TILL STRATIGRAPHY IN NORTH AMERICA AND NORTHERN EUROPE

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Abstract. In glaciated areas, the chronology and the knowledge of the climatic fluctuations are derived from the study of the alternations between tills, stratified drift and non-glacial deposits. Therefore, studies directed to the distinction and correlation of tills are extremely important for a correct understanding of the climatic fluctuations that characterized the Last Ice Age.

Great progress in the study of tills has been made in Canada and the USA during the last few decades. The ice marginal fluctuations during the Last Ice Age, as reconstructed from till stratigraphy in the eastern Great Lakes region of North America and in southern Scandinavia, are extraordinarily similar, indicating a global climatic background and justifying the establishment of a stratigraphic correlation scheme.

TILL

Till (Swedish *morän*) is a Scottish word given to glacial sediments deposited more or less directly by or from the ice (basal till, ablation till, waterlaid till and deformational till). There are several other names for till, for example, non-stratified drift (Flint's earlier expression), boulder clay (an English word), moraine (a French word: in America only a landscape form, in Europe a landscape form and sometimes also a sediment type), tillite (cemented or metamorphosed till), and glacially deformed bedrock.

For till-like (unsorted) material (i.e. material of glacial as well as other origin) there are several names: diamicton (a very useful term), paraconglomerate, mudstone, muddy conglomerate, conglomeratic graywacke, and loamy soil. In every case of uncertainty whether a deposit is a real till or just a (non-glacial) till-like deposit, the term diamicton should be used. Dreimanis (1970) has established "criteria for distinction of till from other diamictons".

TRANSPORT AND DEPOSITION

Dreimanis (Dreimanis, 1969; Dreimanis and Vagners, 1971) has given an excellent scheme of the derivation of till from glacial drift and from bedrock and older sediments deformed by a glacier (Fig. 1). This scheme is here proposed also as a European standard. Material still in the glacier is termed drift (basal, englacial and superglacial). It should be noted, however, that drift is also a common American term for glacial deposits in general. The material deposited is called till and can be of four main types: basal, ablation, waterlaid and deformational tills.

In Sweden, the great majority of tills of Late Weichselian age were deposited in connection with the glacial recession. In places, however, till was also deposited at the advance (Mörner, 1972*a*, 1972*c*). These advance accumulations have several common structures (till wedges, thrust planes, sediment dikes, structures of glacial pressure, etc.) which are not found or are only occasionally found in recessional accumulations. Advance till is often separated from recessional till by a boulder pavement or a sharp limit, sometimes emphasized by a thin layer of stratified drift (for example, Mörner, 1972*c*). In the area studied by Dreimanis, much of the till was deposited at the advance.

GLACIAL DYNAMICS

Transportation and deposition are the result of glacial dynamics. It must be remembered that there are two main types of glaciers and that these behave quite diffe-

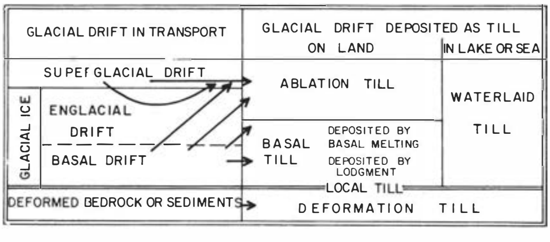

Fig. 1. Derivation of till from glacial drift and from bedrock and older sediments deformed by a glacier (from Dreimanis, 1969, Table 1, and Dreimanis and Vagners, 1971, Fig. 2), here proposed also to be used as a European standard classification scheme.

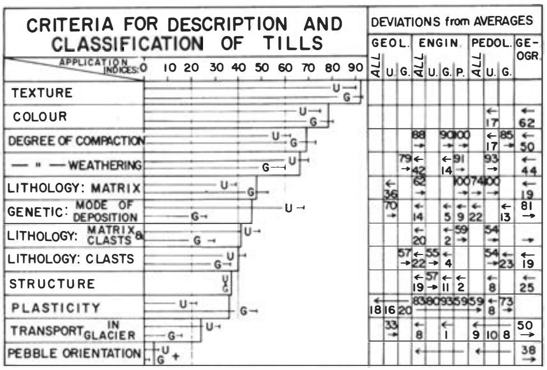

Fig. 2. Criteria for description and classification of tills (from Dreimanis, 1971, Fig. 1). All numbers are application indices. Abbreviations: U = Universities, G = Non-academic governmental institutions, P = Private companies. The horizontal bars and lines are general averages from all answers: the numbers in the right-hand columns refer to the indices of separate groups listed in their headings. Only those with notable deviations are given.

