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Le modèle glaciaire, la stratigraphie du Quaternaire et les fluctuations isostatiques et eustatiques dans les Maritimes

D. R. Grant

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Résumé de l'article

Un certain nombre de faits prouvent que les glaciers, à la fin du Wisconsinien, se sont écoulés vers les côtes actuelles, et dans plusieurs cas, ne sont pas allés au-delà : les coupes stratigraphiques, les liens entre une série d'indicateurs de l'écoulement glaciaire et la plateforme marine interglaciaire relevée, ainsi que les rapports entre les limites des dernières régions englacées et les régions dont la roche en place a été altérée. Ces glaciers étaient nourris par un ensemble de petites calottes localisées sur de vastes étendues. Toutefois, les profonds chenaux qui entaillent la région, en ont empêché l'extension. Le glacier laurentidien s'est donc confiné au nord du golfe du Saint-Laurent. Ce mouvement centripète vers le golfe a d'ailleurs épargné de vastes secteurs. Les données géologiques appuient maintenant davantage l'hypothèse de Fernald au sujet des refuges biologiques des nunataks, bien qu'au début du Wisconsinien, une calotte et un glacier émissaire aient occupé le golfe et le chenal laurentien. Les lignes de rivages soulevés postglaciaires sont conformes au modèle d'ensemble, avec un relèvement différentiel davantage marqué vers le glacier laurentidien mais également avec la présence de deux larges dômes associés aux calottes du Nouveau-Brunswick et de Terre-Neuve. Toutefois des littoraux plus anciens, émergés et immergés, au-delà de la limite glaciaire, compliquent ce plan. Au nord, les régions se relèvent encore, alors qu'une zone de subsidence se déplace vers l'intérieur des terres.

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GLACIAL STYLE AND ICE LIMITS, THE QUATERNARY STRATIGRAPHIC RECORD, AND CHANGES OF LAND AND OCEAN LEVEL IN THE ATLANTIC PROVINCES, CANADA

D. R. GRANT, Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A OE8.

ABSTRACT Evidence from scattered stratigraphic sections, from the relationship of a sequence of ice flow indicators to a raised interglacial marine platform, together with the limits of freshly glaciated terrain against weathered bedrock areas, indicates that late Wisconsinan glaciers spread weakly toward, and in many areas not beyond, the present coast. These were fed by a complex of small ice caps located on broad lowlands and uplands. The limiting factor was the deep submarine channels that transect the region. Thus, Laurentide ice was limited to northern Gulf of St. Lawrence. With this pattern of centripetal flow toward the Gulf, large areas remained unglacierized. There is now better geological corroboration of Fernald's hypothesis of nunatak botanic refugia, though there was, perhaps during early Wisconsinan time, grounded ice in the Gulf and an outlet glacier in Laurentian Channel. Raised postglacial shorelines fit the model, with a general tilt toward the main shield ice sheet, but with two broad domes reflecting the ice complexes over New Brunswick and Newfoundland. Older emerged and submerged shorelines beyond the glacial limit complicate the pattern. At present northern regions are still rebounding while a zone of subsidence is migrating inland from the continental margin.

RÉSUMÉ *Le modèle glaciaire, la stratigraphie du Quaternaire et les fluctuations isostatiques et eustatiques dans les Maritimes.* Un certain nombre de faits prouvent que les glaciers, à la fin du Wisconsinien, se sont écoulés vers les côtes actuelles, et dans plusieurs cas, ne sont pas allés au-delà: les coupes stratigraphiques, les liens entre une série d'indicateurs de l'écoulement glaciaire et la plateforme marine interglaciaire relevée, ainsi que les rapports entre les limites des dernières régions englacées et les régions dont la roche en place a été altérée. Ces glaciers étaient nourris par un ensemble de petites calottes localisées sur de vastes étendues. Toutefois, les profonds chenaux qui entaillent la région, en ont empêché l'extension. Le glacier laurentidien s'est donc confiné au nord du golfe du Saint-Laurent. Ce mouvement centripète vers le golfe a d'ailleurs épargné de vastes secteurs. Les données géologiques appuient maintenant davantage l'hypothèse de Fernald au sujet des refuges biologiques des nunataks, bien qu'au début du Wisconsinien, une calotte et un glacier émissaire aient occupé le golfe et le chenal laurentien. Les lignes de rivages soulevés postglaciaires sont conformes au modèle d'ensemble, avec un relèvement différentiel davantage marqué vers le glacier laurentidien mais également avec la présence de deux larges dômes associés aux calottes du Nouveau-Brunswick et de Terre-Neuve. Toutefois des littoraux plus anciens, émergés et immergés, au-delà de la limite glaciaire, compliquent ce plan. Au nord, les régions se relèvent encore, alors qu'une zone de subsidence se déplace vers l'intérieur des terres.

РЕЗЮМЕ ГЛЯЦИАЛЬНЫЙ ТИП И ПРЕДЕЛЫ ЛЬДА, ЧЕТВЕРТИЧНЫЕ СТРАТИГРАФИЧЕСКИЕ ДАННЫЕ, ИЗМЕНЕНИЯ УРОВНЯ МОРЯ И ПОВЕРХНОСТИ ЗЕМЛИ В ПРИ-АТЛАНТИЧЕСКИХ ПРОВИНЦИЯХ КАНАДЫ. Данные взятые от различных стратиграфических секций, связь между индикаторами стока и приподнятой межледниковой морской платформой вместе с пределами свежей оледененной земной поверхности на фоне выветреных коренных пород показывают, что поздне-висконсинские ледники слабо распространялись в сторону морского берега, и во многих случаях не наступали дальше его. Эти ледники исходили из комплекса небольших ледниковых куполов находившихся на обширных низменностях и возвышенностях. Ограничивающим фактором являлись те глубокие подводные мульды которые пересекают этот район. Из-за этого, Лаврентийский лед был ограничен северной частью залива Св. Лаврентия. Много земной поверхности не было покрыто ледниками так как существовало их центростремительное движение в направлении этого залива. Сейчас появилось более основательное геологическое подтверждение гипотезы Фернальда касающейся нунатакского ботанического рефугия. Однако возможно что при ранне-висконсинском периоде была стамуха в заливе и выводной ледник в Лаврентийском русле. Приподнятые послеледниковые береговые линии соответствуют нашей схеме и даже имеют общий наклон к главному щиту покровного льда. Существование, в те времена, ледяных формации в Нью Бранзвике и Ньюфаундленде указывает что там образовались два больших куполообразных ледника. Но более старые поднятые и погруженные береговые линии лежавшие за пределом оледенения усложняют эту схему. В настоящее время северные области все еще продолжают свое послеледниковое восстановление и зона оседания мигрирует от материкового края внутрь материка.

