

**STRENGTH AND ELASTIC MODULI OF MAGNESIUM SULFATE HYDRATES UNDER MARTIAN CONDITIONS.** P.M. Grindrod<sup>1,2</sup>, M.J. Heap<sup>2</sup>, P.G. Meredith<sup>2</sup>, and P.M. Sammonds<sup>2</sup>, <sup>1</sup>Centre for Planetary Sciences at UCL/Birkbeck, Department of Earth Sciences, University College London, UK, <sup>2</sup>Rock and Ice Physics Laboratory, Department of Earth Sciences, University College London, UK (p.grindrod@ucl.ac.uk).

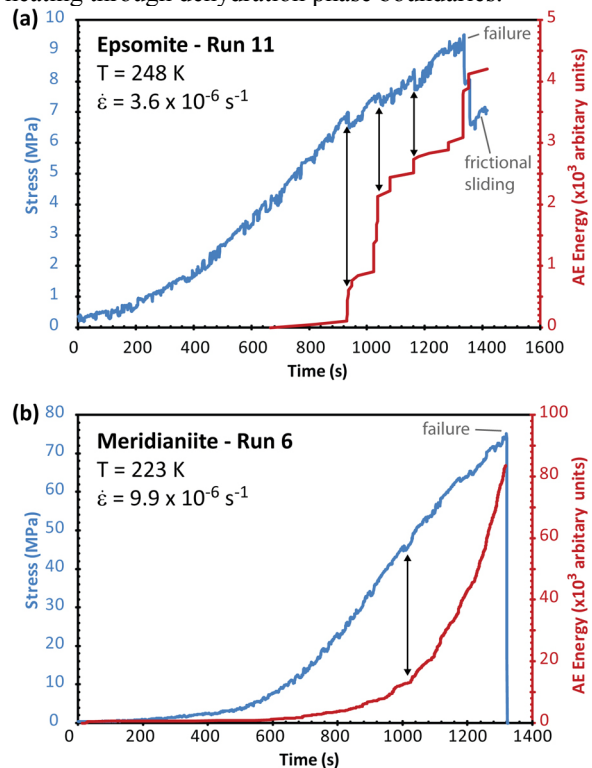
**Introduction:** Indirect mineralogical evidence for water has been found on the present martian surface with the identification of hydrated sulfate hydrates both from orbit and in situ. OMEGA and CRISM observations have identified gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ) and kieserite ( $\text{MgSO}_4 \cdot \text{H}_2\text{O}$ ) [1,2], with epsomite ( $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ ) and meridianiite ( $\text{MgSO}_4 \cdot 11\text{H}_2\text{O}$ ) also likely [3,4]. Sulfate hydrate-rich layers, of the order of tens of meters thick, of differing hydration state, have also been identified in the Valles Marineris region [e.g. 2]. Elevated concentrations of sulfur observed in Meridiani Planum are probably due to the presence of magnesium and calcium sulfates [5]. Determining the location and role of liquid water on Mars today, and its effects over geological time, requires a proper understanding of the properties of sulfate hydrates under martian conditions.

The goal of this study is twofold: (1) to determine the mechanical properties of sulfate hydrates in general, in order to better understand collapse processes on Mars, and (2) to quantify the relationship between hydration state and strength, in order to assess the role of waters of hydration in the distribution and ongoing evolution [6] of light-toned layered deposits. Ultimately, we hope to better understand the mechanical response of sulfate hydrates to changes in obliquity on Mars.

**Sample Preparation:** We use the magnesium sulfate-water system as a proxy for the mechanics of similar hydrated deposits on Mars. In the case of kieserite and epsomite, reagent grade powders from Sigma-Aldrich are ground and sieved to less than 200  $\mu\text{m}$ ; for meridianiite we make up a stoichiometric solution (37.78 wt. %  $\text{MgSO}_4$ ) at 100°C, which is quenched in liquid nitrogen before being powdered in a similar manner to the lower hydrates. To produce consistent and repeatable mechanical results we prepare samples with a length/diameter ratio of 3:1 (25 mm diameter by 75 mm long) by packing powders into a split die assembly and pressing to ~150 MPa. Effective and total porosity are determined by wet (saturation in silicone oil) and dry (digital calipers) methods respectively. For each phase we check purity of a representative sample using XRD analysis with a micro cold stage that controls temperature and limits humidity changes.

**Experimental procedure:** We apply well validated experimental rock physics techniques, used in the study of terrestrial volcanic samples and systems [e.g.

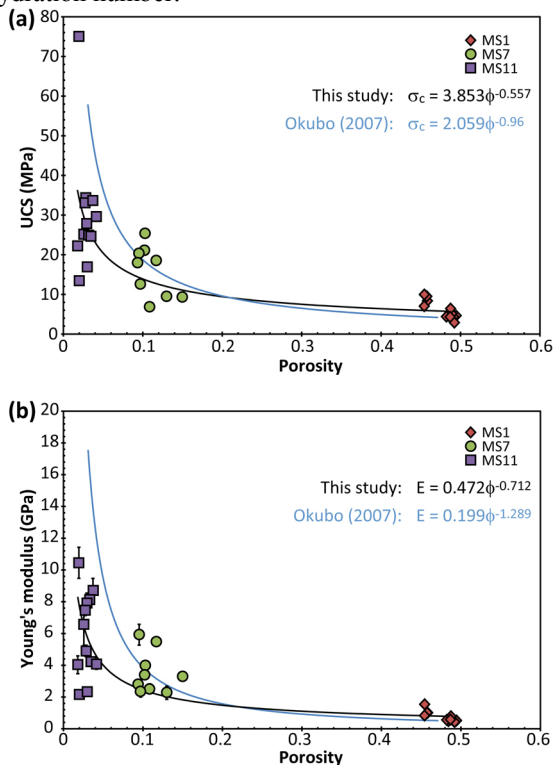
7], to synthetic magnesium sulfate hydrates. We use a servo-controlled 200 kN uniaxial load frame, with an environmental chamber capable of temperatures of between -150°C and 350°C, to conduct unconfined compression tests. Using an external displacement transducer we deform samples at a constant axial strain rate, whilst monitoring the resultant axial load, radial strain, and acoustic emissions. We determine the static elastic moduli (Young's modulus and Poisson's ratio) of each sample during the elastic portion of the loading cycle. We carry out two main types of constant strain rate tests: (1) compression to failure to determine unconfined compressive strength (UCS) and elastic moduli during a single loading cycle, and (2) cyclic stressing tests with incrementally increasing load to determine the evolution of elastic moduli with increasing crack damage. We have also recently begun a series of phase change tests, by applying a constant load and heating through dehydration phase boundaries.



