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The Saalian glaciation in the Dutch part of the North Sea

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Abstract

Compilation of available data from boreholes and seismic surveys in the Dutch part of the North Sea has led to a new map of Saale glacial features. The distribution of Saale sediments in this map in combination with the morphology enable a tentative reconstruction of the Saalian ice margin parallel to the Dutch coast. This suggests a revision of recent theories of Saale glacial events based on land data.

Introduction

Since 1969 the Marine Division of the Geological Survey of The Netherlands carried out detailed seismic surveys in the Dutch part of the North Sea. In cooperation with the British Geological Survey the central part of the Dutch sector between 2° and 4° E has been mapped at a scale of 1 : 250,000. In this area features of at least three glaciations have been found (Cameron et al., 1988).

Data from this survey together with available data east of 4° E have been used to compile a map of Saalian glacial features in the Dutch part of the North Sea. These features consist of both sedimentary and morphological elements: fluvioglacial, eolian, glaciolacustrine and diamictic sediments, glacial basins, ice-pushed ridges and tunnel-valleys.

During the coldest phases of the Saale glaciation sea level stood at least 100 m lower than at present (Van Rees Vellinga & De Ridder, 1973; Jelgersma, 1979). Consequently, most of the southern North Sea was dry. The average summer temperature dropped from 20° C during the Holsteinian to less than 5° C during the coldest phases of the Saalian (Zagwijn, 1973).

Saalian deposits

North of about 53° N the Cleaver Bank Formation (Cameron et al., 1986) is wide-spread (Fig. 1). This formation consists of stiff dark brown clay with silt laminae and silts with clay laminae. In the northern F blocks at or near the seabed fine micaceous sands are found locally. In the southern blocks Q1 and Q4 similar deposits are found. However, it is not clear whether these are of Elsterian or of Saalian age. The thickness of the Cleaver Bank Formation varies from 2 to 15 m and it is usually found between 50 and 70 m below Dutch Ordnance Datum (NAP). In glacial basins and valleys it may reach as low as 90 m − NAP, while in the N-blocks (E of Schiermonnikoog) the formation has been found at only 20 m − NAP. The Cleaver Bank Formation is interpreted as a glacio-lacustrine and glacio-fluviatile formation, deposited both during advance and retreat of the ice sheet.

