AN IMPACT CRATER POSSIBLY FORMED DURING A SNOWBALL EARTH PERIOD: STRANGWAYS.

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Introduction: The current understanding of the geological history of the Earth, based on direct observations, proposes that the Precambrian Earth episodically has been globally covered by ice [e.g., 1]. Two known so-called Snowball episodes lasted about 660-710 Ma and 645-655 Ma (besides an earlier phase, the Huronian glaciation at around 2.4-2.1 Ga). The idea to check if any impact event has influenced the initiation or the ending of any of the Snowball episodes has been discussed in the literature [e.g., 2, 3]. However, none of the currently known terrestrial impact craters has been discussed in a Snowball context.

Our recent publication on the effects of impacts on a glaciated Earth [2] mentions a single example of listed terrestrial craters with the age that approximately fit the later of the two Snowball episode – the Strangways impact structure in Australia, with an estimated age of 657±47 Myr [4, 5].

Some researchers believe they have found large impact craters under thick glacial ice sheets, e.g., in Antarctica or Greenland [6-8], but these interpretations are very hypothetical, as no direct observation of the rocks in question is so far possible, which is a prerequisite for determining the impact origin of any terrestrial structure - see [9]. This issue also needs some consideration regarding impact cratering in ice-covered terrains on Earth.

Following our recent study [2], we present here a few further thoughts about the crater diameter and physics of crater formation in rocky targets covered with a layer of ice.

The Strangways impact structure: According to geological mapping, the eroded crater preserves only the ~10 km-wide central uplift, which comprises gneiss basement, and was originally buried at a depth of 1 to 2 km under sandstones [4, 10]. Published estimates of the original crater diameter are in the range of 20 to 40 km. Comparing remnants of the central uplift with the well-preserved central mound of the Puchezh-Katunki impact structure [11], we tentatively assume the same impact scale for Strangways (remembering that this assumption may overestimate the original crater size).

The reconstruction of plate tectonics [12, 13] predicts the position of the Strangways site at the continental margin at about 30^{o}N. One could assume the presence of continental ice, a glacier, with thicknesses from a few hundred meters to a few kilometers (as in modern Antarctica and Greenland).

Numerical model: We follow the pioneering work of [14], where the main effects of cratering in ice-covered rocks are described. Technical details of the model may be found in [15]. A few reconnaissance model runs have been done for Puchezh-Katunki-sized impacts (crater diameter ~40 km, see details in [16]) and smaller (crater diameter ~25 km). The ice/rock target is assumed to be isothermal with a temperature of 263 K (-10^o C). Ice cover varies in thickness from a few hundred meters to 3 km.

The models result, as expected, in the formation of complex craters with a central uplift (Fig. 1). The main residual heat reservoir is located within the central mound, as in all previous publications (cf. Fig. 2).

The resulting crater topography for ice layers with thicknesses of 1/20 to 1/30 of the crater diameter is in general the same as for pure rock targets. For the thickest ice sheet in our models, with 3 km (for D ~40 km), we observe a noticeable change of the central uplift morphology. Further investigations are needed to determine if this effect could be used to distinguish under-ice craters at modern erosion levels.

Discussion and conclusions: A potential value of under-ice craters is permanent melted ice/water delivery into the crater cavity. Most previously published papers are devoted to Mars. In [17], the authors discuss the cooling of a hot central uplift in a crater with D >30 km. The model predicts the production of water vapor for about 1000 years. Simple conductive cooling estimates demonstrate that the size of the hot central region decreased twice during ~ 1 Myr after D~40 km crater formation [18]. From this point of view, the presented modeling indicates that the formation of a medium-sized impact crater in a glacier-covered region may create a source of water vapor production for a duration of 10^3-10^4 years after the impact.

As in the case of an oceanic impact [2], a full-scale GSM modeling is needed to connect an impact with the whole Snowball regime stability. In contrast to [2], we present here the possible case of a relatively weak, but long-term water vapor source, which potentially is able to change the regional cloud formation regime [19].

In connection with suspected under-ice terrestrial craters, we note here possible morphometric changes on a crater geometry in areas with 2 to 3 km thick ice shields, similar to modern Antarctic and Greenland shields. The other interesting possibility is the search for remnants of early rock/water/ice post-crater interaction recently described in [20]. A further step would also be to investigate in more detail the possible effects of the formation of the ~70 km-diameter, deeply eroded Yarrabubba impact structure in Western Australia, which was recently dated at 2229 ± 5 Ma, possibly coinciding with the termination of the Huronian glaciation. Extending our models to such an impact size and adding GSM modeling might further constrain the effects of impacts into ice on Earth.

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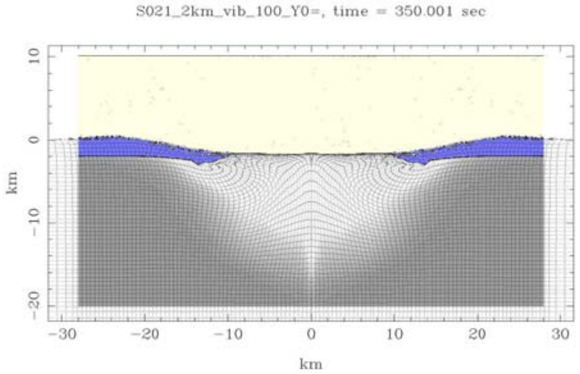

Fig. 1. The model crater profile for an impact consistent with the formation of the Puchezh-Katunki structure. Here a 2-km-thick ice cover is assumed (ice-to-rim diameter ratio of ~1/20).

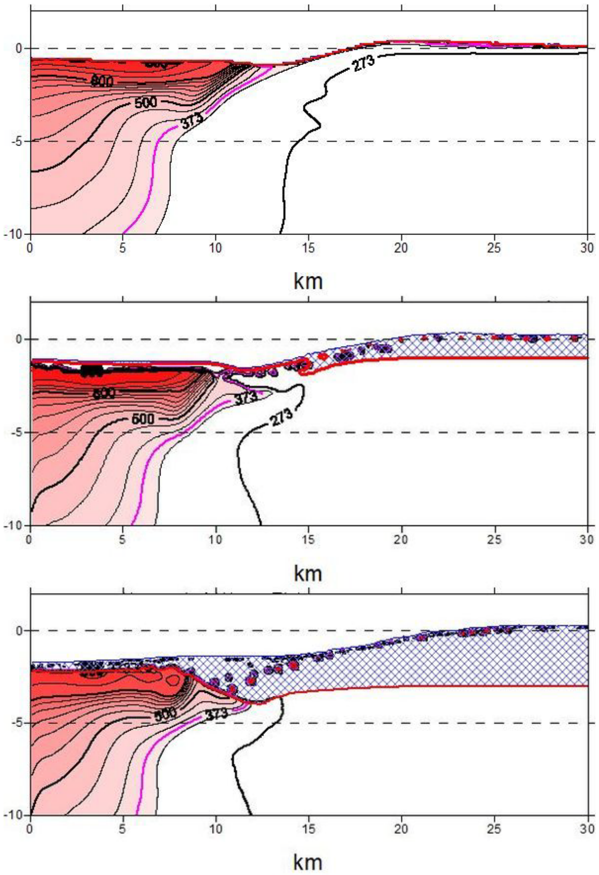

Fig. 2. Temperature fields under the crater formed in granitic rocks covered with (top to bottom) zero, 2, and 3 km of ice. All of the target has an initial temperature of 263 K (-10^{o}C).