INTRODUCTION

This paper summarizes the author's interpretations presented in several interim reports published over the past ten years of study in the region. Many of these embody new aspects, or are at variance with the commonly held beliefs on the general topic of glaciation in the area. For this reason the body of literature that has accumulated over the last century is outlined below to identify the main concerns and illustrate the evolution of concepts. Initially, in the late 1800's, as elsewhere, the main controversy was whether the features observed were due to a flood of glacier ice or sea ice, largely due to the confusion of markings made by sliding or floating ice, and the realization that there had indeed been a considerable but imprecisely defined submergence associated with the period of ice activity. For the Newfoundland area the case was debated by JUKES (1843), KERR (1870), MILNE (1876), MURRAY (1882), WRIGHT (1895), and CHAMBERLIN (1895), while in the Maritimes region, following somewhat later on DAWSON's (1855) treatise, CHALMERS (1888, 1890, 1896), BAILEY (1898), and HONEYMAN (1890) grappled as well with the problem of very divergent directions of ice movement and drift dispersal. Situated in the heart of the region, the Magdalen Islands with their decidedly unglaciated aspect have from the beginning presented a special problem. Opposing views with few moderate or compromising positions, were presented by RICHARDSON (1881), CHALMERS (1895), GOLDTHWAIT (1915), COLEMAN (1919), ALCOCK (1941), SANSCHAGRIN (1964), PREST (1970), and LAVERDIÈRE and GUIMONT (1974).

During the first half of this century, once the glacial theory had been adopted and the action of sea-ice relegated to a minor role, there were sporadic papers dealing more with the local character of glacial deployment and upwarped shorelines, including inferences as to how these aspects elucidated regional glacial behaviour. For the Newfoundland sector, FAIRCHILD (1918), DALY (1920, 1921), and FLINT (1940) plotted raised shorelines purportedly exhibiting the effect of Labradorean ice cover, whereas COLEMAN (1926), TANNER (1940), MacCLINTOCK and TWENHOFEL (1940), and TWENHOFEL and MacCLINTOCK (1940) documented their arguments for or against an independent island ice cap, and its possible interplay with mainland ice. Meanwhile, in the Maritimes nothing comparable developed except for, and perhaps because of, GOLDTHWAIT's (1924) monograph on Nova Scotia wherein he discounted all evidence suggesting the activity of local ice caps and invoked only ice sheets from external sources.

Parallel studies of plant distribution by botanists culminated in a landmark paper by FERNALD (1925) who identified, on the basis of disjunctive Arctic-Alpine suites, several uplands and highlands which he believed could not have been ice-covered, at least during the last glaciation. This corroborated COLEMAN's (1926) contention but was disputed by WYNNE-EDWARDS (1937) and FLINT (1943) though LINDROTH (1963) concurred. The concept has never been seriously re-appraised by glacial geologists, but will be treated further below, in the light of recent findings.

The intervention of World War II not only curtailed much of the research but seemed to mark a watershed in the direction and scope of study. Thereafter no overall consideration was given to the region. Studies of local features or problems in Nova Scotia and New Brunswick were made by WICKENDEN (1941), HUGHES (1957), HICKOX (1962), LEE (1962), SWIFT and BORNS (1967) and KING (1969). Some of these contributions revealed a strengthening conviction in favour of localized glacier deployment, in contrast to Goldthwait's concept of a single overriding ice sheet. The same shift in interpretation was even more evident in Newfoundland where several studies pointed to local centres and an island-based ice sheet (SUMMERS, 1949; Van ALSTINE, 1948; WIDMER, 1950; MURRAY, 1955; JENNESS, 1960; and LUNDQVIST, 1965).

Research entered a vigorous phase in the 1960's, spurred by massive intervention by the public sector to more generously endow the academic sector and to create an information base for the private sector. The lead role was played by V. K. Prest of the Geological Survey who co-ordinated systematic surficial mapping of Prince Edward Island by Crowl, Frankel and Owen, and who in 1973 eventually collated the results, elucidating a complex sequence of local and regional glacial episodes. Meanwhile, oceanography was blossoming and the techniques of bottom sampling and seismic profiling gave marine geologists of the Bedford Institute and Lamont Geological Observatory the means to investigate large areas of the adjacent continental shelf. In this way the offshore sedimentary manifestation of Quaternary events was being studied in its own right. At Dalhousie D.J.G. Nota directed an integrated study of both onshore and offshore sediments, involving D.R. Grant and F.J. Nolan working on the tills and heavy minerals of Nova Scotia, while J.M. Pezzetta and A.E. Cok dealt with sediments of the Scotian Shelf. Later Grant studied the Laurentian Channel while Nota and D.H. Loring co-operated to investigate the Gulf and River St. Lawrence.

GLACIAL STYLE

The study of tills in Nova Scotia (GRANT, 1963 *in* PREST *et al*, 1972) yielded data on transport of erratics that was corroborated by dispersal of indicator heavy minerals (NOLAN, 1963). These revealed the main trends of ice flow which gave an insight into the general position of glacial centres. In addition to surface till phases related to the main rock terranes, there were superposed tills of different age; these were emplaced by ice flowing at times radially from the uplands (as earlier demonstrated by HICKOX (1962) for one area) and as a unidirectional flow from the north and northwest. Incidental to studies of recent sea-level change, observation of glacial features yielded new evidence for an ice cap over southern Nova Scotia, and for a complex ice-flow sequence over southern Cape Breton (GRANT, 1967, 1968). Preparation of the *Glacial Map of Canada* (PREST, GRANT and RAMPTON, 1968) afforded an opportunity to examine airphotos of the entire region and this, together with a review of existing ice-flow data, culminated in a hypothesis that the topography and maritime setting prevented and confined the penetration by Labradorean ice, and promoted the growth and determined the retreat pattern of upland and lowland ice caps (PREST and GRANT, 1969).