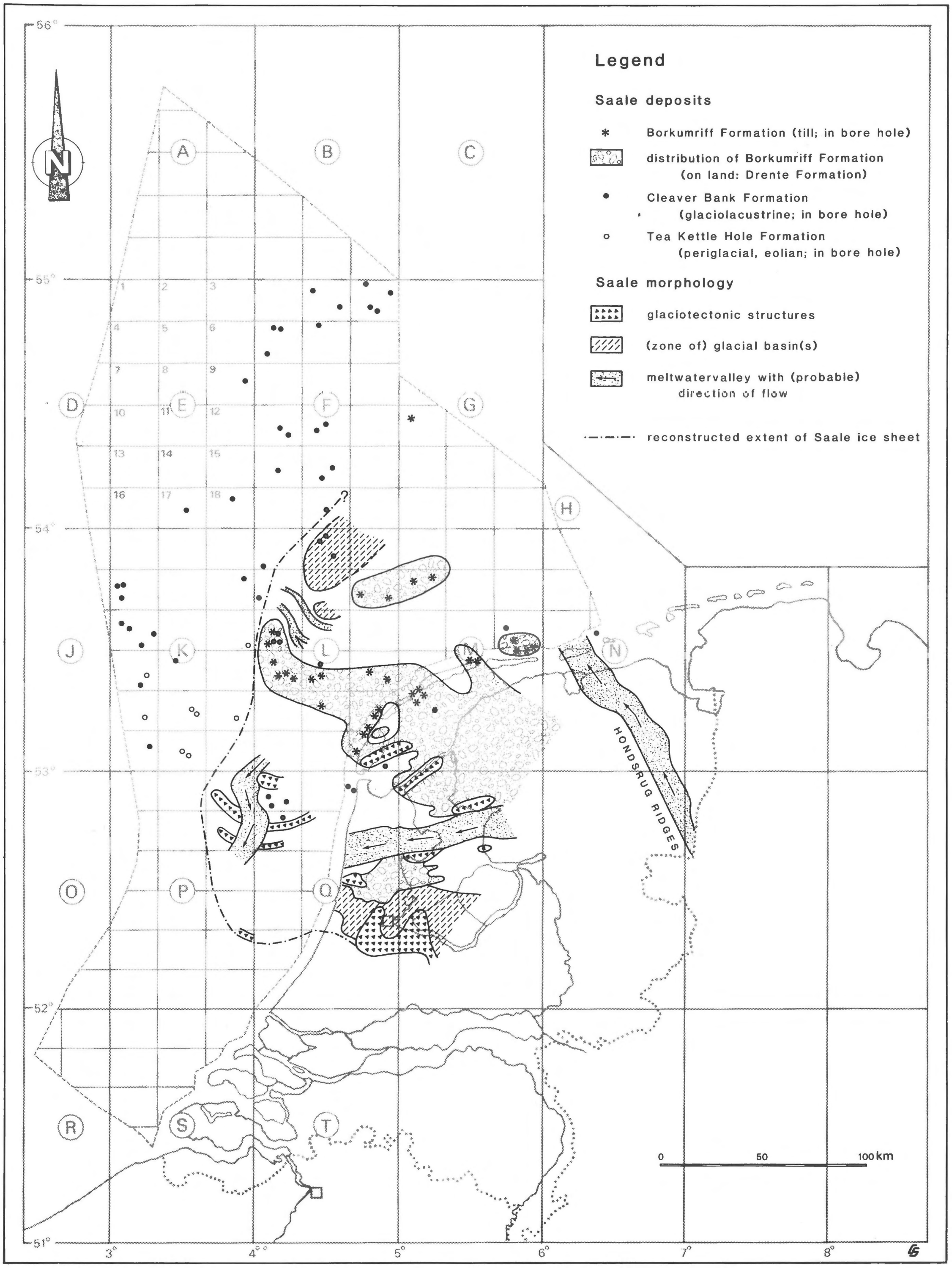

Fig. 1. Distribution of Saale sediments and landforms in the Dutch part of the North Sea; subdivision of blocks indicated in E-block.

West and north of the Frisian Islands a calcareous, sandy loam with pebbles has been mapped (Fig. 1). For this diamicton the new name Borkumriff Formation will be introduced. It is interpreted as a subglacial till and it is the continuation of the gently dipping Drente Till Plateau. Like the Drente Formation on land the thickness is variable: from less than 1 m near the islands of Texel and Vlieland to more than 10 m in block L10. Along the Frisian Islands it is found at a depth of 20 m – NAP, towards the NW it reaches depths of 70 m – NAP in block L7. West of Texel a number of several metres large erratics have been observed on side scan sonar records, as well as by divers (Th. Maarleveld, 1986, pers. comm.). These erratics lie on a bed of fine eolian sands, the Tea Kettle Hole Formation (Cameron et al., 1988). Northwest of this island, in blocks L12 and L14, gravel deposits occur near the seabed. Side scan sonar registrations made by the Directorate North Sea of the Ministry of Public Works, (pers. comm.) reveal some linear gravelly ridges. These ridges show a NE-SW orientation and a similar orientation has been found on the Drente Till Plateau (Rappol, 1987). Comparable gravel deposits have been found in blocks Q4 and Q7. Further studies have to be carried out to assess their mutual relationships as well as their origin. For these (fluvio-glacial) deposits the new name Molengat Formation will be introduced (formal introduction of new formation names in prep. by RGD).

The stratigraphic position of the Cleaver Bank Formation and the Borkumriff Formation can only be treated in relation to the Tea Kettle Hole Formation (Cameron et al., 1988). The latter formation consists of eolian sands, deposited under periglacial conditions. In six boreholes in the southern K-blocks in the Dutch sector (Fig. 1) the Tea Kettle Hole Formation is found between the marine Egmond Ground Formation (Holsteinian) (Cameron et al., 1986) and the marine Eem Formation (Eemian) at a depth of about 50 m below sea level. The formation consists of greyish brown well sorted fine sands with locally lamination of clay and organic detritus. The formation reaches a thickness of up to 6 m. During the Eem transgression much of this formation was eroded (Laban et al., 1984). Recently this formation has also been found west of the island of Texel. Here it locally underlies the Borkumriff Formation and it also occurs near the seabed, only covered by a veneer of Holocene marine deposits. The occurrence of the Tea Kettle Hole Formation underneath the Borkumriff Formation establishes that in the Texel area it predates the latter formation.

