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Asian Ice Shields and Climate Change

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About the author

Robin graduated in Geology and Zoology at Manchester University in 1970 where he completed a Masters Degree in Geology before lecturing at Wigan Mining College for ten years. Robin's career includes 9 years on Planning and Development Committees in Greater Manchester, and he has published widely in planning, business development, geology, mining and freshwater ecology. Having survived harsh Mongolian winters since 1995, he became fascinated by naled ice shields while conducting remote sensing interpretation of Ulaanbaatar.

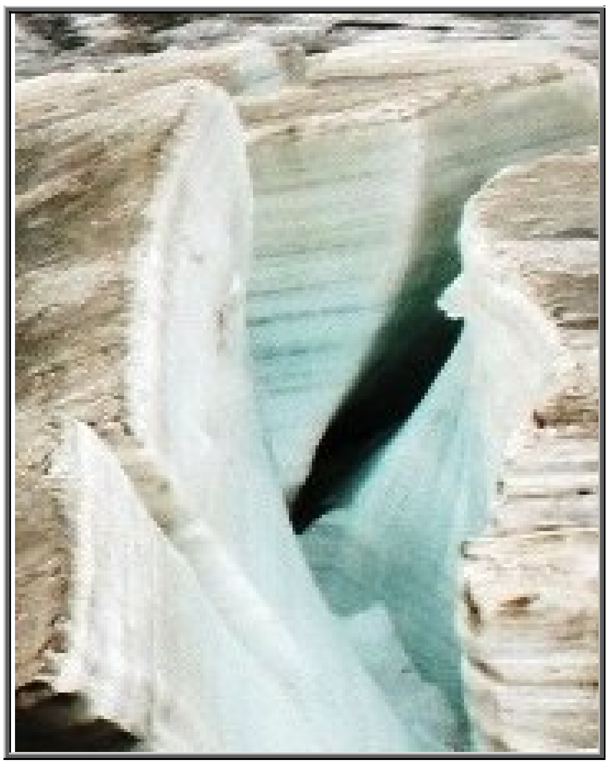

Figure 1. layers inside a naled ice shield
Fresh fractures revealing the stack of many layers of ice that accumulated one on top of each other to form a thick naled ice shield. (photo: Jim Reichert, World Bank)

Purpose of study

While glaciers, ice sheets and icebergs grab the headlines, naled ice shields remain "out in the cold".

The purpose of the study is to highlight the large number of naled ice shields in Asia, and to draw attention to their value as a buffer to Climate Change.

The author first trawled the internet on the topic of naleds, and presents a short bibliography with some analysis.

Next, using high definition satellite images, many hundreds of naled ice shields were detected in Mongolia, China and Central Asia, often far away from permafrost.

Naleds require only harsh winters and water to form, ideally with little or no snowfall. Many survive into spring to irrigate pastures naturally and yield drinking water for nomads, livestock, large wild mammals and birds.

Climate Change is expected to eliminate melt permafrost from most of Central Asia, yet the study suggests most naleds will survive. The author claims that protecting naleds would enable Climate Change Mitigation across vast regions of Asia.

Artificial naleds can be made at low cost and the author suggests permafrost can be repaired or even created by this means, so preventing Greenhouse Gas emissions and allowing the Taiga Forests and Tundra to survive.

Finally the author draws attention to the ease of thickening sea ice sufficient to maintain Arctic ice cover at low cost.

Special thanks are due to the EMI/ECOS Consortium for valuable discussions.

Contents

1 Introduction

While glaciers and ice sheets grab the headlines, naled ice shields receive scant attention. Unlike glaciers and ice sheets, naled ice shields do not grow from snow. Instead naled ice shields develop directly from water, by freezing while flowing on top of ice. By dint of repetition the ice gets thicker and thicker. In just a few months a naled ice shield can become several metres thick, sufficient to persist into summer and some become permanent.

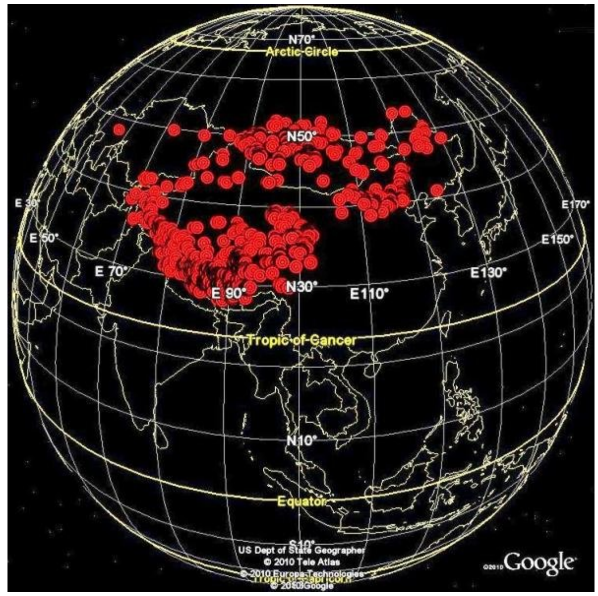

Figure 2. distribution of naled ice shields in Asia
Red dots show locations of Naled Ice Shields. (plotted in Google Earth by Robin Grayson [5])

Ample water may exist in summer, but not in winter if the ground freezes. Yet copious water may still be available underground and in iced-over rivers. When springs and rivers freeze over, water is trapped under the ice. The water may become over-pressurised and jack the ice into blisters that crack to release the water over the ice, and the water duly freezes so thickening the ice. Repeated over a few months, a huge naled ice shield may form in a single winter. Melt-water in spring irrigates pastures and supplies water for people, livestock and wild animals in semi-arid and arid regions such as the Steppe and Gobi Desert. Some naleds, although much diminished, survive the summer and become permanent ice shields.

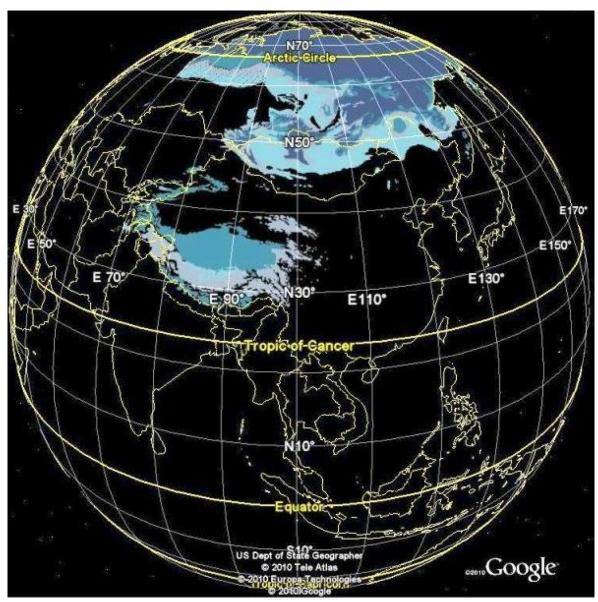

Figure 3. distribution of permafrost in Asia and Siberia
Continuous Permafrost (>90% area) in darkest blue; Discontinuous Permafrost (50-90%) in medium blue; Sporadic Permafrost (10-50%) in pale blue; Isolated Permafrost (<10%) in faintest blue. (image: Google Earth, plus overlay from [4], with black background added)

2 Definitions

To understand 'naled ice shields', it is first necessary to clarify the terminology:

Naled - a Russian term for a mass of surface ice formed in winter by the successive freezing of sheets of water that seep from the ground, from a river, or from a spring (A.M. Chekotillo 1940 in Carey 1970) [89].

Naled ice shield - a new term for the slab of ice created by a period of *"successive freezing of sheets of water that seep from the ground, from a river, or from a spring"*. The term is extended here to embrace artificial 'naled ice shields' produced by pumping or spraying water, provided the essence of *"successive freezing of sheets of water"* is maintained. The expression 'naled ice shield' is lugubrious, but circumvents English speakers' resistance to embrace "*naleds"* or *"aufeis"* in speech and in writing, and emphasises the shield-like slab of ice that is the end result. The wording *"...ice shield"* is an attempt to avoid confusion with *"ice sheet",* a term with other connotations.

