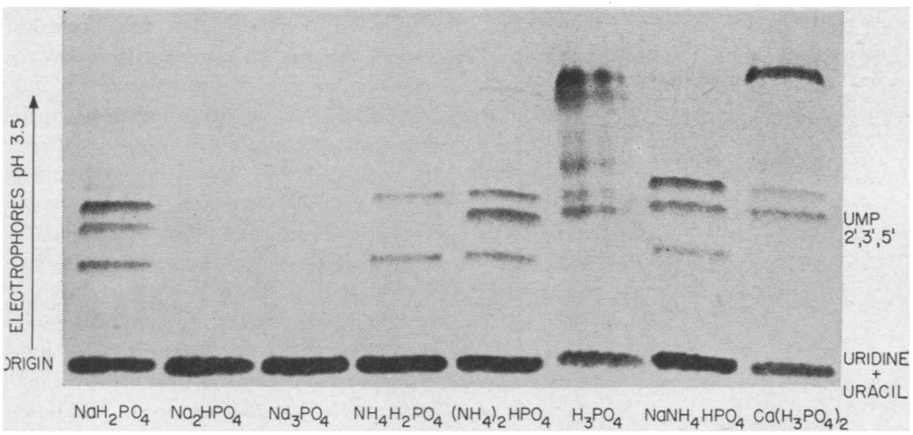

Fig. 4. Autoradiograph showing reaction between ^{14}C-uridine and different sources of phosphorus. Electrophoresis of products at *p*H 3.5.

the total monophosphate formed reached a peak around 4 hours and remained fairly constant, with a gradual decline after 8 hours. After 2 hours, the cyclic phosphate was present in greater amount than the noncyclic. This established that some cyclization process was taking place. The 2′-, 3′-, and 5′- were perhaps being converted into cyclic forms. We have so far identified only the cyclic 2′,3′-monophosphates.

The percentage yields of monophosphate of different types of nucleosides were adenosine, 3.1; guanosine, 9.8; cytidine, 13.7; uridine, 20.6; thymidine, 6.3. Thus uridine monophosphate was obtained in highest yield and adenosine monophosphate in lowest. The pyrimidine nucleosides gave higher yields than the purine nucleosides.

We also have preliminary evidence for the presence of dinucleoside phosphates ApA, GpG, UpU, CpC, and TpT (A, adenosine; G, guanosine; C, cytidine; U, uridine; T, thymidine). Their presence was indicated by the relative rate of migration at *p*H 3.5 (*6*) and separation by paper chromatography with a mixture of 95 percent ethanol and 1*M* ammonium acetate (5:2 by volume) (*7*). Further examination of this product is necessary before its identity can be definitely asserted. There is also an indication from the electrophoretic migration that the nucleoside diphosphates and nucleoside triphosphates are formed in this reaction.

It has been successfully demonstrated that methane, ammonia, and water can, by the action of various forms of energy, give rise to some of the constituents of the nucleic acid molecule and of the protein molecule. Different solutions to this problem have been proposed. Amino acids have been copolymerized to give compounds of high molecular weight by heating them in the absence of water (*12*). Dehydrations have also been effected in dilute aqueous solutions (*13*). In our laboratory several possibilities have been studied—dry conditions, a dilute aqueous milieu, an environment with a relative absence of water, and reactions in contact with the surface of a clay bed (*14*).

We have presented the results of reactions in an environment with a relative absence of water. Since water is not incompatible with this reaction and does not hinder it unless present in large excess, the conditions under which the reaction proceeds may be described as hypohydrous. The maximum temperature was 160°C. Whereas we obtain a yield of about 20 percent at that temperature in 2 hours, experiments at 80°C have given us a yield of monophosphate of about 3 percent in 12 days. The 3 percent was made up of 2′-, 3′-, and 5′-monophosphates and cyclic 2′,3′-phosphate. At this temperature the yield of dinucleoside monophosphate was about 2 percent. At a temperature lower than 80°C the reaction may still take place, but at a much slower rate. We do not know how catalytic or surface reactions could accelerate this process. Preliminary evidence from our own experiments suggests that the surface of clay can promote such a reaction. Our report establishes very clearly that the five nucleotides present in RNA and DNA can be prepared in good yield under conditions which may be considered to be genuinely abiotic and which could reasonably have existed on the primitive earth.