New mapping programs in Newfoundland lent support to the concept. GRANT (1969a) reported that Labradorean ice had invaded only the lower parts of the northern extremity of Northern Peninsula, and that the main local source, an ice cap on the Long Range Mountains, re-advanced extensively *ca.* 11,000 years BP. Revealing comparable situation in adjacent lowland areas GRANT (1969b) depicted a number of arcuate end moraines evidently constructed by piedmont glaciers issuing from troughs in the Long Range plateau. Later, this moraine complex was extended over the entire western lowlands and dated, from overlying fossiliferous marine sediments, as having been deposited prior to 12,600 years BP; no evidence of invasion by Laurentide Ice was found (GRANT, 1972a). Meanwhile, working at the southern end of the Long Range Mountains on deposits initially described by MacCLINTOCK and TWENHOFEL (1940), BROOKES (1969, 1970, 1974, 1975) concluded that the lower drift was deposited by late Wisconsin glaciers spreading from an independent ice centre over Newfoundland, without intervention by Labradorean Ice except in terms of crustal warping, and that, following a marine incursion, there was a final readvance *ca.* 12,750 years BP.

At the same time systematic mapping of Cape Breton Island was substantiating and adding new aspects to the earlier inferences. GRANT (1971a, 1972b) discerned from ice-flow features on the southern lowlands three glacial phases apparently related to distant sources: an early powerful movement eastwards toward Laurentian Channel; an intermediate phase directed northward toward Gulf of St. Lawrence, seemingly stemming from an ice cap located on the continental shelf that carried marine shell fragments dating more than 34,000 years BP; and a final much weaker superficial flow from an ice mass inferred to lie over the Bras D'Or Lake basin. Glacial movements on the upland and highland portions of the island included a south and east flow against the Gulf coast, transcurrent northward flow through intermontane valleys, and radial flow from a plateau ice cap (GRANT, 1971c).

Further work in several areas added new data to strengthen the concept of separate ice caps during the last glaciation. Follow-up studies in southwestern Nova Scotia (GRANT, 1971b) differentiated three main glacier episodes: an early expansion of a local interior ice cap: followed by a southward flood of ice from across Bay of Fundy prior to 39,000 years BP; a retreat about 38,000 years ago; and a re-expansion of Nova Scotian ice during the late Wisconsinan until *ca.* 14,000 years BP. The data were once again assembled for scrutiny by participants of the International Geological Congress (PREST *et al.*, 1972) and the model of glaciation by several local ice caps, at least during the latest phases, further refined. A new project to map the entire island of Newfoundland enabled a detailed airphoto examination (GRANT, 1973a) that revealed meltwater features indicating late glacial recession to at least fourteen centres (GRANT, 1974b).

The model of ice-cap complexes contrasted with adjacent areas, probably because in the case of New England only features suggestive of a southward moving Laurentide ice flood were recognized and in the case of the rest of Canada no regions exist that embody the aspects of topography and setting that were inferred to be the operative factors in the Atlantic region in promoting the growth of small but vigorous ice caps. Clearly a different approach was needed. After further work in Cape Breton Island began to clarify timing of local versus early Laurentide overriding (GRANT, 1974a, 1975a) and an analysis of fragmentary stratigraphic sequences (GRANT, 1975d), GRANT and PREST (1975c) emphasized the difference in «style», or local glacial dynamics to be expected in a region of uplands cut by deep-water ocean leads separated from the Laurentian shield ice sheet by an inland sea. This was contracted with the simple unidirectional glacial fabric of the interior Shield, and an analogy was drawn with northwest Europe where Fenno-scandian Shield ice expanded independently of, but occasionally crossed the North Sea to merge with, the local upland glaciers of the British Isles. To illustrate the comparison, maps showed the theoretical progress of expansion and coalescence of outlying ice caps, with centripetal flow into Gulf of St. Lawrence, and contact with Laurentide Ice only at Strait of Belle Isle, and upper St. Lawrence River. Thus re-phrased, the proposition appeared to meet with greater acceptance, and the next step, prompted by the continual problem of when and where the individual ice caps had merged, was to consider and if possible define the extent of the successive glacial pulses.

GLACIAL LIMITS

INITIAL GEOLOGICAL AND BOTANICAL INFERENCES

More attention seems to have been given in the earliest stages of Quaternary investigation to the problem of defining limits of glacial features than has been recently. Early workers, though struggling to comprehend the mechanism of ice erosion, were ever conscious of the contrast between glacial and non-glacial terrains, whereas later, in spite of the development elsewhere of a four-fold succession of glaciers based on stratigraphic sequences, reports seemed couched in terms of one glaciation completely inundating the region. The reason for this is not clear. Several authors (*e.g.* CHALMERS, 1888; COLEMAN, 1922, 1926) drew attention to sharp elevational and areal limits to fresh glacial features or conversely, to degrees of weathering greater than might be expected during the last postglacial in Gaspé, northern New Brunswick, Cape Breton Island and high coastal and interior areas of Newfoundland. These were taken to mark the extent of separate glaciations.

Independently, biological studies revealed analogous contrasts in the same areas. FERNALD (1925) described disjunctive assemblages of arctic-alpine plants in the same upland areas, as well as in Anticosti Island and, although the significance was disputed by WYNNE-EDWARDS (1937), his conclusion that these areas had to have remained ice free during the last glaciation has since been corroborated by LINDROTH's (1963) work on beetle distribution. It is significant that the same controversy between biologist and glacial geologist exists in the case of the coastal tablelands of western Norway vis-à-vis the extent of Fennoscandian ice, as IVES (1975) has summarized. Later, however, GOLDTHWAIT (1924) dealing with Cape Breton Island, and MacCLINTOCK and TWENHOFEL (1940) for Newfoundland, acknowledged the contrasts but minimized the implied time difference and concluded that the separate phases of broad continental versus local ice-cap glaciation were both phases of the Wisconsin glaciation, without explaining the compressed time scale. Those monographs appear to have remained unchallenged until recent work in the area led to a renewed appreciation of the alleged contrasts, in terms of similar relationships described in Arctic mountains where datable materials afforded a time scale (PHEASANT and ANDREWS, 1973).

