

MOSSBAUER SPECTRA OF OLIVINE-RICH WEATHERED ACHONDRITES: I. UREILITES

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INTRODUCTION. Olivine, the dominant ferromagnesian silicate in many meteorite-types, is susceptible to low temperature and oxidative weathering reactions, particularly in aqueous environments. On surfaces of terrestrial planets such as Earth and Mars, olivines in basaltic rocks may be oxidized to iddingsite, a complex mixture of hydrated ferric oxide and phyllosilicate phases [1]. In studies to assess whether oxidation of olivine has occurred on the frozen surface of Mars, Mossbauer spectral measurements have been made on olivine-bearing achondritic meteorites found in Antarctica. Earlier studies of chondrites, eucrites and diogenites from Antarctica demonstrated that ferric-bearing phases in weathered meteorites may be distinguished in their Mossbauer spectra [2]. This paper summarizes results for a suite of ureilites; an accompanying abstract [3] describes measurements made on olivine-bearing SNC meteorites.

METEORITE SPECIMENS. Several ureilites, typically consisting of olivine-pigeonite assemblages in a carbonaceous matrix composed of graphite, diamond or lonsdaleite plus accessory Fe-Ni metal and sulfides [4], are catalogued in the Antarctic Meteorite Collection [5]. Samples of seven such ureilites listed in Table 1 were acquired as ~100 mg chips from the interiors of each meteorite. Each sample was pulverized to <45 microns, mixed with sucrose, and mounted in sample holders for Mossbauer spectral measurements at ambient (295K) and liquid helium (4.2K) temperatures. From some samples, the metallic fraction was later removed by a hand magnet and separate spectra were acquired for the metal-depleted powders.

MOSSBAUER SPECTRA. Spectral measurements and curve-fitting procedures are described in detail elsewhere [2]. The 295K spectra were acquired in two velocity ranges, $\pm 5 \text{ mm s}^{-1}$ and $\pm 12 \text{ mm s}^{-1}$. The expanded range enabled magnetic hyperfine sextets originating from metallic Fe and traces of Fe(III) oxide phases to be identified and allowances made for their contributions in the narrow velocity range where paramagnetic Fe^{2+} and Fe^{3+} quadrupole doublets are better resolved. The 4.2K spectra were acquired in the $\pm 12 \text{ mm s}^{-1}$ range, enabling magnetically-ordered Fe(III) oxide/hydroxide phases to be identified.

RESULTS. Room-temperature and 4.2K Mossbauer spectra of two of the ureilites (PCA 82506 and EET 87517) representative of the suite of meteorites are illustrated in Figure 1 and include spectra for a bulk sample (Figs 1a and 1c) and for an ureilite separated from its metallic iron (Figs 1b and 1d). The 295K spectra were resolved into two ferrous and one ferric doublet (shaded), in addition to the four inner peaks of the metallic Fe sextet spectrum. The relative intensities of the outer and inner ferrous doublets, originating from Fe^{2+} ions in olivine and the pigeonite M2 sites, respectively, indicate that olivine predominates in PCA 82506 (Fig. 1a) and is less abundant in EET 87517 (Fig. 1b). The proportion of Fe^{3+} ions is also higher in this olivine-depleted ureilite. The 4.2K spectra show the appearance of sextets originating from magnetically-ordered Fe(III) oxide phases and from metallic Fe. The ferric sextet peaks are sharper in PCA 82506 (Fig. 1c) and yield a magnetic hyperfine splitting, H , of approx. 50.3T indicative of goethite (G), compared to the broader sextet peaks in EET 87517 with $H = \sim 48.6\text{T}$ indicative of ferrihydrite (F) and, perhaps, akaganeite or nanophase goethite [6]. Table 1 summarizes the proportions of olivine and pyroxene, normalized percentages of ferric iron, and percentages of metallic Fe obtained from computed peak areas of fitted 295K spectra for all of the ureilites.

DISCUSSION. Olivine is the dominant silicate mineral in most of the ureilites, in accordance with modal abundance data reported for other ureilites [4]. However, in two of the specimens (ALHA 84136 and EET 87517), clinopyroxene is the dominant ferromagnesian silicate by analogy with the Yamato 74659 ureilite also from Antarctica [7]. Ureilites ALHA 84136 and EET 87517 also have the highest Fe^{3+} percentages (Table 1), and their 4.2K spectra indicate that most of the ferric iron is present as ferrihydrite. Metallic iron occurs in all ureilite samples and is a major constituent of some specimens. Much of this metallic phase is pure kamacite that has resulted from carbon-induced reduction of ferrous iron in the outermost 10-100 μm rims of olivine grains in contact with carbonaceous material in the ureilites [4,8]. Oxidation in the polar environment of kamacite included in olivines accounts for the presence of ferrihydrite identified in the 4.2K Mossbauer spectra of many of the ureilites. The goethite identified in some ureilite spectra, on the other hand, appears to have formed by oxidation of the high-Ni metallic Fe phase occurring along silicate grain boundaries and as veins in the carbonaceous matrix [4,8]. This goethite is analogous to the FeOOH phase present in oxidized chondritic meteorites from Antarctica [2].

