SYMPOSIUM ON GLACIER BEDS: THE ICE-ROCK INTERFACE. Ottawa, 15-19 August 1978. Journal of Glaciology, Volume 23, 1979. Organized by NRC Subcommittee on Glaciers, and sponsored by the Royal Society of Canada and Carleton University.

This symposium was particularly significant as it brought together glacial geologists, glaciologists, and others from around the world at a time when various workers are paying more and more attention to investigations in other disciplines in order to solve problems in their own areas. Over the last ten years, glacial geologists have not been satisfied with merely describing glacial deposits and landforms and speculating on their origin — they want to know how and under what conditions various types of glaciers produce certain features. On the other hand, glaciologists have looked toward the research results of glacial geologists in order to develop models and experiments to determine the behavior of glaciers and to explain the significance of direct glacier observations. The results presented at this symposium clearly indicate major advances in our understanding of glaciers and their effects and should act as a catalyst for further cooperative study.

The symposium was organized into ten sessions over a five-day period. The sessions accommodated invited and contributed papers, papers on current research, and discussion periods. The final session was reserved for a general discussion. Although the majority of papers were published in this volume, a number of significant contributions were not for a variety of reasons. However, the abstracts of all the presented papers do appear.

Session A, Erosion and Depositional Processes, was opened by G. S. Boulton who reviewed the processes of glaicer erosion on different substrata. He concluded that, on erosional bedrock landforms, plucking is quantitatively more important than abrasion. Further, in cases where the glacier bed is composed of unlithified sediment, subglacial measurements show that deformation can produce large discharges of subglacial material that may form the nuclei for the formation of drumlins. Two papers dealt with glacial abrasion. B. Hallet presented these preliminary results, based upon a quantitative model for abrasion by a temperate glacier with basal layers containing few rock fragments: other things being equal, abrasion is fastest where basal melting is most rapid; glacier thickness does not affect abrasion through its influence on basal pressures since these do not affect the stress changes at or near the sole/bed contact; and lodgment of rock fragments is only possible if the sliding velocity is very low, approximately equivalent to the rate of basal melting. W. H. Mathews simulated glacial abrasion by turning a grindstone made of ice and crushed quartz between two stone plates within a domestic deep-freeze. Limestone plates which were tested were eroded predominately by plucking, rather than by abrasion of individual crystals, whereas tested surfaces of granite showed abrasion features such as the formation of striations on individual crystals and rupture of cleavage planes along individual striae. Only the abstracts of the final two papers were published in this volume. R. J. Rogerson and N. Eyles discussed subglacial, englacial and supraglacial sediment differentiation and erosion in glacial basins, and I. M. Whillans analysed erosion by continental ice sheets. The latter contribution has been published in the Journal of Geology [V. 86 (1978): 516-524].

R. Vivian commenced Session B, The Nature of the Ice-Rock Interface, by presenting the results of investigations of the rock bed of temperate glaciers. Unfortunately his paper was not included in this volume, although it will be published in a future issue of the Journal of Glaciology. Using spectral power density to analyse wavelengths of longitudinal profiles of roche moutonées, J.-P. Benoist succeeded in quantitatively describing them with only a few parameters. The last paper of this session, by G. Laverdière, P. Guimont and M. Pharand, presented a tabular summary of glacier sole features classified by size and form.

L. Lliboutry presented the first of three invited papers in Session C, The Sliding Boundary Condition. He demonstrated through mathematical modelling that a unique sliding velocity exists for each t_B under any specified normal pressure. Weertman's law is then valid only for thick glaciers with subglacial waterways at approximately atmospheric pressure; otherwise one must consider normal stress in glaciers where interconnected hydraulic regimes exist (in other words, where the bed is not "water-tight"). J. Weertman discussed the earlier work of Nye and Kamb. He exphasized that more work is needed on regelation, cyclic creep, ice behaviour over cavities, and the nature of the basal water film. The abstract of the last paper, by B. Kamb, H. F. Engelhardt and W. F. Harrison, is a report of direct observation of basal sliding processes along the ice-rock interface beneath the Blue Glacier, Washington. An earlier paper reported much of this work [Journal of Glaciology 20 (1978): 469-508].

