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Ian A. Brookes

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Résumé de l'article

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ICE MARKS IN NEWFOUNDLAND: A HISTORY OF IDEAS

Ian A. BROOKES, Department of Geography, York University, Toronto, Ontario M3J 1P3.

ABSTRACT This essay traces the evolution of ideas on the origin of features in Newfoundland now ascribed to glaciation, through the period 1822-1981. It identifies "Pre-cognitive," "Drift," and "Glacial" phases, with the last phase divided into seven sub-phases. In the Glacial Phase, debate centred on 1) the relative roles of Labrador ice and ice from the island of Newfoundland, 2) the areal and vertical extent of ice masses, and 3) the number and chronology of glacial episodes. Alexander Murray is credited with first recognizing glaciation in Newfoundland in 1866, and the background to his perspicacity is discussed. The evolution of ideas from the late-nineteenth century to the present is related to improving access, exploration by increasingly widely experienced scientists, the import of concepts from outside the region, the development of chronological tools, and improvements in glaciological theory.

RÉSUMÉ *Les marques glaciaires à Terre-Neuve.* Le présent article retrace l'évolution de la pensée quant à l'origine des formes, qu'on sait aujourd'hui glaciaires, à Terre-Neuve, pour la période allant de 1822 à 1981. On y reconnaît trois phases: la phase dite "précognitive", la phase au cours de laquelle on attribuait les formes à l'action des glaces flottantes et, enfin, la phase au cours de laquelle on reconnut l'action des glaciers. Dans la section traitant de cette dernière phase, dont on a dégagé sept étapes, la discussion porte: 1) sur l'influence relative des glaces du Labrador et de Terre-Neuve; 2) sur l'extension régionale et altitudinale des masses glaciaires; 3) sur le nombre de glaciations et leur chronologie. Alexander Murray fut, en 1866, le premier à reconnaître l'action des glaciers à Terre-Neuve. On expose ici son interprétation du phénomène. L'évolution de la pensée, de la fin du XIXe siècle jusqu'à nos jours, tient à une plus grande accessibilité du terrain, à une intensification des explorations par des scientifiques de mieux en mieux préparés, à l'influence d'idées venues de l'extérieur, à la mise au point d'outils permettant d'établir des chronologies et à l'amélioration des théories de glaciologie.

РЕЗЮМЕ *Следы ледника на Ньюфаундленде.* Эта работа описывает эволюцию теорий происхождения рельефа Ньюфаундленда за период с 1822 по 1981 год, который в настоящее время объясняется действием ледников. В работе даются названия отдельным фазам: „допознавательная", „дрейф" и „ледниковая" (последняя делится на семь подфаз). Во время ледниковой фазы дискуссии концентрировались главным образом на 1) относительной роли лабрадорского льда и льда с острова Ньюфаундленда, 2) размерах ледяных масс, включая толщину, и 3) количестве и хронологических датах ледниковых периодов. Александр Мёррей считается первым ученым, признавшим в 1866 году действие ледников на Ньюфаундленде. В работе обсуждаются основания для его проницательности. Эволюция теорий за период с конца девятнадцатого века до настоящего времени связана с улучшением доступа, исследованиями все более опытных ученых, заимствованием идей из других стран, развитием способов определения хронологических дат и усовершенствованием ледниковой теории.

INTRODUCTION

The title of this essay is taken from a communication by Staff-Commander J. H. Kerr, R.N. to the Geological Society of London in 1870, entitled "Observations on Ice-Marks in Newfoundland" (KERR, 1870). I choose to retain the archaism in this historical review since, despite a steadily increasing sophistication of terminology and concept, glacialists today are attempting to explain the same phenomena as were the earliest writers on the subject, and these are nothing if not "ice marks" of one kind or another.

Newfoundland's ice marks have attracted the attention of an impressive list of eminent geologists. One would wish to avoid selection, but the point may be emphasized by mention of Murray, Chamberlin, Daly, Coleman, and Flint. Inasmuch as geologists are often disposed to choose "scientific enquiry, especially when combined with wild adventure," (MURRAY, 1877) Newfoundland's long-time isolation, its rugged terrain, and its difficulty of access go some way towards explaining the attention it has received from glacialists. Also, to colonial British eyes, the similarity to the scenery of Scotland seemed to compel comparisons with the hearth of British glacial studies. More important, the homologous positions of the British Isles and insular Newfoundland — both islands on a broad continental shelf, adjacent to mainland centres of glacial outflow, in Scandinavia and Labrador, respectively (GRANT, 1977a) — warrant comparison with respect to the degree to which they were glaciated by "accumulation" or "invasion" (UPHAM, 1895).

This essay treats the literature on ice marks in Newfoundland chronologically A brief review of most substantive works was given by TUCKER (1976). My purpose here is to illuminate the conceptual background to the evolution of ideas. From a literature spanning 160 years, this can be most broadly divided into three phases. The first phase may be called "Precognitive." Geological writings dating to 1822 and 1842 either did not recognize ice marks or did not attempt to explain them. Apart from an early mention of "glacial" features in Newfoundland by MURRAY (1866), in a report which may be termed "procognitive", and the reference of KERR (1870) to "the former action of ice", nothing more was offered until 1874, when the second or Drift Phase may be recognized. In this, explanation of ice marks relied upon either icebergs or coast ice, both related to a sea level higher than present (MILNE, 1874, 1876). This phase was brief, ending in 1882, when, following his passing mention of 1866, Murray called upon glaciers, both from Labrador and the island of Newfoundland, to explain the ice marks. This third phase may therefore be referred to as the Glacial Phase. It is subdivisible into seven sub-phases, in which opinions have swung between assigning Newfoundland's ice marks either to invasion by an ice sheet from the Labrador-Nouveau-Québec peninsula or to an island-centred ice cap.

In summary form, these phases and subphases can be tabulated, and the authors listed chronologically, as follows:

Pre-cognitive Phase — CORMACK (1822), JUKES (1842).
Drift Phase — MILNE (1874, 1876).
Glacial Phase. 1. Formative sub-phase — MURRAY (1866), KERR (1870), MURRAY (1882), BELL (1884), CHAMBERLIN (1895). 2. Crustal warping patterns — DE GEER (1892), DALY (1902), FAIRCHILD (1918), DALY (1921). 3. Multiple glaciation sub-phase — COLEMAN (1926). 4. Labradorean invasion ("Flintian") sub-phase — FLINT (1940), MacCLINTOCK and TWENHOFEL (1940). 5. Newfoundland accumulation sub-phase — JENNESS (1960), LUNDQVIST (1965), GRANT (1969) BROOKES (1970), HENDERSON (1972). 6. Multiple Newfoundland glaciation sub-phase — BROOKES (1977b), GRANT (1977b, c), TUCKER & McCANN (1980). 7. "Neo-Flintian" sub-phase — DENTON & HUGHES (1981).

PRE-COGNITIVE PHASE

Scientific exploration of Newfoundland began with the journey of William Epps Cormack across the island on foot in the early winter of 1822. Cormack was born in St. John's in 1796, of Scots parents. Upon the death of his father, he returned with the family to Scotland, where he was raised and educated. He returned to Newfoundland in 1822, and late that year set out on what remains to this day the only trans-island walk accomplished by a European. His main objective was to explore the interior, particularly to ascertain the true conditions of livelihood of the native Beothuks, in order to counter "the most besotted conjectures... entertained, particularly by the chief delegated public authorities" (CORMACK, 1822).

While in Scotland, Cormack had attended lectures in mineralogy by Robert Jameson at Edinburgh University. Jameson was then an adherent of the geological doctrine of WERNER (1791), which proposed that the rocks of the earth had been precipitated from a 'Universal Ocean.' In the early 19th century this had only begun to be challenged by followers of James Hutton who, in his "Theory of the Earth" (HUTTON, 1795), had identified rocks as either magmatic or sedimentary in origin. Certainly, Jameson's lectures were useful enough to Cormack to enable him to give a descriptive account of the rocks and minerals he encountered on his journey from Trinity Bay to St. George's Bay (Fig. 1)[1], and the debt

1. The reader is referred to Figure 1 for the location of all place names of Newfoundland mentioned in the text. The map will not be referred to subsequently.

he owed was great enough to warrant his naming Mt. Jameson (now Jameson's Hills, near Meelpaeg Lake) for his former instructor.

Unhappily, Jameson's interests in the development of landforms had not been aroused by the time Cormack studied with him. The period 1825 to 1836 saw the growth of his acceptance of the notion that glaciers had played a role in shaping landforms (DAVIES, 1969, p. 268). This was not a majority opinion in Britain at that time, although the Swiss (VENETZ, 1833; CHARPENTIER, 1835) and Norwegians (ESMARK, 1826) had begun to publish similar conclusions. Much more dominant was the traditional conception, that the unconsolidated deposits so widespread over northern Europe were the products of a great submergence by the sea. This "Diluvial Theory" (from the Latin, meaning "deluge") originated in the biblical accounts of the Deluge: "And the waters prevailed so mightily upon the earth that all the high mountains under the whole heaven were covered" (Genesis 7:17, HOLY BIBLE). Clearly, calling upon a great submergence did the least injustice to teleological views of earth history. The presence of seashells in some of those deposits could be seen as adequate proof.

Cormack, although quite obviously impressed with the grandeur of some of Newfoundland's scenery, thus appears not to have been conceptually equipped to offer insightful interpretive comments upon it. Other factors enter into explaining this. He was very likely preoccupied scientifically with fulfilling his main desire to describe the rocks and minerals of the country, and with his personal interest in the ill-fated Beothuks. (O'FLAHERTY, 1979). The following quotation illustrates Cormack's often emotional response to landscape. It describes his feelings upon gaining his first panoramic view of the island's interior: "to our inexpressible delight, the interior broke in sublimity before us. What a contrast did this present to the conjectures entertained of Newfoundland! The hitherto mysterious interior lay unfolded below us, a boundless scene, an emerald surface, a vast basin. The eye strides again and again over a succession of northerly and southerly ranges of green plains, marbled with woods and lakes of every

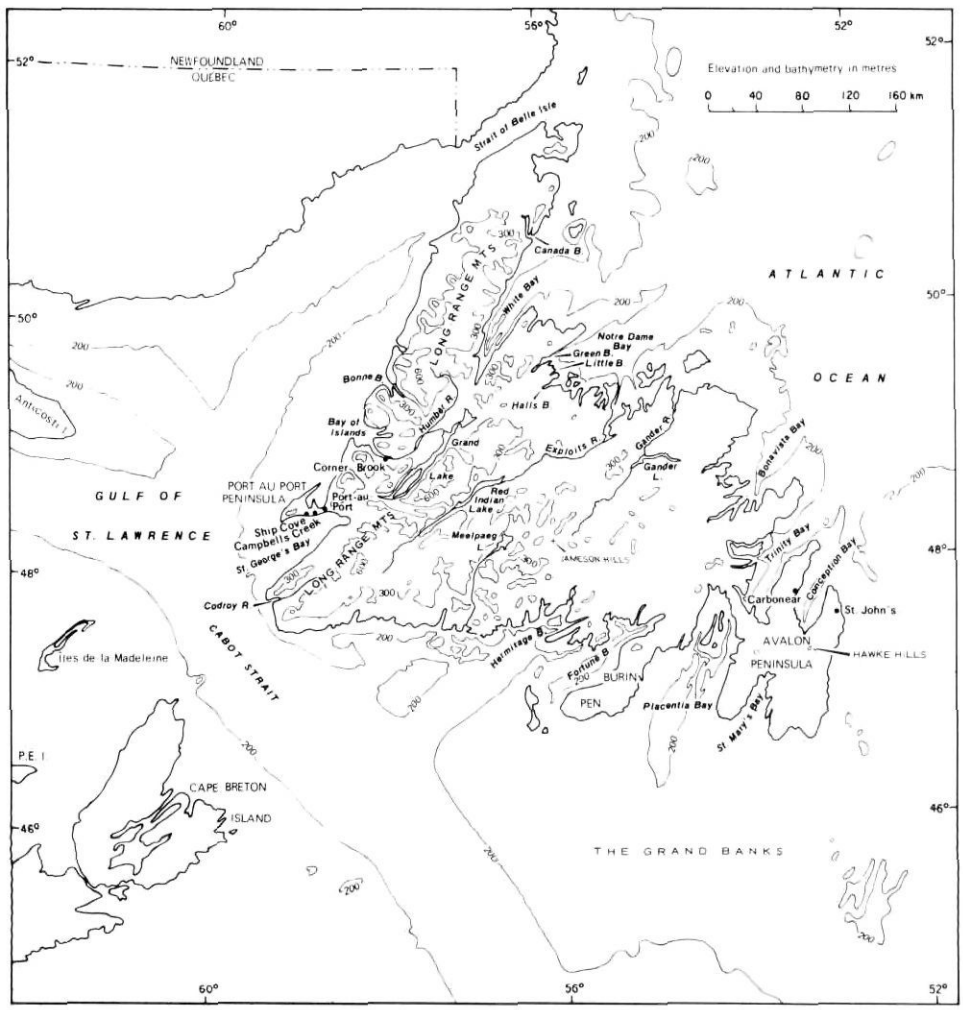

FIGURE 1. Island of Newfoundland and adjacent waters, showing places and features mentioned in the text, contours at 300 m and 600 m above sea level, and at 200 m below sea level.

