ACTA GEOLÒGICA HISPÀNICA, t. 18 (1983), n.º 3/4, pags. 199-205

Micromorphological and preliminary X-ray observations on a basal till from Lunteren, The Netherlands

by J.J.M. van der MEER, M. RAPPOL, J.N. SEMEIJN

Physical Geography and Soil Science Laboratory,
University of Amsterdam,
Dapperstraat 115,
1093 BS Amsterdam, The Netherlands

ABSTRACT

Undisturbed box samples have been taken from a Saalian till complex and associated shear zone in the Central Netherlands. Microscopic studies of vertical thin sections of so-called mammoth-size (7 x 14 cm) and microdensitometer readings taken from X-ray images reveal amongst others (1) a closely spaced textural banding, (2) the presence of two types of unconsolidated pebbles, i.e. mud pebbles and till pebbles, (3) different types of plasmic fabric, i.e. skel-lattisepic fabric for most of the till matrix and till pebbles and a strong unistrial fabric associated with shear zones. The present observations are in accordance with earlier macroscopic field and laboratory studies, indicating till formation under conditions of continuous subglacial shearing, by which much local material is reworked as well.

RESUM

S'han pres mostres sense distorsionar del complex de till Saalià i de la zona de trituració associada a la part central dels Països Baixos. Els estudis microscòpics amb làmina prima del terreny anomenat "mammoth" (7 x 14 cm) i les lectures microdensimètriques de les imatges de raigs X, mostren entre altres coses: (1) un bandat estructural molt apretat, (2) la presència de dos tipus de còdols tous, còdols de fang (mud pebbles) i còdols de till (till pebbles), (3) diferents tipus de fàbrica, com són la fàbrica "skel-lattisepic" a la majoria de matrius de till i en els còdols tous de till, i la fàbrica fortament "unistrial" associada a les zones de trituració. Aquacions encaixen amb els estudis anteriors macroscòpics de camp i de laboratori, i mostren la formació de till sota condicions de trituració contínua subglacial per lo qual trobem tanmateix molt de material local retreballat.

RESUMEN

Se han tomado muestras sin distorsionar del complejo de till Saaliense y de la zona de trituración asociada en la parte central de los Países Bajos. Los estudios microscópicos en láminas delgadas del tamaño llamado "mammoth" (7 x 14 cm) y las lecturas microdensimétricas de las imágenes en rayos X, revelan entre otras cosas: (1) un bandeado estructural muy apretado, (2) la presencia de dos tipos de cantos blandos, cantos de barro (mud pebbles) y cantos de till (till pebbles), (3) distintos tipos de fábricas, como son la fábrica "skel lattisepic" en la mayoría de matrices de till y en cantos blandos de till, y la fábrica fuertemente "unistrial" asociada a las zonas de trituración. Estas observaciones encajan con anteriores estudios macroscópicos de campo y de laboratorio, demostrando la formación de till bajo condiciones de continua trituración subglacial con los que encontramos mucho material local también retrabajado.

INTRODUCTION

A sequence of glacial deposits has been exposed for a number of years in sandpit "Vink" in the Goudsberg, near Lunteren (fig. 1). The Goudsberg forms part of a system of Saalian ice-pushed ridges in the Central Netherlands. The lithostratigraphy and genesis of the deposits have been described by Van der Meer et al. (in press). The sedimentary sequence consists of ice-pushed preglacial deposits overlain by two fluvioglacial deposits separated by a till complex. The till complex consists of two basal till increments of different petrographic and textural composition, i.e. a flint-poor upper till and a

