chem13 news special edition

FALL 2022 | NUMBER 452

CHEMISTRY AND INUIT LIFE AND CULTURE

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UNIVERSITY OF WATERLOO | FACULTY OF SCIENCE Department of Chemistry

Message from the Department

On behalf of the University of Waterloo Chemistry Department, I am pleased to present this special issue of *Chem 13 News* on the intersection of Inuit Life and Culture with Science and Chemistry. We have collected and curated the wonderful contributions of Chaim Christiana Andersen, Rosalina Naqitarvik and Prof. Geoff Rayner-Canham over the last several years in a single edition, to promote and present them in a coordinated form, for the benefit of all who want to learn more about the Northern lands, peoples and ways of life through a scientific lens provided by the Inuit themselves. We hope this strengthens both knowledge and appreciation for the innovation, tremendous respect and care with which the Inuit inhabit their climate – a climate that is both seemingly difficult for many of us, and, more worryingly, increasingly under threat. It is through this new perspective I have enjoyed taking in these articles, and a journey I hope each of you will share as well.

PROFESSOR BILL POWER
DEPARTMENT OF CHEMISTRY
FACULTY OF SCIENCE

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TERRITORIAL ACKNOWLEDGEMENT

This special issue of *Chem 13 News* aims to bring light to the chemistry behind the traditional knowledge of the Inuit People. Not included in the Indian Act, the Inuit People hold a separate legal status in Canada from First Nations and we acknowledge their importance in Canada's history.

Inuit Tapiriit Kanatami (Inuktitut meaning "Inuit are united in Canada") is a non-profit organization that represents over 65,000 Inuit across the four constituent regions of Inuit Nunangat (homelands): Nunavut, Nunatsiavut[1], Nunavik, Inuvialuit, and the rest of Canada.

Nunavut was established as a Territory in 1999 after a decision from the Nunavut Land Claims Agreement Act allowed the Inuit people the ability to self-govern.

Nunatsiavut land claim agreement of 2005 provided for the establishment of the Government of Nunatsiavut to represent the residents of the land claim area and any Labrador Inuit living elsewhere in Canada.

Nunavik is part of the administrative region of Nord-du-Québec. The James Bay and Northern Quebec Agreement of 1978 led to greater political autonomy for most of the Nunavik region with the founding of the Kativik Regional Government.

Inuvialuit Settlement Region, located in Canada's western Arctic, was designated in 1984 in the Inuvialuit Final Agreement by the Government of Canada for the Inuvialuit people.

NunatuKavut is a currently-unrecognized Inuit territory in Labrador which encompasses Southern Labrador.

Chem 13 News also acknowledges the traditional Mi'kmaq territory of the Qalipu First Nation on which the Grenfell Campus of Memorial University is situated. Newfoundland and Labrador are located in the traditional territory of the Beothuk, Mi'kmaq, Inuit, and Innu People.

Chem 13 News is headquartered at the University of Waterloo's main campus. The University of Waterloo is located on the Haldimand Tract, land granted in a legally binding treaty to the Six Nations, and within the traditional territories of the Neutral, Anishinaabeg and Haudenosaunee Peoples.

As our issue is being distributed across Canada in recognition of the Second National Day for Truth and Reconciliation, we encourage each of our readers to learn about the local history of the land they live and work on. Reconciliation is a continuous process and requires all Canadian citizens to be invested in repairing the harms of colonization.

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INUIT TAPIRIIT KANATAMI

Logo of the Inuit Tapiriit Kanatami representing the four constituent regions of Inuit Nunangat

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MAP

The Inuit Nunangat (homelands) in Canada.
Adapted from: https://www150.statcan.gc.ca/n1/pub/89-619-x/2006001/4159203-eng.htm

AN INUIT INTRODUCTION

Inuit Nunangat (homelands)

In order to appreciate this compilation, it helps to have a knowledge of the names and locations of Inuit Nunangat (homelands) in Canada. They comprise over 35 per cent of Canada's land-mass. The figure below shows the names of the different homelands: Nunavut, a territory itself; Nunatsiavut, northern Labrador; Nunavik, northern Québec; and Inuvialuit; northern parts of the Northwest Territories and Yukon. In addition, the southern coastal settlements of Labrador, NunatuKavut, are Inuit-claimed lands.

Inuit Nunangat (homelands)
COMPRISE OVER 35%
of Canada's land-mass

LANGUAGES AND DIALECTS OF THE INUIT

Included in the discussions of the Chemistry of Inuit Life and Culture are some of the Inuit terms. To appreciate any culture, it is important to know a little about the language. The language of Inuit peoples, from northern Alaska, across northern Canada, to Greenland, is unique and has no resemblance to any other language. As you can imagine, spread over thousands of kilometres and over thousands of years, the oral language differentiated regionally into different constituent languages. In Canada, Inuktitut is spoken throughout much of Nunavut and Nunavik, though Inuktitut is not unitary but has several regional dialects. Inuttut, a dialect, is spoken in Nunatsiavut, while Inuinnaqtun, a significantly different language, is spoken in western Nunavut.

In these articles, you will encounter singular and plural terms. For example:

INUK **one Inuit person**

INUUK **two Inuit persons**

INUIT **three or more Inuit persons**

In English, we use adjectives to define a noun more precisely (such as light rain, heavy rain, torrential rain, etc.). In the Inuit languages, the way to provide more information is to add-on to the end of the word – hence, making some extremely long words at times!

Some words are common across Inuit lands. For example, a woman's knife is called an *ulu* (plural: *uluit*) from Alaska to Greenland (see "The *Ulu*: Chemistry and Inuit women's culture" – article five). By contrast, the term for aurora is called: *atsanik* (Inuttut); *aqsarniit* (Inuktitut); or *akhaliak* (Inuinnaqtun) (see "The Arctic atmosphere: Unique and amazing" – article seven). We, the authors, hope that as you learn of the links between chemistry and Inuit life, you will also come to appreciate the fascinating and unique language of the Inuit peoples.

THE LANGUAGES OF THE INUUK CO-AUTHORS

Chaim Christiana Andersen lives in Nunainguk (Nain), Nunatsiavut, where Inuttut is spoken. German missionaries settled there and developed written Inuttut using the European alphabet. Thus, the terms she uses in her co-authored articles reflects this background.

Rosalina Naqitarvik comes from Ikpiarjuk - ᐃᒃᐱᐊᕐᔪᒃ (Arctic Bay), northern Baffin Island, Nunavut, which has its own unique dialect called Iglulingmiut. The missionaries arriving in eastern Nunavut came from southern Canada. There, they had devised a syllabic written form of the Cree language. These missionaries used the same syllabic set for a written form of Inuktitut. Thus, Inuktitut can be written in both syllabics and in the European alphabet.

HOW IT CAME ABOUT

FIGURE 1

Chemistry Outreach, 2009, Quqshuun Ilihakvik Junior School, Uqsuqtuuq, ᐅᖅᓱᖅᑑᖅ (Gjoa Haven), Nunavut.

Credit: Geoff Rayner-Canham, used with permission

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SUMMER 2022

How did this compilation on Chemistry and Inuit Life and Culture come to be? A good question! And one which provides important context. This author, Geoff Rayner-Canham, is Professor Emeritus at the Grenfell Campus of Memorial University, Corner Brook, Newfoundland. A significant concern of mine is that, in my view, chemistry is so much more interesting than the endless mole calculations of conventional chemistry courses. I therefore developed a set of household chemistry demonstrations and experiments to take to grade schools across Labrador and western Newfoundland.

On each Outreach visit, I was accompanied by one or two volunteer chemistry students. The presentations were well received everywhere, but the reception was phenomenal in the Inuit schools of Nunatsiavut, the Inuit self-governing portion of northern Labrador. Eager to extend the Outreach to other Inuit communities, I was able to obtain funding for the Chemistry Outreach team to visit schools across Nunavut. The reception was equally enthusiastic in the Nunavut Inuit schools, one example being shown in Figure 1.

Subsequently, I was asked to devise an Indigenous-contextualized chemistry presentation for a group of Inuit and Innu high school students visiting the Grenfell Campus. This proved highly successful.[1] The following year, there was a gifted Inuit student, Chaim Christiana Andersen, from Nain, Nunatsiavut, in one of my chemistry classes. She eagerly agreed to join the Chemistry Outreach team (Fig. 2). During the travels we had many discussions how chemistry really was fundamental to aspects of Inuit life and together we produced a series of articles on specific aspects which would interest the readers of *Chem 13 News*.

Ms. Andersen moved on in life. However, in Winter 2022, I was asked to co-adapt and co-instruct an Inuit-indigenized version of the Memorial University distance course, Chemistry in Everyday Life. This course was for Inuit students attending the Iqaluit Campus of the Nunavut Arctic College. Among the gifted students in the class was Rosalina Naqitarvik (Fig. 3), who grew up in the High Arctic community of Ikpiarjuk, ᐃᒃᐱᐊᕐᔪᒃ (Arctic Bay). Thus, in addition to having a knowledge-base in science and in Inuit culture, she brought a perspective from a very different part of the

FIGURE 2

Chemistry Outreach, 2017, Lake Melville School, North West River, NunatuKavut, Labrador, with Chaim Andersen in multi-coloured lab coat.
Credit: Geoff Rayner-Canham, used with permission

Inuit Nunangat (homelands). Together, we constructed some more broadly-based articles on aspects of Inuit culture to provide a second part of the series.

In contributing my chemistry expertise to this series, I acknowledge that none of it would have been possible, but for the contributions and enthusiasm of my two co-researchers and co-authors: Chaim Christiana Andersen and Rosalina Naqitarvik – my thanks and admiration. I also wish to state my infinite respect for the life and culture of the Inuit peoples of Inuvialuit, Nunavut, Nunavik, Nunatsiavut, and NunatuKavut, and of those Inuit beyond the boundaries of their homelands.

FIGURE 3

Rosalina Naqitarvik in Mittimatalik, ᒥᑦᑎᒪᑕᓕᒃ (Pond Inlet), Nunavut. Credit: Rosalina Naqitarvik

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RAMAH BAY

7,000 years of Indigenous culture – and chemistry

AUTHORS

CHAIM CHRISTIANA ANDERSEN
and GEOFF RAYNER-CANHAM

With this issue of *Chem 13 News*, we have the first in a series of articles on chemistry in northern Canada, focussing specifically on the Inuit context. The unique Inuit life and culture has developed experimentally over thousands of years in response to the challenges of limited material and food resources. And now life is being impacted by new material additions to daily lives (including pollutants).

Chemistry, like all sciences, depends upon definitions. For our own studies, we see the definition of Inuit Chemistry as being: "The molecular basis underlying aspects of traditional and modern Inuit life and culture together with that of the northern environment." It is our hope that this series will make chemistry more appealing and specifically relevant to Inuit youth and also to all Indigenous youth throughout Canada. We hope, too, that all *Chem 13 News* readers will be interested in how chemical principles apply to life in the Canadian north.

If you travel to the far north of Labrador, you will find a mine: no, not the mine at Voisey's Bay, site of one of the world's richest nickel deposits, but way farther north at Ramah Bay (Fig. 1). One difference is that the mine (or more accurately, quarry) at Ramah Bay was first being worked at least 7,000 years ago. What was so prized was a specific type of the mineral, chert.[1] Chert was first excavated at Ramah Bay (Fig. 2) by the Maritime Archaic peoples (ca. 7,000 to 3,500 years ago); then by the Dorset Paleo-Inuit (ca. 2,200 to ca. 600 years ago); and finally, by the ancestors of the modern Innu.

In a previous contribution to *Chem 13 News*,[2] we contended that indigenous students would become more interested in chemistry if they could perceive the links between chemistry and their traditional ways of life and culture. In Ramah Bay chert, there is such a link.

All chemists are familiar with silicon dioxide, which, following melting under extremes of temperature and pressure, crystallizes to form the hard mineral, quartz. Less-commonly known are the aqueous marine deposits of silicon dioxide, generically named chert. Chert consists of beds of compressed microcrystalline silicon dioxide together with small proportions of other minerals.[3] Within the microcrystals, the atoms are arranged in the standard network-covalent diamond-type silicon dioxide structure with silicon atoms tetrahedrally bonded to four oxygen atoms in an infinite lattice (Fig. 3).

Chert was prized by peoples around the world. In fact, chert is one of the 50 substances chosen in the book: *Fifty Minerals that Changed the Course of History*.[4] The mineral was exceptionally useful to early humans for two reasons. First, it is hard, with a hardness of seven

FIGURE 1

Location of Ramah Bay, Labrador

Credit: https://www.heritage.nf.ca/articles/environment/landscape-ramah-chert.php

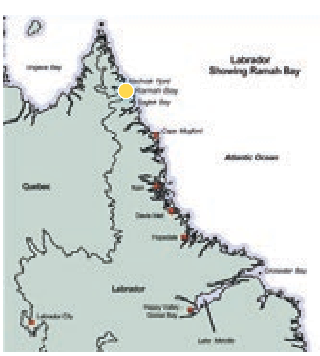


FIGURE 2

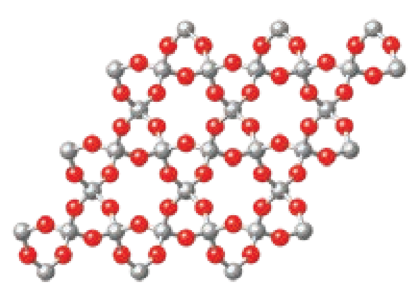
Ramah Bay quarry

Credit: https://www.pc.gc.ca/apps/dfhd/page_nhs_eng.aspx?id=14192

FIGURE 3

Ball-and-stick representation of part of the network covalently bonded structure of silicon dioxide

Credit: https://commons.wikimedia.org/wiki/File:Beta-quartz-CM-2D-balls.png



on the Mohs scale. Second, it conchoidally[5] fractures upon impact; that is, it flakes to give sharp-edged tools.

To fracture network covalent substances, covalent bonds have to be severed. Covalent bonds are strong, and for silicon dioxide, the silicon–oxygen bond is exceptionally strong, as the Table shows, accounting for the hardness of the material.[6]

TABLE Comparative bond strengths

Bond	Bond strength $kJ \cdot mol^{-1}$
O-O	142
Si-O	452
Si-Si	222

In Ramah Bay, there are beds of chert varying in thickness from one metre to three metres. Artifacts made from Ramah Bay chert are found throughout Labrador, and as far away as Quebec, Ontario, Maine, Massachusetts, Vermont, Rhode Island, New York, and even Maryland, Virginia and Michigan. A Ramah chert arrowhead was even found at a Norse settlement at Sandnes in Greenland. The earliest Ramah chert artifact so far identified is approximately 7,500 years old. It was found at a Maritime Archaic peoples burial mound, at L'Anse Amour in southern Labrador, over 1,000km south of Ramah Bay.

There are chert deposits in many places, so why was Ramah chert so highly prized? The answer lies in its exceptional purity of composition and also with its unique colour (hence its ease of identification). Ramah Bay chert has a semi-translucent appearance, near to colourless, usually with dark bands. Chemically, it is 97 to 99 per cent pure silicon dioxide, the small impurity being mostly iron(II) disulfide, FeS_2.[1] Being so pure, the formed chert arrowheads and knives had no structural weaknesses as would happen if they had inclusions of other compounds.

Most chert formations were deposited from the silicon dioxide skeletal remains of tiny marine organisms from about 500 million years ago onwards. However, Ramah Bay chert dates back to at least 1.9 billion years ago. The chert was therefore not biogenic in origin, but purely inorganic. In what way could thick beds of such an insoluble substance have formed? Under extremes of pressure and temperature, silicon dioxide dissolves in superheated water to form silicic acid, simplistically represented as H_4SiO_4 and its conjugate base, $H_3SiO_4^-$.

In fact, solubility of silicon dioxide (as silicic acid) in water increases from 6×10^{-3} g per kg of water at 20 °C to 7 g per kg at 300 °C.[7]

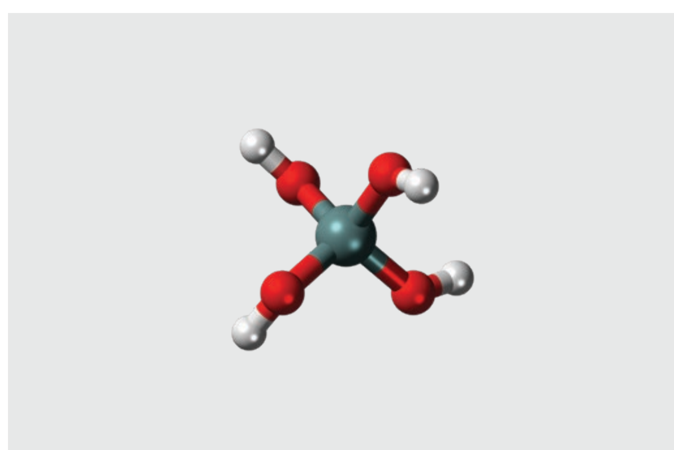
Nearly two billion years ago, the crust was much hotter than it is today, so such near-surface solubilisation is easier to consider. The exceptional purity of the silicon dioxide in the chert would suggest

FIGURE 4

A piece of worked Ramah Bay chert.
Credit: http://www.avataq.qc.ca/en/content/view/full/2220/(page)/1)

FIGURE 5

Ball-and-stick representation of silicic acid.
Credit: https://en.wikipedia.org/wiki/Silicic_acid#/media/File:Orthosilicic-acid-3D-balls.png



that it was a result of solubilisation of a pure quartz intrusion in the igneous rocks under that segment of the then-seabed. Escape of the hot, pressurized saturated silicic acid solution through vents, much like the mid-ocean vents of today, would result in extremely rapid cooling and immediate precipitation as microcrystals:

$$H_4SiO_4(aq) \longrightarrow SiO_2(s) + 2\ H_2O(l)$$

Subsequent burial under seafloor sediments and the ensuing compression would produce this almost-pure, layered, silicon dioxide of Ramah Bay.

When the Thule Inuit (ancestors of the present Inuit) came to occupy the coast about 700 years ago, they preferred nephrite, slate or whalebone for their harpoon heads and cutting needs, as did their descendants, the modern Inuit. Nephrite and whalebone are workable substances as a result of their very different chemical structures from that of chert[2] enabling precise manufacturing of an artifact, rather than relying upon fracturing, as with chert.

For the readers' information, Kijigattalik – the Ramah Bay Quarries – is now a National Historic Site within Torngat Mountain National Park.

ACKNOWLEDGEMENT

Dr. Scott Neilsen, anthropologist of the Labrador Institute of Memorial University, North West River, Labrador, provided helpful comments. Marelene Rayner-Canham is thanked for critical readings of the draft versions.

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[6] The strength of the Si-O bond suggests that it has significant multiple-bond character.