Dipping reflectors on the seismic records point to imbricate structures, indicating that the Tea Kettle Hole formation has been influenced by ice-pushing. This pushing must have taken place during a (renewed) advance of the Saalian ice sheet; whereby ice-pushed ridges were formed at geohydrological suitable sites (Van den Berg & Beets, 1988).

The K-blocks were not covered by ice during the Saalian glaciation (Cameron et al., 1988) and deposition of periglacial eolian sands there may have occurred over a longer period.

Morphology

Morphological elements were mainly mapped using seismic profiles obtained with a Sonia 3.5 Kc subbottom profiler system, while also deeper seismic information from a 4.7 KJ Sparker system was used.

The most striking geomorphological elements are some large glacial valleys. The best known valley in the Dutch part of the North Sea runs parallel to the Dutch coast in the P and Q blocks (Fig. 1; see also Oele, 1971; Oele & Schüttenhelm, 1979; Laban et al., 1984). It is between 7 and 10 km wide, and its length is about 40 km. The beginning and end of this valley are not clearly visible on the seismic records.

The shoulders of the valley lie between 25 to 40 m below sea level, and the base of the valley between 55 to 80 m. The valley is cut into the Yarmouth Roads Formation (Cameron et al., 1988). In the valley no deep boreholes have been drilled; only a number of shallow cores and a few 10 metre boreholes are available. A CPT which was made in the valley gives evidence for a thick clay layer on the eastern side. The seismic records at this side

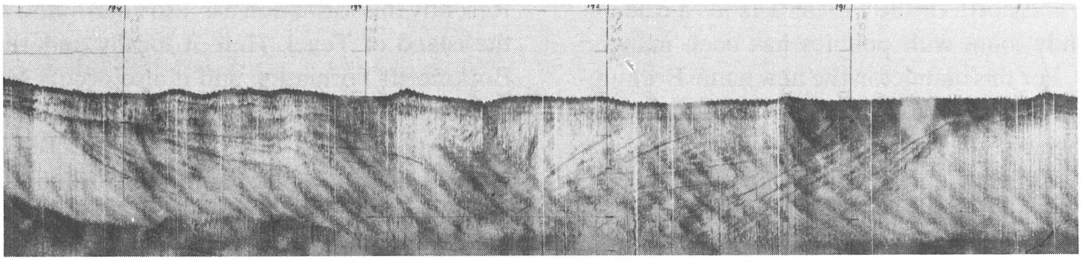

Fig. 2. Seismic profile showing glacial valley cut into the Yarmouth Roads Formation; for location see Fig. 3.

show a number of straight, dipping reflectors (Fig. 2). The clay was probably deposited during the Saalian glaciation, as the valley is incised in pre-Saalian (Holsteinian) deposits. The remaining infill of the valley consists of marine Eemian, Early Weichselian fresh-water clays (Brown Bank Formation) and Holocene sediments in a succession of small channels. Along the valley a set of three ice-pushed ridges consisting of sediments of the Yarmouth Roads Formation are found (Fig. 3), as evidenced by seismic profiles and boreholes. These pushed structures were formed by the Saalian ice-sheet, which implies that the incision of the valley must have taken place after the formation of the ridges. This means that the valley either was formed by an ice marginal meltwater stream, as has been stated by Oele (1971), or as a subglacial tunnel-valley if the ice-pushed ridges were formed during the advance of the ice, whereby the ice overrode the ridges. The enormous size of the valley under discussion shows great similarity with subglacially formed valleys described by e.g. Van Rees Vellinga & De Ridder (1973) in The Netherlands (Gelderland), by Jansen (1976) in the northern North Sea and by Sjørring (1979) in Denmark. This gives support to the latter origin mentioned. One of the main arguments for a subglacial origin of the valleys by meltwater escaping under high pressure, is the fact that they have no gradient. Whether this is the case here, is not certain because the bottom of the valley is not visible on the Sonia profiles. It is certain, however, that there was at least one erosional phase in a later stage of the infill, probably during the Weichselian sea level lowstand.