Khalia toshin - a Mongolian term meaning exactly 'naled'.

Galan mos - a local Mongolian term for *"brilliant ice"* in reference to permanent naled ice shields [163].

Aufeis - a German term meaning exactly the same as a naled. However the term 'naled' is preferred due to the numerous naleds existing in the former Soviet Union and with a voluminous Russian literature on this phenomenon.

Taryn - a Yakutian term meaning exactly the same as naled (Russian) and aufeis (German).

Icing - an English term used in North America to refer to: a) naled ice shield; b) the process leading to the formation of a naled ice shield; or c) both of these. Unfortunately 'icing' is now widely for ice that builds up on aircraft wings, blades of wind turbines, and 'icing' of airport runways. The original meaning of 'icing' has been hijacked in common parlance and scientific literature, leading to confusion. Particularly so as in English lthe expression *"icing over"* also refers to simple freezing over of water in a lake, pond, river or tub - with or without the special thickening due to *"successive freezing of sheets of water"*. The author suggests the expression *"icing over"* remains valuable as a general term for ice covering the land or water by any process, but should be avoided for the special process of naled formation. This is contrary to the views expressed by many other North American writers [93,122].

A particular difficulty with 'icing' is highlighted by Deborah Harden and colleagues (1977) [99]: *"Icing is a term which refers to the process of progressive ice growth or accretion on a frozen surface. It is imprecise in that it is also used to designate many other related phenomena. In reference to rivers, it has been used to designate both the process of ice build-up and the actual bodies of ice formed as a result. The present authors prefer to use the term [icing] for the processes only"*.

In conclusion, the term 'icing' is now used so variably and elastically that abandonment of the term 'icing' is recommended for naled processes and naled end-product.

Ice hummock - a small mound in the surface of ice. The hummock is up-arching of the naled surface by hydrostatic pressure of water, occasionally by gas.

Figure 4. disintegrating naled ice shield in summer
Structural failure of a naled ice shield in summer due to enlargement of a phreatic tube leading to collapse of the tube. (photo: Jim Reichert, World Bank)

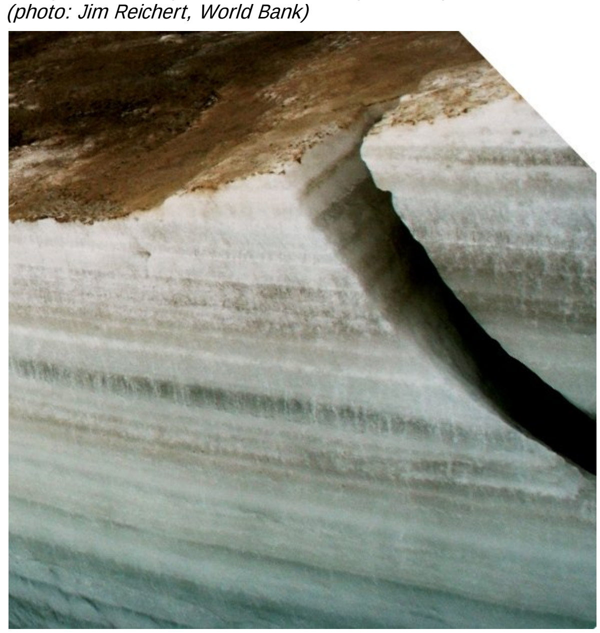

Figure 5. layers inside a naled ice shield
Fresh fractures revealing the stack of many layers of ice that accumulated one on top of each other to form a thick naled ice shield. (photo: Jim Reichert, World Bank)

3 Aims

The initial aim was limited – to appraise the literature on naled ice shields to shed light upon their widespread occurrence in Mongolia.

The aim became more ambitious when it was realised the literature rarely mentioned the benefits of ice shields for humans and biodiversity; did not flag up the potential of artificial ice shields in combating permafrost degradation and Urban Heat Islands; and paid little attention to naled ice shields far from the nearest permafrost that were evident in Google Earth high-definition satellite imagery of southern Mongolia, Inner Mongolia and the Beijing region.

4 Methods

A literature study was conducted to determine the worldwide distribution of naled ice shields, and to gain understanding of both natural and artificial naleds. The search was mostly by internet in English, and this 'skewed effort' caused underestimation of articles, papers and reports written in other languages. The literature search was also limited by 'search effort' and there remains a substantial amount of relevant literature in English that awaits examination.

Special attention was paid to articles, papers and reports with links to free PDF downloads and these are highlighted in the bibliography.

A remote sensing study was undertaken of naleds in using high-definition satellite images freely available on Google Earth. This was in tandem with interpretation of Google Earth coverage of Mongolia and northern China into more than 70 kmz files, each assigned to a different topic, as part of an assignment with the Netherlands-Mongolia Environmental Trust Fund (NEMO) of the World Bank and the Mongolian Ministry of Nature, Environment and Tourism (MNET). Some of the 70 kmz files are available on www.mine.mn. Later the remote sensing study was extended to cover the Beijing area, Tibet and the Central Asia states for naled ice shields.

Once a naled ice shield was detected by eye, a Google Earth pin was inserted to mark its location, and added to a kmz file. Where a shield extends for many kilometres, additional pins were often added. Where many shields occur in dense clusters then only a selection was assigned pins. The intention was NOT to attempt to plot every ice shield but rather to insert pins to guide the eye to areas where ice shields are prevalent, and to particular ice shields in isolated locations that would otherwise be difficult to find without such assistance.

Areas with 'old' Google Earth low definition imagery were generally ignored as naleds could rarely be recognised within them with confidence. In part this was due to insufficient resolution, and in part due to the low definition imagery often having been acquired in late summer when naleds are diminished. Accordingly the study was limited to about 5-10% of the region that enjoys high definition Google Earth coverage, and further limited by this imagery being irregularly distributed.

5 Results - Previous Literature

5.1 Size of Literature

The global Internet search on naleds yielded a bibliography of 188 articles, papers and reports, as listed at the end of this paper.

5.2 Geographical Spread

The geographical spread is uneven, as follows:

country	references
Regional	3
Russia (mostly Siberia)	68
USA (mostly Alaska)	47
Canada	23
Mongolia	19
Svalbard (incl. Spitsbergen)	17
China	4
Greenland	4
Korea	1
Mars	2

Global coverage is heavily skewed in favour of the English language. This is partly due to the author being a native speaker of English and lacking knowledge of other languages.

It is evident that a full bibliography of the Russian literature on naleds would exceed that for the rest of the world, as Russian scientists and engineers have been focussed on the economic problems posed by thousands of naleds in Siberia. On the basis of these studies, Vladimir Kotlyakov and Tatyana Khromova (2002) [32] estimate naled ice shields cover a remarkable 128,000km^2 of Russian territory and contain about 94 km^3 of ice, of which 45% are river naleds and 55% spring naleds. It is conjectured that a detailed search on naleds in Russian would yield several hundred articles and reports.

In spite of these caveats, the geographical spread of literature on naleds approximates to the global distribution of permafrost. Initially the author believed that this was due to naleds and permafrost sharing a common origin or being mutually self-reinforcing. While such factors are important they are not absolute, as naled ice shields often occur far from the nearest known permafrost district as will be demonstrated later in this article.

Rather, the geographical coincidence between permafrost and naleds is overemphasised by the permafrost regions being the 'comfort zone' of scientists specialising in cryosphere topics - ice caps, ice sheets, ice glaciers, rock glaciers, snowfields, permafrost etc. It follows that the thousands of naled ice shields away from the permafrost zones have received little attention. This anomaly is exacerbated by Eurasia's leading naled specialists being in Siberia, and most of the Continuous Permafrost being confined within the southern border of the Russian Federation. Across the border the Ulaanbaatar-based Institute of Permafrost conducts important research on permafrost but with a few important exceptions [155,167] has insufficient funding from the government and international sources to thoroughly investigate naled ice shields.