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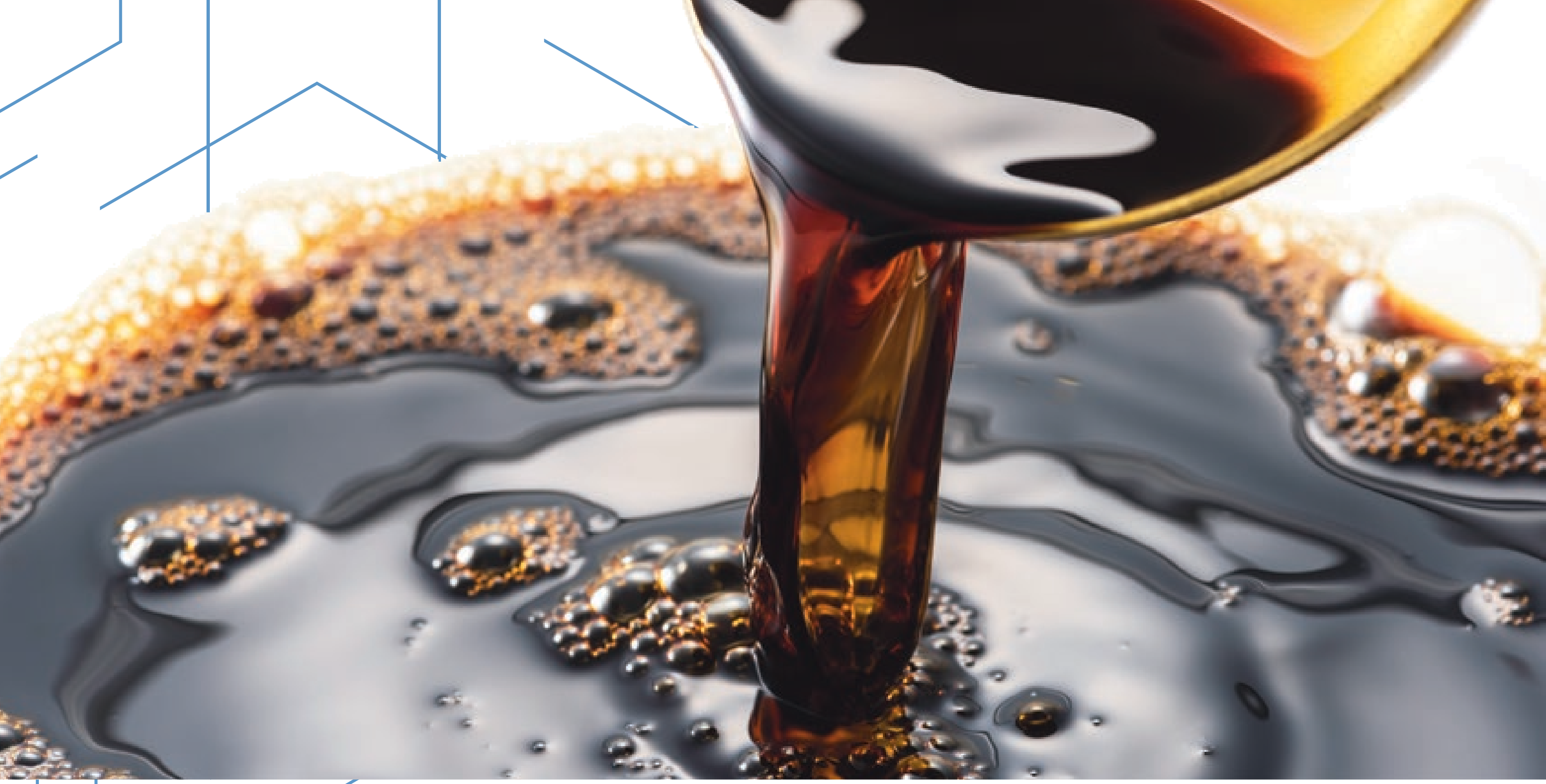


SOY SAUCE

An essential Inuit condiment

AUTHORS
CHAIM CHRISTIANA ANDERSEN
and GEOFF RAYNER-CANHAM

Living and thriving cultures innovate, adapt and incorporate from other cultures. As the next topic in our series on chemistry and Inuit life and culture,[1] we have chosen soy sauce. Though part of Chinese cuisine from way back in the mists of time, it is a relatively recent addition to the Inuit diet and in a unique context: Arctic char, both frozen (*Kuak* in Inuttut) and dried (called *Pitsik*) are dipped in soy sauce.

FIGURE 1

Chaim Andersen with Arctic char.
Credit: Paul McCarney

FIGURE 2

Arctic char, filleted and cut to hang and dry
Credit: C. Andersen

Arctic Char

The Arctic char, known as *iKaluk* in Inuttut, is closely related to both salmon and lake trout. It is native to Arctic and sub-Arctic waters. With bright red to pink flesh, Arctic char can weigh up to 9 kg, though about 5 kg is more typical (Fig. 1).

The flesh of Arctic char contains significant concentrations of carotenoids, hence the red colour (Fig. 2), which are known antioxidants and provide a variety of health benefits.

Even more importantly, Arctic char contain exceptionally high concentrations of omega-3 fatty acids which are vital to good health.[2] Omega-3 fatty acids specifically contain a double carbon-carbon bond three carbon atoms away from the (end) methyl carbon atom. A space-filling representation of eicosapentaenoic acid, one of the omega-3 fatty acids in Arctic char, is shown in Fig. 3.

Soy Sauce

The Inuit have made soy sauce their condiment of choice for Arctic char and other marine food sources. Believed to have been first produced in China about 2,200 years ago, real soy sauce is made from a fermented paste of soybeans, roasted wheat grain, salt water and specific moulds (fungi).[3] The fermentation or brewing process takes about three months. Soy sauce produced by the traditional method is usually identified on the label as having been 'naturally brewed' or 'traditionally brewed' (Fig. 4). The contents of such a sauce are typically: water, soy beans, salt, wheat flour.

Among many other healthy molecules, soy sauce is rich in niacin. Niacin (Fig. 5) is one of the B3 family of vitamins (insufficient niacin in the diet can cause nausea, skin and mouth lesions, anaemia, headaches and tiredness). As an added health bonus, fermentation of soy beans produces a number of antioxidants. In fact, real soy sauce is far richer in antioxidants than red wine.

FIGURE 3

Space-filling representation of the eicosapentaenoic acid molecule
Credit: https://commons.wikimedia.org/wiki/File:Eicosapentaenoic_acid_spacefill.png

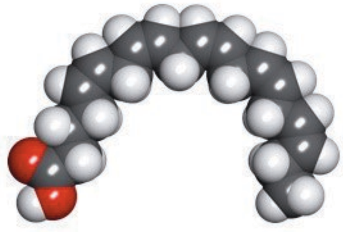
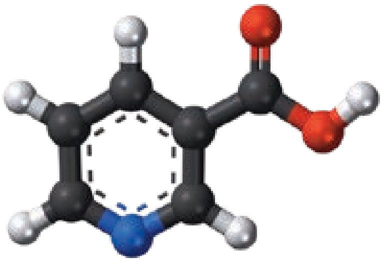


FIGURE 4

The label of a bottle of traditionally brewed soy sauce

FIGURE 5

Ball-and-stick representation of niacin
Credit: https://en.wikipedia.org/wiki/Niacin#/media/File:Niacin-3D-balls.png



Fake soy sauce is everywhere!

Before soy sauce users congratulate themselves on eating healthily, they should realize it is unlikely that they have been consuming brewed soy sauce but instead have been consuming chemically-hydrolyzed soy sauce. Soy-sauce-producing companies do not want to wait three months for each batch: instead, the soy beans are acid-processed as Joe Schwarcz has described:

"The cheaper 'chemical' version can be produced in a day simply by adding hydrochloric acid to a defatted mash of soybeans, followed by neutralizing with sodium carbonate. But this is a brutal method that breaks proteins down to individual amino acids and the resulting flavour and aroma are quite different from fermented soy sauce. Undesirable compounds such as dimethyl sulphide and formic acid are also produced. Absent, though, is the brown colour produced by fermentation products, and this is solved by the addition of caramel colouring.[4]"

In addition, chemically-hydrolyzed soy sauce is high in added sugars. A typical label will note the contents as: water, glucose-fructose, salt, caramel, hydrolyzed soy protein, corn syrup, citric acid and sodium benzoate. There are no health-beneficial compounds produced during chemical hydrolysis. Unfortunately, the only common brand of soy sauce in stores in Inuit communities is that of the chemically-hydrolyzed soy sauce.

An additional concern in consuming chemically-hydrolyzed soy sauce is that the glycerol by-product of soy chemical hydrolysis reacts with hydrochloric acid to produce 3-chloro-1,2-propanediol (3-MCPD)[5] and 1,3-dichloropropane-2-ol. Some imported brands of chemically-hydrolyzed soy sauce contain excessive levels of these probable carcinogens and teratogens (Health Canada has established 1 ppm as the maximum 'safe' level of 3-MCPD in chemically-hydrolyzed soy sauce).

$$CH_2(OH)CH(OH)CH_2(OH)(aq) + HCl(aq) \longrightarrow CH_2(OH)CH(OH)CH_2Cl(aq) + H_2O(l)$$

$$CH_2(OH)CH(OH)CH_2Cl(aq) + HCl(aq) \longrightarrow CH_2ClCH(OH)CH_2Cl(aq) + H_2O(l)$$

Food for thought!

Our message is one of caution for all soy sauce consumers (always read the label – and know some consumer chemistry!). For Inuit, whose diet for thousands of years has enabled them to live healthy lives (a topic for a future article), it is regrettable that one of the condiments incorporated into their diet should commonly be one which is actually unhealthy. For Inuit, we contend, consumer activism is necessary to ensure that healthy foodstuffs are imported to the northern communities. Sadly, 'imitation' soy sauce is the least of Inuit health worries relating to chemical compounds, as we will describe in our next article.

chem 13 news

This article is a reprint from the October 2018 issue of *Chem 13 News*. Read more online:

uwaterloo.ca/chem13-news-magazine

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PFOS

The newest Arctic pollutant

AUTHORS

CHAIM CHRISTIANA ANDERSEN
and GEOFF RAYNER-CANHAM

There is one chemical concept which has become of critical importance to northern peoples: distillation. Yet chemistry students think of the principle of distillation only in the context of a chemistry laboratory, such as the separation of two liquids as shown in Fig. 1.

In the distillation process, a compound of lower boiling point (higher vapour pressure) is preferentially vaporized in the hot flask, the molecules in the gas phase passing down the condenser tube where they revert to the liquid phase and are collected in the receiver flask.

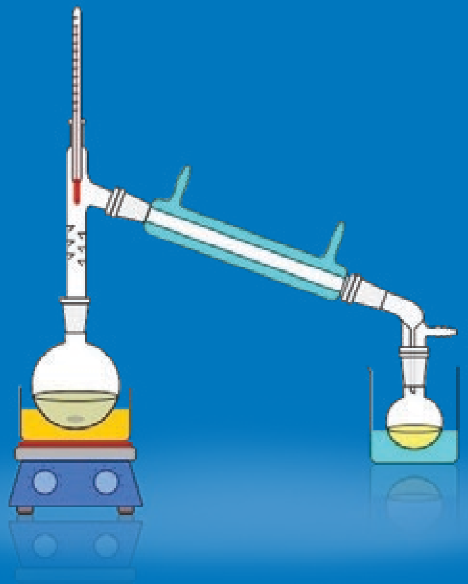


FIGURE 1

A laboratory distillation apparatus

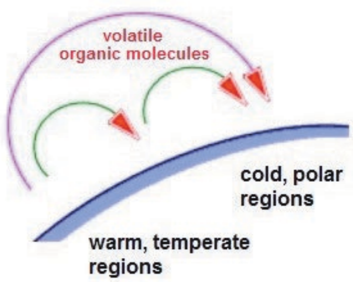
Credit: https://en.wikipedia.org/wiki/Distillation

The Grasshopper Effect (Global Distillation)

The Earth is a giant distillation apparatus. Unreactive volatile organic molecules vaporize from the warmer tropical and temperate regions and then condense in the cold polar regions. This process is known as the Grasshopper Effect, or more scientifically, Global Distillation[1] (Fig. 2).

FIGURE 2

A schematic of the Grasshopper Effect. Credit: Environment Canada. *The Science and the Environment Bulletin.* May/June 1998



POPs: The traditional 'dirty dozen' and more

So which organic molecules are of concern? Most organic compounds naturally decompose in the environment; however, there are many halogen-containing organic compounds which are resistant to decomposition. These are the persistent organic pollutants, POPs.[2] POPs not only persist in the environment but, being of low polarity, when ingested, accumulate in fatty tissues of animals and fish. This phenomenon is known as biomagnification.[3] In turn, when humans eat the animals and fish, the pollutants are further concentrated in our fatty tissues, causing health issues. Of particular concern are the levels of these pollutants in the bodies of Inuit women of child-bearing age as these toxic molecules can cause birth defects and can also be transferred through breast milk into their children.[4]

In the recent past, the 12 most toxic and long-lasting pollutants became known as the 'dirty dozen' though more POPs have since been added to the list. The majority of the compounds are pesticides. Molecules of all of these compounds migrate to the Arctic (and, to a much lesser-extent, Antarctic) where they are concentrated at the low temperatures and pass into the food chain. To stop this problem from becoming worse, in 2001, The Stockholm Convention on Persistent Organic Pollutants[5] was instituted, banning the production and use of the POPs.

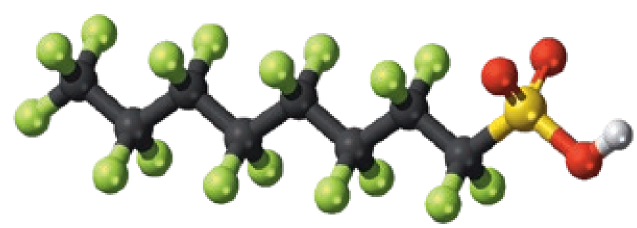
Unfortunately, one of the few countries not to ratify the Treaty was the United States, though that country did ban the original 'dirty dozen'.

PFOS and its relatives: The new hazard

The POPs have infiltrated the environment and been carried to the poles for decades. Now there is a new threat to northern (predominantly Inuit) well-being: the PFOS family. PFOS itself is perfluorooctanesulfonic acid (Fig. 3), formula $CF_3CF_2CF_2CF_2CF_2CF_2CF_2CF_2SO_3H$.[6] The relatives all have the same 'backbone' of fluorocarbon groups, but different functional groups on the end.

FIGURE 3

The ball-and-stick model of perfluorooctanesulfonic acid.
Credit: https://commons.wikimedia.org/wiki/File:Perfluorooctanesulfonic-acid-3D-balls.png



Having a long fluorocarbon chain, PFOS and its relatives are extremely hydrophobic ('water-hating') organic compounds while the polar $-SO_3H$ group on the end adds polarity to the molecule which renders the molecule also repellant to non-polar liquids (oleophobic).

PFOS and its relatives were produced in large quantities and used for over 40 years as a fire-retardant, such as in textiles, upholstery, carpeting and in fire-fighting foams. They were also used as catalysts, insecticides and surfactants. In 2000, the production of chemicals in the PFOS family was estimated to be 4,650 ton.[7] These compounds – especially the fluorocarbon chain part – are extremely resistant to decomposition. This stability is reflected, in part, by the strength of the carbon-fluorine bonds at 485 $kJ \cdot mol^{-1}$, the strongest of any single bond with carbon. In addition, the fluorine atoms are larger than the hydrogen atoms in hydrocarbons, so it is difficult for any other species to get close to the chain to break it. For the same reason, the chain is quite rigid.

In a 1997 review of fluoro-compounds in the biosphere, the PFOS family was dismissed as 'non-volatile' and therefore incapable of dispersing widely and of no concern environmentally.[8] It was only in 2001 that research showed that molecules of the PFOS family were sufficiently volatile that they had spread throughout the surface of the Earth.[9] Extensive research then began, and is continuing, on the levels of the compounds in the Arctic resulting from global distillation. With the belated realization that these compounds were accumulating in the environment, attempts have been made to phase out production but with only partial success so far.

There are no common pathways for decomposition and because of this, PFOS and its relatives will remain in the Arctic environment for hundreds, perhaps thousands of years. Therefore, the phenomenon of global distillation will cause ever-higher levels of PFOS and its relatives to accumulate in the North.

The effect of PFOS accumulation in the Arctic

There are Inuit lands across the Canadian Arctic (Nunangat) from Nunavik and Nunatsiavut in the east, to Nunavut and to Inuvialuit in the west. To access food resources, Inuit depend on their skills of hunting, fishing and gathering. The Inuit rely, in particular, on marine life for survival. Research has shown significant bioaccumulation of PFOS in fish, seabirds and marine mammals.[10] Furthermore, PFOS is found in marine organisms across the Canadian Arctic. Fig. 4 shows the concentration of PFOS and its relatives in seal liver near the communities of Nain (Nunatsiavut); Inukjuak (Nunavik); eight communities in Nunavut, and Sachs Harbour (Inuvialuit).[11]

Using levels of PFOS in seal liver as an indicator was deliberate. Animal liver particularly concentrates PFOS. And it is not just in seals: all food sources, including polar bears, show high levels of PFOS in their livers.[12] In this article, it was commented that

> *PFOS and its relatives will remain in the Arctic environment for hundreds, perhaps thousands of years.*

The high levels of PFOS in liver is of specific worry, for as we will discuss in a future article, liver is a major source of minerals and vitamins in the Inuit diet. And presumably it would selectively concentrate in human livers too.

The health effects of the PFOS family on humans is of extreme concern. The PFOS and its relatives are known to cause cancers, physical development delays, endocrine disruption, neonatal mortality, and low birth size in animals.[13] In a recent study, PFOS accumulation has also been linked to reduced female fertility, decreased sperm quality, low birth rate, attention deficit hyperactivity disorder (ADHD), and changes in thyroid hormone levels.[14] However, some results are inconsistent and further work is needed to confirm initial findings. There is a sense of helplessness as there is nothing Inuit can do to prevent the accumulation of

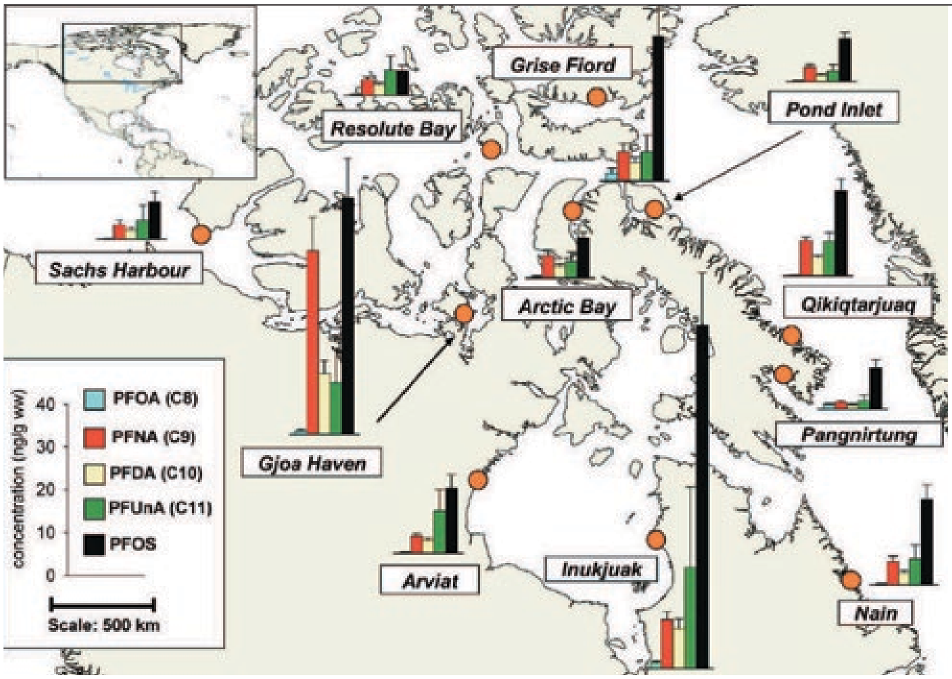


FIGURE 4

(Shown to the right) Concentrations of perfluorooctanoic acid derivatives in seal liver near 11 Arctic communities.

Credit: C.M. Butt et al., *Environmental Toxicology and Chemistry* **2008**, 27 (3), 542–553

PFOS in their food supply. The only long-term hope is for the Canadian Government to keep working towards an international agreement to ban the production of PFOS world-wide.

The importance of environmental chemistry and biochemistry for Inuit

At this time, Arctic molecular pollution monitoring of POPs, PFOS, mercury (another problem!) and other toxic molecules is largely carried out by visiting environmental scientists from more southern locations, though Inuit participation is increasing.[15] It is crucially important that Inuit students become encouraged to study environmental chemistry and biochemistry, particularly analytical methodologies. We hope that in the not-too-distant future, sampling and analysis can be performed by significant numbers of scientifically trained Inuit from across the Inuit regions. And hopefully the analyses can be performed in a large analytical facility in the north, such as in Iqaluit, capital of Nunavut. Perhaps reading our series of articles about Inuit chemistry will provide inspiration to future scientists towards that goal.

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SEA ICE

Essential for northern survival

FIGURE 1

Chaim Andersen going to *imittak* (fetch water), drinking surface fresh water out of a tin bowl on the sea ice. Credit: Mary Andersen

AUTHORS

CHAIM CHRISTIANA ANDERSEN and GEOFF RAYNER-CANHAM

This article is the fourth part in a continuing series on chemistry and Inuit life and culture. Inuit culture is passed down from generation to generation orally, and the use of storytelling is an important function. For this particular article, we consider that such a digression here not only illustrates this, but also provides a linguistically-rich way of showing how essential sea ice is to the very survival of the peoples.

Sikuk (Sea Ice): A gateway to freedom

The Inuit are geographically located in the circumpolar Arctic where temperatures reach extreme cold. Temperatures do not start to climb back up until late spring while the summer months are shorter and cooler than what are experienced in southern Canada. Essentially, then, Inuit live half of their lives in subzero temperatures. So, along with the sometimes elegant and sometimes aggressive snowfalls, sea ice is part of Inuit life for a substantial portion of the year (Fig. 1).