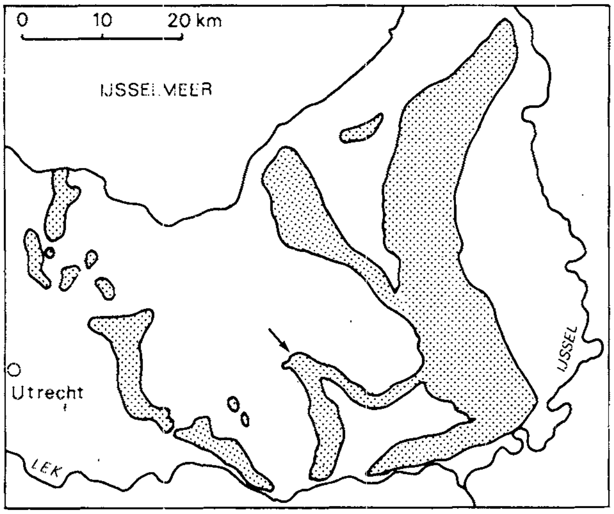


Figure 1. Position of pit "Vink" and the Goudsberg (arrow) in the Central Netherlands. Ice-pushed ridges shaded.

flint-rich lower till. It is underlain by a shear zone and overlain by an ablation till and resedimented till material.

One of the methods to study the till complex was by use of mammoth-sized thin sections (7 x 14 cm). These were collected from the shear zone and the till at a number of sites in the pit (fig. 2). For this study only "vertical" samples were collected, meaning that the plane of the thin sections is vertical with the longest axis generally in a vertical position. They were studied using a polarizing light microscope.

The same samples were used for X-ray analysis. This was done by making X-ray photographs of the rejects of the thin sections (thickness 9-10 mm).

To obtain the X-ray photographs we used a Macro-B tank, employing a tube current of 4 mA., a voltage of 20 KV, an exposure time of ca. 10 minutes and a distance of 70 cm. between tube and film (Agfa curix). The differences in density of the grey tones on the X-ray film have subsequently been measured by use of a microdensitometer.

In this paper we will present some examples of the observed features in the thin sections as well as some notes on the X-ray images. In describing the microfabric characteristics of the thin sections we used Brewer's (1976) classification. Although this classification was originally developed for pedological studies, it can be used for sedimentological studies as well. Pedologists have studied the pattern of the plasmic fabric for a long time and developed a sophisticated classification. In our opinión this plasmic fabric should be considered as complementary to macro- and microfabric.

Description of the shear zone and the lower basal till

The till complex floors a basin with a length of some 300 m and a width of about 250 m (fig. 2). This basin could be a primary feature of the surface of the original ice-pushed ridge. The ice-pushed preglacial deposits underlying this basin indicate that the directions in which the glacier lobe exerted pressures varied between S and W. Fabric analysis indicates an ice movement towards the SE during deposition of the till, which is more or less parallel to the trend of the ice-pushed ridge. This suggests lateral pushing of the ridge followed by subsequent overriding.

The shear zone below the till consists of massive to faintly banded gravelly sand of local origin overlying either fluvioglacial or ice-pushed fluviatile deposits. The zone is up to 1.5 m thick. In the central part of the pit, silt/clay rhythmites form a distinctive element of the shear zone. The layer of rhythmites has a maximum thickness of 15 cm. It may be present in the upper part of the massive bed, at the base of the lower basal till as well as within it. Partly these rhythmites have been remarkably well preserved, indicated e.g. by the preservation of ice-needle casts, partly however they have been strongly deformed and incorporated in the till (fig. 3; see also fig. 17 in Van der Meer et al., in press).

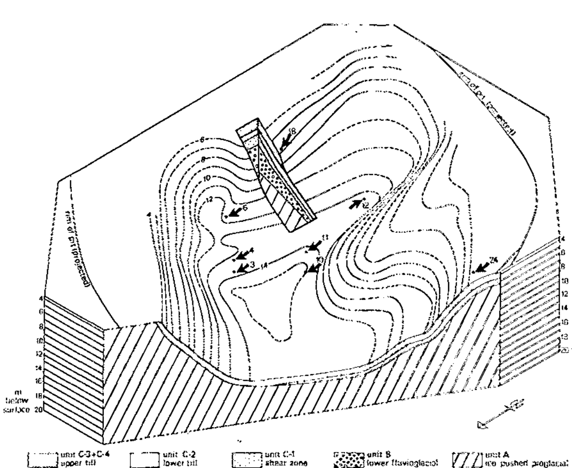


Figure 2. Block diagram with contours of the top of the till complex (upper fluvioglacial deposits omitted) in the "Vink" pit. Site numbers refer to those used in Van der Meer et al., (in press).

