NMR SPECTROSCOPY OF EXPERIMENTALLY SHOCKED COCONINO SANDSTONE AND THE EFFECT OF PORE WATER; R. T. Cygan[1], M. B. Boslough[1], and R. J. Kirkpatrick[2], [1]Sandia National Laboratories, Albuquerque, NM 87185 and [2]University of Illinois, Urbana, IL 61801

We have extended our solid state ^{29}Si nuclear magnetic resonance (NMR) spectroscopic study of shocked Coconino Sandstone from Meteor Crater, Arizona. Previously we showed that the NMR spectra of naturally-shocked samples taken from the crater are in excellent agreement with the classification scheme of Kieffer [1], and we identified a new hydroxylated amorphous phase [2,3]. To follow up that work, we have now collected data on Coconino Sandstone explosively shocked to independently-known pressure-temperature states. In addition, we performed identical explosive loading experiments on water-saturated samples to characterize the effects of groundwater in a natural impact. The magic-angle spinning (MAS) spectra for the shocked sandstone powders exhibit no additional phases; resonances for coesite and stishovite are not observed. However, a broadening of the quartz resonance is exhibited for both dry and wet samples relative to the narrow resonance for quartz in the unshocked material. The cross-polarization magic-angle spinning (CPMAS) NMR experiments exhibit an enhanced single resonance, probably associated with hydroxylated silicon in kaolinite clay. This peak broadens with shock-loading for both dry and wet samples. There is no clear distinction between the NMR spectra obtained for the dry and wet samples recovered from the shock-loading experiments.

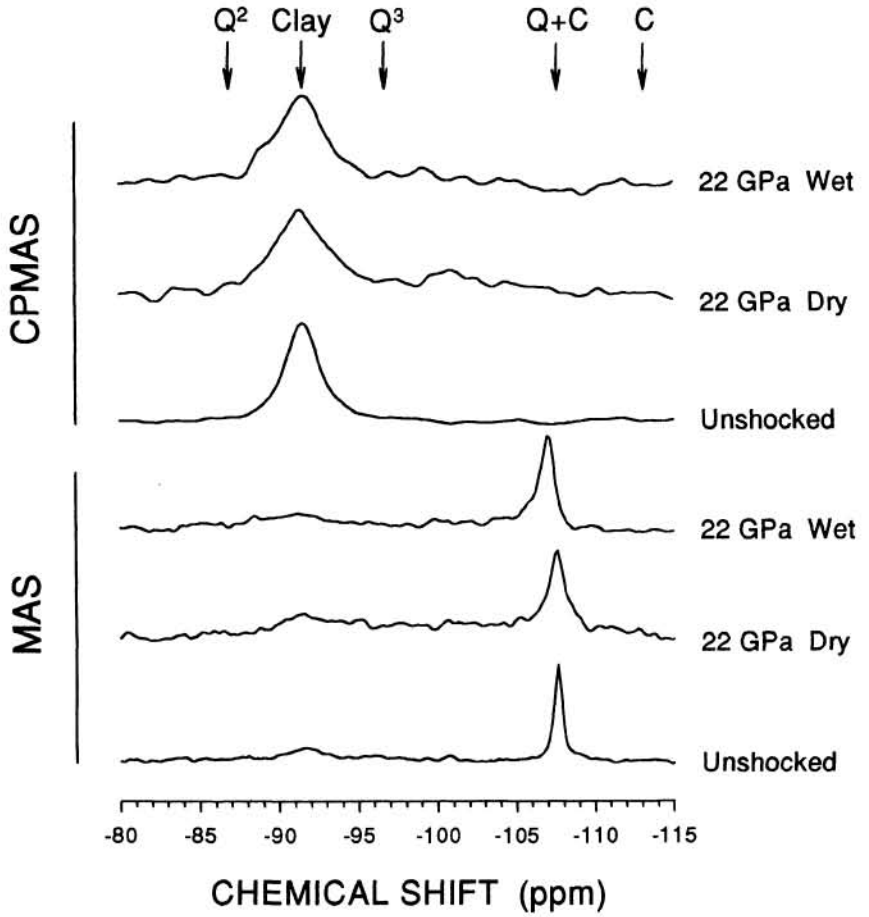

Figure 1. ^{29}Si NMR spectra of unshocked and experimentally-shocked (dry and wet) Coconino Sandstone samples. MAS (all Si sites) and CPMAS (hydrated Si species) spectra are presented for each sample. Arrows denote approximate chemical shift observed in previous studies [2,3] for quartz (Q), coesite (C), clay, and hydrated amorphous silica, including Q^3 (one OH) and Q^2 (two OH) silicon sites.

