FAULT FORMATION AT IMPACT CRATERS IN POROUS SEDIMENTARY ROCK TARGETS W.R. Orr Key[1] and R.A. Schultz, Geomechanics-Rock Fracture Group, Department of Geological Sciences and Engineering/172, Mackay School of Earth Sciences and Engineering, University of Nevada, Reno, NV 89557-0138, [1]orrw@unr.nevada.edu.

Summary: We present results of a study in which the mechanics of faulting at high strain rates in porous sedimentary rocks were evaluated at the Upheaval Dome impact crater in southeast Utah. We find that at high strain rates, deformation band damage zones are absent and instead a cracking-dominated behavior generating pulverized rock occurs. Using the measured grain sizes of the pulverized rock, strain rates under which this material formed are ~ 10^3 s^{-1}.

Introduction: Faulting in porous sedimentary rocks subjected to typical tectonic strain rates has been extensively studied [1-3]. These studies have shown that the strain is first accommodated by a localized reduction of porosity resulting in the formation of individual deformation bands and as the strain continues to accumulate, deformation band damage zones (DBDZs) develop [2]. The mechanical contrast between the strain-hardened deformation bands and the relatively undeformed porous rock ultimately leads to failure of the DBDZs as a result of additional strain, resulting in fault formation [2].

By contrast, theoretical work suggested that at sufficiently high strain rates DBDZs do not have time to form prior to faulting in porous sedimentary rocks. Using computer models and laboratory data, Fossum and Brannon [4] showed that the process of porosity reduction (i.e., deformation bands) occurs with a characteristic timescale that is longer than that allowed under hypervelocity impact loading rates, and instead a cracking-dominated behavior occurs. Noticeably absent from this study was the consideration that this prediction could be tested in the field.

We chose to field-test the hypothesis that DBDZs do not form in porous sedimentary rocks subjected to high strain rates at the Upheaval Dome impact structure (Figure 1). An impact structure is an ideal location to evaluate fault formation at high strain rates in sedimentary rocks as these structures are known to form as a result of strain rates in excess of 10^1 s^{-1} [5-7]. After an extensive literature review of all confirmed impact structures in sedimentary rock targets [8], we found that faulting was best documented at Upheaval Dome [9,10] and the Haughton impact structure on Devon Island, Canada [6]. We chose to conduct our study at Upheaval Dome because the rock units affected by the impact event are the same rocks that have been extensively studied at typical tectonic strain rates throughout the Colorado Plateau (i.e., Navajo Sandstone), and thus provides a unique opportunity to compare the mechanics of faulting at high and low strain rates.

Results and Implications: It was decided that faults would be evaluated within the Navajo Sandstone and the rim syncline of the crater because mechanical observations relating to fault formation are best observed where offsets on the faults are minimal. Two of these faults were identified for field investigation within the rim syncline of Upheaval Dome and are shown in Figure 1. By contrast, offsets within the central uplift at Upheaval Dome [10] are too great to allow for the mechanical observations required for this study.

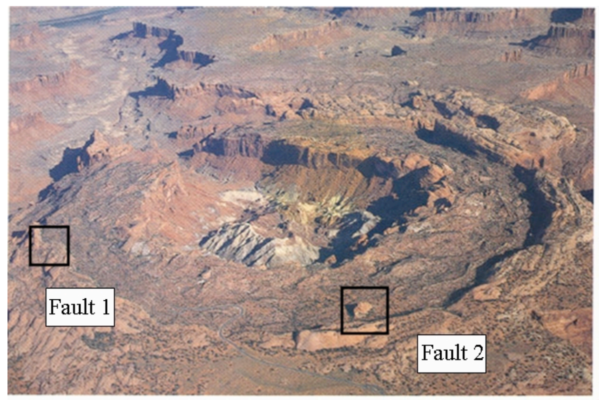

Figure 1. An aerial photograph of the Upheaval Dome impact crater, southeast Utah [11]. Faults evaluated in this study are shown.

As predicted by Fossum and Brannon [4], DBDZs were not observed along these faults. Instead, we found pulverized rock along the fault planes (Figure 2). Pulverized rock is defined as rock that yields a white, powdery texture in the field and is observed to be shattered in place to the micron scale maintaining its original grain fabric with no evidence for rotation or shear in thin section [12,13]. To date, pulverized rock has also been documented along the Mojave section of the San Andreas Fault in southern California [12–15] and the Bosman Fault in underground gold mines in South Africa [15]. Pulverized rock along a fault is now recognized as distinct from gouge, which requires shearing and grain flow to form, and is considered to be diagnostic of high-velocity slip events along the fault [12–15] rather than the shearing associated with true gouge formation. Field studies by several research groups world-wide are demonstrating that material along major faults is pulverized rock, instead of gouge as had previously been mapped or inferred [e.g., 12], with important revised implications for the mechanical behavior of the faults.