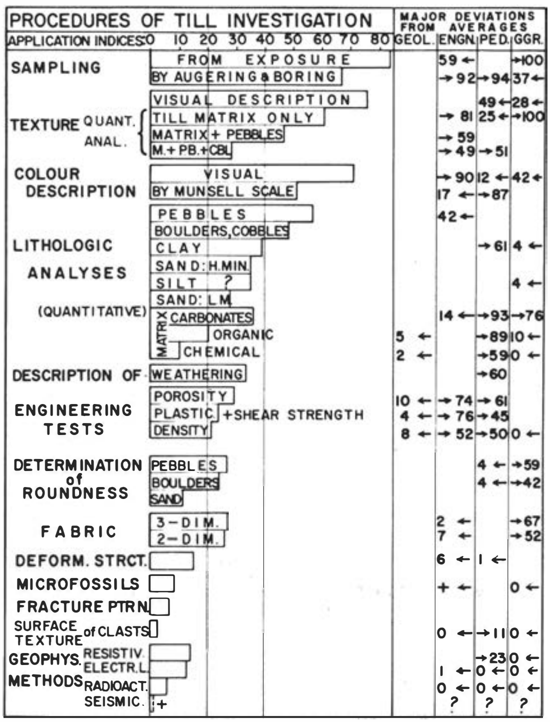

Fig. 3. Procedures of till investigation (from Dreimanis, 1971, Fig. 2). See Fig. 2 for explanations.

rently: (*a*) warm glaciers or temperate glaciers or wet-base glaciers and (*b*) cold glaciers or polar glaciers or dry-base glaciers. The Scandinavian Ice was a warm glacier (at least in Sweden), giving rise to its own typical morphology and stratigraphy. The North American Ice Sheets (the Laurentide and Cordilleran) were, at least in several places, cold glaciers, giving rise to their own typical morphology and stratigraphy.

STRATIGRAPHICAL INVESTIGATION OF TILLS

Dreimanis (1969) found that the following parameters were the most significant for till investigation: (1) structure, (2) fabric, (3) compactness, (4) granulometric composition, (5) lithology, and (6) abrasion of clasts and the mineral matrix.

As a project under the INQUA Commission on the Genesis and Lithology of Quaternary Deposits, a questionnaire was sent to geologists in North America who had studied till and related problems. A report (based on the answers to the questionnaire of 545 till investigators) was presented at the Annual Meeting of the North-Central Section of the Geological Society of America in 1969 (Dreimanis, 1971). The results concerning the "Criteria for distinction and classification of tills" and "Procedures of till investigation" are shown in Figs. 2 and 3.

THE BIMODAL DISTRIBUTION OF ROCK AND MINERAL FRAGMENTS IN TILL

Dreimanis and Vagners have demonstrated that every lithological component of a till has a bimodal particle distribution: one mode (the rock fragments) in the clast size and another mode (the minerals) in the till matrix (Dreimanis and Vagners, 1969, 1971; Dreimanis, 1969). With increasing distance of transportation, the matrix mode becomes larger and the clast-size mode becomes smaller or may even disappear (Fig. 4). This nicely illustrates the whole process of glacial comminution. The matrix modes are restricted to certain particle sizes, "terminal grades", typical for each mineral (Fig. 5). The terminal grades are the final product of glacial comminution. Finer particles (clay) are derived from other processes than glacial comminution.

The results obtained by Dreimanis and Vagners (1971) mean that all studies of the lithological composition of tills require investigations of at least two particle sizes: (1) the clasts (rock fragments) and (2) the till matrix (the terminal grades). Investigations restricted to the clast size may yield quite misleading results for the distinction and correlation of tills.