L'île de Terre-Neuve et les mers qui l'entourent. On y indique en outre le nom des entités mentionnées dans le texte, les courbes de niveau de 300 et de 600 m, ainsi que la courbe bathymétrique de 200 m.

form and extent, a picture of all the luxurious scenes of national cultivation, receding into invisibleness." (Quoted in O'FLAHERTY, 1979, p. 45).

We must therefore proceed to the years 1839-1840 in search of an indication that scientific explorers had begun to perceive in Newfoundland phenomena worthy of interpretation in the light of current theory on the origins of landforms. It was in those years that Joseph Beete Jukes undertook a geological survey of the island for the colonial government. Jukes, an Englishman born in 1811, was educated at Cambridge in geology, under Sir Roderick Murchison. Murchison was an outspoken opponent of the "Glacial Theory", which had in the years of Jukes' survey just begun to gain adherents, due mainly to the efforts of its daring Swiss proponent, Louis Agassiz.

While several of Agassiz' compatriots (CHARPENTIER, 1835; VENETZ, 1833) had earlier discussed past glacial activity on local and regional scales in Switzerland, AGASSIZ (1837) propounded a sweeping theory that northern lands had been invaded by a polar ice sheet. Perhaps, working into the early hours of the morning on a paper announcing the theory which he delivered to the Société helvétique that evening[2], Agassiz called for too radical a change in the earth's geography, and neglected the more easily conceivable possibility that northern Europe had once nourished glaciers of its own.

Whether of polar or local origin, Agassiz' ice sheet met with a reception in Britain which, while mixed, was certainly not glacial. Respected long-time proponents of the Diluvial Theory, particularly Rev. William Buckland of Oxford, were quickly convinced, upon hearing Agassiz apply his theory to the landforms of Scotland (AGASSIZ, 1840-41). Charles Lyell, author of the "Principles of Geology" (LYELL, 1830-33), which accompanied and inspired Charles Darwin on his epochal voyage on H.M.S. "Beagle" in 1831-1836, was another early convert to the glacial theory, although he withdrew support a year later and withheld it until 1858 (DAVIES, 1969, p. 291-292) in favour of his own empirically derived scientific version of diluvialism. Murchison at Cambridge was a diehard diluvialist who clung to the Deluge to explain all the surface features of the earth, not merely the superficial gravelly mantles and foreign boulders. Not until 1862 (DAVIES, 1969, p. 294) did he admit his error in dismissing the glacial theory.

In Newfoundland during 1839-1840, Murchison's former student, J. B. Jukes, was apparently unwilling even to speculate on the glacial theory from evidence he found there. He was hard-pressed even to find diluvial evidence. Jukes appears ambivalent and prevaricatory in his statements on the most recent period of earth history in Newfoundland. He reported "that fragments of rock, frequently of great size, have been removed from their original position, in all directions for a few miles" (JUKES, 1842 [vol. 2], p. 337), but offered neither a diluvial nor a glacial explanation. Nor did he observe "diluvial grooves, or scratchings of the surface" (p. 337), although he admitted that they might be found under the peat cover and may have been weathered from bare outcrops.

Except for one report of stratified clay in the lower Exploits River, which he interpreted as evidence "that the country once stood at a lower level" (p. 339), Jukes was entirely sceptical of a "Great Submergence" of Newfoundland. He justified his lack of observations of raised beaches around the island by commenting: "In a country like Newfoundland, where nothing like a beach can be seen, except a small pebble bank at the heads of coves and small bays, raised beaches can hardly be expected" (p. 240). Even finding a clam shell near the top of a cliff on the north shore of St. George's Bay did not lead him to alter his opinion, since he would not discount the activity of sea birds in carrying it there (p. 341).

Such conclusions, reached after two years of geological survey in Newfoundland, are, to say the least, surprising, especially when at that time, as now, local inhabitants would be well informed of the whereabouts of 'unusual' phenomena, such as seashells high in coastal cliffs. Many of Newfoundland's west coast and northeast coast bays, where raised marine features are so common, were inhabited by that time (MANNION, 1977).

Since he reacted as neither a diluvialist nor a glacialist to the superficial deposits of Newfoundland, Jukes can hardly be accused of bias. We may perhaps seek an explanation for the peculiar absence of observations of grooves and striae, and of raised beaches, which have attracted so many later investigators, in the interpretation of Jukes as one whose "youth, energy, natural curiosity, and adventurous temperament often took him away from the study of rocks into the activities of men" (O'FLAHERTY, 1979, p. 65). Further, ZASLOW (1975) observes that: "Jukes soon fell into disfavour with the colony's legislature, which tried to reduce his grant after one year and discontinued the survey at the end of the second year" (p. 16). Certainly, as a more mature scientist in the 1850's and 1860's Jukes accomplished distinguished work as the Local Director of the Geological Survey of Ireland, and was a respected champion of the efficacy of rivers in accomplishing extensive denudation.

Shortly after Jukes completed his geological survey of Newfoundland, North America was visited by two of

2. For an account of events preceding and surrounding announcement of the Glacier Theory and complete bibliographic information, partially cited here, see CAROZZI (1967).

the most prominent natural historians of the 19th century — Lyell and Agassiz. Both were major figures in the debate over the role of glaciers in shaping the surface of mid-latitude lands. In 1841, Charles Lyell (yet to be knighted for service to scientific exploration) visited eastern North America. He came fresh from Britain a few months after avidly embracing the glacial theory, expounded to English audiences in 1840 by Agassiz. Arriving in Halifax and travelling to Boston, New York, Québec, Montréal, Toronto and Niagara, Lyell was confronted with phenomena such as striations and grooves on bedrock, hummocky sand and gravel deposits, stratified sediments accumulated in seas and lakes, and foreign boulders perched precariously on rock knobs — for the most part in areas where the former existence of marine and freshwater bodies was plainly in evidence.

Recalling earlier experience with similar phenomena around the shores of the Baltic Sea, which, before the advent of the glacial theory, he had attributed to the action of icebergs and drift ice, LYELL (1845) reverted to the Drift Theory to explain these North American features. His words on the Niagara region, regarding the origin of the striae and furrows in bedrock, eloquently summarize his views of all these phenomena encountered on his North American travels: "Large islands and bergs of floating ice came from the north, which, as they grounded on the coast and on shoals, pushed along all loose materials, of sand and pebbles, broke off all angular and projecting points of rock, and when fragments of hard stone were frozen into their lower surfaces, scooped out grooves in the subjacent solid strata" (Vol. 2, p. 83). Then "... after the surface of the rocks had been smoothed and grated upon by the passage of innumerable icebergs, the clay, gravel, and sand of the drift were deposited, and occasionally fragments of rock, both large and small, which had been frozen into glaciers, or taken up by coast ice, were dropped here and there at random over the bottom of the ocean, wherever they happen to be detached from the melting ice" (Vol. 2, p. 84).

That the sea had earlier stood at a higher level was not to be doubted, from evidence of raised beaches and fossiliferous marine sediments around the New England-Acadian coast and in the St. Lawrence valley. That icebergs carried debris and dropped it to the sea floor as they melted was plain from sightings of bergs in the North and South Atlantic. And that drift ice could incorporate debris into itself upon contact with the shore and could deposit it somewhere else was also an often-observed phenomenon. Lyell's arguments, well marshalled and eloquently expressed, reinforced the prevailing notion of the drift as the product of a great submergence, with or without floating bergs and floes. This is not to mention his established and deserved prestige as a natural successor to Hutton in the interpretation of geological features in accordance with processes that can be observed at present.

So it was against this doctrine that Agassiz had to struggle in North America after his arrival in Cambridge, Massachusetts, in 1846 to take up a chair in geology and zoology at Harvard College in 1847 (MERRILL, 1924, p. 629). Lyell before him had placed the Drift Theory on a firm scientific foundation, strengthening the somewhat weak and teleological arguments of North American geologists in favour of diluvialism. In the United States, AGASSIZ (1848) published only once on a glacial subject, that on the Lake Superior region. Twenty years were to elapse before he returned to the subject of glaciers. In the meantime, J.D. DANA (1855) had embraced his theory, and RAMSAY (1862) and Murchison (DAVIES, 1969, p. 294) in England had done the same.

In the Canadas, William Edmond Logan, first director of the Geological Survey, had in 1846 been the first to apply the Glacial Theory to explain features in the Ottawa River valley (LOGAN, 1847). By 1863, both he and one of his assistants, Robert Bell, had fully embraced the theory in Bell's chapter on "Superficial Deposits" included the monumental "Geology of Canada" (GEOLOGICAL SURVEY OF CANADA, 1863). The Drift Theory, however, died hard north of the border, with the arguments of its most persistent proponent, J. W. Dawson, being heard from 1855 in his "Acadian Geology" (DAWSON, 1855) to 1893, six years before his death, in *"The Canadian Ice Age"* (DAWSON, 1893).

Dawson persistently argued that climatic conditions had been unsuitable for the existence of a vast glacier in temperate latitudes, and that peat beds found below the drift in Nova Scotia indicated a climate similar to the subarctic regions of the present day, where no glaciers exist (DAWSON, 1872). He rightly noted that the drift was deposited while the sea was higher than today, and there was thus no evidence that a great elevation had occurred to cool northern latitudes and lead to glaciation, as most adherents of the glacial theory then believed. Dawson also opined that glaciers could not move upslope to deposit boulders on hilltops, and that it was inconceivable that a vast glacier had moved from the Atlantic Ocean towards the interior of Canada. This last was on oversimplification of the evidence of striae in the St. Lawrence and lower Great Lakes lowlands, which indeed indicated that the striating agent had followed that topographic depression into the American Midwest. Dawson's antithesis to the glacial theory[3] is relevant to this discussion of Newfoundland 'ice marks' since his major works were on the Acadian region,

3. See O'BRIEN (1971, p. 151-180) for a more complete discussion of Dawson and the Glacier Theory.

where features similar to those seen in nearby Newfoundland were abundant.

Before discussion of the next phase of investigations on ice marks in Newfoundland, the "Drift Phase" mention must be made of the early recognition of glacial action in Newfoundland by Alexander Murray, Director of the Geological Survey of Newfoundland from 1864 to 1883. After a year as an amateur with the Geological Survey of Great Britain, in 1842 Murray returned to Canada as assistant to Logan of the newly-established Canadian Survey, a position he held until Logan recommended him to the Newfoundland Government as Director of its new Geological Survey.

It is remarkable that Murray's career as geologist should have hinged in no small way on the coincidence that he and Logan had brothers who were law partners in Edinburgh (ZASLOW, 1975, p. 20). But for this connection, Murray might have acted upon his serious consideration of rejoining the Royal Navy, which he had left eight years earlier in search of professional advancement (STAVELEY, 1981).

In the second year of his service under Logan, Murray set to mapping rock formations from the Niagara Peninsula to Georgian Bay. Commenting at length on the nature and probable origin of the superficial deposits and boulders overlying the bedrock of that area, Murray concluded that: "the evidence they [the boulders] present is in unison with that derived from the gravel and sand, to prove that at some remote period the surface has been covered with water having a current from the north" (MURRAY, 1844). He also used the evidence from grooves and scratches on bedrock of the Niagara Peninsula to bolster his conclusion that this current had come from the north. Thus, we first encounter Murray as an adherent to the Drift Theory. It was possibly his association with Logan which later led him to reject it in favour of glaciers. If Logan's influence was not enough, that of a younger colleague, who joined the Survey later, must surely have been decisive.