5.3 Topics Spread

The topics spread of the bibliography is uneven:

topic	references
Artificial Naleds	34
Economic cost of Naleds	17
Freshwater Biodiversity	9
Groundwater	9
Tectonics	5
Forests	1

Global coverage is heavily skewed in favour of economic issues. Of the 34 articles on 'artificial naleds', nearly all are on civil and military methods of how to form naleds for ice bridges across frozen rivers to allow passage of cars, trucks and tanks; how to create ice runways and ice roads particularly in the Arctic regions of North America; and how to thicken Arctic sea ice sufficient to support oil and gas rigs without the need for expensive offshore platforms.

In Alaska, naled ice shields have long been investigated by engineering geologists, for instance the formidable naleds along the Alaska Highway route in WWII [96] and again with the construction of the Trans-Alaska Pipeline route [122]. Even more serious were the naleds encountered by Soviet engineers constructing the Baikal-Amur-Railway (BAM) in Siberia leading to massive delays and huge cost overruns sufficient to imperil the stability of the Soviet Union [38,42,43,49,51,59,60,68]. Even today, the BAM naleds are a major source of concern to engineers. Such difficulties stimulated applied research in naleds in permafrost regions of the world.

Several articles deal with the potential of using naleds as indicators of fracture zones of importance for mineralisation in Alaska [125] and Siberia [41]. Other articles draw attention to the value of naleds as indicators of ground-water seeps, springs, or streams with perennially flowing water [91,136].

The presence of naled ice shields in an Alaskan drainage basin *"tends to stabilize river discharge in the same way as a glacier does, by providing melt water during hot dry periods"* (Li and colleagues 1997) [109].

While many articles deal with the geomorphologic role of naleds in permafrost regions and downstream of glaciers, few examine the role of naleds in biodiversity. Those that do, focus mostly on the impact of naleds on freshwater fisheries and the geomorphology of river floodplains in Arctic regions. Little attention has been paid to the positive role of naleds as sources of water for pastures, livestock and wild mammals in arid regions. An important exception are papers by Polish scientists [159,160,161,162,163] that draw attention to the potential of naled ice shields in irrigating pastures, based on fieldwork in the Khangai Mountains of Mongolia.

Although many articles draw attention to the relationship of naleds to permafrost, none suggest the potential of artificial naleds to strengthen permafrost or to tackle urban heat islands of high-latitude cities.

Finally, no article was found mentioning the potential of naleds for ice sport tourism on lowlands in summer.

5.4 How Naled Ice Shields Form

The literature review revealed a broad consensus on how naled ice shields form, as summarized below with comments by the author.

In essence, naled ice shields form by the *"successive freezing of sheets of water"*. In a frozen-over river, three different sources of sheets of water are generally available to flow over the surface ice [142]:

- discharge through fractures in ice.
- discharge along stems of trees etc protruding through ice.
- seepage from channel banks.

In addition, less common possibilities exist to enable sheets of water to flow across the ice surface:

- water discharging from pingos [173].
- water from side streams flowing across the ice.
- effluent discharge from treatment plants (figure 6).
- effluent discharge of water from industrial plants.
- cooling water discharge from heating plants (figure 7).
- geothermal springs [173].
- saline springs.
- tidal flows.
- surges of meltwater.

Figure 6. sheet of cool water on a naled ice shield
Water flowing across a naled ice shield on the Tuul River floodplain. The water is warmed by effluent from the Ulaanbaatar Water Treatment Plant. (photo: Robin Grayson)

Figure 7. sheet of hot water on a naled ice shield
Water flowing across a naled ice shield on Sharin Gol ('Yellow River') in north Mongolia. The water is a daily pulse of hot water effluent from a heating plant. (photo: Robin Grayson)

A fresh sheet of water can be added artificially (e.g. by pumping, flooding or spraying) and some artificial ice skating rinks are a type of naled ice shield.

Natural naled shields grow for many reasons, as summed up by Sloan, Zenone and Mayo (1976) [122]: *"The complex interaction of several factors, rather than a single factor, controls the incidence of icings. At any site, topographic, geologic, hydrologic, and meteorological factors determine the dynamics, regime, and magnitude of the icing process."*

Figure 8. naled ice shield in Alaska
Geologist measuring a thick naled ice shield formed near the Alaska Pipeline Route. (photo: C.E. Sloan and colleagues 1997, courtesy of US Geological Survey USGS)

The distinctive layering of an ice shield (figure 8) has been noted by many authors, but detailed descriptions are scarce. In the literature survey only Hideki Narita and colleagues (1997) [186] illustrate ice layers in thin section (low power in crossed polarized light):

- large columnar ice grains: in a thick layer which does not contain many air bubbles - forms from water pools on the surface of the ice shield and freezes slowly.
- spherical ice grains: in a thin layer - forms when water flows on the surface of the ice shield and freezes gradually.
- fine ice grains - in a layer containing many air bubbles - forms if new snow covers the ice shield, and water flowing on the ice shield infiltrates the snow and freezes.

Creation of naled ice layers involves substantial energy exchanges. This has been investigated by Xiaogang Hu, Wayne Pollard and John Lewis (1999) [142] for ice layers of a naled in the Yukon:

- thick layers of overflow - ice layers require a longer time to freeze completely due to greater latent heat stored in larger water volumes. Milder air temperatures will slow growth even further. Under such conditions, flowing water between the top ice cover and the underlying ice body provides significant amounts of energy. As much as 60-87% of the energy may be supplied by running water.
- colder temperature conditions - faster growth rates reduce the duration of water flow, so reducing the relative amount of energy supplied by flowing water. In this case energy is provided mainly by the latent heat released by the freezing of water contained in the overflow layer.
- solar radiation - under certain conditions, absorption of solar radiation adds a considerable amount of energy, released mostly through sensible and radiative heat losses.
- latent heat - during formation of an ice layer, latent heat is the least important accounting for 6-17% of total heat loss.

Consensus exists that naled ice shields form on river AFTER the river has iced over. River ice in northernmost Canada is rarely as much as 2 metres thick, yet when converted to a naled it can be 4 to 5 metres thick. In Siberia the maximum thickness is 10-12 metres [32].

Generally water continues flowing below the ice shield. The author suggests this is analogous to phreatic streams in cave systems where the phreatic passages ('tubes') are completely filled with water to the roof. If the flow slackens then the hydrostatic pressure drops and the ice roof is liable to warp downwards, crack and partially collapse. Conversely if the flow increases then the hydrostatic pressure rises, doming the naled roof into hummocks of ice that may split open allowing the pressurised water to escape.

When a naled starts to disintegrate, channels may be carved in the top of the ice shield by meltwater. The channelling can be severe enough to cut through the ice shield [172], especially if under-melting has occurred, as photographed in the Canning River of Alaska (figure 9):

Figure 9. naled ice shield in Alaska
Meltwater having carved a channel on a naled ice shield breaks through to the underside and drains as a vadosic tunnel. The photo is of a large naled ice shield discovered in summer 1910 on the Canning River by the Canadian-American Joint Expedition. (photo: Leffingwell 1910, courtesy of the US Geological Survey)

The author speculates that channelling would be sufficient to liberate trapped water from a phreatic tube, the liberated water forming a fresh layer of ice on top of the naled. But the literature survey was unclear on this point. More likely the channelling would puncture the phreatic tube at several points, so allowing water to drain downstream and converting the phreatic tube into a vadosic tube. This seems to have happened in 2010 in Orkhon naled ice shield in Mongolia (figure 10):

Figure 10. breached phreatic tube in a naled ice shield
A breached phreatic tube revealing a stream. The remnant of the phreatic tube is now a vadosic tunnel, as the water no longer touches the ice roof. The ice roof may have been breached by melting, sublimation, abrasion, loss of hydrostatic support, and/or loss of strength of the ice. (photo: Jim Reichert, World Bank)

In Alaska, large naled ice shields are reported to commonly have "*uplifted ice ridges, broad humps, or smaller conical domes*" and *"the pressure is relieved as water bleeds out through radial or circular cracks"* (Sloan et al 1976) [122]. This may release *"a sheet of water"* that then freezes over the ice resealing the hole in the roof.