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29 March 1965

Late Glacial Ice-Wedge Casts in Northern Nova Scotia, Canada

Abstract. *Ice-wedge casts in northern Nova Scotia and the relation of the casts to the outwash that contains them indicate that the ice wedges formed in a permafrost environment after the accumulation of the outwash. This permafrost environment is tentatively correlated with pollen zone L-3 of the Gillis Lake deposit, Cape Breton Island, Nova Scotia, and with the Valders time of the midcontinental sequence.*

My observations indicate that the last Pleistocene ice sheet to cover northern Nova Scotia dissipated primarily by downwasting, probably by downmelting (*1*). When the crest of the Cobequid Mountains (Fig. 1) became exposed, the ice to the south between the mountains and Minas Basin stagnated and separated. Rivers of meltwater deposited valley trains south of the mountains. These valley trains merged into outwash fans where the valleys broadened and into deltas where the outwash reached the sea.

Casts of ice wedges are common in the outwash and are particularly well-

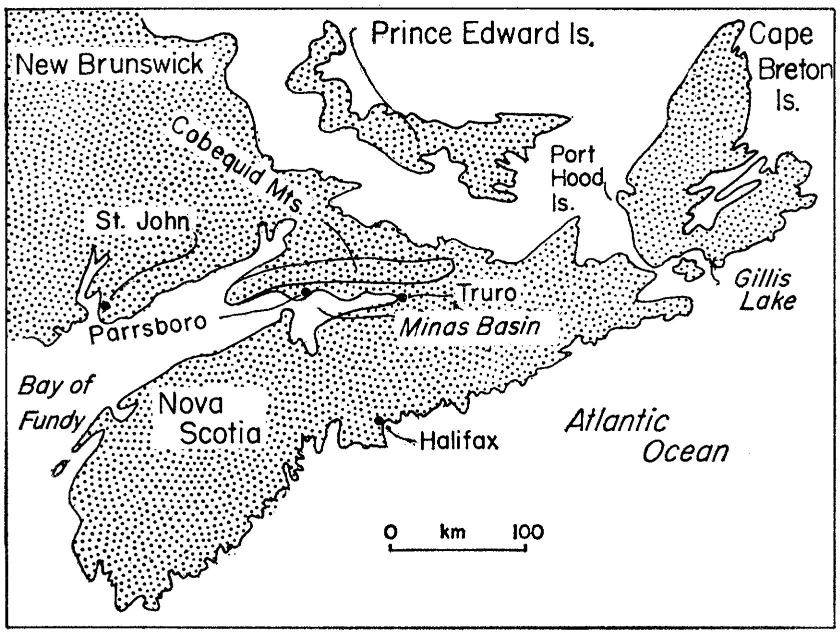

Fig. 1. Index map of Nova Scotia.

displayed in most of the exposures along the north shore of the Minas Basin and Cobequid Bay (Fig. 1). I have examined over 50 ice-wedge casts along the shoreline between Truro and Parrsboro (Fig. 1); of this number, 6 casts extended to a depth of over 3 m but less than 6 m, about 30 extended to a depth of approximately 1.5 m, and the remainder to less than 0.9 m. The best of these frozen-ground features can be seen in shoreline exposures of the outwash fans and emerged outwash deltas between Truro and Parrsboro. The largest ice-wedge casts were found along the seaward-facing shoreline exposure of the emerged outwash delta at Lower Five Islands (Figs. 2 and 3). Here, in spite of their excellent two-dimensional exposure, it was impossible to determine whether or not the casts were parts of polygonal fracture systems, unless large quantities of earth were moved. Several casts were excavated as much as 0.9 m into the cliff to determine that they actually were three-dimensional. The casts found in this exposure (Figs. 2 and 3) most probably developed in a permafrost environment, and there is no evidence to suggest that the smaller wedges were not formed contemporaneously.

The thickness of the structureless gravel, represented by distance between the surface and the top of the ice-wedge casts (Figs. 2 and 3), is considered to be the thickness of the active zone associated with the former ice wedges. In all the exposures examined, the depth of the active zone was never greater than 0.6 m. Presumably, permafrost existed below this level to at least as deep as the bottom of the deepest ice wedge.