The first attempt to actually delimit areas not overridden by the last glacial expansion appeared in GRANT (1969a, 1969b, 1970a) where high summits (*e.g.* Doctors Hills) along the western Long Range escarpment, characterized by felsenmeer and patterned ground, were interpreted as having been nunataks during moraine-building phases as late as 11,000 years BP. Further mapped revealed the same situation farther south. A series of maps covering the northern half of the Long Range Mountains (GRANT, 1973d) depicted three types of rock terrain differentiated as to degree of weathering or relative presence of glacial features: a lower deeply scoured zone of "fresh" glacial landforms, a middle higher zone of weathered but still obviously glaciated character, and an upper zone of deep "colluvium" composed of frost riven debris on the summits. A report on the terrain of Gros Morne National Park (GRANT, 1973b) concluded that the "locally strong weathering on the coastal summits is thought to be in part relict from a nunatak phase of valley deglaciation...".

For the southwestern end of the Long Range Mountains, BROOKES (1975) described an identical situation of "piedmont glaciers which fed ice from the Newfoundland ice cap around whalebacked nunatak summit areas, through glacial troughs in the mountain front on to Codroy Lowland." However, an obscure unpublished reference to glaciation of that area by PHAIR (1949), which has only recently come to light, illustrates three landscapes related to separate glacial phases: broad flat summits above 660 m covered by frost-riven rock with few or no erratics, separated by cols with rock basin lakes, glacial boulders and roches moutonnées leading to abrupt cliffs descending into cirques and troughs ending in moraines. Phair envisaged that during the Wisconsin Age (*sic*) a separate ice cap on the Long Range, fed ice radially down valleys, and may have merged with an interior ice cap; no continental ice sheet to the north ever overrode the mountains. To his interpretation might be added the inference, based on the sharp heads of cirques and troughs, that the latest stage, perhaps representing the late Wisconsinan, involved only small glaciers confined to valleys on the flanks of the Long Range Mountains.

ICE-FLOW SEQUENCE AND GLACIER BOUNDARIES IN CAPE BRETON ISLAND

Mapping of Cape Breton Island revealed a feature that made it possible to establish the Wisconsin age and extent of three or four separate glacial pulses that impinged on the island (GRANT, 1976b). That feature is a wavecut bedrock platform a few metres above present high tide that rings the island and is inferred to date from the last interglacial because of an overlying peat at Bay St. Lawrence dating more than 38,000 years (GSC-283) and because of its essentially horizontal attitude. By observing the nature of the covering till and the sequence of ice-flow markings inscribed on it, the first or earliest known event was found to be a powerful flow of ice from beyond the island that moved eastward across the northern lowlands and southward through Laurentian Channel, before deposition of the above-mentioned peat. Striae and drumlins on the highlands plateau are parallel to this flow, and hence may signify complete inundation of the island during that episode. Subsequently, however, large upland and highland areas remained beyond the limits of later expansions. Several sub-till cool-climate organic beds yielding non-finite radiocarbon ages throughout Cape Breton Island and mainland Nova Scotia point to a considerable deglaciation presumably during an early Wisconsinan or lower middle Wisconsinan interstadial period. Thereafter two main ice flows are recognized: one from south to north from an ice dome apparently centred on the continental shelf that affected mainly the southern lowlands but failed to reach the north and west coasts; and a final radial re-expansion from a smaller ice cap centred in the interior over the Bras D'Or Lake basin. During one of or both of these later pulses, the northern highlands had only a few valley glaciers on the northwest coast. The plateau may also have supported a carapace of snow but extensive tracts of rotted rock and frost-riven debris indicate considerable duration of subaerial exposure. In summary, Cape Breton Island shows evidence of several glacial events since the last interglacial (providing the reference surface is correctly assigned), progressively more restricted to the southern lowlands, and to local sites on the highlands.

WISCONSINAN STRATIGRAPHY AND ICE LIMITS IN SOUTHWESTERN NOVA SCOTIA

Similar relationships in southwestern Nova Scotia point to a comparable sequence and extent of glacial pulses. GRANT (1976b) described a thick extensive sequence of glacial, glacio-marine and nonglacial marine deposits exposed along the Bay of Fundy coast between Yarmouth and Digby. Overlying a slightly emerged wave-cut platform, presumably correlative with that in Cape Breton, is a veneer of marine gravel covered by a thin patchy grey till of local derivation evidently deposited during the growth of a local ice cap on the southern uplands. Over this is a ubiquitous reddish-brown till usually several metres thick containing marine shell fragments of cool-temperature affiliation dating more than 39,000 years. This till is also characterized by erratics from New Brunswick and hence indicates the passage of a powerful ice flood that incorporated fine red material from the Triassic sediments underlying Bay of Fundy. This event is tentatively believed to correlate with the southward ice flow over Cape Breton because of similar stratigraphic position and implied distant and northern origin. The red till is locally overlain by a grey marine sand with *in situ*, relatively warm water shells presumably deposited during a middle Wisconsinan interstadial, because it dates 38,000 ± 1300 by ^{14}C (GSC-1440) and 33000-40000 years by U/Th (L-1348a). This unit is succeeded by pinkish grey shell-bearing tills and/or glacio-marine drifts and finally by a rubbly locally-derived till evidently deposited by ice again spreading from interior Nova Scotia. Since it is veneered by marine gravels of postglacial offlap deposition, dated in one place at 14,000 ± 200 y BP (GSC-1259), the upper till is late Wisconsinan in age. Significantly, this upper drift sheet does not everywhere extend to the coast, but terminates a few miles inland at small moraines, while the older deposits form the surface and are locally weathered, ironstained and cemented compared to the fresh younger gravels. As well, where streams cross from the older tills to the younger marine gravels, they are much deeper incised above the gravel limit than below, indicating a correspondingly greater duration of subaerial exposure for the pre-late Wisconsin surface. At opposite ends of Nova Scotia, then, there is evidence that the Wisconsinan stage began with the growth of local ice caps at an early stage, culminated with a relatively early flood of ice over nearly the whole area, then after a widespread withdrawal more than 40,000-50,000 years BP, readvanced with declining vigor at least twice again but only from local midland or lowland sources that were not competent to override much of the area.