Murray had been assisted in his 1844 survey in Upper Canada by the Reverend Andrew Bell, an amateur, of L'Orignal, near Ottawa. Bell's son, Robert, later recalled being much impressed as a young child by Murray's visits to the Bell home (BELL, 1892). With an amateur geologist as a father and early exposed to a model of the professional geologist in the figure of Murray, Robert Bell chose a career in geology himself. He was to become one of the leading figures in glacial research in Canada in the second half of the century (AMI, 1927).

With Logan and Bell as colleagues and friends, Murray, when he left Canada in 1864 to take up his directorial post in Newfoundland, had fully divested himself of drift notions. In his report of the first year's survey in Newfoundland, we read Murray referring to "erratic blocks" as indicators of glacial action on the Northern Peninsula of the island, and to "parallel grooves and scratches bearing S25°E" (MURRAY, 1866, p. 42-44) at Canada Bay. He further noted stratified sediments containing marine shells at 40 feet (19 m) above sea level at Little Bay and Halls Bay, but he delayed scientific comment on them, since his work was directed more towards mineral exploration and topographical survey.

Staff-Commander Kerr, R.N., from whom the title of this essay is taken, was in command of the British Admiralty Survey in Newfoundland waters in the late 1860's. He had made himself familiar with Murray's topographical survey in charting bottom depths from St. John's to north of Bonavista Bay, and had made complimentary remarks on that work to the Select Committee of the Newfoundland government investigating it[4]. Unfortunately, only an abstract is available of Kerr's paper to the Geological Society of London in which he listed many striation azimuths in the coastal areas of his survey. He referred them to glacial action, discussed "the extent and effects of the glacier system to which these markings are due, and indicated that its great terminal moraine is probably the 80-fathom bank across the mouth of Conception Bay" (KERR, 1870, p. 705).

DRIFT PHASE

Recognition of ice marks may have come late to Newfoundland, but when Alexander Murray first reported them it was to glacial action that they were ascribed. Two papers on ice marks by John H. Milne represent a brief scientific reversion to Lyell's concept of the drift. According to a recent biography of Milne (HERBERT-GUSTAR and NOTT, 1980), he was 22 years old when he came to Newfoundland, under contract to the Newfoundland Land Company, Ltd. to assess the mineral, soil, and forest resources of the island (NEWFOUNDLAND LAND COMPANY, LTD., 1875). He had made himself familiar with Murray's geological survey, but it appears that they had not discussed ice marks and their significance, since in two papers Milne chose to explain them with reference to drift or coast ice.

In the first, MILNE (1874) was obviously faced with a dilemma. He appears to have known of Agassiz' Glacier Theory, but only through a popular article in 'Atlantic Monthly'. Milne acknowledged Agassiz' view that a dome of glacier ice over northern North America had once moved into southern regions. While he did not argue against this theory, Milne proceeded to call upon

4. "I have been much interested in his [Murray's] progress, and have consequently made it a point to confer with him on it." (Kerr in SELECT COMMITTEE, 1869, p. 49).

icebergs drifting over the island when it was submerged by approximately 1,000 feet (300 m).

Milne recognized the difficulty of explaining those striae which depart from the topographic grain and sought assistance in a suggestion that, after emergence from the berg-laden sea, Newfoundland had been glaciated by a local ice dome. He ended in indecisive confusion, suggesting that both the parallel and the deviant striations could have been formed by glacier ice, and cited Jukes' evidence (JUKES, 1842, p. 337) that foreign boulders are never very distant from their bedrock source areas to argue *against* their deposition by icebergs.

Two years of thought on this dilemma led MILNE (1876) to present a more reasoned, if somewhat diversionary, argument in favour of "coast ice" as a neglected agency productive of ice marks. Here, he acknowledged the importance of the glacial theory then being championed by (a reverted) Lyell, RAMSAY (1862) and A. GEIKIE (1863) in Britain, and that of drift ice also, but wished to make the case for "coast ice" in the formation of scratches, and in the erosion, transportation, and deposition of sediment. Milne now rejected his earlier reliance on icebergs, noting that these would not produce extensive, parallel scratches because they were too subject to winds (because of their freeboard) and to currents (because of their draft). Also, any blocks which they dropped to rest precariously on submerged hilltops would be toppled by wave agitation as the land emerged.

From what were obviously painstaking observations of Newfoundland's coast, MILNE (1876) recognized a common feature of cold-climate beaches — the 'ice-foot'. This, he said, could form from grounded ice floes, landfast ice pushed ashore by winds, and freezing of thawed snow or sea spray on the beach. The scratching and grooving effects of the ice foot were documented in several cases, as was the incorporation of debris into coast ice, its movement on currents and its deposition elsewhere. In arriving at a general scheme, he tentatively reconstructed a three-phase history for Newfoundland's ice marks. In the earliest phase the island was submerged and affected by drift ice with bergs. During emergence in the second phase, coast ice formed most of the parallel ice marks and deposited a thin mantle of gravelly sediment. Finally, after complete emergence, local glaciers grew over the highlands and moved the larger foreign boulders into their present perched positions.

GLACIAL PHASE

1. FORMATIVE SUB-PHASE

If Milne's earlier paper was the first hint of a 'drift vs. glacial' dilemma in Newfoundland, his second paper was the last. In 1882 Alexander Murray saw fit, after 18 years as Director of the Newfoundland Geological Survey, to pronounce upon ice marks on the island. As previously noted, MURRAY (1866) had ascribed foreign boulders, grooves, and scratches in northern Newfoundland to glacial activity. The reasons for his long intervening silence on the subject, even after Milne's papers appeared, may lie in several factors.

First, Murray continually suffered from inadequate direction and support for his survey of Newfoundland. He more than once complained to the government that he did not receive permission or assignments for the summer field work until well into the season, and that the financial provision was inadequate to hire suitable assistants and field guides, even to purchase clothes sturdy enough to survive several months in the bush (Murray, in SELECT COMMITTEE, 1869, p. 42-44). Second, he may have been discouraged by his superiors from spending time in purely scientific pursuits. Third, his work became increasingly focussed on land survey for settlement, rather than geological survey (STAVELEY, 1981). Last, upon being elected a founding Fellow of the Royal Society of Canada, when he presented the paper at its first annual meeting of May 26, 1882 he might have felt freer to express his views on glaciation in Newfoundland to that academic, rather than administrative, audience.

Whatever the reason for his long silence on the matter, MURRAY (1882) forwarded an interpretation of ice marks in Newfoundland which appears astonishingly radical in relation to the previous 40 years of 'diluvial' or 'drift' thinking. He opened with a direct comparison of the topography and features such as grooved, striated, and polished bedrock in Newfoundland with those of Britain, following this with an embrace of Agassiz' theory of a vast ice dome over northern latitudes.

The body of the paper presents evidence in favour of glaciation and can be briefly reviewed here. First, the depths of the three great interior lakes — Grand Lake (more than 184 fathoms), Red Indian Lake (unplumbed but "reputed to be of great depth", p. 57), and Gander Lake (97 fathoms at one point) — all much below sea level — favoured glacial action. RAMSAY (1862) had first proposed this origin for Swiss lakes. Second, evidence of land emergence was abundant, but that for the extensive submergence called for by the drift theorists was less clear. Third, grooves and scratches, while predominantly oriented NE-SW showed movement towards northeasterly points as often as in the opposite direction, as well as showing many transverse orientations. Fourth, foreign boulders precariously perched on hill summits showed a variable pattern of movement from their source outcrops.

MURRAY (1882) concluded that, firstly, glaciers had deepened the preglacial valleys and had left the ridges in much the same condition today as before the glacial period; secondly, the "boulder drifts and scattered boulders are the remnants and ruins of great terminal and lateral moraines" (p. 67); thirdly, the glacier which produced these features had arrived in Newfoundland from the northwest, and had "in its course easterly, received numerous confluent glaciers on either side, the courses of which are to some extent indicated by the present courses of the various tributary rivers and streams" (p. 68); fourthly, "that the land has risen, and is probably still rising; but that the evidences only point to a moderate submergence — which seems particularly to apply to recent times" (p. 68); and last, "that the stratified clays and sands were deposited, after the glaciers retreated or altogether disappeared, partly by salt and partly by fresh water" (p. 68).

Murray then proceeded to draw comparisons between the glacial deposits of Newfoundland and those of Canada, attempting to place them in stratigraphic order — again a first for the island's youngest gelogical formations. The sequence of boulder drift resting on abraded bedrock and overlain in coastal regions by fossiliferous, stratified clay and sand was recognized as identical to that of Canada (GEOLOGICAL SURVEY OF CANADA, 1863).

Once it had been proposed that glaciers rather than icebergs were responsible for Newfoundland's ice marks, the obvious question of the source of the glaciers was raised. Murray's assignment of that source to a northwesterly direction appears somewhat more speculative than reasoned, and was based on the prevailing notion, descended from Agassiz (though modified by Dana in America), of the predominance of a vast ice dome over the northern part of the continent. Strangely, Murray specifically mentioned that there were no signs of glaciation on the highest summits along the island's western backbone, yet went on to propose that they were the first to bear the brunt of the invading glacier. A sufficient number of crossing striations were recorded in Newfoundland for Murray to suggest that they were "the result of local glaciers descending from the hills after the land had risen considerably, and the great Mer-de-Glace had retreated" (p. 61).

Alexander Murray was the first geologist to base a hypothesis of ice marks in Newfoundland upon a long period of diligent observation of the phenomena over the entire island. His predecessors had been transient investigators who were there for other purposes and who had not travelled so widely, especially through the interior. His paper was a milestone, placing interpretation in the mainstream of rapidly expanding ideas on the history of landscape in northern and middle latitudes. It was the first to assign a dominant role to glaciers; the first to call upon glaciation by invasion rather than accumulation; the first to argue against a great submergence to explain the ice marks; the first to recognize complexity in the record of sea level change; and the first to use stratigraphic evidence to erect a sequence of glacial events.

Murray's 1882 paper was of its time. His glacialist colleagues in America were beginning to recognize the complexity of glacial history from evidence that ice had flowed from different directions at different times over the same area and had laid down a sequence of deposits which contained a record of those movements. In Canada in the 1880's, the influence of J. W. Dawson was waning and the views of his equally influential son, G. M. Dawson, were changing from his earlier application of the Drift Theory to western Canada to a recognition of glacial action there.

Before the century was out, glacial investigations in the lands bordering the western Gulf of St. Lawrence had revealed a pattern of glaciation by accumulation over the highlands of New Brunswick and Gaspé, but a restricted seaward extent of ice which left most of the western Gulf, and some of the promontories projecting into it, free of ice (CHALMERS, 1895). This was a major change of opinion on the dominance of a northern ice dome.

The question of the extent of the Labrador ice sheet has dominated glacial studies in Newfoundland since the 1880's. Robert Bell of the Geological Survey of Canada was focussing his studies on the Labrador peninsula in the early '80's. He did not directly study Newfoundland's glacial features, but he was not unfamiliar with the island's geology. He had visited his friend Murray in St. John's for three weeks in 1868 (BELL, 1892), and must have had the opportunity for discussions on Murray's occasional visits to Montréal. Bell had gained the impression from cursory examination that "the glaciation [of Newfoundland] appears to have been from the centre towards the sea on all sides" (BELL, 1884, p. 37).

One of the most prominent glacial geologists in America in the late 19th and early 20th century was Thomas Crowder Chamberlin. He had mapped the southern border of the drift deposited during the final expansion of ice over the northern United States, from the Dakotas to Cape Cod (CHAMBERLIN, 1883) and had written a major monograph on the origin and significance of ice marks scored into bedrock (CHAMBERLIN, 1888). He briefly visited the Avalon Peninsula of Newfoundland in 1894, as a member of the Peary

relief party en route to Greenland[5]. Observing the local nature of the glacial deposits inland of St. John's, and the absence of rock types in them which could have been transported from the island interior or from the mainland, CHAMBERLIN (1895) proposed that the glaciation of the peninsula had been accomplished by a local icecap flowing radially towards the sea. He viewed this icecap as contiguous with one over the island interior, meeting it over the isthmus of Avalon, and further agreed with Murray that Newfoundland glaciers were contiguous with that of Labrador. However, aware of the conclusions of CHALMERS (1895) in New Brunswick and of RICHARDSON (1881) in the Magdalen Islands, regarding the limited extent of ice in those regions, Chamberlin felt that Newfoundland glaciers did not reach far beyond the present coast of the island in the southwest, south, and east.

