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Submarine Permafrost Dynamics Along the Arctic Shelf Edge

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Recent exploration in the Canadian Beaufort Sea offshore of the Tuktoyaktuk Peninsula has revealed a remarkable coalescence of seafloor morphologic features (pingos, pockmarks, slope parallel ridges, and slide scars), which form a band rimming the shelf edge and upper slope. Detailed investigations utilizing a Autonomous Underwater Vehicle (AUV) to provide 1-m grid bathymetric and Chirp profile, supported by sediment cores and Remotely Operated Vehicle observations, have been made to determine the origins of these features. We infer the concentrated band of features to be related to on-going degradation of relict permafrost under the shelf, the expulsion of the released waters, and the formation of ground ice within the near seafloor sediments. These all have geohazard implications, which may be unique to the Arctic setting.

A distinctive seafloor morphology occurs along a ~95 km long stretch of the shelf edge in the Beaufort Sea within a band between 100 and 200 m water depths characterized by circular topographic features (similar to Pingos), that are up to 10 m high and ~50 in diameter, occur in places at a density of ~6 per km^2. Circular and crescent shaped topographic depressions (similar to Pockmarks), which are up to 20 m deep, occur at a density of ~1 per km^2, within this band. Between these topographic highs and ridges the upper layers contain laterally continuous reflector packages that are similar to those that occur below 200 m water depths, but with variable dips and some even dipping to the southeast back into the regional slope. To the west of this band there is an extensive area of disturbed topography approximately 24 km wide which is made up of several large coalesced landslide features with headwall scarp frequently occurring along the ~150 m contour. These topographic features are developed within Holocene sediments, indicating they formed within the submarine environment. Pore waters sampled in 20 sediment cores taken from 90 to 220 m water depths in this area characteristically freshen with sub-bottom depth, indicating the shelf edge and upper slope associated with this dynamic seafloor environment are bathed in brackish waters.

Two unusual environmental factors pre-condition the sediment dynamics, which are unique to Arctic continental margin settings. First, during the sealevel lowstand associated with the last glaciation the exposed shelf experienced ~-20°C mean annual surface temperatures, which resulted in substantial permafrost formation. The postglacial marine transgression imposed a large thermal change as the mean annual sea bottom temperatures are ≥-1.8°C. This thermal disturbance is still propagating into the subsurface, stimulating the decomposition of both terrestrial permafrost and gas hydrate at depth, which liberates water and methane. Models and observations indicate some areas of the Beaufort Shelf are still underlain by a >600 m thick wedge of relict ice-bonded permafrost and methane hydrate down to >1000 m depths. This wedge of relict permafrost is inferred to extend out to the glacial shelf edge (~120 m) and is coincident with the distinctive topography. Second, the bottom seawater temperatures

that imping on the seafloor at the shelf edge in the Beaufort Sea are <-1.4°C, cold enough to refreeze brackish pore water within near seafloor sediments.

Buoyant brackish ground water supplied from the base of decomposing relict permafrost is hypothesized to migrate along the base of the relict permafrost, to emerge at the shelf edge and refreeze when it encounters the colder seafloor. Sediment deformation caused by intra-sediment ice growth has uplifted the seafloor and created numerous pingos and deformation ridges. Deformation is also enhanced by settlement following thaw consolidation along the outer edge of the decomposing relict permafrost, producing the pockmark depressions. The dynamics of ice formation and decomposition within the near seafloor sediments collectively weaken the sediments within this zone leaving them prone to failure along the edge of the decaying relict permafrost wedge.