The Physical Properties of Carbonaceous Asteroids

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The rendezvous and sampling of asteroids 162173 Ryugu and 101955 Bennu have opened a new window on carbonaceous asteroid physical properties. Both objects have the structure of low-density rubble piles [1], with surfaces that are extremely rough, covered in starkly angular blocks and boulders, and depleted in fine particle sizes and dust [2]. The returned Ryugu material is similar to CI carbonaceous chondrites [3] and Bennu is likely either CI or CM-like materials. The surface of Ryugu exhibits very low thermal conductivity and high porosity [4]. What does this imply for the link between the physical properties of carbonaceous asteroids and hydrated carbonaceous meteorites?

The mineralogy these objects are dominated by phyllosilicates, primarily serpentines and saponite [3]. For Ryugu the serpentines are the magnesium-rich endmember similar to CI mineralogies. For Bennu the serpentine mineralogy is still unknown but may be the iron-rich endmember Cronstedtite. One major characteristic of serpentines is a strong negative excursion in the coefficient of linear thermal expansion in the range of 200°-250° K [5]. This effect is shown in Figure 1 for five CM carbonaceous chondrites. Since the carbonaceous materials are basically conglomerates that include some very dissimilar minerals, this negative thermal expansion excursion in serpentines may be key to understanding their surface properties as they evolve in the inner solar system. Cobbles and boulders exposed on the surfaces of carbonaceous asteroids will undergo extreme temperature excursions as they rotate into the Sun and then are exposed to deep space. All the minerals in the conglomerates will expand and contract according to their thermal expansion coefficients. For most minerals the expansion is a linear, positive function of temperature. However, for carbonaceous chondrites the serpentines and other phyllosilicates will expand, contract, and then expand again in a course of their heating and subsequent cooling. This will produce an extreme energetic effect on the mineral grain boundaries, essentially pushing them apart, contracting to open space, and then pushing apart again. The overall effect will be to weaken the conglomerate and induce increasing porosity into what appear to be coherent cobbles/boulders. This will leave the surface covered with boulders and cobbles that are extremely friable, porous, and weak. Because the effect is limited to the penetration depth of the rotational thermal pulse, it may be that only the surface materials are significantly weakened by this process. Cobbles buried at some modest depth and do not undergo temperature excursions may retain significantly more coherence and strength than the surface material.

One important observation is the lack of small particle size and dusty materials in the surface regolith. With the stresses induced by the thermal excursions, it would be expected that at least some of the boulder and cobble material would disaggregate to form a dusty regolith. However, the surface appears much like a “desert pavement” where active processes extract the fine materials from the surface and armor it with particle sizes too large to be moved by the active processes. Active ejection processes have been observed on Bennu with rocks as large as 10 cm being ejected. Because of the low gravity, fine particle sizes are likely to be entrained in the solar wind once ejected, resulting in a depletion of fines on the surface. Below the surface on both Ryugu and Bennu sampling activities revealed horizons more enriched in fine materials [1].

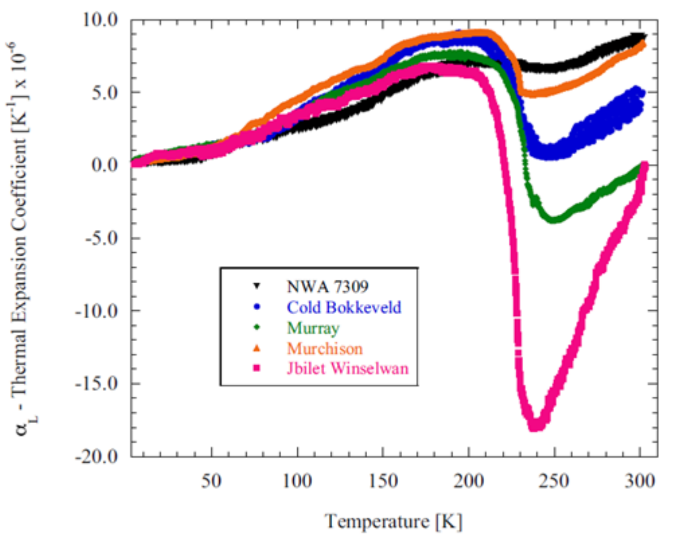

Figure 1. Thermal Expansion Coefficient for CM carbonaceous chondrites

References

[1] Sugita S. et al 2019. Science 364: 252 [2] Michikami T. et al. 2019. Icarus 331: 179. [3] Yokoyama T. et al. 2022. Science 10.1126/science.abn7850 [4] Gott M. et al. 2019 Nature Astronomy 3(11): 971. [5] Opeil C. et al. 2020. MAPS 10.1111/maps.13556. [6] Lauretta D. et al. 2019 Science 366:6470.