Except for the tunnel-valley in the P and Q blocks, a system of at least four Saalian tunnel-valleys has been found in the L-blocks (Kok & Mesdag, 1982). This area (see Fig. 4) was mapped by a close grid of deep and shallow seismic profiles. Below the Saalian valleys, systems of Elsterian and Cromerian glacial valleys and basins occur (Kok &

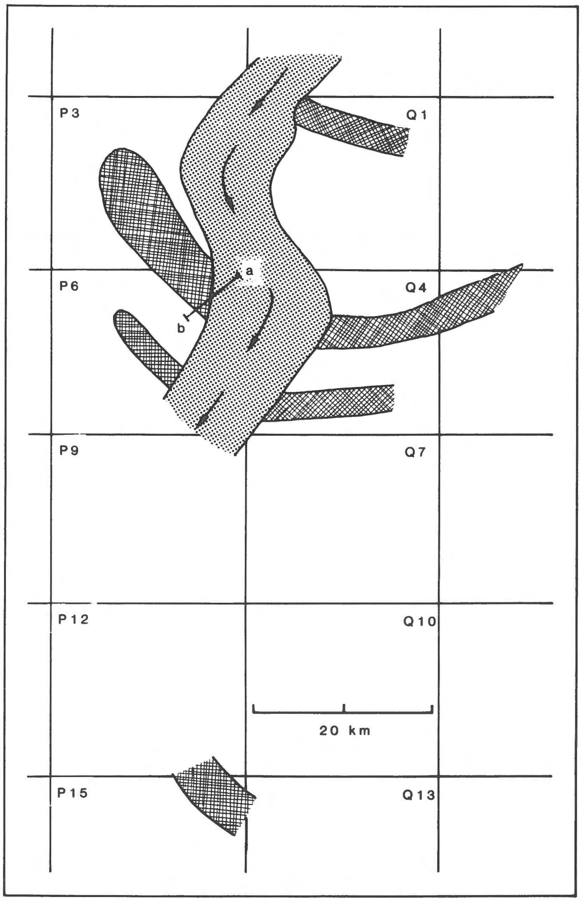

Fig. 3. Glacial valley (dotted) and ice-pushed ridges (hatched) in the P- and Q-blocks; a–b indicates approximate location of profile in Fig. 2.

