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Dynamics of Large Ice Masses

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A symposium, held by the International Glaciological Society under the organizing chairmanship of L. Gold, on the dynamics of large ice masses, took place at the Carleton University, Ottawa, between 21-25 August. It followed immediately on the symposium on the bed/rock interface held at the same venue the previous week (see *Geoscience Canada*, v. 6 no. 1). Over 100 people attended, many of them staying over from the previous week's symposium. There were nine sessions including ice sheets present and past, ice shelves, sea ice, valley glaciers and a final discussion. The lectures may as well have been divided into modelling of present and past ice masses, field measurements of ice flow and mass balance (principally in Antarctica) the internal properties of ice bodies, and a logically separate section on sea ice.

The symposium showed that glaciology is beginning to reap the benefits of modern technology in terms of satellite imagery and the use of sophisticated navigation equipment. Thus the blanks in our knowledge of the ice velocities (both vertical and horizontal) in Antarctica are slowly being filled in. This is enabling more accurate assessments to be made of the mass balance of this, the world's largest, ice mass. The first day of the conference in fact considered the state of our knowledge of general ice sheet dynamics (Budd) and the latest contributions to it, and of a specific area of the West Antarctic ice sheet (Whillans). Boulton and Jones presented a particularly interesting paper the same

day, in which they introduced a new complication to modellers in the form of beds deforming under the ice sheets. They then introduced their own ice sheet model which showed that deformable beds effect a lower ice sheet profile than a steady state one. If correct, this will ease our explanations of why and how the Wisconsin age ice sheets retreated so rapidly 10,000 or more years ago as there was less ice to go. Two papers in the same session, one by Lliboutry and another by Hutter and Legerer, gave theoretical considerations of ice masses. Field evidence from Antarctica was given in five papers and showed mass balances that vary between slightly negative and slightly positive. The main weakness behind these values is that while the surface velocity field and snow accumulation pattern is becoming better known, the vertical velocity profile of the main body of East Antarctic ice is still largely drawn from theoretical considerations. Robin welcomed the Antarctic mass balance estimates as they were close enough to a steady state to stand as evidence against the Antarctic surging at some time in the past. Up to now Wilson's theory of Antarctic surging and, more recently, Hughes' work suggesting that the West Antarctic ice sheet is unstable, have guided many researchers to investigate the role of an unstable Arctic ice sheet in effecting climatic change. Robin, however, together with the new mass balance data, presented good evidence in the nature of steady state isotopic profiles in ice cores and steady state layering in the Antarctic ice sheet (from radio echo sounding) to suggest that surging has not occurred for at least 50,000 years. It is unlikely to surge because the stiffness of the cold Antarctic ice and strong convergence of flow lines towards ice streams make for stable conditions.

The important Australian contribution to our knowledge of the East Antarctic ice sheet was strongly evident during the second day of the symposium. This group presented five papers which show they are concentrating on ice dynamics problems. Surface velocities and strain have been measured over large networks in East Antarctica and several surface-to-bed cores have been drilled. Another part of their work, consisting of a series of creep measurements on artificial ice and Antarctic ice from cores

in addition to bore-hole tilt measurements, stressed the importance of ice fabric, rather than texture, in enhancing ice flow.

The third day began with a session on past ice sheets. A group from the University of Maine, headed by Hughes, presented the theory and results of early and late Wisconsin age ice sheet reconstructions. The work was controversial and not too well received. There are criticisms that the model was incompatible with the field evidence. The models are in fact being fitted to only a part of the available field evidence. Drewry, on the other hand, presented good, although not necessarily conclusive, evidence for a considerably different ice age model for the Ross Sea Region of Antarctica.

The afternoon session on ice shelves was of a mixed nature. While Thomas reviewed the work done on Antarctic ice shelves, Robin introduced new ideas on freezing and melting at the sea/ice interface of shelves. Glaciological results of the Ross Ice Shelf Project followed, based mostly on radio-echo seismic and resistivity soundings. Bentley was co-author in five of these seven papers which discussed the irregularity of the bottom relief of the Ross Ice Shelf, lateral density differences, bottom crevassing and bottom melting and freezing zones there.

The Thursday morning was devoted to sea ice work. This session was poorly attended and showed a general lack of interest of glaciologists in this important branch of ice research. The invited papers were devoted to modelling, i.e., Rothrock on sea ice features and processes, and Hibler on large-scale dynamics. Rothrock reviewed the state of the art and the problems of calculating large-scale stress and then relating it to local processes. Hibler presented models to simulate various parameters such as average ice thickness, velocity fields and sea ice mass balance. He found that a rigid plastic approach produced more satisfactory results than a linear, viscous one. Four papers then dealt with energy transfer from the atmosphere into the sea ice and then into the ocean (by modelling techniques), predicting ice floe motion around the edge of the Arctic pack ice, calculating the compactness of ice floes and the mass balance of the Weddell sea pack ice. It is clear that the recent AIDJEX project has greatly

increased our knowledge of sea ice dynamics, particularly in the Arctic Ocean, but the problems are both immense and complex and much remains to be done. Ackley's paper on the Weddell sea ice and pack showed how different the much less restricted Antarctic sea ice patterns are compared to those in the Arctic Ocean and how even less is known about sea ice motions in the various southern oceans.

The last paper session, devoted to valley glaciers, was a mixed bag. Meier reviewed work on surging glaciers and stressed the many problems remaining to be solved. The other papers were mathematical analyses and modelling of glacier flow and calving. One paper was presented on the use of bubble elongation in ice to deduce glacier flow. There was also an out-of-place paper which showed the value of satellite imagery in a study of Icelandic ice masses.

The discussion on the final day suffered from the absence of many of the more established scientists, some of whom represented university groups that had presented papers during the week. The main topic discussed was modelling and the general consensus of opinion seemed to be that while we need a better understanding of the physical controls of ice caps today, models themselves may allow us to learn about some presently-unmeasurable parameters. In this respect Hibler's modelling of the Arctic Ocean pack ice provided a good example of how modelling should be handled. The rest of the discussion was rather unco-ordinated and tended to show that a large part of the audience was suffering from a glut of two weeks of new glaciological data and their interpretation which had stricken them with mental indigestion. However, some researchers will probably alter the direction of their work as a consequence of what they had heard. For example, despite several decades of work on the creep rate of ice, we still do not know well enough what effect impurities in the ice and the texture and fabric of the ice itself have on its creep rate. While Baker and Gerberith presented a paper on the effect of crystal size and its first solid inclusion, on the activation energy for creep of ice, this was just a start, and even then there were murmurings of disagreement. Budd's group in Australia are tackling the problem, but consider the c-axis orientation all-important. Yet,

as the present author and Fisher showed, ice of Wisconsin age in cores from the Devon Island and Ellesmere Island ice caps in the Northwest Territories has unique textural and impurity properties which give it a higher creep rate than ice of Holocene age. However, this ice does not have a c-axis fabric. More laboratory work on natural ice and more borehole deformation measurements are clearly needed.

The symposium will be published by the International Glaciology Society in approximately one year and it will constitute one volume of the *Journal of Glaciology*.

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