More dramatic consequences ensue if fresh ice forms inside the phreatic ice tube sufficient to impede the water flow. The author suggests fresh ice may line the phreatic tube if a temporary slackening of the water flow occurs, but this scenario was not encountered in the literature. Fresh ice can accrete be on the underside of the naled roof, the side-walls of the tube and even on the floor of the tube, even by settling of frazil ice from supercooled water.

If the flow resumes then the hydrostatic pressure spikes. Analogous to a heart attack, the ice roof bulges upwards, cracks and finally bursts, releasing a massive flood of water that spreads out across the frozen surface of the stream. The flood freezes, so turning the frozen surface into a 'naled ice shield'.

For a while, the situation is calm, but the ruptures in the roof of the phreatic tube have now been re-sealed under a fresh layer of naled ice. Deprived of a 'safety valve' the hydrostatic pressure of the confined water in the phreatic ice tube again soars to a critical level, heaving the ice roof and once more a sheet of water pours out when the ice cracks. Repeated *"successive freezing of sheets of water"* builds up a naled ice shield far thicker than possible by simple freezing over of a stream.

Each time a naled is thickened in this manner, the added weight may cause the ice shield to press down on the phreatic water and increase the hydrostatic pressure sufficient to trigger fresh eruptions of *"sheets of water"*.

Figure 11. small ice hummock
A small ice hummock in the naled ice shield on the Tuul floodplain downstream of Ulaanbaatar, Feb 2010. (photo: Robin Grayson)

Figure 12. small ice hummock
Nick Grayson trying to open the crack. (photo: Robin Grayson)

Figure 13. large ice hummocks
Large hummocks on a naled ice shield near the Alaska Pipeline. (photo: C.E. Sloan et al 1996, courtesy of US Geological Survey)

Figure 14. Exploded ice hummock
Formed on a large ice shield on the Orkhon River in Mongolia. Trees have been uprooted and soil ejected. (photo: Jim Reichert)

Figure 15. wrecked ice hummock after exploding
A breached hummock in the Yolin Am Naled Ice Shield in the Gobi Desert of Mongolia. The hummock appears to have exploded to release over-pressurized water confined in a phreatic tube below. (photo: Joergen Hartwig, Projekt-Consult GmbH)

An extreme case occurs whenever water freezes solid to the bottom of a stream channel (Sloan et al 1976) [122]. Then the cracking of ice and eruption of water and the formation of a naled is almost inevitable. A more mundane, but more likely, scenario is that freezing over a stream is rarely a neat or synchronous process, and so the resultant phreatic tube is likely to be rather irregular and consequently the hydrostatic pressure is locally abnormally high enough to trigger an eruption of naled water. For instance, trees may protrude though the ice; floes and logs may accumulate; gravel beds may shift; and sand may erode the walls of the ice tube.

Figure 16. river naled squatting on floodplain
Floodplain and forest invaded by naleds on the Tuul downstream of Ulaanbaatar. (image: Google Earth - 31st March 2006)

A different genesis of some Alaskan naled ice shields is suggested by Sloan et al (1976) [122]: *"As ice freezes downward, pockets of water may become isolated. The volume expansion that results from the freezing process in these pockets sharply increases the hydrostatic pressure."*

Yet another origin is reported [122], *"pressure in icings can result from accumulations of entrapped gas, such as air or methane. Pockets of gas under pressure have been discovered by drilling into domes that show no evidence of overflowing water. Occasionally, relief of gas pressure can occur suddenly and explosively, resulting in displaced and shattered blocks of ice"*.

Abnormally large naled ice shields commonly form on Alaskan braided streams as *"the channels are shallow and readily frozen."* [122]. The same authors assert that thick naled ice shields *"can be the cause of braided channels by diverting flow during spring breakup and also by inhibiting plant growth on the flood plain."* This is also the normal situation in Mongolia, with naled ice shields tending to aid the creation of the wide braided floodplains. Once a large shield has clamped itself across a braided floodplain, then the surge of spring melt-water from upstream is often diverted to the very edges of the floodplain, so refocusing its erosive energy on widening the floodplain by eroding the foot of the adjacent mountain. Prior to recognising the decisive role of naled ice shields in creating, sustaining and widening braided floodplains, the author had assumed that such wide floodplains could never be produced by such diminutive streams. With the annual assistance of naled ice shields, it is not only possible but probable.

A characteristic of the naled-prone braided floodplains of Alaska and Mongolia is the cleanliness of the gravel where the naled ice shields tend to form. As noted by Sloan et al (1976) [122], this may in part be due to the physical presence of the ice shields *"inhibiting plant growth on the floodplain"* at least in spring. In addition, it seems likely that the confinement of flowing stream water in a confined phreatic ice tube will encourage the water to accelerate and scour away of mud and silt to leave a lag deposit of clean gravel.

On large rivers in Alaska, naled ice shields *"are not common on large rivers where the flow is confined to a narrow or single channel because of the greater channel depth"* [122]. In contrast, naled ice shields *"form readily along small, single, shallow channels in those areas where winter streamflow is sustained by ground water."* This is also evident in Mongolia.

Large springs are the source of major naled ice shields in *"some river valleys*" in Alaska [122]. This is also seen in Mongolia, particularly as the semi-arid climate means stream flows are low, and therefore the impact of a large spring is emphasised.

Small springs and seeps of ground water form small upland or hillside naled ice shields in Alaska [122]. These are particularly important in Mongolia due to the general lack of water in spring for livestock, forests and pastures in spring. The aridity of Mongolia renders these - and larger - naled ice shields starkly visible in the field and in high-definition satellite images such as Quickbird and Geo-Eye presented in Google Earth.

Figure 17. disintegrating naled ice shield
Rotational failure in summer due to erosion by water in a phreatic tube that collapsed. (photo: Jim Reichert, World Bank)

Figure 18. disintegrating naled ice shield
People inspecting a large naled ice shield on 22nd May 2010 that formed in winter on the floodplain of the Orkhon River and survived into summer. (photo: Jim Reichert, World Bank)

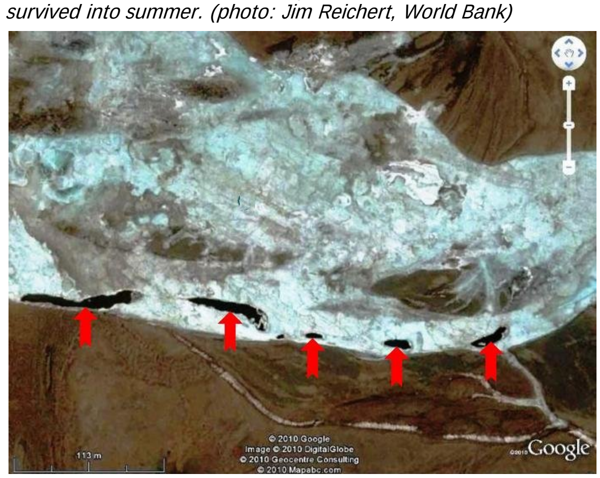

Figure 19. phreatic tube in disintegrating ice shield
Unroofed phreatic ice tube containing water (red arrows). Tset floodplain, Mongolia (image: Google Earth - 9th March 2004)

5.5 Survival of Naled Ice Shields

The literature review revealed a broad consensus on how naled ice shields survive, as summarized below with comments by the present author.

Naled ice shields may survive at least for some weeks into summer, while all other forms of ice and snow are likely to have disappeared. Snow vanishes quickly by melting and sublimation, especially in arid regions such as Mongolia characterised by thin snow and dry air. Streams rapidly cease to be iced-over due to melting, sublimation, cracking, thinning and liberation of floes of ice.