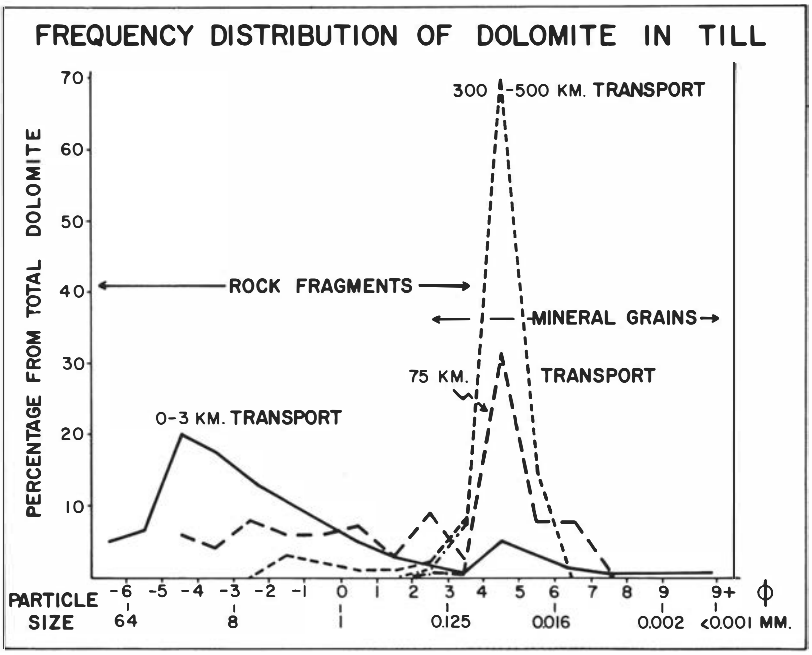

Fig. 4. Frequency distribution of dolostone-dolomite in three selected till samples from the Hamilton-Niagara area (from Dreimanis and Vagners, 1971, Fig. 4), nicely illustrating the process of glacial comminution. With increasing distance of transportation, the matrix mode becomes larger and the clast-size mode becomes smaller and may even disappear. The matrix modes are restricted to certain particle sizes, "terminal grades", which are the final products of glacial comminution.

TILL STRATIGRAPHY AND TILL CORRELATION

In glaciated areas, the chronology and knowledge about the climatic fluctuations are derived from the alternation of tills, stratified drift and non-glacial deposits. However, overriding by ice usually meant that older layers were eroded away. A complete picture has therefore almost always to be based on correlations between several different localities. In a few places, complete sequences are preserved, for example, in the Scarborough Bluffs at Toronto (Karrow, 1967), on Whidby Island in Washington State (Easterbrook, 1969; Mörner, 1971) and at Dösebacka in southwestern Sweden (Mörner, 1972*a*). It is significant that these stratal sequences are correlatable (Fig. 8), though representing quite different glacial regions.

The Erie-Ontario lobe area in Canada is surely unique for the deciphering of the glacial chronology of the Last Ice Age:

1. Together with the areas south of Lake Erie and Lake Michigan, the Canadian side of the Erie-Ontario basin has been better studied that any other glaciated area in the world.

2. In the Scarborough Bluff at Toronto, there is a complete, or almost complete, stratal sequence of the Last Ice Age (Fig. 6; Dreimanis and Karrow, 1965; Karrow, 1967). This is an ideal, world type section for the continental, glacial chrono-stratigraphy of the Last Ice Age.

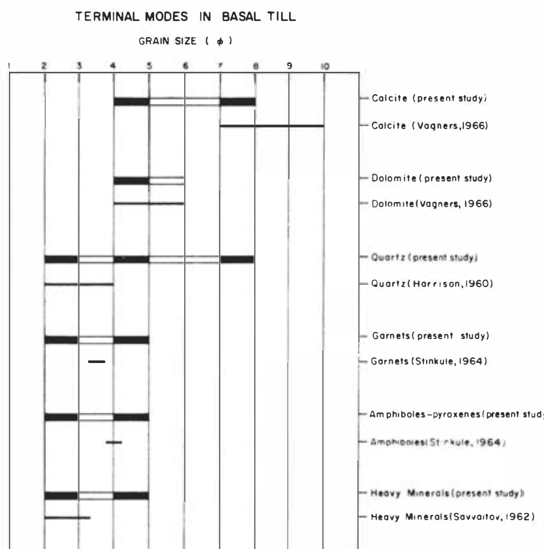

Fig. 5. "Terminal grades" and major modes in them (black bars) of selected minerals and their groups in basal tills (from Dreimanis and Vagners, 1971, Fig. 5).

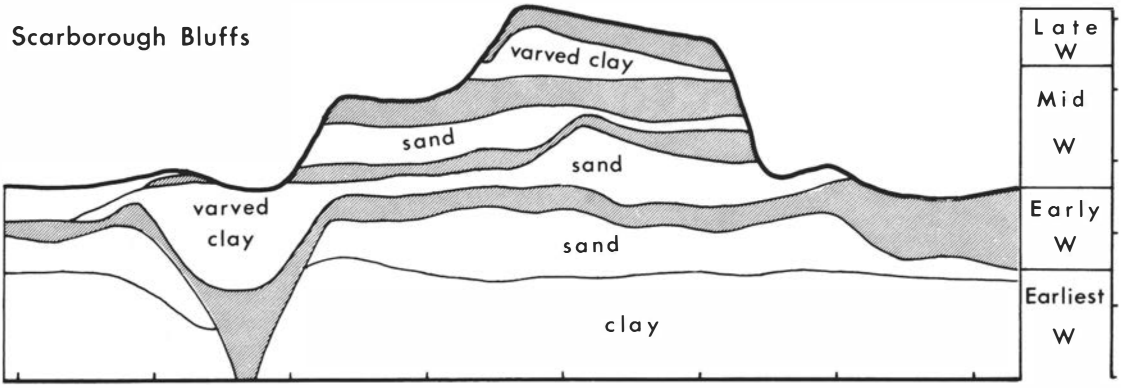

Fig. 6. The Scarborough Bluffs Section in Toronto (redrawn from Karrow, 1967). Dark layers = till beds. Confer Figs. 8 and 9. The Scarborough Bluffs section provides an ideal world standard section for the continental glacial chrono-stratigraphy of the Last Ice Age.