In terms of utilization, Inuit use the sea ice mainly for transportation. For a people who live in isolated Arctic communities, access to the outside is only by very expensive seats on small Twin Otter aircraft or, in the brief summer, by the weekly coastal boat. The ability to travel from their permanent homes to their home on the land is crucial: to go hunting and fishing; to carry out their culture/traditions; and to rid themselves of cabin fever. These are major privileges, among many others, provided by the sea ice. In this way, Inuit can not only provide for themselves, their families and their community, but also heal their mind, their body and their soul. Thus, the sea ice is a crucial infrastructure in Inuit culture, and it is a gateway to freedom across their lands and (frozen) seas.

FIGURE 2

Maria Merkuratsuk and Chaim Andersen.
Credit: Maria Merkuratsuk

A small personal tangent

"There are two times throughout the year where we are stranded in our communities, in the spring when the ice is starting to melt and between fall and winter when the ice isn't formed enough. I have a friend, Maria Merkuratsuk (Fig. 2); she is also an Inuit from Nain, Nunatsiavut (our hometown) and my elder. She has taught me many things about our culture/language and continues to do so through stories of her life growing up. One of my favourites is the story of the "first freeze up". Every year when the ice is finally thick enough to travel on, she and her family (a big one at that) and friends get ready early in the morning to go fishing for iKaluk *(Arctic char) in a place we call Anaktalik. If you've ever seen a bunch of Inuit ice-fishing for* iKaluit *(plural of* iKaluk*) you might think there was a spiritual ritual happening of some sort. It is the most exciting event and one of my most favourite things to do! Everyone is either screaming out "Woo, I got a fish" or "Bugger, I dropped it" although I cannot capture Maria's beautiful and vivid accounts in Inuttitut (our own language[1]). The ice allows us to engage in activities that bring us together, to break free of our town-boundaries. Even just the smell of the air while travelling makes me happy. I always say, and I've always felt in my heart, I am a person of the land and sea, both when it is frozen and when it is not, and I am sure all other Inuit can relate."*

Oxygen solubility in sea water

It may seem odd to discuss the topic of oxygen solubility in an article on Inuit life and sea ice, but it is a crucial component. There are very few food resources on land in the far north, while the sea is rich in fish and mammals. Access to the sea is essential to survival, hence nearly all of the Canadian Inuit communities are on the coast. The prolific sea life is largely dependent upon the high oxygen concentration necessary for the gills of the fish. In fact some species, such as Arctic char (see part two of our series[2]), thrive only in high dissolved-oxygen levels.[3] Oxygen solubility is inversely proportional to temperature;[4] thus the near-zero temperature of Arctic waters provides this marine bounty (see Fig. 3).

Why does ice float?

Outside of the brief warm months, to access the marine food resources, the surface sea ice is essential. Thus the fact that ice floats on liquid water is key to survival in northern Canada. Yet this behaviour is unique to water – or nearly so.

For 'normal' compounds, the solid form is denser than the liquid form. We explain this observation in terms of the Kinetic-Molecular (K-M) Model of Matter: that is, in the solid phase, molecules are locked in fixed locations in the crystal lattice. The molecules vibrate about these fixed locations, with the vibrational energy increasing with increasing temperature. Melting occurs when the vibrational energy exceeds the intermolecular forces between neighbouring molecules. As the molecules become free to move, spaces open up, reducing the bulk density in the liquid phase.

Why is water so different? We must compare the molecular structure of liquid water and of ice (Fig. 4). In liquid water, the molecules are free to move over each other. However, in ice, the water molecules are held in their crystal location by hydrogen bonds at fixed angles to the neighbouring water molecules. How can it expand to form such an open structure? The answer lies with the high strength of the hydrogen bonds (21 $kJ \cdot mol^{-1}$).[6] This rigid open structure means that there are molecule-size channels through the ice, reducing the bulk density to about 0.9 that of liquid water.

Sea water and northern ice formation

Of course, sea water is not pure H_2O: it contains several dissolved ions, as shown in Fig. 5.

FIGURE 3

Worldwide concentration of dissolved oxygen in oceans[5]

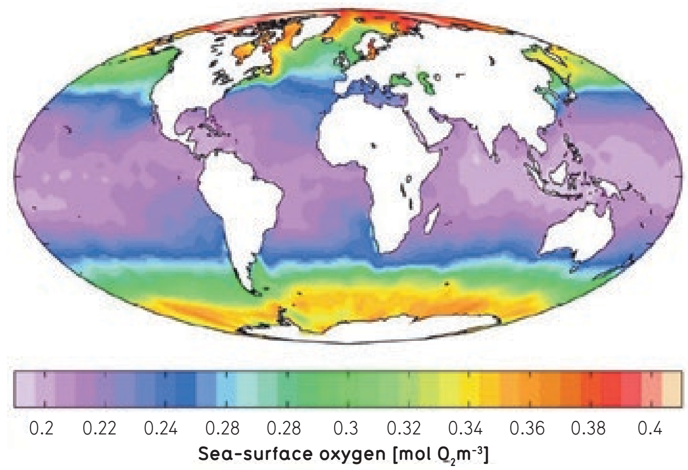


FIGURE 4

Space-filling representations of the structure of liquid water and solid water (ice)[7]

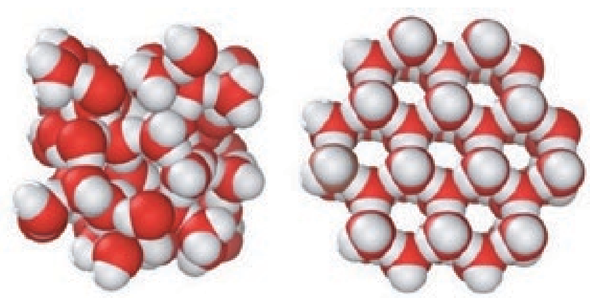
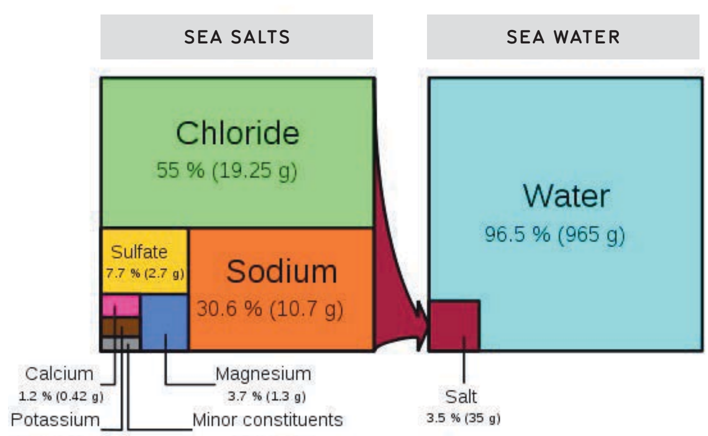


FIGURE 5

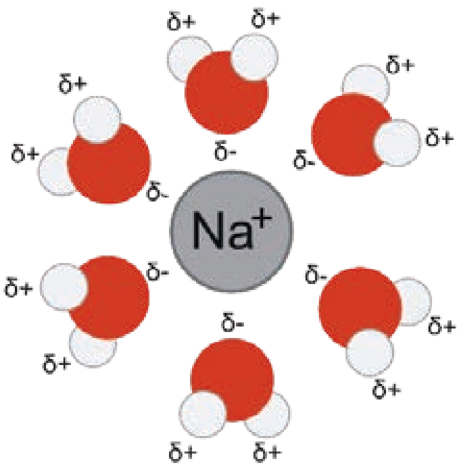
The ion composition of sea water — quantities in relation to 1 kg or 1 litre of sea water[8]



The presence of these ions lowers the temperature of the solid-liquid transition. We can explain this behaviour in terms of the electrostatic interaction between each ion and the neighbouring polar water molecules (Fig. 6). These interactions inhibit the formation of the hydrogen-bonding network amongst the water molecules themselves, lowering the liquid-solid transition temperature to about -2 °C.

FIGURE 6

Clustering of polar water molecules around a sodium ion[9]



In the freezing process for salt water, the molecular vibrations of the water molecules decrease until they are less than the strength of the intermolecular hydrogen bonds. As the water molecules lock into fixed positions, the ions are 'pushed out'. Thus frozen sea ice is essentially fresh water while the water beneath the ice becomes richer in ions (more saline) and denser, thus sinking to the bottom of the Arctic Ocean and driving the deep water currents. In fact, in spring, freshwater pools form on the surface, as shown by Chaim drinking fresh water in Fig. 1.

The worrying future for the Inuit

To southern Canadians, the dramatic reduction in months of ice coverage of Arctic waters is usually discussed in terms of shipping access to the Arctic. It is rarely (if ever) mentioned that the loss of Arctic ice will be catastrophic for the Inuit. If Inuit are unable to travel widely over the sea ice, traditional way of life and the marine harvesting, which provides the basis of their healthy diet, will be difficult, if not impossible, to continue. The resources themselves (particularly Arctic char) are also likely to diminish as warming water will reduce the oxygen concentration of the seas.

PHOTO

Chaim's three-year-old daughter, Avery Andersen, ice fishing.

FOOTNOTE

Chaim Andersen has also been involved in the development of the Labrador Inuit Settlement Marine Management Plan – *Imappivut*.

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THE *ULU*

Chemistry and Inuit women's culture

AUTHORS

CHAIM CHRISTIANA ANDERSEN
and GEOFF RAYNER-CANHAM

FIGURE 1

The two Andersen family *ulok*:
(top) Chaim's paternal grandmother's;
(bottom) Chaim's mother's maternal grandmother's.
Credit: Chaim Andersen

What is an *ulu*? An *ulu*[1] is a multi-purpose cutting tool with a semi-circular blade and a handle. It has been a major part of an Inuit woman's life and culture for at least the last 4,500 years. The *ulu* has a great advantage over a conventional knife, as a physicist or kinesiologist would tell you. With an *ulu*, one is pressing directly down, providing the most efficient force, while a standard knife is held at right-angles to the direction of applied force and at a distance from the cutting blade.

Using knowledge and skills passed down from generation to generation, women use the *ulu* for such things as cleaning skins, cutting up meat for food sharing, filleting fish, making clothes, cutting a child's hair, trimming blocks of snow (see later article in this series) and for a wide range of communal activities. This tool is so central to Inuit life that the same word "*ulu*" is used for it in the diverse languages and dialects of northern peoples, all the way from the Russian Aleut, to the Alaska Yupik, across the various groups of northern Canadian Inuit, to the western Greenland Inuit. Using an *ulu* is one of the ways that Inuit women connect to Inuit culture as well as give back to it, while the *ulu* itself is a unique implement which makes Inuit culture and traditions very rich and very much alive.

Chaim Andersen: the *ulu* and an Inuit woman's identity

In Inuit tradition, it is considered an honour to receive an ulu *from an older female relative. My mom was given two* ulok *(Inuttitut for two* ulu*): one from my* ânak *(paternal grandmother); and the other from her* anânsiak *(maternal grandmother). To clean animal skins, my mom would use the* ulu *given to her by her* anânsiak*. Though she values my* ânak's ulu *greatly, she feels more pride in using something that was given to her by someone who played such an important role in her childhood years. So she uses her* anânsiak's ulu *more often, and it is evident in the size of the blade (the more you use it, the more it needs sharpening; the more you sharpen, the smaller the blade gets). In Fig. 1, the reader can see both* ulok *that, to this day, are still stored in the exact spot they've always been displayed: above the stove.*

Chaim Andersen's *ulu* reminiscences

As a child, I always remember being told never to touch the two ulok *that were stuck up above the kitchen stove, where my mom had dug them into the crevasses of the cupboards and the wall. She has always had them there, where they could remain untouched, where risk of damage was low and preservation was optimal. However, on some days, my siblings and I would come home from school to see her in the middle of the living room hunched over, cleaning a seal skin (*Kisiligek *– to clean a seal skin). The skin was given to her by a family member who had been hunting the previous day. Sometimes, when she would clean two, maybe three skins in the duration of two whole days, our house would smell of seal fat for what felt like weeks. And I knew she would come and ask me to stretch the skin with her – which, I might add,*

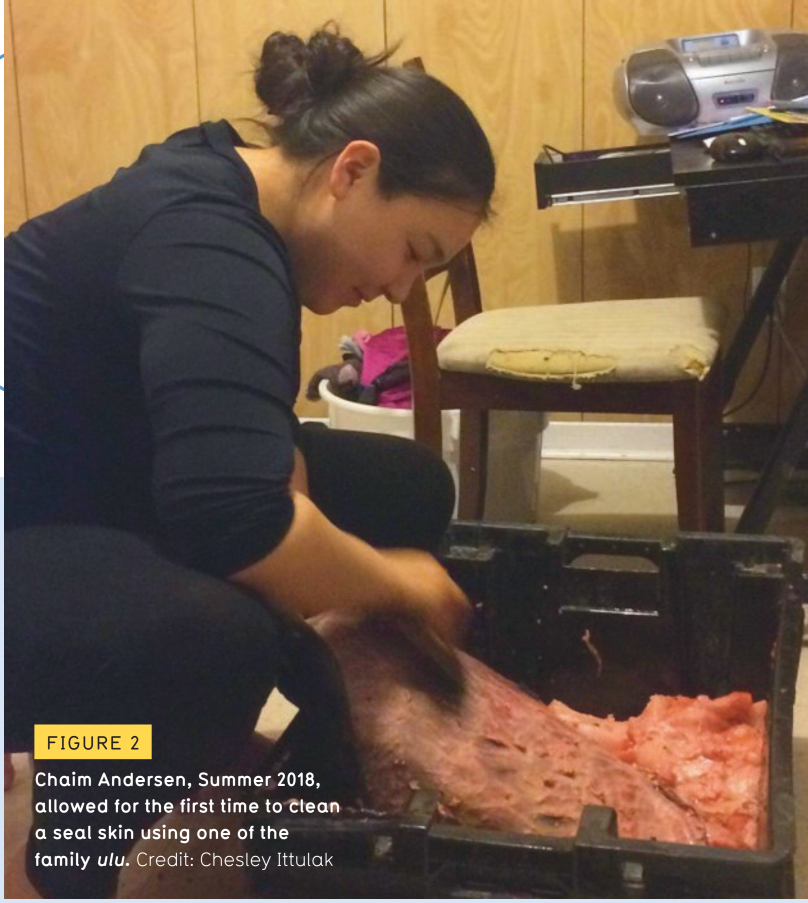


FIGURE 2

Chaim Andersen, Summer 2018, allowed for the first time to clean a seal skin using one of the family *ulu*. Credit: Chesley Ittulak

if you're not used to it, causes your hands to turn into jelly from trying to grasp onto the slippery skin while pulling it tight. But I was always so proud to be her daughter in those moments, and I remember thinking "One day, I'm going to do that with my daughter."

Along with the smell of seal fat, the tired hands and the pride of being a little Inuk girl, I remember asking frequently: "Mom, can I try?" to try to get her permission to help her clean the skin. My mom, with her perfectionistic qualities (positively speaking), no matter how bothered she was with my frequent interruptions, would always answer with "no, you're going to ruin it." At first, I figured how hard could it be? After all, I've watched her time and time again clean a seal skin without flaw. How naïve I was! In the summer of 2018, I finally found the time, had the skin, and with the same ulu *my mom uses, I had the privilege of cleaning my first one. It took me five to six hours! I cut through the skin up to ten times, and in some parts, I left a bit too much fat. Let's just say, my first time was unsuccessful. It takes extreme precision, immense patience, muscular strength, and the inherited knowledge of Inuit women to skillfully clean a seal skin with an* ulu*. Over time, it becomes second nature to do so, and it is a skill that Inuit women must retain in order to honour their female ancestors.*

Ulu chemistry

The handle of an *ulu* has usually been wood, bone, or ivory; three of the composite materials used by the Inuit (see "Composites in Inuit life: What was old is new again", a subsequent article in this series). In this article, we will focus upon the materials used for the blade. Of the surviving historic *uluit* (Inuttitut for more than two *ulu*), slate has been the most widely-used blade material, but as we discuss below, always inventive, where available, the Arctic peoples have long used both iron and copper for this purpose.

Slate-bladed *ulu*

In a previous part of this series,[2] we described how the chert deposits in Ramah Bay were used by early Indigenous peoples to manufacture cutting implements. Chert, almost pure silicon dioxide, has a network covalent structure. When a piece of chert is struck hard by a stone, flakes fracture off (called conchoidal fractures), leaving an uneven, serrated edge to the tool.

Inuit preferred slate for their sharp-edged tools, including the *ulu*. Slate[3] is a very different mineral from chert. Slate has a layer-structure enabling thin sheets to be cleaved off, providing a smooth-surfaced tool which can be ground (and re-ground) to a sharp edge. With a wood, bone, or ivory handle, the slate *ulu* (Fig. 3) was a very proficient tool for its many uses.

Why does slate have this layered structure? Slate was formed in seas from clay and volcanic ash deposits. Buried under millions of years of deposit and subject to heat from the Earth's interior, a series of chemical changes occurred, known as metamorphism. The strong compression caused the ions to reassemble as different minerals with the crystals spreading in the planes at right angles to the compression direction. Thus, the sheet nature of slate is reflective of the molecular/ionic structure.

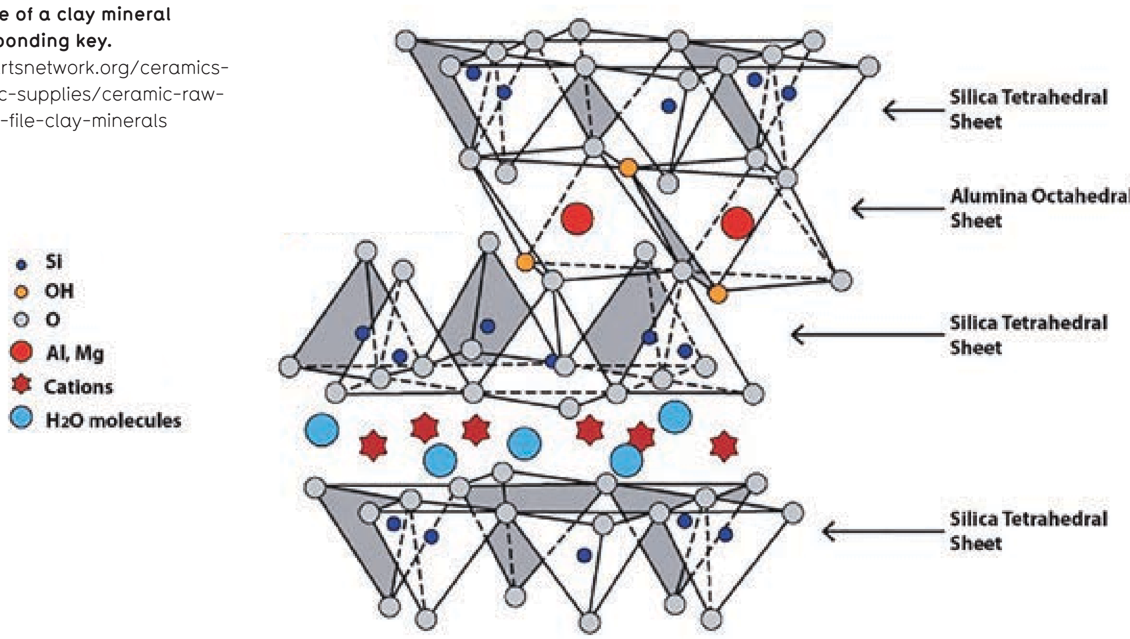
FIGURE 3

Ancient slate-bladed *ulu*, several hundred years old
Credit: Newfoundland Heritage, by permission

The composition of any particular slate depends upon the chemical composition of the clay but an approximate generic formula can be written as: $(K)(Al,Mg,Fe)_2(Si,Al)_4(O)_{10}(OH)_2$. This formula looks very intimidating, but the structure is reasonably

FIGURE 4

Typical structure of a clay mineral with the corresponding key.
Credit: ceramicartsnetwork.org/ceramics-monthly/ceramic-supplies/ceramic-raw-materials/techo-file-clay-minerals



simple (Fig. 4). There are layers of joined tetrahedra with Si^{4+} ions at the centre, surrounded by four O^{2-} ions. Then there are joined octahedra with Al^{3+} at the centre, surrounded by six O^{2-} ions. The large K^{+} cations, combinations of the small Al^{3+}, Mg^{2+}, Fe^{3+} cations, and large OH^{-} anions then fit in spaces in between and balance the charges to make the mineral electrically- neutral. It is the gaps between the layers (shown on the figure where the star-shaped cations and water molecules are located) that provide the horizontal cleavage characteristic of slate.

Iron-bladed *ulu*

In addition to slate-bladed *uluit*, there were once iron-bladed *ulu* which did not have a European origin. How could the Inuit have had iron metal when, in their environment, iron-smelting would have been impossible? The answer lies in Greenland.