In polar climates, many naled ice shields are able to survive through to the following winter.

The most famous, and possibly the largest permanent naled ice shield is the Ulakhan-Taryn on the Moma River in Yakutia, Siberia. This naled ice shield is between 70 and 110 km^2 in extent, is often 5-7km wide and about 40km long, and the ice is as much as 7 metres thick. In the harsh climate of Siberia this naled ice shield, like many in other permafrost regions, is permanent. Although diminishing, enough ice survives the short summer to await regeneration next winter.

To survive the summer, a shield must be thick enough to withstand the loss of ice due to melting (ice>water) and sublimation (ice>vapour). The loss of ice is assumed to be greatest due to direct solar heat, but considerable losses may also occur from dry air, warming by contact with flowing water, physical erosion by silt-laden melt-water, and warming by underlying gravel and rock. Melt-water channels incised into the top of the ice may carve down through the shield to its base in a short time, encouraging calving of rotational blocks of naled ice when the shield loses its structural integrity.

In the midst of all these destructive processes, 'repairs' of holes and cracks may occur overnight if sub-zero temperatures prevail.

A large ground-based and airborne study of naleds reported by Topchiev (1978) [68] in Abakoumenko and Usachev 1983 [6]) determined the *"general process"* of naled formation and destruction in Siberia as follows:

- formation interval - the area of a typical naled ice shield increases approximately 2.5 times quicker than its volume, since the freezing water flows widely over the ice surface. About 50% of the maximum area and 20% of the maximum ice volume form during this interval.
- middle of cold interval - the rate of increase of naled ice volume and area equalize. The ice shield area increases by about 35%, and its volume by 30%.
- end of cold interval - the naled volume increases 3 times faster that its area.
- later warm intervals - the area and volume of the naled ice shields diminish at about the same rate.

In Mongolia, Lomborinchen (1993) [163] asserted naleds to be *"widely distributed"* in northern Mongolia and to be mostly *"seasonal (one year)"* but with some *"perennial"* naleds. The perennial naleds are *"seldom seen"* but one example observed by Lomborichen in Renchinlhumbe Sum, Hovsgol Aimag was *"at maximum 500 metres in width, 1.2 kilometres in length and with ice cracks 2.0 to 2.5 metres in width"* [163]. The thickness of the ice was not reported.

In the middle of the Gobi Desert, throughout the very hot summer, a permanent naled ice shield is a source of wonder and an important tourist attraction. The ice in Yolin Am is referred to in the literature as 'permafrost' which is a misnomer, being a permanent naled ice shield ON TOP of the ground. As yet, no investigation has been made to verify if the ground beneath the naled is permanently frozen. The author suggests this is unlikely, as the naled ice shield is very narrow and much of its width is underlain by a phreatic ice tube whose trapped water would deter freezing of the ground below.

Figure 20. a permanent naled ice shield in the Gobi
The Yolin Am Naled Ice Shield in the Gobi Desert in summer. Ice survives in spite of melting and ablation. (photo: Joergen Hartwig, Projekt-Consult GmbH)

Figure 21. water under a permanent naled ice shield
The Yolin Am Naled Ice Shield in the Gobi Desert in summer. Ice survives in spite of melting and ablation, including under-melting from the vadosic stream tunnel. In winter the ice tunnel is stronger and becomes a phreatic ice tube that traps water. Over-pressurized water then creates ice hummocks which rupture releasing sheets of water over the ice. Freezing of the sheets of water increases the thickness of the ice shield. (photo: Joergen Hartwig, Projekt-Consult GmbH)

5.6 Naled Ice Shields and Glaciers

According to the literature survey, naled ice shields are found associated with glaciers in many regions of the world. Such naleds are commonly fed with water from the snout of glaciers, and are accumulate on the braided outwash plains. However, these naled ice shields, albeit often permanent, are rather small compared to many river naleds and spring naleds. As reported for Greenland by Ole Humlum and Harald Svensson (1982) [191], naleds are rare in areas with supposedly cold glaciers but common in areas with temperate glaciers. This phenomenon is reported worldwide, and can be attributed to the essential requirement of meltwater IN WINTER to create a naled ice shield. Cold glaciers may release copious meltwater in summer but naleds cannot form in warm weather.

5.7 Naled Ice Shields and Carbonates

The literature survey shows naled ice shields are often associated with carbonate precipitates, notably forms of calcite and dolomite. Fieldwork in Spitsbergen by several research groups [173, 174, 175, 176, 177, 179, 180, 181, 184, 185] emphasise cryo-chemical precipitation of calcium carbonate is frequently associated with both glaciers and pro-glacial naled ice shields. Several workers present evidence for chemical fractionation leading to precipitation of calcium carbonate from supersaturated bicarbonate waters associated with glaciers and naleds.

Such chemical fractionation can probably account for the large tonnages of carbonate deposited by naleds annually in Spitsbergen as calculated by Elżbieta Bukowska-Jania (2007) [176]. A similar mechanism is suggested by researchers in Canada, USA and Siberia.

Although similar studies have been conducted on naleds in Mongolia, it is tentatively assumed that carbonates will be found with them.

In the arid Gobi Desert, where the climate is sharply continental characterised by very hot summers alternating with severe winters, it is conjectured that the tonnages of carbonate that are precipitated by crypto-chemical fractionation during naled waxing and waning may be exceptionally large, sufficient to contribute to the production of ubiquitous carbonate 'caliche' soils of the Gobi, Gobi-Steppe, Steppe and Forest-Steppe climatic zones. These soils are characterised by prolific 'dropstones' created by encrustation of the undersides of pebbles, cobbles and boulders by whitish-buff calcium and magnesium carbonates.

If confirmed, this will complement the widespread production of pedogenic carbonates evident in several thousand 'soda lakes' that characterise these climatic zones in southern Siberia, Mongolia, Inner Mongolia and parts of the Tibet Plateau. Many of these lakes are ephemeral and upon shrinking or drying out an exodus of wind-borne carbonate-rich dust is observed, so *"liming the desert"* across vast regions.

By such mechanisms the soils of these climatic zones are buffered against acid rain and acid mine drainage (AMD), and have become enriched in a wide range of trace elements, including locally uranium and fluorine.

5.8 Geophysics and Ice Shields

5.8.1 Ground-penetrating Radar (GPR)

GPR has successfully used in the field by Heather Best, James McNamara and Lee Liberty (2005) [87] to detect unfrozen water under river ice at 10 sites along the Kuparuk River and its main tributary, the Toolik River in Alaska using 250 MHz and 500 MHz antennas to image both the ice-water interface and the river channel in late April 2001, when daily high temperatures were consistently below freezing and river ice had attained its maximum seasonal thickness. The river ice consisted of normal floating ice plus naled ice shields, including *"bedfast ice"* [87] attached to the river bed.

5.8.2 UHF Short-Pulse Radar

Helicopter-borne ultra-high frequency (UHF) short-pulse radar has been successfully deployed by the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) to detect water under naled ice shields in Alaska. The equipment consisted of *"a Xadar control unit mated to a GSSI Model 3102 antenna unit mounted off the skids of a Bell Long Ranger helicopter"* [79,80]. Details of this equipment and its operation for river-ice surveying have been discussed by Arcone and Delaney (1987) [81]. The output is a graphic transect resembling a seismic line consisting of thousands of echo scans where darkness is proportional to signal intensity and the vertical axis is proportional to time of return of the pulses. The helicopter flew very low altitude, typically about 4 metres above the ice at a flight speed of about 5 metres/second. Valuable results were obtained in spite of fluctuations in altitude and helicopter clutter being apparent in the radar data.

5.9 Remote Sensing of Ice Shields

5.9.1 Aerial Surveys of Ice Shields

Naled ice shields typically form in harsh winter conditions and therefore are most conveniently studied by remote sensing coupled with limited fieldwork.