3. Thanks to intensive till studies by numerous geologists (for example, Dreimanis, Goldthwait, Karrow and White), the different till beds at Toronto can be correlated across the Ontario-Erie basin (Fig. 9).

4. Having a well established stratigraphic sequence, radiocarbon dates can be used and evaluated with much greater certainty than in areas without good stratigraphic control.

In Scandinavia, as in most other areas, information from different localities has to be combined via correlations, which are usually based on the information from the interstadial beds. Good and reliable correlations have been established from pollen assemblages in Europe. The genesis of the sediments, i.e. their relation to ice margin and sea level, provides other ways of establishing correlations. In some cases, the mollusc faunas have provided important information. Radiocarbon dates are probably the most commonly used tool for establishing correlations. This works perfectly well back to about 20,000–25,000 B.P. For older material, radiocarbon dates may be quite misleading, however (Mörner, 1971, 1972*b*). Every "dead" (or almost "dead") sample contaminated by 5 % or less (a few tenths of 1 %) of modern radiocarbon will yield apparent dates of Mid Weichselian-Wisconsin age (Mörner, 1971, Fig. 1). Single dates of Mid Weichselian-Wisconsin age without stratigraphic control simply cannot be trusted. Finite shell dates of more than 15,000–20,000 years are quite unreliable and must be treated as infinite dates only (for example, Mörner, 1971). The well established till stratigraphy in the Erie-Ontario lobe area provides a control of all dates obtained from this area. A clustering of dates around certain ages (= the interstadials) is obtained (Fig. 7). The European pollen stratigraphy also provides a control (though less certain) of the dates. It is of the greatest interest to note that the Mid Weichselian chronology of Europe is almost identical to the Mid Wisconsin chronology, as established in the Erie-Ontario lobe area, in Illinois, and in Washington State (Fig. 8).

Radiocarbon dates of samples of Earliest Weichselian-Wisconsin age are quite unreliable and have only caused confusion. This can be exemplified by the dates obtained from the interstadials of St. Pierre (about 65,000 B.P.), Brörup (about 59,000 B.P.), Chelford (about 54,000 B.P.), Karuküla (about 48,000 B.P.) and Peräpojhola (about 45,000 B.P.), which apparently all represent the same interstadial: the very temperate one at about 80,000 absolute years B.P. (Mörner, 1971, 1972*a*, 1972*b*).

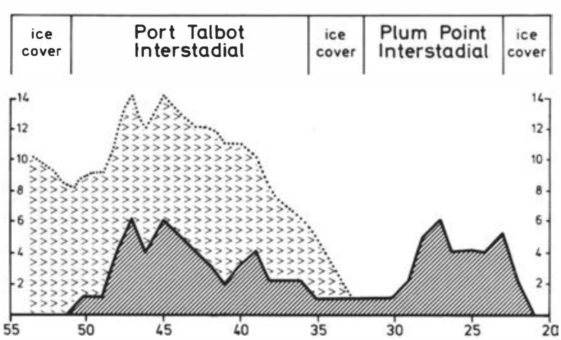

Fig. 7. Chronological distribution of all radiocarbon dates older than 20,000 B.P. obtained from the Erie-Ontario lobe area (redrawn from Dreimanis and Goldthwait, 1972). Explanation: Horizontal scale = time in 10^3 years B.P., vertical scale = numbers of dates, hatched area = finite radiocarbon dates, dotted curve = infinite, "greater than" dates. An obvious clustering of dates around certain ages (= the interstadials) is obtained.