In the zone between the Cobequid Mountains and the sea, the meltwater and outwash were intimately and extensively associated with masses of stagnating ice, as indicated by widespread areas of ice-contact stratified drift (that is, stratified drift deposited in contact with the melting ice) within, and adjacent to, the valley trains, outwash fans, and emerged deltas. Many of the stagnating ice masses melted completely before the outwash had stopped accumulating, and left depressions and other large structures caused by melting of the ice, which were then buried by later deposits. Nothing was found to suggest the presence in the area of outwash of more than one age.

An analogy can be drawn between this process of simultaneous melting of ice blocks and accumulation of outwash and processes that take place in some modern glacial environments of temperate climates. For example, Goldthwait and I have shown (*2*) that at the terminus of Kaskawulsh Glacier, Yukon Territory, separated ice blocks surrounded by outwash are melting into progressively lower, flatter, commonly discoid-shaped masses that are being buried by continuing deposition of outwash. Permafrost is not present in this outwash.

Although some ice masses in northern Nova Scotia completely melted during the accumulation of the outwash, some appear to have melted afterward. Outwash containing kettles is common south of the Cobequid Mountains, which implies that some ice masses melted after the accumulation of outwash had ceased. This temporal relationship may be explained in at least two ways. It would be expected that the larger ice masses would have melted more slowly than the smaller masses. This can be demonstrated, for example, at Port Greville, 16 km west of Parrsboro (Fig. 1), where a kettle hole, approximately 60 m in diameter

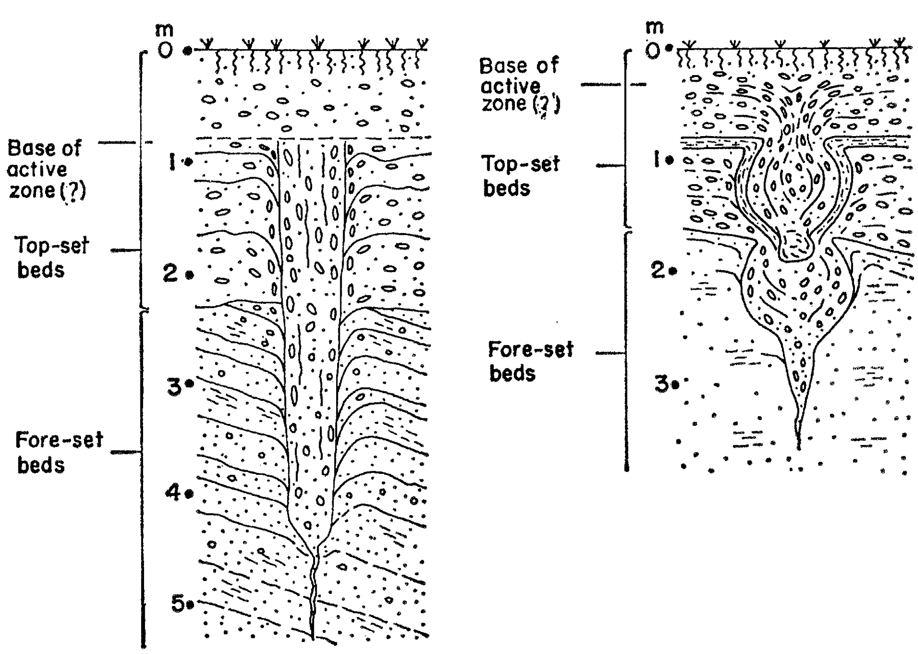

Fig. 2. Schematic diagrams of the two ice-wedge casts shown in Fig. 3.

and 9 m deep, developed after the cutting of the first terrace about 8 m below the depositional surface of the outwash. This relationship indicates that the peak of outwash aggradation at this place had passed before the melting of the ice mass.

However, the majority of kettle holes are smaller than the one at Port Greville. Depressions about 15 m in diameter and 6 m deep are more typical. Comparison with ice blocks of similar size that did melt completely when the outwash was accumulating suggests that many of the kettle holes developed during the accumulation of outwash, but were not filled by outwash because of the shifting positions of the meltwater streams.