2. CRUSTAL WARPING PATTERNS

Since the first glimmering of a strengthening support for the Glacial Theory in the early 1860's, a major barrier to its acceptance by staunch diluvialists had been the explanation of marine submergence in coastal lowlands and fjord areas when glaciers were still active nearby. Rejection of the extensive and deep submergence called for by diluvialists left the less extensive and shallower submergence accompanying glaciation unexplained. In 1865, S. V. Wood, in reply to an article by J. Croll, enunciated the theory that withdrawal of water from the oceans to form massive ice sheets would lower the world ocean level rather than raise it. This aggravated the problem of explaining submergence during glaciation. Then, in the same year, T. F. Jamieson suggested that the earth's crust would be depressed under the weight of the glaciers (DAVIES, 1969, p. 299-300). Thus, a submergence of coastal areas would be experienced if crustal ("isostatic") depression exceeded the global ("eustatic") fall of sea level. This idea was slow to take hold, and it was not until the 1880's and '90's that glacial-age raised shorelines were studied for evidence of crustal deformation.

Gerhard De Geer, a Swedish baron who was to become world-famous 20 years later for a chronology of ice retreat across Sweden, drew a map of eastern North America showing the elevations above present sea level of glacial-age shorelines (DE GEER, 1892). Lines joining points of equal shoreline elevation, called "isobases", describe the three-dimensional form of crustal uplift. Over an area as large as eastern North America, differences in shoreline age do not grossly invalidate the method. De Geer's map, the first of its kind for North America, showed a southeastward bulge of these lines over Newfoundland, and a corresponding northwestward indentation over the Gulf of St. Lawrence. The bulge indicated that an ice dome had existed over Newfoundland and the lesser uplift over the Gulf of St. Lawrence indicated that ice had been either absent or thin in that area.

Accurate measurement of the elevations of raised glacial-age shoreline features in Newfoundland drew the attention of Reginald Daly, another major figure in glacial research in the United States. Daly was primarily interested in the earth's physical behaviour, and sought evidence of the crustal depression beneath the larger Labrador glacier relative to that beneath the much smaller mass of Newfoundland's icecap. Daly's early work in Newfoundland (DALY, 1902) contained several errors of identification of elevated marine features. In a later paper, DALY (1921) corrected these measurements, and modified his earlier interpretation that Labrador ice had completely dominated crustal warping, admitting that the uplift pattern contained a trace of the influence of an ice dome over Newfoundland.

Another of these uplift maps was compiled shortly before Daly's second paper by Herman Fairchild of Rochester, who had gained prominence in applying the glacial theory to northern New York State. From second-hand data on shoreline elevations in northeastern North America (including Daly's subsequently corrected figures from Newfoundland), FAIRCHILD (1918) showed a much more prominent dome of uplift over Newfoundland. The construction must be viewed as somewhat fanciful with so little data available, but can be explained as a response to Fairchild's entrenched idea, gained from the literature and from personal communications, that the island had supported an ice dome and had not been overrun by Labrador ice. One of these personal communications was from Joseph Burr Tyrrell, whose explorations for the Geological Survey of Canada in northern Manitoba and Keewatin District of the Northwest Territories had led him to propose a "Keewatin" centre of glacial outflow in that area (TYRRELL, 1895). Tyrrell had visited Newfoundland in 1917 and subsequently wrote to Fairchild: "In Newfoundland the last glaciation, which was very strong, was from the center outward both eastward and westward. If the glacier from Labrador had ever reached the island, evidence of its presence would have been discernible on the west coast, but in the short time I was there I was not able to find any such evidence" (FAIRCHILD, 1918, p. 227-228). Tyrrell travelled more widely in Newfoundland than his published works indicate, for, in another letter, to E. M. Kindle of the Geological Survey of Canada, he reported the elevation of raised glacial-age marine deposits and landforms in St. George's Bay, White Bay and St. John's (KINDLE, 1922).

5. Chamberlin's presence in this party is mentioned by PEARY (1898, Vol. 2, p. 153). The author's attention was drawn to Chamberlin's participation by GEIKIE (1894, preface).

An indication of the deductive method which FAIRCHILD (1918) employed in his argument for an independent centre of glaciation over Newfoundland comes from this eloquent statement in his 1918 paper: "All available information on the glacial geology of Newfoundland favors an independent ice cap, with radial flow. And when we consider the large area and mountain heights of the island; the northern position; exposure to the ocean on all sides; and location in the paths of the cyclonic storms of America, it appears certain that the island was the locus of heavy snow precipitation and a massive ice cap — the Newfoundland continental glacier" (p. 229). All this was premised on the "available information," which consisted only of several dozen readings of striation azimuths, taken in coastal locations, and fewer measured altitudes of uplifted shoreline features. No detailed evidence had yet come to light on directions of boulder transport by ice, particularly on the west coast where, as Tyrrell said, evidence of Labrador ice would be found, if it had ever had any influence.

Fairchild's 1918 paper marks the end of the second phase of investigations into Newfoundland's ice marks. Up to this time there had been no debate over the age of the glaciation, over whether more than one episode of glaciation was in evidence, or over the details of the extent and thickness of ice over Newfoundland.

3. MULTIPLE GLACIATION SUB-PHASE

Studies of ice marks in eastern Canada took a leap forward in sophistication with the explorations between 1915 and 1925 of Arthur Philemon Coleman, Professor of Geology at the University of Toronto. On visits to northern Labrador's Torngat Mountains in 1915 and 1916 and to the Chic-Chocs Mountains of Gaspé, Québec in 1919, COLEMAN (1920, 1921, 1922) found no evidence that these highlands had ever been overswept by the Labrador ice sheet. This view was congruent with that held by CHALMERS (1895), that lowland glaciers had been of restricted extent around the western Gulf of St. Lawrence. Atop those highland areas Coleman found weathered bedrock, which he thought would have been swept away if ice had passed across them; nor did he observe erratic boulders on the higher parts of the Torngats and Chic-Chocs.

In the summers of 1924 and 1925 (at age 72-73), Coleman turned his attention to Newfoundland (COLEMAN, 1926). He was impressed by the same weathered character of plateaus and hilltops standing above areas which showed, in their striated bedrock surfaces and fresh glacial deposits, that they had been recently glaciated. Over the higher areas, including summits at about 300 m in the Avalon Peninsula and plateaus over 600 m high in the Long Range Mountains, glacial boulders were recorded perched on weathered bedrock eminences, or seated within blocky mantles of weathered rock. In the southern Long Range Mountains, above the Codroy River lowland, COLEMAN (1926) could find no evidence of glaciation at all: "No foreign bowlders [*sic*] were found, and the conclusion was reached that the southern part of the Long Range had never been glaciated" (p. 209).

Coleman assigned the glaciation of the Long Range and other weathered plateaus and summits in Newfoundland to an early stage, which he correlated with the Kansan or Jerseyan stages of the American chronology of glaciations. The younger glaciation was referred to the Wisconsin stage of that chronology.

Between 1894 and 1909 glacial geologists had erected a scheme of four glacial stages in the American Midwest, from evidence of glacial deposits separated by well-developed soils. The soils were thought to represent long periods when the climate was at least as warm as today. Some sections showed layers of glacial deposits separated by lacustrine sediments. These sediments contain fragments of plants which grow in these areas or further south at present. Thus, the concept of multiple glaciation grew from the early 1880's[6], the glacial stages being named after the states in which the geological relationships were identified, and the interglacial (warm) stages, mainly after localities where the intervening soils or non-glacial beds were identified:

Glacial	*Interglacial*
Wisconsin	
	Sangamon
Illinoian	
	Yarmouth
Kansan	
	Aftonian
Nebraskan	

While the Wisconsin-age glacial deposits could easily be correlated from west to east, the older ones could not. Thus, in New Jersey, the drift south of and underlying the Wisconsin-age deposits had been called "Jerseyan" by SALISBURY *et al.* (1902), because he could not demonstrate correlation with Illinoian deposits in the Midwest. Subsequently, "Jerseyan" became equated with Kansan.

Coleman assigned the older glaciation of Newfoundland to the antepenultimate glacial stage for two reasons. First, he was impressed by what he interpreted to be the advanced stage of weathering exhibited on glaciated summits in western and central Newfoundland, and was compelled to postulate a long ice-free period

6. FLINT (1965) reviews the evolution of glacial stratigraphic schemes in the United States.

between their glaciation and that of lower areas. Second, in his home area, he had doubted that the Illinoian glaciation was represented at all in the glacial deposits below the warm-climate, non-glacial "Don Beds" (COLEMAN, 1894). If this were true, then that area at least must have remained ice free throughout the 'glacial' Illinoian, and was therefore previously glaciated in the so-called Kansan stage. If the Illinoian was also missing in eastern Canada and Newfoundland, the long ice-free period he sought was readily available.

COLEMAN (1926) found further support for two glaciations in Newfoundland by giving interglacial status to marine clay with shells found between glacial deposits at Curling, near Corner Brook (p. 213). Similar marine clays, containing unfossilized shells of many species which inhabit eastern Canadian waters today, had been commonly known since the mid-19th century in the valley and Gulf of St. Lawrence regions, and had early been assigned by Logan (GEOLOGICAL SURVEY OF CANADA, 1863) to the period following the formation of the glacial deposits. Also, DAWSON (1878), who vigorously and long applied the Drift Theory to such deposits in Canada and the eastern provinces, believed these clays to be younger than the "unstratified boulder clay" (p. 59).

Coleman, however, conferred interglacial rank on all non-glacial formations, whether or not they indicated a climate as warm as today's or warmer, and so wrongly applied the term "interglacial." Such usage is illustrated by his interpretation of a section at Baie-Saint-Paul, Québec, where the shelly, marine 'Leda Clay' is underlain by glacial boulder clay and overlain by "kame materials" (of glacial origin). There, he concluded, "The Leda clay is therefore interglacial" (COLEMAN, 1927, p. 396).

On the question of the source of the two glaciations of Newfoundland, COLEMAN (1926) proposed that the earlier one, of "Kansan or Jerseyan age", "covered all of the island except the southern part of the Long Range,... It is probable that the Newfoundland ice was really the margin of the Labrador sheet which more or less completely filled the Gulf of St. Lawrence and expanded over all but the highest tableland of the southern part of the island. ... Probably hundreds of thousands of years elapsed after the early glaciation before the stiff fresh boulder clay and striated surfaces were formed by the less extensive Wisconsin ice sheets. ... The Wisconsin ice probably covered less than half the island and was in the form of small separate sheets or valley glaciers" (p. 220-221).

Shortly after his paper on Newfoundland was published, Coleman joined an international committee, brought together by Ernst Antevs for the purpose of compiling maps of the glaciated parts of the world to show the maximum extent of the ice and its extent at the last stage. Antevs, a Swede by birth and education, had earlier applied De Geer's method of counting annual sediment layers deposited in lakes in front of a receding ice margin to erect a chronology of ice-sheet disappearance from the coast of New England into northern Québec and Ontario (ANTEVS, 1928).

In the article which Antevs edited on behalf of the committee (ANTEVS, 1929), the map produced from Coleman's works is reproduced here as Figure 2. It is very obviously a compromise between the view of GOLDTHWAIT (1924), who considered that Wisconsin-age ice had swept south from Labrador over Cape Breton Island, and that of more conservative glacialists who felt that Cape Breton Island and the Magdalen Islands had escaped complete inundation in the Wisconsin. Coleman's interpretation for Newfoundland was not much at variance with all previous interpretations as far back as that of MURRAY (1882).

There is, however, an important mistake in Antevs' map (Fig. 2). COLEMAN (1926, p. 209) had said that the southern part of the Long Range had never been glaciated. But it is the northern part of the range that is shown on the map as a 'nunatak' at the Jerseyan/Kansan stage of most extensive glaciation. The southern Long Range is shown as ice-covered not only during this older stage, but also during the Wisconsin glaciation (ANTEVS, 1929, p. 655). I can only think that the mistake arose from Antevs' hasty compilation of information provided or published by Coleman, since Antevs' text reiterated Coleman's opinion of the southern Long Range as a perpetual 'nunatak' (p. 654).

