ISSN 0029-3865

CNPq

CBPF - CENTRO BRASILEIRO DE PESQUISAS FÍSICAS

# Notas de Física

*CBPF-NF-069/93*

*Fe-NI Alloys in a Unique Antarctic Meteorite: Yamato 791694*

*by*

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1993

Abstract: Phase composition and structure of iron-nickel alloys in Y-791694 are discussed and compared to other non-Antarctic Ni-rich ataxites using the results obtained by Mössbauer spectroscopy and X-ray diffraction.

Key-words: Fe-Ni alloys; Antarctic meteorites; Mössbauer.

## 1. INTRODUCTION

Yamato 791694 (Y-791694) is an Antarctic iron meteorite classified as an ataxite (YANAI, 1979) whose uniqueness is due to the composition. The high concentration of Ni (35%) and other elements as Cu, In, Sn, Sb,Pb and Bi (SHIMAMURA, 1979) is one of the highest among all known iron meteorites. The average Ni composition, similar to Santa Catharina and Twin City meteorites, is the one in which Fe-Ni alloys present the structural and magnetic Invar anomalies. Due to the slow cooling in their asteroidal bodies, iron meteorites are important as indicators of phase transformations which occur in Fe-Ni alloys. In the Invar composition range, Fe-Ni alloys may undergo segregation and/or ordering (depending upon Ni content) provided that the conditions favor atomic diffusion. Since the discovery of the ordered phase obtained by irradiation (PAULEVÉ, 1962), it has been observed that alloys in the Invar region (30% - 50% Ni), when subjected to irradiation, separate into two phases, one ferromagnetic and the other paramagnetic, both with fcc structure.

The ordered phase with $L1_0$ superstructure was observed for the first time in 1962 in neutron irradiated Fe-Ni alloys. The tetragonal distortion of the superstructure $L1_0$ has its origin in an electric field gradient at the level of the iron atoms of the alloy. This gives rise to a Mösssbauer spectrum that is singular among the Fe-Ni alloys, because it presents a typical asymmetry, that results from a relatively small quadrupolar interaction with the $^{57}$Fe nucleus, superimposed on a large magnetic interaction of the ferromagnetic alloys.

Investigations by Mössbauer spectroscopy of taenite fields from meteorites of different chemical groups have disclosed differences in the state of order of tetrataenite (ordered Fe-Ni 50/50 alloy with superstructure $L1_0$) which are attributed to different cooling histories below $\sim 350°$ C. Since taenite fields containing tetrataenite occur in the majority of the meteorites, including ordinary chondrites, pallasites, mesosiderites and iron meteorites, Mössbauer spectroscopy turns out to be a very powerful method to study cooling rates of meteorites below $\sim 350°$ C. These cooling rates might give important information about genetic relations between the meteorites and provide new information upon their origin.

This paper presents preliminary results of our investigation on phase composition and structure of iron-nickel alloys in Y-791694 compared to previous results obtained with non-Antarctic Ni-rich ataxites using Mössbauer spectroscopy (MS), scanning electron microscopy (SEM), energy dispersive X-ray analysis (EDS) and X-ray diffraction (XRD).

## 2. EXPERIMENTAL

Thin slices of the Y-791694 meteorite were cut with a precision saw, carefully avoiding to submit the sample to thermal stresses. Absorbers for Mössbauer measurements were prepared by polishing the slices to a thickness of about 70 μm. The spectra were recorded with a $^{57}$C0/Rh source in a conventional spectrometer.

The lattice parameters were determined by refinement with the Rietveld method applied to X-ray diffraction patterns obtained in a powder diffractometer with Bragg-Brentano focalization geometry operating in a step mode. The counting time per step was 10 s in the angular range $20° \leq 2\theta \leq 100°$ using Cu radiation ($\lambda$ = 1.5418 Å) and a quartz monocromator plane (1011) .

Scanning electron microscopy (SEM) was performed using a JEOL JSM-U3 working at 20 kV coupled to a Tracor Northern (model 5500) energy dispersive X-ray spectrometer (EDS). Sample compositions were determined using a computer program in the EDS software package based on ZAF technique.

