This was possible with the help of 70 painted stone cairns installed in the glacier forefield, their positions and altitudes being measured with theodolite and altimeter. Photographic pictures were very useful in this respect.

At the Arie Glacier forefield detailed geomorphological and geological studies were undertaken which resulted in constructing a map of the region in the scale 1:10,000. Besides making several pits and exposures, ten rock and morainic samples were taken from the region for laboratory examination.

The process of dead ice ablation under the morainic cover and without it and the process of melting-out and translocation of the rock surface material on the distal slopes of the Hans Glacier lateral moraine underwent careful observation and measurements. For comparison the ablation of the active part of the Hans Glacier near its end was measured. Five samples were taken for further analysis in Poland.

Observations and measurements regarding the development and distribution of the block covers on the ridges of the Fugleberget, Ariekammen, Skodefjellet and Rotjesfiellet mountains were also made as well as observations of rock forms on raised sea beaches in the vicinity of the Hornsund Base.

The *geophysical* investigations concerned glaciological problems to a considerable degree. The natural tremors of the Hans Glacier were studied on the basis of microseismographic recordings taken with the help of a vertical seismograph.

Apart from their research work the expedition members collected many specimens of rock and took photographs for didactic purposes.

The expenses connected with the stay of the expedition on Spitsbergen were covered by the Wroclaw University (food for 5 persons, medicine, the main part of the equipment, instruments, material and fuel), and by the Geophysical Department of the Polish Academy of Sciences (food and equipment for 1 person). For the first time in the history of Polish expeditions certain amounts of sauerkraut and apples had been taken which preserved very well over the larger part of the summer and were welcomed by the expedition members. To a considerable degree the equipment and the instruments that had been used in previous Spitsbergen expeditions were still available. Some of the equipment was borrowed.

It is expected that the publication of the material and the results of the expedition will appear in English (with Polish summaries) in one of the volumes of Geographical Studies of the "Acta Universitatis Wratislaviensis".

Since this summary report was written, the Geographical Institute of the University of Wroclaw sent another expedition to Spitsbergen, in the summer of 1971. The report on that expedition with some preliminary results of the work done during the two summers will appear in a future issue of *Arctic*.

There are certain grounds for expecting that after the successful series of expeditions in the years 1957-1962 the 1970 and 1971 expeditions were the first of a new series of four or five Polish expeditions that will be sent to Spitsbergen in coming years.

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Leader of the Expedition

Note on the No-stress Boundary Condition at the Edge of the Ice Pack

The theoretical modelling of the large-scale motion of the arctic ice pack is receiving increasing attention as the economic importance of the region increases. One of the most widely used types of model is the so-called "viscous fluid" model. The early development of such models has been described by Campbell[1]. Recent developments are described by Doronin[2], and by numerous authors in the AIDJEX Bulletin[3].

The boundary condition at the edge of the ice pack is an important feature of most such models. In some cases a no-slip condition seems appropriate, but in others, when the ice near the boundary has a low compactness (fraction of ice coverage) or the boundary occurs away from a coast, some other condition may be more appropriate. One that is often suggested is a no-stress condition, which is often assumed to imply that there is no velocity gradient perpendicular to the boundary. When the edge occurs away from a coast, the latter assumption is wrong.

It suffices for present purposes to assume that we are dealing with an incompressible two-dimensional fluid. In this case the viscous force per unit of area (corresponding to volume in three dimensions) is $\nabla\cdot(A\nabla\vec{v})$, where A is an isotropic but possibly variable coefficient of eddy viscosity, and $\vec{v}$, the large-scale averaged horizontal ice velocity, has components u and v in the x and y directions respectively. The notation $\nabla\vec{v}$, as used by Morse and Feshbach[4:65] is equivalent to the tensor $[\partial v_i/\partial x_j]$, where i and j vary independently over all coordinate directions, and $(\nabla\cdot\nabla\vec{v})_i = \sum_j \partial/\partial x_j\ (\partial v_i/\partial x_j)$. In the real ice pack one may want to allow A to be anisotropic but this is beyond the scope of, and irrelevant to, the present discussion.

Since the viscous force is the divergence of the stress, the quantity $A\nabla\vec{v}$ is often thought of as the eddy stress (or "internal ice stress"). That this is not true is easily seen by noting that the tensor $A\nabla\vec{v}$, to be referred to here as the "pseudo-stress" tensor, is not symmetrical. The non-diagonal elements of the stress tensor, which must be equal, are $\frac{1}{2}A(\partial v/\partial x + \partial u/\partial y)$.

The distinction made here is irrelevant in determining the viscous forces, since the stress tensor and the pseudo-stress tensor differ by a tensor of zero divergence (see also the "apparent paradox" given by Batchelor[5:148]). In large-scale ocean models which employ eddy viscosity, the stress itself is often required in connection with boundary conditions, particularly at the sea surface, or naviface (defined by Montgomery[6]). Here, however, those who use the pseudo-stress are saved both by scale considerations and by the fact that $w = 0$ (where w is the vertical or z-component of velocity), hence $\partial w/\partial x = 0$ and $\partial w/\partial y = 0$, at the naviface, so that the stress components there reduce to $A(\partial u/\partial z)$ and $A(\partial v/\partial z)$.