UREILITE MOSSBAUER SPECTRA: Martinez, S.L. and Burns, R.G.

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TABLE 1. Relative Abundances of Fe Minerals in Ureilites Determined by Mossbauer Spectroscopy

Specimen*	% Fe ²⁺ as olivine	% Fe ²⁺ as pyroxene	% Fe ³⁺ / (Fe ²⁺ +Fe ³⁺)	% Fe Metal/ total Fe	H (T) at 4.2°K
A 77257	65.4	34.6	11.6	8.9	49.0
P 82506	89.1	10.9	19.8	26.7	50.2
E 87511	87.9	12.1	20.6	n.d.	n.d.
M 78008**	>90	<10	25.2	17.8	48.6
A 81101	85.9	14.1	25.8	n.d.	48.6
E 87517	29.0	71.0	48.5	n.d.	48.6
A 84136	29.4	70.6	69.9	35.0	48 - 50

* A: Allan Hills (ALHA); P: Pecora Escarpment (PCA);
 E: Elephant Moraine (EET); M: Meteorite Hills (META);
 ** pyroxene is augite

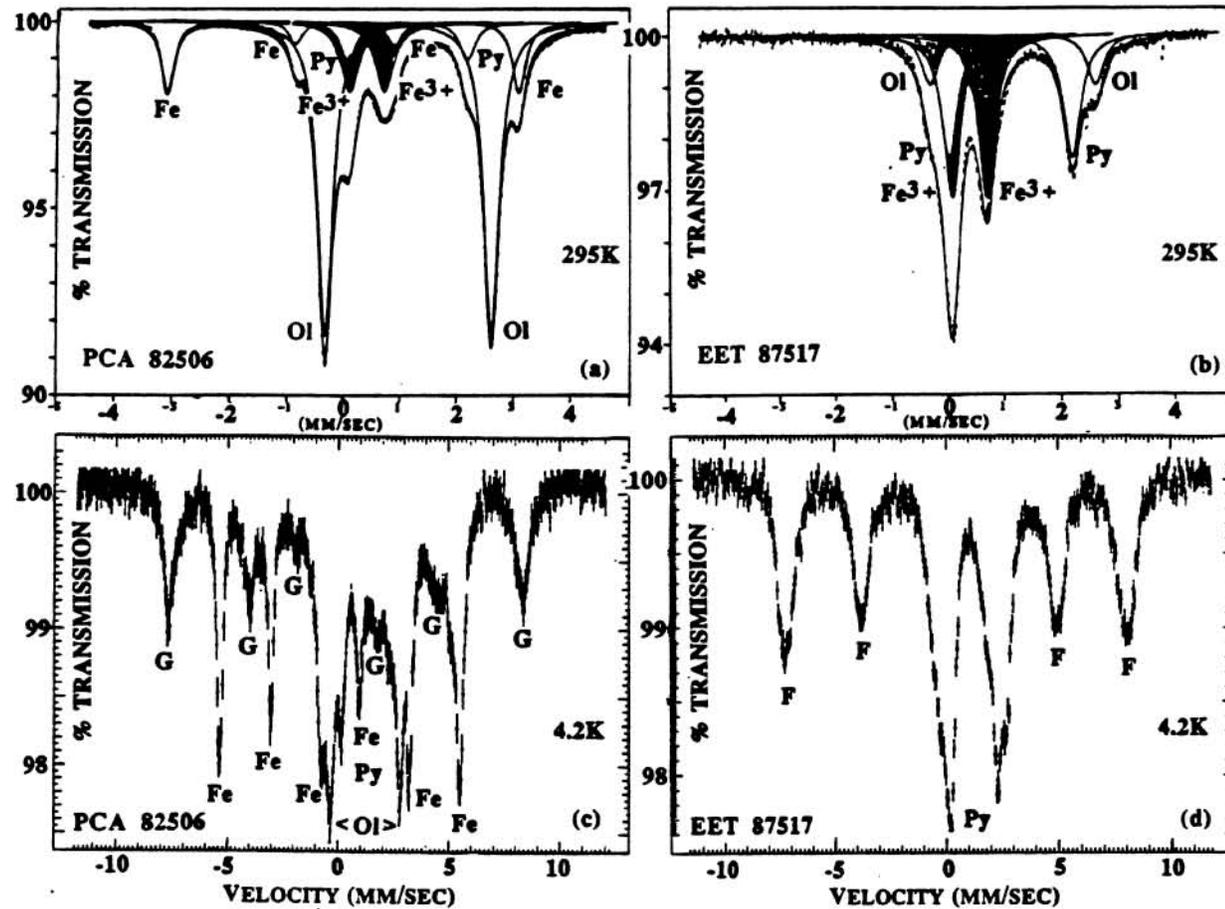


FIGURE 1. Mossbauer spectra of two ureilites described in the text.