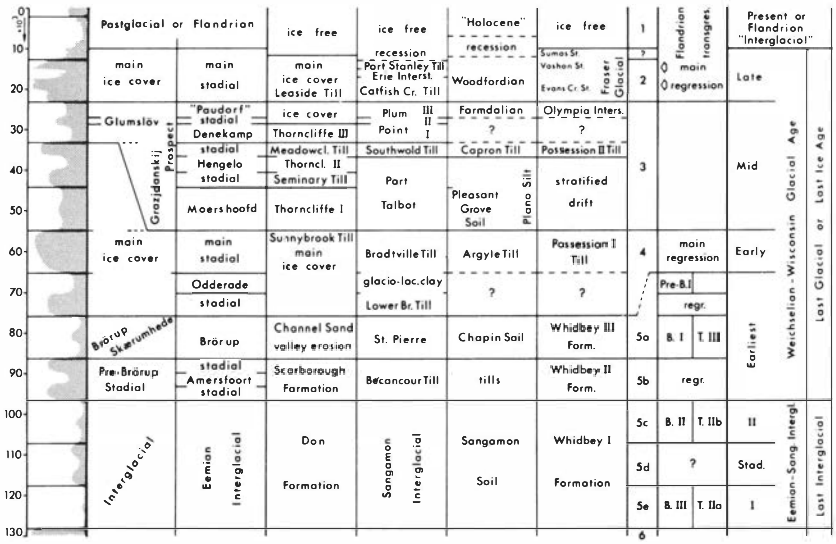

Fig. 8. Regional correlation scheme (from Mörner, 1972*a*). The curve to the left gives a generalized picture of the major cold/warm changes during the last 130,000 years (dark = cold). The time scale (in 10^3 years B.P.) is hypotetical and is based on a periodicity of 10,500 years for the major cold/warm changes (corresponding to complete cycle of 21,000 years), which was found to agree well with available dates (and precessional cycle). The first two columns illustrate the northern European stratigraphy (Fig. 10) in glacial areas (southern Scandinavia) and non-glaciated areas (the Netherlands). The following four columns illustrate the North American stratigraphy in the Scarborough Bluffs Section in Toronto (Figs. 6 and 9, point 3), the eastern Great Lakes region in general (Fig. 9), the Illinois State region, and the Washington State region, respectively. The next two columns show Emiliani's palaeotemperature stages, and the main sea-level information (B = Barbados, T = Tyrrhenian). The last columns give ages and sub-ages according to Mörner (1971).

WEICHSELIAN TILL STRATIGRAPHY IN THE NORTH AMERICAN REGION

Fig. 9 (Mörner, 1972*a*) illustrates the till stratigraphy and ice marginal fluctuations in the Quebec-Ohio region in North America. It is based on information from the following six areas (from Mörner, 1972*a*): (1) the Becancour area in Quebec, (2) southeastern Quebec, (3) the Toronto area, (4) the Hamilton area, (5) the Port Talbot - Plum Point area, and (6) northeastern Ohio.

WEICHSELIAN TILL STRATIGRAPHY IN THE SCANDINAVIAN REGION

Fig. 10 (Mörner, 1972*a*) illustrates the till stratigraphy and ice-marginal fluctuations in the Scandinavian region. It is based on the following ten areas (numbered vertical lines in Fig. 10): (1) the Jämtland area, (2) the Stockholm area, (3) the Billingen area, (4) the Gothenburg area, (5) northwestern Skåne (southwesternmost Sweden), (6) the Store Belt area, (7) the Lille Belt area, (8) the Skærumhede area, (9) the Brørup area, and (10) the climatic curve from Holland (van der Hammen *et al.*, 1967, Zagwijn and Paepe, 1968) outside the glaciated area (for details, see Mörner, 1972*a*). The most complete Swedish sequence comes from Dösebacka (Fig. 11), where three till beds occur, separated by interstadial beds (Mörner, 1972*a*). Other records (discussed in detail in a separate paper, Mörner, 1972*a*) can easily be placed in Fig. 10, for example, the climatic curve for northeastern USSR published by Vigdorchik *et al.* (1970).

On a whole, the ice marginal fluctuations in North America and northern Europe are extraordinarily similar, indicating a global climatic background.

FINAL REMARKS

Studies directed to the distinction and correlation of tills are extremely important for a correct understanding of the climatic fluctuations that characterized the Last Ice Age. It is therefore hoped that the great progress made in Canada and the USA during the last few decades will inspire intensive investigations in the Scandinavian region.