About 5,000 years ago, a massive meteorite crashed into western Greenland.[4] After impact, causing a 30 km diameter crater, some of the ejected meteorite fragments fell at Cape York near Savissivik, Meteorite Island, Greenland. The more precise chemical composition of the meteorite is 92.3 per cent iron, 7.6 per cent nickel and traces of other elements. Uniquely, embedded among the alloy crystals, there are crystals of chromium(III) nitride, CrN (Fig. 5).

To account for the metallic composition, we must assume that the meteorite had once been part of the core of a primeval planetoid large enough and hot enough to have a molten metal core.

A subsequent collision with another large body would have resulted in large chunks hurtling through space, this meteorite having been one of them.

As no other meteorite on Earth contains this mineral, iron artifacts can be conclusively identified as having come from the meteorite. From about the mid-eighth century, the Indigenous people used iron from the meteorite to manufacture blades for both harpoons and *uluit*. The archeologist, V. F. Buchwald has commented:

> *Small meteorite fragments in situ are rarely reported because the Inuit for centuries with their unerring and keen observance long since have collected all that was available. … The small fragments were useful because they, on cold working, could be shaped into lanceheads, knives and* ulus.[5]

This cold-working required the use of basalt rocks as hammer stones (the igneous silicate-rich basalt is about six on the Mohs hardness scale while iron is about four to five). Not only did the Greenland Inuit prize iron-bladed tools (including *uluit*) (Fig. 6) but iron from this meteorite has been found across northern Canada.[6]

FIGURE 5

The packing arrangement in chromium nitride (chromium-silver; nitrogen-blue). https://en.wikipedia.org/wiki/Chromium_nitride#/media/File:Chromium-nitride-xtal-3D-SF.png

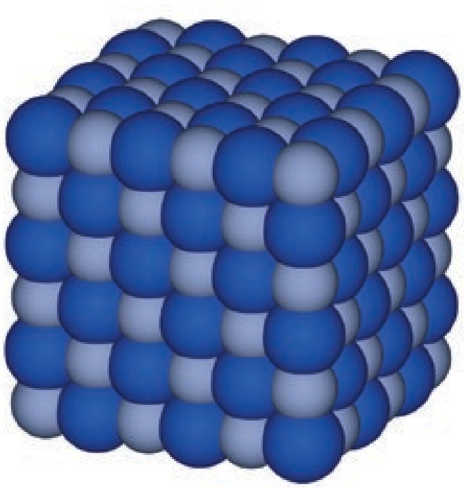


FIGURE 6

Ancient (meteoritic?) rusted iron-bladed *ulu*.
Credit: National Museum of Greenland collection

Artifacts (including *uluit*) made with Cape York meteoritic iron have been found on Ellesmere Island and Somerset Island in northern Canada. There have even been Greenland meteoritic iron objects found south of Hudson Bay, 2,400 km from the Cape York meteorite site, implying the existence of elaborate trade networks.[7]

In more modern times, contact with European explorers and settlers provided a new source of iron. For example, by the 1600s, Inuit were acquiring iron from European fisher-people on the north-east coast of Canada. An iron *ulu* from an abandoned Inuit settlement on the Labrador coast has been dated back to that very early period of European settlement.[8]

Copper-bladed *ulu*

During the spring of 1851, a British expedition to the Arctic on the ship *Investigator* encountered the Inuit of Victoria Island (now part of the Northwest Territories). Much to the crew's amazement, copper was being used for artifacts (including *uluit*). The captain, Robert McClure, commented:

> *… their knives, arrows, needles, and other cutting and piercing instruments were all made of copper … fashioned into shape entirely by hammering. No igneous power [smelting] being had recourse to, it was surprising to see the admirable nature of the work, considering the means by which it was effected, and the form reflected great credit on their ingenuity and excellence in the adaptation of design.*[9]

These Indigenous peoples were using lumps of naturally-occurring malleable copper metal found on the bare rocky surface. The copper had not oxidized, even over millennia. This should come as no surprise to a chemistry student, as copper is near the bottom of the Reactivity (or Activity) series, just above silver and gold of the common metals.[10] In the archaeological explorations of the Victoria Island region, copper *ulu* blades were found to be quite common (Fig. 7).[11]

Called the Northern Copper Inuit[12] by Europeans, in recent times the peoples have been centrally-resettled on Victoria Island at a place the Inuit have named *Ulukhaktok*.[13] The name of the community, *Ulukhaktok*, means "the place where *ulu* parts are found" in the local Kangiryuarmiutun dialect, signifying the importance of the *ulu* in Inuit life.

FIGURE 7

Copper-bladed *ulu* from the copper Inuit region made between 1800 and 1850 (British Museum collection)[15]

The question arises: "How can we be sure an artifact was made from the free element rather than from copper hull-sheathing of abandoned European explorer ships?" Actually, there are two ways. First, the metal crystal grain size is much larger for the free-element copper. This is because the liquid copper, embedded in rock magma, cooled slowly. Smelted copper, on the other hand, cooled very quickly, resulting in small grain size. But there is an even more precise technique: that of elemental analysis. The free copper on Victoria Island was found to be of very high copper purity, while smelted European-source copper contained significant concentrations of arsenic, antimony, nickel and selenium.[14]

From Inuit tool to kitchen must-have

The design of the *ulu* as the perfect cutting instrument has led it to become a must-have modern kitchen implement. For example, Amazon.com, Inc. lists several pages of different commercially-manufactured *uluit*, all with steel blades but with every possible handle-material from birchwood to caribou antler to silicone rubber.

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ACKNOWLEDGEMENT

We think it fitting to dedicate this article to the Inuit women who have used their skills with the *ulu* to contribute to the survival of their people in such a challenging environment for countless generations.

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[13] The Inuit communities are spread across the thousands of kilometres of the northern coastline of Canada. As a result, in each part, the Inuit have specific names for their own location identities (ending with –*miut*) together with their own local dialects and traditions. Thus, the so-called "northern Copper Inuit" now call themselves the *Ulukhaktokmiut*.

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CHEMISTRY OF THE CURE

Case studies of some Inuit remedies

AUTHORS

CHAIM CHRISTIANA ANDERSEN
and GEOFF RAYNER-CANHAM

Before modern synthetic and analytical chemistry, every civilization and culture had to find cures or palliatives for illness and disease from the natural world. We do not know how physiologically active materials were identified, but it was presumably by a trial-and-error basis. In this article, we have chosen to focus upon a few Inuit remedies and show how their action can be linked in many cases to specific, active molecules. But first, we need to give some background.

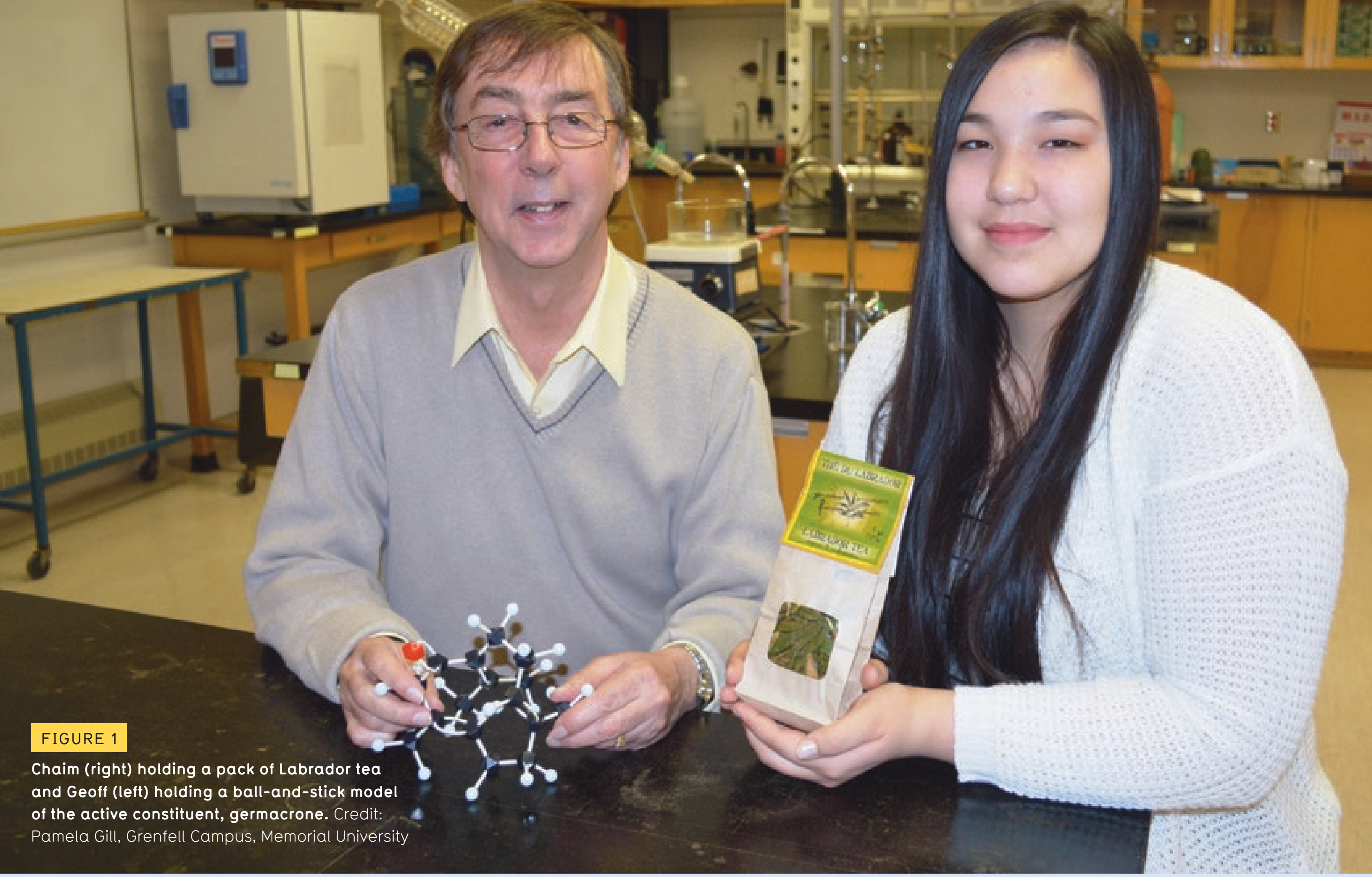


FIGURE 1

Chaim (right) holding a pack of Labrador tea and Geoff (left) holding a ball-and-stick model of the active constituent, germacrone. Credit: Pamela Gill, Grenfell Campus, Memorial University

The essentiality of Inuit remedies – a personal view by Chaim Andersen

Prior to resettlement, Inuit lived nomadic lives and moving with season changes and animal migration was crucial to survival. My ancestors lived in a world where their decisions always had to be certain and consequence would never yield. Wrong decisions or erroneous choices meant certain death. For Inuit, resilience and adaptation were – and still are – great strengths which we possess. Through Elders and experience, just like Inuit women have with uluit,[1] *it quickly becomes second nature to have the knowledge and skills required to maintain a good quality of life. For us, there was no stable settled community and there were certainly no medical facilities, so traditional methods and medicines were the primary form of care.*

For survival, Inuit had to be very healthy people with a varied diet containing all the essential nutrients, including vitamins and minerals (see "Living on the edge: Some chemistry of the Inuit diet" – article nine of this issue). Cautionary measures had to be taken to ensure that food sources would not in any way endanger their health, such as smelling a piece of fish for possible bacterial contamination. Until the arrival of European diseases, such as the Spanish Flu pandemic of 1918 (which killed about one third of the Labrador Inuit), bacterial infection and injuries were the major source of ill-health.

Inuit culture is one of sharing information and caring for each other, and it was women who had the responsibility of tending to an ill or injured person. Inuit women passed down from generation to generation, and between themselves, the knowledge of which medicinal plants can be used, what specific times of the year they should be harvested and what illness or injury they pertain to.[2] *In this article, we will focus on just two of the medicinal plants that Inuit have used for remedies: the Labrador tea plant and the Dwarf Willow tree. We will show that the use of these traditional medicinal sources has an underlying biochemical basis.*

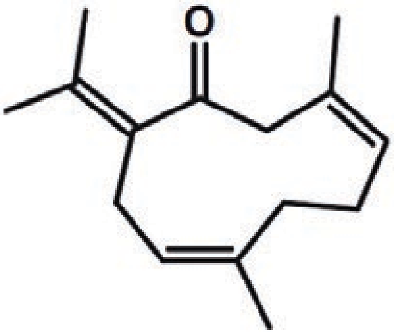
Labrador tea (*Mamaittuqutik*)

Though commonly called Labrador tea,[3] in fact this member of the Rhododendron family is ubiquitous in northern climates around the world. There are, in fact, three different species: northern Labrador tea (*Rhododendron tomentosum*); bog Labrador tea (*Rhododendron groenlandicum*) (Fig. 2); and western Labrador tea (*Rhododendron columbianum*). Labrador tea is sometimes drunk as a herbal tea (tisane), which may not be such a good idea in view of some toxic components of the leaves: in particular, they contain variable concentrations of the poisonous cyclic alcohol, ledol.[4]

What is more interesting for this article is the employment of Labrador tea as an antibiotic.[5] Elizabeth Green Solis, an Inuk of Nain, Nunatsiavut, recalled that, in about 1940, when she was a little girl: "I remember falling down and cutting my leg and my grandmother chewed Indian [Labrador] tea leaves to put on my wound. It didn't even get infected."[6] It is of note that the leaves are usually mixed with oil or fat. For example, the Inuit of Nunavik use it as: "A strong ointment … made by boiling the leaves and mixing them with a little clear fried seal oil and water."[8] Also, there are several references to making an ointment of Labrador tea with seal fat to treat eye disorders.[9] Is there any evidence that Labrador tea really is an antibiotic? The key active compound in Labrador tea is germacrone. The molecule is shown in Fig. 3 as a bond-line diagram.

FIGURE 3

Bond-line diagram of germacrone. Credit: https://en.wikipedia.org/wiki/Germacrone#/media/File:Germacrone_structure.svg



As can be seen from the figure, germacrone is essentially a poly-alkene with one ketone functional group (germacrone is chemically-classed as a terpene). Apart from the ketone, then, the molecule is non-polar and would therefore have very low solubility in water. However, in oil or fat, it would be expected to be highly soluble – hence the importance of seal oil or seal fat in making up the ointment.

FIGURE 2

Bog Labrador tea in flower.
(sp. *Rhododendron groenlandicum*)[7]

Other plant families contain germacrone. It is striking that germacrone-containing plants in Indonesia are also valued for their medicinal properties.[10] There is also evidence of anti-viral properties of germacrone.[11] Finally, why does Labrador tea synthesize germacrone? It has been discovered that germacrone prevents Labrador tea from being eaten by snowshoe hares.[12]

Dwarf Willow (*Amaallinaaq*)

With the very short growing season, harsh climate and very few nutrients in the rock crevices, one response of plants in the Arctic is to become very much smaller.[13] The willow tree is one such example. A member of the willow family grows as a tiny bush in the Arctic environment, between one cm and six cm in height (Fig. 4), and it is called the dwarf willow (*Salix herbacea*).[14]
The Inuit utilized the analgesic properties of this plant, and in a compendium of Inuit medicinal plants, it was reported that: "To ease the pain of a toothache … the peeled root of a dwarf willow is bitten on top of the sore tooth. This numbs the pain … ".[15]

The analgesic properties of parts of the willow tree have been known for thousands of years in the West.[17] Yet isolated in North America since the Ice Age, the Inuit must have gone through the same steps of experimentation independently in order to deduce

FIGURE 4

Dwarf Willow with seed capsules.
(sp. *Salix herbacea*)[16]

its efficacy as a pain-killer. We now know that the pain-killing compound is salicin[18] (Fig. 5) which is decomposed in the human body to salicylic acid, a relative of acetylsalicylic acid (commonly called Aspirin™).

Modern traditional remedies

As we have mentioned previously in this series, a living culture is one which changes and adapts, and Inuit philosophy fits this definition. For example, snowblindness (or more correctly, photokeratitis) is a common problem in the north, even though Inuit have always worn snow goggles when feasible. According to Wikipedia, there is no specific cure for this ailment.[20]

The treatment adopted in recent times by Inuit of the Nunavimmiut is to squeeze the orange oil from orange peel/rind into the eye. As one Inuk commented: "Not truly traditional is it? But it works!"[21] Is there medical evidence? Indeed there is!

FIGURE 7

Rock Tripe growing on a rock (with ice crystals).
(sp. *Umbilicaria esculenta*)[30]

Orange oil contains over 90 per cent of limonene[22] (Fig. 6), a cyclo-alkene (also classed as a terpene). Limonene has been established as a potent anti-inflammatory[23] and almost certainly acts in this way as a treatment for snowblindness.

Commentary

For the Inuit living in such harsh lands, illness has not been an option. Every resource had to be investigated for its potential healing properties. In this article, we have included specific case-studies in which the active molecule is established by modern science and medicine. Are there useful pharmaceuticals yet to be identified in

FIGURE 5

Ball-and-stick representation of the salicin molecule[19]

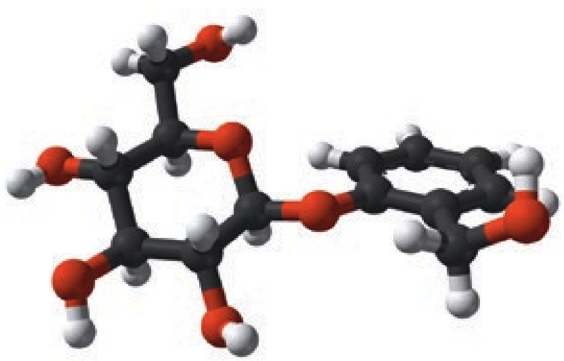
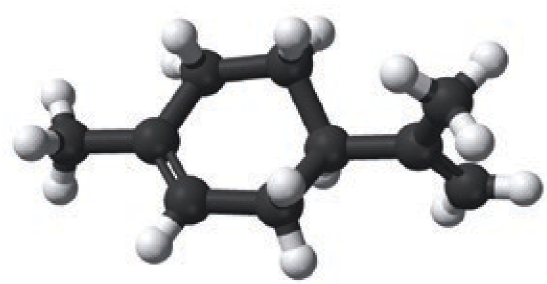


FIGURE 6

Ball-and-stick representation of the limonene molecule[24]



remedies used by indigenous peoples? Tulp and Bohlin consider that there are many novel, naturally-occurring molecules remaining to be discovered: "Nature always has been a valuable source of drugs and, despite the unprecedented opportunities afforded by medicinal chemistry, continues to deliver lead compounds."[25]

Some of these sources may be in the North. For example, another Inuit remedy is a black lichen (*Umbilicaria esculenta*), commonly called Rock Tripe (Fig. 7).[26] According to Inuit knowledge, this: "… can be boiled and the tea is drunk by those suffering from tuberculosis."[27]

Tuberculosis is still, today, a major health issue for the Inuit.[28] As some lichens are known to contain broad spectrum antibiotic compounds,[29] maybe the answer is growing on the Arctic rocks (especially considering Rock Tripe has been used since ancient times for medicinal purposes in China, Japan and Korea).

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THE ARCTIC ATMOSPHERE

Unique and amazing

AUTHORS

CHAIM CHRISTIANA ANDERSEN
and GEOFF RAYNER-CANHAM

The Arctic atmosphere is different. There are specific pollutant problems.[1] There are also unique types of clouds: nacreous and noctilucent. But it is the awe-inspiring aurora that are the most well-known phenomena. For Inuit, the aurora light up the darkness in the long winter nights, and have a profound spiritual role in their culture. To chemists, the chemistry underlying them is of equal fascination and even today, there are still gaps in our knowledge about them.

PHOTO

Aurora, showing the blue and green layers, at sea off Kitlineq (Victoria Island), an island shared between Inuvialuit and Nunavut. Credit: Getty Images

FIGURE 1
Aurora (*Atsanik*) over Arctic Bay, Nunavut, taken on January 3, 2022.
Credit: Mark Long

Atsanik – The Northern Lights

As the reader would know from our previous articles, I (Chaim) am from a small, isolated Inuit community. There are no unfamiliar faces except for the few outsiders who fly in from the south. There are no roads beyond the perimeter of the town. So you can imagine as a little kid (of course, that was when I was mature enough to understand where I was, and how to get home) I had freedom to roam and explore what I thought was my big world as much as I pleased. I remember that little of my time was spent indoors, and anytime I was inside, it was because I was either sleeping or eating, or because my mom had told me to come in. This was the case for most of the children in our community.