The deglaciation pattern of this region and the great quantity of meltwater indicated by the amount of stratified drift show that probably a warming trend was in progress and that the environment was not "polar." The broad implication of a warming climate coupled with contemporaneous melting of stagnating ice masses and accumulation of outwash is not compatible with the existence of a climate in which permafrost would develop. Therefore, the colder environment in which the ice wedges developed postdated the dissipation of the last ice sheet to cover this region.

The last ice sheet is tentatively correlated with the ice sheet which constructed the end-moraine system that extends approximately 160 km roughly parallel to the coast, discontinuously from Cherryfield, Maine, through the Eastport, Maine, area to at least as far as St. John, New Brunswick. Ice was probably present here 13,325 ± 500 years ago (I-GSC-7) (*3*). Livingstone and Livingstone (*4*) concluded from their study of pollen that the last ice to cover the Gillis Lake area, Cape Breton Island, Nova Scotia, was of Cary age.

The end moraines at St. John, Woodstock, and Grand Falls, New Brunswick, and at St. Antonin, Quebec (*5*), are probably recessional features of this ice sheet. However, Gadd's inclusion of the St. Antonin moraine in the more extensive "highland front" morainic system suggests that the St. Antonin moraine may have stadial significance (*6*). The dissipating ice stood at St. John 13,325 ± 500 years ago and in the St. Antonin–Trois Pistoles area approximately 12,720 ± 170 years ago (GSC-102) (*7*), placing deglaciation within the limits of Port Huron time of the midcontinental sequence.

It is suggested that the pattern of deglaciation in most of Maine, New Brunswick, and Nova Scotia was primarily one of thinning, separation, and stagnation. While recessional moraines were being constructed by fluctuations of local ice margins, large stagnating ice masses were probably present throughout the region. The stratified drift containing the ice-wedge casts is associated with the dissipation of the ice sheet of Cary age.

Livingstone and Livingstone (*4*) correlate the L zones of the pollen sequence from the Gillis Lake deposit with those described by Deevey (*8*) from northern Maine and with events that produced the classic stratigraphic sequence at Two Creeks, Wisconsin. The age of 10,340 ± 220 years (Y-524) (*9*) at the top of zone A-1, immediately above the L-3 boundary, in the Gillis Lake sequence supports this correlation. Therefore, the stratified drift south of the Cobequid Mountains probably accumulated during the time span represented by the Gillis Lake pollen zone L-1 which Livingstone and Livingstone related to Port Huron (Mankato) time of the midcontinental sequence.

