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Configuration and Dynamics of the Laurentide Ice Sheet During the Late Wisconsin Maximum
La configuration et la dynamique de l'inlandsis laurentidien au cours du pléniglaciaire du Wisconsinien supérieur
Конфигурация и дипамика лаврентьевского ледникового щита во вретя поздневиского максимального оледения

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Résumé de l'article

Avant 1943, on croyait que l'inlandsis laurentidien était constitué de trois dômes principaux centrés sur le Keewatin, le Labrador et le District de Patricia (TYRRELL, 1898 a et b et 1913). FLINT (1943) a plaidé que ces centres avaient seulement une importance locale et temporaire et il a plutôt favorisé le concept d'un inlandsis à dôme unique. Malgré l'absence de preuves géologiques, et malgré la proposition subséquente de l'existence du Dôme de Foxe (IVES et ANDREWS, 1963), le concept du dôme unique n'a pas été sérieusement remis en question avant la fin des années 70. Il est d'ailleurs encore vigoureusement appuyé par certains (HUGHES et al., 1977; DENTON et HUGHES, 1981). Cet article complète et modifie des travaux récents qui affirment que l'inlandsis laurentidien était en réalité constitué de plus d'un dôme au cours du pléniglaciaire du Wisconsinien supérieur. Nous proposons un modèle, basé sur la position des lignes de partage des glaces, les patrons de l'écoulement glaciaire, la composition des sédiments glaciaires, les formes tardi-glaciaires, les patrons du relèvement isostatique postglaciaire et les anomalies gravimétriques à l'air libre, qui fait appel à cinq dômes (ceux de M'Clintock, de Foxe, du Labrador, d'Hudson et (?) de Caribou). Nos dômes du Labrador et d'Hudson correspondent étroitement aux calottes labradoriennes et patriciennes de Tyrrell. Les dômes de Caribou et de M'Clintock avec le Complexe glaciaire de Franklin sur les îles de la Reine-Élizabeth, au nord de la calotte laurentidienne, correspondent à la calotte originelle du Keewatin de Tyrrell. Le style de glaciation de la région du bassin de Foxe n'était pas connu de Tyrrell, mais notre reconstitution du Dôme de Foxe est en accord avec la proposition initiale de Ives et Andrews.

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CONFIGURATION AND DYNAMICS OF THE LAURENTIDE ICE SHEET DURING THE LATE WISCONSIN MAXIMUM

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ABSTRACT Prior to 1943 the Laurentide Ice Sheet was considered to have three major domes centered in Keewatin, Labrador, and Patricia (TYRRELL, 1898 a, b; 1913). FLINT (1943) argued that these centres were of only local and temporary importance and favoured a single-domed ice sheet. Despite the lack of supporting geological evidence, and despite the proposition of a Foxe Dome in the interim (IVES and ANDREWS, 1963), the single-dome concept was not seriously challenged until the late 1970's and, in fact, is still strenuously supported (HUGHES *et al.*, 1977; DENTON and HUGHES, 1981). This paper extends and modifies recent conclusions that the Laurentide Ice Sheet had more than one dome at the Late Wisconsin maximum. We propose a model incorporating five domes (M'Clintock, Foxe, Labrador, Hudson, and(?) Caribou) based on the position of ice divides, ice flow patterns, drift composition, late-glacial features, postglacial isostatic recovery and free-air gravity anomalies. Our Labrador and Hudson domes closely correspond to Tyrrell's Labradorean and Patrician ice sheets; our Caribou and M'Clintock domes together with the Franklin Ice Complex over the Queen Elizabeth Islands north of the Laurentide Ice Sheet, correspond to Tyrrell's original Keewatin Ice Sheet. The style of glaciation of the Foxe Basin region was not known to Tyrrell, but our reconstruction of the Foxe Dome is in close agreement with the original proposal of Ives and Andrews. Like Tyrrell, our reconstruction is based on field evidence obtained through extensive mapping; the single dome model continues to be unsupported by geological data.

RÉSUMÉ *La configuration et la dynamique de l'inlandsis laurentidien au cours du pléniglaciaire du Wisconsinien supérieur.* Avant 1943, on croyait que l'inlandsis laurentidien était constitué de trois dômes principaux centrés sur le Keewatin, le Labrador et le District de Patricia (TYRRELL, 1898 a et b et 1913). FLINT (1943) a plaidé que ces centres avaient seulement une importance locale et temporaire et il a plutôt favorisé le concept d'un inlandsis à dôme unique. Malgré l'absence de preuves géologiques, et malgré la proposition subséquente de l'existence du Dôme de Foxe (IVES et ANDREWS, 1963), le concept du dôme unique n'a pas été sérieusement remis en question avant la fin des années 70. Il est d'ailleurs encore vigoureusement appuyé par certains (HUGHES *et al.*, 1977; DENTON et HUGHES, 1981). Cet article complète et modifie des travaux récents qui affirment que l'inlandsis laurentidien était en réalité constitué de plus d'un dôme au cours du pléniglaciaire du Wisconsinien supérieur. Nous proposons un modèle, basé sur la position des lignes de partage des glaces, les patrons de l'écoulement glaciaire, la composition des sédiments glaciaires, les formes tardi-glaciaires, les patrons du relèvement isostatique postglaciaire et les anomalies gravimétriques à l'air libre, qui fait appel à cinq dômes (ceux de M'Clintock, de Foxe, du Labrador, d'Hudson et (?) de Caribou). Nos dômes du Labrador et d'Hudson correspondent étroitement aux calottes labradoriennes et patriciennes de Tyrrell. Les dômes de Caribou et de M'Clintock avec le Complexe glaciaire de Franklin sur les îles de la Reine-Élizabeth, au nord de la calotte laurentidienne, correspondent à la calotte originelle du Keewatin de Tyrrell. Le style de glaciation de la région du bassin de Foxe n'était pas connu de Tyrrell, mais notre reconstitution du Dôme de Foxe est en accord avec la proposition initiale de Ives et Andrews.