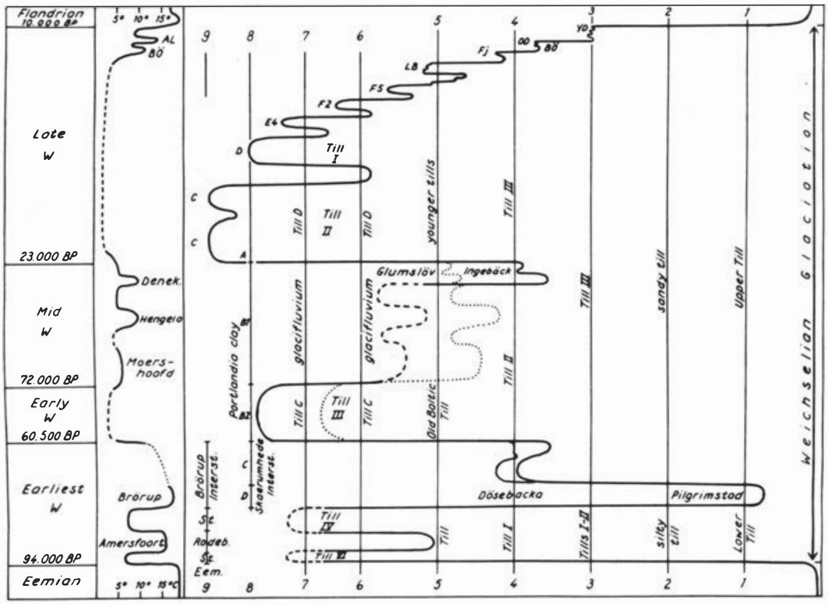

Fig. 9. Wisconsin ice-margin fluctuations between Quebec and Ohio in eastern North America, based on six main areas given in the text (from Mörner, 1972*a*). Confer Figs. 8 and 10.

ADDENDUM: TILLS AND ICE STREAMS IN SOUTHERN SCANDINAVIA

In considering Late Weichselian tills in southern Scandinavia and their mutual correlations–which several papers at the Uppsala Meeting dealth with–it seems necessary to call attention to the complexity of the ice streams (at both the advance and the recession) and the stratigraphical gaps in most till sections.

The Late Weichselian advance over southern Scandinavia was characterized by competition between three major ice streams; the Norwegian, the Baltic and the Northeast (or Smålandian) ice streams (Mörner, 1969, 1972*c*). This is illustrated in Fig. 12. The recession from the maximum extent in Jylland, the C line, was characterized by an analogous splitting into separate ice streams (Mörner, 1969, Pl. 2), especially the separation of one Baltic ice lobe after the other from the main N.E.-ice.

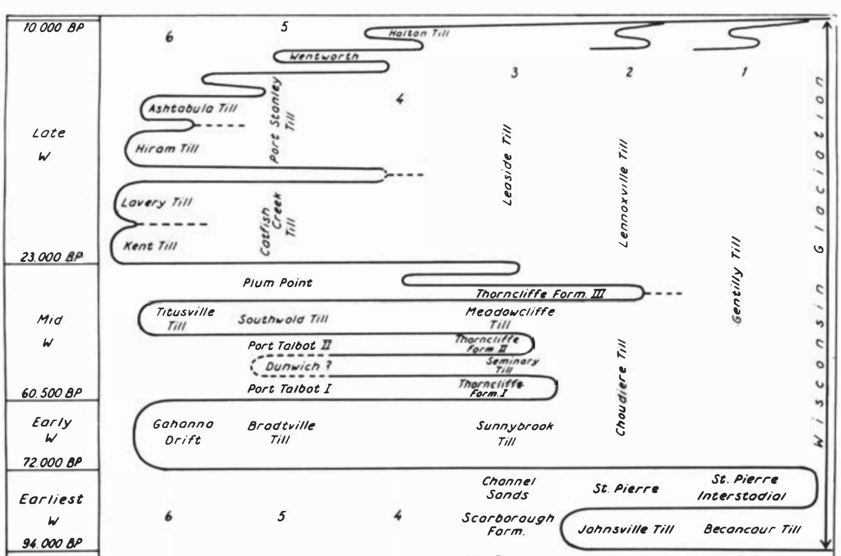

Fig. 10. Weichselian ice-margin fluctuations between the area of ice divide and the Netherlands outside the area glaciated, based on information from ten main areas given in the text (from Mörner, 1972*a*). Confer Figs. 8 and 9.

