Eclogae geol. Helv.	Vol. 73/3	Pages 839-854	8 figures in the text and 1 table	Basle, November 1980

Different types of wedges in deposits of Würm age from the Murten area (Western Swiss Plain)

By JAAP J. M. VAN DER MEER[1])

ABSTRACT

Three different types of wedges were observed in Würmian deposits in the area northwest of Fribourg. Of these three the type one wedges are interpreted as fossil permafrost soil wedges, indicating a maximum mean annual air temperature of −6 °C during their formation, possibly between 30,000 and 25,000 BP. The type two wedges appear after all not to be real wedges, but glacitectonically distorted varve-like beds, sometimes having a wedge-like form. The type three wedges differ from the first two types in position and also in their filling. They consist of till instead of vertically oriented fine laminations. They are interpreted as till wedges as defined by DREIMANIS (1969).

ZUSAMMENFASSUNG

Drei verschiedene Typen von Keilen sind in würmzeitlichen Ablagerungen nordwestlich von Freiburg beobachtet worden. Von diesen drei sind Keile vom Typ 1 als «fossil permafrost soil wedges» interpretiert, was auf eine maximale mittlere jährliche Lufttemperatur von −6 °C während ihrer Entstehung hinweist, vermutlich zwischen 30000 und 25000 Jahren vor heute. Der 2. Typ hat sich nachher nicht als richtiger Keil erwiesen. Es sind glazitektonisch deformierte warvenartige Ablagerungen, die vereinzelt eine richtige Keilform haben. Der 3. Typ unterscheidet sich von den beiden ersten in Position und Füllung. Statt einer feinen Vertikallaminierung haben diese eine Grundmoränenfüllung. Sie werden interpretiert als «till wedges» nach der Definition von DREIMANIS (1969).

1. Introduction

While studying Quaternary deposits in the Murten area different types of wedges were found in five gravel pits. At first several of these wedges were thought to be frost wedges of Late Glacial age (VAN DER MEER 1976). Some of these have been described (VAN DER MEER 1979), but no indication of their genesis was given. Macro- and microscopical studies of these wedges resulted in a reassessment of their age and partly of their genesis.

Type one: General description

In all five gravel pits (Fig. 1) wedges of type one have been found. They occur in sand and gravel deposits, with some intercalated varve-like beds. These are considered to be sandur deposits, belonging to the waxing phase of the last glaciation. Although the wedges are not in all pits visibly capped by till, the hosts in which they

[1]) Fysisch Geografisch en Bodemkundig Laboratorium, Dapperstraat 115, NL-1093 BS Amsterdam, The Netherlands.