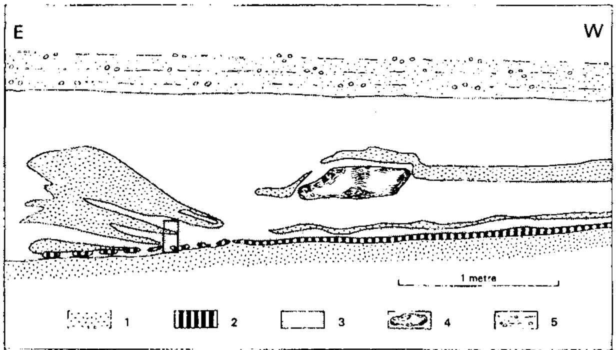


Figure 3. Till profile near site 12, with position of thin section R747 indicated (rectangle). Ice movement towards SE/SSE. 1. shear zone and intra-till sheared sand, 2. silt/clay rhythmites, 3. till, 4. boulder, 5. upper fluvioglacial deposit.
The layer of silt/clay rhythmites is disrupted in the left-hand part of the figure. Internal structure of one of the clasts is given in Plate IG.

The lower till generally overlies the shear zone with a sharp transition. It is a predominantly sandy diamicton with a relatively constant thickness between 0.5 and 1.0 m. It is characterised by a compositional layering (banding) showing in the field through differences in colour. This layering is the result of differences in grain-size and petrographic composition, due to differences in the amount of preglacial and/or fluvioglacial material incorporated in the till by subglacial shear deformation. The successive till bands contain a variable amount of small fine grained unconsolidated pebbles which can be easily discerned macroscopically.

PREVIOUS WORK

Few papers have been published exclusively on the subject of till micromorphology, while some additional references on the use of thin sections in till studies can be found in other works. Most of these only describe the orientation of elongated coarse silt and sand grains (sometimes called "microfabric") determined in thin sections, sometimes in comparison to clast fabric (e.g. Harrison, 1957; Ostry & Deane, 1963; Evenson, 1970).

Sitler & Chapman (1955) consider three aspects of the microfabric of fine-grained till S of Lake Erie, U.S.A., i.e. (1) microfoliation, which refers to the preferred orientation of platy and elongated silt-sized grains, (2) coarse fragment orientation, being usually parallel to microfoliation, and (3) vein structures, being narrow zones in which the parallel orientation of silt flakes is better developed than in the microfoliation, and interpreted to represent sharp flexures in the microfoliation. According to Sitler (1968) the microfoliation trend parallels ice movement.

Microfoliation was also described by Johnson (1983) from a fine-grained till in Wisconsin, where microfoliation trends are predominantly perpendicular to the direction of ice movement. The microfoliation bands dip upglacier and seem to be related to shear zones.