SPECULATIVE LIMITS OF SUCCESSIVE GLACIAL EPISODES

However, it was the recognition in 1976 that areas of weathered rock in western Newfoundland (more fully described by GRANT, 1977) could be organized into at least three distinct zones with a systematic areal and elevational distribution, particularly with respect to ice-marginal features, that led to the realization that late Wisconsin ice had a very limited extent. This had important implications for only partly understood relationships previously described by Cape Breton Island, southern Nova Scotia, eastern Prince Edward Island, northern New Brunswick, Gaspé Peninsula, and Anticosti Island. It also had a significant bearing on the problematical extent of Laurentide glaciers within Gulf of St. Lawrence. These tentative conclusions were presented by GRANT (1976b) as a map showing the extent of late Wisconsinan, and locally earlier, glaciers throughout the region. Figure 1 is a revised adaptation of that map. The general pattern is one of centripetal ice flow toward, but not across, Gulf of St. Lawrence. Newfoundland is depicted as having its own ice cap, or more accurately ice-cap complex, that barely reached the present coast, and where it did, was limited more or less by 100-metre depths offshore. This ice cap skirted numerous coastal nunataks including the western table-

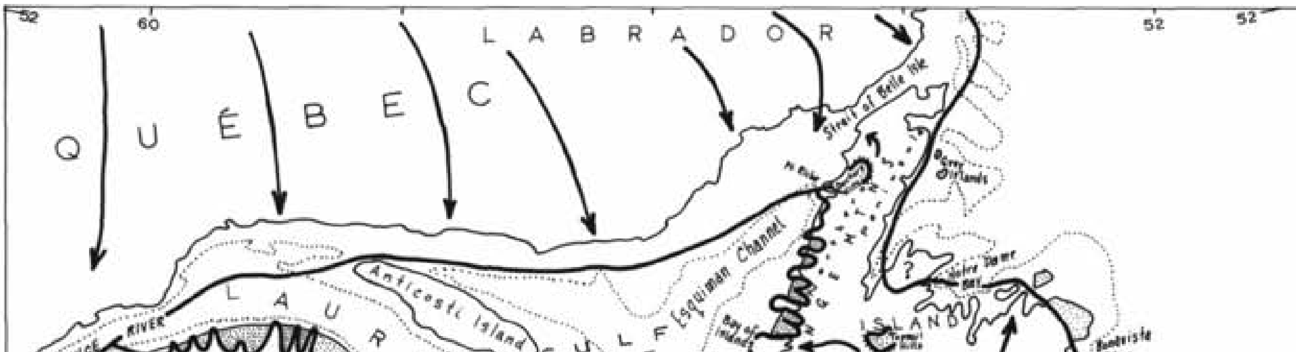

FIGURE 1. Location map with places referred to in the text, showing inferred limit of late Wisconsinan glaciers (bold line), nunataks and other extra-glacial areas (stippled), main directions of ice flow (arrows), and speculative limits of earlier ice masses (pecked lines).

Carte de localisation et sites étudiés: limite proposée des glaciers du Wisconsinien supérieur (trait large); nunataks et zones épargnées (pointillés); principaux sens de l'écoulement glaciaire (flèches); limites hypothétiques des masses glaciaires antérieures (barbules).

lands of Long Range Mountains, possibly small enclaves along the south coast, the Hermitage Hills where only local cirque and valley glaciers existed (WIDMER, 1950), most of Burin Peninsula, and terminal parts of Avalon Peninsula. On the north coast, the Grey Islands were definitely not overridden, while large parts of peninsulas in Notre Dame Bay may also have escaped, as Coleman suggested. If there was a connection with Laurentide ice it was only in the Strait of Belle Isle area, with an interlobate moraine formed in the lee of Doctors Hills nunatak, extending to Point Riche. A few high summits in the interior, like the Topsail Hills, appear to have projected through the ice. With Labradorean ice thus confined to north side of Esquimau Channel its position to the west may have lain north of Anticosti, to permit the refuge inferred by FERNALD (1925), while at the same time producing submergence up to 80 m, well within the 180-km zone of peripheral depression. If the Gaspé Peninsula supported only small ice caps with valley glaciers extending to tide water, then the other point of coalescence of Laurentide with Appalachian ice was well up the St. Lawrence River perhaps along the Highland Front — St. Antonin morainic system. For New Brunswick, except for a throughgoing movement southward down St. John River valley, an ice cap in the interior appears to have spread mainly east and southeast, as described by CHALMERS (1896) and GAUTHIER (1977). Its eastward extent may lie across Shippegan peninsula, as Chalmers believed, and thence across Magdalen Shallows to include the subglacial tunnel valleys mapped by LORING and NOTA (1966). With no evidence of late Wisconsin ice on Magdalen Islands or western Cape Breton Island, the ice front must have curved south toward Prince Edward Island. There, the limit might be very tentatively placed across the central waist of the island for no other reason than that the ice flow pattern and glacial deposits are dissimilar across this line, and the eastern part has long been regarded as having a residual soil or regolith, as PREST (1970) acknowledges.

The confluence of New Brunswick ice with Nova Scotia ice in the Northumberland Strait area is problematical. The latter trended directly south into Bay of Fundy, with a vigorous lobe moving southwestward down Chignecto Bay, while ice in northern Nova Scotia appears to have moved in an opposite direction northward from the vicinity of Cobequid Mountain. As it is unlikely the two opposing currents co-existed, it is therefore suggested that either the movements are of different ages or they were not in contact. If the latter is correct the evidence could be accommodated by supposing a separate centre over eastern Nova Scotia, in the Truro-Antigonish area, sending lobes toward Pictou Island to emplace Cobequid erratics (PREST, 1970) and down George Bay a short distance along western Cape Breton Island, thus leaving Antigonish Highland in an ice-free interlobate position. This source thus shared a common ice divide with that located over lowland Cape Breton Island. The two centres over Nova Scotia uplands then had a natural continuation to the southwest where a radially moving ice cap has long been invoked to explain west and northward transport of erratics. Free flow of ice directly into Bay of Fundy implies the bay was not fully glacierized. Hence the limit is placed just offshore, though parts of North Mountain may well have formed an insurmountable barrier. This is suggested by non-systematic change of marine limit elevations northward along Fundy coast (GRANT, 1976b) and the dissimilarity of marine overlap expression in central and upper Bay of Fundy stressed by WELSTED (1976). As mentioned before late Wisconsinan ice failed to reach the outer Fundy coast at all points which means that, apart from a possible ice shelf, Gulf of Maine was not overridden unless New England glaciers had greater vigor. Finally, the limit of Nova Scotian ice onto the continental shelf to the south may have been at the submarine moraine mapped by KING (1969), but as long as the time of formation is unknown, and because the moraine trends across Gulf of Maine, a position inside this feature is preferred.

