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Article abstract

In papers published in 1895 and 1901, and in undated notes for a 1907 paper he did not deliver or publish, Robert Bell of the Geological Survey of Canada interpreted the pattern of glacial striae, stossing of rock knobs, and surficial sediment composition along the margins of Hudson Strait, between Labrador, Ungava Bay and Baffin Island, as evidence of what he called an ice-stream, a long river-like glacier, fed from Hudson Bay and Foxe Basin, that had moved eastward along the Strait during the Late Glacial period. This was the earliest mention of such a glaciological feature within the Laurentide Ice Sheet (LIS). It was not until ice-streams were recognized in the West Antarctic Ice Sheet in the 1970's that Bell's concept was revived in the next decade and subsequently, in recognition of several ice-streams within the Late Wisconsinan LIS.

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FIRST RECOGNITION OF A LAURENTIDE ICE STREAM : ROBERT BELL ON HUDSON STRAIT

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ABSTRACT. In papers published in 1895 and 1901, and in undated notes for a 1907 paper he did not deliver or publish, Robert Bell of the Geological Survey of Canada interpreted the pattern of glacial striae, stossing of rock knobs, and surficial sediment composition along the margins of Hudson Strait, between Labrador, Ungava Bay and Baffin Island, as evidence of what he called an ice-stream, a long river-like glacier, fed from Hudson Bay and Foxe Basin, that had moved eastward along the Strait during the Late Glacial period. This was the earliest mention of such a glaciological feature within the Laurentide Ice Sheet (LIS). It was not until ice-streams were recognized in the West Antarctic Ice Sheet in the 1970's that Bell's concept was revived in the next decade and subsequently, in recognition of several ice-streams within the Late Wisconsinan LIS.

RÉSUMÉ. *Première identification d'un fleuve de glace laurentidien : Robert Bell dans le détroit d'Hudson*. Dans des articles publiés en 1895 et 1901, et des notes inédites pour lesquelles il n'a pas donné suite ou publié, Robert Bell de la Commission géologique du Canada a interprété le patron des stries glaciaires, le profilage des collines rocheuses et la composition des dépôts superficiels le long des marges du détroit d'Hudson, entre la péninsule du Labrador, la baie d'Ungava et l'île de Baffin, comme étant les indices d'un fleuve de glace, un glacier s'apparentant à une rivière, comme il l'a nommé, alimenté par la baie d'Hudson et le bassin de Foxe, et s'est écoulé vers l'est à travers le détroit pendant la période glaciaire. Il s'agit alors de la première mention d'un tel phénomène pour l'inlandsis laurentidien. Il faudra attendre que les courants de glace de la calotte antarctique-ouest soient reconnus dans les années soixante-dix pour que le concept de Bell soit repris dans les années quatre-vingt et par la suite, par l'identification des nombreux courants de glace de la calotte laurentidienne au Wisconsinien supérieur.

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INTRODUCTION

The earliest modern recognition of an ice-stream within the Laurentide Ice Sheet (LIS) was by Hughes *et al.* (1977), where the most obvious example depicted occupies Hudson Strait. This important advance in the conception of the dynamics of the LIS and other Late Quaternary ice sheets was driven by recognition within the West Antarctic Ice Sheet (WAIS) of ice-streams — comparatively narrow zones of fast-moving, marginally crevassed ice flowing seawards between more extensive, higher, slower-moving or stagnant ice-plateaus (Hughes, 1977 ; Stuiver *et al.*, 1981 ; Bentley, 1987). Quaternarists researching palaeoglacial dynamics in Canada cautiously adopted the term ice-stream with the reconstruction of the LIS at intervals between 18 000 and 5 000 years ago by Dyke and Prest (1987a, 1987b). This reconstruction accorded more with field evidence than with the theoretical basis of the Antarctic Ice Sheet (AIS) and LIS reconstructions of Stuiver *et al.* (1981) and Hughes *et al.* (1977) respectively. Between 18 000 and 10 000 yr BP, the LIS reconstruction of Dyke and Prest (1987b) showed narrowly confined ice-flows, presumed or argued to have been basally lubricated, fast-flowing, often, but not exclusively, located over linear topographic lows. Examples later more fully studied include the St. Lawrence Valley (Parent and Occhietti, 1999), basins flooded by the Great Lakes (Breemer *et al.*, 2002), and Hudson Strait (Laymon, 1992 ; Manley, 1996), all now recognized as ice-streams.