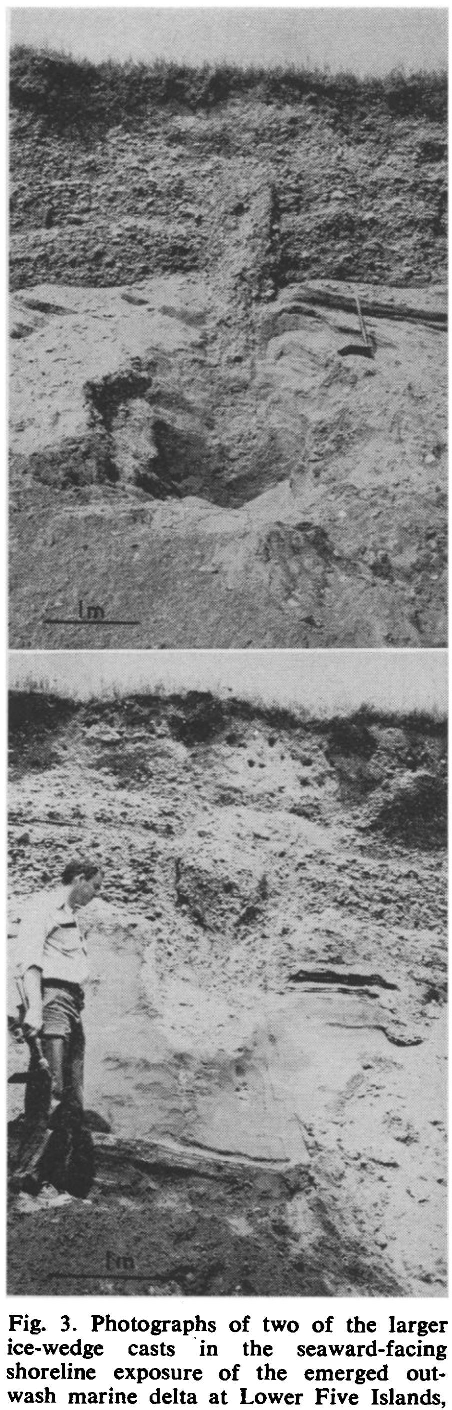

Fig. 3. Photographs of two of the larger ice-wedge casts in the seaward-facing shoreline exposure of the emerged outwash marine delta at Lower Five Islands, Nova Scotia, approximately 23 km east of Parrsboro (Fig. 1).

The ice wedges developed during a cold time following the accumulation of the stratified drift. If the above correlations are correct, the next cold time would relate to pollen zone L-3 from the Gillis Lake deposit which in turn would relate to Valders time of the midcontinental sequence.

Although the Gillis Lake area has been free of ice since Cary time, the possibility that other parts of Nova Scotia were covered with ice at later times is not excluded (*4*). Hickox (*10*) suggested that the Cape Breton Highlands supported an expanding ice cap after the Two Creeks interval. Take (*11*) disagrees with this, stating that this event took place at least 14,500 years ago, but has not presented supporting evidence.

Although the Nova Scotia peninsula is relatively low and broad, it is bordered by the Atlantic Ocean on the south and east and by the Bay of Fundy on the west, a geographic setting which was probably of primary importance in the development and maintenance of an ice cap during Valders time. Residual ice of Cary age may also have persisted along the axis of the peninsula because of this geographic setting, and perhaps thickened and flowed radially outward during Port Huron time. Whether this ice actually existed and whether it persisted or disappeared during the Two Creeks interval is not known.

My studies indicate that although the Cobequid Mountains were not a center of radial outflow after the dissipation of the last ice sheet to cover the region, they have supported more extensive and persistent snow accumulation than at present.

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29 March 1965

Low Deuterium Content of Lake Vanda, Antarctica

Abstract. *Lake Vanda in Victoria Land, Antarctica, is permanently ice-covered and permanently stratified, with warm, salty water near the bottom. Deuterium analyses of lake water from several levels indicate that the lake has a low deuterium content, and that it is stratified with respect to this isotope. This low deuterium content supports the evidence from the lake's ionic content that the saline layer is not of marine origin, and it indicates that evaporation from the ice surface has taken place. The stratification of the lake with respect to deuterium suggests that the upper and lower layers of water were formed at different times from different sources of glacial melt water.*

Lake Vanda, a permanently ice-covered lake lying in ice-free Wright Valley in Victoria Land, Antarctica (Fig. 1), has exceptionally high water temperatures near the bottom but is permanently stratified, due to the high salt concentration of this warm bottom water. Deuterium analyses of the water indicate that the lake has quite a low deuterium content and that it is stratified with respect to this isotope. Its low deuterium content supports the evidence from the ionic composition that the saline layer is not derived from sea water but results from the evaporation of glacial melt water from the ice surface of the lake. It is postulated that the lower, more saline layers, which are depleted in deuterium relative to the upper layers, formed at an earlier time than the immediate past, and from a different source of glacial melt water than the upper layers.

Within the lake there are four separate layers of isothermal, isohaline water, at depths of 6 to 9 m, 18 to 37 m, 41 to 42 m, and 62 to 63 m, in which convective circulations are undoubtedly occurring (Fig. 2). The water balance of the lake represents primarily the difference between inflow of glacial melt water and evaporation from the ice surface. The valley is extremely arid, and any snow which falls evaporates directly to the atmosphere and does not enter the lake as melt water. These matters and an analysis of the heat balance of the lake during the antarctic summer are discussed in detail elsewhere (*1*). The chemical composition of the water of Lake Vanda and Lake Bonney, another ice-covered lake in an adjacent valley, has been discussed by Angino and Armitage (*2*). The concentrations of the most abundant ions in the near-bottom water of these two lakes are given in Table 1.