The sizes of individual fragments of pulverized grains can be related to the strain rate under which pulverization occurred. We find that pulverized material collected at Upheaval Dome has an average grain size of 39 microns, and by utilizing the relationship derived by Grady and Kipp [16] with parameters appropriate to Navajo Sandstone, is therefore associated with strain rates of ~ 10^3 s^{-1}. Strain rates of these magnitudes are well above the values typically associated with tectonic rates (10^{-11} s^{-1} and below) and laboratory testing rates (between 10^{-7} s^{-1} and 10^{-5} s^{-1}) and are comparable to, or even greater than, values inferred along major crustal faults such as the San Andreas, demonstrating the importance of high strain-rate processes associated with faulting of porous sandstones and further supporting an impact origin for Upheaval Dome.

We propose that the presence of pulverized rock may provide an additional criterion for identifying and evaluating potential terrestrial impact craters. Additionally, understanding strain rate conditions at an impact site provides a new source of information regarding the mechanical responses of typical sedimentary rock types affected by deformation at impact strain rates.

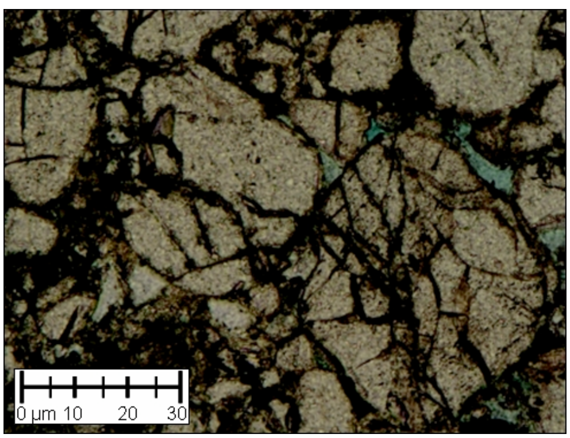

Figure 2. Example of pulverized rock observed along the fault planes at Upheaval Dome. Note the lack of rotation or shear within the fractured quartz grains. Image of thin section recorded at 10x magnification, plane-polarized light.

References: [1] Shipton, Z.K. and Cowie, P. (2001) *Journal of Structural Geology*, v. 23, no. 3, p. 1,825–1,844. [2] Schultz, R.A. and Siddharthan, R. (2005) *Tectonophysics,* v. 11, p. 1–18. [3] Fossen, H. et al. (2007) *Journal of the Geological Society, London*, v. 164, p. 755–769. [4] Fossum, A.F. and Brannon, R.M. (2005) *Acta Geotechnica*, v. 1, p. 69–106. [5] Melosh, H.J. (1989) *Impact Cratering: A Geologic Process*. [6] Osinski, G.R. and Spray, J.G. (2005) *Meteoritics and Planetary Science*, v. 40, p. 1,813–1,834. [7] Pati, J.K. and Reimold, W.U. (2007) *Journal of Earth System Science,* v. 116, no. 2, p. 81–98. [8] Earth Impact Database (2007) and references therein. [9] Kriens, B.J. et al. (1999) *JGR*, v. 104, p. 18,867–18,897. [10] Kenkmann, T. et al. (2005) *GSA Special Paper 384*, p. 85–115. [11] Upheaval Dome, http://lasp.colorado.edu/ [12] Dor, O. et al. (2006) *Earth and Planetary Science Letters*, v. 245, p. 642–654. [13] Dor, O. (2007), Ph.D. Dissertation, University of Southern California. [14] Brune, J.N. (2001) EOS, Transactions American Geophysical Union, v. 82, no. 47, Abstract S22B–0655. [15] Reches, Z. and Dewers, T.A. (2005) *Earth and Planetary Science Letters*, v. 235, p. 361–374. [16] Grady, D.E. and Kipp, M.E. (1987) *Fracture Mechanics of Rocks*, p. 429-475.

Abstract published in: Lunar and Planetary Science XL, CD-ROM, Lunar and Planetary Institute, Houston (2009).