GROUND ICE ON CERES? B E. Schmidt[1]*, K. G. Hughson[2], H. T. Chilton[1], J. E. C. Scully[3], T. Platz[4], A. Nathues[4], H. Sizemore[5], M. T. Bland[6], S. Byrne[7], S. Marchi[8], D. P. O'Brien[5], N. Schorghofer[9], H. Hiesinger[10], R. Jaumann[11], J. Lawrence[1], D. Buczowski[5], J. C. Castillo-Rogez[3], M. V. Sykes[5], P. M. Schenk[12], M. C. DeSanctis[13], G. Mitri[14], M. Formisano[13], J-Y Li[5], V. Reddy[5], L. LeCorre[5], C. T. Russell[2], C. A. Raymond[3] and the Dawn Science and Operations Teams. [1]Georgia Tech [2]UCLA [3]JPL [4]Max-Planck. [5]PSI. [6] USGS. [7] Univ. Arizona. [8]SWRI. [9] Univ. Hawaii. [10]Westfälische Wilhelms-Universität,. [11]DLR. [12]LPI. [13]INAF. [14]Universite de Nantes.

Introduction: Five decades of Ceres observations suggest a carbonaceous-chondrite-like composition, and the possibility of an ice-rich outer shell protected by a silicate lag. Details of the shell composition are heavily debated but estimating the abundance of water ice is a high priority for assessing Ceres' astrobiological potential. Although unlikely on its surface, ice can last in Ceres' subsurface over billions of years if protected by an insulating layer; the necessary burial depth may be less than 1 m above ~40° latitude. During impact events, this ice can be excavated, exposed, and/or melted, and while kick starting ice-related geologic activity, complicating the survival of ice within the subsurface. We adopt the term "ground ice" to describe silicate material rich in ice, or silicate-covered ice deposits. We primarily analyze Framing Camera clear filter images from Dawn's Survey and High Altitude Mapping (HAMO) Orbits. Here we describe morphological evidence for ice-rich substrate on Ceres from flows associated with craters, beginning with our observations of three different types of material flow.

Mass Wasting in Cerean Craters: Across Ceres' surface there is evidence for mass wasting that operates in a very different manner from that on Vesta. Noted examples include scalloped and "breached" craters that are characterized by mass wasting by which recession of crater walls occurs in asymmetric patterns; these appear analogous to scalloped terrain on Mars and both rock glaciers and protalus lobes formed by mass wasting in terrestrial glaciated regions. Often contacts between craters are completely degraded, leaving behind lobate, or fan-shaped debris deposits.

Arguably the most intriguing mass wasing features on Ceres manifest as debris flows with varying characteristics that originate at crater rims. In a survey of 20-35 km craters on Ceres (a good subset of features not strongly influenced by relaxation or secondary populations), a surprising number possess mass wasting features that extend 10's of km from their sources—over 20% contain such flows. The number of flows also varies with latitude, from 10-15% of craters below 30 degrees latitude to ~30% of craters above 50 degrees latitude. This poleward positive trend suggests that whatever is controlling the behavior of large mass wasting features on Ceres also varies with latitude. Thus, we consider ice as a likely culprit.Moroever, the style of mass wasting also changes over the surface of Ceres. We have identified three classes of flows that can be separated by their geomorphological characterstics. We refer to these as Typoe 1, 2, and 3.

Type 1: Several high latitude, high elevation craters feature long, thick flows that emanate from degraded or slumping cirque-shaped crater rims. In each of these cases it appears that a small impact into the rim of a larger, older crater has destabilized material in and exterior to the crater rim. In at least three cases, these flows bear strikingly similar morphology to terrestrial rock glaciers and lobate debris aprons found on Mars. Similarities include stepp-fronted lobate toes, longitidunal furrows and ridges, and thicknesses of up to 300m. These flows may be consistent with downslope motion of ice-cemented material. Type 1 flows are only found above 50 degrees latitude.

Type 2: Pervasive thinner (10's of m) elongate to fan-shaped flows have been observed to start at crater rims and flow outward down the exterior of the crater. These flows have conical to lobate shapes, and impressive length despite their shallow slopes, characteristic of long-runout landslides observed on other bodies such as Mars and Iapetus. Figure 2 shows examples of type 2 flows on Ceres, alongside one from Iapetus. The length and low slope angle of these flows suggests that friction reduction may help to explain these features. These flows are thinner than type 1 flows, and traverse generally longer distances. Type 2 flows are found across the surface, though they are found in over 10% of craters above 30 degrees latitude.

Type 3: Rare cases of sheeted flows are observed extending outward from crater rims. In these features, thin broad sheets of smooth material terminate in layered sets of lobes or cusps. These flows are generally wider than the Type 2 flows and thinner than Type 1. Their acute lobes, absence of deep furrows, and textures--relatively smooth but occasionally hummocky—are similar to the morphology of fluidized ejecta blankets in Martian rampart craters and those on Ganymede that form by impacts into ice-rich ground. These flows may be consistent with melted material derived from the impact or post-impact melting. These are found in ~10% of craters below 50 degrees latitude and never at the poles.

Discussion and Implications: We identify three distinct lobate flow morphologies: (1) steep, wide, furrowed flows hundreds of meters thick, (2) shallow, thin long-runout flows and (3) sheeted fluidized flows that appear to have rapidly dispersed from craters. These flow types are morphologically analogous to ice-rich flows found on Earth, Mars and the icy satellites. It is important to note that no similar flow morphologies or fluidized materials were found on Vesta, which shares a comparable impact environment to Ceres. This indicates that the primary difference in impact response derives from target compositional differences. Material on Ceres appears weaker, more deformable, and flows more rapidly, than that on Vesta, which we interpret as evidence for ground ice. The increase in number of these flows towards the poles is evidence that Ceres' subsurface contains ground ice and that the ice is most abundant near the poles.

Figure 1: Type 1 flows that occur at Ceres' high latitudes. Blue solid lines show the margins of the flows. White dashed lines delineate craters. Yellow lines follow furrows along the path of inferred motion. Red lines trace the rims of the crater that sources the flow.