To sum up, late Wisconsin glaciers springing from numerous local ice caps, as well as from the Laurentide ice sheet, extended to and only slightly beyond the present coast, leaving many upland and highland nunataks and large areas of emerged shelf as potential biologic refugia. Ice shelves may have existed in parts of Gulf of Maine and St. Lawrence. Somewhat thicker ice and correspondingly greater extent during an earlier, possibly also Wisconsinan, stade is inferred from higher weathering limits in western Newfoundland and coastwise flow along western Cape Breton. Laurentian Channel may have held a glacier at least as far as Cabot Strait during earliest Wisconsinan time, and Nova Scotia completely overridden by ice stemming well to the north. It is significant however, that ALAM and PIPER (1977) conclude from late Quaternary sediments deposited off the mouth of Laurentian Channel that glaciers remained restricted to the inner reaches of Gulf of St. Lawrence throughout the Wisconsinan, in contrast with a severe glaciation of the Gulf during the latest Illinoian stadial.

THE STRATIGRAPHIC RECORD

PHILOSOPHY OF INTERPRETATION

Quaternary sedimentary sequences in the region are fragmentary, sporadic and varied. As yet most are too poorly understood to yield information on depositional age and agent. Instead, because most effort is being expended on surface mapping rather than on topical inquiry, the main processes of glaciation and sea-level change are being elucidated, and this has in turn permitted some appreciation of the significance and approximate stratigraphic position of certain formations. This approach has serious drawbacks: it puts theory before fact, and enshrines unfounded assumptions as to the age and significance of sedimentary members. With this pre-amble to outline the current dilemma of trying untangle a web of false premise and superficial description, there follows a review of published stratigraphic material.

EARLY WORK

Virtually all workers appeared to see nothing noteworthy in the surface till, and regarded it as a homogeneous unit relating only to the last glaciation, veneered over rock with lithologic differences reflecting local bedrock type. One notable exception, emphasized by HONEYMAN (1890) was a red drift found as drumlins along the Nova Scotian Atlantic coast, that contained abundant indicator stones from North Mountain and Cobequid Mountain tens of kilometres to the north. The till forming these "red heads", as they were then known, originated in the Carboniferous red bed terrane of the Fundy area. Much was written on the exact distance and direction of transport. Otherwise, many of the early references dealing with Quaternary stratigraphy described single exposures such as DAWSON's

(1855) note about a peat bed beneath till at River Inhabitants, Cape Breton Island, or PREST's (1898) account of stacked tills, gravels, weathered horizons and "conglomerate" near Bridgewater. The former was the first mention of an organic deposit predating the glaciation and the latter gave the first indication of more than one glacial episode and the intervening nonglacial periods. Dawson also described an end moraine underlying shell-bearing marine sediment at Saint John, N.B. that served to exemplify the post-glacial submergence, and which incidentally promoted the misconception about glaciation as a phenomenon with marine mechanisms. (The shells in that deposit were later to provide the first ^{14}C date (13,325 ± 500 BP; I-GSC-72), that proved the late Wisconsinan age of a prominent ice marginal stand.)

The attention of several writers was attracted by a peculiar iron-cemented gravel, the Bridgewater Conglomerate, that occurs sporadically along the Nova Scotia coast, contains northern erratics, underlies the surface till, and is found as fragments in it. Its age was variously interpreted as Tertiary (SAGE, 1954), Carboniferous (HONEYMAN, 1870; POOLE, 1903), pre-Wisconsinan (PREST, 1898) and late Wisconsinan (GOLDTHWAIT, 1924). The truth is probably somewhere between the latter two interpretations in view of one or two sites in southwestern Nova Scotia where it overlies a rock bench at the same elevation as the presumed interglacial emerged marine platform. The whole matter of its age and origin is complicated by its similarity to locally cemented phases of late Wisconsinan glacial gravels. The "conglomerate" deserves special study, including its exact degree of weathering and oxidation.

TWENTIETH CENTURY PROGRESS

Three stacked tills of different provenance were described by WICKENDEN (1941) at Joggins, N.S. These were probably deposited by the regional and local glaciers inferred for the Chignecto area. MacNeill also noted a tripartite till section near Weymouth, N.S. A survey of lithologic variation in surface tills by GRANT (1963) brought to light several exposures along the Atlantic coast where the exotic red drumlin till of northern provenance was underlain by a dark grey, compact «old-looking» local till, and overlain by a light-colored, «fresh-looking» till. All were assigned to separate pulses of the Wisconsinan Stage. Next, a study of Holocene sea-level change gave access to the entire coastline and a complex sequence of thick tills and marine members pre-dating the last glaciation was noted along the Bay of Fundy coast between Yarmouth and Digby (GRANT, 1968a) and the separate members distinguished and correlated by GRANT (1971b) and later discussed in greater detail with more certain age assignments (GRANT, 1976a). CLARKE, GRANT and MacPHERSON (1972) reported on the paleoecological aspects.

Apart from the above mentioned case of shell layers beneath tills, there is evidence of non-glacial intervals between episodes of till deposition in the form of organic deposits of carbonaceous nature buried by tills. MOTT and PREST (1967) and PREST (1970) describe seven occurrences of subtill organic silt or woody peat in Nova Scotia all of which yield nonfinite radiocarbon ages and are of cool climate affiliation, suggesting deposition in an early Wisconsinan or older interstadial period. Also on Cape Breton Island, GRANT (1972b) described cliff sections on East Bay, Bras D'Or Lake exposing tills, sands and organic silts more than 52,000 years old (GSC-1619). Giving further data on the age of successive glacials are the occurrences of marine shells in the middle red drumlin till on Janvrin Island that date more than 34,000 years (GSC-1639) and in esker gravel at Grantville that date 32,100 ± 900 y (GSC-1408). Additional evidence includes mastodon bones dating 31,900 ± 630 y BP (GSC-1220) found on a modern flood plain near Middle River, Cape Breton I., and the nearly complete skeleton of a mastodon dating 13,600 ± 200 y BP (GSC-1222) that was excavated from a sink hole near Hillsborough, N.B. containing peat that oddly enough dated more than 43,000 years (GSC-1680).

