Researchers mimic high-pressure form of ice found in giant icy moons

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This May 2001 photo of Jupiter's moon Callisto, taken by NASA's Galileo spacecraft, is the only complete global color image of Callisto obtained by Galileo, which has been orbiting Jupiter since December 1995. Scientists believe the brighter areas are mainly ice and the darker areas are highly eroded, ice-poor material. (Jet Propulsion Laboratory/NASA)

That everyday ice you use to chill your glass of lemonade has helped researchers better understand the internal structure of icy moons in the far reaches of the solar system. A research team has demonstrated a new kind of "creep" or flow in a high-pressure form of ice by creating in a laboratory the conditions of pressure, temperature, stress, and grain size that mimic those in the deep interiors of large icy moons.

The research appears in the March 3 issue of the journal *Science*.

High-pressure phases of ice are major components of the giant icy moons of the outer solar system: Jupiter's Ganymede and Callisto, Saturn's Titan, and Neptune's Triton. Triton is roughly the size of our own moon; the other three giants are about 1.5 times larger in diameter. Accepted theory says that most of the icy moons condensed as "dirty snow balls" from the dust cloud around the sun (the solar nebula) about 4.5 billion years ago. The moons were warmed internally by this accretionary process and by radioactive decay of their rocky fraction.

The convective flow (much like the swirls in a hot cup of coffee) of ice in the interiors of the icy moons controlled their subsequent evolution and present-day structure. The weaker the ice, the more efficient the convection, and the cooler the interiors. Conversely, the stronger the ice, the warmer the interiors and the greater the possibility of something like a liquid internal ocean appearing.

New research reveals in one of the high pressure phases of ice ("ice II") a creep mechanism that is affected by the crystallite or "grain" size of the ice. This finding implies a significantly weaker ice layer in the moons than previously thought. Ice II first appears at pressures of about 2,000 atmospheres, which corresponds to a depth of about 70 km in the largest of the icy giants. The ice II layer is roughly 100 km thick. The pressure levels at the centers of the icy giant moons eventually reach 20,000 to 40,000 atmospheres.

Researchers from Lawrence Livermore National Laboratory, Kyushu University and the U.S. Geological Survey conducted creep experiments using a low-temperature testing apparatus in the Experimental Geophysics Laboratory at LLNL. They then observed and measured ice

II grain size using a cryogenic scanning electron microscope. The group found a creep mechanism that dominates flow at lower stresses and finer grain sizes. Earlier experiments at higher stresses and larger grain size activated flow mechanisms that did not depend on grain size.

The experimentalists were able to prove that the new creep mechanism was indeed related to the size of the ice grains, something that previously had only been examined theoretically.

But the measurement was no easy feat. First, they had to create ice II of very fine grain size (less than 10 micrometers, or one-tenth the thickness of a human hair). A technique of rapid cycling of pressure above and below 2,000 atmospheres eventually did the trick. Adding to that, the team maintained a very steady 2,000 atmospheres of pressure within the testing apparatus to run a low-stress deformation experiment for weeks on end. Finally, to delineate the ice II grains and make them visible in the scanning electron microscope, the team developed a method of marking the grain boundaries with the common form of ice ("ice I"), which appeared different from ice II in the microscope. Once the boundaries were identified, the team could measure ice II's grain size,

"These new results show that the viscosity of a deep icy mantle is much lower than we previously thought," said William Durham, a geophysicist in Livermore's Energy and Environment Directorate.

Durham said the high-quality behavior of the test apparatus at 2,000 atmospheres pressure, the collaboration with Tomoaki Kubo of Kyushu University, and success in overcoming serious technical challenges made for a fortuitous experiment.

Using the new results, the researchers conclude that it is likely the ice deforms by the grain size–sensitive creep mechanism in the interior of icy moons when the grains are up to a centimeter in size.

"This newly discovered creep mechanism will change our thinking of the thermal evolution and internal dynamics of medium- and large-size moons of the outer planets in our solar system," Durham said. "The thermal evolution of these moons can help us explain what was happening in the early solar system."

Source: Lawrence Livermore National Laboratory