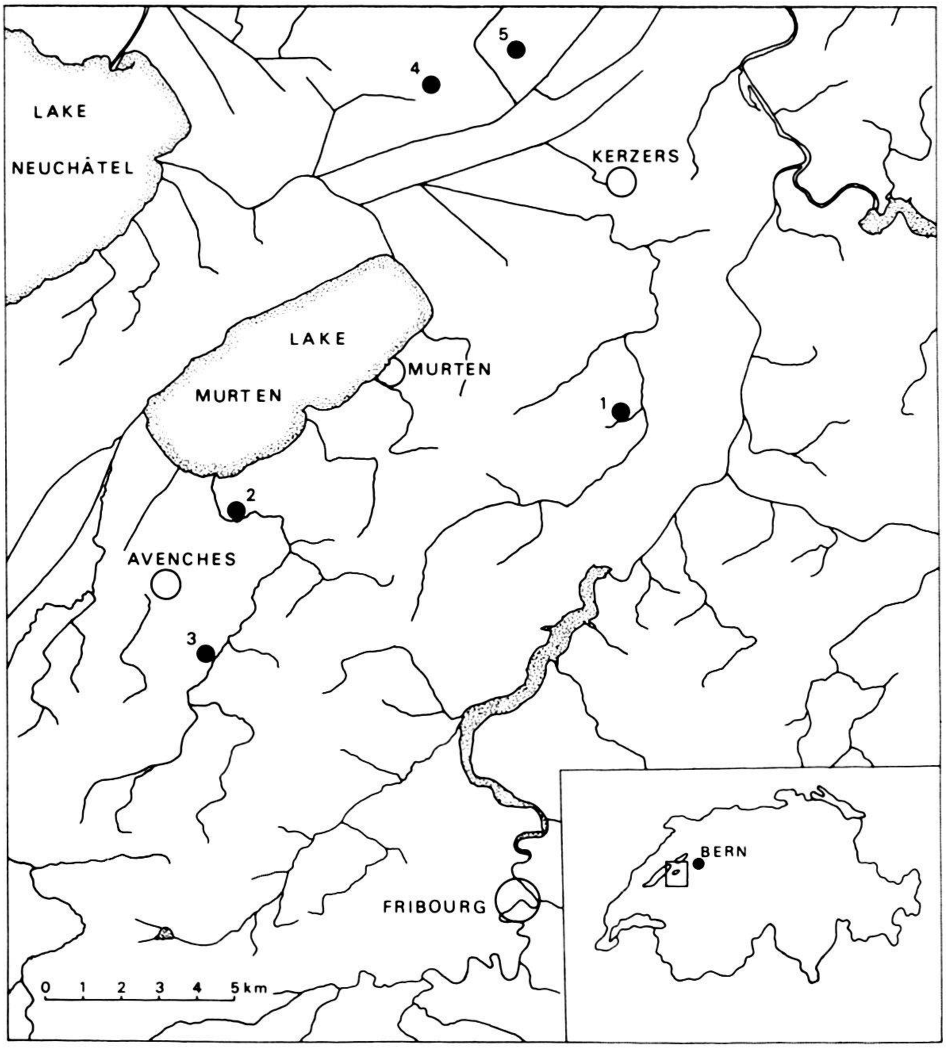

Fig. 1. Location of the five gravel pits where wedges were found.

occur do. The till is either a flow-till or a lodgement-till. Type one wedges cut more or less vertically through the sand and gravel beds. At the transition of beds of different texture they sometimes take a more horizontal position before cutting through the next bed. In these cases they sometimes show offshoots.

The beds that are cut be the wedges show neither upturning nor downturning at the contact with the wedges. Only in the Müntschemier pit a gravel bed was observed that had been slightly upturned where a wedge cut its upper boundary obliquely (Fig. 2).

The shape of the wedges differs, some of them are wide at the top and are tapering downwards. The others have a more regular width over most of their length, only to become thinner near their lower end; these might be called fissures. The filling consists of fine laminae of sand, silt and clay with some strings of fine gravel. These laminae are not continuous for the full length of the forms, but cut each other obliquely. They do however follow the general trend of the wedges. The filling of the wedges has also been studied in thin sections (see below) and for their pollen content (see below).

Type one: Description of the individual wedges

No. 1: In a now abandoned gravel pit, south of Ulmiz, a single type one wedge has been found (1971). The pit is situated along a postglacial valley and where the wedge was found the till and the top of the gravel have been eroded. The wedge has a length of about 4 m and a width of 20 cm and is cut off by slope and soil profile. It is no longer exposed. A sand and a gravel bed are cut by the wedge which starts in a vertical position, to take a more horizontal position in the gravel bed. On top of the gravel bed an offshoot of the wedge follows its top.

No. 2: In the gravel pit of Faoug, now also abandoned, a single wedge was observed (probably the same) in 1971 and again in 1978. The upper part of the wedge could not be reached, but it seemed to disappear before reaching the overlying till. This might be due to an oblique cutting of the wedge by the pit face. This wedge was rather simple in outline, cutting through gravel and sand beds with slight changes in inclination. It did not show any offshoot. The total depth was about 5 m and the maximum width 10 cm.

No. 3: In a gravel pit southeast of Donatyre (VAN DER MEER 1979) only recently abandoned one large and probably several small wedges were studied. The wedge, with a minimum depth of 8 m and a maximum width of 60 cm, was the largest one studied. Its lower end could not exactly be determined, because it ended horizontally in a varve-like bed. No visible relation existed between the large and the smaller wedges. The latter occurred at different levels in the gravel. The top of the large