For the protection of us fearless, exploring children, our parents would use a method in which they would tell us stories and "legends" about some of the potential threats to our safety. This was done in such a way that it was playful and we enjoyed it, while at the same time making us think very critically about our actions and the possible consequences of those actions. There are various versions of each story told, but all have similar resulting messages. Such parental monologues could range from short stories to – what children would perceive to be – a three-hour lecture. One of the stories told was that of the atsanik *(northern lights), a story passed down through many, many generations of Inuit parents, and probably for thousands of years. The story is meant to keep children from staying out too late during the evening/night – a time that provides great opportunity for risks, and a time that parents prefer their little ones to be inside.*

I was told (in parts) by my grandparents, my older siblings, and my friends, that the atsanik *were a sign of our ancestors coming out to visit, to play, and to enjoy dancing in the night sky while everyone slept. Also, I was told, if you are whistling and playing in the night while they are out, they will become more colourful, more vibrant, and they will dance harder. As a child, this story was a great attention-grabber. I was very excited about the* atsanik*, and the next night I was going to stay up past my bedtime to go and play with the ancestors in the sky. However – and this is the part of the story that made me think very hard about what I was going to do – it was made clear to me that the brighter the lights got, the more they danced around, and the more they would have fun. There was a greater chance of them reaching down, chopping my head off, and using it to play soccer. A very effective method of making sure I was home safe every night! Variations of this story are told to children in every Inuit community from Greenland to Alaska – and probably across northern Russia.[2] The legend has been turned into a beautiful story-book for Inuit children (Fig. 2).[3]*

Science of belief

Growing into my adolescence and early adult years, the belief that the atsanik *would use my head as a soccer ball dissolved, as did my childhood, and as would any other stories I was told as a child. However, the belief that the* atsanik *are our ancestors, dancing in the sky, coming to visit us, is still a part of my life. I believe the* atsanik *have the ability to make us Inuit feel very peaceful, comforted, and connected to each other as well as to the environment, feelings that simply cannot be explained by science: a belief.*

Following from that, I want to express how interesting it has been to discover a world of core science, specifically chemistry, and to learn about the science underlying my beliefs. Throughout elementary grades, all the way up to high school, I was taught that the northern lights were waves of solar energy hitting the magnetic field produced by Earth's gravitational pull. However, it was not until university studies that I learned the chemistry causing the light emissions (of which you will read below). So, being from a place of belief and little knowledge on the concept, and coming to a setting surrounded by scientific information on the northern lights, it has been an intriguing intellectual journey. Another great attention-grabber; but in this case, for chemistry.

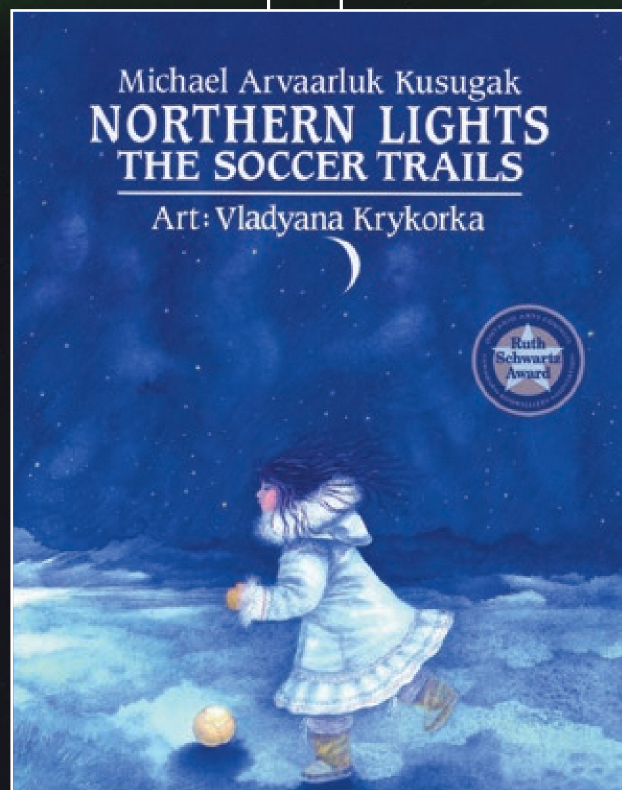


FIGURE 2

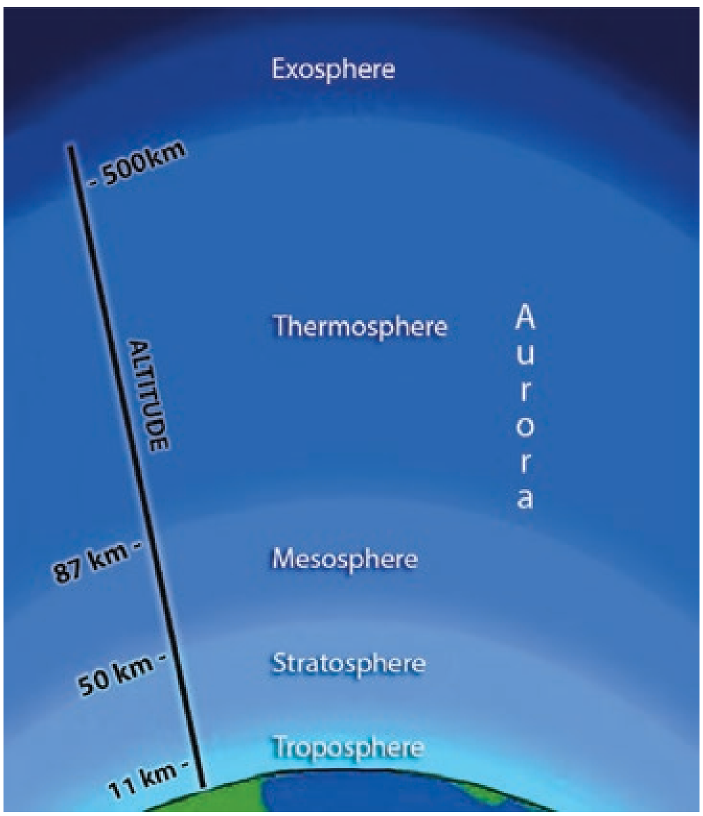
Cover of an Inuit children's book on the *atsanik* legend.

The atmospheric layers

Before we can make sense of the Arctic atmospheric phenomena, we must briefly review the structure of the Earth's atmosphere.[4] Though it looks as if the aurora are just overhead, they are, in fact, at the edge of space: above our own troposphere; above the stratosphere; and even above the mesosphere. They occur in the lower thermosphere, where the atmospheric pressure is incredibly low. These layers are shown diagramatically in Fig. 3.

FIGURE 3

Schematic of the layers of the atmosphere. Adapted from: https://sites.google.com/site/layersofearthsatmosphere

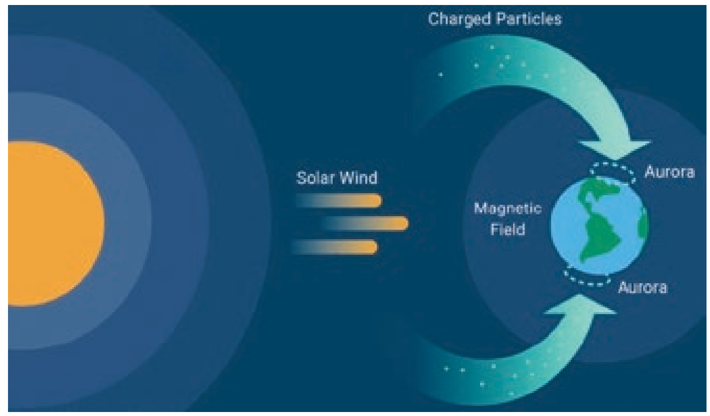


Aurora borealis

Almost everyone has heard of the aurora borealis,[4] the northern lights, or their southern counterpart, aurora australis. However, only those privileged to live in polar regions, like Chaim, really appreciate their beauty. What causes an aurora? As a result of motions within the Earth's liquid metallic core, our planet has a magnetic field. The Sun expels streams of fast-moving sub-atomic charged particles, mainly electrons and protons, which we call the solar wind. The Earth's magnetic field, known as the magnetosphere, deflects most of the particles as they approach the Earth; however, some travel down the polar ring of lines of force (Fig. 4). It is the collisions between these charged particles and the molecules of our upper atmosphere that result in the aurora.

FIGURE 4

A schematic of the solar wind causing the aurora. Adapted from: https://www.timeanddate.com/astronomy/northern-southern-lights.html



The aurora occur mostly between altitudes of 90 km and 150 km, though they can occur at altitudes of up to 1,000 km.[5] The aurora borealis are most intense between latitudes of 10° and 20° from the geomagnetic poles, but during solar storms they can be observed in much more southern locations. In the thermosphere, the atmosphere is so thin that seconds, or even minutes, can elapse between collisions of molecules, atoms, or ions. As a result, exotic species exist for measurable times, and it is reactions involving these that give rise to the aurora.

The most common colour of aurora is green, and the emission is known as the auroral green line. The origin of this emission is as follows. At an altitude of about 90 km to 100 km, dinitrogen molecules are common. A solar-wind particle can impact a dinitrogen molecule, causing an electron in the molecule to be raised to a higher (excited) energy state, which we depict by an asterisk:

$$N_2 + \text{energetic particle} \longrightarrow N_2^* + \text{particle}$$

At this altitude, the dioxygen covalent bond is weaker than the dinitrogen bond (498 vs. 946 kJ·mol^{-1}). Therefore, as a result of the high energy impacts occurring, most dioxygen atoms are broken apart into free oxygen atoms. These free oxygen atoms are then able to react with the excited N_2^* particles. A collision between an excited dinitrogen molecule and an oxygen atom excites an electron in the oxygen atom to a much higher energy state:

$$N_2^* + O \longrightarrow N_2 + O^{**}$$

This energy state only has a lifetime of 0.7 seconds. Since this high energy state cannot be sustained, the electron falls back down to a lower energy level, emitting energy to do so. This emitted energy is in the form of an electromagnetic wave, with a wavelength corresponding to the green part of the visible spectrum:

$O^{**} \longrightarrow O^{*}$ + green photon

The lower-excited energy state oxygen atom has a lifetime of 110 seconds and usually in the intervening time the atom has collided with some other atom or molecule and lost the energy, returning to the ground state of the oxygen atom.

The second most common colour of aurora is red. The auroral red line emission occurs at a higher altitude, typically about 150 km. Up at this altitude, there are free electrons from the solar wind, and the collisions between atoms are so infrequent that excited oxygen atoms have time to lose their energy by photon emission:

$O + e^{-*} \longrightarrow O^{*} + e^{-}$

$O^{*} \longrightarrow O$ + red photon

Then higher still, there is the blue emission. At this altitude, bombarding electrons can ionize dinitrogen molecules (1,503 $kJ{\cdot}mol^{-1}$), leaving a molecular cation with an electron in an excited state. As the electron drops to the ground state, it emits a photon in the blue part of the spectrum.

$N_2 + e^{-*} \longrightarrow N_2^{+*} + 2e^{-}$

$N_2^{+*} \longrightarrow N_2^{+}$ + blue photon

Fig. 5 shows an auroral display where both blue and green are visible.

FIGURE 5

Aurora, showing the blue and green layers, at sea off Kitlineq (Victoria Island), an island shared between Inuvialuit and Nunavut.
Credit: Getty Images

Commentary

Observations of the polar atmosphere provide a special link between Inuit and scientists everywhere. We are all in awe of these amazing natural phenomena. And it is through atmospheric chemistry that we can understand their causes. Yet to Inuit, they are also a spiritual link. Heading back north after time in the south, the sight of the *atsanik* reunites Chaim, and all Inuit, with their people and their homeland.

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uwaterloo.ca/chem13-news-magazine

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SNOW

Making life possible in the Arctic

AUTHORS
CHAIM CHRISTIANA ANDERSEN
and GEOFF RAYNER-CANHAM

In this series, we have shown the importance of ice coverage of the Arctic Ocean for Inuit survival.[1] But equally important, particularly through the long, cold, winters, is the solid crystalline form of dihydrogen oxide – snow. For this article, we will look at the chemistry of snow and its importance in Inuit life.

FIGURE 1

Inuit woman in Okak, Nunatsiavut (possibly one of Chaim's ancestors), packing snow blocks around her house as insulation, photo taken around 1910.[2]

Aputik – snow that fell/ *Kannik* – snow falling

Just like ice, snow is an integral part of our lives for most of the year in the Arctic. I (Chaim)remember as a child, from the first big snowfall until the snow began to melt, myself and my siblings would play outside day and night either making tunnels through the snow and building snow inuksuit *(plural of* inuksuk*), a human-like figure. 'Real'* inuksuit *are made of stone and are usually used as landmarks on hilltops, but we just loved building snow-*inuksuk *and snowmen.*

Snow can be elegant with the big snowflake, light, sparkly snow falls. However, it can also be aggressive with the heavy snowstorms. Whether the snowfall was light on a still day, or heavy in swirling intense snowstorms, nothing stopped my siblings and I from going out and playing in the snow. We loved it and we still do. Snow is essential to our identity.

In nomadic times, snow was vital as a means of providing homes for Inuit. Using skilled techniques, passed down from generation to generation, hard packed blocks of snow were cut and fitted together into domed-shaped dwellings which we call an iglu*. There were three categories of* igluit *(plural of* iglu*) that served different purposes: one made for housing purposes where families would sleep and eat; another which men would construct as temporary shelters while taking long hunting trips away from permanent*

FIGURE 2

Chaim's home town of Nain in the winter. Nain is now the farthest north occupied Inuit community in Nunatsiavut.
Credit: Chaim Andersen

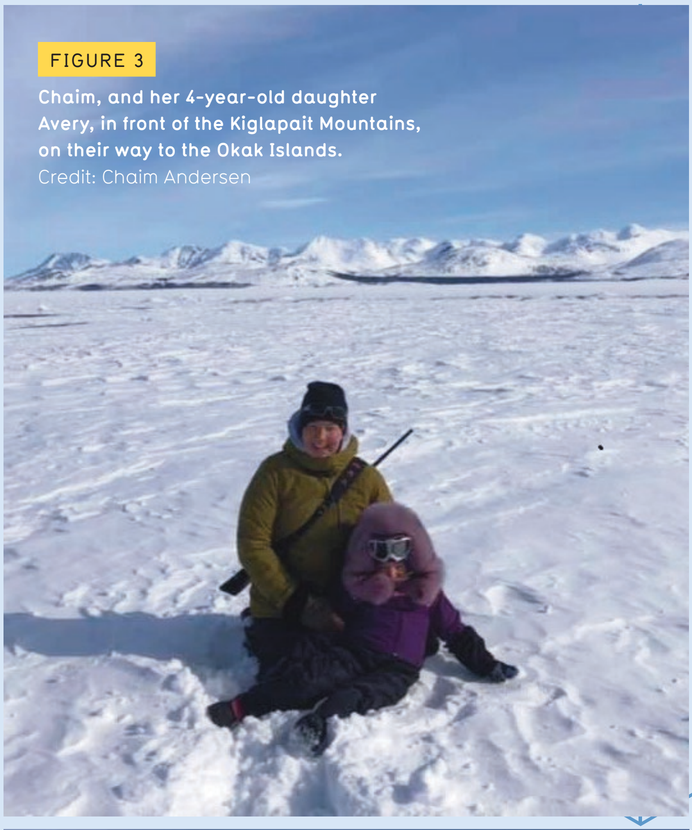


FIGURE 3

Chaim, and her 4-year-old daughter Avery, in front of the Kiglapait Mountains, on their way to the Okak Islands.
Credit: Chaim Andersen

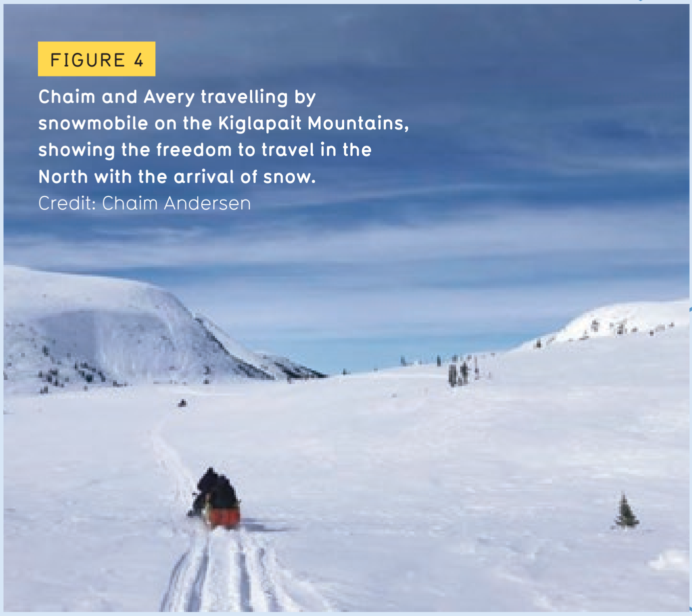


FIGURE 4

Chaim and Avery travelling by snowmobile on the Kiglapait Mountains, showing the freedom to travel in the North with the arrival of snow.
Credit: Chaim Andersen

settlements; and the third type, very large iglu *made for recreational purposes, where the community would gather to play Inuit games and feast together.*

When Inuit transitioned from building igluit *to using cabins and houses, we used the snow instead to pack tightly against the walls to insulate our homes (Fig. 1). Like our ancestors, as children, we delighted in packing snow around our houses to see who could do it the fastest and pack the most. It must have been the easiest chore that I had ever done because the competition between us made it so fun!*

Snow also plays a major role in winter-time travel. Without it there would only be land and ice, which would make for extremely difficult roads. However, because we do have snow, we are able to take our regular travel routes. Historically, Inuit traveled by Kimutsik *(dog team) but today we travel by snowmobile.*

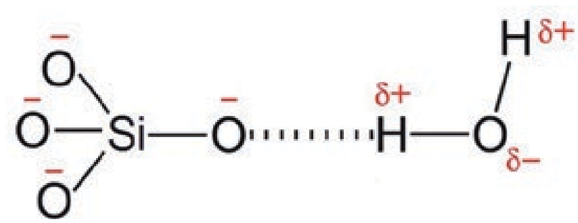
Every year, at least twice a year (once in the summer and once in late winter), my family and I travel to the Okak Islands. These islands are where my grandparents, great grandparents and my ancestors before them lived, until they – and all the northern Labrador Inuit – were forcibly resettled to Nain, farther south, in 1956. When we visit Okak in the late winter, the weather is beginning to warm. It takes approximately four to six hours by snowmobile, mainly across snow-covered frozen ocean, to travel there (Figs. 3 and 4). Every day that we spend in Okak, we go out hunting or visiting old family homesteads.

The nature of snow

How do snowflakes form? High in the cold atmosphere, water molecules in the gas phase lose kinetic energy until the energy is less than the deposition hydrogen-bond energy into the solid phase. However, deposition requires the existence of tiny solid particles (that is, dust) as nuclei. Some of those particles are silicates, containing the tetrahedral silicate ion. The surface oxygen atoms of the silicate particles possess a partial negative charge; thus the partially positive hydrogen atoms of water molecules are attracted to an oxygen atom in the silicate ion, forming hydrogen bonds (Fig. 5).

FIGURE 5

Attraction between a silicate ion and a water molecule by means of hydrogen bonding.



Once this layer is deposited, subsequent low-kinetic-energy water molecules will hydrogen bond to the molecules already on the surface. Layer after layer will form. The formation of crystals usually produces solid structures such as the cubic sodium chloride crystals. Almost uniquely among solids, water molecules crystallize to form very open structures, which we call 'snowflakes'.

FIGURE 6

A colourless transparent snowflake.[3]

FIGURE 7

Not an *iglu*, but a snow-hut, built in Nutak by Chaim and her sisters out of the "old snow" as discussed in the article. Chaim and her youngest sister, Raine, are shown in front. Nutak was another Inuit settlement from which the population were forcibly expelled by the Provincial Government in 1956. Credit: Chaim Andersen

Snowflakes are colourless and transparent, as Fig. 6 shows. It is internal light reflection which causes them to appear white. A snowflake is defined as a single ice crystal which has accreted enough water molecules to descend through the atmosphere under the influence of gravity. A snowfall, then, is the descent from the upper-atmosphere of an incredibly large number of individual snowflakes.

Snow as insulation

As a result of the unique open crystal structure, snowflakes do not pack well together. This phenomenon results in one of the most important attributes of snow: its thermal insulation properties. Chemists and physicists usually report thermal data as thermal conduction, the opposite of thermal insulation. Thermal conduction is defined as the transport of energy due to random molecular motion across a temperature gradient. Thus, a high value of thermal insulation will have a very low thermal conduction (and vice versa).