## 3. RESULTS AND DISCUSSION

The Mössbauer spectrum at room temperature of a thin slice of the Y-791694 indicates the presence of at least two Fe-Ni alloy phases, a major one corresponding to a Ni-rich disordered taenite and a small amount of $\alpha$ or $\alpha_2$-bcc alloy (fig.1). However, due to the broad linewidths typical of disordered alloy, the best fit of the spectra was obtained using a distribution of hyperfine fields, with a maximum of the distribution curve at ~300 kOe with hyperfine parameters typical of a ~ 40% Ni disordered taenite.

X-ray diffraction pattern (fig. 2) indicates the presence of a fcc Fe-Ni alloy (space group Fm3m) with lattice parameter $a_0$ = 3.6001±0.001 Å corresponding to the disordered taenite and a bcc Fe-Ni alloy with $a_0$ = 2.873 ± 0.003 Å in lower proportion.

EDS analysis showed a Ni distribution ~ 40% Ni and local enrichment of P in some regions, probably due to the presence of schreibersite. EDS mapping of the components is in progress to determine the influence of P in the Ni distribution.

In the Invar composition range, the slow cooled iron meteorites contain a cloudy zone structure composed of an ordered tetrataenite phase and a surrounding honeycomb phase poorer in Ni either of a $\gamma$ or $\alpha$-phase. This microstructure results from a spinodal reaction below 350° C (REUTER,1988; GOLDSTEIN, 1990) and has been characterized using a variety of electron optical techniques in Santa Catharina (~35% Ni) and Twin City (~30% Ni) meteorites (ZHANG, 1990). The presence of tetrataenite was investigated by XRD and MS in several Ni-rich ataxites and was detected in both meteorites Santa Catharina and Twin City (SCORZELLI, 1985; SCORZELLI, 1990), cannot be excluded in San Cristobal (~25% Ni) (DANON, 1985) and is absent in Lime Creek (~29% Ni) and Tishomingo (~32% Ni). ZHANG et al. (1990) found important differences between Santa Catharina and Twin City. The Mössbauer results showed that the bulk of Twin City contains about 50% of tetrataenite similar to Santa Catharina, however the hyperfine parameters (hyperfine field and quadrupolar interaction) suggest a degree of long range ordering smaller than that observed in Santa Catharina (SCORZELLI, 1990).

Although the Ni content is similar in these meteorites, important differences were noticed between Lime Creek, Tishomingo and the others, as can be seen in fig. 3. A detailed microstructural study of the Thisimingo meteorite done by Ives et al. (1978) gives good reasons to expect differences in Mössbauer spectra between Tishomingo and other meteorites of similar bulk Ni contents.

The presence of the ordered phase Fe-Ni 50/50 with $L1_0$ superstructure in S. Catharina, Twin City (fig. 4) and San Cristobal indicates that phase decomposition has occurred at low temperatures since the ordering reaction proceeds below ~320° C. The different proportions of ordered phase and different degree of ordering between them is probably related to their Ni content and to different reactions that can take place at very low temperatures.

The Mössbauer spectra of Lime Creek and Tishomingo shows that segregation has occurred but ordering has been affected. The quadrupole splitting typical of the ordered phase is absent in these meteorites, indicating that the Fe-Ni 50/50 is not ordered. The disordered ferromagnetic taenite can be attributed to a destruction of the ordered superstructure. Both Lime Creek and Tishomingo meteorites show metallographic evidences of a shock event (BUCHWALD, 1975; IVES,1978), whereas no evidence for shock has been reported for San Cristobal, Twin City and S. Catarina meteorites.

In the case of the Antarctic Ni-rich ataxite Y-791694, in spite of the high nickel content, the Mössbauer spectrum showed a completly different phase composition. The results obtained up to now suggest that the main component corresponds to a fully disordered Fe-Ni alloy with ~ 40% Ni, which can be an indication of a fast cooling rate for this meteorite. However, since Mössbauer spectroscopy is a bulk property measurement, detailed microstructure observations are required in order to have a better understanding of the phase composition and structure of this complex system.