The LIS now has its own ice-stream maps while the ice-stream paradigm has regenerated multi-pronged palaeoglacial and geomorphological researches (Winsborrow *et al.*, 2004 and references therein). It is not within the scope of this notice to discuss the profusion of recent researches on ice-streams, in particular those in Hudson Strait emanating from the Institute of Arctic and Alpine Research, University of Colorado, and the Geological Survey of Canada's Atlantic Geoscience Centre (the most relevant here being those of Laymon, 1992 ; Manley, 1996 ; Andrews and MacLean, 2003). The focus here is antecedent, and more so than hitherto recognized.

ROBERT BELL ON HUDSON BAY AND STRAIT

Robert Bell (1841-1917) began his half-century career with the Geological Survey of Canada in 1857, at the age of 16, when, after his father's early death the year before, he was signed on as an assistant in the Survey by its Director, Sir William Logan (Waiser, 1998). To 1866, Bell worked with survey parties in the Province of Canada (now southern Ontario and southern Québec), in Magdalen Islands and western Newfoundland in 1867. After five years as a professor at Queen's College/University at Kingston (1864-1868), he rejoined the Survey full-time in 1869, beginning several years of exploration as party chief in the Canadian hinterland of Lake Superior, westward to the Red River plain, eastward to Nottaway River and northward to Hudson and James Bays.

Bell's first close encounter with these bays was in 1877, when he canoed from Lake Superior up to Lake Missinaibi, and down the Missinaibi and Moose Rivers to Moose Factory on James Bay. From there, he followed the shore eastward and northward into Hudson Bay and along its east coast as far north as Portland Promontory (later Cape Harrison), the northern end of the Bay's great coastal arc, near present-day Inukjuak. Along the east coast of Hudson Bay striae showed westward flow (Bell, 1879 ; map in Bell, 1895). By 1890, Bell had mapped striae over the shield of what is now northern Ontario. They showed an overall southwesterly ice-flow. So, with eastern Hudson Bay striae, it was no great leap to infer long-distance flow across northern Ontario from an ice divide over Québec-Labrador (Bell, 1890), a divide confirmed by Low (1896). Brief visits to the west coast of Hudson Bay in 1884 and 1885 revealed easterly-directed striae, which led Bell (1890) to envisage Hudson Bay as the focus of ice-flows from east and west.

In 1878, Bell became involved with proposals for a railway from (the smaller province of) Manitoba to a port to be established on Hudson Bay, which would allow entry of expected immigrants, and to export of agricultural products from the Prairies. The Canadian Department of Marine and Fisheries was commissioned to assess ice conditions during the shipping season in Hudson Strait. It made four voyages for this purpose in 1884, 1885, 1886, and 1897. Bell was on each, except in 1886, acting as scientific and medical officer (he had qualified MD, CM at McGill in 1878).

Each voyage sailed from Halifax, in commissioned and commanded Newfoundland sealing vessels, north across the Gulf of St. Lawrence, down the Labrador coast to the first observation station at the mouth of Nachvak fjord (identified as 1 on Fig. 1). Six other stations, each named for the observer, and each with huts built for personnel and equipment, were established in 1884, at Port Burwell, near Cape Chidley (2), Port McNaughton, Resolution Island, on the north side of the entrance (3), Stuparts Bay, on the east side of Cape Prince of Wales peninsula, on the south side of the Strait (4), Ashe Inlet, on Big Island, on the north side (5), Port Boucherville, Nottingham Island, in northern Hudson Bay (6), Port Laperriere, Mansfield Island (7), and at Churchill and York Factory on the southwest coast of Hudson Bay. Prolonged stops at these stations allowed Bell to geologize, botanize, etc., also at intermediate stops, such as at the Ottawa Islands Group (as A on Fig. 1, named by Bell) in northeast Hudson Bay, Digges Island (8), close to Cape Wolstenholme (9), Southampton Island, and Marble Island, off Rankin Inlet, northwest Hudson Bay. Bell was able to examine rocks and landforms at each station during the 1-2 days taken to erect huts for observers and equipment.

BELL AND THE HUDSON STRAIT ICE-STREAM

Reporting on the first of his Hudson Bay and Strait voyages, Bell characterized the broad-scale glaciological picture, thus : "... the basin of Hudson's Bay may have formed a sort of glacial reservoir, receiving streams of ice from the east, north, and northwest, and giving forth the accumulated result as broad glaciers, mainly towards the south and southwest, and also to the northeast and east through Hudson Strait" (Bell, 1885 : p. 36-37).