РЕЗЮМЕ *Конфигурация и динамика лаврентьевского ледникового щита во время поздневисконсинского максимального оледенения.* До 1943 года считалось, что лаврентьевский ледниковый щит имел три крупнейших купола с центрами в Киватине, Лабрадоре и Патриции (Гирреллл, 1898 год, a, b и 1913 год). Флинт (1943 год) утверждал, что эти центры были временными и имели только местное значение. Он отдавал предпочтение гипотезе одноокупольного ледникового щита. Несмотря на отсутствие геологического подтверждения и несмотря на предложение признания купола Фокс в этот промежуток времени (Ивз и Эндрюз, 1963 год), концепция одноокупольного ледникового щита не вызывала серьезных возражений до конца 1970-х годов и, фактически, все еще энергично поддерживается (Хьюз и др., 1977 год; Дентон и Хьюз, 1981 год). Эта работа расширяет и разъясняет недавние выводы о том, что лаврентьевский щит имел более одного купола в поздневисконсинский период максимального оледенения. Мы предлагаем модель, включающую пять куполов (МакКлинток, Фокс, Лабрадор, Гудзон и (?) Карибу), основанную на положении ледоразделов, направлений движения льда, наносов, позднеледниковых образований, позднеледникового изостатического уровня и гравитационных аномалий воздушных пустот. Наши купола Лабрадор и Гудзон близко соответствуют ледниковым щитам Гиррелла, лабрадорскому и патрицианскому. Наши купола Карибу и МакКлинток вместе с франклинским ледниковым комплексом на островах королевы Елизаветы к северу от лаврентьевского ледникового щита соответствуют первоначальному киватинскому ледниковому щиту Гиррелла. Наше воссоздание купола Фокс находится в близком соответствии с первоначальным предположением Ивза и Эндрюза. Подобно концепции Гиррелла, наше воссоздание основано на полевых исследованиях местности, проводившихся при интенсивном составлении карт.

INTRODUCTION AND HISTORICAL PERSPECTIVE

The concept of the Laurentide Ice Sheet has alternated between (a) an equilibrium ice sheet with a single central dome over Hudson Bay, which generated radial flow to its margins, and (b) a nonequilibrium ice sheet with two or more domes, each generating its own flow pattern. TYRRELL (1898a, b; 1913; Fig. 1) suggested, on the basis of large radial patterns of striae, that the ice sheet had three distinct areas, or centres, of dispersal: one in the District of Keewatin, one in Labrador, and the other in the District of Patricia (northern Ontario).

FLINT (1943, p. 327), however, argued that it was "improbable that these centers were ever the sites of independent glaciers (except possibly toward the end of the last deglaciation) and that either of them persisted long." He favoured "...an ice sheet that was thickest over the site of Hudson Bay itself" and one "...in which the Labradorean, Keewatin, and other centers were of local and temporary importance...". Flint's primary reason for rejecting Tyrrell's conclusions was that he saw them as being in conflict with his own ideas concerning the mode of inception of the Laurentide Ice Sheet, yet he had no actual field evidence that supported his ideas. In fact, Flint's ideas were based primarily on "topographic and climatologic data". The topography he used was far from real and his model of "highland origin and windward growth" is no longer tenable (IVES, 1957, 1962; IVES *et al.*, 1975). FLINT (1971) continued to favour his single-dome model although he expressed some doubt. Following MACKAY (1965), he suggested that flow patterns shown on the *Glacial Map of Canada* (PREST *et al.*, 1968), which obviously relate to dispersal areas over Keewatin and Labrador, could possibly relate to the form of the ice sheet at its maximum. Despite this, the single dome concept remained popular, largely because it seemed to be supported by the pattern of postglacial isostatic rebound. For example, marine limit isoline maps, particularly those of DALY (1934) and FARRAND and GAJDA (1962), showed maximum marine limit elevations in the Hudson Bay region. Uplift centres over Hudson Bay were shown even more clearly on isobase maps prepared by ANDREWS (1970) and by WALCOTT (1973). Thus, the single-domed ice sheet was taken as a "fait accompli", was illustrated in several important studies, and was used as the basis of modelling the ice sheet (ANDREWS, 1973; IVES *et al.*, 1975; ANDREWS and PELTIER, 1976; SUGDEN, 1977; HUGHES *et al.*, 1977; DENTON and HUGHES, 1981; Fig. 2).

Recently, analysis of drift composition patterns over broad areas has lead to a questioning of the single dome centred over Hudson Bay and a reversion to ideas similar to those that prevailed prior to 1943. SHILTS *et al.* (1979) contended that southeastward flow across Keewatin toward Hudson Bay had been sustained throughout the Late Wisconsin maximum and that there was no evidence that ice had flowed from Hudson Bay onto Keewatin at any time. In addition, on the basis of the composition of till in northern Ontario and northern Manitoba, SHILTS (1980) suggested that these regions had been covered by ice flowing from Labrador, and hence, he proposed that the ice sheet had two major domes, one over Labrador and the other over Keewatin (Fig. 3). In the meantime, ANDREWS and MILLER (1979) proposed another dome over Foxe Basin, resurrecting the important earlier conclusion of IVES and ANDREWS (1963, their Fig. 19), and HILLAIRE-MARCEL *et al.* (1980) summarized evidence that supported a dome over Labrador-Ungava.

