

PROPERTIES OF GLACIAL, ICEBERG AND PERMAFROST WATER

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Summary

The most precise method of obtaining age-depth relationships is by counting seasonal changes distributed by $\delta^{18}\text{O}$, dust particles or acidity. Beyond the Holocene or latest Pleistocene in the case of GISP2, less precise methods are used such as (1) matching reference horizons of known age; for example, in the Byrd core by volcanic acidity maxima; (2) radioactive dating of carbon-14; by $^{36}\text{Cl}/^{10}\text{Be}$ ratios, or for a short term, ^{32}Si or ^{210}Pb ; (4) matching of the δ record with another dated climatic record, principally deep sea records; and (5) by the less precise method of ice flow models.

Examination of climatic records shows that solar minima correlate not only with increased cosmogenic production, as evidenced in the ^{10}Be record over a solar cycle, but also with periods of lower temperature. The ^{10}Be profiles in both Greenland and Antarctic cores match very well and are well correlated with atmospheric $\Delta^{14}\text{C}$. A detailed comparison of ^{10}Be and $\Delta^{14}\text{C}$ improves the depth–age relation for the ice cores.

Ground ice may be dated using ^{14}C from air bubbles and from organic material incorporated into ground ice. Air bubbles in ground ice may give valuable information

about genesis and age of the ice. Tabular massive ground ice has been dated in the Pleistocene Mackenzie Delta at Peninsula Point by Late Wisconsin. By means of AMS, the ice wedges themselves can now be dated directly by their organic remains found in the ice. Direct ^{14}C dating of Late Pleistocene and Holocene ice-wedges by AMS, shows a clear age stratification of the ice wedges. Tritium in permafrost mainly associated with modern ice formation. Ice body of Miocene age has been found in Beacon valley in the Dry valley region, Antarctica. It is of interest that oscillations of $\delta^{18}\text{O}$ in syngenetic ice wedges are close to $\delta^{18}\text{O}$ variations in another Quaternary cryosphere objects (i.e. ice cores) for the same time interval.

Properties of different forms of ice use to study of environment, palaeoclimatic changes, modern condition for building constructing and future.

1. Palaeoclimatic Studies

Palaeoclimatic studies in glaciers, ice sheets and ground ice first of all connected with precise **dating** of ice age. The most precise method of age–depth relationship is seasonal variations of $\delta^{18}\text{O}$, δD dust particles or acidity counting. The chronology of GRIP core in Greenland is determined by counting annual layers back to 14 500 years and beyond this date, by ice flow modeling. Annual layers have been counted back almost 80000 years in the GISP2 core (in Greenland also). Beyond the Holocene or latest Pleistocene in the case of GISP2, less precise methods are used such as matching reference horizons of known age; for example, in the Byrd core by volcanic acidity maxima; radioactive dating of carbon-14; by $^{36}\text{Cl}/^{10}\text{Be}$ ratios, or for a short term, ^{32}Si or ^{210}Pb ; matching of the δD and $\delta^{18}\text{O}$ records with another dated climatic record, mainly deep sea records; and by the less precise method of ice flow models.

The incorporation of radioisotopes into ice layers involves contributions from three types of material: gas trapped from ambient atmosphere, atmospheric particulates of contemporary origin (e.g. biogenic material) or having quite different radioisotope content (e.g. wind-born loess and volcanic ash), ice irradiated *in situ* by cosmic rays during the period before it becomes buried to a depth of the order of 10 m, when self-shielding reduces radioisotope production to insignificant levels; *in situ* production also occurs at the margins of the ice sheets, where old ice is again exposed to a cosmic rays; the ratios of ^{14}CO to $^{14}\text{CO}_2$ are not the same for *in situ* and atmospheric ^{14}C transferred to ice. In the case of ^{14}C , about 60% of the radioisotope produced *in situ* during ice formation is retained as ^{14}CO and the remainder as $^{14}\text{CO}_2$ – providing a signature for *in situ* produced ^{14}C (atmospheric ^{14}C occurs as CO_2 with much less than 1% CO). Age of carbon dioxide from air bubbles has been obtained in Dye 3 (Greenland); the corrections were made according to counting annual layers. At the depth 1665 m corrected age of the ice is 6790 +310/ –330 yr, 1709 m - 7670 +170/ –190 yr and 1777 m - 9670 +420/ –580 yr (Andree et al., 1986).

