

X-Ray Diffraction with Synchrotron Radiation of Fe-Ni-bearing Meteorites

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INTRODUCTION

Fe-Ni-bearing meteorites provide very unique minerals due to their very slow cooling rates. The iron-nickel metal in iron, stony-iron and in metal particles of chondrites are basically composed of two minerals: *kamacite* with BCC structure (α -phase) containing ~ 5 -7 at % Ni, and *taenite* having a FCC structure (γ -phase) generally with ~ 25 - 50 at % Ni. *Taenite* contains in its microstructure some special phases, which are formed at low temperatures (below ~ 400 C) as a result of the very slow cooling rates (~ 1 C/Ma) of meteorites in their parent bodies, like *tetrataenite* - atomically ordered Fe₅₀ Ni₅₀ phase -and *antitaenite*- the paramagnetic FCC phase with ~ 25 % Ni. *Tetrataenite* is formed when meteorites cool slowly below 320 C, which is the order-disorder transition temperature. *Antitaenite*, as revealed by Mössbauer spectroscopy, has always been observed in association with *tetrataenite*, and the two phases form an epitaxial intergrowth, which was proposed by Rancourt & Scorzelli [1] as a possible equilibrium state in the Fe-Ni system at ~ 20 - 40 at % Ni. *Tetrataenite* and *antitaenite* have similar lattice parameters, differing only in the formation of a superlattice or their compositions, conditions hard to detect by conventional X-rays diffraction equipments and exposure times. However, the weak superlattice reflection of *tetrataenite* with the L₁₀ superstructure has been detected by conventional XRD [2, 3]. The difficulty in detecting the superlattice reflections arises from the fact that Fe and Ni have almost similar scattering powers for X-rays. In particular, the coexistence of the ordered *tetrataenite* (L₁₀) with disordered paramagnetic Fe rich phase has been previously proposed based on Mössbauer evidence [4], but has never been unambiguously observed by a diffraction method. Using the high brilliance of the synchrotron radiation, however, the superlattice reflections of *tetrataenite* can more easily be detected. These meteoritic minerals have been extensively studied by Mössbauer spectroscopy, which is very sensitive to the local environments of the Fe probe. However, XRD, which provides a direct evidence for the presence of superstructures, has never been used in a systematic way to study atomic ordering in meteoritic Fe-Ni alloys and its connection to meteorites cooling histories. In the present work, we intend to conduct a systematic synchrotron X-ray diffraction study on *taenite* samples from some iron, stony-iron and metal particles of ordinary chondrites in order to i) explore the presence of *tetrataenite* in these meteorites and study the degree of atomic ordering through the tetragonal distortion of the FCC structure by ordering process. ii) try to detect *antitaenite* in samples dominated by the intergrowth *tetrataenite/antitaenite*.

This paper reports the results of x-ray diffraction from meteorites using a synchrotron radiation.

EXPERIMENT

X-ray diffraction experiments were conducted at the Brazilian Synchrotron Radiation Facility (Laboratório Nacional de Luz Sincrotron, Campinas) on the beamline XRD1. The goniometer was used with a Bragg-Brentano geometry, with divergence and scattering slits (1.5 mm) and a 1 mm detector slit. The X-ray wavelength was chosen to be 0.174565 nm (7102.5 ± 2.5 eV), a value which is near the minimum scattering power of Fe, to increase the scattering power difference between iron and nickel. The LaB₆ NIST standard (660a) was used to check the angular position and to evaluate the instrumental profile. TOPAS 3.0 Rietveld program [5] with fundamental parameters was employed to fit the diffraction data.

RESULTS AND DISCUSSION

In the meteorite work, Mössbauer measurements gave the first conclusive evidence for the existence of a ferromagnetic atomically ordered FeNi (50 at % Ni) phase that was later called *tetrataenite* [6]. Mössbauer spectra of: a) taenite lamella from octahedrites, b) ataxites, c) metal fractions of Fe-bearing chondrites and d) mesosiderites exhibit together with *tetrataenite* a single-line paramagnetic contribution at room temperature identified [1] as *antitaenite*. Whenever this

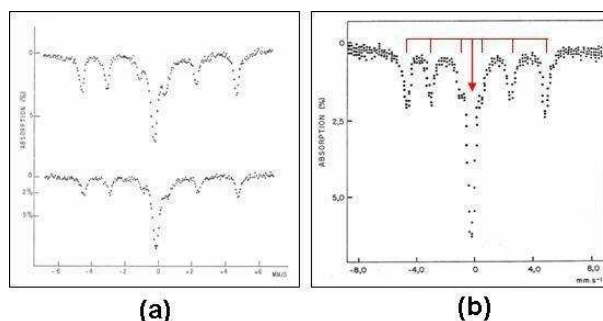


FIG. 1: Mössbauer spectra of (a) Toluca (upper spectrum) and Cape York (lower spectrum) octahedrites; (b) Santa Catharina ataxite (arrow indicates antitaenite)

paramagnetic contribution is observed, it always coexists with a hyperfine sextet pattern that is unambiguously attributed to *tetrataenite* (atomically ordered or partially ordered FeNi

phase). Figure 1 shows the typical Mössbauer spectra of the intergrowth *tetrataenite/antitaenite*, in different meteorites. The XRD experiments with synchrotron radiation have been

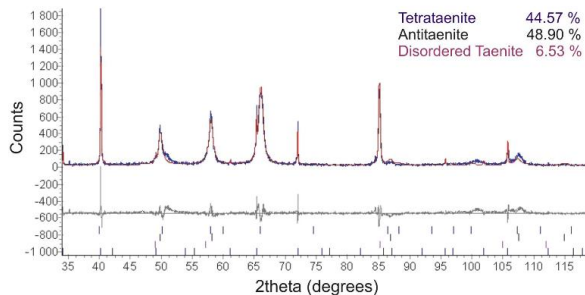


FIG. 2: SR- DRX diffractogram of the Santa Catharina meteorite

performed on samples of different groups of meteorites: Santa Catharina (ataxite), Yamato 79614 (ataxite), Toluca (octahedrite), metal particles of Saint-Séverin (chondrite), Vaca Muerta (mesosiderite) and Estherville (mesosiderite).

The results for the Santa Catharina meteorite (fig. 2) confirmed for the first time the presence of a disordered face centered cubic phase (FCC), space group Fm-3m, with stoichiometry $\text{Fe}_{0.6665}\text{Ni}_{0.3335}$ and lattice parameter of 0.3588 nm. This phase agrees with the previously proposed paramagnetic *antitaenite* [1]. The other two Fe-Ni phases were an ordered phase and iron deficient *tetrataenite* ($\text{Fe}_{0.4356}\text{Ni}_{0.5644}$) and a disordered phase, face centered cubic, with almost the same composition of the ordered phase ($\text{Fe}_{0.4385}\text{Ni}_{0.5615}$).

The relative amounts of these phases are 44.6 wt % *tetrataenite*, 48.9 wt % *antitaenite* and 6.5 wt % disordered FCC phase, in very good agreement with the results previously obtained

by Mössbauer spectroscopy for the Santa Catharina meteorite.

CONCLUSION

To our knowledge, this is the first synchrotron XRD pattern evidencing the superstructure lines of *tetrataenite* together with *antitaenite*. The intergrowth of both phases has also been detected in the Toluca meteorite. The results obtained for the other meteorites are still being analyzed and will also be reported.

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