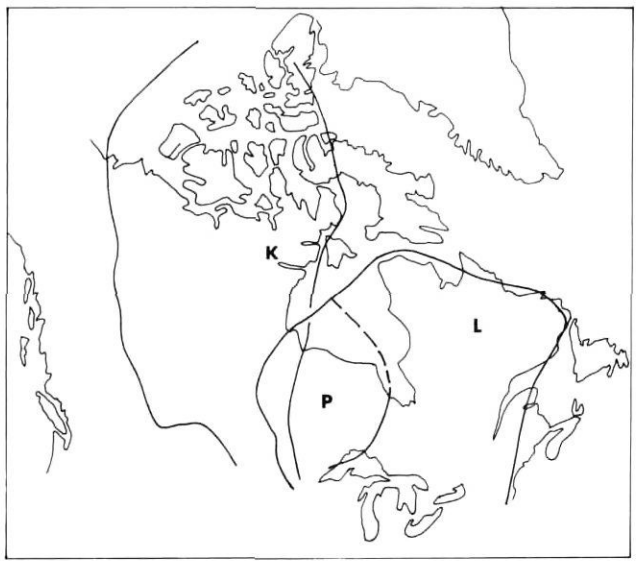

FIGURE 1. Tyrrell's concept of the Laurentide Ice Sheet consisting of Keewatin and Labradorean ice masses (TYRRELL, 1898b) and a Patrician ice mass (TYRRELL, 1913). Letters K, L and P are placed at their respective gathering grounds. Tyrrell considered that the different ice masses had reached their maximum extents at different times.

Le concept de l'inlandsis laurentidien, selon Tyrrell, constitué des masses de glace keewatinienne, labradoréenne (TYRRELL, 1898b) et patricienne (TYRRELL, 1913). Les lettres K, L et P sont localisées sur les centres respectifs d'accumulation. Tyrrell croyait que les diverses masses de glace avaient atteint leur étendue maximale à des moments différents.

New work in northern Canada and consideration of some of the glaciological implications of the two-dome reconstruction (SHILTS, 1980) requires further refinements of the multidome model. Below we describe the domes and associated flow patterns, explain where and why we depart from Shilts' and Andrews' and Miller's reconstructions, and point out some deglacial events that are more clearly explained by our model than by the others. We also add some speculative com-

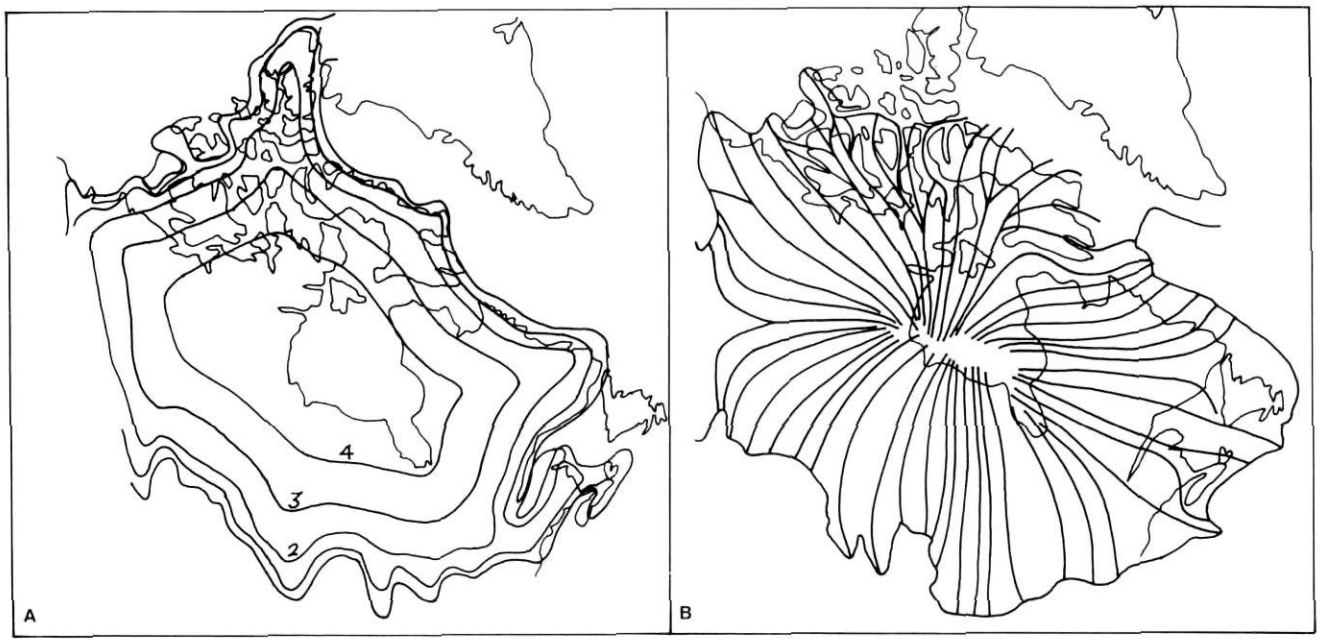

FIGURE 2. Two complementary views of form of the Laurentide Ice Sheet using the single-dome concept made popular by FLINT (1943). (A) Contours on the surface of the ice sheet at 12 000 BP, with elevations in kilometres (modified from ANDREWS, 1973); (B) Flow pattern at 18 000 BP (modified from HUGHES *et al.*, 1977; see also DENTON and HUGHES, 1981).

Deux visions complémentaires de la forme de l'inlandsis laurentidien utilisant le concept du dôme unique rendu populaire par FLINT (1943). (A) Courbes de niveau (en km) de la surface de la calotte vers 12 000 BP (modifié de ANDREWS, 1973); (B) Mode d'écoulement vers 18 000 BP (modifié de HUGHES et al., 1977; voir aussi DENTON et HUGHES, 1981).