E. M. Morris began Session D, The Sliding Boundary Condition. Using equations of motion and heat conduction of ice flowing around a cylindrical solid inclusion and over a solid plane boundary, he demonstrated that unless a clast is far from the glacier bed, the classical regelation boundary conditions cannot be obeyed over the whole of its surface. Using a mathematical approach, A. C. Fowler concluded that regelation can be neglected in flow studies only if the bed roughness is about 1 mm. Also, arguments demonstrating that sliding laws are functions of temperature were presented. In the third paper, R. Brepson discussed simulated glacier sliding over an obstacle and observed that delayed elasticity of bubbly ice modifies drag behaviour, and that at the base of the ice a fine-grained bubble-free blue ice layer develops, which is not necessarily the result of regelation. Tertiary creep rates are enhanced by the presence of ions within the ice. W. F. Budd, P. C. Keage, and N. A. Blundy reported results of experiments simulating temperate ice. They were able to determine ice-sliding velocities for wide ranges of roughness, normal stress, and shear stress relevant to real glaciers. The abstract of the paper by W. F. Budd, B. J. McInnes and I. Smith dealt with the derivation of ice sliding properties from the numerical modelling of surging ice masses. The last paper of the session, by C. S. Weaver and S. D. Malone, discussed seismic evidence for discrete glacier motion at the rock-ice interface in Cascade Glacier, Washington. A stick-slip type of motion was observed, with more events being recorded in the summer than in the winter.

Section E, Physical and Chemical Properties of Debris-Laden Basal Ice and Remote Sensing, was opened by P. J. Gow, S. Epstein, and W. Sheehy's paper on the origin of stratified debris at the bottom of the Antarctic ice sheet. Stratified debris found within the lower 4.83 m of the ice sheet is believed to originate from "freezing in" at the base. In addition, the debris-laden ice is bubble-free, suggesting that the debris is not mechanically incorporated. S. Herron and C. C. Langway, Jr. described similar results from the base of the Greenland ice sheet, and similar conclusions were obtained from the Devon Island ice cap as reported by R. M. Koerner and D. A. Fisher, although some shearing is expected near the base. The last paper of the session concerned remote sensing. A.H.W. Woodruff and C.S.M. Doake suggested that polarization changes of radio waves could allow floating and grounded ice to be distinguished.

R. Souchez, M. Lemmens, R. Lorrain and J-L. Tison began Session F, Physical and Chemical Processes at the Glacier Bed, but only their abstract was published. Their topic was pressure-melting within the basal ice of an alpine glacier as indicated by the chemical composition of regelation ice. R. C. Metcalf followed with a paper on energy dissipation during subglacial abrasion at Nisqually Glacier, Washington. He found that subglacial abrasion involves brittle fracture and plastic deformation which act to dissipate basal sliding energy, assuming that the amount subglacially abraded is about equal to the suspended sediment flux. D. N. Collins outlined the results of work on an alpine glacier in Switzerland. He suggested that erratic variations of suspended sediment concentration in meltwater are due to rapid fluctuation and channel switching in subglacial areas, and also due to diurnal changes in water budgets. The paper by D. J. Goodman, G.C.P. King, D.H.M. Millar and G. de Q. Robin concentrated on the pressure-melting effects in basal ice of temperate glaciers. Among other points, they concluded that patches of basal ice may freeze to bedrock even in temperate alpine glaciers due to regelation. Two types of strain events were recorded from observations in a tunnel beneath Glacier d'Argentière: 1) rapid jumps or offsets in the recorded strain; and 2) strain excursions initiated by a change in strain over a period of up to 10 seconds and then a recovery over some minutes. W. H. Theakstone reported in his presentation that within cavities at the bed of the glacier Østerdalsisen in Norway the ice deformed under stress, but that some ice subjected to rapid strain failed in a brittle manner. He also noted that regelation ice formation has a significant influence on the distribution of rock debris at the ceilings of subglacial cavities. K. Tusima and S. Tozuka presented a paper concerning the importance of plastic deformation in regelation of ice.