Before leaving Coleman, this mainly geological essay needs to digress into botany, since it was from that field that he quite unexpectedly and, judging by his tone, delightedly received support for the view that large areas of Newfoundland had remained ice-free during the Wisconsin glaciation: "This convergence of two lines of evidence drawn from different sciences by workers having entirely different objects in view strongly supports the conclusions reached in regard to the Pleistocene history of the regions around the Gulf of St. Lawrence; and all geologists working on our glacial problems should take account of the extremely interesting results obtained by Dr. Fernald from a study of plants and their distribution" (COLEMAN, 1926, p. 220).

By the time Coleman visited Newfoundland, M. L. Fernald at the Gray Herbarium of Harvard University, had for two decades been botanizing in the upland areas of eastern North America, from New England to Labrador. He had recognized three hundred species of vascular plants which occurred only in the highest parts of the Chic-Chocs Mountains, the Long Range Mountains,

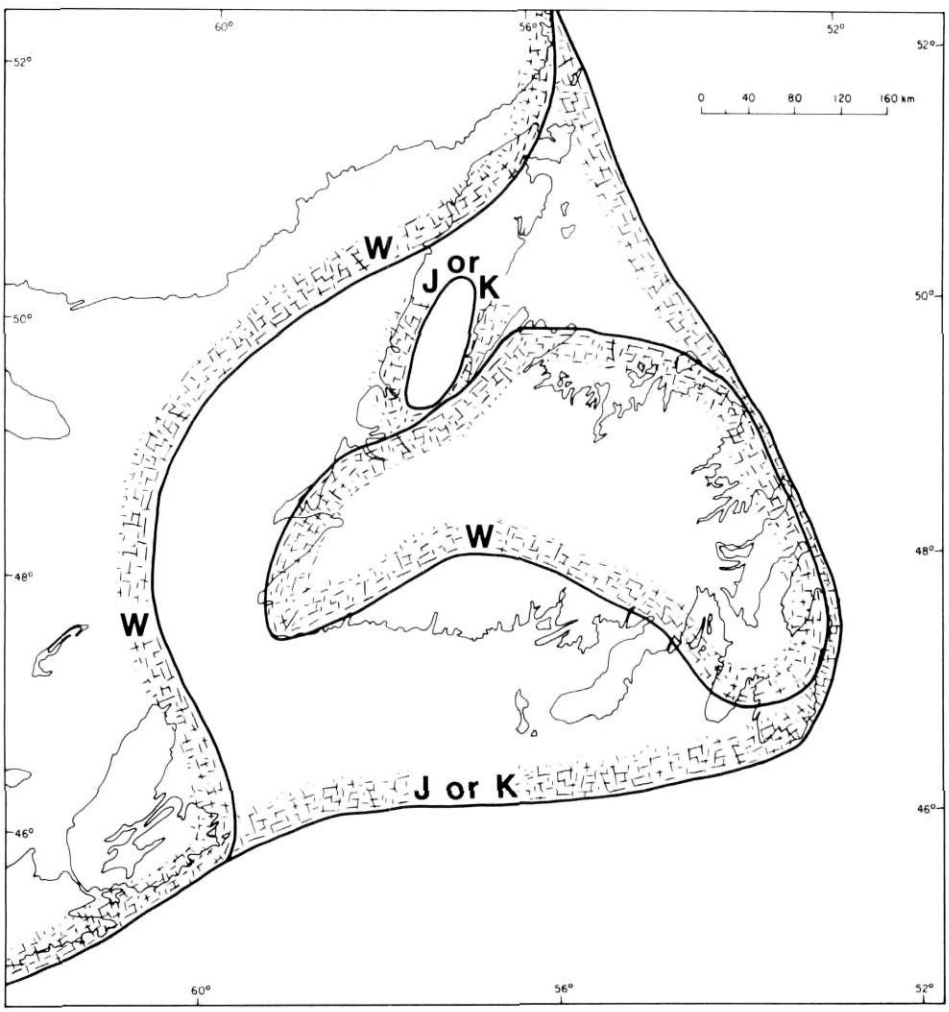

FIGURE 2. Island of Newfoundland and adjacent areas, showing limits of earlier glaciations (J or K, Jerseyan or Kansan) and later glaciation (W, Wisconsin), according to ANTEVS (1929), after COLEMAN (1926).

L'île de Terre-Neuve et ses régions avoisinantes. On y indique la limite des glaciations anciennes jerseyienne ou kansienne (J ou K) et celle du Wisconsinien (W) selon ANTEVS (1929), d'après COLEMAN (1926).

some in the Torngats, and some on the Îles de la Madeleine. They were not found to the southwest atop the New England mountains; nor had most of them been reported from areas north of the Gulf of St. Lawrence. The only other ranges of these plants were in similarly restricted mountain areas in the western Cordillera of North America and the east Siberian mountains.

Fernald recognized the coincidence of the distribution of these plants with the areas which COLEMAN (1920, 1921, 1922, 1926) had proposed were 'nunataks' within the Labrador and Newfoundland ice sheets during the Wisconsin age: "Analysis of the local distribution on the Gaspe peninsula of the cordilleran and other western plants and of their endemic allies brings out very strikingly the fact that their stations are just exactly on the spots which escaped extreme glaciation and, more amazing still, that they have signally failed to migrate westward into the closely adjacent and lithologically similar areas which were occupied by the Labrador ice sheet and its Chaleur lobe. This failure of the plants of the unglaciated spots to extend their ranges into closely adjacent areas which, upon the melting of the Labrador sheet, became open territory ready for invasion, is interpreted as a further evidence of the antiquity of these plants; at the close of the Pleistocene they were already too old and conservative to pioneer, although they are able to linger as localized relics in their special undisturbed crannies and pockets."

"It is, therefore, concluded that the distinctive plants of Gaspe, the Magdalen Islands, Western Newfoundland, and the Torngat Mountains there outlived the Pleistocene, and that their absence from the regions which were denuded by the Labrador and Newfoundland ice sheets is due, in the first place, to their extinction from these areas; in the second, to the fact that they are so ancient and conservative that they have failed to occupy the recently available lands which lie between their now isolated refuges" (FERNALD, 1925, p. 241-242).

The picture of the distribution of Wisconsin glaciers in eastern Canada, which had been built up by Coleman over more than a decade from geological

evidence, and which drew so much support from Fernald's botanical work, was not to stand for long unchallenged. Other botanists challenged Fernald's interpretation. Coleman's proposed 'nunataks' would have experienced too harsh a climate for the survival of plants (WYNNE-EDWARDS, 1937), and these must therefore have recolonized sites where special bedrock, soil, and surface stability conditions prevail (WYNNE-EDWARDS, 1939). Much later, in answering a query about his response to the critics, Fernald wrote: "Another selfstyled geologist (Wynne-Edwards) won a prize for his "demonstration" that I was wrong in treating much of the Long Range as not recently glaciated. I wrote and asked where he had climbed the Long Range and I have his reply, that he knew it only from a motorboat! While studying shore-birds!" (FERNALD, 1949).

The Coleman hypothesis must be seen as another milestone in the interpretation of ice marks in Newfoundland. It wedded the idea of invasion by Labrador ice to that of independent glaciation in proposing that the former had preceded the latter, with an intervening long interglacial period. It was the first to propose the limited extent of Wisconsin-age glaciers and to postulate a perpetual 'nunatak' in the Long Range Mountains. Lastly, it was the first to attach stage names with chronological meaning to the two glacial periods and thereby to correlate the island's glacial history with that of the mainland.

In his time Coleman's objective, independent turn of mind, in the face of many previous studies which had concluded to the contrary, marks him as an important figure in the history of these ideas. As with most scientists, he was prone to allow his concepts to rule the interpretation of evidence. In Coleman's case, when one reads him interpreting evidence from locations outside his main field areas to fit his concept of restricted Wisconsin glaciation, one may wonder how objective and strict he was with himself on more familiar ground.

Following his explorations in the eastern regions, Coleman returned his attention to the glacial deposits around Toronto, as well as to his earlier studies of glaciation that were recorded in the Precambrian rocks of northern Ontario.

4. LABRADOREAN INVASION ("FLINTIAN") SUB-PHASE

Coleman's view of the last glaciation of eastern Canada by an ice sheet centred in Québec-Labrador, and by peripheral icecaps in the highlands south of the St. Lawrence, was directly descended from opinion which had stood unchallenged since the 1880's. This held that two main centres of ice outflow could be identified, east and west of Hudson Bay, from radially oriented glacial landforms. It was also felt that the now-submerged area of Hudson Bay was also an ice outflow zone which, gaining contributions from the east and west, discharged ice northeastwards through Hudson Strait and southwest and south over the upper St. Lawrence and Great Lakes region. This view was summarized by BELL (1890).

With the increasing density of information on glacial features of the Canadian Shield and on raised shoreline features around the Great Lakes, the St. Lawrence valley and Gulf, and the Atlantic coasts, doubts began to be raised as to whether these two major ice centres had grown and moved independently. In a wide arc around the shield, from the lowlands of Manitoba, through the Great Lakes-St. Lawrence lowland, to the Atlantic coasts, the varying elevations of raised shorelines indicated a warping of the crust up towards the southern Hudson Bay region. This implied that the load of ice which had earlier depressed the crust had thickened to a maximum there. Hand in hand with this evidence, indicators of glacial movement from two outflow centres flanking the bay were reinterpreted as patterns produced mainly by late-stage ice flows during wastage of a former massive ice sheet centred over Hudson Bay.

The dominant antagonist to the "two-centre" concept of glaciation became Richard Foster Flint at Yale University. Born in 1902, by the end of the 1930's he had gained wide experience in interpreting deposits of the Wisconsin-age glaciers in Washington State, New England, and in Greenland. He had been a member of the Boyd expedition to northeast Greenland in 1937 (FLINT, 1948). In New England, he was familiar with the glaciation of the White Mountains, which had been assigned by J.W. GOLDTHWAIT (1916) and by his son R.P. GOLDTHWAIT (1940) to an overriding Wisconsin-age ice sheet from across the St. Lawrence valley to the north. If Mt. Washington, over 2,000 metres above sea level, had been overidden, it was only natural to query Coleman's view that lower summits in the Gaspé, northern Labrador, and Newfoundland — closer to the long-accepted Labradorean centre of outflow — had not been similarly affected.

In order to reexamine the field evidence from some of these highlands, Flint made excursions to Newfoundland in 1938 and 1939, with Paul MacClintock and William Twenhofel of Princeton University, continuing the long association of Yale and Princeton with the geological exploration of the island (SNELGROVE, 1974), and to the Gaspé highlands in 1941 with A. Lincoln Washburn of Yale, and Max Demorest of Wesleyan University, Connecticut. In Newfoundland, Flint concentrated his attention on the raised shoreline features of the western and southern coasts of the island, for evidence of the pattern of postglacial crustal warping. MacClintock, a glacial geologist, and Twen-

hofel, a stratigrapher with an interest in geomorphology (he had earlier written on the preglacial development of the surface of Newfoundland — TWENHOFEL, 1912), accompanied Flint in a chartered vessel to study the glacial deposits and landforms of the west coast, also spending some time in the western interior along the island railway.

FLINT (1940) grouped the raised shoreline features of the west coast of Newfoundland into two sets on the basis of elevation above sea level. A higher group fell on a former sea-level plane which had been warped up towards the northwest, from (30 m) in the St. George's Bay area to 137 m near the Strait of Belle Isle. Projecting this plane southwards, he found that it would lie approximately at present sea level along Cabot Strait, where he had seen no evidence of raised marine features. The lower set of shorelines was tilted in the same direction and was believed to have formed during a 5000-year pause in the emergence of the land. The interpretation was summarized as follows: "...the pronounced northwestward rise of the marine features on the west coast implies that the former glacial mass was thickening toward the northwest. From this it may be regarded as likely that at least western Newfoundland was invaded by the Labrador ice sheet, flowing from the nortwest, and that local Newfoundland glaciers were not massive enough to interfere seriously with the regional crustal influence of the Labrador ice" (p. 1775). Flint (probably following the interpretation of his companions) recognized that the ice, which had receded from the west coast of Newfoundland to permit submergence by the sea, had moved from an island icecap. By implication, he would have viewed this as a relatively late movement.