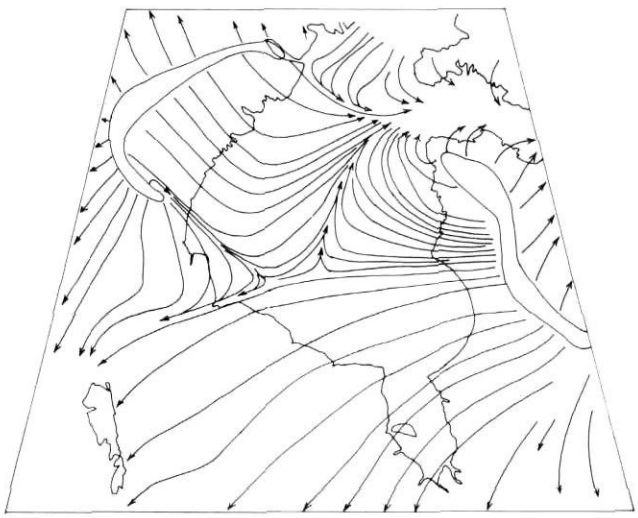

FIGURE 3. Flow pattern in the central part of the Laurentide Ice Sheet modified from SHILTS (1980).

Mode d'écoulement dans la région centrale de l'inlandsis laurentidien (modifié de SHILTS, 1980).

ments concerning the form of the ice sheet over the Interior Plains of Canada.

THE PROPOSED DOMES

At the last glacial *maximum* (*ca.* 18 000 to *ca.* 10 000 BP), the Laurentide Ice Sheet consisted of at least four coalescent domes (Fig. 4): the M'Clintock Dome, the Foxe Dome, the Labrador Dome, and the Hudson Dome. These domes were similar in size and were roughly symmetrical, as indicated by their radial flow patterns. These flows left fields of bedforms (drumlins and flutings) of regional extent, conspicuous patterns on the *Glacial Map of Canada* (PREST *et al.*, 1968). The flows also resulted in long-distance dispersal of erratic material, which indicates that they must have been operative for a considerable period. During that period, dispersal centres, ice divides, and zones of confluence shifted, perhaps considerably.

M'CLINTOCK DOME

The M'Clintock Dome (DYKE, 1978[1]; in press) had a central north-south oriented divide (Fig. 4). From the divide, ice flowed westward across Victoria Island and eastward to northeastward across Somerset Island, Boothia Peninsula and northern Keewatin. This eastward flow generated two dispersal trains 150 and 210 km wide, which must represent large basal ice streams (DYKE, in press; Fig. 4).

A zone of southwestward oriented flow features in northeastern District of Mackenzie probably describes

1. M'Clintock Dome is not discussed in the abstract but was dealt with in the oral presentation.

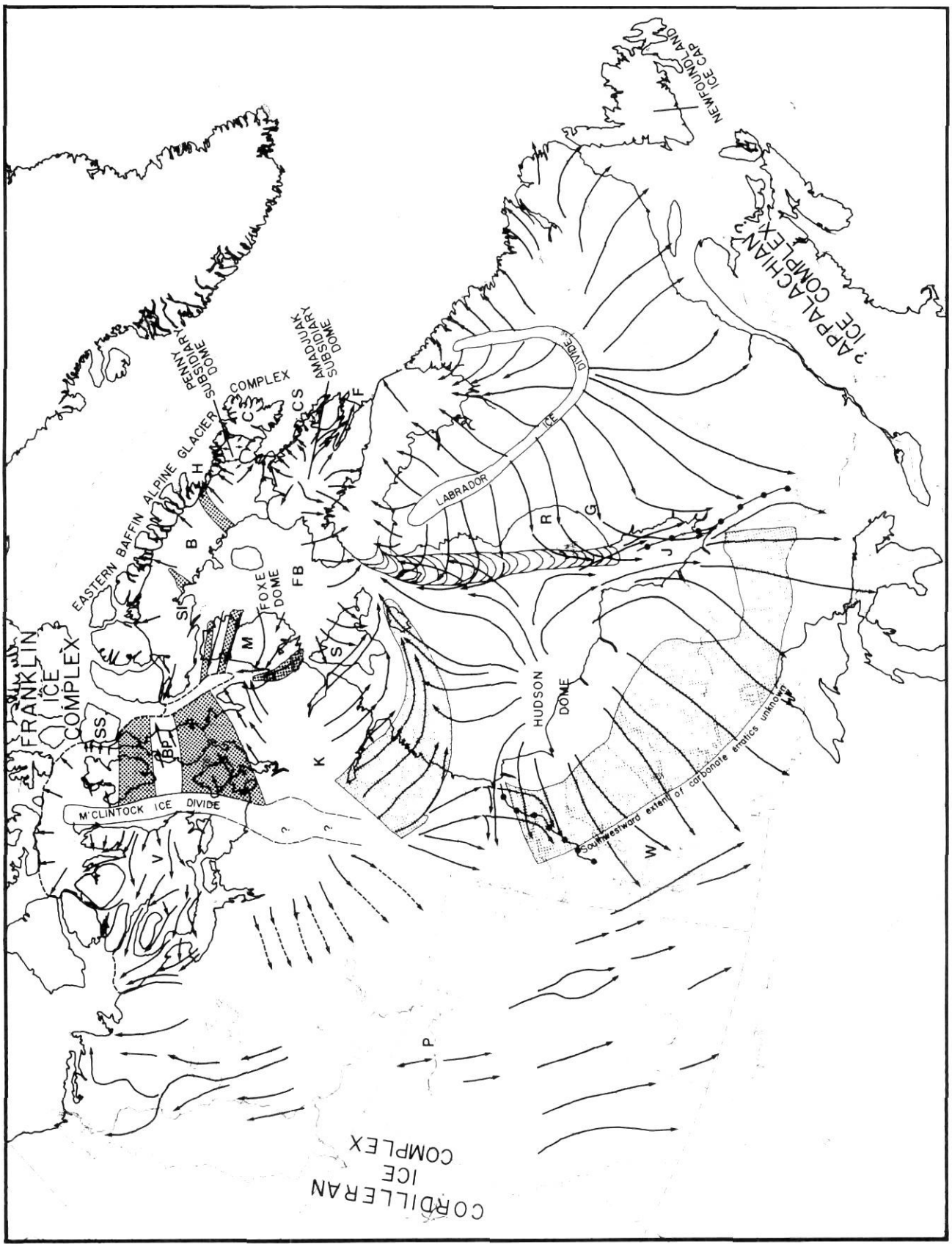
NEWFOUNDLAND ICE CAP
?APPALACHIAN ICE COMPLEX
DIVIDE
LABRADOR ICE
BENNAR SUBSIDIOME
AMADJUAK SUBSIDIOME
GLACIER
COMPLEX
ALPINE
EASTERN BAFFIN
FOXE DOME
HUDSON DOME
FRANKLIN ICE COMPLEX
M'CLINTOCK ICE DIVIDE
Southwestward extent of carbonate erratics unknown
CORDILLERAN ICE COMPLEX
H
C
CS
F
B
SI
M
FB
S
K
R
G
J
W
P
V
SS
BP

