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An Alternative Model for "Pingo" Formation in Permafrost Regions

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Abstract

Pingos are a characteristic geomorphologic feature of certain Arctic regions in which dome-shaped dimples can form in the permafrost layers of otherwise flat landscapes. It is widely accepted that the formation of a "pingo" results from the development of an excess pore water pressure in the unfrozen ground, the "talik", underlying the permafrost layer. This paper argues that these prevailing models for pingo formation contain some serious mechanical inconsistencies. An alternative model is postulated. It relies upon the development of high levels of in-plane compressive stress in the permafrost layer. These compressions would arise from the restraint to the expansions otherwise occurring when in a thickening of the permafrost layer water turns to ice and/or when the ice in the permafrost layer is subject to a seasonal increase in temperature. An upheaval buckling under these conditions is consistent with the local dimples associated with pingos.

Pingos are a commonly observed geomorphologic formation in areas of permafrost. They take the form of a dome shaped upwelling of the frozen surface ground layers occurring in areas of recent exposure to the effects of permafrost surface penetration. They tend to occur in the beds of lakes that have for some reason been drained of the water that previously insulated the bed layers from permafrost penetration. The generally accepted explanation for their formation is that a hydraulic pressure builds up beneath the recently frozen layer pushing it up into the characteristic dome or sometimes ridge formation. The build-up of pore water pressure in the underlying "talik" is said to result from either ground water flow resulting from a hydrostatic head associated with elevated water tables in the surrounding higher landforms or from the confinement caused by the advancing ice formation within the sealed talik.

While it is almost certainly the case that these pressures contribute to the developments of pingos, the geometry of the pingo has certain characteristics that are not consistent with just this explanation. If a generalised underlying pore pressure were formed the likely response of the frozen surface layer would be a generalised upheaval involving the whole, usually very large, area of the recently frozen permafrost layer. This is not the case. What tends to happen is that a number of seemingly random, relatively small diameter, dimples are formed. These would have to be associated with either highly localised pore water pressure peaks, which is highly unlikely, or localised areas where the permafrost layer is thinner. The latter explanation is the most plausible except for the fact that if they were due to localised thinned areas of permafrost it would be most unlikely that they would exhibit the very regular dome shaped formation which on plan has such a consistently regular circular shape. Much more likely, if this latter consideration were to provide the explanation, the distortions induced by a relatively uniform underlying pore pressure would reflect the inherent irregularity of the thinner than average regions of permafrost. This does not appear to be the case.

This paper will suggest that another mechanism might be at work. In-plane compressions resulting from the restraint to expansion of the ice within the permafrost layer, could induce a thermal uplift buckling. For 2-dimensional sheets subject to a uniform biaxial compression stress, this form of thermal buckling takes the form of a localised dimple closely related to the geometric characteristics of the pingo. The compression needed to generate the buckles could result from the expansion occurring either as the groundwater turns to ice as the thickness of the permafrost layer increases over time, or as the already formed ice sheet experiences an average increase in temperature associated with seasonal cycles. A brief account will be given of the mechanics involved in the thermal uplift buckling and indicative calculations will demonstrate that such a mechanism is consistent with the good deal of recorded observation on pingo formation. It is suggested that this alternative explanation of the formation of pingos will allow some of the physical inconsistencies of the current models to be resolved.