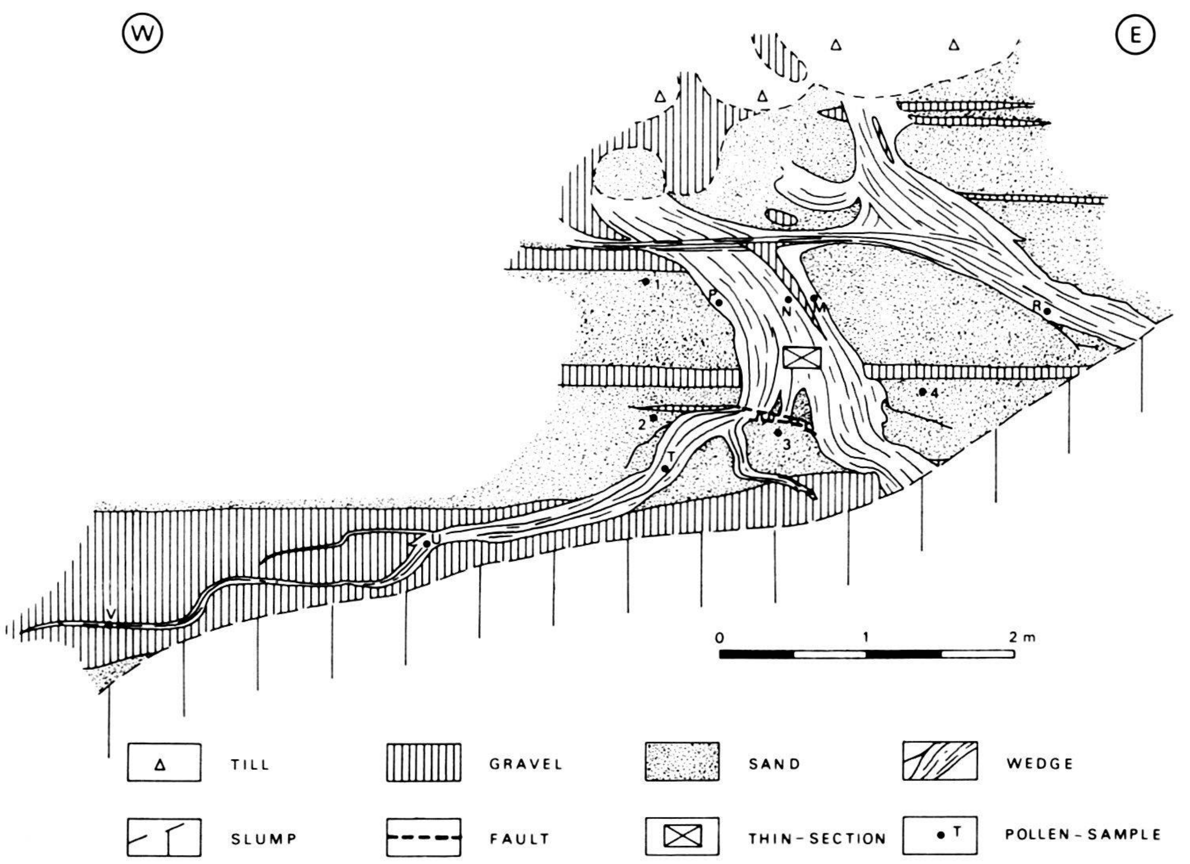

Fig. 2. Gravel pit 4; west of Müntschemier: type one wedge(s). No vertical exaggeration.

wedge seemed to be cut off by a thick varve-like bed. About 1 m above this varve-like bed several meters of till had been removed by dredging operations. The wedge could not be located in the horizontal plane formed by the dredging. So it seems to end within the gravel deposits.

No. 4: One of the most interesting gravel pits is located west of Müntschemier (VAN DER MEER 1979). Not only one or two type one wedges could be studied, but only here type two wedges were found. The type one wedge (Fig. 2) consisted of two distinct parts or may be the pit face is located near the connection of two wedges. One of these was fully exposed. This may also be only an offshoot though because about 1 m below its upper end it splits into two, the right half of which disappears below the slump. Some 15 cm below this splitting the left hand part is cut by a double fault along which a slight displacement occurred. This is probably due to glacier overriding. The fully exposed (depth 7 m, maximum width 75 cm) left hand wedge is connected to the right hand one by a laminated horizontal band, which cuts through the left hand wedge (top of Fig. 3) and disappears, the laminae turning downwards in the right-hand wedge. The sediments around this wedge or, connection of wedges, form a bulge in the underside of the till. Laterally the wedge could only be studied over a short distance, because the pit face in which the wedge occurs was only slightly put back in the years it has been studied.