FIGURE 4. Structure and dynamics of the Laurentide Ice Sheet during the Late Wisconsin maximum showing ice divides; flow patterns; dispersal trains (light stipple), including trains formed by major ice streams (heavy stipple); and zones of confluence. Also shown are large interlobate moraine systems (line with dots) formed along the lines of separation of Hudson ice from adjacent Labrador and M'Clintock ice during deglaciation and the calving bay formed by the initial incursion of the Tyrrell Sea along the east side of Hudson Bay. (B: Baffin Island; BP: Boothia Peninsula; C: Cumberland Peninsula; CS: Cumberland Sound; F: Frobisher Bay; FB: Foxe Basin; G: Great Whale River; H: Home Bay; J: James Bay; K: Keewatin; M: Melville Peninsula; P: Peace River; R: Richmond Gulf; S: Southampton Island; SI: Steensby Inlet; SS: Somerset Island; V: Victoria Island; W: Lake Winnipeg.)

Structure et dynamique de l'inlandsis laurentidien au cours du pléniglaciaire du Wisconsinien supérieur. Sont illustrés: les lignes de partage des glaces; les patrons d'écoulement; les nappes de dispersion (grisé pâle), incluant les traînées formées par les lobes majeurs de glace (grisé foncé), les zones de confluence, les systèmes morainiques interlobaires (ligne avec points) édifiés le long des lignes de scission entre le glacier d'Hudson et les glaciers de M'Clintock et du Labrador lors de la déglaciation; et finalement, l'emplacement de la baie de vêlage formée lors de l'incursion initiale de la mer de Tyrrell dans le secteur est de la baie d'Hudson. (B: Terre de Baffin; BP: péninsule de Boothia; C: péninsule de Cumberland; CS: baie de Cumberland; F: baie de Frobisher; FB: bassin de Foxe; G: Grande Rivière de la Baleine; H: baie de Home; J: baie de James; K: Keewatin; M: péninsule de Melville; P: rivière de la Paix; R: golfe de Richmond; S: île Southampton; SI: baie Steensby; SS: île Somerset; V: île Victoria; W: lac Winnipeg.)

flow beneath the southwestern slope of the M'Clintock Dome. Because that flow pattern has been cross-cut by younger flow from the Keewatin Ice Divide (LEE, 1959), we are unable to locate precisely the southern end of the M'Clintock Ice Divide and we do not know how far to the southwest M'Clintock ice reached.

The flow southeastward across Keewatin and northeastward across Hudson Bay is thought to have lasted throughout the Late Wisconsin maximum because it left a dispersal train of red till and red erratics more than 300 km wide and more than 1000 km long (SHILTS, 1980; Figs. 3 and 4). Although Shilts showed the flow originating from the last position of the Keewatin Ice Divide (Fig. 3), which became established only during the latest phase of deglaciation, he recognized that "precursors" of this divide had been located to the northwest. We suggest that *the* precursor of the Keewatin Ice Divide during the Late Wisconsin maximum was the southern end of the M'Clintock Ice Divide. Hence, the Keewatin Ice Divide *per se*, as defined by LEE (1959), became established only after marine calving had destroyed the northern, marine based part of the M'Clintock Dome (DYKE, in press). Therefore, the southeastward migration of the Keewatin Ice Divide to its final position (Fig. 3) represents the systematic and continual readjustment of the profile of the M'Clintock ice remnant, centred over Keewatin, as the northern half of the dome disappeared.

FOXE DOME

The Foxe Dome (IVES and ANDREWS, 1963; DYKE, 1978[2]; ANDREWS and MILLER, 1979) had a radial flow pattern that spread from Foxe Basin (Fig. 4). It left large dispersal trains of carbonate debris on Melville Peninsula (SIM, 1960), which, like those on Boothia Peninsula, must have been formed by large basal ice streams. The Foxe flow pattern is well inscribed also on Southampton Island but not so on Baffin Island. Similarly, much less carbonate debris was carried onto Baffin Island than onto Melville Peninsula. However, there are two important exceptions: (1) the Late Wisconsin till in the northern part of the Home Bay area, eastern Baffin Island, and on the plateau inland from there (IVES and ANDREWS, 1963, p. 24; ANDREWS *et al.*, 1970; Fig. 4) contains a considerable proportion of carbonate erratics, and (2) till inland from Steensby Inlet is also highly calcareous (IVES and ANDREWS, 1963, p. 25; Fig. 4). Both of these zones of calcareous till likely represent dispersal trains crossing Baffin Island from Foxe Basin.