**Figure 1.** Typical experimental results at different temperatures. (a) Epsomite with UCS of ~9.4 MPa at 248 K; (b) meridianiite with UCS of ~74 MPa at 223 K. Jumps in cumulative acoustic energy correspond with stress drops.

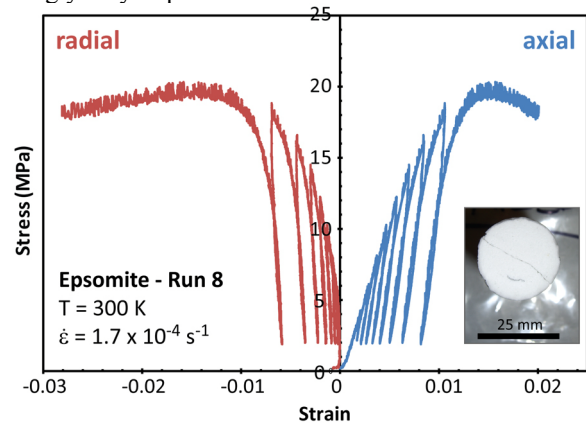
**Results:** We have carried out 37 uniaxial compression tests on the magnesium sulfate system, with 12 on kieserite, 13 on epsomite, and 12 on meridianiite. We varied the controlling strain rate between  $1.2 \times 10^{-4}$  and  $6.8 \times 10^{-6} \text{ s}^{-1}$ , and environmental temperatures between 223 and 323 K. Of these tests, 3 runs were cyclic-stressing tests, and 3 were dehydration-related failure tests. Typical results are shown in Figure 1.

Determined values of UCS for the magnesium sulfate series varied between 2.9 and 75.0 MPa, and are similar to estimates of the UCS of light-toned layered deposits determined from Rock Abrasion Tool (RAT) data from Opportunity [8]. Our experiments show little correlation between UCS and strain rate or temperature, except for meridianiite at or above temperatures of about 248 K, where the failure mechanism is ductile. Thus the brittle-ductile transition for meridianiite is between 85 and 90 % of its (incongruent) melting temperature. The main factor in determining the UCS in our experiments is the sample porosity (Figure 2a), which is dependent on a number of factors including grain size and density, and powder packing pressure. Due to the porosity variation in our samples, we have not yet determined a relationship between UCS and hydration number.



**Figure 2.** (a) Unconfined compressive strength ( $\sigma_c$ ) and (b) Young's modulus ( $E$ ) as a function of porosity ( $\phi$ ) for kieserite (MS1), epsomite (MS7) and MS11 (meridianiite), compared to compilations from Okubo (2007) [8].

We determined Young's modulus and Poisson's ratio, where possible, during the elastic portion of the loading cycle. Determined values of Young's modulus for the magnesium sulfate series varied between 0.4 and 10.5 GPa (Figure 2b), again similar to the Opportunity RAT estimates [8] and is predominantly controlled by sample porosity. Poisson's ratio is more difficult to measure in our experiments, due to movement of the radial linear voltage displacement transducer (LVDT), but in 3 tests on epsomite we measured mean values of Poisson's ratio between 0.03 and 0.17. During a typical loading cycle, Young's modulus and Poisson's ratio increase and decrease respectively until pore collapse is complete, after which true deformation of the sample reverses the trends. Changes in elastic moduli during cyclic-stress tests are mainly the result of pore collapse, with increasing crack damage seemingly only important close to the UCS.



**Figure 3.** Typical example of cyclic-stressing results. Axial and radial stress-strain curve for epsomite, with inset image showing axial fracture after failure.

**Conclusions:** Our experiments show that the UCS and elastic moduli of magnesium sulfate hydrates is similar to those estimated for light-toned deposits in Meridiani Planum. Temperature has little effect on the overall strength of a sample, except close to the brittle-ductile transition. Porosity is the most important factor in determining the strength of sulfate hydrates, even during cyclic stressing tests. Volume change during dehydration dominates the load response of magnesium sulfate hydrates.

**References:** [1] Gendrin, A., et al., 2005. *Science*, 307, 1587-1591. [2] Roach, L.H. et al., 2008. *LPSC*, XXXIX, #1891. [3] Vaniman, D.T., Chipera, S.J., 2006. *Am. Min.*, 91, 1628-1642. [4] Peterson, R.C., Wang, R., 2006. *Geology*, 34, 957-960. [5] Christensen, P.R. et al., 2004. *Science*, 306, 1733-1739. [6] Catling, D.C., et al., 2006. *Icarus*, 181, 26-51. [7] Heap, M.J. et al., 2008. *Tectonophys.*, in press. [8] Okubo, C.H., 2007. *Geophys. Res. Lett.*, 34, L20205.