## Acknowledgments

We thank NIPR curator Dr. Yanai for the opportunity to study this meteorite. We are grateful to D.T. Gomes for technical support on SEM/EDS analysis.

## FIGURE CAPTIONS

Figure 1 - Mössbauer spectrum of a thin slice of the Y-79694 meteorite

Figure 2 - XRD pattern of a thin slice of the Y-79694 meteorite.

Figure 3 - Conversion electron Mössbauer spectroscopy (CEMS) of Ni-rich ataxites:
a) Santa Catharina; b) Twin City; c) San Cristobal; d) Lime Creek; e) Tishomingo.

Figure 4 - Mössbauer spectrum of a thin slice of the Twin City meteorite.

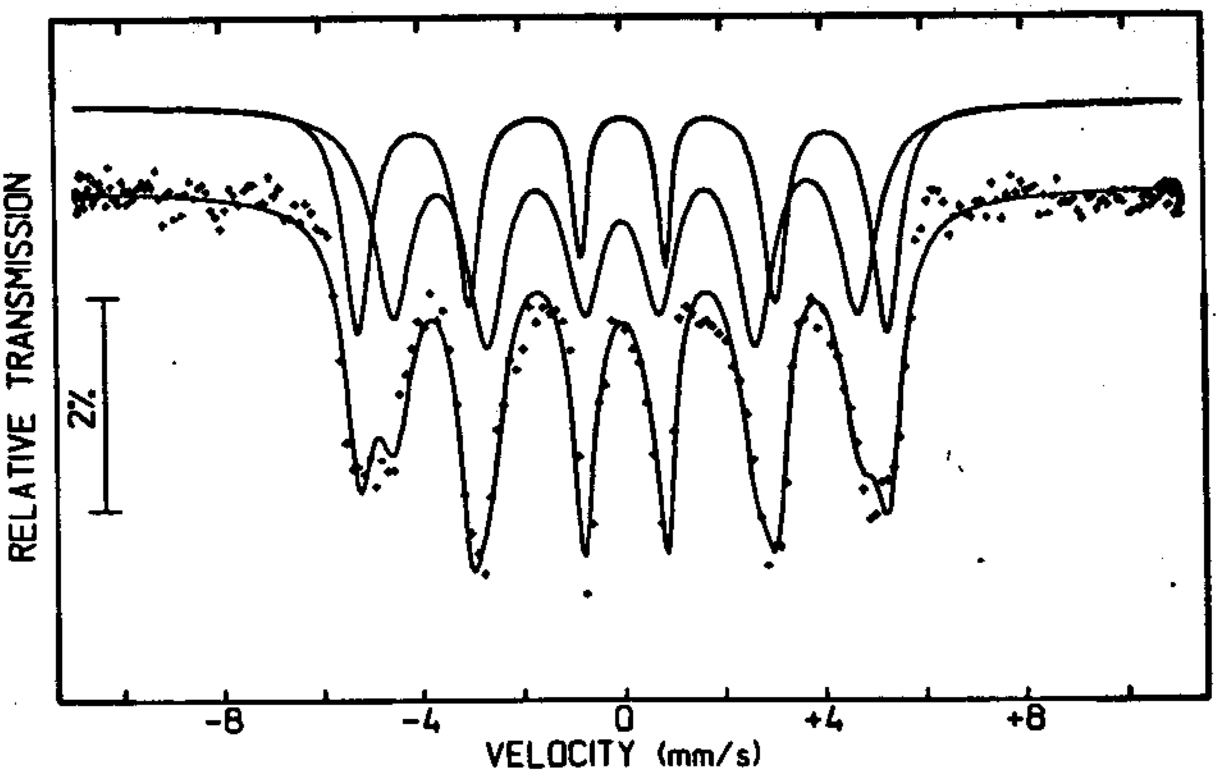


FIG. 1

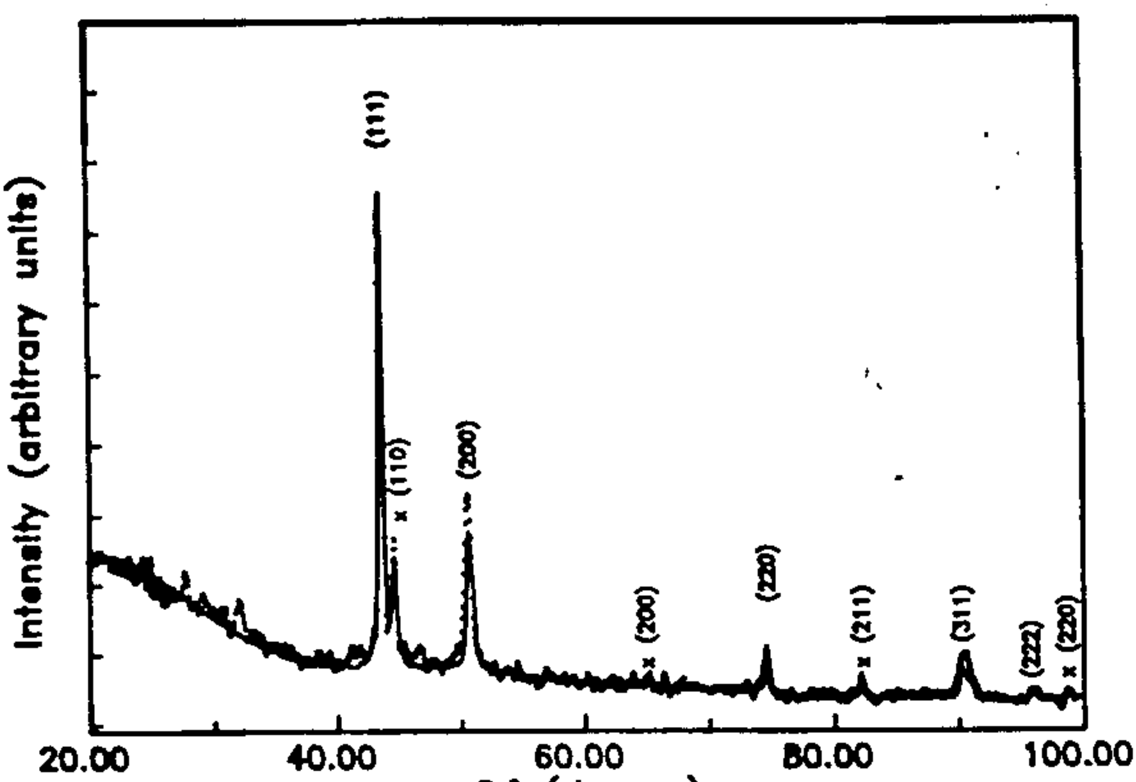
Intensity (arbitrary units)
(111)
(110)
(200)
(200)
(220)
(211)
(311)
(222)
(220)
20.00
40.00
60.00
80.00
100.00
2ϑ (degree)