The relatively small amount of carbonate debris derived from Foxe Basin on Baffin Island led ANDREWS and MILLER (1979) to suggest that the Foxe Dome had a linear divide near the west coast of Baffin Island, slightly east of the carbonate bedrock contact. In this case, carbonate debris would have been transported westward. Although this may have been the case, we prefer an alternative explanation: that the Foxe Dome coalesced with two or more subsidiary domes on its eastern side and that these subsidiary domes buffered the eastward flow from the main dome. The Foxe Dome certainly coalesced with an expanded Penny Ice Cap on Cumberland Peninsula (ANDREWS *et al.*, 1970; DYKE, 1979; DYKE *et al.*, in press; Fig. 4), but the Penny ice maintained an independent flow pattern on three sides and buffered flow from Foxe Basin on the west. As well, a subsidiary Amadjuak Dome covered southern Baffin Island, generated a radial flow pattern, and prevented transportation of limestone debris eastward towards Frobisher Bay (BLAKE, 1966; ANDREWS and MILLER, 1979; Fig. 4). The strong buffering effect of the Amadjuak and Penny domes, rather than an eastwardly displaced ice divide, is considered the best explanation for the lack of carbonate erratics in the Late Wisconsin till near the head of Cumberland Sound and is likely the reason why Late Wisconsin ice from Foxe Basin failed to extend far into Cumberland Sound (DYKE, 1979), while at the same time Amadjuak ice extended to the mouth of Frobisher Bay (MILLER, 1980).

2. Again the Foxe Dome is not discussed in the abstract but was dealt with in the oral presentation.

LABRADOR DOME

The Labrador Dome had a horseshoe-shaped divide, perhaps the most conspicuous element in the glacial geomorphology of Labrador-Ungava (WILSON *et al.*, 1958; MACKAY, 1965; PREST *et al.*, 1968; HILLAIRE-MARCEL *et al.*, 1980). Ice flowed from the divide eastward to the Late Wisconsin glacial limit at a presently unmapped position somewhere near the Labrador coast. It flowed westward into Hudson Bay (HILLAIRE-MARCEL, 1976) and prevented transport of debris landward from Hudson Bay (SHILTS, 1980). Shilts proposed that the westward flow from the Labrador Ice Divide extended at least as far as Lake Winnipeg (Fig. 3). This was proposed in order to explain the transport of dark erratics from the Richmond Gulf areas to northern Ontario and to account for the massive dispersal of calcareous till from Hudson Bay and the Hudson Bay Lowlands southward and westward to Ontario and Manitoba. The Labrador Dome, as proposed here, differs from Shilts' in that its western limit is confined by Hudson ice to a position near the Québec-Ontario border and, farther north, to a position near the east coast of Hudson Bay.

HUDSON DOME

We propose a fourth dome, centred over southwestern Hudson Bay and northwestern Ontario. The Hudson Dome lies slightly north of, but occupies the same general area as, TYRRELL's (1913) Patrician Ice Sheet (Fig. 1). Hudson ice was confluent with M'Clintock ice on its northwest margin and with Labradorean ice on the east. The confluence between M'Clintock and Hudsonian ice shifted during the Late Wisconsin maximum as shown by crossing ice flow features and till lithologies. This dome is responsible for the massive transport of carbonate debris southwestward from the Hudson Bay Lowlands across the Shield of Ontario and Manitoba (Fig. 4). Because of the great distance of dispersal of carbonate debris, we see this dome as a Late Wisconsin maximum feature, rather than as a residual ice mass that became separated from the Labrador Dome during the latest phase of deglaciation (HARDY, 1976; HILLAIRE-MARCEL *et al.*, 1980).

DISCUSSION

REASONS FOR PROPOSING A HUDSON DOME

The addition of a Hudson Dome (a) avoids the ice mass asymmetry implicit in the two-dome model; (b) still accounts for dispersal patterns, and (c) explains deglacial features and events.

a) Symmetrical ice masses

The addition of a roughly symmetrical Hudson Dome eliminates the east-west asymmetry of Shilts' Labrador ice mass (Fig. 5). In Shilts' model, flow lines extend westward from the Labrador Ice Divide to Lake Winnipeg, a distance of 1600 km, whereas eastward they can only extend as far as the Labrador coast and the mount of Hudson Strait, a distance of only 500 km. If the ice sheet had a "normal" profile — one similar to present Antarctic and Greenland ice sheet profiles, and one expected from the physical properties of ice (NYE, 1952; PATERSON, 1969; ANDREWS, 1975) — the surface of the ice at the Labrador Ice Divide must have been at least 6000 m above the elevation of Lake Winnipeg (presently *ca.* 220 m a.s.l.). If the ice sheet also had a normal profile from that point on the divide to the Labrador coast, then there must have been a 5000 m ice cliff at the coast (Fig. 5), a physical impossibility.

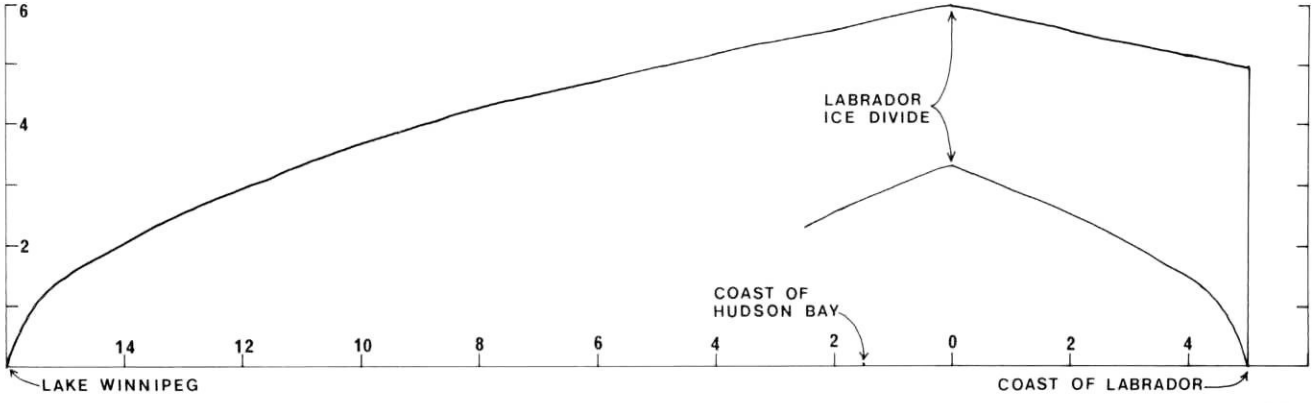

FIGURE 5. Ice sheet profiles illustrating the problems of asymmetry inherent in SHILTS' (1980) model. Horizontal axis shows distance from the ice divide in hundreds of kilometres and vertical axis shows elevation in kilometres. The profiles are calculated from NYE's (1952) formula using a 1 bar basal shear stress because that profile matches closely the present Antarctic and Greenland profiles.