No. 5: In a small gravel pit near Treiten two thin wedges (maximum width only 7 cm) have been found. Because of this width they should be termed "cracks"

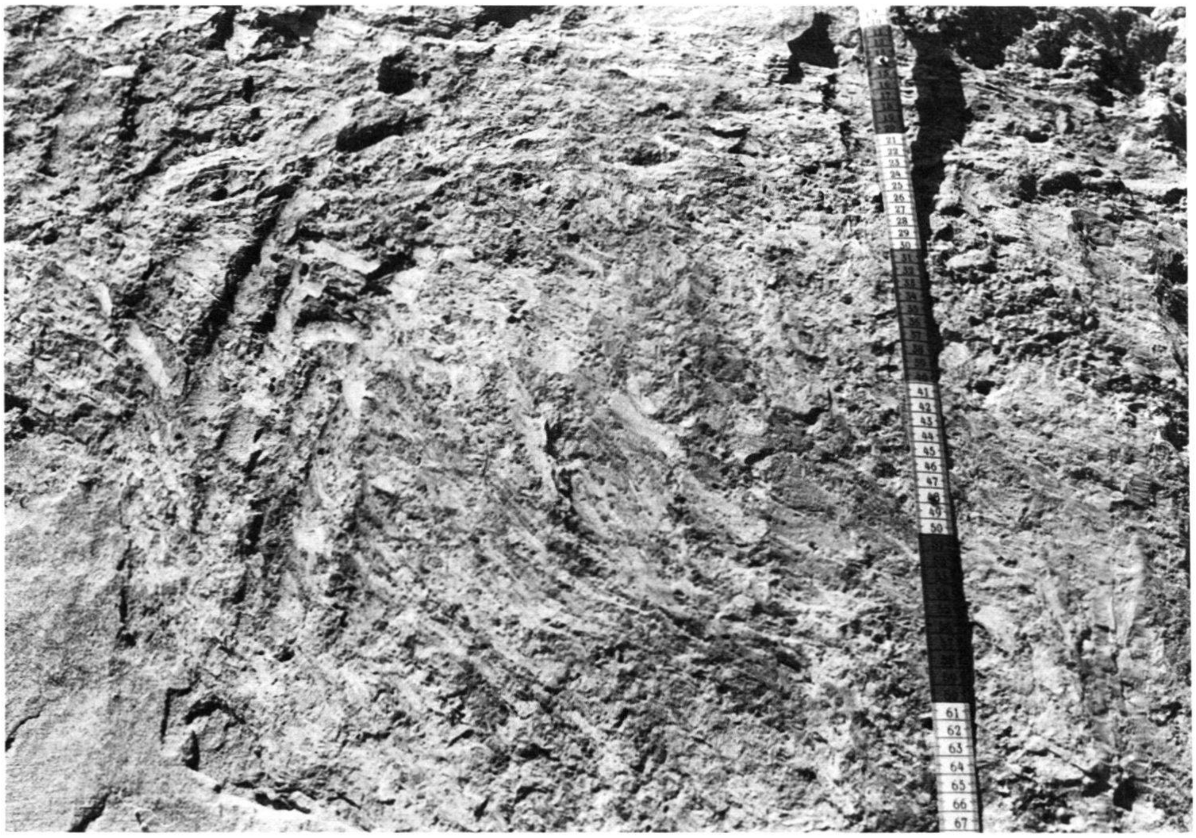

Fig. 3. Gravel pit 4; west of Müntschemier: example of the laminated filling of type one wedge.

(DYLIK & MAARLEVELD 1967). The shortest one had a depth of about 3.5 m. The depth of the largest wedge could not be determined because it disappeared below the level of dredging. Its visible depth was about 5.5 m. Both wedges are rather simple in outline. They are slightly curved and show only minor offshoots (Fig. 7).

Type two: Description

The type two wedges, which were observed only in the Müntschemier gravel pit, occur in the upper, more sandy part of the sandur deposits. They were studied in a long W–E oriented wall (see Fig. 8 in VAN DER MEER 1979) and in a small N–S