Newfoundland has even fewer exposures of multiple Quaternary sediments. Along St. Georges Bay, MacCLINTOCK and TWENHOFEL (1940) described what has since tended to become the unofficial reference area for Newfoundland glacial stratigraphy: a lower till (St. Georges Bay Drift) deposited by Labradorean and/or island ice, a middle bed of basal clay transitional to sandy gravel (Bay St. George Delta) deposited during a postglacial marine transgression, an upper sandy till (Robinsons Head Drift) produced by a late glacial readvance, and a surface marine formation relation to the final regression. BROOKES (1969, 1970, 1974, 1977) has studied these in detail and concluded that all were deposited since 14,000 y BP and that only ice from interior Newfoundland was responsible. Elsewhere the general condition is one shallow sandy stony till, with a marine veneer to 0-130 m elevation near the coast. Notable exceptions occur on Burin Peninsula where van ALSTINE (1948) and WALTHIER (1955) report both in the interior and on the coast waterlaid clay, sand and gravel between tills, the lower of which is «weathered». Walthier also reported both southward and northward ice movement, which would explain the two separate tills and reason for ponded sedimentation locally. GRANT (1975c) described more fully the ice-flow sequence, placing the southward flow in an early stage, succeeded after a nonglacial period of subaerial weathering, by northward flow from an ice source apparently offshore on the continental shelf, culminating presumably during the late Wisconsinan in an advance only partly down the northern part of the peninsula.

THE CONCEPT OF WEATHERING ZONES

The most recent aspect added to the Quaternary stratigraphic record of Newfoundland, after COLEMAN (1926) first drew attention to it, is the recognition of discrete areas exhibiting different degrees of weathering (GRANT, 1977). First described in terms of the conspicuously etched bedrock surface and comparative lack of glacial features on certain distal parts of major peninsulas in Bonavista and Notre Dame Bays, the weathering zones, at least three in number, are best developed on the fjord walls and intervening summits of the high western Long Range Mountains. Since the weathering breaks coincide with moraines and ice marginal features they must therefore manifest the duration of subaerial exposure and weathering since they were last glaciated. Strictly speaking, the weathering products constitute a stage of soil development, and as such each weathering interval defines a soil-stratigraphic time unit. Other than Zone A which corresponds to the last 10,00-12,000 years since late Wisconsin ice disappeared the other two are undated, though the oldest or Zone C is believed to be at least 10 times older judging by relative depth of fluvial dissection of it.

INFERRED QUATERNARY EVENTS

Organizing the known Quaternary sequences, prior to the recognition of weathering differences and implications of restricted ice extent, GRANT (1975d) presented a provisional correlation chart which is summarized below with revisions necessitated by subsequent work. The record begins with the development of the «weathering zones» referred to above, as well as the kaolinization of granitic rocks noted on Cape Breton highlands by GRANT (1975a), probably the formation of Bridgewater Conglomerate, and possibly the «regoliths» in New Brunswick uplands (LEE, 1962; GADD, 1973). Some of these are partly attributable to the Sangamon Interglacial. This period however is represented mainly by the effects of a sustained higher than present sea-level stand that is believed responsible for the lengthy stretches of an emerged wave-cut rock platform and minor beach gravel veneer found a few metres above present high tide, preserved widely in the region in southern Nova Scotia (GRANT, 1976b), around Cape Breton Island, (NEALE, 1963; GRANT 1975a), and on Avalon Peninsula of Newfoundland (HENDERSON, 1972). Its restriction to the southern edge of the region may be significant, but similar rock platforms are known along Northumberland Strait as glacial pavements, as the MicMac Terrace in St. Lawrence estuary (GOLDTHWAIT, 1911), and as the Bay of Islands Surface (FLINT 1940) in western Newfoundland. The onset of Wisconsinan glaciation, that is to say the glaciation subsequent to the formation of the marine bench, is known from fragmentary depositional and erosional features to have begun with the growth of small local ice caps that laid down immature, locally derived tills. Next, evidence from Cape Breton and Yarmouth suggests a powerful overriding of ice from the north, but this is contradicted by the absence of glacial deposits postdating the last interglacial on the Magdalen Islands (PREST, in press) and of evidence that southwest Newfoundland ever received Laurentide glaciers. In any case, evidently glaciers disappeared nearly completely throughout all of Nova Scotia, if not much of the region, and a cool non-glacial period intervened sometime in the first half of the Wisconsinan during which organic sediments beyond the range of radiocarbon dating were deposited. This was followed by a second flood of ice from the north, laying down the red drumlin till of northern provenance over the Atlantic slope of Nova Scotia. Judging by the deployment of this ice to the east over lowland Cape Breton, the overall thickness was not great, suggesting that perhaps these glaciers were reconstituted from remnants on the Appalachian highlands to the north, rather than as outpourings of Laurentide ice. The minimum age of this advance may be inferred from the shrinkage that is recorded by raised marine deposits between solifluction layers at Bay St. Lawrence (PREST, 1970) and the marine shell-bearing Salmon River Sand between tills near Yarmouth that dates 38,600 ± 1300 y BP (GSC-1440). This deglaciation is of middle Wisconsinan age when glaciers apparently shrank minimally inland of the present coast onto uplands. In Newfoundland this shrinkage left not only coastal mountains ice-free but also caused the recession of inland ice to expose isolated high areas such as the Topsail Hills and Buchans Plateau. Thereafter only the final re-expansion of late Wisconsinan age is recognized, during which time these remnant ice caps moved again toward, but not everywhere beyond the present coast. It was during this weak movement that rubbly immature tills of local derivation were laid thinly over the deeper older finer-grained tills from the earlier more pervasive episodes.