Profils de calottes glaciaires illustrant les problèmes d'asymétrie inhérents au modèle de SHILTS (1980). L'axe horizontal indique la distance, en centaines de kilomètres à partir de la ligne de partage des glaces et l'axe vertical, l'altitude en kilomètres. Les profils sont calculés en se basant sur les formules de NYE (1952) où la force de cisaillement basal est de 1 atmosphère. Ce profil s'approche davantage de celui des calottes de l'Antarctique et du Groenland.

Or, to look at the problem from the other direction: assuming a "normal" profile from the Labrador coast to the same point on the ice divide, the divide lay only 3300 m above the margin (above sea level for all practical purposes). Unless the basal shear stress in the westward flowing ice was radically lower than in the eastward flowing ice, Labrador ice could not have flowed much beyond the east coast of Hudson Bay. In other words, although we should not necessarily constrain our reconstruction of former ice sheets by a rule of strict symmetry (because regional changes in basal shear stress can induce *some* asymmetry), gross asymmetry seems to be unwarranted.

Another minor glaciological problem inherent in Shilts' model is that it creates a 200 km long vertical shear zone in the ice sheet in west-central Hudson Bay. This is indicated by parallel flow lines with opposite directions (Fig. 3). This problem and similar ones do not exist in the model proposed here.

The Labrador Dome, as shown (Fig. 4), is roughly symmetrical along a north-south axis. In this reconstruction we assume that Labrador ice coalesced with a Appalachian Ice Complex, as proposed by PREST and GRANT (1969). If, however, Labrador ice reached as far south as Long Island, during Late Wisconsin time the Labrador Ice Divide could have been as much as 250 km south of the position shown on Figure 4 during construction of the Ronkonkoma-Vineyard-Nantucket moraines.

b) Till composition and indicator lithologies

In addition, a Hudson Dome can account for the transport of carbonate debris previously ascribed by Shilts to Labrador ice, and can account for the dispersal of *most* dark erratics. However, the model proposed here does not *totally* explain the distribution of "dark" erratics on the Hudson Bay Lowlands and adjacent shield. We suggest that those erratics not explained by the Late Wisconsin flow lines were brought there by pre-Late Wisconsin ice. This likely occurred cumulatively during successive glacial buildup periods when northern Ontario is thought to have been invaded by ice coming from Labrador (ANDREWS and MAHAFFY, 1976; ANDREWS and BARRY, 1978). The occurrence of dark erratics in pre-Late Wisconsin tills and in nonglacial sediments throughout the Hudson Bay Lowlands (NIELSEN and DREDGE, 1982) supports the suggestion that they are polycyclic.

c) Late glacial features and events are better explained by a multidome model than by a two-dome model

(i) *Interlobate moraines*: The Burntwood-Etawney moraine in Manitoba (KLASSEN, in press, DREDGE and GRANT, 1982) and the Harricana moraine in Québec (HARDY 1976, 1977) are considered to be interlobate moraines (Fig. 4). We suggest that these moraines formed during separation of Hudson ice from other ice masses and that separation occurred where the ice was thinnest along the pre-existing zones of confluence. In Shilts' model, the ice has no predisposition to separate along the Harricana Interlobate Moraine. Even though in Shilts' model Labradorean and M'Clintock (Keewatin) ice *are* predisposed to separate along the Burntwood-Etawney Interlobate Moraine, the implication of this is that Labradorean ice continued to penetrate as far westward as Manitoba at a time when ice in Keewatin had nearly disappeared. We suggest that the moraine formed during separation of the Hudson and M'Clintock ice (DREDGE, 1982), both of which disappeared shortly thereafter.

(ii) *Radial surges from Hudson Dome*: Immediately before total disruption of the ice cover over Hudson Bay, substantial readvances, the Cochrane surges (HARDY, 1976), occurred in the James and Hudson Bay Lowlands of Québec and Ontario. Similar and roughly contemporaneous readvances occurred in adjacent areas of Manitoba (DREDGE and GRANT, 1982). We feel these readvances represent a re-equilibration of the profile of the Hudson Dome, produced in part by extensive oversteepening of its margin, brought on by calving into glacial lakes Ojibway and Agassiz. Again, with a dome over southwestern Hudson Bay and northwestern Ontario, the ice was predisposed to respond in this manner and it is not necessary to ascribe the Cochrane readvances to a remnant ice mass "shrinking toward a Keewatin centre" (SHILTS, 1980, p. 5).

(iii) *Incursion of Tyrrell Sea along lines of confluence*: HARDY (1976) concluded that the Tyrrell Sea penetrated southward from western Hudson Strait along a corridor situated on the east side of Hudson Bay between longitude 80° W and the present coast and that Lake Ojibway catastrophically drained northward into that corridor (Fig. 4). He based this conclusion on several lines of evidence: (1) Lake Ojibway extended as far north as Great Whale River (beyond the mouth of James Bay) but contacted ice to both east and west; (2) the lake drained northward as indicated by a characteristic drainage horizon on Lake Ojibway sediments over a wide area east of James Bay; (3) De Geer moraines built into Tyrrell Sea are found up to the present coast north of Richmond Gulf indicating that the corridor was situated in Hudson Bay to the west. Again, we suggest that Tyrrell Sea penetrated along the eastern side of Hudson Bay, following the pre-existing zone of confluence where the ice was relatively thin (Fig. 4).