We measure values of thermal conductivity in units of watts per metre per second. Some values at 25 °C are: air, 0.026 $W \cdot m^{-1} \cdot s^{-1}$; and copper, 384 $W \cdot m^{-1} \cdot s^{-1}$. For fresh snow, the thermal conductivity is about 0.03 $W \cdot m^{-1} \cdot s^{-1}$ which is lower than that of modern house insulation! The reason for the very low conductivity is not the ice crystals themselves, but all the air trapped in between the crystals.

Snow as building material

Inuit are well aware of the insulating properties and construction potential of snow, even though it is through qualitative experience, not numerical values. The powdery, fluffy snow is not suitable for building purposes. However, if the snow is wind-blown, the snow is compacted with the ice-crystals interlocking. This meshing provides mechanical strength while still having a significant proportion of air trapped within. For this 'old' snow, thermal conductivity is typically about 0.4 $W \cdot m^{-1} \cdot s^{-1}$ – still a good value for an insulator.[4] Blocks of old snow can then be used as a building material (Figs. 7 and 8), sometimes carving out the blocks using an *ulu*.[5]

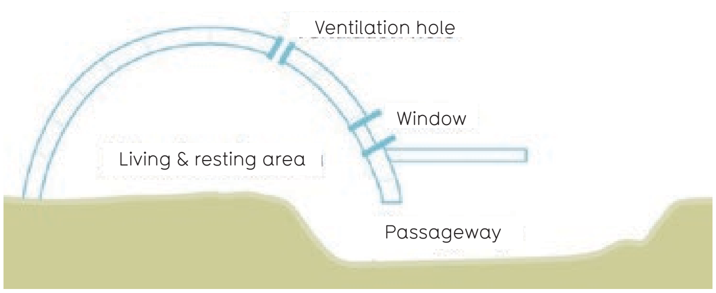
FIGURE 8

An Inuit family constructing an *iglu* using snow blocks, photo taken in 1924.[6]

Snow *igluit* are not spherical, but are built in a shape more closely resembling a paraboloid. The interior of the *iglu* is sufficiently warm that the interior snow surface of the shell melts, then refreezes, forming an ice layer, further strengthening the structure. A correctly-built *iglu* will support the weight of a person standing on the roof. The cross-section of an *iglu* is shown in the schematic below (Fig. 9).

FIGURE 9

Cross-section of a typical *iglu*.[7]



The depression, from which the blocks are cut, usually serves as the base of the *iglu*. A clear piece of ice serves as a window. The entranceway, a short tunnel, is therefore below ground level. This design is of crucial importance. The habitability of the *iglu* relies upon the different density of cold and warm air, warm air being much less dense than cold air (in which the molecules have significantly less kinetic energy). Thus the interior of the *iglu* stays comfortably warm, even when the external temperature is bitterly cold.

Calculation

We can calculate the difference in density of cold air outside (perhaps -30 °C) and warm air inside (often about +20 °C from body heat plus a small lamp).

Density = $\left(\dfrac{\text{mass}}{\text{volume}}\right)$ and here we use the special case of

$$\left(\frac{\text{molar mass}}{\text{molar volume}}\right)$$

The mean molar mass of air can be found knowing the molar composition of dry air as 78.1 per cent nitrogen, 21.0 per cent oxygen, and 0.9 per cent argon.

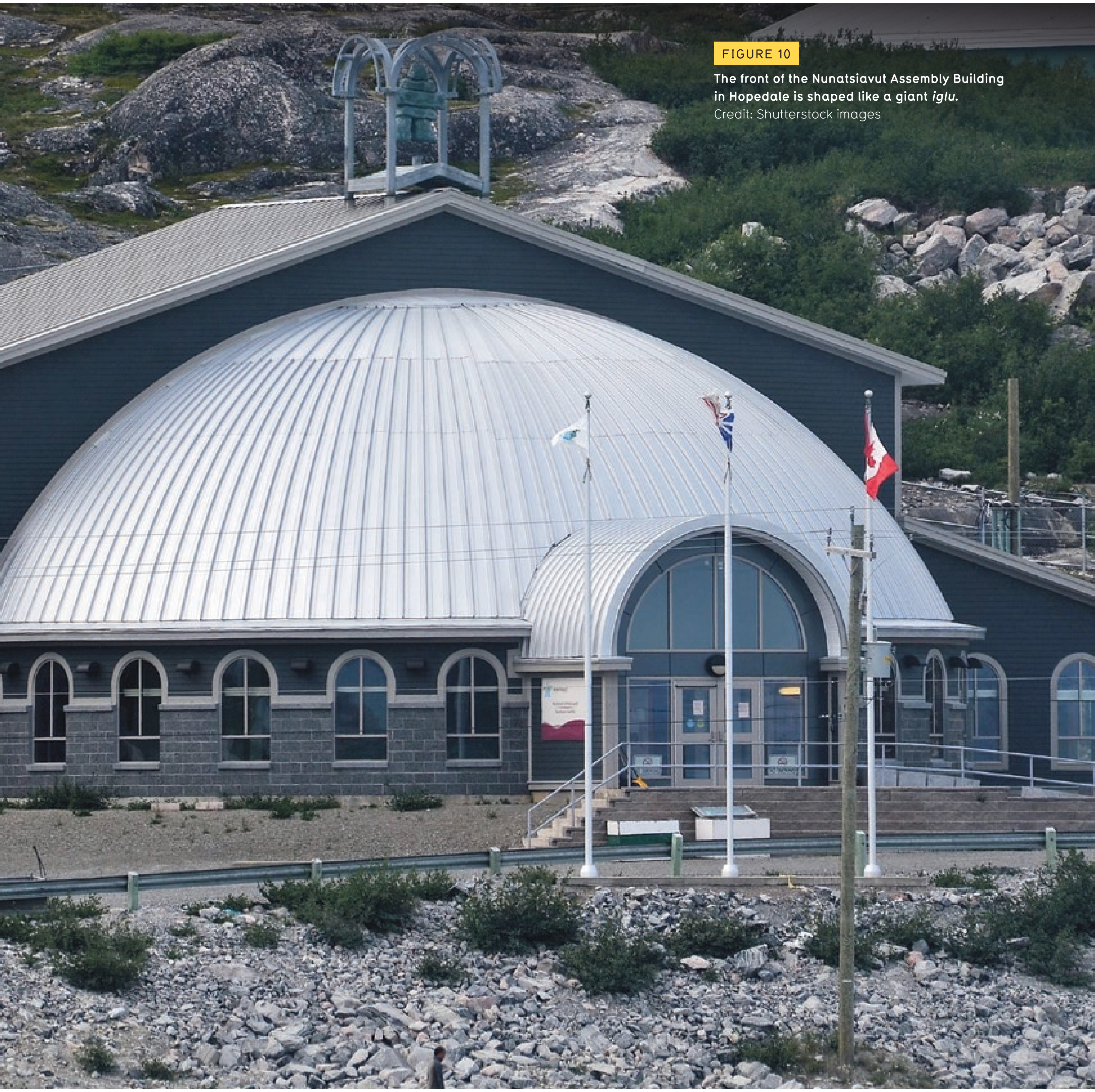


FIGURE 10

The front of the Nunatsiavut Assembly Building in Hopedale is shaped like a giant *iglu*.
Credit: Shutterstock images

Mean molar mass = (28.0 g × 0.781) + (32.0 g × 0.210) + (40.1 g × 0.009) = 28.95 g [per mole of air mixture]

The molar volume at any temperature can be found from the Ideal Gas Equation, PV = nRT, where P is the pressure in kPa, V is the volume in litres, R is the gas constant 8.31 $kPa \cdot L \cdot mol^{-1} \cdot K^{-1}$, and T is the temperature in Kelvin.

If the atmospheric pressure is 100 kPa, the temperature -30 °C, we can calculate the volume of a mole of air as:

$$V = \left(\frac{nRT}{P} \right) = \left(\frac{1\ mol \times 8.31\ kPa \cdot L \cdot mol^{-1} \cdot K^{-1} \times 243\ K}{100\ kPa} \right) = 20.2\ L$$

$$Density = \left(\frac{28.95\ g}{20.2\ L} \right) = 1.43\ g \cdot L^{-1} \text{ at } -30\ °C.$$

Similarly, the density at +20 °C can be calculated as 1.19 $g \cdot L^{-1}$. A significant differential!

The *Iglu* as an Inuit cultural symbol

The *iglu* is recognizable by people around the world as a defining feature of the Arctic peoples. As the Arctic climate undergoes catastrophic warming, the skills of building an *iglu* will no longer be ones of necessity, but simply a means of reconnecting with the past. To illustrate the centrality of the *iglu* to the culture, the front portion of the Assembly Building of the Nunatsiavut Government is shaped in the form of an *iglu* (Fig. 10).

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LIVING ON THE EDGE

Some chemistry of the Inuit diet

FIGURE 1
Arctic Bay (Ikpiariuk), taken on 29th January 2022, at sunset, a week before the first true sunrise of the year.
Credit: Mark Long

AUTHORS

ROSALINA NAQITARVIK and CHAIM CHRISTIANA ANDERSEN and GEOFF RAYNER-CANHAM

We, the Inuit people, have a different diet because we are people of a cold land. Because we are people of a cold land, wildlife is our main diet. … Right to this day we eat what our forefathers used to eat, food with no price tags on it, food created for us ever since the Earth was created, so said Martin Martin, Inuk Elder of the Nunatsiavummiut in 1976.[1]

Eating cannot be considered in isolation from Inuit culture. Martin Martin, explained: *When I was a young man every time I went hunting and came back successful I invited the poor, the less fortunate and the old Inuit to share my kill. After they had eaten they would joke around and tell stories of the past. … I had made my fellow people happy through sharing.*[1]

FIGURE 2

Rosalina using an *ulu* to cut caribou meat.
Credit: Rosalina Naqitarvik

In the Arctic, food resources are very scarce. When a food resource is identified, every edible part must be consumed. In this article, we will look at some of these foods, though it should also be kept in mind that only a few will be available to any specific community. This is because Inuit communities occupy locations over a tremendous geographical area and climate range.

Rosalina recalls: *"I was raised in Arctic Bay (Ikpiarjuk), at the north-west corner of Baffin Island, where the flat-topped King George V Mountain dominates the landscape. It is the third most northerly community in Canada."*

*"I grew up eating raw and cooked Arctic char[2] (*iqaluk*), ringed seal meat (*nattiq*), narwhal skin (*maktaaq*), Canada geese (*kanguq*), polar bear meat (*nanuq*) and caribou meat (*tuktu*). I most enjoyed fish and seal eyeballs; they are a special delicacy. Starting from the age of a young toddler, I went camping and hunting around the Arctic Bay area. When we travelled in Winter by snowmobile, we would hunt for seals and fish. I most enjoyed jigging in the springtime when the Arctic char are plentiful and biting."*

"In the Summer and Fall, we would hunt for narwhals and a variety of seals such as harped seals, bearded seals, and ringed seals. When we hunted for narwhal, we would ride in a boat and chase them towards the shore, they would get harpooned and shot. For seals, we would wait for their heads to bob up out of the ocean."

FIGURE 3

Mountain sorrel.
Credit: https://en.wikipedia.org/wiki/Oxyria_digyna#/media/File:Oxyria_digyna_-_Mountsorrel-1.jpg

FIGURE 4

Mountain campion.
Credit: https://en.wikipedia.org/wiki/Silene_uralensis#/media/File:Apetalous_Catchfly.jpg

Sea urchins, blue mussels, and edible seaweeds are also part of the Inuit diet, where available.[3] However, Rosalina comments: *"Arctic Bay has the lowest tidal range in Canada, so seaweed, mussel, or sea urchin collecting is not very feasible there."*

Eggs are a significant source of protein, wherever they can be harvested. On the coastal islands of northern Nunatsiavut, seabird eggs could be collected from the precipitous cliffs. By contrast, Rosalina started collecting Canada geese eggs at the age of three by snowmobile. It was a journey of approximately 12-15 hours from Arctic Bay to the nesting sites. She recalls:

> *"We were taught not to gather all the eggs from the nest. We had to leave one or two eggs so that the geese will continue to return North."*

Then Rosalina's family moved to Cambridge Bay (Inuinnaqtun: Iqaluktuuttiaq – Inuktitut: ᐃᖃᓗᒃᑑᑦᑎᐊᖅ). This involved a change in diet, she remembers: *"This is where I was introduced to musk-ox meat. The flavour is similar to caribou meat. There were far more caribou closer to the community and my father hunted them a lot and they were our main source of diet."*

Fruit and vegetables in the Arctic

Though fish and animals provide the mainstay of the Inuit diet, Arctic peoples from Greenland to Alaska[4] are well aware of the importance of fruit and vegetables in the diet. Much effort goes into harvesting them during the short summer months. For fruit, berries are a dietary component, such as crowberry and cloudberry. Part of the harvested berries are preserved in seal oil for eating in the winter months. Some small contribution of carbohydrate is provided by roots and tubers, such as those of tuberous spring beauty (*Claytonia tuberosa*) and sweet vetch (*Hedysarum alpinum*). The roots of sweet vetch taste like young carrots though the Inupiat of Alaska call it wild potato.[5] The stems and seeds of cottongrass (*Eriophorum angustifolium*) are also a vegetable source.

Rosalina recalls: *"I grew up blueberry picking on the mountains around Arctic Bay. Due to the short summers, blueberries were all that grew up there. I love to pick blueberries up to the present. We also picked an abundance of mountain sorrel (*Oxyria dygyna – qunguliit*). These are red and have green sour leaves which are delicious. I would also eat mountain campion (*Silene uralensis arctica*); by opening up the flower and eating the rice looking edible plant inside."*

FIGURE 5

Inuk Elder preparing bannock.

Credit: https://en.wikipedia.org/wiki/Bannock_(Indigenous_American)#/media/File:Bannock_1995-07-01.jpg, photo by Ansgar Walk

Fat, carbohydrate, and protein

Though Inuit try to obtain as varied a diet as possible, meat and fish are the major food source. Thus, the traditional Inuit diet is mostly protein and fat with minimal carbohydrate. Such a diet, with fats being the major source of energy instead of carbohydrate are called ketogenic diets, as the metabolic pathway produces ketones.[6] The Arctic peoples have survived in the north for thousands of years[7] on a ketogenic diet by means of genetic adaption.[8]

Seal blubber (*uqsuq*)[9] and oil is central to the Inuit diet. It is a particularly rich source of the dietary-essential omega-3 polyunsaturated fatty acids (PUFAs) and the Inuit metabolism has adapted to benefit from very high concentrations of PUFAs in their foods. Rosalina explains how the oil is extracted and used. *"Inuit use a rock or a hammer to extract the oil. My late grandmother (*ningiuq*) used to use narwhal fat when she made bannock[10] (frybread/ *palaugaaq*) when we were out camping."*

The arrival of grocery stores in every Inuit community, has resulted in the introduction of large quantities of carbohydrates into the Inuit diet. Bodies attuned to the fat-protein diet are now swamped with carbohydrates: potato chips, hamburger buns, and so on which can be purchased at the stores. Such a dietary change has led to massive increases in high blood pressure, tooth decay, and a hardening of the arteries,[11] together with obesity and type-2 diabetes.

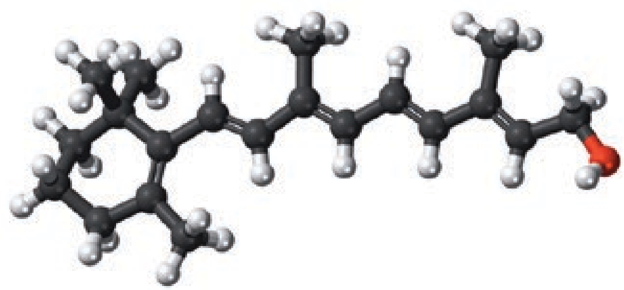
Vitamins and minerals

Chemists have analyzed most of the traditional Inuit foods for protein, fat, mineral, and fatty acid content.[12] Thus, we can now gain a clear appreciation of the breadth of nutrition in the traditional Inuit diet.

In animals, vitamin A (chemical name: retinol) is stored in the liver. In fact, liver, usually eaten raw, is a main source of vitamin A for Inuit. As can be seen from Fig. 6, vitamin A is totally non-polar except for the one alcohol group on the end. This means that vitamin A is soluble preferentially in fatty tissues where it can accumulate. As a result, it is possible to absorb a toxic level of vitamin A, especially from vitamin A-rich polar bear livers. Inuit are aware of this hazard and are careful not to eat an excess amount.

FIGURE 6

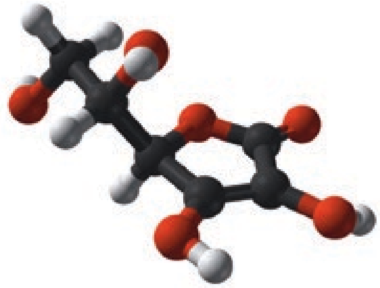
A ball-and-stick model of a vitamin A (retinol) molecule.
Credit: https://en.wikipedia.org/wiki/Retinol#/media/File:Retinol_3D_balls.png



Liver is also a source of vitamin C (and D). The liver must be eaten raw in order to obtain the vitamin benefits, for vitamin C, in particular, is decomposed upon cooking.[13] Berries, raw fish eggs, and raw whale skin (*maktaaq/mattak*) are also major sources of vitamin C for Inuit. There is no danger from overdose with vitamin C as the small molecule has four alcohol groups (Fig. 7), making it very water-soluble and any excess intake is excreted in urine.

FIGURE 7

A ball-and-stick model of a vitamin C (ascorbic acid) molecule.
Credit: https://en.wikipedia.org/wiki/Vitamin_C#/media/File:Ascorbic-acid-from-xtal-1997-3D-balls.png



There are two metal ions which are essential to healthy living: zinc and iron. Animal liver is rich in both of these ions, too. Animal blood is another source of iron. The iron in liver and blood is locked within the haemoglobin molecule, known as heme-iron. Heme-iron is readily absorbed by the human digestive process. By contrast, the iron ion in vegetables is comparatively poorly absorbed. This is a particular problem for Inuit women used to a traditional heme-iron rich diet who travel or live in the 'outside' world where they can suffer from insufficient iron in their 'western' diet, a disease called anaemia.

The traditional foods (TFs) for Inuit are much healthier than the market foods (MFs).[14] In a study of young Inuit, those raised more on TFs had higher blood levels of vitamins A and D, iron, magnesium, and zinc, than those raised on MFs.[15]

FIGURE 8

Elder Annie Evans, Inuk of the Nunatsiavummiut, with rhubarb at Ben's Cove, near Makkovik, Nunatsiavut.
Credit: Erica Oberndorfer

The adaptable Inuit

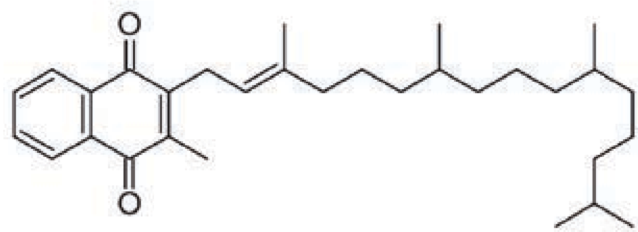
Any new food source is incorporated into the diet. A most interesting case history is that of rhubarb in Nunatsiavut. Among the first settlers on the northern Labrador coast were Christian missionaries of the Moravian sect. They brought with them a passion for gardening and seeds of a range of European vegetables, one of which was rhubarb.[16] By 1864, rhubarb was flourishing in Labrador. Rhubarb is now an established part of the diet of the Nunatsiavummiut, and Inuit women there make jams and preserves with it.

The rhubarb of the abandoned community of Okak is important both health-wise and culturally. It has been commented that: *"… Okak … is home to some of the most famous rhubarbs legendary for their abundance and size."*[17] Many Inuit visit the site of Okak and take Okak rhubarb to their own community. Along with the flourishing rhubarb plant comes the memory of the peoples of Okak, 80 per cent of whom died during the Spanish Flu epidemic of 1918, while the remainder were forcibly resettled elsewhere.

Rhubarb provides an additional source of vitamin C, but it is also an excellent source of vitamin K1 (Fig. 9). Vitamin K1 (chemical name: phylloquinone) is one of a family of structurally similar, fat-soluble vitamins which the human body requires for synthesis of certain proteins.[18]

FIGURE 9

A bond-line diagram of a Vitamin K_1 (phylloquinone) molecule.
Credit: https://en.wikipedia.org/wiki/Phytomenadione#/media/File:Vitamin_K1.png



The challenges of climate change

Forty years have elapsed since the Inuk Elder, Martin Martin, reflected upon Inuit life, yet his words are as true today as they were then.