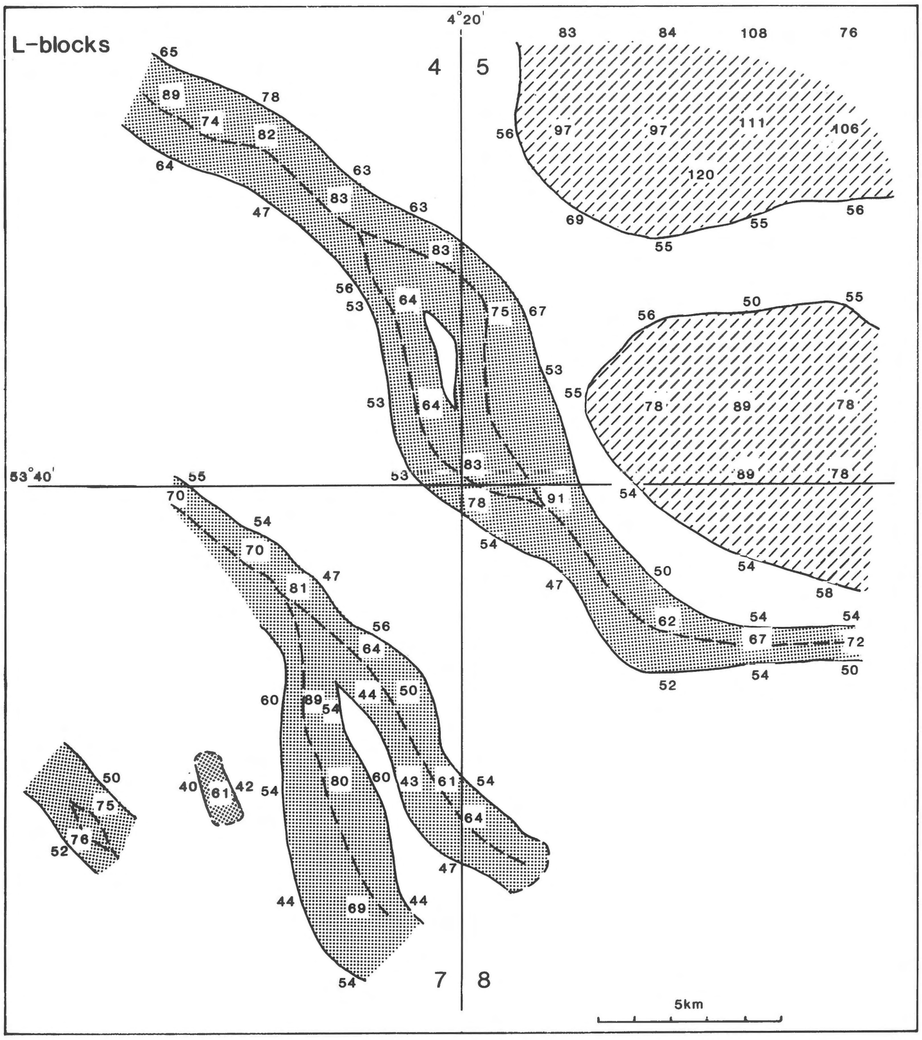

Fig. 4. System of glacial valleys (dotted) and basins (strokes) in the L-blocks; figures indicate depth in metres below sealevel.

Mesdag, 1982). Fig. 4 only shows the major valleys and basins filled with the Cleaver Bank Formation and younger deposits. A geologic profile through these valleys is presented in Fig. 5 (Zagwijn, 1971).

The valleys have a more or less parallel, northwest-southeast orientation. Depth is indicated in metres below sea level and it shows that the top of the Saalian surface lies between 50 and 60 m. The largest valley can be followed for 25 km and continues outside the surveyed area. The smallest feature in L7 cannot be followed for more than 1 to 2 km, and looks more like a local depression. The width of the valleys is about 3 km and the depth is roughly 30 m. The bottoms of the valleys shows no gradient, which probably points to a subglacial genesis by meltwater escaping under high pressure (Jansen, 1976; Sjørring, 1979). The longest valley seems to be divided into two separate valleys, which merge again after about 8 km. At the merging and separation points the greatest depths and widths are found. This is also the case in the longest valley in L7, where two valleys, in separate beds, merge. This deepening may have been caused by the turbulence of meltwater at these locations.

As mentioned above three more or less parallel ice-pushed ridges border the valley in the P and Q blocks (Fig. 3). South of this valley, in block P15, steeply dipping structures are visible on the seismic