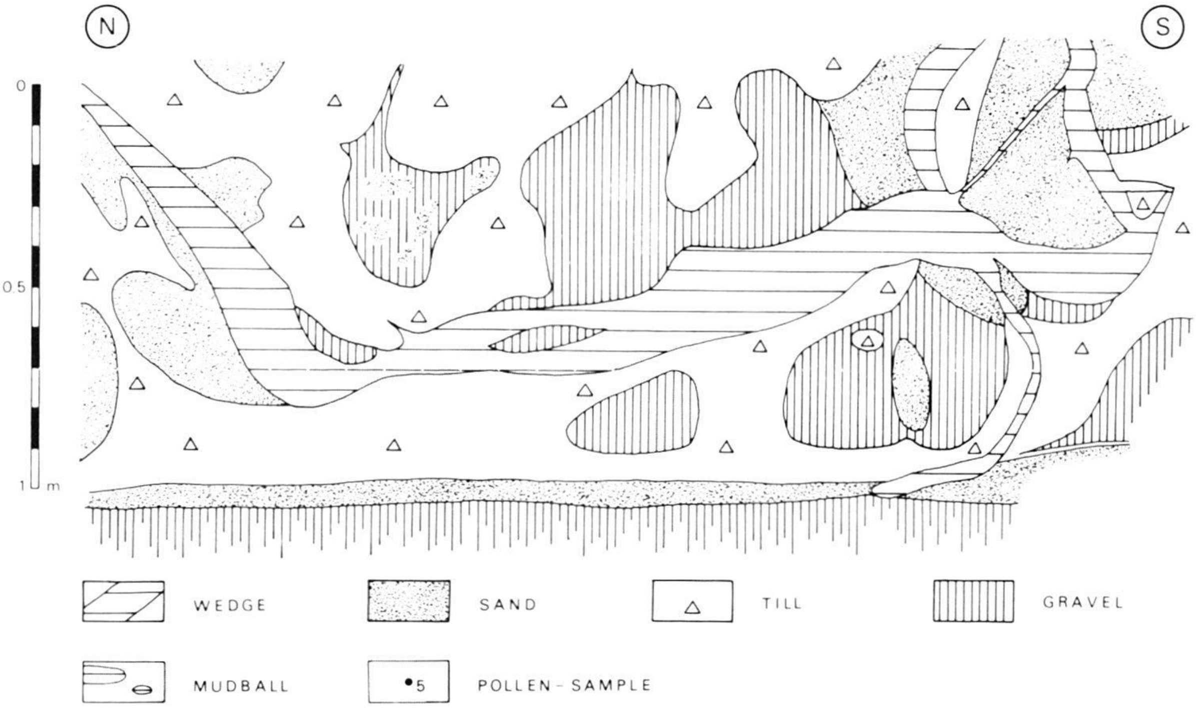

Fig. 4. Gravel pit 4; west of Müntschemier: type two wedge as exposed in a gully. No vertical exaggeration.

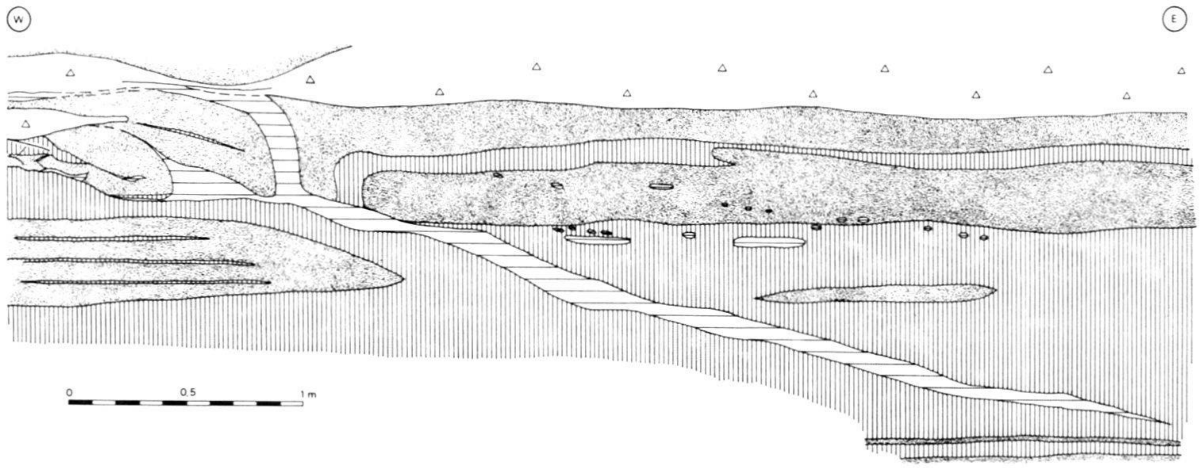

Fig. 5. Gravel pit 4; west of Müntschemier: type two wedge as exposed on the long W–E wall. For legend see figure 4; no vertical exaggeration.