> *We have not lost all our traditions and culture yet. … Our young men [and women] still try to hunt in the traditional ways but they have difficulties because there is less game now. But our young Inuit have not given up trying their best to hunt for wildlife food.*[1]

The stress-level has become even more acute for Inuit women, who are facing dwindling access to TFs and very high cost in the Arctic of air-freighted MFs when trying to feed their families.[19]

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COMPOSITES IN INUIT LIFE

What was old is new again

AUTHORS
ROSALINA NAQITARVIK and
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PHOTO
two Inuuk women throat singing *(kataqjjaq)* up in north Baffin Island near Rosalina's home.
Credit: Arctic Kingdom, Inc. Iqaluit

Previously in this series, we showed that solid water, as ice[1] and as snow,[2] is an essential material in Inuit culture. Water is a pure substance. However, most materials used in Inuit life are not pure substances, but composites. So the first question to answer is: "What is a composite?"

A composite

Composites are the favoured materials of the 21st Century. A composite material can be defined as:[3]

> … a material made from two or more constituent materials with significantly different physical or chemical properties. When they are combined, a material is produced with characteristics different from the individual components. The individual components remain separate and distinct within the finished structure.

One of the most common and familiar modern composites is fibreglass, in which small glass fibres (glass is mostly silicon dioxide, an inorganic compound) are embedded within an organic polymer. The glass fibre is relatively strong and stiff (but also brittle), whereas the organic polymer is flexible (but also structurally-weak). Thus, the resulting fiberglass, a combination of inorganic and organic compounds, is relatively stiff and strong, and yet flexible.

Fibreglass is a relatively new synthetic composite. However, scientists and structural engineers are becoming increasingly interested in composites composed of naturally-occurring materials, including biologically-sourced ones. Organisms synthesize composites out of three main components: proteins (chains of amino-acid units), polysaccharides (chains of sugar units), and minerals. And these biological composites are seen as key to a more sustainable materials economy.[4]

The Arctic

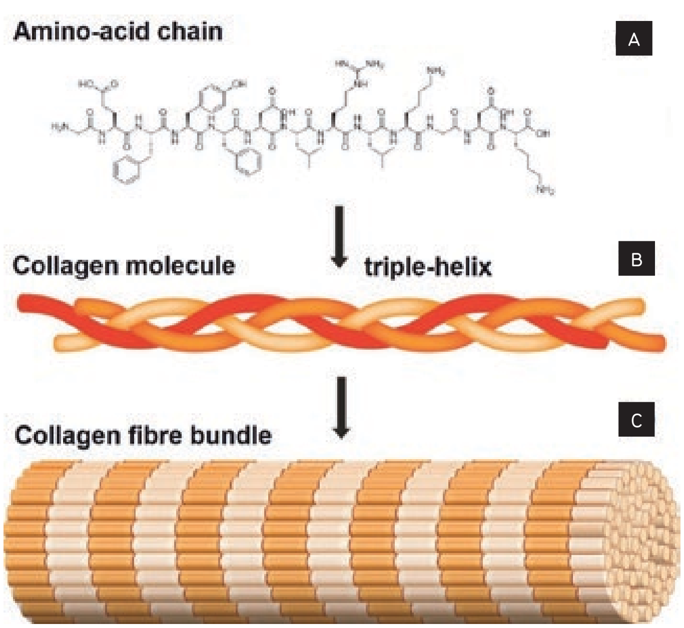
The Arctic is a hostile environment for human life – not just because of the temperature, but also it is a land of a very limited range of natural resources. Incredible ingenuity must be employed to make the most of this limited range of materials together with those materials provided by the animal inhabitants of the region. Most of these materials are composites. In fact, the Inuit have appreciated the benefits of composite materials for thousands of years. Here we will discuss the chemistry and utility of three crucial composite materials: animal skin, bone (such as caribou and whale), and wood.

Animal skin

Life would be impossible in the Arctic without materials for making clothing.[5] Fortunately, the skins of land and marine mammals provide such a resource.[6] But what do skins consist of? There are two major components, both organic polymers, but very different in chemical composition. The major component is called collagen, a protein consisting of amino acid units.[7] Every third amino acid in the collagen sequence is the simplest amino acid, glycine. Glycine has no side chain, and, as a result, three strands of this amino-acid polymer can tightly intertwine to form a triple-helix, the actual collagen molecule. These molecules then pack in bundles to form the solid but flexible collagen fibre matrix (Fig. 1).

FIGURE 1

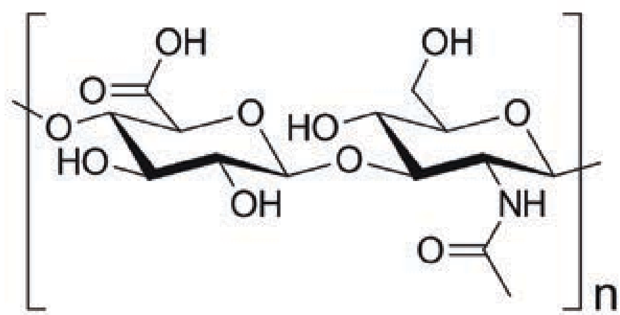
A) part of the amino-acid strand. B) the triple helix of the collagen molecule. C) the bundling of the molecules to form collagen fibres in animal skins.



The second significant component is a muco-polysaccharide, a polymer containing chains of sugar-molecules and amino-sugar molecules (also known as glycosaminoglycans). A segment is shown in Fig. 2. This provides the filler between the collagen strands and it has a 'cushioning' effect. Having lots of hydroxy (-OH) groups, these polymer molecules are water-absorbing and need to be removed from the skin in order to use it for clothing.

FIGURE 2

A segment of the muco-polysaccharide chain in animal skin
Credit: https://en.wikipedia.org/wiki/Glycosaminoglycan#/media/File:Hyaluronan.svg



After the skin is removed from the dead animal, it is dried on wooden frames, then placed on the knees or on a flat surface and scraped free of fat and other tissues using an *ulu*.[8] Chewing, rubbing, and soaking in liquid are among the ways to make the skin soft and pliable.[9] Although Inuit women have had a greater role in the treatment of skins, Inuit men also perform these tasks when needed – just as women fill in for men sometimes in hunting for seals.

Rosalina recalls: "*My late grandmother used to clean many sealskins during the spring hunting season, possibly up to 40 skins, as many of her sons and grandchildren would catch many seals. She would wash them in salt water then stretch them and use pegs and have it leveled off of the ground to dry. Removing the seal fat is called* majjak. *When women are ready to use a dried skin, it is first tied up into a ball and stomped on using their feet. Once it has been softened that way, it is washed then laid flat to dry. When it is partially dry, they start the stretching process using a* tasiuqquti. *This is a traditional tool with a curved metal which is kind of sharp. It is now ready to use.*"

Kamiik (boots)

Only after this lengthy processing can the skin be cut and sewn. One necessity is that of *kamiik* (boots) (*kamiik*, two boots; *kamik*, one boot; *kamiit*, many skin boots).[9] Articles of clothing, such as *kamiik*, are not just utilitarian, but they are each works of art by the individual seamstress (Fig. 3). According to Elder Ulayok Kaviok of Arviat, Nunavut:[10]

"…during the skin boot production process, elders pass on oral traditions to young seamstresses who are interested in traditional rituals and sharing systems. The first pair of skin boots sewn by a young sibling is a symbol of her bond with the traditional lifestyle and the importance of sharing Inuit and Inuvialuit culture."

FIGURE 3

Three pairs of hand-made *kamiik*, the bottom pair is waterproof
Credit: Rosalina Naqitarvik

Amauti

The *amauti* (*amautiit*, plural) is one of the most beautiful and useful of Inuit clothing.[11] *Amautiit* is the parka worn by Inuit women with very young children (Figs. 4a and 4b). Up until about two years of age, the child nestles against the mother's back in the *amauti*, the built-in baby pouch just below the hood. The pouch is large and comfortable for the baby. The mother can bring the child from back to front when necessary, without exposure to the elements. In addition to keeping the child warm and safe from frostbite, wind, and cold, it also helps to develop bonding between mother and child.

FIGURE 4

A. (left) Rosalina Naqitarvik's mother in *amauti* with Rosalina in the pouch
B. (right) Rosalina Naqitarvik in *amauti* with Iris Kilabuk in the pouch.
Credit: Rosalina Naqitarvik

Rosalina adds: "Amautiit *are still very popular as they are the best protection against the cold for the baby. There are different styles and back sizes.* Amautiit *need to be form fitted to the woman's body or else it will be too uncomfortable for the baby. Carrying a baby in the* amauti *creates a closer connection and bond between mother and baby, although, some men carry their babies too wearing the* amauti. *They are a special symbol for special occasions and gatherings in which the pouch is made to not fit a baby as it is more for formal wear. Sewing an* amauti *takes a lot of different kinds of material such as commander, hollofill, bias tapes, sealskins, caribou skin, and fox fur. It takes a special talent to sew an* amauti *as it has to be sewn in a specific way to be able to carry the baby properly. I grew up in an* amauti. *Below (see next page) is a poem I wrote back in high school that is now showcased as a big wooden painting in Inuktitut."*

TRANSLATION IN ENGLISH:

I am in my dear mother's *amauti*;

I feel the warmth of our love while
my body is against hers.

I am noticing the world for the first time.

I point at the stars in awe.

They are as bright as my mother.

I observe the many flowers in the summer
while I'm in the *amauti*;

I am being introduced to different
colours and scents.

My mother and I have an inseparable bond
that could be described in many ways;
which cannot be broken.

As I sleep in the *amauti*, I dream of a calm life.

Waterproof clothing

Sealskins which are dehaired and black in colour are waterproof. The garments made from them are called *iqaqti*, and they are used for spring *kamiik* and mittens. Specific stitches are used to ensure that the seams prevent water leakage. Also very warm, *iqaqti* are still made today and are popular during the weather transition. To make light-weight rainwear, seal gut is used. Fig. 5 shows a waterproof jacket constructed by sewing together sections of seal gut.

Bone

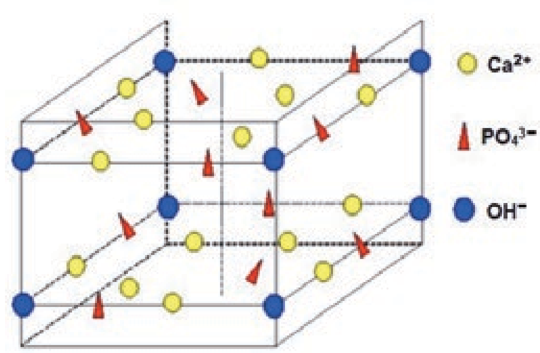
There are two common sources of bone: caribou antler and whale bone. Like most composite materials, bone consists of two components which complement each other: one, known as the matrix, provides the tensile strength and the other which provides the compressive strength.[12] In bone, the matrix is comprised of the organic polymer, collagen (discussed above). The other component, which comprises about 70 per cent of the structure is the inorganic mineral, calcium hydroxyapatite, $Ca_5(PO_4)_3(OH)$. It is the interlocking hard crystals of the mineral which provide the rigidity. In Fig. 6 below, the three constituent ions are represented diagrammatically to show how they fit together to form a very strong, rigid structure.

FIGURE 5

Girl's waterproof parka made from seal gut skin, eastern Greenlandic Inuit group. Credit: https://en.wikipedia.org/wiki/Inuit_clothing#/media/File:Inuit_seal_gut_parka.jpg

FIGURE 6

A diagrammatic representation of the packing of the ions in the crystal lattice of calcium hydroxyapatite, $Ca_5(PO_4)_3(OH)$. Adapted from: https://www.wikiwand.com/vi/Hydroxyapatite



Thick, warm clothing is essential for Inuit survival. To sew together the seal skins, caribou skins, and bear fur, needles were essential, and these were made of bone. Every Inuit family traditionally had a set of bone needles, together with a needlework kit and case (Fig. 7). Carving needles from bone (often bird bone) has to be one of the most painstaking of the many tasks involved in traditional Inuit life.

FIGURE 7

Inuit bone needles and walrus tusk case
Credit: https://www.artstation.com/artwork/mqLZoe

There is a specific use for whale bone: the framework of boats. Though non-Inuit are familiar with *kayak* (one of several Inuit words appropriated into English), few realize that the means of family and group marine travel is an *umiak* (Fig. 8). The framework is made of whale bones (or wood, when available) pegged together with antler bone or walrus ivory.[13] The frame is covered with skins, often walrus skins which are sewn together with caribou sinew, and seal oil is used to coat and waterproof the seams. Propelled by oars (women) or paddles (men), an *umiak* can be anywhere from six to ten metres long. In the eastern Arctic, *umiak* were usually used for the transportation of families to-and-from summer fishing camps.

Wood

Like animal skins, wood is an organic-organic composite. There are two primary components of wood: cellulose (up to 50 per cent) and lignin (up to 25 per cent). As with all these useful composites, one provides the rigid framework, in this case, cellulose fibres, while the other, lignin, the matrix, fills the spaces within the framework and provides the flexibility. Cellulose is a long-chain polymer consisting of linked sugar units (Fig. 9). Lignin is an unusual enormous biomolecule in that it has no standard composition, but with a general formula approximating to $(C_{31}H_{34}O_{11})_n$, where n is a large number.[14]

FIGURE 9

Part of the chain of sugar molecules forming the cellulose chain.
Credit: https://en.wikipedia.org/wiki/Cellulose#/media/File:Cellulose-Ibeta-from-xtal-2002-3D-balls.png

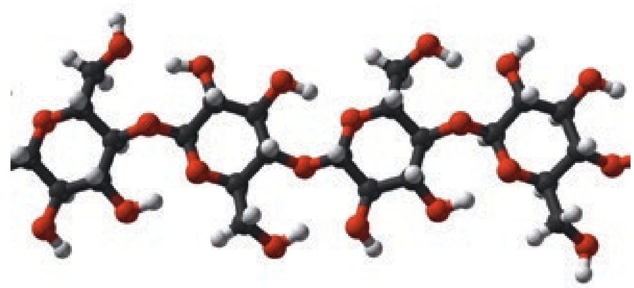
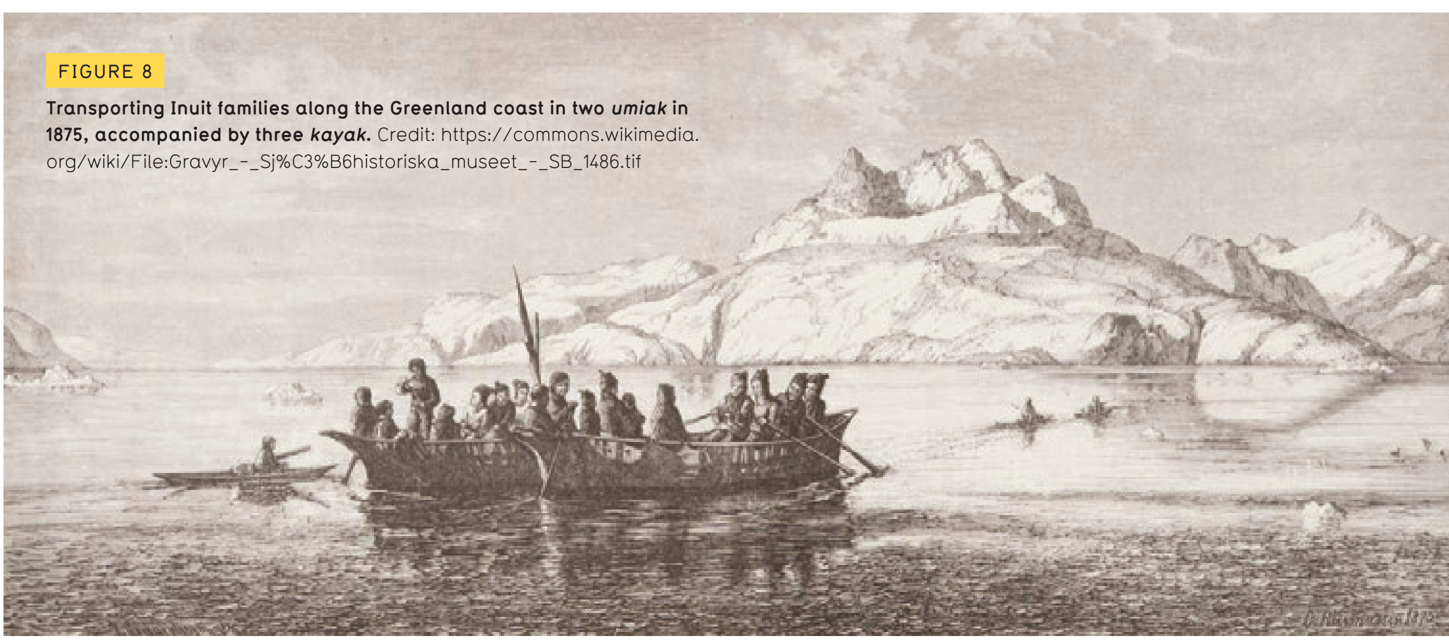


FIGURE 8

Transporting Inuit families along the Greenland coast in two *umiak* in 1875, accompanied by three *kayak*. Credit: https://commons.wikimedia.org/wiki/File:Gravyr_-_Sj%C3%B6historiska_museet_-_SB_1486.tif



In more southerly latitudes, wood is treated as something that is ubiquitous and unremarkable. However, in the High Arctic, north of the tree-line, the only wood available is driftwood, as no trees grow in the Arctic. Collected by the northern Inuit, these pieces found on the shorelines were valued for the many roles that wood could be used for. Fig. 10 shows the use of drift-wood framework for the construction of an Inuit summer dwelling.

FIGURE 10

Framework for an Inuit summer dwelling. Credit: https://commons.wikimedia.org/wiki/File:Frame_of_Inuit_Dwelling.jpg

Commentary

Jago Cooper, British archaeologist and Curator of the Americas at the British Museum encapsulates the world of the Inuit beautifully:[15]

"The unique materiality of frozen Arctic landscapes has encouraged people, both past and present, to learn technological resourcefulness and adopt technical ingenuity. ... The underlying principle for Arctic communities is that their way of life is based on the careful management and efficient use of available resources. ... The role of objects in Arctic society, the intrinsic value they contain and respect they demand, go far beyond the utilitarian associations of their everyday function."