Session G was devoted to reports on current work. Ten presentations were made and the abstracts published. Subjects discussed included ice sheet erosion; characterization of glacier beds; estimates of basal heat flux, basal sliding, melting, and velocity; glacier seismicity; and water movement at the base of ice sheets.

Session H was concerned with conditions at the base of Pleistocene Ice Sheets. S. R. Moran, L. Clayton, M. M. Fenton, L. D. Andriashek and R. Le B. Hooke's paper dealt with large-scale landforms on the continental glacier bed, including both descriptions and modes of origin. Once again, only the abstract was available for publication. B. E. Broster, A. Dreimanis and J. C. White commented upon the importance of bedrock wedging as a process in glacial erosion. It was suggested that detrital material can be forced down into pre-existing cracks, aiding joint development and eventually causing the entire bedrock block to be wedged out of position and transported. I. M. Whillans's presentation attributed the erosion of grooves on Kelley's Island, Lake Erie, to subglacial meltwater channels. R. P. Goldthwait discussed the same grooves, but argued for their creation by fast moving ice under compressive flow. The last paper was by T. J. Hughes, who discussed the CLIMAP project and his interpretation of the nature of Pleistocene ice-sheets.

Session I, Subglacial Hydrology, was the last session consisting of formally presented papers. S. M. Hodge reported on progress and problems of direct measurement of basal water pressure on South Cascade Glacier, Washington. He concluded that 90% of the bed is hydraulically inactive and that only a few active subglacial conduits were present. The sealed-off areas were thought to control large-scale changes in glacier sliding, and water pressures in active areas are 50-75% of ice overburden pressure. Therefore, sliding is controlled largely by the basal water pressure. The abstracts of the next two papers are published. These are by A. Iken, A. Flotron, W. Haeberli and H. Roethlisberger, on the uplift of the Unteraargletscher at the beginning of the melt season, and by W. St. Lawrence and A. Qamar, who discussed transient water flow in subglacial channels. B. Hallet presented a paper concerning subglacial regelation water film that outlined the evidence for precipitated carbonate deposits, associated solutional furrows, and chemical exchange at the glacier bed. Channelized water is chemically distinct from film water, as is proglacial stream water. One implication is that a temperate cirque glacier is separated from its bed by a thin water film. J. Walder and B. Hallet described the geometry of surficial features on recently deglaciated limestone bedrock, and used these to recognise formerly active processes. They concluded that a nearly continuous, non-arborescent network of cavities and incised channels existed as primary drainage for meltwater, 20% of the glacier sole was separated from the bed by water-filled cavities, and abrasion was locally intensified relative to chemical alteration in 5-10 m wide zones paralleling the ice flow direction. D. N. Collins dealt with the subglacial hydrology of two alpine glaciers. He found two internal hydrological systems which could be separated on chemical grounds. Increased ionic concentrations were noted in film waters relative to the values for conduit waters. B. Wold and G. Østrem presented results on investigations made during construction of a hydroelectric power station in Norway. They observed that most meltwater discharge from the Bondhusbreen Glacier flowed in a single main subglacial channel. The last paper presented in this session, by W. H. Theakstone and N. T. Knudsen, concerns the englacial and subglacial hydrology of Austre Okstendbreen, Okstindan, Norway.

Session J was a general discussion of the entire symposium. Discussion covered many of the points brought out during the formal sessions but centered around such items as the need for coordination and cooperation between glacial geologists and glaciologists, and areas where more work is required. For example, we need to know more about the method of incorporation of debris into ice and its influence on the physical properties and rates of abrasion of glaciers, the relative importance of plucking versus abrasion, the importance of subglacial streams in abrasion processes and modification of till, and the provenance of till. Some participants mentioned problems in flow law modelling, especially in regard to the assessment of creep rates. It was also thought by some that remote sensing methods may be valuable in solving some of problems discussed during the meeting.

