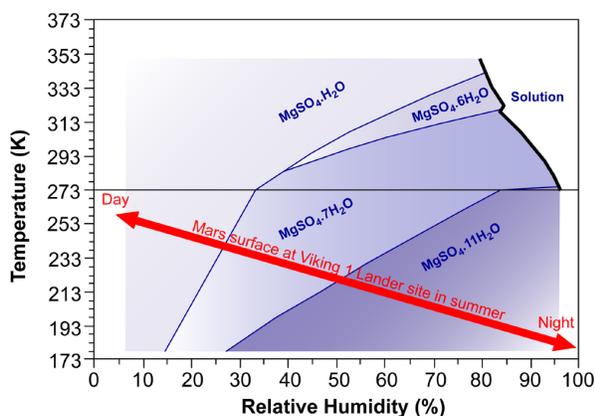


**EXPERIMENTAL RHEOLOGY OF PLANETARY ICES: TRIAXIAL DEFORMATION TESTS ON  $\text{MgSO}_4 \cdot 11\text{H}_2\text{O}$  (MERIDIANIITE).** P. M. Grindrod,<sup>1</sup> A. D. Fortes,<sup>1</sup> I. G. Wood,<sup>1</sup> P. R. Sammonds,<sup>1</sup> D. P. Dobson,<sup>1</sup> C. A. Middleton,<sup>1</sup> and L. Vočadlo,<sup>1</sup> <sup>1</sup>Centre for Planetary Sciences, Department of Earth Sciences, University College London, Gower Street, London WC1E 6BT, United Kingdom ([p.grindrod@ucl.ac.uk](mailto:p.grindrod@ucl.ac.uk)).

**Introduction:** The hydrated sulfate salt meridianiite ( $\text{MgSO}_4 \cdot 11\text{H}_2\text{O}$ ) may be the most likely source of liquid on Mars, especially in low latitudes where ice is less common or even absent in the regolith [1]. Stability studies in the  $\text{MgSO}_4$ - $\text{H}_2\text{O}$  system show that there could be cycling between different phases during the course of a martian day (Figure 1), although sluggish hydration reactions and metastability in this system mean that, at present, it is difficult to predict accurately the phase transitions under martian conditions [2]. On the basis of their presence in chondritic meteorites, hydrated sulfate salts, including meridianiite, have been suggested to be major rock-forming minerals in the mantles of large icy moons [3].



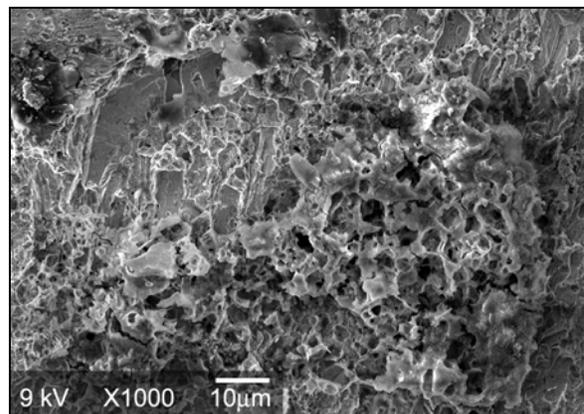
**Figure 1.** Phase relations for the  $\text{MgSO}_4$ - $\text{H}_2\text{O}$  system at 0.1 MPa (after [1]). The red line indicates the conditions at the Viking Lander 1 site in summer.

Mono- and poly-hydrated sulfates have been identified from orbit in several different places on Mars, in outcrops several kilometers thick in the walls of Valles Marineris for example [e.g., 4], and inferred *in situ* at the Opportunity landing site in Meridiani [e.g. 5,6]. The Near Infrared Mapping Spectrometer (NIMS) instrument aboard the Galileo space-craft has also found evidence for hydrated salts on the jovian satellites [7,8].