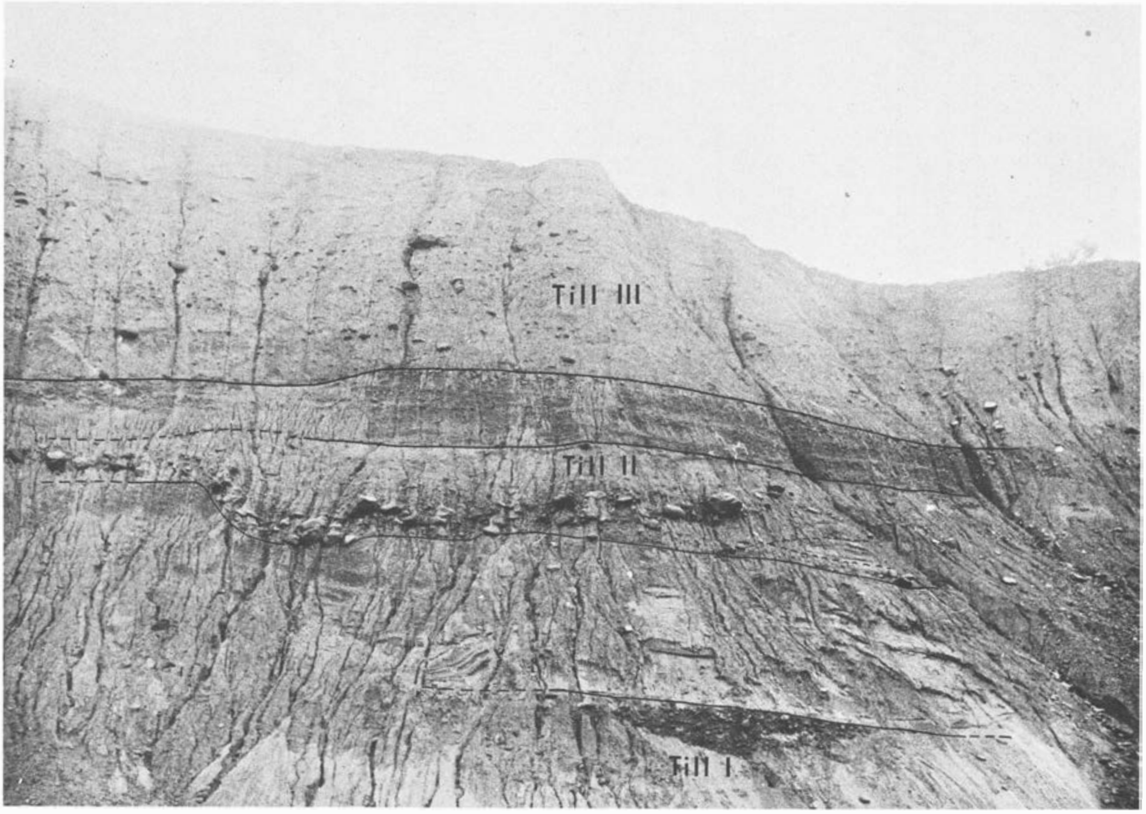

Fig. 11. Complete stratal sequence at Dösebacka: three Weichselian till beds separated by two interstadial beds (see Mörner, 1972*a*).
Till III: The Brandenburg Stadial
Interstadial 2: Proximity to the ice, high sea-level, Arctic conditions
Till II: The Anholt Stadial
Interstadial 1: Ice margin far inland, low sea-level, boreal conditions
Till I: The Pre-Brörup Stadial
Interglacial: Eemian Interglacial conditions

Theoretically, we may assume a constant accumulation of till, giving rise to the section shown in Fig. 13. In reality, however, there are numerous extensive gaps (the till mainly being accumulated at the recession, sometimes at the advance, and in the peripheral areas also at the maximum). Absence of a specific till in a locality does not prove that the corresponding ice stream did not reach over that area. A specific till in one area may not be time-equivalent to the same till in another area; for example, thousands of years may separate a Baltic till in Jylland from a Baltic till in Sjælland. The presence of stratified drift below tills of the same type but not of the same age in two different areas may therefore lead to the false concept of one extensive advance (instead of several minor re-advances or oscillations). Some papers at the Uppsala Meeting called for consideration in these respects.

Fig. 13 is an idealized section from central Jylland eastwards to central Sjælland and northeastwards up across southwestern Sweden, assuming constant accumulation of till. In reality, it is cut by extensive gaps, making correlations merely based on the presence and type of till unreliable. The Late Weichselian ice marginal fluctuations in southern Scandinavia cannot be reconstructed without detailed studies and mapping of the ice marginal lines, which fortunately is made easy by the presence of several distinct stages (Mörner, 1969).