All in all, the reviewers were impressed by the variety and scope of research that has taken place in the past few years in order to resolve various problems connected with glacier beds. Impressive also was the Organizing Committee's success in bringing together many of the key workers, both in glacial geology and glaciology, from around the world. Our main criticism is that not all eligible papers were published in this volume. The reviewers realize, of course, that if the volume is to be timely editors cannot wait forever for late contributions. We believe, however, that this volume will be a valuable reference for some time to come to those interested or actively engaged in glacial research.

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GEOBOTANICAL ATLAS OF THE PRUDHOE BAY REGION, ALASKA. By D. A. Walker, K. R. Everett, P. J. Webber and J. Brown. United States Army Corps of Engineers, Cold Regions Research and Engineering Laboratory. Hanover, New Hampshire, U.S.A. CRREL Rept. 80-14. 69 p. $25.00 U.S.

The publication of this atlas represents the culmination of a long-term study begun in 1971, conducted jointly by the U.S. Tundra Biome portion of the International Biological Programme and the U.S. Cold Regions Research and Engineering Laboratory. The study objectives were to: 1) document the history of industrial and scientific development in and adjacent to the region; 2) describe the environment in terms of climate, geology, soils and vegetation; and 3) describe mapping techniques and show how the methods are suited to the derivation of special purpose maps for land use consideration. A fourth objective, that of providing baseline data for monitoring future site changes, could easily have been added as the atlas provides this information very adequately. This latter objective would have been particularly appropriate as one of the aims of the International Biological Programme was to provide environmental monitoring sites.

The atlas is profusely illustrated in both colour and black and white and the text is clearly and concisely written. It measures 44.4 x 39.3 cm with map foldouts up to 1.2 m, and consists of seven summary papers and two appendices. The content of each of the papers is as follows:

Paper 1, by J. Brown, is an overview that outlines the objectives of the study and, through sequential chronological maps and aerial photographs at various scales, reconstructs the sequence of road and installation developments within the area from 1970 to 1977.

Paper 2, by K. R. Everett, outlines the geology and permafrost features and conditions within the area. It shows diagramatically the development of ice wedges and provides a cross-section indicating the relationship of various surficial deposits.

Paper 3, by D. A. Walker, summarizes climatic conditions providing basic information on temperature, precipitation, and wind velocity, frequency and direction (annually).

Paper 4, by K. R. Everett, focuses on landforms such as thermokarst lakes, polygonal ground, sand dunes, hummocky ground and pingos. Polygonal ground is subdivided into five landform units based on whether the polygons are high- or low-centered and on their location in the topography. Two black and white photgraphs, one aerial and one surface, illustrate each of the landforms described.

Paper 5, by K. R. Everett, describes the U.S. soil classification as it pertains to the area and gives brief description of Entisols, Inceptisols, Mollisols and Histisols. Colour photographs with descriptions of typical soils are presented.

Paper 6, by D. A. Walker and P. J. Webber, examines the vegetation in terms of soil moisture, temperature gradient from coast to inland, and soil pH. Four broad vegetation categories, based on aerial photographs, include: 1) vegetation growing on dry, barren or exposed sites (map code B); 2) vegetation growing on moist, well-drained upland sites or well-drained microsites (map code U); 3) vegetation growing on wet or lowland sites (map code M); and 4) vegetation growing on sites where water is present during the entire growing season (map code E). Each of these categories is further subdivided on the basis of associated plant species, i.e. B1 is a dry, alkaline tundra characterized by *Dryas integrifolia, Oxytropis nigrescens* and *Lecanora epibryon*, whereas in B2 *Saxifraga oppositifolia* replaces *Carex nigrescens*. Each in turn is related to the landform and soil type. Colour photographs of each of the vegetation categories are given. Disturbed sites are identified, classified and characterized in terms of types of disturbance and their effect on vegetation.

The final chapter presents a numerically-coded master map which outlines the distribution of dominant vegetation, soil type, landform and slope class. This is followed by specialized derivative maps, in colour,