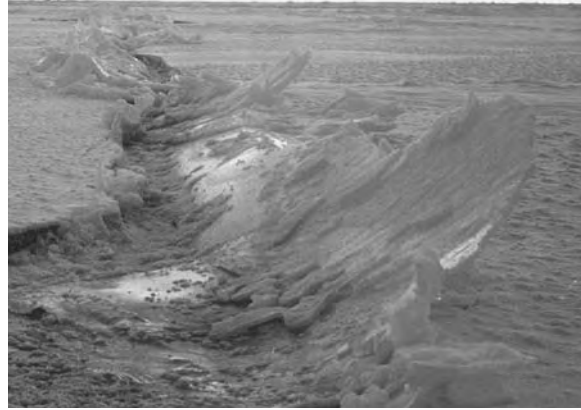




with low brine volumes, as the ice sheets try to override, rather than bending and flexing, sheets of ice fracture at low strain and blocks are broken off by their own weight as they are cantilevered out of the water. The characteristic length between fractures is of the order of the ice thickness, i.e. from a few tens of centimeters to 1-3 meters (maximum), leading to linear ridges of a few meters width consisting of piles of ice blocks, as shown on the right side of Fig. 2.

**Dynamic Transition from Ductile to Brittle Behavior:** Sinuous ridges represent a dynamic transition from the overthrusting sheets (ductile behavior) to narrow linear ridges (brittle behavior). They are formed first from 10 to 20m sheet overthrusts. During the process of overthrusting, the ice at the leading edge of the sheets undergoes a thermal or hydraulic transformation where the relative brine volume is lowered, leading to a stiffening of the ice and its transition to a brittle structure. The breaking into short blocks observed in brittle behavior is then found, outlining the outer edges of the thrusts, representative of the failure occurring there. The center ridge in Fig. 2, above the scale, is a sinuous ridge formed by this two stage process, ductile overthrusting of adjacent sheets, followed by brittle failure of the edges of the overthrusts, creating a narrow blocky outline of the thrust structures in a sinusoidal form.

**Thermal Stiffening of Sea Ice:** The thermal process to reduce brine volume and stiffen the ice is probably the most applicable to the Mars case. Stiffening occurs from the freezing of liquid water into ice and precipitation of solid salts within the ice as the ice sheet is exposed on its edges and bottom to lower atmospheric temperatures than the ocean as the ice sheet is pushed out of the fluid and onto the solid surface. An Arctic example of this process is shown in Fig. 4. Here we see the ductile thin sheet bent through a large angle leading to a curved ice sheet at high angle. If the ice remained ductile it would crawl out onto the adjacent sheet as shown in Fig. 3. However, as the sheet is exposed to the low air temperatures as it is moved out of the water, it freezes and stiffens and is able to maintain the curved structure and move almost vertically. Once the cantilever length is too long however, its rigidity transfers the bending moment due to its weight to the hinge point, leading to a stress riser there. The stress eventually causes a tension failure to occur by a crack propagating through the thickness, and the blocks fracture off in brittle failure as shown further along the ridge in the background of Fig. 4.



**Fig. 4.** Example of Arctic's thin, ductile sea ice frozen into its curved shape, while deforming. Brittle failure of the frozen sheet occurs when the stress induced by its weight exceeds the bending strength of the sheet at the hinge.

**Conclusions:** Side-by-side comparisons of Earth and Mars image pairs have indicated highly similar structures in both sets of imagery. From these, we have also made characteristic measurements on for example, the lengths and widths of rafting thrust structures, the "wavelengths" of sinuous ridges, and floe sizes. From these statistics of characteristic structures, we suggest strong similarities in the apparent material behavior on the two planets. Particularly important and more characteristic of sea ice than other materials is that small temperature changes in the material near the melting point (<5 C) cause large phase changes that result in the highly dynamic transition from ductile to brittle behavior. In the Arctic, these temperature changes take place over time scales of the same order as the deformation rate, i.e. of the order of minutes to hours and result in a continuum of structures, (from rafts to sinuous ridges to linear ridges) that track the mechanical behavior of the material as it transitions from ductile to brittle while deforming (Fig. 4). From the similarity of structures on Mars, we infer that they too first started from a ductile (two-phase) material that underwent a transformation to a single phase while deforming, resulting in brittle behavior near the end of the ridging process. Inferences from the large-scale behavior are also interpretable in terms of characteristic material properties giving potentially fuller information in future on the microstructural composition of the ice cover on Mars and its thermodynamic evolution.

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