MacCLINTOCK and TWENHOFEL (1940) made the first detailed examination of the stratigraphy of glacial deposits so excellently exposed in approximately 80 km of coastal cliffs around St. George's Bay. One hundred years before, JUKES (1842) had failed to recognize these thick accumulations of varied deposits, which would have excited a diluvialist, with their evidence of submergence. Nor had Murray, or his successor J.P. Howley, recognised them, although they form the basis of good agricultural soils, which they were assigned to identify and recommend for government-sponsored settlement. Before the turn of the century, access from the land to this shore was impossible, and that from the sea difficult without a small boat. When the railway was built at the turn of the century it did not pass within three kilometres of this coast, except near the head of St. George's Bay, where there are few coastal exposures. Notwithstanding these difficulties of access, it is tempting to speculate that in the 19th century, due perhaps to slightly lower sea level, reduced storminess, little interference with the coastal vegetation by human activities, or a combination of two or more of these factors, the deposits in these cliffs were so covered by vegetation as to be invisible from seaward and difficult to recognise from land.

Be this as it may, by the late 1930's, the cliffs were bare enough of vegetation for MacClintock and Twenhofel to recognize three distinct formations within them. The lowest was identified as glacial till and kame gravel, deposited by advance and then retreat of ice across the present shoreline. No indications of its derivation were obtained from boulders within it, but on bedrock beneath it in the Port au Port area striations were recorded from two main directions — first north and then east. These were interpreted as showing that ice had first crossed the Port au Port area from the north, probably from Labrador, and later from the east, as part of a island-centred ice cap.

Above these glacial deposits, clays and sandy deltaic beds, each with marine shells, indicated that submergence had followed ice retreat from the St. George's Bay coastline. It was during this submergence that the higher group of shorelines recognized by FLINT (1940) had formed. Over these marine sediments, in turn, MacCLINTOCK and TWENHOFEL (1940) recognized glacial deposits underlying a morainic landscape, formed by a westward readvance of ice from the mountains of west Newfoundland into the sea. "This succession of events would fit well within the proposal ... that Newfoundland was at first affected by ice from Labrador and later had its own outward radiating ice cap. ... The ice which moved southward may have either been Labrador ice or Newfoundland ice which, further north, moved out into the St. Lawrence Gulf, there encountered south-moving Labrador ice, and was pushed southwards by it" (p. 1753).

MacClintock and Twenhofel attempted to harmonize their cautious interpretation of the evidence from striations in one small area with Flint's broader conclusion that Labrador ice had dominated Newfoundland ice in warping the crust, thus: "glaciation from Labrador took place at the climax of the Wisconsin stage, when ice may well have passed not only over Newfoundland but out to deposit the well-known drift of the Grand Banks. ... As the Labradorian glacier waned part of it may have persisted on Newfoundland, acquired radial motion as impeding ice melted away from its margins, and thus became a local ice-cap whose movement would have largely obliterated any earlier striae" (p. 1750).

In both of these papers it was concluded that glacier ice had completely covered the mountain summits of western Newfoundland. Even in the southern Long Range, where COLEMAN (1926) had seen no evidence of any glaciation, MacClintock and Twenhofel recorded glacially eroded rock knobs and lake basins, as well as

perched erratic boulders. Both there, and atop summits where Coleman had assigned glacial erratics to a pre-Wisconsin glaciation, they felt that the erratics were fresh enough to have been emplaced there in the more recent Wisconsin glaciation.

Thus, Coleman's hypothesis for Newfoundland, and the botanical evidence which it seemed so well to explain, was overturned. Since Coleman had died the year before Flint's and MacClintock's papers appeared, no rejoinders could be made. Soon after the Newfoundland work, Flint led another party to the Chic-Chocs Mountains of Gaspé, from where he amassed evidence of high-altitude erratics and glacial erosional landforms, as well as other arguments, to contradict Coleman's view of those mountains as a perpetual ice-age 'nunatak' (FLINT, DEMOREST, and WASHBURN, 1942).

Flint proceeded from these regional field studies to derive an hypothesis, backed by topographical and climatological arguments, for the origin of a "Laurentide" ice sheet in the highlands of eastern Labrador and Baffin Island, and its growth into a subcontinental ice dome over Hudson Bay nourished by snowfall on its southwestern margin (FLINT, 1943). The name "Laurentide" was in itself a return to earlier notions, primarily that of Chamberlin (*in*: GEIKIE, 1894), that glaciation east of the Rocky Mountains had been achieved by a continuous ice sheet. Flint now returned to this, supporting it with evidence from his recent field studies in the southeastern highlands, as well as with arguments against growth of independent ice sheets over low plateaus east and west of Hudson Bay. His concept was supported, apparently independently, by DEMOREST (1943) who, from a theoretical physical argument, concluded that: "Piedmont growth of glaciers in mountains or high plateaux may thus be a forerunner of ice-sheet formation in which the mountains or plateaus would eventually become buried" (p. 389). Then, "Extension of the Laurentide ice sheet would also have been favoured towards the west, and towards the southwest, for those are the probable directions from which migrating cyclonic disturbances approached. As the ice sheet expanded over the central Canadian lowlands, the advancing high borders would have intercepted greater amounts of precipitation than had previously fallen on the lowland surface. ... Thus the ice sheet's growth was presumably favoured by its own high borders, and, as a result, it would probably expand westward over lands on which névé accumulation was less favoured" (p. 390).

The Geological Society of America had received Demorest's manuscript on April 7, 1942 and Flint's on June 26. While on an expedition later that year, Demorest died at age 32, on November 30. He would have had little time between learning of Flint's manuscript and departing for the field to do more than recognize their independent arrival from different directions at a similar hypothesis of ice-sheet growth. Nevertheless, it is hard to understand how Flint and Demorest, whom Flint later memorialized as "outstanding glaciologist, generous and thoughtful friend" (FLINT, 1947, p. ii) had not communicated their mutual interest in ice-sheet growth during their field excursion to the Chic-Chocs the previous year.

As MURRAY (1882) had done, FLINT (1943) assigned ice marks in Newfoundland to the dominating influence of an ice dome. Centred over Hudson Bay, the eastern sector of this Laurentide ice sheet had invaded the island across the Gulf of St. Lawrence: "Beyond the southeastern sector of the ice sheet, where conspicuous highlands stood in the common paths of many storm tracks, the cold climates induced by the growing ice sheet coupled with exceptional snowfall resulted in the local development of glaciers. Newfoundland, the highlands of Gaspé, and perhaps the highlands of New Brunswick and the White and Adirondack Mountains were among these. *All, however, probably coalesced with or were overwhelmed and surrounded by, the Laurentide ice sheet at its maximum*" (p. 357, my emphasis).

Thus, another chapter in the study of ice marks in Newfoundland concluded with a statement of more than local import. The concept of the glaciation of North America east of the Rocky Mountains had been radically changed. In Newfoundland, many additional glacial features had been surveyed; their meaning had been radically revised into a different concept of the style of glaciation; so also had the chronology of glaciation, with rejection of Coleman's two-stage hypothesis. IVES (1978) gives a thorough review of the evolution of the broader concept.

Thirty years were to elapse before studies of glaciation in western Newfoundland led to modification of Flint's scheme. In the interim, between the end of the Second World War and the early 1970's, several local glacial studies were undertaken. Strangely, western Newfoundland, where proximity to Labrador, together with optimal topographic diversity, could have been expected to reveal a complex glacial history, was ignored until the mid-1960's. These studies, in central and eastern Newfoundland, added extensive information on glacial and marine features. While in each case little support for Flint's scheme was implicit in the evidence, no major conceptual shifts occurred to modify the idea of an overriding late Wisconsin Laurentide ice sheet.

Reports to the Newfoundland Geological Survey, under the direction of A.K. Snelgrove of Princeton University, between 1934 and 1943, originated as theses, mostly at Princeton but some at Yale. Their standard

format included brief descriptions of physiography and glacial geology, which added information from local areas. Interpretations did not veer from the prevailing concepts of Coleman, before 1940, or of Flint after that.

One of these theses (WIDMER, 1950), however, deserves mention for its recognition of raised pre-Wisconsin wave-cut benches in the Hermitage-Burin area, as well as for a report of fresh-water raised shoreline now fronting the sea, which were interpreted as the margins of lakes dammed by ice blocking the mouths of Fortune and Placentia Bays.

5. NEWFOUNDLAND ACCUMULATION SUB-PHASE

The work of Flint and MacClintock did not extend to the Avalon Peninsula, which has always yielded information to indicate only radial Wisconsin ice flow from one or more centres. SUMMERS (1949) located elongated centres of ice dispersal on the peninsula on the basis of flow indicators, while HENDERSON (1972) modified this picture to show not only these centres but a more dominant one north of St. Mary's Bay. He proposed that late-glacial retreat of ice into the head of the bay left a series of recessional moraines between it and the base of the Carbonear Peninsula. ROGERSON and TUCKER (1972) later refined this interpretation, finding that those moraines were formed beneath actively flowing ice, and thus that the ice need not have receded towards St. Mary's Bay. Rather, it appeared not to have receded at all, at least in linear fashion, since they saw evidence of its final stagnation *in situ* in the Hawke Hills, east of the morainic tract.

In a major regional work on glaciation in eastern Newfoundland, stemming from a bedrock geological survey, JENNESS (1960) concluded that the region between the isthmus of Avalon and a north-south line from Notre Dame Bay to Fortune Bay was completely glaciated by ice radiating from a dome over west-central Newfoundland, towards and beyond the coast on all sides. Recognizing contrasts between glacial terrain beyond and inland of a relatively inconspicuous moraine, Jenness attributed the moraine to a stillstand of the ice margin at, or a minor readvance to, this position following retreat from the coast. Jenness also described raised, post-glacial, marine shoreline features, and felt that they showed a pattern of crustal warping up towards the northwest, which "cannot but promote speculation that Newfoundland was invaded by the Labrador ice sheet" (p. 177). Apart from this speculation, Jenness failed to find any evidence to support Flint's idea of invasion by Labradorean ice.

Similar conclusions were reached by LUNDQVIST (1965) in an adjoining area, where evidence pointed to complete glaciation by an island icecap, and to a halt in declaciation inland of the coast. However, Labrador ice again entered into the interpretation, since a few striations trending northwest-southeast did not easily fall into a picture of island-centred glaciation.

Thus, from the Avalon Peninsula to the eastern flanks of the Long Range Mountains, these studies of glacial features showed no clear evidence of overriding Labradorean ice at the Wisconsin glacial maximum. The view that glaciation extended beyond the present coastline, however, conformed to the interpretations of FLINT (1940) and MacCLINTOCK and TWENHOFEL (1940). Only one report appeared in this interval which cast some doubt on this last notion. It came from the discipline of entomology and therefore, lying outside the main stream of geological literature, was largely overlooked. LINDROTH (1963) found that the distribution of certain flightless Carabid beetles in North America showed a disjunct range in Newfoundland, among other places, and that, within the island, these species were overrepresented in the population of the western part. Discounting immigration in late- and postglacial time, as well as European introduction, Lindroth postulated that parts of western Newfoundland remained as ice-free coastal refugia for these beetles during the Late Wisconsin glacial maximum. Siding with COLEMAN (1926), Lindroth opined: "geologists should not be entitled to ascribe almost every trace of glacial drift as an effect of the last glaciation, as now commonly practised" (p. 105-106).

In western Newfoundland, the author concentrated doctoral studies (BROOKES, 1970a) on the glacial and associated deposits and landforms between St. George's Bay and Bonne Bay, the focal area of the earlier work by Flint, and by MacClintock and Twenhofel. Boulders in the lower of two glacial till units (the "St. George's River Drift" of the latter authors) were obviously derived from the east; that is, the till was deposited by ice from Newfoundland. Striations on the bedrock beneath it therefore deserved reexamination, especially in the Port au Port area, where MacCLINTOCK and TWENHOFEL (1940) saw in them a movement first from the north, and later from the east. At one locality, Campbell's Creek on the southern shore of Port au Port Peninsula, not only were the relations between sets of striae startlingly clear, it also was apparent why the earlier workers had thought that striae made by ice from the north were the first formed. Here, most westward-directed striae were scored by the southward ones, but a few, deeper westward ones were not scored across their entire width. It could thus appear that some southward striae were later scored by westward ones. Everywhere over this coastal region evidence from striae and boulder transport indicated movement of ice from the east. No evidence of Labrador ice action was found. South-moving Newfoundland ice over Port au Port Peninsula could more logically be explained by changes in the orientation of

the icecap margin as late-glacial marine waters calved a bay into it, roughly parallel to the shores of St. George's Bay (BROOKES, 1970b).

