TRANSIENT AND STEADY-STATE CREEP RESPONSES OF ICE-I/MAGNESIUM SULFATE HYDRATE EUTECTIC AGGREGATES. C. McCarthy, D.L. Goldsby and R.F. Cooper, Brown University Geological Sciences, Box 1846, Providence, RI 02912, christine_mccarthy@brown.edu.

Introduction: Magnesium sulfate hydrate has been suggested as a possible non-ice phase on the surface of Europa [1, 2]. In particular, the stable phase with the highest level of hydration, recently identified as magnesium sulfate undecahydrate ($MgSO_4 \cdot 11H_2O$; “MS11”) [3], is a better fit to spectral data [4]. As part of our ongoing experimental study to better understand the rheology of potential candidate systems of a multiphase icy crust of Europa, we present preliminary results from compression creep tests of two-phase aggregates of Ice-I/MS11. The results provide information about both the steady-state (plastic) and the transient (anelastic) responses of the material (at planetary conditions.)

Samples in this study crystallized from a liquid solution. In employing this method of synthesis, we attempt to recreate material likely found at a crust/ocean interface, within crack systems, or anywhere a catastrophic melting event is followed by crystallization. As a result of this solidification reaction, classical lamellar microstructures form, in which the hydrate phase forms an interconnected network [5].

Approach: Fully-dense, cylindrical samples of H_2O-$MgSO_4$ with a composition equal to that of the eutectic (17.275wt%$MgSO_4$) were subjected to compression creep tests (240<T<250K; P=1atm) in a dead-weight cryo-apparatus; the apparatus is fully described in [6]. Sample shortening was measured by use of a gravity-fed extensometer and collected at a rate of 1Hz. The strain-versus-time data thus produced were smoothed and regressed against the creep compliance, J(t), corresponding to the Andrade model (Fig. 1) [7], which takes the form:

$$J(t) = \frac{1}{k_E} + \frac{t}{\eta_{ss}} + At^m, \qquad (1)$$

where k_E is the elastic modulus, η_{SS} represents the steady-state viscosity (in this case an effective viscosity), and A and m are constants (1/3<m<1/2). The last term, At^m, represents essentially an infinite number of Kelvin elements producing a continuous distribution of anelastic compliances; the approach has been found to effectively represent the anelastic response of many materials [8]. The regression is used to obtain measures of the parameters $1/k_E$, A, m, and $1/\eta_{ss}$ (Fig. 2). The corresponding complex compliance, J*(ω), can be obtained by taking the Laplace transform of (1). The real part, $J_1(\omega)$, of the complex compliance is the “storage compliance” and the imaginary, $iJ_2(\omega)$, is the “loss compliance”. Attenuation, Q^{-1}, can be defined in terms of the two parts of the complex compliance, such that:

$$Q^{-1} = \frac{J_2}{J_1}. \qquad (2)$$

where the ratio J_2/J_1 denotes the mechanical energy dissipation per cycle [9]. Use of this method allows determination of both the plastic and the anelastic response of the aggregage from the same creep experiment.

Results/Discussion: Data from the steady-state portion of the creep response was used to obtain the stress/strain-rate plot in Fig. 3. The results show that the eutectic aggregates have an effective viscosity that is at least an order of magnitude greater than that of strongest reported polycrystalline ice (i.e. coarse-grained). These data are in good agreement with previously reported results obtained at high pressure [5].

Using the values obtained from the numerical regression of the strain curve in Fig. 2, we calculated the attenuation versus frequency spectra shown in Fig. 4. The transient response plots with a slope ~-1/2, while the elastic and steady-state portions (which together form the Maxwell model) plot with a slope of -1. The contribution from the latter, however, is so small, that the sum (straight line) plots within the box of the transient data.

Ultimately the attenuation information that is revealed with this method will be compared to the direct measurements that come from cyclic loading experiments. The two methods combined should be very powerful in understanding how mechanical energy such as that from tidal forces are dissipated and turned into heat.