1. Nachvak fjord
2. Port Burwell - Cape Childey
3. Port McNaughton - Resolution Island
4. Stuparts Bay - Cape Prince of Wales
5. Ashe Inlet - Big Island
6. Port Boucherville - Nottingham Island
7. Port Laperrière - Mansfield Island
8. Digges Island
9. Cape Wolstenholme - Southampton Island
10. Amadjuak Lake

FIGURE 1. Location of Hudson Strait and surrounding landmasses.

Localisation du détroit d'Hudson et des masses terrestres avoisinantes.

Although he had not visited the interior of what was then known as the Labrador Peninsula, Bell's explorations of the coasts of eastern Hudson Bay (1877), northern Labrador and Hudson Strait (1884, 1885) resulted in a paper on the peninsula (Bell, 1895), in which a large fold-out map depicted bedrock geology, glacial features, and forest limits from his own explorations and other sources. He might have felt rushed for publication, with results appearing of explorations of the interior by his younger colleague Low (Low, 1889, 1896). This densely informative map records easterly directed striae on the shores of Hudson Strait — across the tip of the Labrador Peninsula, around Stuparts Bay, on Big Island, and on Digges Island (these also with northeasterly striae). On ice-flow in Hudson Strait, Bell concluded "... along the north slope of the [Torngat] mountain chain overlooking the south side of Hudson Strait they [striae] all run eastward. The same course is maintained everywhere on the north shore of the Strait. The stoss or rounded ends of glaciated ridges on both sides are always towards the west, showing that during the glacial epoch a great ice-stream passed down the channel into the Atlantic. The composition of the drift on the shores of the Strait also proves this movement, its materials at any point having come from the westward. General conditions, both during the glacial epoch and at the present day, would also show that this must have been the direction of the movement in the valley now occupied by the Strait, since the course of glaciers has always been from the continent towards the ocean and not vice versa" (Bell, 1895 : p. 352-353).

Then, "[t]he very high and bold land at Cape Wolstenholme seems to have acted as a *piece de resistance* [sic] against the ice-stream from Hudson Bay. On outer Digges Island, off the Cape, ... the striation and the forms of the glaciated buttresses show that the ice here moved north-eastward, round the corner, as it were, ..." (Bell, 1895 : p. 353).

And, from evidence of northerly striae recorded on the Ottawa Islands, in northeastern Hudson Bay, and northeasterly striae on Digges Island, at the western entrance to the Strait, "... that part of the ice which lay upon its bed [of Hudson Bay] moved northward to join another stream from Foxe Channel, and ... the united glacier then passed down the great valley now occupied by Hudson Strait" (Bell, 1895 : p. 353).

In the two quotes immediately above, Bell's seemingly casual use of the term ice-stream for flow northward out of Hudson Bay, and the same for an ice-stream flowing south-eastward out of Foxe Channel, suggests that he had not perceived the dynamic difference between unconfined and confined flows. Further, while he made no comment on it, ice-flow features along and adjacent to the Hudson Strait shores are not deflected by topography, indicating the dominance of glaciological rather than topographic control of flow. In the late 19th century such considerations did not warrant the attention recently focussed on them by studies of extant ice streams.

Geological exploration played a more mainstream, rather than incidental, role on the 1897 ice-survey. As part of this exploration Bell walked with an Inuit companion about 150 km northward across southern Baffin Island, from Crooks Inlet (named for a distant ancestor) up Alice River (named for his second daughter), to overlook Amadjuak Lake (as 10 on Fig. 1). Although they do not figure on the map in the account of this exploration (Bell, 1901a), he made observations *en route* leading to significant conclusions on bedrock geology, Tertiary uplift, contrasts in glacierization between Labrador and Baffin Island, ice-flows, glacial deposits and landforms, two phases of glacier movement, ground-ice and thermokarst, and Siberian driftwood on emerged beaches (Bell, 1901a, 1901b).

On glacial effects in Hudson Strait, he wrote : "After the close of the Tertiary period, the elevated land on either side of Hudson Strait became covered with ice. A study of the glacial striae of those regions shows that in Baffin land, to the north of the great depression, ice moved southward and fell into it, while to the south, in Labrador and the southern part of the present bed of Hudson Bay it moved northward to the same huge reservoir [Bell's Survey colleague, Low, had made a similar walk to and from Wakeham Bay, Ungava]. The ice from both directions, which thus came together, filled the wide valley and moved eastward or down-grade to the ocean, as shown on either side, by the forms of the glaciated rocks, the directions of the striae, and the composition of the drift" (Bell, 1901a : p. 31).