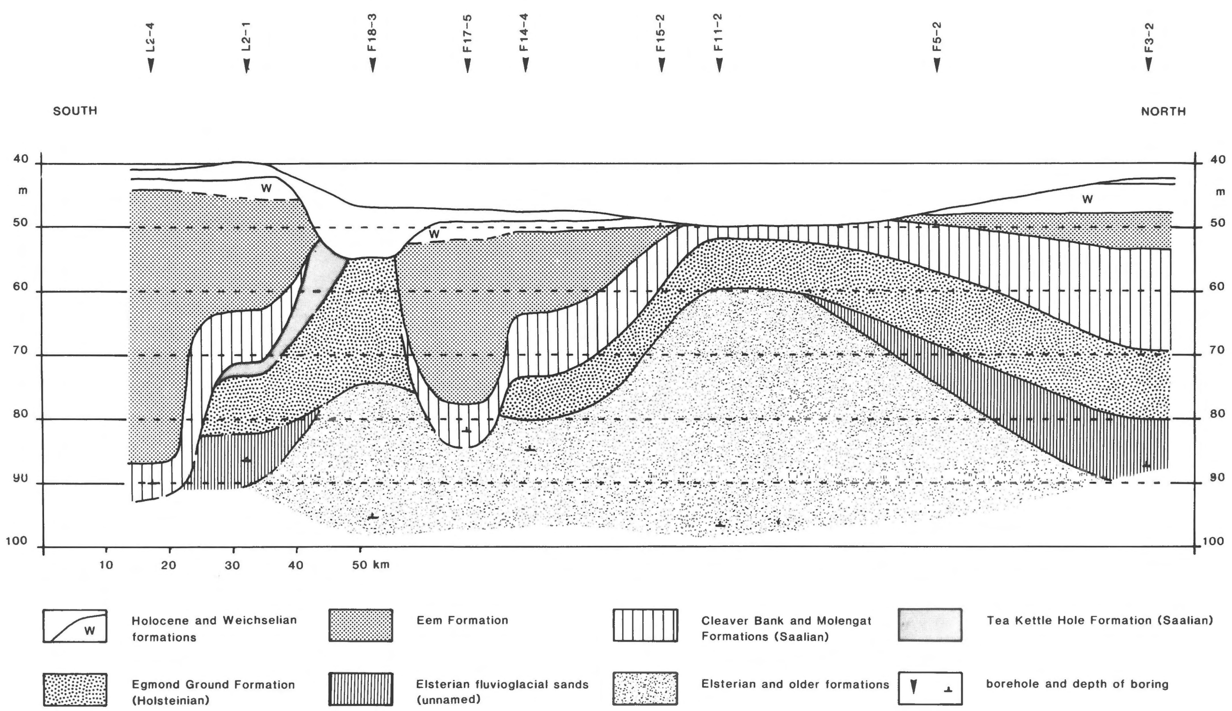

Fig. 5. South-north profile through glacial valley and basins in the L- (and F-blocks) after Zagwijn (1971).

records. Most likely these have also been caused by ice-pushing during the Saalian. Another indication for this is the height of the Yarmouth Roads Formation in this structure: only 9 metres below the seabed. In the surrounding area the top of this formation lies tens of metres deeper (Cameron et al., 1984). Another argument is the location: it is in line with the prominent belt of ice-pushed ridges in the central part of The Netherlands. This belt, which can be followed almost to the coast south of Haarlem, lies only some 30 km away from block P15. The ice-pushed structures in P15 are the southern most glacial features found in the Dutch part of the North Sea.

In blocks L5 and L8 the rims of two glacial basins can be seen on the seismic records (Fig. 4). Here the Saalian surface shows a depression of more than 50 m. The northern basin continues to the north into block L2, where the Cleaver Bank Formation is found in three boreholes at a depth of 70 to 90 m below sea level. The floor of both basins is irregular.

Discussion and conclusions

From the data available in the Dutch sector of the North Sea the maximum extension of Saalian ice can be reconstructed as shown in Fig. 1. Since – west of the line indicated in Fig. 1 – there is no morphological or sedimentary evidence for direct deposition by ice followed by erosion, the idea that the margin of the Saalian ice crossed the southern North Sea cannot be maintained. In the area west of the northern part of Noord Holland the southern margin of the Elsterian ice crossed the southern North Sea (Long et al., 1988) in a southwesterly direction towards Ipswich in Suffolk. At about 4° E the margins of the Elsterian and Saalian ice cross. This makes a definite dating of the ice-pushed ridges west of the valley in the P and Q blocks difficult. If these are of Elsterian age and if the valley is ice marginal then the maximum extension of the Saalian ice was even further to the east than indicated in Fig. 1. If, however, the valley was formed subglacially, then the ridges at the west side are most probably also of Saalian age, and the maximum extension of the ice is as indicated in Fig. 1.

The thickness of the Borkumriff Formation in block L10 (> 10 m) is no surprise. It has been found in what seems to be an extension of the line of thick stratified tills which runs along the southern edge of the Drente Till Plateau (see map accompanying Van den Berg & Beets, 1987). Till thicknesses of more than 10 metres have been recorded at a number of places (Rappol et al., 1989).

Fluvio-glacial deposits as present on land in The Netherlands have not been found. These deposits may have been present on and in front of the ice-pushed ridges but have probably been eroded during the Eemian transgression, which may have had more influence in the North Sea than on land.

The reconstruction presented here does have repercussions for reconstructions of Saale glacial events in The Netherlands. Until recently the model in use presumed an ice advance directly to the southernmost position, followed by four retreat stages (Ter Wee, 1962). Recently Van den Berg & Beets (1987) presented a new model in which only one advance was recognized. The former retreat stages were interpreted as ice-pushed ridges formed during the advance and subsequently overridden by the ice. According to the latter authors, in a later stage of the glaciation a NW-SE oriented ice-stream developed, which accounted for the linear Hondsrug ridges on the Drente Till plateau. However, in order to sustain prolonged flow of the ice-stream a large supply of ice NW of the Till Plateau is a prerequisite. The extension of Saalian ice in the Dutch part of the North Sea presented here (Fig. 1) seems to exclude the presence of such an ice supply. Hence the origin of the Hondsrug ridges, with their strong NW-SE orientation, again is open to speculation.

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