In the "viscous liquid" model of an ice pack bounded by open water, we at last have a case in which the distinction between real stress and pseudo-stress assumes geophysical importance. The boundary conditions can be found from the equation (3.3.19) of Batchelor[5]. Assuming (without loss of generality) that the edge is oriented with its outward normal in the first quadrant at an angle of θ to the x-axis, we have for the direction cosines:

$$n_1 = +\cos\theta$$
$$n_2 = +\sin\theta$$
$$t_1 = +\sin\theta$$
$$t_2 = -\cos\theta$$

The appropriate expression of the condition that there be no tangential stress at the boundary becomes:

$$\sin(2\theta)\left(\frac{\partial u}{\partial x} - \frac{\partial v}{\partial y}\right) - \cos(2\theta)\left(\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}\right) = 0$$

This is equivalent to equation (5) in §3 of Jaeger[7].

If the boundary is oriented along a coordinate axis this reduces to $\partial v/\partial x + \partial u/\partial y = 0$, which qualitatively means that shears at the boundary are permitted, provided that they are part of a locally uniform rotation and do not produce deformation of the ice field. If one also wishes to assume zero normal stress at the boundary, there is an additional condition given by:

$$\frac{\partial u}{\partial x}\cos^2\theta + \frac{\partial v}{\partial y}\sin^2\theta + \frac{1}{2}\left(\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}\right)\sin(2\theta) = 0$$

These are purely mathematical deductions; the appropriateness of the physical conditions is a more difficult question which can only be answered experimentally.

The physical condition of zero tangential stress qualitatively means that no deformation of the ice field can take place at the boundary. Techniques for measuring the deformation of the ice fields are now under development. It is suggested that it would be interesting to measure the deformation of ice fields near the boundary, even though a measurement of non-zero deformation (which the author suspects would be found, since external driving forces will in general tend to produce deformation) would not distinguish critically between the correctness of the boundary condition and the basic validity of the "viscous liquid" type of model.

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Growth of Spruce at Dubawnt Lake, Northwest Territories

The interesting note by Hansell *et al.*[1] on tree growth at Dubawnt Lake and on my statements concerning trees at Dubawnt, Ennadai, and Yathkyed Lakes[2] requires comment. Let me briefly state a few points: 1) The concept "tree line" is confusing since a lone tree far beyond the forest border must be included within the "treed" zone; 2) Dwarfed and decumbent black spruce (occasionally white or "intermediate" forms) exist over a wide zone north of the forest border in Keewatin and Eastern Mackenzie; individuals in favoured sites attain "tree" size ($\geqq$ 3 inches in diameter breast height, dbh); 3) While reproduction is primarily by layering (in black spruce at least), seedlings are consistently seen (I have a photo of one at the head of a grave on a hilltop at Ennadai, a site apparently rendered temporarily favourable by a picket enclosure); 4) Seedling mortality in all species in these areas is high, but species survival is most markedly conditioned by the frequency with which very severe seasons occur (i.e., a series of very cold summers); 5) Seedlings that survive a series of favourable years can then live and grow through a fairly long series of rather severe years; 6) At Ennadai and elsewhere, apparently anomalously successful young trees are in places found on exposed sites; they are not, however, a sure sign of a major climatic amelioration but of a few favourable years; 7) An extension of range of "trees" over a few miles, thus, does not in itself, to me at least, constitute indisputable evidence of an extension of the "tree line" especially if this has occurred within the existing range of spruce as a species; 8) The map as presented (p. 233) shows, in my view, the northward extent of the range of spruce, anywhere within which will be found the occasional "tree" on favoured sites, the result of some sequence of events permitting the individual to grow but not necessarily a general change in climatic conditions; 9) A much better indication of climatic change would be a shift in the position of the forest border, defined as the area where the (gently rolling) terrain is 50 per cent covered by forest and 50 per cent by tundra (for my delineation see Bryson[3] and Larsen[4,5]); 10) The comment that I say spruce has not re-established at Ennadai Lake is very misleading since I wrote that spruce is common at Ennadai Lake (part of which lies south of the forest border); my reference was to a grove of spruce (at the northern largely barren end of the lake) cut by natives many years ago which has not regenerated; 11) There is, in fact, a grove of spruce with individuals of dbh $\geqq$ 3 inches and basal diameter of $\geqq$ 8 inches near Yathkyed Lake (at 62°35′N., 98°52′W.) which would put the "tree line" far out into the barrens on the map as presented; 12) There is also a grove of spruce near the outlet of the Kamilukuak River (south end of Dubawnt at 62°41′N., 101°33′W.) larger and with larger individuals, if memory serves, than any mentioned in the literature.

These points are not to be interpreted as disbelief in climatic change. I agree, in general, with the summary Hansell *et al.*[1] present of recent climatic events. The topic invites speculation and, above all, more comprehensive field data from many places.

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