Development of AMS techniques made possible measurements in ice of longer lived radionuclide such as ^{10}Be , and ^{36}Cl . Be^{10} in ice cores is useful for monitoring short-term solar cycles because it has a short residence time in the atmosphere (about 1.5 yr). The Be^{10} record from Dye 3 extends back to 1423 AD with continuing evidence for the 10.8-yr cycle despite the absence of sun spots during the Maunder Minimum (1645 to 1715

AD). Maunder Minimum also is known as Little Ice Age because of the sustained low temperatures recorded in Europe with winter fairs being held on the frozen Thames. Other broad maxima in both radiocarbon and Be^{10} concentrations coincide with Sporer (1420 to 1540 AD) and Wolf (1280 to 1350 AD) minima. Maxima with periods of 93 and 202 years are also seen in Be^{10} data from the Milcent ice core (Greenland) and core from the South Pole. Combined results from Camp Century (Greenland) and Dome C (Antarctica) ice core for the period 2500 BC to 1000 AD also show a considerable similarity in the major features and good concordance with tree ring ^{14}C record (Beer et al., 1988). Examination of climatic records shows that solar minima correlate not only with increased cosmogenic production, as evidenced in the Be^{10} record over a solar cycle, but also with periods of lower temperature. A total depth of 2500 m has been sampled at Vostok, Antarctica, to provide Be^{10} information to an age of approximately 220 ka (Petit et al., 1999). The Be^{10} profiles in both GISP2 and Siple Dome cores match very well and are well correlated with atmospheric $\Delta^{14}\text{C}$. A detailed comparison of Be^{10} and $\Delta^{14}\text{C}$ improves the depth–age relation for the ice cores. Measurements of Be^{10} in an ice core from Camp Century show a dramatic increase in radionuclide concentrations at depths corresponding to the end of the last period of glaciation (approximately 11 ka BP) as defined by $\delta^{18}\text{O}$ results for the same core and hence the ambient temperature during formation of each ice layer (Beer et al., 1988).

Ground ice may be dated using ^{14}C from air bubbles and from organic material incorporated into ground ice. Air bubbles in ground ice may give valuable information about genesis and age of the ice. Tabular massive ground ice has been studied in the Pleistocene Mackenzie Delta at Peninsula Point. ^{14}C age estimates for the gases trapped in the ice range from 13860 ± 100 BP to the greater than 32000 BP. (Moorman et al., 1996). Age of the ice-wedge ice has been determined by ^{14}C measurements from CH_4 in the air bubbles. Obtained ages of ice wedges in Oiyagoskii Yar is 3539 ± 87 yr. BP, and in Big Lyahovsky Island is 4782 ± 113 yr BP (Morizumi et al., 1995).

The Sajama cores contain intact insects; insect fragments and polylepis bark fragments that allowed AMS ^{14}C dating to constrain the time-scale. The sample was divided into two portions that gave dates of $24\,950 \pm 430$ $^{14}\text{C}_{\text{cal}}$ yr (Lawrence Livermore National Laboratory) and $24\,020 \pm 140$ $^{14}\text{C}_{\text{cal}}$ yr (Woods Hole Oceanographic Institution) ago. These dates confirm that the near-basal ice on Sajama is of Late Pleistocene age (Thompson et al., 2000).

Direct ^{14}C dating of Late Pleistocene and Holocene ice–wedges by AMS, shows a clear age stratification of the ice wedges. Six sites in the Siberian permafrost was investigated (Vasil'chuk et al., 2000a, 2001, 2002). The first site is located near the Seyaha settlement in the central part of Yamal Peninsula, at the coast of the Ob Bay (70°N , 72°E). The second site is located in the Shchuch'ya River valley, in the southern part of Yamal Peninsula ($67^\circ10'\text{N}$, $69^\circ5'\text{E}$). Direct dating of Late Pleistocene and Holocene syngenetic ice wedges was done on organic material included in the ice. The time of formation (in ^{14}C years) is 21 000–14 000 BP for Seyaha, and 7100 BP for Shchuch'ya River (Vasil'chuk et al., 2000).

The most important results are the AMS–dating of organic material of micro inclusions directly from Late Pleistocene ice–wedge ice of ice–wedge complex Bison, located on

the right bank of Lower Kolyma River (Northern Yakutia) , in a mouth of Lakeevskaya creek (69°N, 158°E). The in details tested fragment of ice wedge, height 5 m in the main exposure wall is dated on microorganic from 26.4 up to 32.6 thousand years (8 radiocarbon dates): Zelyony Mys (28-13 ka BP), Duvanny Yar (31-23 ka BP), Plakhinski Yar (17 ka BP) in Lower Kolyma River valley and Mamontova Gora in Aldan River valley (19-17 ka BP). A result of ^{14}C AMS-dating of Late Pleistocene syngenetic ice-wedge ice provided precise setting of detail stable isotope plots to a geochronological scale (Yu.Vasil'chuk et al., 2002, 2004).