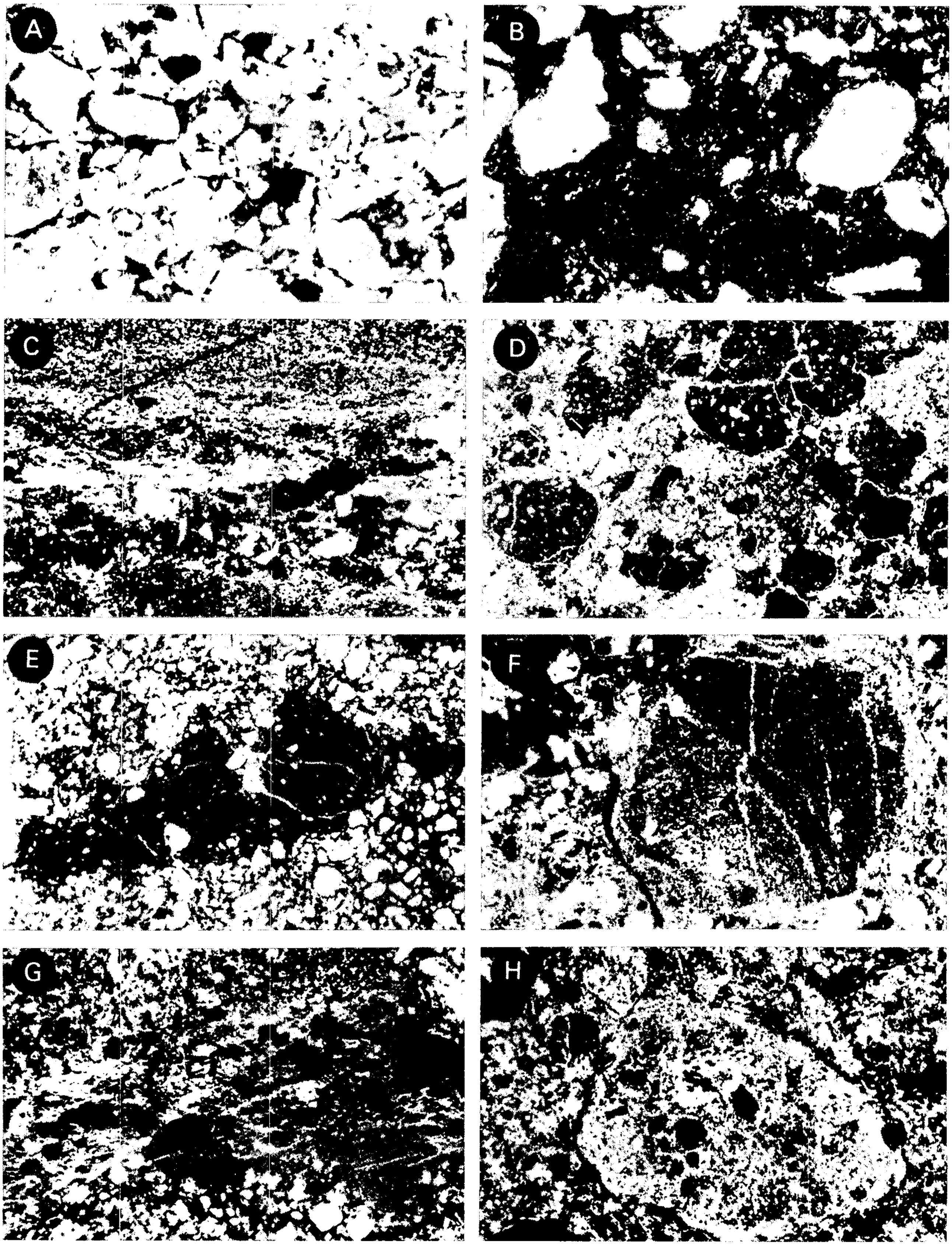
Korina & Faustova (1964) describe microfabric characteristics of a subglacial till from the Russian plain. These authors found a good correlation between the orientation of elongated sand grains and supposed ice movement. The plasmic fabric, however, shows "prependicular fibrous (reticulate) and criss-cross fibrous textures... sometimes superseded by fields of oriented clay, 400-800 mμ in size" (Korina & Faustova, 1964: p. 334). They also mention the concentric orientation of clay particles around sand grains, previously described by Sitler & Chapman (1955). The same microfabric characteristics were reported from SE Drente, The Netherlands (Rappol, 1983). In Brewer's (1976) classification «skel-lattisepic fabric» refers to these plasmic fabric characteristics. It may contain unistrial domains.