FIG. 2

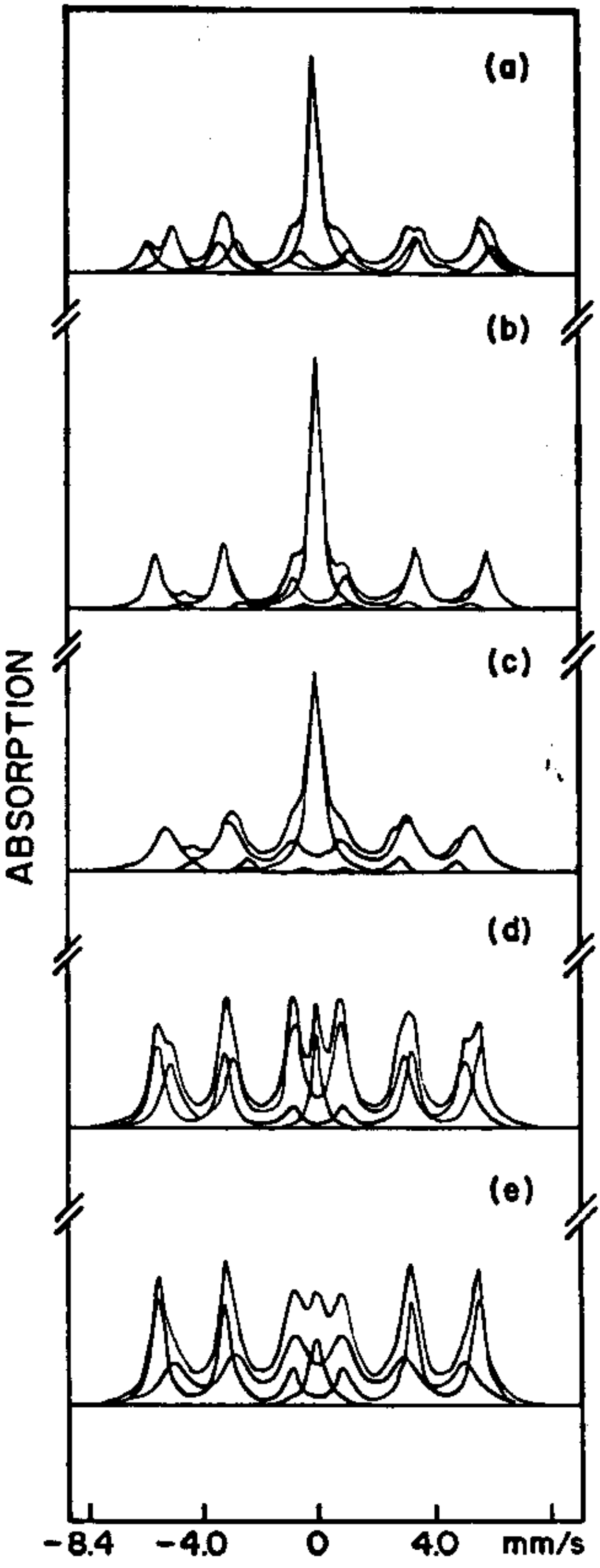


FIG. 3

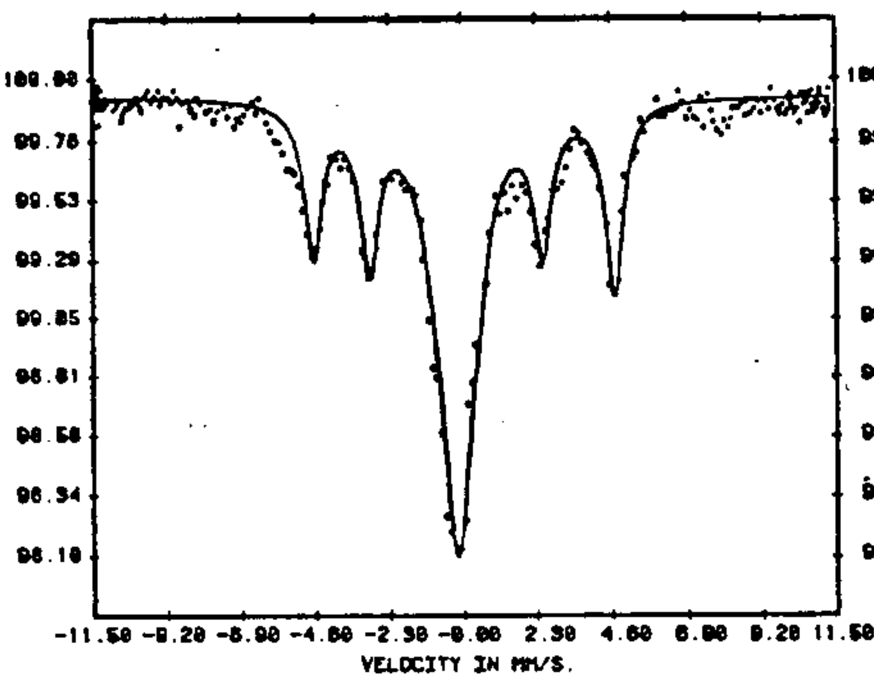
100.00
99.76
99.53
99.29
99.05
98.81
98.58
98.34
98.10
-11.50 -9.20 -6.90 -4.60 -2.30 -0.00 2.30 4.60 6.90 9.20 11.50
VELOCITY IN MM/S.

FIG. 4

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