Strength of LL Chondrites in Laboratory Deformation Experiments with Applications to Internal Structure of 99942 Apophis C. Seltzer[1]*, M. Peč[1], R.P. Binzel[1], H.O. Ghaffari[1] [1]Massachusetts Institute of Technology, Department of Earth, Atmospheric, and Planetary Sciences (*cseltz@mit.edu)

Introduction: As the asteroid Apophis is perturbed by the Earth, the asteroid's spin is predicted to change drastically. [1] Its shape may also change significantly at the surface, but the resultant changes to its internal structure have yet to be investigated. [2] As Apophis is a high-porosity, rubble-pile asteroid, the effects of friction and particle breakup create a number of possible mechanical outcomes. [3] Understanding the predicted strength and velocity structure of LL chondrites such as Apophis is essential for distinguishing between these potential outcomes.

Background: The strength of rubble-pile asteroids varies greatly by scale. Breakup requires relatively low stresses, but individual bodies within tend to be stronger overall. [4] Previous dynamical tests on overall cohesive strength, supported by results from Itokawa regolith, have indicated that much of the total failure strength of a rubble-pile asteroid is dependent on its spin, rather the strength of than its individual components. [4]

This work places constraints on slow, quasistatic deformation under isostatic confining pressures, and will be useful for identifying possible deformation scenarios as the meteorite encounters gravitational forces. Characterizing the acoustic emissions coming from micro-cracking of the asteroid material will be a crucial factor for distinguishing seismic signals originating from cracking of intact material from other seismic signals such as re-organization of larger blocks composing the rubble pile. Knowledge of the body's velocity structure at a range of confining pressures will also aid in interpreting any seismic signals that could be found if seismometers are deployed on a landing mission to Apophis.

Pressures inside rubble-pile asteroids are commonly in the Pa-kPa range, per a total regolith cohesion model. [4] This pressure range occurs in a microgravity environment (~10,000x lower than Earth gravity). As such, we place low, MPa-scale confining pressures on samples from the Kilabo meteorite, an LL6 ordinary chondrite meteorite used as an assumed meteorite analog [5], in order to characterize failure in LL chondrites undergoing deformation. We record acoustic emissions and measure realtime p-wave velocities during deformation.

Results: Stresses were applied using an axial piston driven at a constant displacement rate resulting in a strain rate of $5x10^{-5}$ s^{-1} in the sample. The peak stress increased with increasing confining pressure, but occurred around engineering strains of 0.03 regardless of confining pressure. Based on a porous cap model [6], possible C* states for closing of porosity in LL chondrite before imposing additional deformation fall between 100-150 MPa effective mean stress ($(\sigma_1 + 2\sigma_3)/3$) and 200-275 MPa differential stress ($\sigma_1 - \sigma_3$) . Constraining this stress state will lead to better understanding of compaction and further deformation in the interior of asteroidal bodies.

The Young's modulus ($E = \sigma/\varepsilon$) of the material also showed an evolution with increasing confining pressure, at about 0.7 MPa E per 1 MPa increase in Pc. These results are specific to the quasistatic strain rate used, as Young's modulus is known to increase with strain rate in chondritic materials. [7]

Acoustic emissions and pulse-probe ultrasonic measurements were recorded during deformation, where the amplitude of waveforms of the former shifted in three phases: 1) Porosity decrease due to increasing confining pressure, 2) Fracture formation due to applied differential stress, 3) Fracture closings due to healing and confining pressure. The relationship between the three phases is still being studied.

There is a measurable reduction of Vp wave speeds measured using the ultrasonic pulser after deformation, likely due to closing of porosity as described above. More tests are being completed to assess the impact of confining pressure on evolving compressional and transverse wave velocities in situ.

Implications for asteroid 99942 Apophis: By constraining and identifying markers of cracking under pressures within a meteoritic body, we can put forth a metric by which to understand where that meteorite is cracking, and when. Our measurements also provide a velocity structure model for p-waves under a range of pressures, essential for identifying seismic changes that would occur during an encounter. If in situ seismometers are placed on the surface of asteroid 99942 Apophis during a near-Earth mission, our results will assist in decoding seismic signals as they relate to structure, porosity, and any internal stress gradients.

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References:

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