Van der Meer (1982) describes the plasmic fabric of basal till from the Swiss plain as silasepic to argillasepic, implying poorly recognisable plasma separations, here probably due to low clay content and high carbonate content.

X-ray analysis is frequently used in sedimentological studies to detect structural features in apparently massive sediments (e.g. Hamblin, 1962; Edmondson & Allison, 1970), but has hardly been used in till investigations. Liboriussen (1973) used X-ray radiographs in long-axis fabric analysis of oriented till samples.

1 *Micromorphological observations*

The investigated till is strongly dominated by sand- to clay-sized particles (over 95%), but large variations are present in the relative distribution of the sand-silt-clay fractions. These variations are mainly distributed in a banded configuration reflecting differences in the nature and amount of assimilated local materials. In relation to the compositional layering observed macroscopically fabric properties may vary greatly between successive till bands. Sandy bands are often sand-supported and may contain a high portion of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packing voids. In sandy till bands with a semi-open framework (Plate IA), the mud-sized material is mainly present along the sand-grain surfaces (chlamydic fabric: Brewer et al., 1983).

In dense, silt- and clay-rich till bands (porphyric fabric), the basic plasmic fabric is skel-lattisepic, sometimes with unistrial domains. The lattisepic fabric consists of short and discontinuous plasma orientations (Plate IB), usually oriented at right angles to each other. Plasma separations following coarse fragment surfaces are common, hence the prefix skel (eton grains).

In soils, the skelsepic fabric is generally attributed to swelling pressures against the surface of skeleton grains due to wetting and drying (Brewer, 1976). According to Lafeber (as mentioned in Brewer, 1976: p. 339) skelsepic fabrics may result from rotation and/or translocation of skeleton grains under pressure; on a restricted scale, these processes can also account for lattisepic fabrics. Sitler & Chapman (1955) conclude that their microfoliation, including that encircling the coarse fragments, was produced chiefly by "rotation and packing due to intergranular movement in the till". As we lack information on the plasmic fabric characteristics in horizontally cut thin sections, we cannot contribute to the discussion concerning this matter; it would be important to know whether these would show a unistrial fabric (microfoliation) or not.

Strong unistrial fabrics (Plate IC) were only observed in narrow fine-grained shear zones associated with macroscopically identified intra-till shear planes (Van der Meer et al., in press, figure 16 and 31), and within some of the mud pebbles (see below) (stress cutans, Brewer, 1976). Subglacial shear deformation seems therefore the primary cause for strong preferred orientation of the plasma in such cases (see also Johnson, 1983).

In most thin sections pebbles of unconsolidated material can readily be identified. These are not distributed uniformaly throughout the till, but some till bands may contain only few, while others are loaded with them (Plate ID). The pebbles range in dimension mainly between 3 and 5 mm. Cross sections of the pebbles are of variable shape, but mainly circular to oval. Some pebbles are highly prolate and/or of irregular shape (Plate IE) suggesting attenuation due to subglacial shear.

On account of textual characteristics two types of pebbles can be distinguished, although transitional varieties occur. The first type consists of clay and fine silt only (mud pebble). The whole pebble is commonly strongly birefringent, with domains of different orientation (Plate IF). Textural characteristics of these pebbles are similar to those of the silt/clay rhythmites, although the bedding characteristics are generally completely obscured. The thin sections obtained at the site described in fig. 3 provided a good view on the origin of these mud pebbles. A large clast of disrupted and deformed rhythmites showed an internal structure consisting partly of angular "pebbles" separated by faults (Plate IG). Other pebbles are more rounded with oriented domains surrounding the internally hardly deformed material. These observations suggest mud pebble formation due to brecciation and subsequent rotation of material derived from the silt/clay rhythmites. During deformation coarser grained material is introduced in the fine-grained material, and continuation of these processes may lead to the formation of pebbles transitional to till pebbles (see below). Mud pebbles have been observed within till pebbles.

