NMR RELAXATION BEHAVIOR OF MODERATELY SHOCKED SANDSTONE FROM METEOR CRATER, ARIZONA; R. T. Cygan, M. B. Boslough, S. A. Myers, and R. A. Assink, Sandia National Laboratories, Albuquerque, NM 87185

Nuclear magnetic resonance (NMR) spectroscopy provides a sensitive and reliable tool for the identification and characterization of shocked minerals resulting from natural impact as well as from shock experiments. We previously characterized the relaxation behavior of experimentally-shocked quartz by determining the T_1 relaxation times of crystalline and amorphous phases, showing that time dependence of the magnetization for each phase follows a power-law function before reaching a saturation plateau. We have now applied this method to characterize the complex mixture of silica phases and composition of moderately shocked Coconino Sandstone from Meteor Crater, Arizona. Our new results indicate that, as for the previous work, each phase exhibits power-law behavior followed by saturation. Moreover, the natural samples contain three additional phases, and relaxation analysis can be used to determine the relative abundances of quartz, coesite, stishovite, and a dense hydrated amorphous silica.

The identification and characterization of naturally-shocked minerals is not always a straightforward process even for those materials recovered directly from a known impact crater. Although planar deformation features (PDFs) associated with quartz have been advanced as the principal discriminating characteristic of shock-loading [1], their identification and determination of crystalline orientation require considerable experience and petrographic skill. In addition, the lack of PDFs does not necessarily imply the absence of shock metamorphism; the analysis of

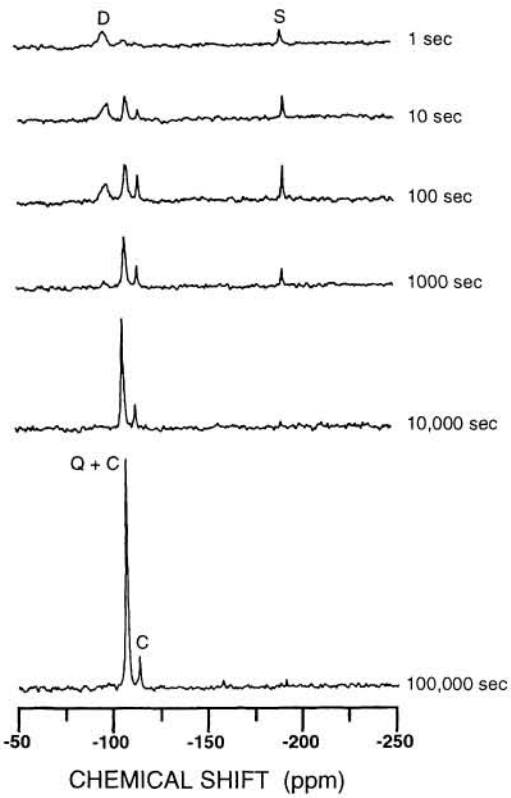

Figure 1. ^{29}Si MAS NMR spectra of the moderately shocked Meteor Crater sample #33 from Kieffer [6]. Data were acquired with variable recycle delays as noted on right side of each spectrum. Resonance identifications are for quartz (Q), coesite (C), stishovite (S), and a dense hydrated amorphous silica (D).

quartz recovered from experimental impact studies often finds a rare abundance of PDFs [2]. Nonetheless, scientists studying impact sites and ejecta have relied heavily on PDFs for identifying shocked minerals and providing evidence of an impact.

The recent application of NMR spectroscopy in the analysis of shocked minerals has provided new insights and a quantitative basis for identifying and examining shock metamorphism [2,3]. We recently demonstrated [4,5] that NMR spectra obtained from naturally-shocked Coconino Sandstone from Meteor Crater, Arizona correlate with the classification scheme of Kieffer [6]. Shocked quartz, coesite, stishovite, and a dense hydrated amorphous silica ("D phase") were identified as a function of the relative shock pressure experienced by the sandstone target rock. In related research, we have shown that NMR relaxation analysis of experimentally-shocked quartz can be used to extract information about the mircostructure of the shock-modified phases [7].

As an extension of both of these studies we have now examined the NMR relaxation behavior of a moderately shocked sample of Coconino Sandstone. We have obtained ^{29}Si MAS (magic angle spinning) NMR spectra for Kieffer's sample #33 at various recycle times (Figure 1). This sample, which represents a low class 3 shock level, includes quartz, coesite, stishovite, and D phase; the crystalline phases have been identified by X-ray diffraction and TEM analysis. The NMR recycle time is the lag time during which the reemissions from the excited ^{29}Si nuclei are counted before the next electromagnetic excitation pulse. Therefore, the intensity of a resonance will vary based on the available time for this decay period or recycle time. Because each phase has a characteristic T_1 relaxation time, this technique allows us to obtain a quantitative analysis of the relative amounts of each phase present in the bulk sample.

Figure 1 provides the ^{29}Si MAS NMR spectra for Meteor Crater sample #33 for recycle delays ranging from 1 sec to 100,000 sec. The resonances for quartz (-108 ppm) and coesite (-108 ppm and -114 ppm) represent tetrahedrally-coordinated silicon, while that for stishovite (-191 ppm) is for octahedrally-coordinated silicon and is shifted considerably downfield in frequency. The spectra suggest that at long relaxation delays peaks due to quartz and coesite dominate the NMR spectrum while at short delays stishovite and D phase are observable. Power-law behavior of the NMR intensity with recycle time is observed for this sample over the six decades of time before reaching magnetic saturation. These data allow us to extract the relative abundances of the various phases that comprise the shocked sample: 78.0 % quartz, 16.3 % coesite, 3.7 % D phase, and 2.0 % stishovite.

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