While earlier views on the role of Labradorean ice had been changed by this work, the notion of a complete glacial cover was not. Evidence from erratics strewn over summit plateaus was interpreted to mean that the Newfoundland icecap had covered them at the last glaciation. The mantle of weathered bedrock in which those erratics lie thus had to have been formed early in the deglaciation of the region, as the summits emerged first from thinning ice (BROOKES, 1974). Similar findings were reported by GRANT (1969a), who had extended this work to the Northern Peninsula. Only over the lowlands bordering the Strait of Belle Isle did he report any evidence of invasion of Newfoundland by Labradorean ice (GRANT, 1969b). By the late 1960's, therefore, while much had been added to the picture of ice-flow directions and late-glacial marine submergence in Newfoundland, the glacial map of the island continued to show a complete ice cover. The map compiled by PREST (1969), part of which is shown in Figure 3, summarized this view.

On the Northern Peninsula, GRANT (1969a) had mapped a set of looped moraines which had been built on the coastal plain by tongues of ice issuing from deep glacial troughs eroded into the western side of the Long Range Mountains. These moraines were apparently built partly below sea level, since marine deposits lap over their margins. Shells in those deposits were radiocarbon dated at approximately 12,700 years before present (GRANT, 1972). This later correlated well with my estimation of the age of a glacial readvance around St. George's Bay, at 12,750 years ago; an estimate which was later confirmed by radiocarbon dating of shells intimately associated with morainal sediments near Stephenville (BROOKES, 1977a).

Grant's work in Newfoundland initially stemmed from airphoto interpretation of glacial terrain for a revision of the *Glacial Map of Canada* (PREST *et al.*, 1968). It expanded in Newfoundland under his direction of the

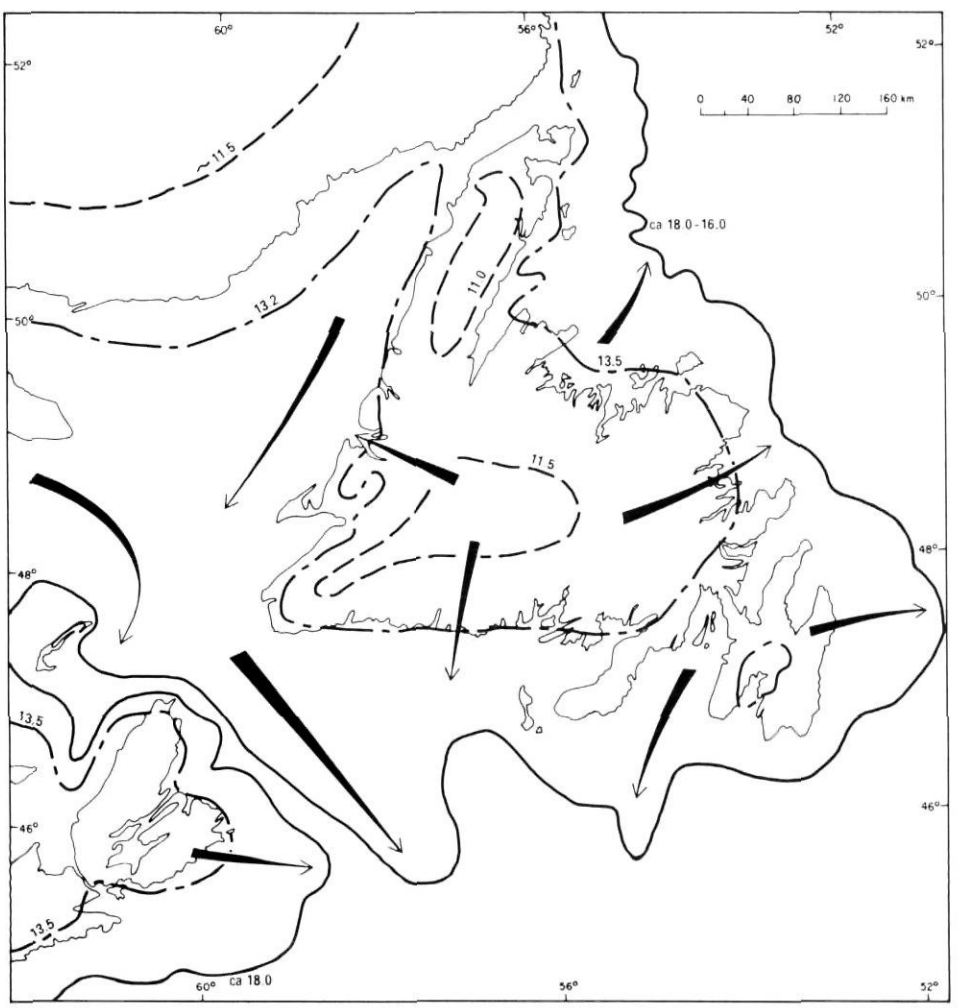

FIGURE 3. Island of Newfoundland and adjacent areas, showing limit of Wisconsinan glaciation (*ca.* 18.0, *ca.* 18.0 — 16.0) and two recessional glacier margins (13.5 — 13.2, 11.5) according to PREST (1969). Numbers refer to 1,000's of years BP. Arrows indicate main ice-flow directions.

L'île de Terre-Neuve et ses régions avoisinantes. Localisation de la limite de la glaciation wisconsinienne (vers 18.0, 18.0 — 16,0) et de deux positions frontales lors du retrait des glaces (vers 13.5 — 13,2 et 11,5), selon PREST (1969). Les chiffres sont en milliers d'années BP. Les flèches indiquent les principaux sens de l'écoulement glaciaire.

Geological Survey of Canada's program of mapping the terrain and surficial materials of the island as part of a federally-funded resource development scheme. In addition to the inventory of soil resources for agriculture and forestry, and of aggregates for the construction of roads, bridges, and dams, increasing attention was being paid to mapping glacial deposits for tracing the source of drift rich in base-metal concentrations. Specific studies, *e.g.*, in the Central Mineral Belt and Newfoundland (*e.g.*, GRANT and TUCKER, 1976), not only demonstrated the value of "drift prospecting" but resulted in GRANT (1974) reconstructing a picture of the shrinkage of the Newfoundland icecap at the close of the Wisconsin stage.

Grant's work for the federal government encompassed parts of Nova Scotia as well. By the mid-1970's an intricate picture of glacial events in Atlantic Canada was beginning to emerge. It had earlier been concluded by PREST and GRANT (1969) that late Wisconsin ice-flow patterns were more complex than GOLDTHWAIT (1924) had proposed for Nova Scotia. Now, with the radiocarbon dating of pre-Late Wisconsin plant beds beneath tills (PREST, 1970), a more definite assignment of intertidal platforms to the Sangamon interglacial stage (GRANT, 1976), and the recognition of tills of different ages and provenance, the ingredients of a radically revised glacial history were now at hand, as were two interrelated catalysts.

6. MULTIPLE NEWFOUNDLAND GLACIATION SUB-PHASE

The first catalyst appeared as a reaction against a view being promulgated by a group of palaeoclimatologists in America, that Late Wisconsin glaciation of eastern and northern North America, Northern Europe and northwestern U.S.S.R. was extensive, encompassing all land areas and extensive areas of continental shelf (CLIMAP PROJECT MEMBERS, 1976). This group, dominated by marine geologists, had built up a chronology of changes in the volume of glacial ice over approximately the last 800,000 years (*e.g.* SHACKLETON and OPDYKE, 1973). Their conclusion was that the Late Wisconsin had seen global ice volumes comparable to those of earlier maxima. This required that ice sheets had been thick enough to cover the mountains of eastern Canada, from Nova Scotia to Ellesmere Island, and to expand outwards beyond the present coasts, either to calve into deep offshore waters or to rest on emerged continental shelf plains.

This view was countered by land-based glacial geologists who had found, from over a decade of intensive research on Baffin Island (ANDREWS *et al.*, 1975), itself stimulated by earlier results from Labrador (IVES, 1960), that Late Wisconsin ice had not only been largely confined to coastal valleys and small plateau icecaps, but that it had reached its maximum extent only about 8,000-9,000 years ago. This was 6,000-10,000 years after the maximum in the classical area of American glacial studies in the Midwest (ANDREWS *et al.*, 1972).

In Labrador in the late 1950's to early 1960's, and in Baffin Island in the 1970's several glacial stages had been recognized in the mountainous terrain bordering the coast, from the evidence of altitudinal variations in the degree of modification of glacial landforms by weathering. These variations, sometimes quantifiable, permitted the recognition of altitudinal "weathering zones," whose boundaries lay along the former margins of successively less extensive ice covers (IVES, 1958, 1975; BOYER and PHEASANT, 1974).

Once opposition to the idea of extensive Late Wisconsin ice began to be voiced, the second catalyst appeared as a result of the more widespread attention given to results of the Baffin Island work. In particular, the idea of weathering zones quickly permeated into the Newfoundland context to unite the observations of the decade from 1965 to 1975 into a new general concept of ice marks in Newfoundland.

In that decade the intricate mosaic of glacial deposits and landforms in the lowlands of western Newfoundland had attracted an amount of attention out of proportion to their area. In the highlands, extensive bedrock outcrop or peat-covered terrain showed little in the way of glacial deposits, beyond inconspicuous moraine segments. However, once the concept of weathering zones was applied, it was clear that these highlands displayed altitudinal variations in landforms comparable to those of Labrador and Baffin Island. Extensive erratic-strewn mantles of weathered bedrock over level summits between 600 and 800 m pass abruptly downslope into more obviously glacial terrain in which the till mantle has been noticeably modified by downslope movements. Small fragments of moraine mark the boundary between these two terrain types, indicating that ice either had halted in its shrinkage from the summits, or had later readvanced only to these peripheral moraines, failing to again overtop the summits. Below the lower glaciated terrain, landforms changed again, becoming more distinct and fresher, with glacial smoothing and striations more obvious. The upper boundary of this zone could be traced from the plateaus, to the heads of deep glacial throughs, and thence down these to the looped moraines, demonstrably built by Late Wisconsin glaciers.

GRANT (1977b) was the first to apply the weathering zone concept to Newfoundland, in the area of Gros Morne National Park, astride Bonne Bay. He attributed the differences in terrain between each zone to the variable time elapsed since the zones had last been

covered by glaciers. Noting that weathering and erosional features were roughly ten times more intensely developed in the highest zone than in the lowest, and knowing that the latter could be assigned a Late Wisconsin age (deglaciated roughly 10,000 years ago), he assigned the glaciation of the highest zone to a pre-Wisconsin ice cover. By implication, the intermediate zone was of early and/or middle Wisconsin age. In the southern Long Range Mountains, BROOKES (1977b) reached similar conclusions, recognizing a Late Wisconsin and an Early Wisconsin glaciation. But over the highest summit plateaux of the Long Range, he found no evidence of glaciation. These were the same summits which COLEMAN (1926) had thought were never glaciated.

From his regional studies of glacial history in the Atlantic Provinces, Grant had, by the mid-1970's, built up a picture of multiple glaciation from pre-Wisconsin putative glacial sediment (MacNEILL, 1972), a Sangamon interglacial shore platform and associate marine gravels, and multiple tills of Wisconsin age (GRANT, 1976). This was fitted to the weathering zone concept, clearly illustrated in western Newfoundland, and a comprehensive regional review was published by GRANT (1977c). From this, a map is here, with omissions, shown as Figure 4. It shows Late Wisconsin glaciers not extending far from the present coastlines, except in the western Gulf of St. Lawrence. There, low-relief terrain was overrun by ice flowing strongly from the New Brunswick highlands. This pattern is one with which CHALMERS (1895) and COLEMAN (1926) would have broadly concurred.