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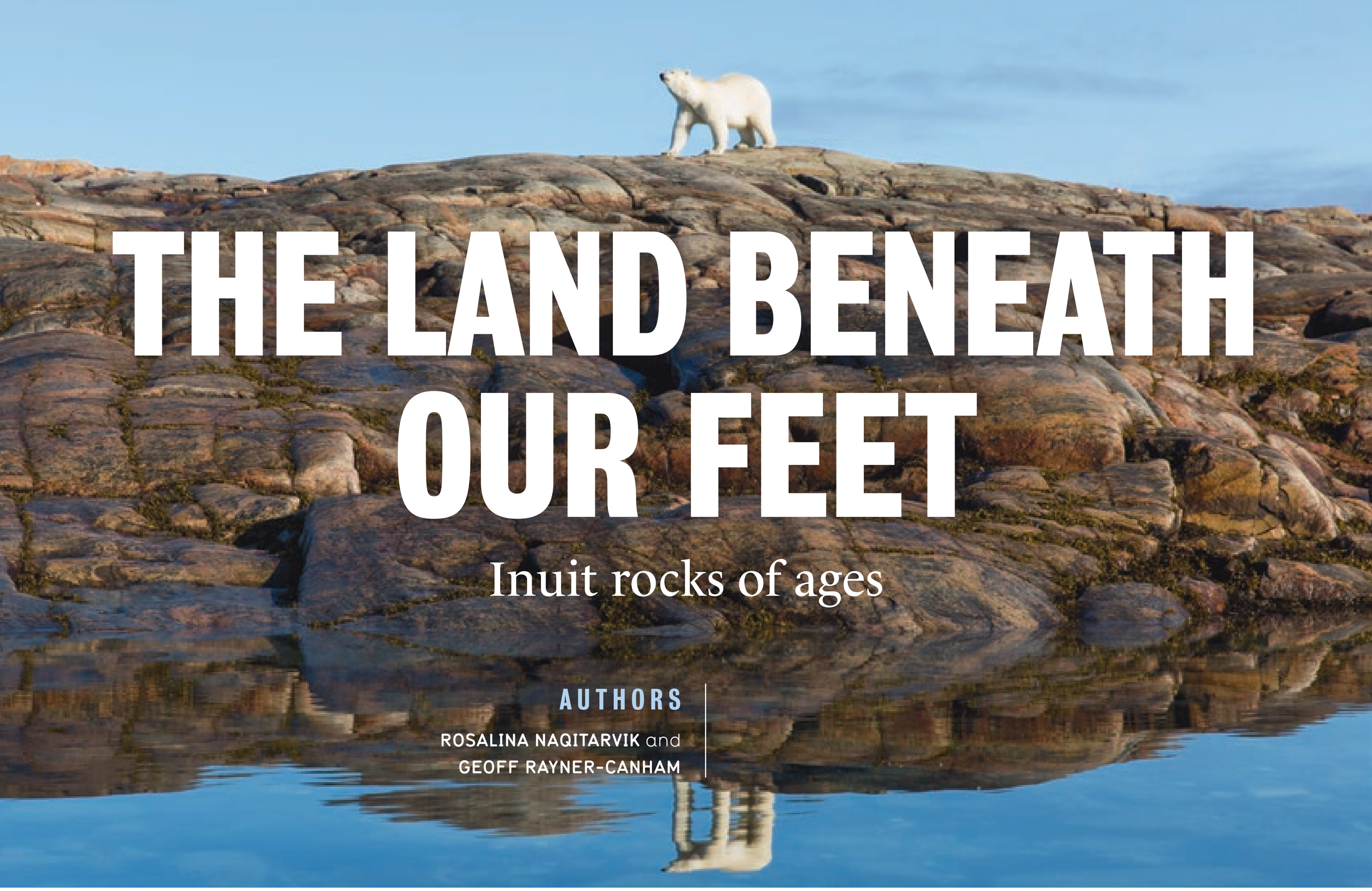


THE LAND BENEATH OUR FEET

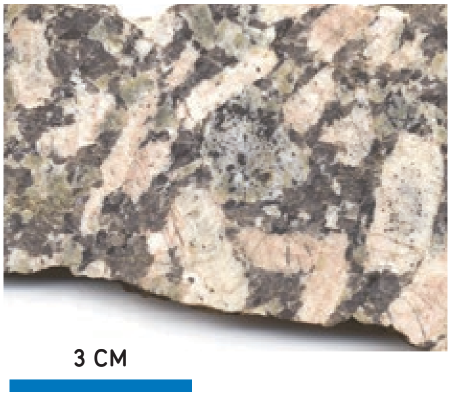
Inuit rocks of ages

AUTHORS
ROSALINA NAQITARVIK and
GEOFF RAYNER-CANHAM

Three of the Inuit homelands: Nunavut, Nunavik, and Nunatsiavut, are all located upon the oldest rocks on the planet: the Canadian Shield. The Canadian Shield is the original core of the North American continent. The formation of the Shield involved the collision and build-up of a large number of rock plates, beginning more than three billion years ago.[1] Originally consisting of mountain chains up to 12,000 m high, over geologic time, the mountains eroded away. The main component of the Shield is granite. Granite was formed deep in the Earth as a red-hot molten mixture (magma). As it cooled, minerals of different chemical composition crystallized out (Fig. 1). In the granite sample shown, black, grey, pink, and colourless crystals can be seen. Such large crystals indicate that the magma must have cooled slowly, deep within the mountain core, giving time for the crystals to grow.

FIGURE 1

Crystals of the different chemical components in a sample of granite, Nueltin Lake; Nunavut. Credit: NRCan Photo Collection



There is a particular interest in the rocks found on the north-eastern shore of Hudson Bay, 40 km south of Inukjuak, Nunavik. Using the two dating methods described below, the rocks of the Nuvvuagittuq greenstone belt (Fig. 2), are at least 3.8 billion years old![2] This makes them among the oldest rocks on the planet.

Dating the age of rocks

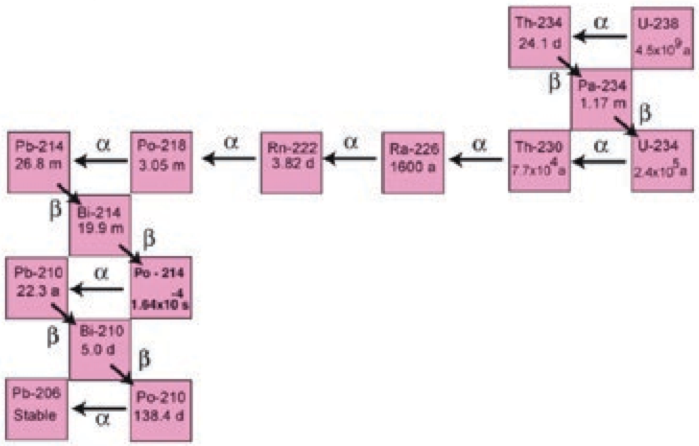
How do we know how old the rocks are? To accomplish this, radioactive dating is used. Each radioactive isotope has a specific half-life – the time it takes for half of that isotope to change into another isotope – often of a different element. One useful decay for determining the age of rocks is that of radioactive samarium-147, which changes to neodymium-143 at a rate of one-half every 106 billion years. Therefore, a rock can be dated by measuring how much of its original samarium-147 content has changed into neodymium-143.

$$^{147}_{62}\text{Sm} \longrightarrow {}^{143}_{60}\text{Nd} + {}^{4}_{2}\text{He}$$

However, scientists are cautious. We should always try and find more than one way of determining the age of rocks. A second route is the transformations of the radioactive uranium-238 to lead-206. This is not a single decay step but a series of steps with an overall half-life of 4.5 billion years (Fig. 3). Thus we can compare the results from these two methods (and those of others) to ensure the age is valid.

FIGURE 3

The common decay sequence of uranium-238 to lead-206
Credit: https://www.epa.gov/radiation/radioactive-decay



When measuring the proportion of lead, how can we be sure the lead has all come from uranium and not some fraction which was already in the rocks? If the rock contains zircon crystals, then we can determine the date at which the zircon started to solidify very accurately. Zircon is the mineralogical name for zirconium(IV) oxide, an extremely hard colourless solid. A beautiful crystal of zircon is shown in Fig. 4 (the colour is the result of traces of other cations trapped within the crystal).

FIGURE 2

A view across the at least 3.8 billion-year-old rocks near Inukjuak, Nunavik
Source: https://www.nsf.gov/news/news_images.jsp?cntn_id=112299&org=NSF; Credit: Jonathan O'Neil

FIGURE 4

Zircon (zirconium(IV) oxide) crystal, ZrO_2, embedded in a lump of calcium carbonate ($CaCO_3$). Credit: https://en.wikipedia.org/wiki/Zircon#/media/File:Zircon-dtn1a.jpg

The crystal lattice contains alternating zirconium ions (Zr^{4+}) and oxide ions (O^{2-}) (Fig. 5). With such high charges, the ionic attractions are very strong. In fact, as molten rock cools, zirconium(IV) oxide is the first compound to crystallize out. This happens when the temperature of the molten rock drops below 2,715 °C, causing the constituent ions to be 'frozen' into the crystal forever.

Any uranium ions in the molten rock are present as uranium(VI) ions (U^{6+}). The U^{6+} ion is almost the same size as the Zr^{4+} ion, and some of these uranium ions will become trapped inside the crystal, occupying the space of a zirconium ion. However, any Pb^{4+} ion in the molten rock is too large to fit into the crystal lattice cavity. Thus any lead found in a zircon crystal can only be the result of radioactive decay. The ratio of zirconium-decayed to lead-formed will therefore give a very precise date of the crystal solidifying.[3]

Inuksuk

The hard rocks of the Canadian Shield serve one specific role in Inuit life: the construction of *inuksuk* (plural: *inuksuit*). *Inuksuk* is a generic term for carefully stacked blocks of granite, or other indestructible rocks, each with a specific meaning for the peoples living in that locality. A common bond among Arctic peoples from Greenland, across Canada, to Alaska, they have been constructed in varying shapes and forms.[4] There are over 100 *inuksuit* located within a few hectares of each other at Inuksualait, Southwest Baffin Island, approximately 90 km from Kinngait (Cape Dorset), Nunavut.[5] This area is now a National Historic Site.

Inuksuit are reliable message centres.[6] To the travelling hunter, *inuksuit* were a welcome sight; some described the course to follow, others pointed to good hunting and fishing areas, and some marked where food was cached. They provided purposeful information and assistance to those who knew how to read their forms. Fig. 6 shows an *inuksuk* on the King George V Mountain, overlooking Ikpiarjuk (Arctic Bay).

FIGURE 5

Crystal packing of zirconium/uranium cations and oxide anions in zircon. Adapted from: https://ars.els-cdn.com/content/image/1-s2.0-S0039602813000654-gr1_lrg.jpg

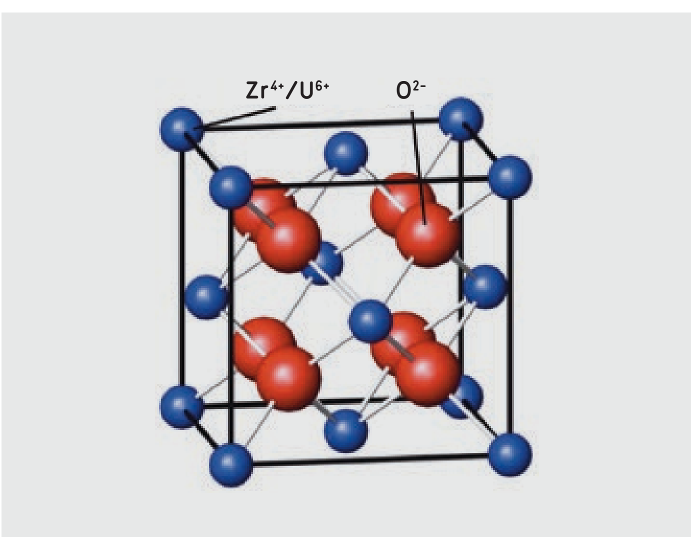


FIGURE 6

Rosalina Naqitarvik sitting on an *inuksuk* overlooking Ikpiarjuk (Arctic Bay). Credit: Rosalina Naqitarvik

FIGURE 7

Inunnguag on a promontory overlooking the sea as a navigation aid for Inuit hunters in winter. Credit: Getty Images

An *inuksuk* can be any shape; a small proportion are in the shape of a human person and these are called an *inunnguaq* (ᐃᓄᙳᐊᖅ, 'imitation of a person', plural *inunnguat*).[4] Fig. 7 shows an *inunnguaq* near Iqaluktuuttiaq (Cambridge Bay).

To Inuit, *inuksuit* are embedded in the roots of Inuit society within songs, myths, legends and stories. Archaeological research suggests that some *inuksuit* were built by the Inuit predecessors, around 4,000 years ago.[5] The flags of Nunavut and of Nunatsiavut both consist of *inuksuk* images (Figs. 8a and 8b), indicating its importance in Inuit culture.

Soapstone

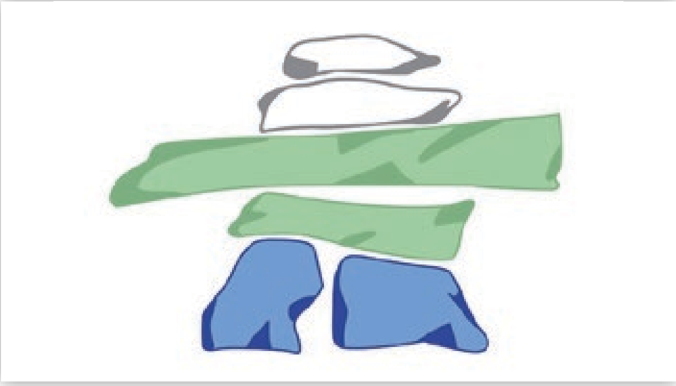
Most of the Arctic consists of the very hard ancient rocks which, with few exceptions, such as Ramah Bay chert,[7] are difficult to transform into any useful function. However, there is one very useful soft rock found in small deposits across the Arctic: soapstone.[8] Soapstone is a structurally-composite material.[9] The major component of soapstone is the mineral talc (Fig. 9), which is comprised of layers of silicate ions, SiO_4^{4-} (yellow tetrahedrons), alternating with layers of magnesium hydroxide, $Mg(OH)_2$ (blue-green octahedrons). It is the weakness of the chemical bonding between these separate layers that gives soapstone its softness.

The colour of the soapstone depends upon the concentration and identity of impurities in the structure. The colour-centres occur when some of the sites normally occupied by magnesium ions, Mg^{2+}, are occupied by other cations, such as chromium(III), Cr^{3+}, or iron(II), Fe^{2+}. The differences in colours become particularly noticeable when viewing soapstone carvings of different Inuit sculptors. Gertzbein, in their book on the minerals of Nunavut, comments:[10]

FIGURE 8

A. (left) flag of Nunavut

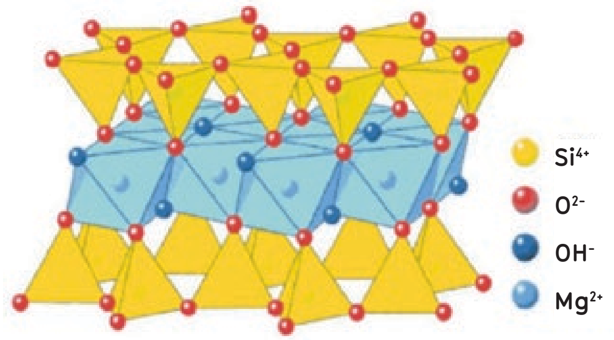
B. (right) flag of Nunatsiavut



"The beautiful, bright apple green material from Markham Bay, near Cape Dorset (Kinngait), is in dramatic contrast to the black-and-dark-grey soapstone from around Baker Lake (Qamani'tuaq). Anyone who sees many carvings from around Nunavut can soon learn to identify the unique community from which the rock and the art originate."

FIGURE 9

Crystal structure of the mineral talc.
Adapted from: A.L. Camara, Master's Dissertation, 2003



Qulliq

Soapstone has been essential to Inuit life as it can be carved and made into bowls, known as *qulliq*,[11] *qulliq* were, and are, made in a variety of sizes and shapes (Fig. 10).

FIGURE 10

***Qulliq* are made in whatever size and shape is required.**
Credit: https://en.wikipedia.org/wiki/Qulliq#/media/File:Descriptive_booklet_on_the_Alaska_historical_museum_(1922)_(14758775556).jpg

Filled with seal oil, the flame from wicks in a *qulliq* was the sole source of heat and light, and it was the only means of cooking food. The wick of the *qulliq* is made of *pualunnguat*, Arctic cottongrass (Fig. 11),[12] which is dried and rolled with seal fat.

FIGURE 11

***Pualunnguat*, Arctic cottongrass.** Credit: https://en.wikipedia.org/wiki/Eriophorum_callitrix#/media/File:Arctic_cottongrass,_Inuvik,_NT.jpg

Lighting and tending the *qulliq* is another way that Inuit women are passing down the traditions of their ancestors. In contemporary Inuit culture, it is a custom to light the *qulliq* before ceremonial events. Fig. 12 shows Esteemed Elder Mary Pudlat, an extraordinary Inuit artist,[13] lighting a *qulliq* on April 1, 1999, the day of birth of the Territory of Nunavut.

FIGURE 12

Esteemed Elder Mary Pudlat lighting a *qulliq*. Credit: https://en.wikipedia.org/wiki/Inuit_women#/media/File:Qulliq_1999-04-01.jpg

Rosalina reminisces:

"My household currently doesn't have a qulliq *handed down from generation to generation. But my grandma gifted me one when I was 16 years old, and I still have it and cherish it. I plan to pass it down to my future daughters.*

I remember my first time lighting one was in high school, being surrounded and taught by respected Elders whom were my Inuktitut teachers. I was nervous at the time, but proud to learn. The flames of the qulliq *were nice, bright and orange. I loved focusing on the flames and thinking that that was the only source of light and heat back then.*

The next time I lit one was on the high school gymnasium stage when the gym was packed. I was again surrounded by inspiring wise Elders. The feeling I felt was great and they were my role models during that moment.

The memory that I love regarding qulliit *was when the oldest Elder of Arctic Bay, Qaapik Attagutsiak, lit some at ceremonies. She is over 100 years old right now. When I used to witness her lighting some, it was so respectful and soothing. The whole building felt at peace as we sit quietly watching her light a* qulliq.*"*

Commentary

In previous articles, we showed that ice and snow were key attributes of the lands of the Inuit. Here, we have shown that the rocks themselves, dating back to the formation of the first continents, are also an integral part of Inuit culture.

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CLIMATE CHANGE

Our way of life will change, our culture will survive

AUTHOR
ROSALINA NAQITARVIK

FIGURE 1

Rosalina Naqitarvik ice-fishing near Ikpiarjuk (Arctic Bay), NU.
Credit: Rosalina Naqitarvik

In the Preface of her book, *Our Ice is Vanishing / Sikuvut Nunguliqtuq*, Shelley Wright encapsulates the issue,[1]

> *The Arctic is ruled by ice. For Inuit, it is the platform on which life is lived. But the ice is melting and becoming dangerous. Inuit are* silaup aalaruqpalianigata tusaqtittijiit – *witnesses and messengers of climate change.*

Rosalina's reflections on climate change

I shall begin with my own family reminiscences.

"In my home community of Ikpiarjuk (Arctic Bay), 20 years ago, my father used to go hunting every mid-July by snowmobile to the floe edge outside of Arctic Bay. Today, that isn't possible since the ice melts much earlier towards the end of June and early July. My cousins said that this year too, the seals were sunbathing earlier than they did."

Now I am living in Iqaluit. Even in recent years, I have seen dramatic changes:

"This past winter, I think there has only been one blizzard that occurred. Even just five years ago, I remember the blizzards used to frequent way more often and every building would shut down. This year's spring is super early as well! In March, the snow melted quick, and the roads became clear. It is becoming muddy, and the weather has been calm way earlier than usual. Spring usually arrives in May here in Iqaluit, but it seems to be over a month in advance this year."

In Article nine, "Living on the edge: Some chemistry of the Inuit diet," we quoted the words of Martin Martin, Elder of Nunainguk (Nain) Nunatsiavut on climate change and its effects there. For this closing article, I have interviewed Elders from across Nunavut to obtain their thoughts and recollections.

Inuit quotes about climate change in their communities

Qaumajuq Oyukuluk, Elder of Ikpiarjuk (Arctic Bay) contrasts the former stability of the climate to now, and the thinness of the ice:

"Long ago, when I was a young boy, the weather did not seem so different – from one year to the next – compared to now. It is very noticeable how now the weather is getting warmer. The ice is getting thinner throughout the whole winter."

Annie Demcheson, Elder of Iqaluit notes that the Spring is no longer sunny and cold. The weather now is cloudy and food resources are less:

"In the past during the spring season it would get warmer, and we would get snow-blind in the springtime. It was brighter during that season. Right now, it is cloudier out. Every year in the fall we used to go blueberry picking, they'd grow abundantly. Now, the blueberry population seems to be different. In the low tide, there seemed to be more seaweed and ugly fish in the past. I don't see many barnacles on the rocks anymore either. We used to have plentiful of snow buntings and more birds called sijjaria*. We used to have more bumblebees in the summers too, back then."*

Tony Manik, Elder of Qausuittuq (Resolute Bay), one of Canada's northernmost communities, expresses worry about climate instability:

"I remember the weather used to be more stable, now it's so unpredictable. It is all over the place, it becomes warm in January, then the next week it is really cold."

Ulujuk Sateana of Kangiqliniq (Rankin Inlet) is concerned by the lack of snow compared even to 20 years ago:

"Twenty years ago, we had tons of snow on our rooftops and the temperature was mostly around -50 °C. Even during our spring fishing, we would have to shovel three to four feet of snow in order to drill through the ice. Today, the temperature is warmer and there's hardly any snow according to our local hunters. Their snowmobiles are having some ski-rod issues due to no snow out in the hunting land area."

A younger voice

The young people of the North are very concerned about the climate change to come. Katie Yu, a 15-year-old grade 10 student in Iqaluit (Fig. 2), has become a vocal activist:[3]

"Our northern community is warming about three times faster than the global average. This is already thinning the sea ice that many of us (and Arctic species) depend on for hunting and land travel as well as thawing the permafrost that underlies our roads, water systems and buildings. I want Arctic ecosystems to be preserved because with that comes appreciation of the land and preservation of Inuit culture, along with food security, good health and wellbeing."

Our future

In this series, we have touched on several aspects of our way of life and culture as they relate to chemistry. Our culture and our way of life are inseparable.[2] As the Inuit activist, Sheila Watt-Cloutier has stated:[4]

> *Inuit people have a right – a human right – to be cold.*

Our culture will always survive – and Canada will be richer for our contributions. However, we fervently hope that our way of life can be saved.

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FIGURE 2

Katie Yu in front of a *qaggiq* (large communal igloo) near Iqaluit, NU. Credit: © Katie Yu. https://wwf.ca/stories/what-youth-can-do-to-fight-climate-change


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