This work forms part of our ongoing cross-disciplinary research program into planetary ices and hydrates (see contributions by Fortes *et al.*, Brand *et al.*, and Middleton *et al.*, this volume). Here we address the importance of rheology of hydrated phases in

understanding the water budget of Mars and convection in icy satellites, focusing on meridianiite deformation.

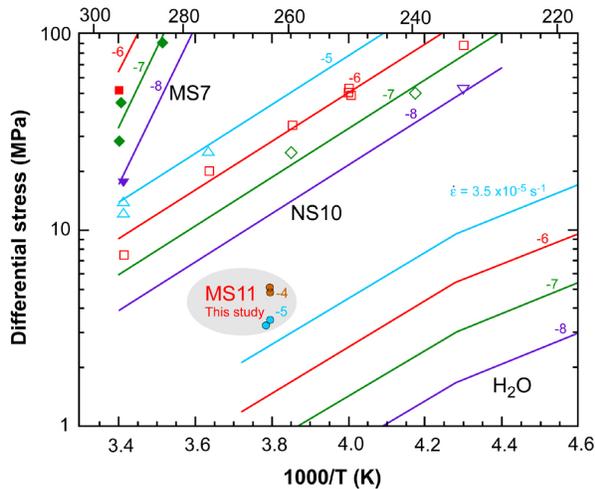
**Sample Preparation:** Meridianiite poses experimental challenges for deformation tests [e.g., 9]. For this study, we prepare stoichiometric solutions (37.78 wt. %  $\text{MgSO}_4$ ) at  $\sim 100^\circ\text{C}$ , which are placed in Perspex sample tubes of 25 mm diameter. These tubes are dipped in liquid nitrogen, thus flash-freezing the solutions. This method successfully avoids the formation of metastable epsomite near the eutectic composition [e.g. 10]. No attempt has been made to control the grain size of the samples in this study. However, preliminary SEM analysis of the surface of a used indium jacket suggests that the mean grain size obtained by rapid quenching is very fine, typically  $< 5 \mu\text{m}$  (Fig. 2).



**Figure 2.** SEM image of the inside of an indium jacket used in one of the deformation tests. Raised material near centre-right is dehydrated meridianiite (probably epsomite), showing crystal molds of the original material.

**Experimental Methods and results:** We use a typical triaxial deformation cell in our experiments, described in more detail in [11], the only significant difference being the use of a balanced ram. Here we report the results of our tests carried out on 25 mm diameter samples under confining pressure of 50 MPa, and at a temperature of 263 K (Figure 3). Our preliminary results show that meridianiite is considerably weaker than other sulfate hydrates (e.g., epsomite and mirabilite), with a rheology at 263 K similar to low-pressure water ice. Further deformation experiments on meridianiite, and other sulfate hydrates, are re-

quired under different conditions to corroborate our findings, although they appear to match well with other preliminary results [e.g., 12,13]. If meridianiite has a similar rheology to water ice, the behaviour of which is quite well-known under planetary conditions, then it may have important implications for studies of martian permafrost, and icy satellite interiors, which we discuss below.



**Figure 3.** Arrhenius plot showing the strength of meridianiite (MS11) from this study, compared with epsomite (MS7), mirabilite (NS10) and water ice (after [9]). Note the relative weakness of MS11, whose behaviour at the stoichiometric composition is closer to water ice than epsomite (MS7), or even mirabilite (NS10).

**Discussion:** The rheological properties of meridianiite have an impact on models of the mechanical stability of 'permafrost' in the martian regolith - with consequences for putative martian glaciers and the origin of gullies - as well as the stability to convection of ice/hydrate shells in the outer solar system. Our preliminary results indicate that meridianiite behaves much more like water-ice than other sulfate hydrates, which may be consistent with the molecular architecture (more non cation-coordinated water molecules than epsomite and mirabilite), but further work is necessary to quantify the effects of temperature and grain size on the creep behaviour.

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