EOS *DRAFT*

MEETINGS

Evolution of Ice-Silicate Bodies in the Solar System

Our knowledge of small bodies in the solar system has vastly increased in the past decade due to observations from spacecraft and large earth-based telescopes. Many of these objects, it turns out, are large and dense enough to experience planetary processes, including heating, melting of ice, redistribution of internal material, convection in water and warm ice. These processes produce features that are now being observed, such as tectonic surface features, volcanism, significant non-spherical shapes, and secondary minerals on the surface. This evidence, some of it unexpected and startling, was produced by the NASA Galileo mission for the Jupiter system and is now resulting from the NASA-ESA Cassini mission for the Saturn system. The Hubble Space Telescope and large ground-based telescope are revealing evidence of active processes at one time for Ceres and Vesta, the largest asteroids [really protoplanets: *c.f. McCord et al.* Eos article, 7 March 2006].), and are discovering numbers of bodies up to and larger than Pluto in the outer reaches of the Solar System.

For example, recent examination of the evolution possibilities for Ceres, ~1000 km in diameter (d), revealed the likelihood that it contains enough water to have approximately a ~100-km deep water mantle, part of which may still be liquid. Vesta (d~500 km) was found earlier to likely be completely differentiated, dehydrated, and have melted its silicates to produce a basaltic surface and an iron core. The Galilean satellites were found to have a range of differentiated states, with Io still the most volcanically active object in the Solar System today and Europa probably having a liquid water ocean below a thin crust that could even sustain life. Currently, a deluge of new and startling observations are arriving from Cassini that show, for example, a huge ring of mountains around the equator of Iapetus and plumes of water and other materials erupting from the south pole of Enceladus. Clearly, these objects have been, and may still be in some cases, much more active and interesting than first thought.

These discoveries and the planning of new missions, such as the NASA Dawn mission to orbit Vesta and Ceres [recently canceled by NASA after over four years of development and construction] and a Europa Explorer Mission, have stimulated new and more sophisticated attempts to explain the existence and current properties of these objects through thermodynamic modeling. This requires a reexamination of major topics, including (a) A better characterization of the initial conditions, which determine the evolution of the satellites: accretion processes, initial composition (content in volatiles, rocks, and radionuclides), initial temperature, structure (porosity distribution), initial dynamical configuration; (b) Evolution processes: heat transfer, tidal dissipation (as heat source and driver for dynamical evolution), structural evolution through melting and differentiation, chemical evolution; (c) Expression of these different processes that might be seen in potential observations and, conversely, information inferred from observations as constraints on the internal evolution.

These three topics have in common a dependency on material properties, e.g., thermal properties and rheology. There are gaps in our knowledge of ice properties as a function of temperature, pressure, composition, and process (e.g. strain rate) that often impedes modeling and observations interpretation. Also, parts of these processes are a function of the environment in which the satellites formed and evolved (e.g., pressure, temperature, chemistry, place in the chronology of the Solar System), and as such are a key to better understanding the history of the Solar System.

Thus, the development of new thermal models to explain these objects requires a mix of expertise and covers a wide range of fields. Several investigators involved in these recent modeling attempts, mostly as a result of involvement in the discoveries themselves, saw the need to talk at length with colleagues in some of the related fields of expertise. As a result, a small group of interested scientists convened a workshop away from the distractions associated with the usual meetings. This discussion was hosted at the Bear Fight Center, near Winthrop WA on the east slopes of the North Cascade Mountain February 15, 16. Experts from nine universities, NASA centers, and research institutes, including from France, described their interests and current activities, identified areas of most importance for improvement in the understanding of small bodies, and defined topics for collaborative efforts in the future. The effort was felt so successful that a second meeting is planned at or near Pasadena CA October 6, 7, 8, 2006. A web site is being set up to facilitate circulation of materials (www.bearfightcenter.com/smallbodies).

One major topic of discussion and of a collaboration is the early Solar System formation stages: The first few million years after formation of the nebula, out of which the sun formed. Because short-lived radionuclides (^{26}Al; ^{60}Fe) can be a major energy source during this early period, it is critical to determine exactly when objects formed that were dense and large enough to trap heat. It is currently thought that the Solar System's solid bodies formed by accretion of dust and ice grains from the nebula. Accretion may have proceeded at a fairly linear rate until object grew large enough to have an escape velocity larger than their orbital velocity, when they would suck in material from beyond their local area and grow more rapidly until depleting the available material. Thus, objects that grew slightly faster than others would end up sweeping up the smaller slowpokes as well as left over dust and ice grains. The slowpokes could have themselves experience heating from short-lived nuclides and lost their ice grains, reducing the amount of water in the dominant object. The ice-depleted larger object would heat more due to lack of ice latent heat and water convection. So, exactly when and of what the small bodies if interest here were formed is critical to their evolution.

Another key issue that arose from Cassini observations at the Saturnian medium-sized satellites regards the origin of heat sources driving endogenic activity and dynamical evolution. Major thermal modeling issues include the initial content of radionuclides, tidal dissipation, and heat transfer styles. The latter processes are functions of material thermal and rheological properties, which mainly depend on composition and structure and are affected by the changes in temperature they create. Because of their small volume-to-surface ratio, the smallest icy bodies are expected to develop a thick undifferentiated outer shell before cumulated heating from long-lived radionuclides decay becomes significant. Besides, recent densities yielded from Cassini data indicate that most of the Saturnian small satellites are underdense with respect to the large Galilean satellites, with a weighted averaged rock mass fraction of only ~30% (vs. ~60%). The question of how a runaway process such as tidal dissipation can develop in such conditions and become the main cause of endogenic activity and dynamical evolution was addressed.

It has been proposed that short-lived radiogenic species might play a role in the early of the satellites by providing a heat pulse, triggering structural and chemical evolution and tidal dissipation. In testing this model – which has so many implications for the Solar System's early chronology – it was felt necessary to better characterize heat transfer processes (*e.g.*, effect of porosity, convection onset), the conditions for the development of significant tidal dissipation, and material properties. These issues are to be treated in collaborations developed at the workshop and discussed again at the fall workshop.

(1223S wds; < 1500 wds required)

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