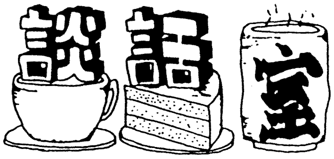

On the cave-ice and ice for rinks in Russia and Japan

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Abstract

The present paper briefly describes ice stalagmites found at the Sugawatari cave（氷渡洞窟, Iwate prefecture）and Hyakujyojiki cave（百畳敷洞窟, Hokkaido）（雪氷写真館）with a few references to other unique cave-ice forms and application of its mono-crystal structure at skate rinks of Japan and Russia.

According to the classification proposed by Shumskiy (1955) there are three main types of underground ice, one of them is cave-lode ice, with carst-cave ice included. This type is different from others since it has no relationship to permafrost, thus has no organic unity with rock stratum and represents an extremely local and rare type of ice-form. Among such forms are ice stalagmites, bead and sublimation formations. Probably, the rarest one is underground glaciers, formed by snow falling through a narrow upper crater of a cave. For example, the biggest underground glacier (50 m thick) in Europe, formed by this process was found 150 m deep in the cave "Snezhnaya" (means *snowy* in Russian, the world's second deepest cave, 1753 m) in Abkhazia (Bzybsky range, Georgia) in 1971 by the Moscow State University speleo-club (Degtiarev, 2006).

Much more familiar forms are ice stalagmites. This type is represented in the photos taken by the author at the Sugawatari cave（氷渡洞窟）, Iwate prefecture on February 18, 2008 and at the Hyakujyojiki cave（百畳敷洞窟）near Shikotsu Lake（支笏湖）, Hokkaido Island on March 1, 2007. In Japan such kind of ice also appears annually near the Kurobe dam as well.

Photos 1 and 2 on the cover pages of this issue were taken at Sugawatari cave during small speleological expedition organized by the Niigata University adventure-club. The entrance to the cave was covered with 1.5 m snow. Distribution of ice stalagmites were limited by vertical heat gradient inside the cave. The main clusters of ice stalagmites were situated at the widest parts of cave in 20–40 m from the entrance. These forms are the result of specific heat exchange inside the cave — they suddenly disappear completery when cave geometry starts to go up. This means there was a significant temperature gradient which separates cold air flowed from outside (−10℃) with a quasi-stable within-year cave air (+5℃). The height of these transparent ice stalagmites was about 1.5–3.0 m, with average thickness about 0.07–0.15 m.

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As it was shown by Tusima *et al.* (1983) and Tusima and Kiuchi (1998) each of the ice stalag mite represents one vertical mono-crystal of ice. Such kinds of structure is determined by a number of factors, the main one is probably competitive evolution of many ice crystals, which is taking place under vertical conditions of growth. Vertical growth is slowly forcing out all crystals oriented to other sides and favours only to crystal with a vertical c-axis. Hence the transverse section of ice stalagmite on the c-axis has very low friction and high strength. This made a proposal to use such kind of ice structure for ice-skating during Nagano 1998 XVIII Olympic Winter Games (but realized later at the M-wave, the Nagano Olympic Memorial Arena) (Tusima et al., 1998), but, unfortunately, were never used since then anywhere in the world, due to high labour-output ratio and high-price.

Such super slippery ice for skating (its friction was 22% lower than the friction of the usual poly-crystal ice) can be a serious factor for a number of sport records, goodwill of skating rink and, accordingly, an authority on realization of international competitions and economics. (Much cheaper technology for producing the “superslippery” ice was patented by Goncharova *et al.* in Russia, number - 2005103415/12(004554), published on the 10th of Feb. 2005. This technology was used at the *Krylatskoe* ice rink, Moscow (3rd place in the international rank after rinks in Salt Lake City and Calgary) (Shavlov *et al.,* 2007).

