THE FERRIMAGNETIC PHASE IN NAKHLA AND ZAGAMI - IMPLICATIONS FOR THE MARTIAN FINES

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Introduction: In the Viking Missions it was shown that the Martian soil contains a strongly magnetic phase [1]. There are at least three different possibilities for the origin of this phase: a) The magnetic phase could be titanomagnetite/titanomaghemite formed as a weathering product and in this way inherited directly from the underlying basaltic bedrock [2,3], b) The magnetic phase could have formed by precipitation in an ancient sea [4,5] or c) The magnetic phase may have been brought to the Martian surface in the form of micrometeorites [6].

Especially with respect to the first of these possibilities it is of interest to study in detail the iron containing phases in the SNC-meteorites, in particular the ferrimagnetic phases. Here we report on the $^{57}$Fe-Mössbauer spectra obtained from magnetic fractions of the meteorites Nakhla and Zagami.

Experimental: From a small piece of each of the meteorites ($\approx 100$ mg) dark grains were selected in an optical microscope. The grains were gently crushed and among these smaller grains, those that responded to the presence of a hand magnet were selected for the preparation of Mössbauer absorbers (1.5 and 2.0 mm diameter and $\approx 30\mu$m thick). These samples were investigated in a conventional constant acceleration Mössbauer spectrometer at various temperatures. Isomer shifts were measured with respect to the centroid of the room temperature spectrum of a foil of $\alpha$-Fe.

Results and Discussion: The room temperature spectra of the magnetic fractions of Zagami and Nakhla are shown in the figure.

These spectra as well as spectra obtained at lower temperatures show that the ferrimagnetic phase in both Zagami and Nakhla is magnetite, significantly affected by isomorphous substitution. PIXE (Proton Induced X-ray Emission) on single magnetic grains has shown that the substituting element is primarily Ti although minor amounts of Mn cannot be excluded.

The titanomagnetites of the two meteorites are different. The room temperature Mössbauer spectrum of the titanomagnetite in Nakhla consists of three sextets of which two are clearly resolved and displays the typical pattern of magnetite, whereas that of Zagami is broad and complicated, typical of heavily (and in this case also inhomogeneously) isomorphously substituted magnetite [7]. Only at lower temperatures (between room temperature and 80 K) are the magnetic lines in the Zagami spectrum resolved. Describing the titanomagnetite as $\text{Fe}_{3-x}\text{Ti}_x\text{O}_4$ the average concentration of Ti as judged from the Mössbauer spectra is estimated to $x \leq 0.03$ and $x \sim 0.7$ for Nakhla and Zagami, respectively. Titanomagnetite with $x \sim 0.7$ is in a region of the magnetite ulvöspinel solid solution series in which the material is metastable. It is produced in this state by relatively rapid cooling.
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Figure 1: Room temperature Mössbauer spectra of the magnetic fractions of a) Zagami and b) Nakhla.

The striking differences between the titanomagnetites of the two meteorites may be caused by one of two possibilities: either the titanomagnetite of Nakhla has formed in a process of relatively slow cooling/crystallization of the igneous rock or it has in some period of its history been subject to a secondary thermal event that has caused its metastable titanomagnetite to equilibrate and segregate into more stable phases.

Conclusion: It has been shown that the titanomagnetite in Nakhla and Zagami is very different. The presence of titanomagnetite in SNC-meteorites suggest that at least a fraction of the magnetic phase in the Martian fines may have been derived from SNC-type bedrock by weathering.

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