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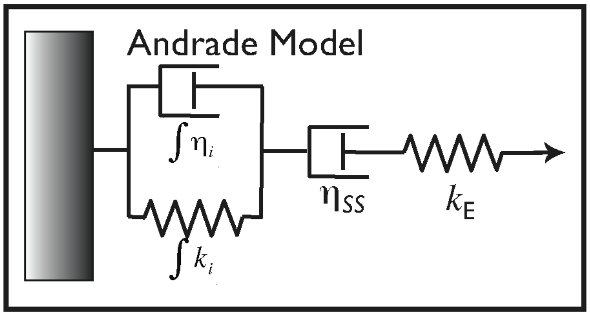

Figure 1: Schematic representation of the Andrade model, which consists of (from right to left) a Hookean spring, a viscous dashpot and an infinite number of Kelvin elements.

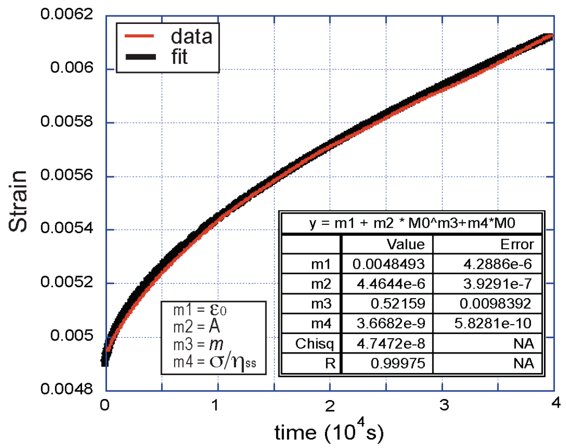

Figure 2: Sample creep curve from one known stress step (σ=3.2MPa) that has been regressesed against the Andrade mechanical model to obtain physical parameters ε_0, A, m, and $1/\eta_{ss}$.

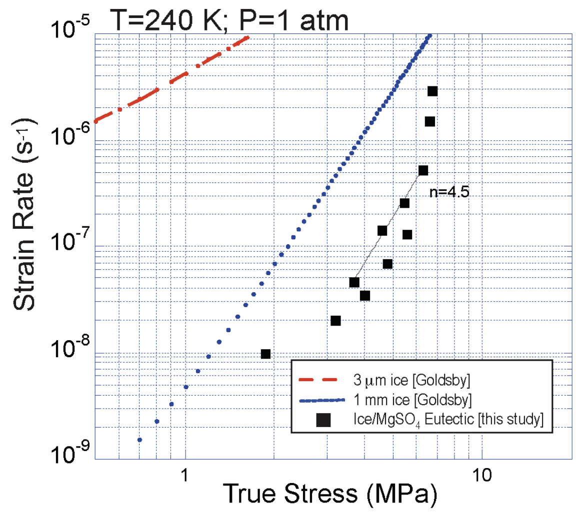

Figure 3: Steady-state creep results for H_2O-$MgSO_4$ eutectic samples plotted against the composite flow laws for 3 µm ice (top) and 1 mm ice. The effective viscosity of the ice-hydrate eutectic is ~10^1 greater than that of pure ice in the grainsize-insensitive creep regime.

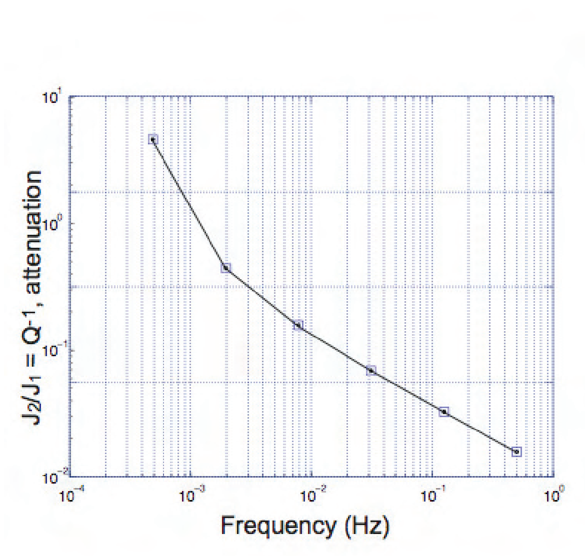

Figure 4: Attenuation data of H_2O-$MgSO_4$ created from the Laplace transform of the creep curve in Fig. 2.