Cave ice in Sugawatari and Hyakujyojiki caves was formed from the water penetrated from relatively warm cave ceiling. There were only few ice forms hanging from above, and no icicles above the ice stalagmites, since the water was coming from warmer cavities. All ice stalactites were formed under very slow rate of crystallization, under warm air temperatures, and from warm water. All these factors

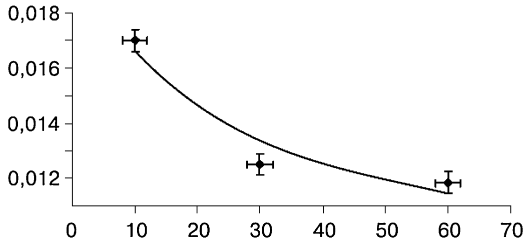

Fig. 1 (The X axis - water temperature, ℃, the Y axis - friction coefficient) Relationship between the friction coefficient of ice (−5℃) and the temperature of water used for ice formation (Adapted from Shavlov *et al.,* 2007).

were proven experimentally as important ones for low friction of ice (Shavlov *et al.,* 2007). Low rate of crystallization is determined by slow water dripping from above, that affords water diffluence, and by water’s high temperature, which decreases the rate of crystallization and as a consequence decreases the friction (Fig. 1).

Also as it was shown experimentally by Shavlov (1996) and Shavlov *et al.* (2007) additional ice processing after freezing by a fan (heating the ice for 1–2℃) decreases it friction coefficient. According to Shavlov *et al.* (2007) such process is equal to “annealing” of ice, which decreases the number of defects and increases the strength of ice. This can be similar to the natural fanning of ice stalagmites due to a special warm air circulation inside the cave.

There are two main types of ice stalagmites determined by water dripping pattern: long narrow (1.5–3 m, 0.07–0.15 m) and short thick ones (max 0.4 m, max 0.4 m). All ice stalagmites of the first type have a similar wavy vertical pattern (Fig. 2). The bumps are pbobably a result of interaction of many processes, like: winter temperature oscillations, oscillations of a flow mass flux of incoming from above water, oscillations of the temperature of this incoming water, some chaotic processes accumulating during crystal growth formation and

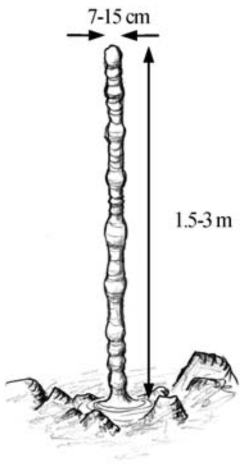

Fig. 2 Schematic sketch of typical ice stalagmite wavy form at Sugawatari and Hyakujyojiki caves (pencil, by E. Podolskiy, on February 18, 2008).

water diffluence.

An Interesting observation is that every ice stalagmite has a similar transparency pattern: the most pure ice is always represented by an upper part of every bump, then its geometry starts to get narrower. Other parts are not so pure and represented by blurred ice with air inclusions.

Ice at the Sugawatari cave forms in the middle of winter and melts in May-June.

Hyakujyojiki cave (Hokkaido island) could be reached by snowshoes from the nearest road; it has a wide entrance and represents a big niche with an increase of ceiling at its deeper part with the temperature slowly warmer than the outside air temperature. This cave had similar ice forms (Photos 3 and 4 in the cover pages in this issue), but their life-period must be shorter due to more intense heat exchange with the outside, probably from the middle of winter to April.

The age of the water, which constitutes these latter ice forms — is an interesting and open question. There must be a gap of a few months, between the formation of ice and last direct contact of water with the atmosphere due to the time which is necessary for water to penetrate from the outside. Probably this can be checked by tritium dating which has a relatively short half-life period of about 12 years.

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日本とロシアにおける洞窟氷とスケートリンクの氷について

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要　旨

このレポートでは岩手県と北海道で確認された氷筍（氷渡洞窟，百畳敷洞窟）（雪氷写真館）について，その他の特徴的な洞窟氷の形状の紹介および日本とロシアのスケートリンクにその特殊な構造の氷を使用するといった逸話を含めて概説する．

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