Both the structure and composition of syngenetic ice wedges have been preserved from their time of formation until today. The $\delta^{18}\text{O}$ and δD values in modern ice-wedges correlate well with mean winter temperatures: the ice formed from the melt water, which penetrates into the frost cracks in early spring, and which had its origin from winter precipitation. Based on $\delta^{18}\text{O}$ and δD measurements collected for many ice wedges from the permafrost zones in Northern Eurasia and Northern America and meteorological data, an empirical relation between $\delta^{18}\text{O}$ values of the ice and winter temperatures could be deduced. Assuming that the relationship derived from modern ice wedges can also be applied to Late Pleistocene and Holocene conditions, therefore, $\delta^{18}\text{O}$ and δD values in ancient ice-wedges enable the reconstruction of paleotemperatures. Radiocarbon dating of organic material yields a timescale (in BP) for such palaeotemperature records.

Caves containing ice bodies occur in many parts of the world. Ice-cave is essentially frozen ground water that had been in contact with the soil atmosphere and contains more than 1000 of CO_2 carbon kg^{-1} ice. The ice is easy to date as it contains by polar ice core standards, very large quantities of CO_2 . Wilson and Donahue (1992) obtain ancient dates (1.8-1.7 ka BP) from the ice caves in New Mexico for both a normal sample and the ice that entrapped it.

Tritium (^3H) is a radioactive isotope of modern age with a short half-life (12.43 years). Its detection in the upper layers of permafrost, in the active layer, and in seasonal ice bodies is useful in determining recent water migration into permafrost, the age of seasonal frost mounds, or recent ice wedge growth. Tritium in permafrost mainly associated with modern ice formation. In modern injected sheet ice and small pingo the maximum tritium concentration was 323 TU and the mean concentration was 191 TU.

2. Physical Properties

Very few glaciers show the entire sequence: dry snow zone, percolation zone, wet-snow zone, superimposed-ice zone. The transformation of snow to ice in the percolation and wet snow zones differs from that in the dry snow zone. A superimposed-ice zone represents the extreme case. Crystal size increases at a constant rate if the temperature remains constant. A single ice crystal deforms under an applied stress. A single ice crystal normally deforms by gliding on its basal planes. In glaciers and ice sheets, the ice is deformed for hundreds or thousand of years. Ablation includes all processes by which snow and ice are lost from the glacier. Ice in glaciers is re-crystallizing continuously. Crystal size of the ice depends on salinity. The ice grain diameter, density and shear modulus increases with the increase of the depth. Porosity of solid transparent

ice is as high as 1 kg (cm³/kg) of solid sea ice is 1–50 cm³/kg. Effective thaw heat of sea ice decreases abruptly with increase of salinity. The regelation is a moving of heavy thing throughout the ice without any ice disturbances. Due to molecular thermal oscillations and defects of ice crystals the water molecules can diffuse. The electrical properties of ice are distinguished by the fact that the charge carriers in ice are protons (Bogorodsky, Gavrilov, 1980; Hondoh, 2000).

Mass balance studies of glaciers are concerned with changes in the mass of a glacier and the distribution of these changes in space and time. More particularly, to measure the change in mass in given year. Such studies form important link in the chain of events connecting advances and retreats of glaciers with changes of climate. Climate fluctuations caused variations in the amount of snow that collects on the glacier and in the amount of snow and ice lost by melting. Accumulation and ablation represent the income and expenditure terms in the glacier's budget. Accumulation normally takes place at or near the glacier surface. Ablation includes all processes by which snow and ice are lost from the glacier. Melting followed by run-off, evaporation, removal of snow by wind, the calving of icebergs are examples.

In glaciers and ice sheets there is an upper layer some 15-m thick, in which the temperature varies in response to seasonal changes in surface temperature. In winter the ice is warmer than the air and so the heat is conducted upwards through ice. Changes of surface temperature with periods much greater than one year, such as those due to climatic changes, penetrate to depth much greater than 20 m. In the most areas, the mechanism of heat transfer in the surface layers in summer differs from winter mechanism. Except in the interiors of Greenland and Antarctica, or near the tops of some very high mountains, there is enough heat in summer to cause melting at the surface. The mean annual air temperatures at 10-m temperatures at the stations in dry snow areas of Greenland and Antarctic are very close – Greenland: Camp Century –23.5 – air, –24.5 – firn; Station Centrale –28.3 – air, –27.6 – firn; Northice –30.0 – air, –28.0 – firn; Antarctic: Byrd –28.2 – air, –28.3 – firn; Vostok –56.6 – air, –60.2 – firn; South Pole station –49.3 – air, –50.8 – firn (Paterson, 1981).