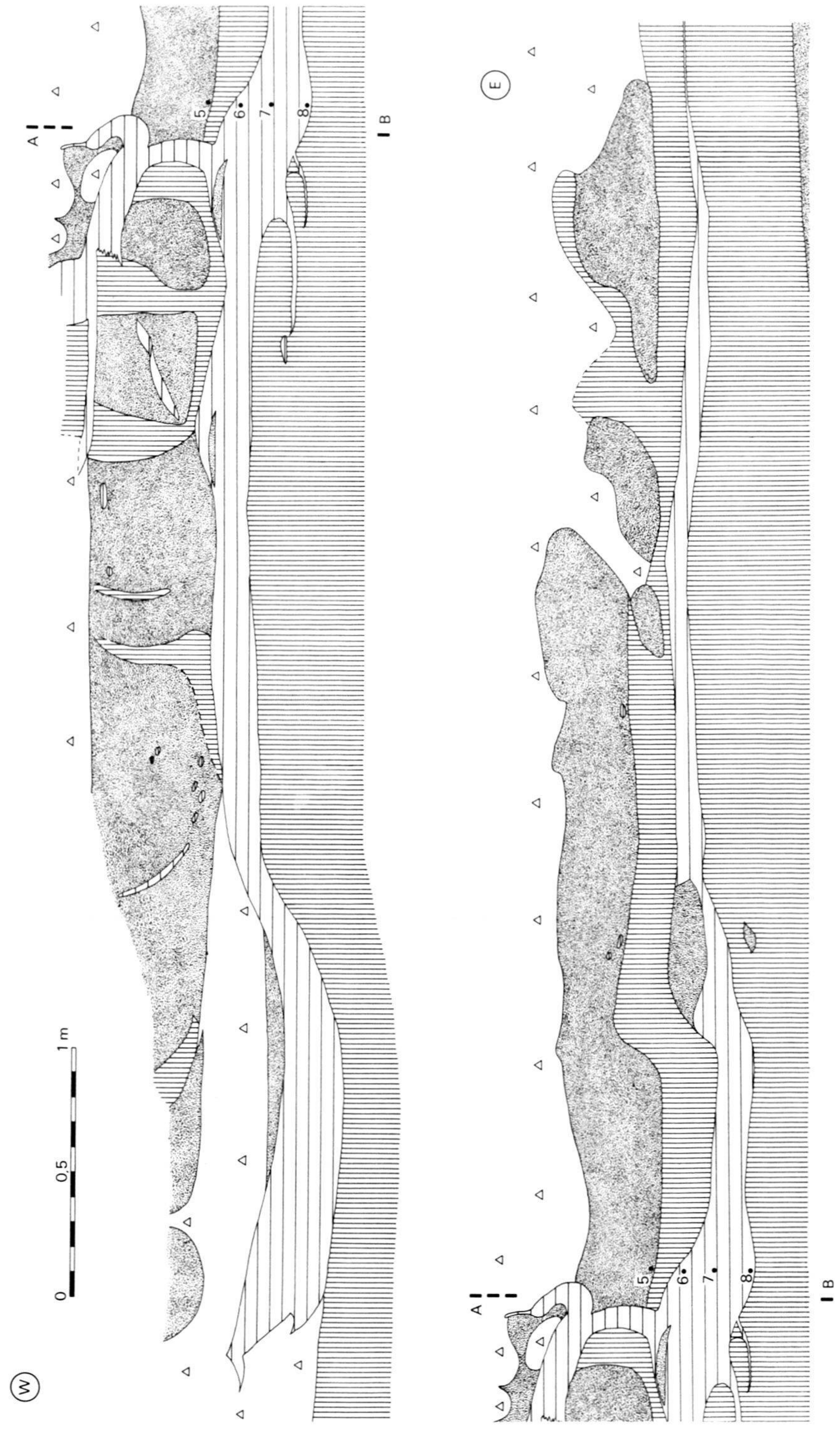

Fig. 6. Gravel pit 4; west of Müntschemier: large type two wedge as exposed on the long W–E wall. For legend see figure 4; no vertical exaggeration. The wedge could be followed several meters to the right as a thin clay bed.