Abakoumenko and Usachev (1983) [6] summarise experience showing the optimum period for making aerial surveys of naled ice shields is the second half of spring, *"a period when snow has melted but [naled ice shield] dimensions are still close to the maximum for the given year"*. However, the authors caution that this is complicated *"due to the non-synchronous melting of snow cover at different altitudinal zones."*

In Siberia, the key factors for aerial surveys in studying naled ice shields are as follows (adapted from Abakoumenko and Usachev 1983) [6]:

- Surveys should be done at the optimum time when naled ice shields are highly developed and contrast with the surrounding landscape.
- A survey should be made simultaneously over a watershed.
- Photographs should overlap to allow stereoscopic viewing.
- The quality of aerial survey imagery should be high enough for naled ice shields to be accurately recognised and for its extent to be determined.
- Near-infrared camera should be added to recognise meltwater streams associated with the naled ice shields.

5.9.2 Conventional Aerial Photographs

Naled ice shields often show up well on conventional air photographs, including old black-and-white prints. This is not only because naleds are white, but also because even seasonal naleds survive into early summer long after the disappearance of snow that is also white. A good example is a survey of 3 study areas in Greenland by Ole Humlum and Harald Svensson (1982) [191] that detected even small naled ice shields by examining 1:50,000 and 1:150,000 scale vertical air photographs.

Many countries such as the Russian Federation and Mongolia have extensive coverage by black-and-white vertical air photographs acquired 30 years or more ago. These archives are a 'treasure chest' for environmental studies by enabling long-term climate change to be detected when compared to modern satellite images.

5.9.3 Airborne Multi-Spectral Cameras

As early as 1978, Topchiev [68] reported the value of multispectral airborne imagery for studying naled ice shields, notably those affecting the BAM railway in Siberia. The imagery was acquired by a multi-spectral space camera (MKF-6) fixed on-board an A-30 plane-laboratory, using 3 spectral bands with effective wavelengths of about 480, 600 and 820 nm for the following reasons:

- 480 and 600 nm correspond to black-and-white photos in the visible spectrum (400-700 nm), allowing comparison.
- 820 nm is in the near-infrared spectrum, so highlighting temperature variations.

The airborne multispectral study area exceeded 42,000 km^2, recorded 1,112 naled ice shields and determined their areas and basic properties.

5.9.4 Airborne Synthetic Aperture Radar

A three-frequency, fully polarimetric imaging radar called AIRSAR was successfully used to study river ice in the vicinity of Fairbanks in Alaska in 1988 [286]. AIRSAR was a version of the NASA/JPL Airborne Synthetic Aperture Radar (SAR) and flew on the National Aeronautics and Space Administration's (NASA's) McDonnell Douglas DC-8 platform. Rae Melloh and Lawrence Gatto (1990) [286] highlighted the following:

- possible to differentiate between hummocked ice covers.
- C- and L-band data are more sensitive than P-band to the range of surface roughness encountered.
- smooth, level ice that is clear or contains small bubbles produces little backscatter.
- snow-covered river ice, whether rough or smooth, is distinguishable from snow-covered river sediments on exposed river beds and unvegetated bars.
- open water leads are readily distinguished.

5.9.5 MODIS Airborne Simulator

The MODIS Airborne Simulator (MAS) is a scanning spectrometer which measures reflected solar and emitted thermal radiation in 50 narrowband channels between 0.55 and 14.2 microns (specifications). MAS produces image data with 50-metre resolution (at nadir) across a 37-km ground swath from a nominal altitude of 20 km onboard a NASA ER-2 aircraft [286].

5.9.6 Space Surveys of Ice Shields

In 1983 Abakoumenko and Usachev [6] recognised the following advantages of space images in Siberia:

- Blanket coverage allows near-synchronous imaging of naleds across vast regions, a task unrealistic for air surveys.
- Optical generalization of images allows assessment of the main factors in formation of naled ice shields.
- A time series of space images allows collection of data on the formation and melting of naled ice shields.
- Different satellite sensors yield extra data, for instance multi-temporal and multi-spectral images assist determining the genesis of naled ice shields; winter-spring images can assist estimation of waxing and waning of naled ice shields.

Since 1983 advances in satellite image sensors have transformed the detection and understanding of naled ice shields, and enhanced the role of remote sensing specialists over that of aerial photo interpreters.

However, the increased resolution of satellite images such as Ikon, Quickbird and Geo-Eye has created a fresh requirement for aerial photo interpretation skills. For instance, to distinguish naled ice shields from snow patches, ice ridges, frozen lakes and carbonate precipitates, and to recognise naled ice shields in forests or under snow.

In arid regions such as the steppe and gobi zones of Mongolia, the whiteness of naleds and blackness of meltwater highlights them again dry soils during spring after the snow has vanished and before green vegetation has appeared, as illustrated in figure 22:

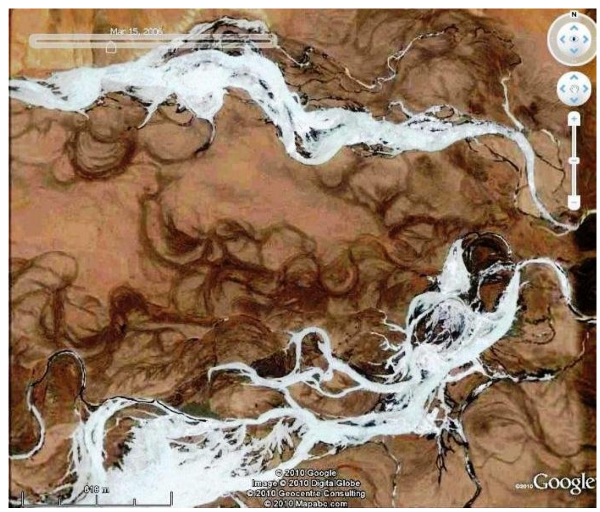

Figure 22. naleds in high-definition satellite image

The scene is of naleds on river floodplains at Tset in Mongolia, showing the ease of detecting naleds in high-definition satellite images that now rival air photos but demand the skills of aerial photograph interpreters. (image: Google Earth - 15th March 2006)

5.9.7 Earth Resources Technological Satellite

Near-infrared ERTS-1 images proved effective in Alaska in pinpointing release of meltwater from naled ice shields. Sloan et al (1976) [122] used ERTS-1 near-infrared images taken on 31st March 1973 and 4th August 1973 to detect and map the *"overflow activity"* of naled ice shields, with meltwater absorbing infrared radiation to appear black in stark contrast to white snow and ice. Detecting some meltwater as late as August helped support the opinion that the large naled ice shield on the Echooka River *"may not melt entirely from year to year"*.

5.9.8 Landsat MSS (Multispectral scanner)

Systematic mapping of Alaskan naleds was completed in 1984 by Kennison Dean [93] of the Alaska Division of Geological & Geophysical Surveys at a scale of 1:250,000 by interpretation of Landsat MSS images acquired during late winter, spring and summer for nine consecutive years up to 1982. The Landsat MSS images allowed residual *"ice sheets"* to be recognised as small as 6 hectares and ranging up to 40,500 hectares (405km^2). The Landsat MSS images also allowed mapping of late-winter outflows of water from the naled ice shields. In addition, braided streams, all considered *"susceptible"* to naled formation were mapped using Landsat MSS images.

Visible-wavelength (band 5) data were used to map residual naled ice shields after spring thaw. These appeared white on band 5 images due to their high reflectance compared to vegetation, soil or rock. Occasionally the ice had a higher reflectance than nearby snow cover. Landsat images recorded in near-infrared wavelengths (band 7) were used to map late-winter naled water flows that appeared dark gray to black due to absorption of these wavelengths by water. The dark signature in the Infrared wavelengths contrasted markedly with the highly reflective snow and ice.

5.9.9 Landsat TM (Thematic Mapper)

Naled ice shields are also clearly visible on Landsat TM images of the British Mountains of Yukon, Canada [282]. Some of the limitations of Landsat TM for studying naled ice shields are discussed by Li et al (1997) [109].