Note here, as in the first quote, evidence adduced for the ice-stream : stossed rock knobs, striae changing direction from towards the Strait inland to along the Strait on the shore, and composition of the drift, which contained Paleozoic carbonates from Hudson Bay or Foxe Basin, transported over crystalline rocks on the shores of the Strait.

Even in the later paper (Bell, 1901a), he avoided differentiating unconfined (Hudson Bay and Foxe Channel) and confined (Hudson Strait) ice-flows. However, in undated notes he prepared for a paper he intended to, but did not, deliver to the Royal Society of Canada in 1907 (Bell, unknown date), he referred the above three lines of evidence to an ice-river, a long river-like glacier in Hudson Strait. His earlier mention of ice-streams flowing out of Hudson Bay and Foxe Channel (Bell, 1895 : p. 353) seem, therefore, to have referred to flows unlike a river, implying at least later distinction between unconfined and confined flows.

PRESCIENCE VS. PRECEDENCE

As noted above, Bell (1885) had summarized the broad-scale glaciological picture for Hudson Bay and Strait. In an epochal comprehensive summary of glaciation in Canada (Bell, 1890), as to "The direction of glacial flow", for the Hudson Bay and Strait region he wrote similarly, "... the mass [of ice in Hudson Bay] discharged itself northward into the deep and wide valley of Hudson Strait ..." (Bell, 1890 : p. 294). In these summaries we see the ice-stream interpretation in embryo, with results from 1884 and 1885 voyages through the Strait not fully developed. Such detail would not, however, have belonged in this paper of much broader scope.

In assessing prescience and precedence, one must ask whether Bell was, was not, or should have been aware of previous identifications of ice streams. The only earlier identification I have become aware of is that of Rink (1877) in Greenland. Arriving in Greenland in 1848 for the purpose of mining exploration, Rink, a geographer, published in Danish a work on the island's physical and human geography, which in 1877 he revised in an English translation. Introducing the English edition, Larsen wrote : "One of the problems that occupied his [Rink's] mind ... in Greenland was the connection between the huge ice sheet ... and ... the floating icebergs. He asked himself whether the [precipitation] ... on the inland ice ... was accumulating and would cover ever larger areas ... or whether these deposits [of precipitation] would vanish — but, if so, how ? The answer was ... according to Rink, in certain areas ... there exist ice-flows in which the ice, faster than the surroundings, moves in the direction of ... ice-fjords. At the head of these ... ice-flows converge, forming one large glacier which, sliding along the bottom, slowly moves out into the fjord until, at a certain depth, the ice is lifted by the water and floats" (Rink, 1877).

In his Preface, Rink (1877) wrote : "A Norwegian geologist [Amund Helland] visited Greenland in 1875 for the purpose of studying its glaciers and discovered the extraordinary velocity with which the inland ice covering is propelled towards the sea, and which proves its essential difference from the Alpine or highland glaciers" (Rink, 1877 : p. vii). This did not indicate variations in flow rate along the ice-sheet margin, but, in an Appendix, Rink concluded "[I]n his map of North Greenland the author has adopted the name "Is-Strom", i.e., ice-stream or ice-current for those outer parts of the inland ice which are moving with greater rapidity towards the ice-fjords than the rest of its outer margin" (Rink, 1877 : p. 369).

As an example, on the subsequently much-studied Jacobshavn glacier, Rink wrote, "[T]he breadth of the Jacobshavn ice-fjord, or rather of the glacier occupying it, was 4 500 metres, the dip [gradient] of the glacier was less than half a degree. Its central part, at a distance of 1 000 metres from the side, proceeded at the rate of 20 metres per diem, while at a distance between 400 and 450 metres, its velocity was 15 metres per diem, and close by the shore only 0.02 metres per diem. The inland ice only moves at ... 0.4 to 0.5 metres per diem" (Rink, 1877 : p. 363).

Bell's (1895, 1901a, 1901b) accounts of a Hudson Strait ice-stream would have gained strength from corroborative examples, which he would surely have quoted had he been aware of them, especially once he was planning to address the Royal Society of Canada on the subject. The accession date of Rink's book in the library of the Geological Survey of Canada is August 17th, 1886 (personal communication from L. Simpson, Library of Natural Resources Canada, Ottawa), so we must choose between Bell not knowing the book or his doubt of the validity of a comparison between the Greenland Ice Sheet (GIS) and the LIS as he knew it. In the latter opinion he would have been in good company, as Chamberlin (1895) had expressed the same view following his brief encounter with the GIS as a member of the Peary relief party in 1895.

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