optical petrological microscope. Quantitative microchemical compositions of the mineral

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