Thermal infrared spectroscopy and modeling of experimentally shocked basalts

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ABSTRACT

New measurements of thermal infrared emission spectra (250–1400 cm⁻¹; ~7–40 μm) of experimentally shocked basalt and basaltic andesite (17–56 GPa) exhibit changes in spectral features with increasing pressure consistent with changes in the structure of plagioclase feldspars. Major spectral absorptions in unshocked rocks between 350–700 cm⁻¹ (due to Si-O-Si octahedral bending vibrations) and between 1000–1250 cm⁻¹ (due to Si-O antisymmetric stretch motions of the silica tetrahedra) transform at pressures >20–25 GPa to two broad spectral features centered near 950–1050 and 400–450 cm⁻¹. Linear deconvolution models using spectral libraries composed of common mineral and glass spectra replicate the spectra of shocked basalt relatively well up to shock pressures of 20–25 GPa, above which model errors increase substantially, coincident with the onset of diaplectic glass formation in plagioclase. Inclusion of shocked feldspar spectra in the libraries improves fits for more highly shocked basalt. However, deconvolution models of the basaltic andesite select shocked feldspar end-members even for unshocked samples, likely caused by the higher primary glass content in the basaltic andesite sample.

Keywords: Shock, infrared, spectroscopy, basalt, deconvolution, Mars

INTRODUCTION

The surfaces of the terrestrial planets have been altered extensively by impact cratering throughout their evolution at scales ranging from mineral boundaries to impact basins. At the smallest scales, minerals experience structural disorder to varying degrees when subjected to high shock pressures from impacts. Such deviations in crystal lattices can be documented with thermal infrared spectroscopy owing to the sensitivity of this technique to vibrational motions in crystal structures. For example, thermal infrared analyses of experimentally and naturally shocked minerals and rocks reveal degradation in the spectral detail and position of absorption features with increasing shock pressure. This is attributable to lattice disordering and increasing glass content, particularly at shock pressures above ~20 GPa for plagioclase feldspars (Lyon 1963; Bunch et al. 1967, 1968; Stöfler 1971, 1972, 1974; Stöfler and Hornemann 1972; Arndt et al. 1982; Ostertag 1983). These types of spectral effects also have been observed in thermal infrared laboratory studies of meteorites (e.g., Cooney et al. 1999; Xie et al. 2001; Wright et al. 2006; Palomba et al. 2006). Although remotely sensed thermal infrared observations of planetary surfaces provide important constraints on surface mineralogy and/or physical properties (e.g., Christensen et al. 1998, 2001; Sprague et al. 2002; Salisbury et al. 1995, 1997; Morris et al. 1999; Ramsey 2002), few studies have investigated the spectral effects of high shock pressures in detail (cf. Wright et al. 2004; Johnson et al. 2006).

Because pyroxene and olivine crystal lattices are relatively resistant to shock pressure compared to feldspars, changes in the structure and thermal infrared spectral features of feldspars provide the best means to study shock effects in basaltic rocks (cf. Johnson et al. 2002). Slight disordering in the feldspar structure begins at pressures >15–20 GPa. Diaplectic glass (maskelynite) formation is complete between ~30–45 GPa and significant melting occurs greater than ~45 GPa (Stöfler 1972; Gibbons et al. 1757; Hörz and Cintala 1997; Velde et al. 1987, 1989), depending on the absolute strain rate, shock-pulse duration, and initial temperature (Stöfler 2001; DeCarli et al. 2002; Fritz et al. 2002). As pressures increase, the mutual existence of crystalline phases and diaplectic glasses cause the characteristic, fourfold (tetrahedral), strong coordination bonds of Si and Al in feldspars to alter to weaker, less polymerized bonds that approach sixfold (octahedral) coordination. This change influences the characteristic vibrational frequencies in the thermal infrared. For example, the bands near 400–550 cm⁻¹ are caused by bending vibrations in the Si-O-Al planar ring structures in tectosilicates and diaplectic glasses. Si-O-Si octahedral-bending vibrations cause several weaker absorptions between about 450–700 cm⁻¹, and SiO₄ octahedral-stretching vibrations occur between 750–850 cm⁻¹. Absorptions in the 900–1200 cm⁻¹ region are due to Si-O antisymmetric stretch motions of the silica tetrahedral units and Al-O vibrations in the structure (Bunch et al. 1967; Iiishi et al. 1971; Stöfler and Hornemann 1972; Arndt et al. 1982; Ostertag 1982; Velde et al. 1987; Williams and Jeanloz 1988, 1989; Heymann and Hörz 1990; Daniel et al. 1995, 1997; Williams 1998; Yamaguchi and Sekine 2000; King et al. 2004).