To add to the complexity of the picture of the last ice age in Newfoundland, recent research in the Burin Peninsula area (GRANT, 1975; TUCKER and McCANN, 1980) has not only recorded four glacial episodes of varying severity affecting that area, but has shown that, in one of these episodes ice appears to have moved onshore from an ice dome on the continental shelf. A similar off-shore ice centre was earlier proposed east of Cape Breton Island by GRANT (1971). It now appears possible that, with heavy snowfall on an exposed conti-

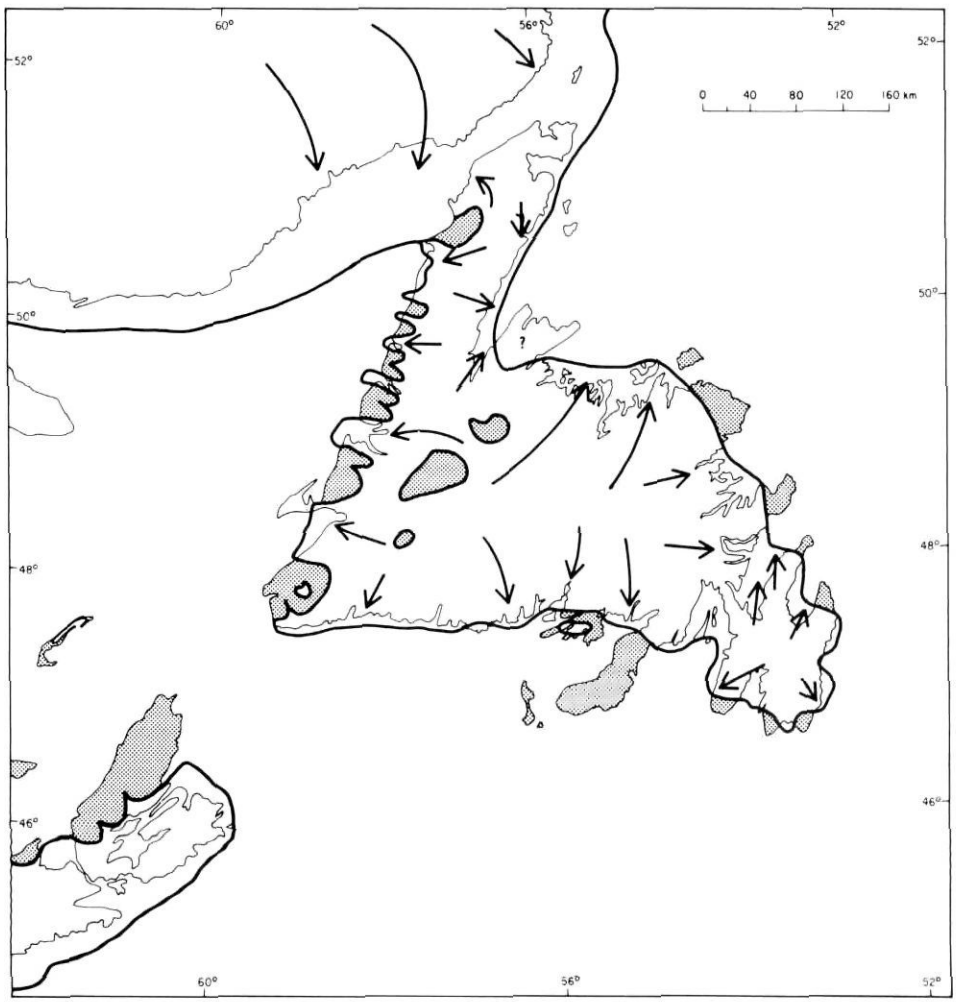

FIGURE 4. *Island of Newfoundland and adjacent areas, showing limit of Late Wisconsinan ice (heavy solid line), nunataks and other extra-glacial areas (stippled), main direction of ice flows (arrows), according to GRANT (1977c).*

L'île de Terre-Neuve et ses régions avoisinantes. Localisation de la limite de la glaciation wisconsinienne (trait large), des nunataks, et des zones non recouvertes de glace (grisé) et indication des principaux sens de l'écoulement glaciaire (flèches) selon GRANT (1977c).

nental shelf, and with cool summers probably due to deflection of the Gulf Stream in a glacial period (RUDDIMAN and McINTYRE, 1977), the broad banks on the eastern Scotian Shelf and the western Grand Banks could have supported independent, dynamic glacial domes.

7. "NEO-FLINTIAN" SUB-PHASE

In the last year the glacial sequence proposed for the island of Newfoundland by GRANT (1977c) has been further challenged by those workers whose objective has been the reconstruction of global ice sheet areas and volumes at the last glacial maximum — for their purposes, 18,000 years BP (CLIMAP PROJECT MEMBERS, 1976). In this work, summarized by DENTON and HUGHES (1981), MAYEWSKI *et al.* (1981) rightly remark upon the paucity of firmly dated evidence for restricted Late Wisconsinan ice extent in the Atlantic Provinces. They question the logic of calling for a time-transgressive Late Wisconsin seaward glacial limit, such as could be envisaged from a range of radiocarbon dates on ice margins in the region, interpreted by GRANT (1977c) to be near-maximal. They further question the interpretation of weathering zones, such as those defined in Newfoundland by GRANT (1977b) and BROOKES (1977b). MAYEWSKI *et al.* (1981) feel it is by no means generally accepted that boundaries between weathering zones exclusively mark altitudinal glacier limits. Rather, because of the glaciological nature of their work, they prefer to explain them as reflections of variations in glacier-bed thermal regime, as SUGDEN (1974) did for somewhat comparable landscapes in Greenland and part of Baffin Island (SUGDEN and WATTS 1977).

According to the glaciological theory, as recapitulated by HUGHES (1981), the tripartite weathering zone sequence in Newfoundland can be explained if those uplands were completely covered by an ice sheet, the base of which was frozen to the substrate over summit plateaus and peripheral areas, freezing to the substrate in an intermediate zone, but melting over lower plateaus and in valleys. Ice frozen to the substrate would be incapable of removing previously weathered debris, which would thus be left intact after deglaciation. Ice freezing to the substrate would be incorporating debris into a basal regelation layer, and thus becoming less and less effective in erosion. Ice melting in contact with the substrate would slide over it, inducing strong glacial abrasion and quarrying.

In their alternative reconstruction of the areal and vertical extent of Late Wisconsinan ice in the Atlantic Provinces, HUGHES *et al.* (1981) thus discount earlier interpretations of radiocarbon-dated glacial deposits and weathering zones. They prefer to accept a few, debatably firmer, indications of a glacial limit 50-100 km beyond the present Atlantic coastlines, projecting beyond the shelf edge southeast of Cabot Strait. From this margin, they construct theoretical ice surface profiles along which ice thickness increases to 4.6 km over Hudson Bay (hence the name "Neo-Flintian" for this subphase). Within this massive ice sheet, ice streamed southeastwards over the Maritime Provinces and through Gulf of St. Lawrence, and flowed radially within a contiguous southeastern salient over Newfoundland. They argue that the outer portion of the ice sheet was grounded below sea level and that, in this condition, the edge of the continental shelf was the only effective seaward limit to its expansion. Ice streams coursed seawards through deep channels, such as Laurentian Channel beneath present Cabot Strait, discharging vast numbers of icebergs into the ocean (see Figure 2-4, DENTON and HUGHES, 1981).

This reconstruction, informally called the "maximum viewpoint" is directly opposed to the "minimum viewpoint" of GRANT (1977c) in the Atlantic Provinces in general, applied to Newfoundland in particular by GRANT (1977b) and BROOKES (1977b). It does, however, attempt to accommodate the interpretation of coastal uplands, such as Newfoundland's Long Range Mountains, as Late Wisconsinan 'nunataks' by suggesting that warming and drying winds draining off high interior ice dome(s) could have ablated ice from these uplands close in time to the attainment of greatest glacial extent (MAYEWSKI *et al.* 1981, p. 135).

A problem that long confronted glaciologists in their attempts to explain deglaciation is the source of energy required to ablate enormous volumes of ice in a short period. ANDREWS (1973) called upon calving along broad ice-fronts standing in proglacial lakes to solve the problem around the margin of the Canadian Shield. MAYEWSKI *et al.* (1981) resort to "downdraw" of ice streams from interior ice domes, through deep peripheral channels, such as Laurentian Channel and Hudson Strait, into the sea. This could quickly establish the lowered deglacial ice-surface profiles which are in accord with radiocarbon-dated stratigraphic evidence from around the Gulf of St. Lawrence and Bay of Fundy.

This most recent phase of debate relevant to Newfoundland's 'ice marks,' with its reference to icebergs and to the importance of marine influence on the dynamics of ice sheets, mutedly recalls an early phase in the evolution of ideas in which icebergs were thought to have dominated the glacial scene over the island (MILNE, 1874). It also brings this essay "out to sea" to consider briefly the importance of marine geological evidence for an understanding of the causes of glaciation.

It is now 40 years since core samples from the North Atlantic sea floor revealed evidence of detrital deposi-

tion from ancient icebergs drifting far south of their present limits. FLINT (1971, p. 727) briefly discusses this early work. The beginning of systematic deep-sea drilling in the late-1960s, and analysis of sediment types, microfossils, and oxygen isotope ratios in the cores recovered has begun to clarify the complex interplay of astronomical, climatic, oceanographic, glaciological, and biological processes in the North Atlantic Ocean.

Recent work by RUDDIMAN *et al.* (1980) is of particular interest to a discussion of 'ice marks' in Newfoundland, since it is off the island's shores that deep-sea sediments reveal evidence of conditions conducive to the onset of glaciation in a location like Newfoundland's. Down-core variations in oxygen isotope ratios in the skeletal carbonate of marine microfossils from these sediments show that northern hemisphere ice volume rapidly increased from an interglacial minimum to a glacial maximum in a 10,000-year interval, beginning approximately 82,000 years ago. The paleoecology of the same microfossils indicates that sea-surface temperatures remained at warm, interglacial levels for the first half of that interval, before rapidly declining to glacial levels at the end of it. In addition, variations in the abundance of debris dropped from icebergs show that bergs were not being formed in the first half of the rapid ice sheet growth period, but increased markedly in the latter half.

Fluctuations in these three functions (ice volume, sea surface temperature, and iceberg abundance) are closely interrelated with fluctuations of summer insolation at 65°N. According to RUDDIMAN *et al.* (1980), declining summer insolation led to progressively delayed summer melting of winter snow cover, which in turn reduced the energy budget over land areas. Those closest to an ocean more slowly losing heat to a cooling atmosphere experienced enhanced winter snowfall, due to the steering of storm tracks along the thermal boundary zone. This led to rapid, land-based ice sheet growth, with little or no discharge to the sea in the early phase. Continuing decline of insolation resulted in continuing growth of ice sheets, which eventually discharged to the sea, with the result that icebergs became more abundant. These enhanced the cooling effect on sea-surface temperatures of a cooling northern hemisphere atmosphere. No doubt, in the earlier phase of ice sheet expansion, when the ocean retained its interglacial warmth, Newfoundland fogs had a similar effect on summer temperatures to that complained about today!

In recent years, Canadian research into the marine geological record of the ice ages has increased in response to needs for information on the offshore environment. For example, ALAM and PIPER (1977) recovered deep-sea core records of alternating glacial and non-glacial marine sedimentation south of the Grand Banks, records which probably extend back at least 500,000 years. In at least the youngest glacial period recorded in these sediments (Late Wisconsinan), land-based ice seems to have been extensive, as holders of the "maximum viewpoint" discussed above believe. As well, FADER *et al.* (1980) mapped submarine moraine segments in Laurentian and other channels, south of Newfoundland. In assigning them on stratigraphic grounds to the Late Wisconsinan, they also provide support for that viewpoint as it applies to Newfoundland.

SUMMARY AND CONCLUSION

It should be apparent from this essay that the 'ice marks' of Newfoundland are a theme upon which many variations have been played since the mid-nineteenth century. Although not exact, the correspondence between these variations and those played on glacial themes in mainland Canada is noteworthy. By way of exception, Alexander Murray's first recognition of glacial action in Newfoundland in 1866 preceded introduction of the Drift Theory to the island by Milne in the 1870's. Murray's perspicacity can be seen as a direct reflection of his early association with Logan and Bell, both early adherents to the Glacial Theory.

Subsequent debate centred on 1) the relative roles of Newfoundland ice and Labrador ice in the glaciation(s) of the island, 2) the areal and vertical extent of glaciation(s), and 3) the number and chronology of glacial episodes. Changes of viewpoint have been sudden, reflecting among other things the import of concepts from outside the region. For example, DE GEER (1892) imported isobase mapping from Scandinavia; COLEMAN (1926) imported multiple glaciation from Ontario; FLINT (1940) imported overriding Labrador ice from New England. Later studies benefitted from longer periods of research, with better access and ancillary information, but borrowing of concepts (*e.g.,* weathering zones from Labrador and Baffin Island by GRANT 1977b and BROOKES 1977b), as well as some conceptual inertia, continue to influence the interpretation of evidence. The most spectacular import so far is that from Antarctica, from whence DENTON and HUGHES (1981) have applied the lessons learned from a marine-based ice sheet to "The Last Great Ice Sheets." One or more of these affected Newfoundland to a degree which, 115 years after Murray's initial report, remains open to debate.

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