Geophysical classification of glaciers bases on ice temperature and mount of surface melting. This categories are temperate, sub-polar, and high polar.

A temperate glacier, as usually defined, is one in which the ice at the melting point throughout except for surface layer, some 15 m thick, is subject to seasonal temperature changes.

Temperature data from glaciers in the Alps are evidenced that accumulation areas at high elevations are not temperate. On Mon Blanc the 15-m temperature is –16.7°C at 4785 m elevation, –10.5°C at 4250 m, and –7.3°C at 3960 m. In Austria, where precipitation is less than in western Alps, the 15-m temperature in the upper part of the ablation area of Hintereisfener Glacier is –1 to –2°C. Only accumulation areas below 3800 m in Alps are temperate, although the critical elevation varies with the aspect of slope.

Deformation in glaciers is simpler than in rocks because there is only one driving force, gravity. Unlike rocks, the ice is a single substance, although the superimposition of several phases of deformation can make its structure extremely complex. Ice deforms sufficiently rapidly that deformation rates can be measured and estimated of total strain made.

Porosity normally is characterized by ratio between total pore volume and sample volume or sometimes total pore volume of 1 kg ice (cm^3/kg). Porosity of solid transparent ice is as high as 1 kg (cm^3/kg) of solid sea ice is 1–50 cm^3/kg . Under high thermodynamic or mechanic action the porosity increases to 10–100 cm^3/g and ice become cloudier. The ice with high porosity (50–400 cm^3/kg) looks like snow.

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Biographical Sketches

Vasil'Chuk Yuriy Kirillovich, Doctor of Sciences, Professor, Academician of the Russian Academy of Natural Sciences (2004, Corresponding Member - 2000), Professor of Cryolithology and Glaciology Department, Head of Regional Engineering Laboratory, Lomonosov's Moscow State University, 119992, Moscow, Lenin Hills, Lomonosov's Moscow State University, Geology Faculty, Engineering and Ecological Geology Department, Main Building, Zone A, room No 111. Prof. Vasil'chuk Yuriy Kirillovich was born in 1954 in Lazo, (Moldova). He graduated Lomonosov's Moscow State University with excellent degree in geocryology and glaciology in 1975. He received a PhD in 1982 and Doctor of Sciences degree in 1991. He is Academician of the Russian Academy of Natural Sciences from 2004. Since 1992 he is a head of Glaciology and Geocryology Data Centre of Theoretical Problems Department of Russian Academy of Sciences. Since 1996 he serves as a professor of Cryolithology and Glaciology Department of Geography faculty of Lomonosov's Moscow State University and from 1997 as a Head of Regional Engineering Laboratory of Engineering and Ecological Geology Department of Geology faculty of Lomonosov's Moscow State University. His principal science interests are in area of isotope geochemistry, geochronology, Quaternary Geology, stratigraphy, geocryology, glaciology and geomorphology. He undertook field investigations in nearly all permafrost regions of Eurasia, such as Gydan and Yamal Peninsulas in the North of Western Siberia, Central and Northern Yakutia, Chukotka, Magadan region, Trans-Baikal region and Arctic Islands. Yu.K.Vasil'chuk is the author of over 200 publications, from them there are 7 monographs, such as: "Oxygen-Isotope Composition of Ground Ice" (Application to paleogeocryological reconstructions) 2-volum issued in 1992 and the textbook "Principles of Isotope Geocryology and Glaciology" (coauthored with Academician RAS V.M.Kotlyakov) issued in 2000 et al., about 20 papers he has published in "Transactions of Russian Academy of Sciences" and more than 25 ones in the International Journals, such as *Radiocarbon*, *Permafrost and Periglacial Processes*, *Nuclear Instruments and Methods in Physics Research B*, *Earth and Planetary Science Letters* etc. His recent textbook, "Soil Engineering» (2005, Lomonosov' Moscow University Press), was co-authored with V.T.Trofimov et al. This textbook characterized the ground ice as a base for constructions. Currently he prepared the new book "Ice wedge: Heterocyclity, Heterogeneity, Heterochroneity" issued in 2006.

Vasil'chuk Alla Constantinovna, PhD, Senior Researcher of the Geography Department, Laboratory of Geoecology of the North, Senior researcher, Moscow State University named M.V.Lomonosov, Vorob'yovy Hills Moscow, Russia, 119899. Dr.Alla Vasil'chuk was born in 1955 in Grozny (formerly USSR). In 1973 she has attended a Russian secondary school in Grozny with gold medal. She graduated

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