The second type of pebble consists of a mixture of silt, clay and sand, generally evenly distributed, and different from the surrounding till by a finer texture. These till pebbles have plasmic fab-

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Plate I. Photomicrographs showing details of the thin sections. A) Very sandy till band, with little mud-sized material present along grain boundaries and small voids. Thin section R747 (site 18), 1 nicol, 25 x. B) Porphyric fabric of till, consisting of sand grains embedded in a matrix of mud-sized material. Plasmic fabric of matrix displayed in lower part of photo as a weakly developed lattisepic fabric, with skelsepic fabric shown as lighter zones around sand grains. Thin section R748 (site 18), 2 nicols, 62.5 x. C) Detail of shear zone, showing textural banding and strong unistrial fabric in clayey and silty layers. Thin section R745 (site 4), 2 nicols, 25 x. D) Mud pebbles (more or less homogeneous black to grey areas) and till pebbles rich in mud-sized material in predominantly sand-supported till with few voids. Thin section R669 (site 11), 1 nicol, 5 x. E) Attenuated till pebble embedded in mostly sand-supported till. The pebble is seen to be nearly torn in two. Thin section R748 (site 18), 1 nicol, 10 x. F) Mud pebble in dense till, showing stress cutan along its surface. Thin section R656 (site 11), 2 nicols, 24 x. G) Detail of unconsolidated clast derived from the layer of silt/clay rhythmites (see fig. 3 for position of the thin section). The photo shows the internal brecciation of mud clasts producing many angular and rounded mud pebbles separated by areas of strong clay orientation. In the lower part of the clast many parallel shears (light streaks) can be seen. Thin section R747 (site 12), 2 nicols, 5 x. H) Internal fabric of till pebble with well developed stress cutans along its auter surface. Internal plasmic fabric is skel-lattisepic. Thin section R669 (site 11), 2 nicols, 18 x.

ric characteristics similar to those of the surrounding till material, although unistrial domains tend to be more common (Plate IH). Both types of pebbles often show an oriented plasma domain along their outer surface, suggesting transport by rotation.

The presence of both pebble types is taken as evidence for continuous reworking of the till and associated sediment by subglacial shear deformation. On the other hand, the often well-rounded cross-sections of many pebbles poses a problem; the presence of these is sometimes taken to be a diagnostic feature for resedimented till deposits formed by mass movement processes. All circumstantial evidence, however points to a subglacial origin for the till discussed here (see Van der Meer et al., in press), which includes clast-fabric characteristics and large-scale deformation structures. Moreover, the internal fabric of the mud pebbles suggests a penetrative deformation rather than transport by rotation only.

Some diagenetic features have been observed as well. The sandy parts of the till display clear evidence of clay translocation through the presence of continuous, strongly oriented clay cutans (ferriargillans), which partly fill up pores and form bridges between sand grains. Clay translocation is commonly regarded as evidence of soil formation. Some of the thin sections with clay cutans were collected at more than 15 m below the surface of the ice-pushed ridge, excluding formation due to near-surface soil-forming processes. Clay translocation is a process occurring under certain physicochemical conditions which can easily apply to unconsolidated sediments. Likewise, iron compounds were observed enriched in some thin, dense fine-grained till bands and is small nodules, apart from being a conspicuous element of the ferriargillans.

Zandstra (1974) mentions the presence of calcareous as well as decalcified till in the "Vink" pit. During our surveys, however, we only found decalcified till. The effect of decalcification on the fabric characteristics may be variable, but difficult to assess. From the northern Netherlands decalcified tills are known to be characterised by the presence of many rounded voids, representing the spaces originally occupied by calcareous clasts. At other places decalcified till does not show such voids, suggesting collapse (Rappol, 1983). In the latter cases, the till is generally strongly oxidised and exposed well above the groundwater table. At Lunteren such voids have not been observed either. In the thin sections studied here, irregular voids are however common, but their origin as a result of dissolution followed by partial collapse must remain uncertain. But then, carbonate content of flint-rich till in the Netherlands is generally low (some 2-7%), and decalcification may only have a limited effect on the total till fabric.