NMR SPECTROSCOPY OF EXPERIMENTALLY-SHOCKED SANDSTONE: Cygan *et al.*

The present work is part of a continuing project to develop solid state NMR spectroscopy as a method of quantifying the effect of shock loading experienced by silicate minerals subjected to natural impact. We have previously suggested that NMR spectra be used as an unambiguous identification technique for shocked quartz, and have shown that it can be used as a "shock barometer" under some conditions [4,5]. In addition to finding a new densified amorphous phase, we have shown that NMR relaxation analysis can provide morphological information about shock-produced amorphous material [6]. However, our measurements to date have been limited to laboratory-shocked synthetic quartz samples, and to naturally-shocked sandstone. Moreover, other workers have obtained quantitatively different results using different starting materials (single crystals as opposed to powder) and different loading conditions [7]. By subjecting Coconino Sandstone to the same shock-loading histories as pure synthetic quartz in our earlier work, we are beginning to bridge the gap between natural and artificial shock-loading histories to help understand the differences. In addition, by using initially water-saturated samples, we attempt to 1) isolate the effect of the presence of water and 2) find out if the dense amorphous hydroxylated phase we found in naturally-shocked sandstone can be synthesized in the laboratory, and if so, under what conditions.

Samples of unshocked Coconino Sandstone were obtained from near Meteor Crater, Arizona and were subjected to explosive loading using the Momma Bear fixtures of Graham and Webb [8]. Wet experiments were performed by first saturating the sandstone powder with deionized water before sealing the copper sample fixture. The dry powder samples were subjected to peak shock pressures of approximately 7.5, 16.5, and 22 GPa. The corresponding pressure values for the wet sandstone samples are somewhat higher. The recovered materials were examined by optical and secondary electron microscopies, X-ray diffraction, and NMR spectroscopy. We use both standard MAS and CPMAS techniques in the NMR experiments to determine the resonances associated with ^{29}Si nuclei. Cross polarization transfers nuclear spin from protons to the ^{29}Si, thereby providing additional structural information and preferentially eliminating spectrum signal produced by anhydrous phases.

The MAS and CPMAS spectra obtained for the shocked sandstone samples do not exhibit any additional resonances compared to the spectra for the unshocked sample (Figure 1). Resonances for coesite (-108 ppm and -113 ppm) and stishovite (-192 ppm) are not observed. The strong four-fold coordinated silicon resonance, with a chemical shift of -108 ppm, dominates the MAS NMR spectra. A broadening of the quartz resonance for both dry and wet samples is observed with increasing shock pressure. These results are similar to our previous work on dry synthetic quartz powders [4,5]. A minor resonance in the MAS spectra, corresponding to the major resonance in the CPMAS spectra, is observed at -92 ppm. These resonances are associated with the hydroxylated silicon site in clay, probably kaolinite; X-ray diffraction analysis of the recovered material confirms this assignment. Some broadening of the clay CPMAS resonance occurs with increasing shock pressure for both dry and wet samples. There is no clear evidence for the formation of a dense hydroxylated amorphous phase in the material recovered from the wet shock-loading experiments. We previously observed for several naturally-shocked samples from Meteor Crater a very strong resonance with a chemical shift of -97 ppm, corresponding to Q^3 silicon [2,3]. These differences in the NMR spectra are related to the distinct loading and unloading histories associated with experimental shock-loading and natural impact events.

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Acknowledgments: John McHone and Susan Kieffer were instrumental in helping acquire samples of Coconino Sandstone from Meteor Crater. We thank Meteor Crater Enterprises, Inc. for allowing us access to the crater. Ed Dunbar performed the explosive loading experiments at EMRTC, Socorro, NM. Gary Turner obtained the NMR spectra. This work was partially funded by NASA's PMG program and was performed at Sandia National Laboratories by the U.S. Department of Energy under contract DE-AC04-94AL85000.