5.9.10 Synthetic Aperture Radar (SAR)

A team of the Geophysical Institute at the University of Alaska used a time series of satellite radar interferometry (SRI) images acquired from January to March 1994 to map changes in naled ice shields near the junction of the Ivishak and the Echooka Rivers in Alaska, *"with promising results"* (Li et al 1997) [109]. They made interferograms of the area from pairs of images acquired by the European Space Agency's First Earth Remote Sensing Satellite in January through March 1994. The study showed naled ice shields can be mapped on interferograms in valleys in which *"the radar phases are poorly correlated and radar backscatter values frequently change"*. The ability of SRI to monitor subtle winter processes of naled ice shields was claimed by the authors to *"fill a major gap in the study of [naled ice shields] by remote sensing."* While this claim is justified for the area studied, it has yet to be demonstrated that this method will prove cost-effective over the vast regions of the planet where naled ice shields are prevalent.

5.9.11 Soil Moisture Active Passive (SMAP) Mission

NASA and partners have developed an instrument capable of distinguishing frozen from thawed land surfaces from an Earth satellite by bouncing signals back to Earth. Details of the instrument are described by Entekhabi and colleagues (2010) [283].

6 Results - Remote Sensing

6.1 Revised geographical spread

The present study detected swarms of naleds in Asia by using high definition remote sensing images on Google Earth. The reader is invited to download a kmz file from www.mine.mn that contains the plotted locations [5]. Even though coverage was small and irregular, the overall pattern is clear (figure 23):

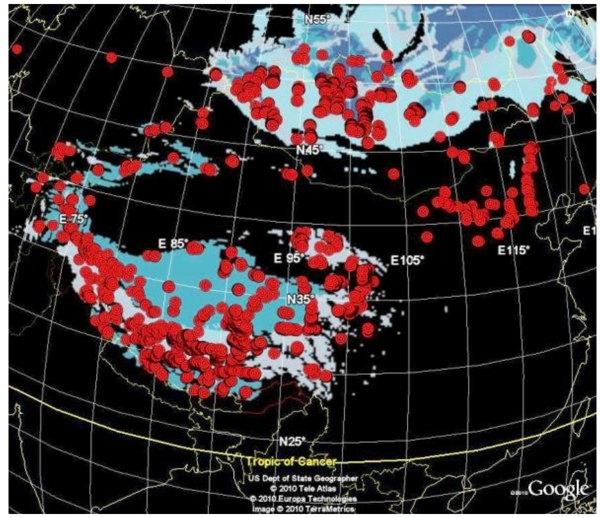

Figure 23. naled ice shields detected in Asia
Each red dot denotes one or more naleds visible on high-definition satellite images. (image: prepared by Robin Grayson)

The study confirms the strong similarity between the distribution of naleds and permafrost (figure 24):

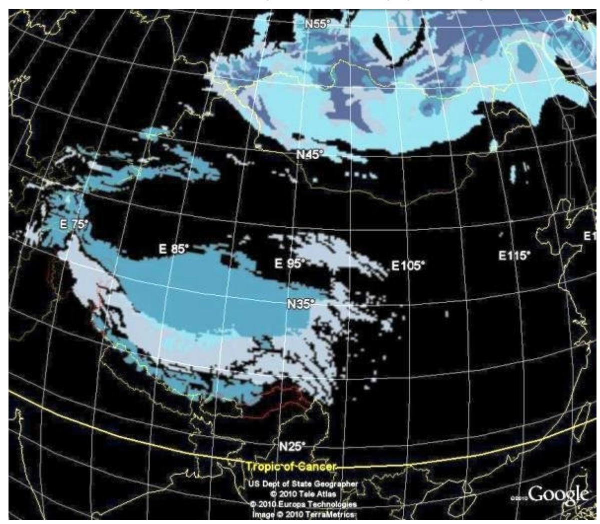

Figure 24. permafrost distribution in Asia
Continuous Permafrost (>90% area) in darkest blue; Discontinuous Permafrost (50-90%) in medium blue; Sporadic Permafrost (10-50%) in pale blue; Isolated Permafrost (<10%) in faintest blue. (image: Google Earth, plus overlay from [4], with black background added).

Closer examination reveals naleds are more widely distributed than permafrost, notably in south Mongolia, Inner Mongolia, near Beijing and possibly in Kazakhstan. While this may indicate permafrost has been overlooked, it suggests naleds can form anywhere with severe winters, regardless of the presence or absence of permafrost.

Figure 25. river naled clamped to a floodplain
Khovd River in Mongolia. (image: Google Earth - 1st March 2003)

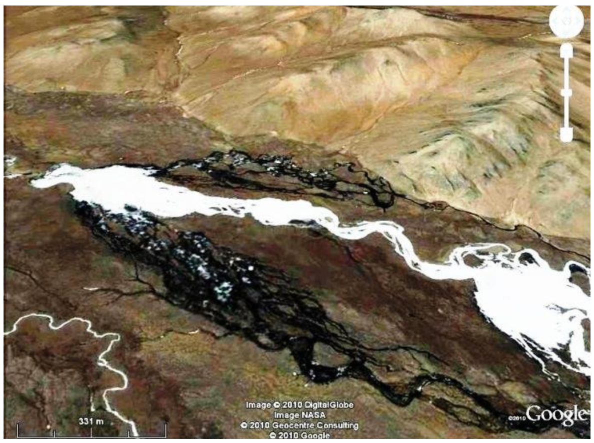

Figure 26. spring naled with overflow water
Frozen spring at Ikh Uul. (image: Google Earth - 9th April 2005)

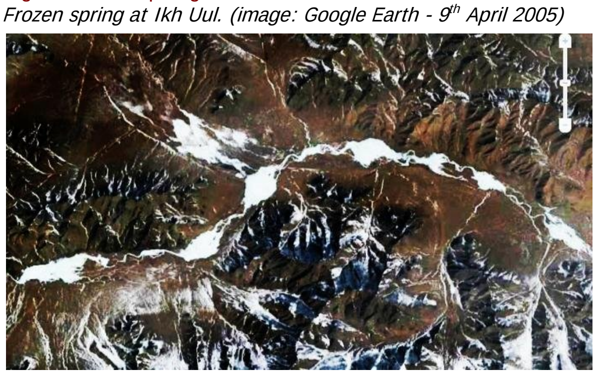

Figure 27. necklace of naleds along major river valley
North-Central Mongolia (image: Google Earth - 23rd March 2003)

Figure 28. naled threatening railway
Naled formed by icing of culvert under Trans-Mongolian Railway, south of Ulaanbaatar. (image: Google Earth - 25th February 2007)

6.2 Accidental Naled Ice Shields

6.2.1 Risk to new mines in Mongolia

Many new open pit mines are opening in Mongolia together with railways, highways and water pipelines. The study shows all are in the 'naled zone', where ice shields - hundreds of metres across, several kilometres long, and several metres thick - may quickly form in a single winter. The study flags up that even in the Gobi the risk exists of an ice shield crippling a mine, road, railway or pipeline. Engineers need to take naleds seriously and learn from the huge cost overruns of the Baikal-Amur Railway (BAM) [201, 202, 206, 214], Alaska Highway [199], Trans-Alaskan Pipeline [213] and the China-Tibet Railway.

It is not only stockpiles that may freeze solid due to icing of interstitial water. Overburden dumps are also liable to freeze over, and in time develop permafrost. Steep north-facing slopes of spoil upon freezing may become 'rock glaciers' that creep unstoppably. Open pit mines require dewatering and protective pumping to keep them free of water. But in winter any water flowing over the ground will transform itself into a naled ice shield that blocks access roads, destabilises pit walls and prevents safe mining. It is naive to assume an ice shield will disappear in summer for many natural ice shields are permanent, with at least one in the South Gobi.