NOTE ON THE X-RAY ANALYSIS

Especially in order to study the banding of the till, rejects of several thin section samples were used to obtain X-ray images. Differences in density are revealed on the X-ray film, which have subsequently been measured by use of a microdensitometer.

Fig. 4 shows the X-ray image of the shear-banded till at Lunteren. On this positive print, sandy bands and cracks show up in lighter tones, dense clayey till bands are dark. Granules and pebbles are revealed in a wide range of grey tones, depending on their minerological composition (Edmondson & Allison, 1970), while their longest dimensions generally parallels the banding. Many of the pebbles are probably mud and till pebbles.

The compositional layering of the till as observed macroscopically in the field, appeared to be much more intricate in the thin sections. The microdensitometer readings shown in fig. 4 illustrate the close spacing of compositionally different till bands. The very small fluctuations in the curves (on the mm-scale and smaller) however, should not

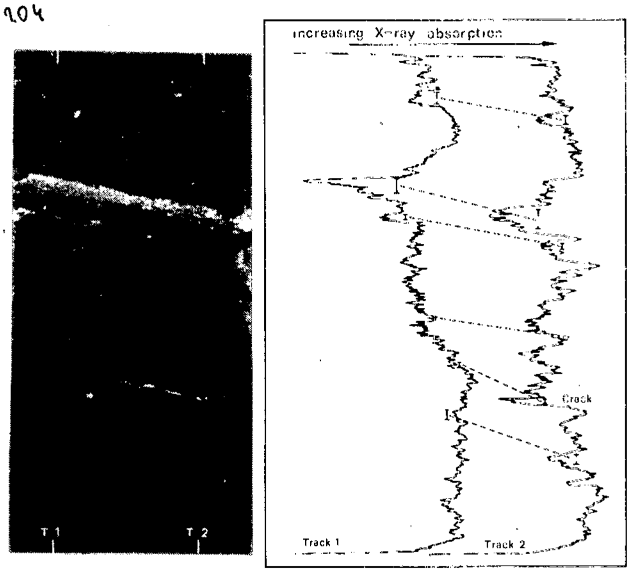

Figure 4. X-ray radiograph (positive print) of the reject of thin section R748 (site 18) and two microdensitometer curves of the negative film. Textural banding clearly displayed in both figures, where sandy bands show up in light tones and low absorption of X-rays. Approximately 0,5 × true Scale.

be interpreted as banding. Comparison with similar curves given by Axelsson & Händel (1972) and Karlén (1981) indicates that such fluctuations are a normal feature of such curves. These may possibly result from small voids and single-grain anomalies.

CONCLUSIONS

Thin section and X-ray analysis may provide valuable information on structural and textural characteristics of till. Macroscopic field studies and previous laboratory analyses did not reveal the presence of two different types of unconsolidated pebbles in the till, nor the intricacy of the compositional layering. The present observations sustain our earlier conclusion that the till was formed under conditions of continuous subglacial deformation by which a considerable amount of local material is reworked as well (Van der Meer et al., in press). Local material seems incorporated predominantly by deformational processes, while the presence of till pebbles of a finer texture than the surrounding till material suggests reworking of till as well. Such till pebbles have not been observed in till at other localities in the Netherlands, where petrographical-/textural analysis indicated a considerable reworking of local material.

ACKNOWLEDGEMENTS

The authors wish to express their sincere thanks to Mrs. O.M. Bergmeijer-de Vré, Mr. C.J. Snabilié and Mr. H.J.M. van Maaren for producing the figures and reproductions; to Mr. B. de Leeuw for making the X-ray and microdensitometer reading; to Mr. C. Zeegers for preparing the thin sections andto Drs. H.J. Mücher for discussions on the nature of certain micromorphological features. Mrs. M.C.G. Keijzer-v.d. Lubbe kindly typed the manuscript.

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