The results of the deuterium analyses are given in Table 2 and are compared with the distribution of temperature and dissolved salts (expressed as conductance) in Fig. 2. The very low concentrations of deuterium (*3*) found in Lake Vanda indicate that the lake water has come from melting glacial ice and is not marine in origin, for the lowest δ for antarctic sea water is -0.1, compared with -27.3 to -29.0 for Lake Vanda. Furthermore, evaporation from the lake could only have increased these values. The stratification of deuterium raises several questions which may bear on the hydrologic history of the lake.

Representative values of deuterium concentrations for antarctic snow are given in Table 2. As might be expected from the discussion given by Friedman *et al.* (*4*), the deuterium concentration in antarctic snow tends to be smaller with increasing altitude and distance from the coast. That these findings are of significance to the present argument is clear when the geographical situation and inferred history of Lake Vanda are taken into account. Lake Vanda

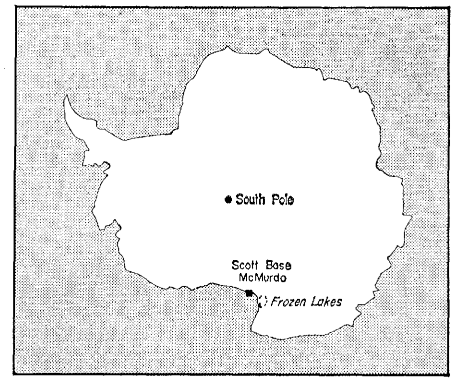

Fig. 1. Antarctica, showing location of frozen lakes in Victoria Land. Greenwich meridian is toward top of map.

lies at the lowest part of Wright Valley. This dry valley is blocked by glaciers at both ends; 26 km east of the lake the valley is blocked by the Lower Wright Glacier, a piedmont glacier which is not connected to the main antarctic ice sheet; to the west the valley ends at the Upper Wright Glacier, 17 km from the lake. This glacier flows directly from the main ice sheet. At present Lake Vanda is fed only by the Onyx River, a stream of melt water from the Lower Wright Glacier which flows only during the summer months. An old stream bed between the lake and the Upper Wright Glacier indicates that melt water flowed from this source at some time in the past. A series of well-preserved terraces indicates that the level of Lake Vanda was once at least 50 m higher than it is now.

The lowest concentration of deuterium in the lake occurs at 60 m ($\delta =$

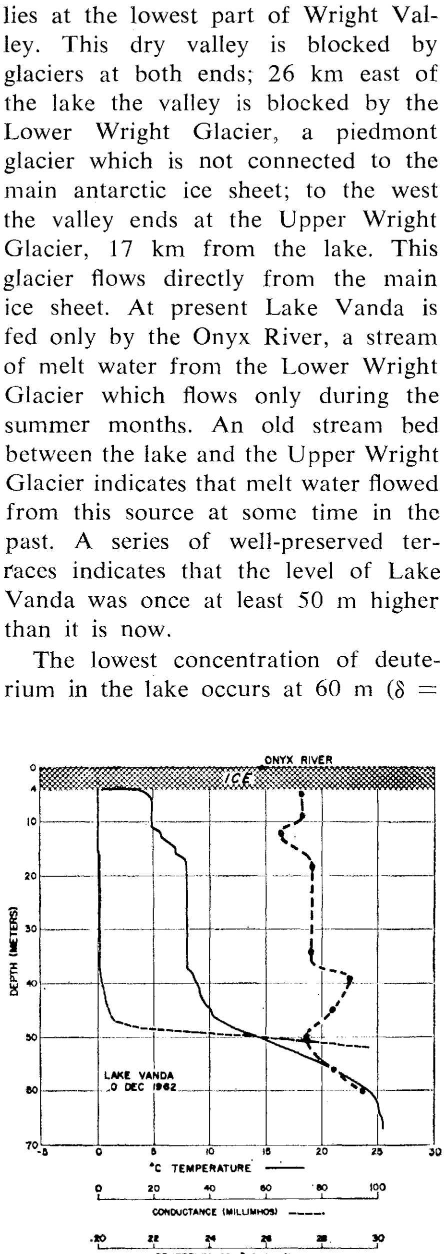

Fig. 2. Vertical distribution of temperature, electrical conductance, and relative deuterium concentration in Lake Vanda.