6.2.2 Special risk to open pit coal mines

Open pit coal mines have special risks. Thin fractured perched aquifers commonly issue water from the floor and walls of open pit coal mines. Water is easily removed in summer. But - counter-intuitively - the springs persist even in winter, due to hydrostatic pressure, geothermal gradient and due to warmth from decomposing pyrite (FeS_2) that is abundant in coalfields. Even a small seepage or spring if left unattended for a few weeks can create a naled sufficient to shut a mine for months due to the difficulty of destroying it and safety concerns about frozen pit walls.

Open pit coal mines are prone to large uncontrollable coal fires worldwide, due to spontaneous combustion associated with methane and chemical decomposition of pyrite. As documented by Robin Grayson and Chimed-Erdene Bataar (2009) [2] open pit coal mines in Inner Mongolia, Mongolia and Xinjiang are acutely prone to wild fires. As rule of thumb, the large the pit, the greater the risk and the larger the fire. Large natural wild fires have occurred at Tavan Tolgoi in the recent geological past and are predicted when large-scale mining commences [2].

The warming of the ground by coal fires, and the creation of voids by combustion and collapse, will facilitate the release of warmed water to create naled ice shields even at minus 30°C in mid-winter. Even without combustion, the abundance of methane will, as documented in Siberia and Alaska, create a pressure head sufficient to explode ice from frozen areas of the mine, constituting a danger from rock and ice falls, and liberating trapped water to form yet more naleds.

6.3 Deliberate Naled Ice Shields

6.3.1 Introducing the concept

Over the last half century, technicians have created naled ice shields to solve many engineering challenges in operating in arctic regions:

- How to get a truck over a frozen river [221 to 230].
- How to get a tank column over a frozen river [221 to 230].
- How to build an ice road across swamps [217 to 210].
- How to drill for oil in the Arctic Ocean [235 to 238].

A vast body of scientific knowledge and engineering know-how has accumulated about how to create naled ice shields to improve access in winter to remote locations.

6.3.2 Natural buffer against global warming

The study highlights the value of naled ice shields as natural buffers against global warming. In a harsh continental climate, an increase of a few degrees in winter will have little effect on naled creation. In spring the naleds will release water faster in a warmer climate, and may diminish and disappear a few weeks earlier than at present. But the role of naleds in spring and early summer in supplying pastures, people and streams with water will be largely unaffected. If desertification intensifies, naled ice shields will be increasingly important as oases vital for rural communities and biodiversity.

6.3.3 Reversing loss of permafrost and forests

Using the engineering know-how about artificial naleds as a start, it is reasonable to consider creating naleds for roles other than military and infrastructure.

Reversing the loss of permafrost is one such role. Naled ice shields are known to trigger permafrost. Hence creating naleds is a proxy for creating permafrost directly – and far cheaper.

Vast areas of Mongolia have permafrost at the threshold of thawing, and likely to disappear over a few decades, imperilling the ecosystem of the Taiga Forest.

The EMI-ECOS Consortium has prepared a modest proposal for 'Reversing Permafrost Loss' in the Selbe and Uliastai valleys in Ulaanbaatar city, by reviving existing naleds. It is envisaged that the naleds will strengthen the permafrost below, and yield steady water flow to irrigate saplings that in time would shade the naled and permafrost from the sun. The goal is to create virtuous feedback cycles, not only between the forest and the permafrost (a well-known loop) but also between forest and naled, and between naled and permafrost.

6.3.4 Urban Cool Parks

It is reasonable to envisage growing naleds in winter to create 'Cool Parks' in summer for the enjoyment and health of urban dwellers. The EMI-ECOS Consortium has a proposal for the world's first Cool Park, appropriately in the world's coldest capital city, Ulaanbaatar. The EMI-ECOS Consortium envisage Cool Parks ranging from an informal nature park on the fringes of a city for leisure and biodiversity, to a city centre Cool Park as an icon for a city and as centrepiece of sustainable urban development.

7 Discussion

Of great benefit to arid regions, 'naled ice shields' melt slowly, surviving into spring and early summer to provide vital cool microclimates and yield a steady flow of meltwater for natural irrigation of pastures and drinking water for nomads, livestock, wild mammals and birds.

Large areas of Asia are expected to lose their permafrost due to global warming. Paradoxically, many naleds seem resistant climate change because a temperature rise of several degrees is unlikely to retard their formation in severe winters. 'Unsung heroes', naled ice shields are already vital for humans and biodiversity across large swathes of Asia, and as the summers become hotter and drier, then the importance of naleds will rise accordingly. Mapping and monitoring naled ice shields and measures to protect and enhance them would ensure climate change mitigation for rural communities and biodiversity across Mongolia, Inner Mongolia, the Tibet Plateau and parts of Central Asia.

While climatic modelling and field measurements show permafrost to be losing ground rapidly across much of Mongolia and other parts of Asia, the buffering role of naled ice shields has not been factored into such models. Apart from a naled assisting the local community and environment in climate change adaptation, the same naled can also protect or enhance the local permafrost.

The role of snow in forming glaciers and ice caps is well-known. It follows those regions such as Mongolia that have little snow on the lower ground could never accumulate lowland glaciers and ice caps, albeit that the more snow-prone uplands certainly could and some still do. Intriguingly, the literature survey drew attention to the counter-intuitive role of snow as a thermal insulator able to blanket the land and retard permafrost. A tantalising comment made 37 years ago by Gravis, Zabolotnik, Lisun and Sukhodrovskii (1997) [1] is illuminating: *"Removal of the snow cover, which is usually from 2 cm to 5 cm thick... ...can lead to the formation of pereletoks [icy soil] or even lenses of permafrost".* Penned in Soviet times doubtless as a warning to farmers and engineers, their words have fresh relevance today. If climate change were to reduce snowfall as predicted, then the waning of the thermal blanket of snow would stimulate permafrost to strengthen and spread. This would be a buffer against permafrost thawing from increasing air temperatures. The Soviet permafrost experts [1] warned that in Mongolia's very extensive zone of isolated permafrost, *"destruction of the snow cover can lead almost everywhere to the formation of pereletoks [icy soil] and permafrost".*

Relevant to naled ice shields, the same Soviet permafrost experts [1] stated *"...local irrigation of the suglinok [clayey loams] can lead to the formation of pereletoks [icy soil] or even lenses of permafrost".* This opens the possibility of artificially creating permafrost by pumping a thin layer of water over the ground in early winter, allowing it to freeze solid and then pumping again, pausing only to allow each fresh layer of water to freeze solid with the ice below. In this manner a naled ice shield can form, frozen on top of nascent permafrost.

There is a role for creating artificial naleds to strengthen or restore permafrost, so enabling the local recovery of the Taiga Forest. Conducted on a regional scale, this would be an expensive but practical method of inhibiting the release of greenhouse gases from defrosted peat and forest soils.

As an aside, attention is drawn to the ease of thickening Arctic ice sufficient to resist climate change, by pumping seawater onto the floating sea ice that freezes to create naleds.

Finally, of interest to planetary scientists, the desert naleds of Asia may assist understanding of naleds thought to exist in the harsh arid climate of Mars [195,196] and able to yield water to sustain future space travellers.

8 Conclusions

In conclusion, the author makes a plea for policy makers and researchers to pay more attention to the waxing and waning of naled ice shields as a major issue, and not merely as a curiosity associated with permafrost regions and glacier outflows. In particular to pay special attention to the thousands of naleds that form every winter in Asia far away from permafrost regions, and are vital in releasing water steadily enabling streams to flow even in droughts, providing vital drinking water, irrigating wetlands, forests, pastures and crops, and serving as a natural buffer against regional warming trends.

The study highlights the potential for creating naleds to strengthen permafrost, protect biodiversity from climate change and to create Cool Parks to combat Urban Heat Islands of cities in summer heat-waves.

The study also noted Soviet reports that assert that vast areas of Mongolia would be at risk of permafrost forming spontaneously if irrigated, or if kept clear of snow. Times have changed, and creating permafrost is a priority.

9 Acknowledgements

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