Vibrational spectroscopic study of minerals in the Martian meteorite ALH84001

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ABSTRACT

Micro-Raman spectra of carbonates, silica and amorphous plagioclase, and both micro-Raman and IR reflectance spectra of phosphates in ALH84001 are reported. Data from these vibrational techniques combined with electron microprobe analyses show that (1) the carbonates exhibit complex compositional heterogeneity on a sub-micrometer scale, (2) the phosphates, chlorapatite and merrillite, are largely anhydrous, (3) amorphous silica and plagioclase experienced peak shock pressures $>$32 GPa and $>$50 GPa, respectively, and (4) vitreous plagioclase was quenched from a shock-induced melt after relaxation of the peak shock pressure. The observed general Raman band broadening of lattice and internal modes of carbonates in ALH84001 indicates complex sub-microscopic compositional heterogeneity and possibly structural disorder. Any search for biogenic markers in ALH84001 must recognize the complex shock and thermal history of these minerals.

INTRODUCTION

The claim of possible evidence of ancient life in the carbonate globules of the Martian meteorite ALH84001 (McKay et al. 1996) has intensified controversy over the origin of these carbonates. Proposed alternatives to biogenic formation include high-temperature hydrothermal (Mittlefehldt 1994; Harvey and McSween 1996); vapor-phase (Bradley et al. 1996) precipitation, low-temperature fluid-mediated precipitation (Romanek et al. 1994; Valley et al. 1997); replacement of maskelynite (Gleason et al. 1997; Kring et al. 1998); or shock melting of preexisting carbonates (Scott et al. 1997). Studies of the chemical and isotopic compositions of the carbonates (Harvey and McSween 1996; Romanek et al. 1994; Valley et al. 1997; Treiman 1997; Leshin et al. 1998; Saxton et al. 1998) have failed to develop convincing constraints on their formation temperatures. Also, there is little agreement on pressures and geological processes that affected the carbonates and associated interstitial phases: silica, vitreous plagioclase, and phosphates. Although chemical (Mittlefehldt 1994; Harvey and McSween 1996; Gleason et al. 1997; Scott et al. 1997) and isotopic (Romanek et al. 1994; Valley et al. 1997) zoning in the carbonates are well characterized, the degree of structural disorder is not known.

Petrographic and structural studies on other accessory phases in ALH84001 can provide additional constraints on the petrogenetic history of the rock. Silica, which is a sensitive indicator of the degree of shock metamorphism (Stöffler and Langenhorst 1994), occurs as a scattered accessory phase in ALH84001, although its structure has not yet been identified. Phosphates are important interstitial trace minerals in ALH84001 (Mittlefehldt 1994) and other Martian meteorites because they might contain significant amounts of water (Leshin et al. 1996). Plagioclase-composition regions in ALH84001, although presumably initially crystalline feldspar, have attained their current amorphous character either by melting or by solid state amorphization. Correct interpretation of the geochemical and petrographic data requires mineralogical and structural information for these minor phases. Vibrational techniques, including infrared (IR) and micro-Raman (e.g., Sharma 1989; Wopenka et al. 1996; El Gorsey 1997) spectroscopy, can give information on the structures of these minerals thereby providing constraints on phase identification, peak shock pressure, and possible sub-microscopic exsolution. This study reports confocal micro-Raman spectroscopy directly on mineral grains in polished thin sections of the meteorite ALH84001.

EXPERIMENTAL PROCEDURES

Samples

Detailed chemical analyses of ALH84001 carbonates in the literature (Mittlefehldt 1994; Harvey and McSween 1996; Gleason et al. 1997; Scott et al. 1997; Kring et al. 1998) indicate a zoning trend from ferroan dolomite to nearly pure magnesite with an abrupt compositional gap between the inner zoned core and the outer magnesite mantle. Figure 1 is a backscattered electron image of a representative irregular carbonate patch showing the locations of Raman microprobe analyses of the mantle and core regions ("1" and "2", respectively, in Fig. 1). These spots are located on either side of the inner ring of opaque inclusions (thin bright strips in Fig. 1)