MULTIPLE CENTRES OF ISOSTATIC RECOVERY

A further strength of the multidome model is that it better accounts for the pattern of postglacial isostatic recovery than does either the single dome or two dome

model. The only *apparently* concrete support that ever existed for the single dome model was that early isobase maps showed a simple pattern with maximum crustal recovery in the Hudson Bay area. For at least a decade, however, we have had strong indications that the real pattern of crustal recovery is more complex. ANDREWS and BARNETT (1972) identified regions of intersection of strandline tilt directions over Labrador-Ungava, Hudson Bay, and Keewatin; DYKE (1974) showed that uplift accomplished since 7000 yr BP proceeded around centres over Foxe Basin, Labrador-Ungava, and Keewatin; VINCENT and HARDY (1979) showed water plains of Lake Barlow-Ojibway rising toward central Labrador-Ungava from the southwest; GRAY *et al.* (1980) showed that raised shorelines in the Ungava Bay area are tilted inland toward central Labrador-Ungava, rather than toward Hudson Bay; and DYKE (1979; in press) shows raised shorelines rising toward the centre of the M'Clintock Dome.

The multidome mode also accommodates WALCOTT's (1970) interpretation of the pattern of negative free air gravity anomalies as being glacio-isostatically induced. In fact, his map can be taken as strong evidence of a multidomed ice sheet, with the M'Clintock, Foxe, and Labrador domes being clearly expressed (WALCOTT, 1970, his Fig. 1). This relieves the need to seek other explanations for the gravity data and avoids the non-*explanation of considering the anomalies to be a "per*manent feature of the crust" (HALL, 1969; SHILTS, 1980, p. 5).

A POSSIBLE WESTERN DOME

If we apply the constraint that individual domes of the ice sheet have to be roughly symmetric, as we have argued above, then it is clear that neither the Hudson Dome nor the M'Clintock Dome can account for the Late Wisconsin glaciation of the Interior Plains of Canada. Therefore, unless the ice sheet did in fact have a single central dome in the vicinity of Hudson Bay (and there is no evidence that it did), it is necessary to invoke one or more other domes, located over the Interior Plains, to account for the glaciation of that vast region.

Although we are unfamiliar with the complexities of the Quaternary history of the Interior Plains, we offer the following speculation: the *Glacial Map of Canada* (PREST *et al.*, 1968) shows an obvious parallel system of southeastwardly oriented ice flow forms that extends from Lake Winnipeg to the foothills of the Rockies. That set of features can be traced up-flow to the northernmost part of Alberta, near Peace River. Northwest of there, in the District of Mackenzie, is another parallel set of ice flow features that extends in the opposite direction toward the Arctic Ocean (Fig. 4). Both these huge regional flow patterns are cross cut in numerous places by other flow patterns, presumably formed during phases of deglaciation. We speculate that the regional flow patterns (Fig. 4) represent flow from an ice divide located near the Caribou Hills, just north of Peace River, during the Late Wisconsin maximum. If that speculation should prove reasonable, the name Caribou Dome might be applied to the ice mass that inscribed the flow pattern.

SUMMARY

The earliest views of the structure of the Laurentide Ice Sheet during the last glacial maximum were those espoused by TYRRELL (1898a, b, 1913; Fig. 1). They were based on the recognition of large regional patterns of ice flow, which in turn were based on years of field mapping by officers of the Geological Survey of Canada. Tyrrell recognized centres of outflow in Keewatin, Labrador, and Patricia (northwestern Ontario).

These ideas were supplanted by FLINT (1943), who felt that they conflicted with his concept of the mode of inception of the Laurentide Ice Sheet. He preferred, instead, a simple ice sheet with a centre of outflow at its maximum over Hudson Bay. Flint's concept of ice sheet inception had little or no geological, geomorphological, topographical, or climatological basis in fact and was challenged as early as 1957 (IVES, 1957; 1962; IVES *et al.*, 1975). However, this single-domed ice sheet concept held sway until the late 1970's. An important exception was the proposition of a dome over Foxe Basin by IVES and ANDREWS (1963). However, that idea was not vigourously promoted after its introduction, and the authors themselves later ascribed all major regional centres of outflow to deglacial phases, preferring a single-domed ice sheet during the maximum (*e.g.* ANDREWS, 1973; IVES *et al.*, 1975).

By the late 1970's new data on ice flow features, till composition, distance of transport, and a more refined interpretation of glacioisostatic recovery patterns prompted many people engaged in field mapping (DYKE, 1978; SHILTS *et al.*, 1979; ANDREWS and MILLER, 1979; SHILTS, 1980; HILLAIRE-MARCEL *et al.*, 1980; DYKE, *in press*; DREDGE, 1982; DREDGE and GRANT, 1982) to return to ideas similar to those of TYRRELL (1898; 1913) and of IVES and ANDREWS (1963).

This paper modifies and extends recent reconstructions by ANDREWS and MILLER (1979) and SHILTS (1980). We propose that at least four major domes, the M'Clintock, Foxe, Labrador, and Hudson, and possibly a fifth, the Caribou existed during the Late Wisconsin maximum. The Foxe Dome has at least two subsidiary domes, Penny and Amadjuak, and it is likely that future work will recognize additional subsidiary domes.

Our reconstruction differs fundamentally from the Antarctic analog reconstruction of the Laurentide Ice Sheet by DENTON and HUGHES (1981), but we feel that it better accommodates the known facts.

CAUTIONARY NOTE

The flow patterns shown reflect the form of the ice sheet at the Late Wisconsin maximum. The location of domes does not necessarily reflect the mode of inception of the ice sheet. Rather, we see the form of the ice sheet at the Late Wisconsin maximum as the product of its middle and early Wisconsin history, involving perhaps an extensive early Wisconsin ice sheet, substantial but incomplete mid-Wisconsin deglaciation, and late Wisconsin re-expansion. This is especially true for the marine-based ice.

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