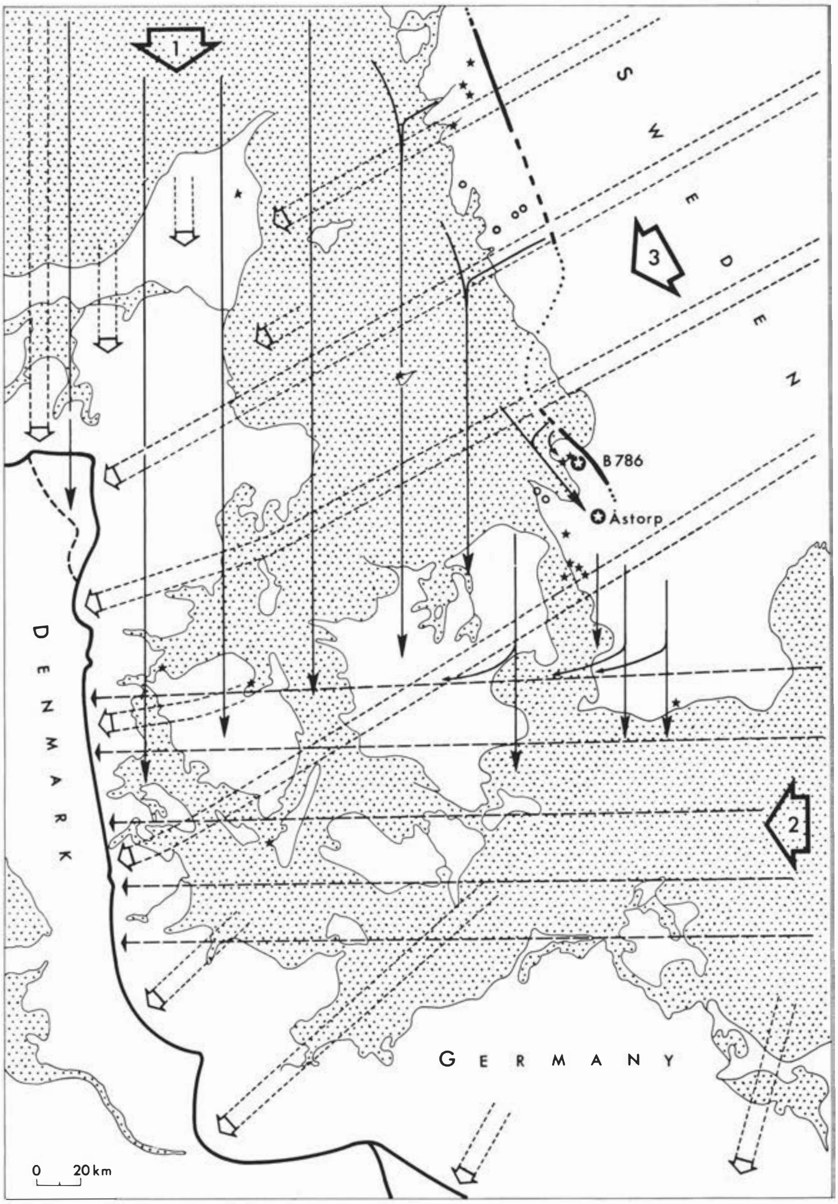

Fig. 12. The Late Weichselian advance was characterized by a competition between three major ice streams: the Norwegian (1), the Baltic (2) and the Northeastern or Smålandian (3) ice streams (from Mörner, 1972*c*). The recession from the maximum extent in Jylland, the C line, was characterized by an analogous splitting up into separate ice streams.

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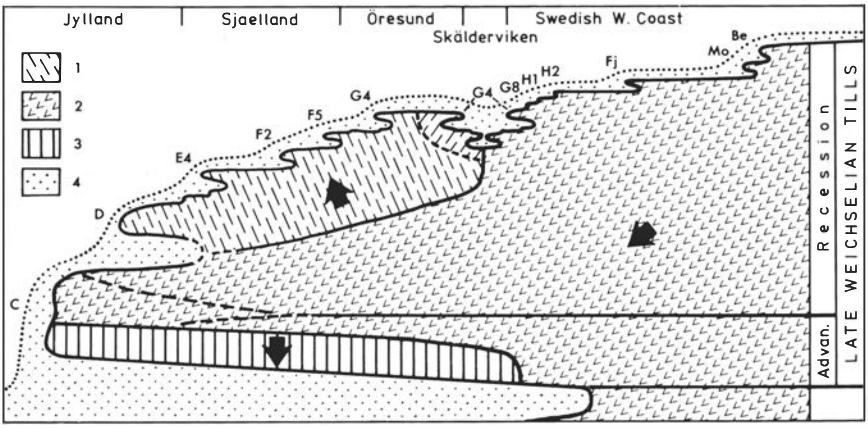

Fig. 13. Idealized section from central Jylland eastwards to central Sjaelland and northeastwards up across southwestern Sweden, assuming constant accumulation of till during the Late Weichselian. Explanation: 1, tills deposited by Baltic ice streams; 2, tills deposited by Smålandian (Northeastern) ice streams; 3, tills deposited by Norwegian ice streams; 4, stratified drift. Arrows show main ice-stream direction. The letters (C, D, E4, etc.) refer to specifically distinct ice-margin lines formed in connection with major halts and/or re-advances (Mörner, 1969). In reality this section is cut up by extensive gaps, making correlations merely based on the presence and type of till unreliable. It should be remembered that the absence of one till does not prove the absence of the corresponding ice stream, that a specific till in one area may not be time-equivalent to the same type of till in another area, and that the presence of stratified drift below tills of the same type may lead to the false concept of extensive advance (instead of several minor re-advances or oscillations).

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