Ultimate recession of this ice from the isostatically depressed coast caused marine overlap to deposit first, and in deeper sites, a basal clay member and eventually shallow water regressional sands and gravels. Local names for these sediments are Five Islands Formation in Minas Basin (SWIFT and BORNS, 1967) and Bay St. George Delta in southwest Newfoundland. In Gulf of

Maine-Bay of Fundy this trangression was termed the De Geer Sea by LOUGEE (1953) and in Gulf of St. Lawrence the Goldthwait Sea by ELSON (1969). However, with the likelihood now recognized that both these marine areas were icefree for much longer than just the last post-glacial, the implications of these terms must be reconsidered, and more explicit definitions proposed. This same complication applies also to the final sedimentary manifestation of glaciation. Whereas the northern edge of the region may be still emerging, and hence still in Goldthwait Sea phase, at least the southern two-thirds has been sinking and submerging, causing up to 50 m of intertidal sediments to accumulate in estuaries. This episode correlates with the Flandrian trangression of northwest European terminology.

Finally, certain climato-sedimentary members relating to the postglacial period (*sensu stricto*) deserve mention. Following deglaciation, extraglacial areas experienced solifluction episodes that correlate with local glacial readvances such as the Robinson Head event *ca*. 12,750 y BP (BROOKES 1974) or the Ten Mile Lake event *ca*. 11,000 y BP (GRANT, 1969). Locally diamictons spread downslope over pre-existing postglacial organic accumulations, such as the peat dating 10,250 ± 250 y BP (Y-762) on Port Hood Island (TERASMAE, 1974) and the peat dating 10,300 ± 150 y BP (GSC-1578) near East Bay (GRANT, 1975a).

CRUSTAL MOVEMENT AND SEA-LEVEL CHANGE

Former shorelines now found above and below present sea-level attest to great variations of relative sea-level position resulting from eustatic fluctuations attendant upon the general world wide progress of glaciation and from crustal distorsion caused by the local pattern of ice movement. Initially there was only the broadest separation of former water level positions into pre- and post-Pleistocene, with the latter assumed to comprise only features related to the most recent glaciation. As well, until recently only features above present sea level were available for discussion. Now several submerged shorelines are recognized and these add a new dimension to the problem of delevelling.

Most of the earliest references to glacial effects included mention of emerged marine features, in fact the latter often became the substance of arguments as to the nature of the glacial phenomenon. Elevation of former shorelines were given by DAWSON (1855), MILNE (1876), MURRAY (1882) and CHALMERS (1888, 1896). Regional syntheses of shoreline elevation were prepared by FAIRCHILD (1918), DALY (1921), GOLDTHWAIT (1924) and FLINT (1940) who all agreed that shorelines were uplifted progressively higher in a northwesterly direction, apparently a reflection mainly of the Laurentide ice gradient. The "isobase" pattern had a slight re-entrant over Gulf of St. Lawrence with lobes over the Maritimes and over Newfoundland, presumably due to subsidiary ice domes. The value of these inferences was however somewhat limited by the fact that they used only the maximum reach of the former sea regardless of age which hence could only reflect the broadest features. The attitude of single sea-level stands of assumed late Wisconsinan age was found for upper Bay of Fundy by HICKOX (1962) and SWIFT and BORNS (1967) to tilt up to the northwest, and for western Newfoundland by BROOKES (1974) to tilt up to the northeast. KRANCK (1972) dated a few emerged and submerged shorelines in Northumberland Strait and found a pronounced northwestward tilt. From this the regionally northward gradient of warping appears to have superimposed on it two more local components directed toward the interior of New Brunswick and Newfoundland, thus supporting the hypothesis that separate ice domes there were significant appendages to the Laurentide ice sheet.

Dated postglacial shorelines bear upon late glacial fluctuations and time of deglaciation in addition to reflecting the nature and progress of delevelling. THOMAS *et al*. (1973) concluded that northeast New Brunswick was ice-free at least 14,000 y BP and that the emergence affect of isostatic rebound was offset by a subsidence causing submergence since 8000 y BP, GRANT (1972d) showed that the emergence of western Newfoundland while exponentially decreasing over the last 13,000 years, was interrupted by two readvances 12,700 y BP and 11,000 y BP. Inflections in the northward rate of rise of marine limit in southwestern Nova Scotia gave independent evidence of two glacial periods and two glacial domes (GRANT, 1971b, 1976b). However the elevation of the emerged warm-water marine Salmon River Sand at first was taken to mean a Sangamonian date of formation in spite of the radiocarbon age (CLARKE *et al*., 1972), but later the sedimentology showed a glacial affiliation, and together with a U/Th date that proved the middle Wisconsinan age, meant that relative sea-level was isostatically higher because of a nearby ice front.

The existence of a raised more or less horizontal intertidal rock platform, probably dating from the last interglacial (WIDMER, 1950; HENDERSON, 1972; GRANT, 1975a, 1976b) is a valuable datum for assessing subsequent changes of land and ocean level, since it represents an equilibrium position during a period free from glacio-isostatic and eustatic adjustments. Since the bench is recognized as yet only on the outer fringes of the region, and this zone is presently sinking and submerging *ca*. 30 cm/100 y (GRANT, 1975; VANICEK, 1976), whereas the north shore of Gulf of St. Lawrence is still slowly rebounding and emerging, the bench may therefore tilt up in this direction. Similar platforms around the Gulf, hitherto regarded as late-glacial like the Bay of Islands Surface (FLINT, 1940) and the MicMac Terrace (GOLDTHWAIT, 1911) may be relict correlatives. There is therefore evidence the area is and has been tilting up to the northwest, while a later subsidence during the Holocene is migrating inward from the continental margin readjusting the older features progressively downward. Since this subsidence amounts to at least 40 m, marine limits have been modified differentially making inferences based on the pattern of marine overlap somewhat questionable.

As well, the paradox of submerged strandlines in areas of emerged strandlines has not been addressed. It is difficult to reconcile the fact that during deglaciation the sea was relatively high against moraines and ice fronts and later raised higher, with the fact the submerged terraces require a simultaneous low stand. This contradiction, together with the indication that the terraces may lie beyond the late Wisconsinan ice margin, suggests that the two are of quite different age. The terraces probably date either from earlier stadials, and mark lower eustatic levels in areas of little glacio-isostatic depression, or from interstadials when uplift was complete, but eustatic levels were lower. Clearly a re-appraisal of all former strandline features is needed, with honest decisions as to the time and agent of formation.

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