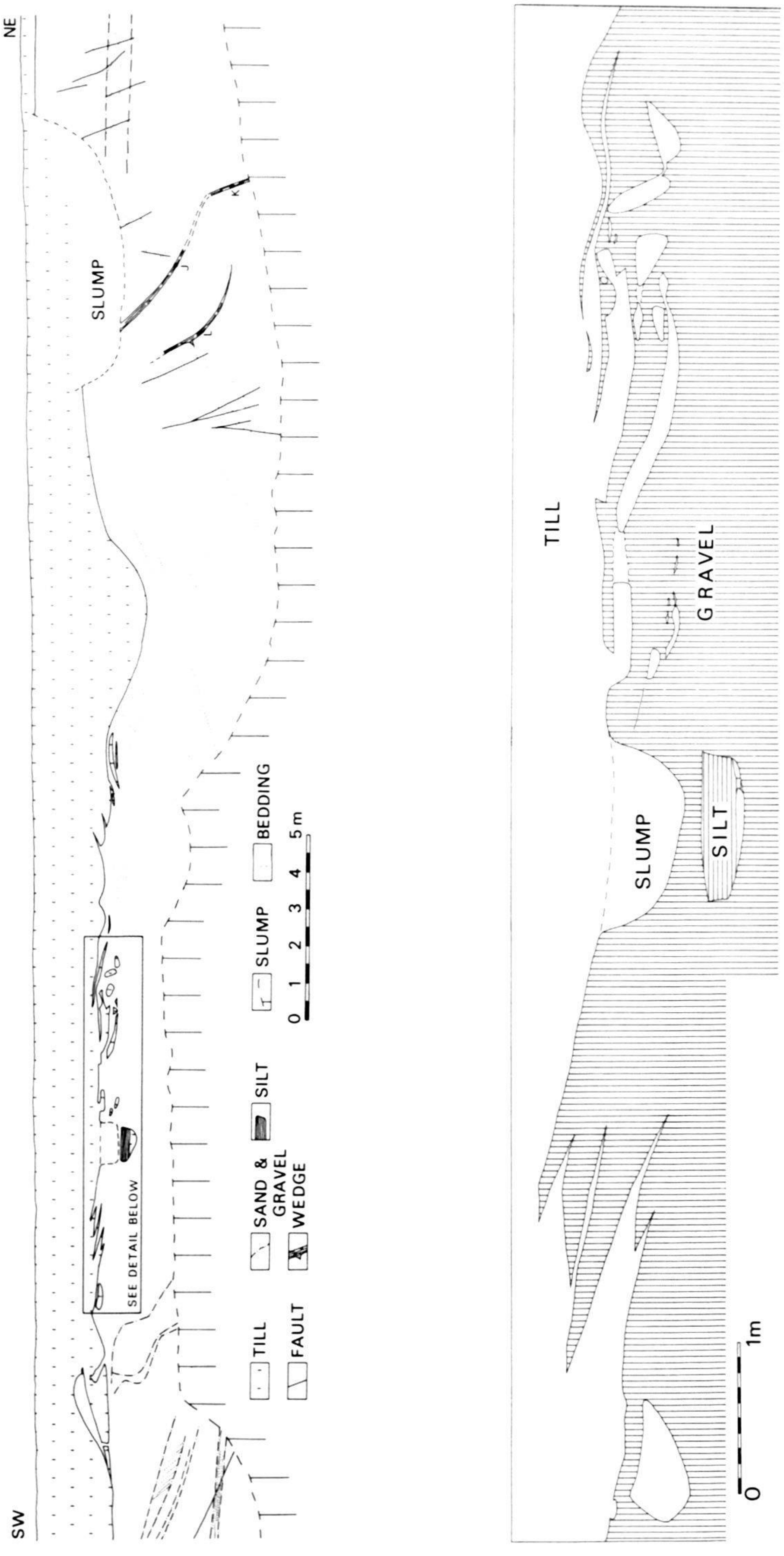

Fig. 7. Gravel pit 5; near Treiten; type one and three wedges. No vertical exaggeration.

oriented gully. The wedges in the long wall all show a more or less upturned part at or near their western end, while the other end slightly dips to the east. A "wedge" in the gully is complexely deformed and almost surrounded by till (Fig. 4). These forms do not cut through the sand and the gravel beds like the type one wedges. Instead they are found in an intricate pattern of sand, gravel and till (Fig. 5, 6). To the east of the upturned parts of the type two wedges flat mudballs occur. They are eroded from these wedges, because they also consist of finely laminated silt, clay and sand. The filling of the type two wedges is laminated like the type one wedges. They do not show any offshoots but parts of the wedges seem to have been torn up.

From this description it can be concluded that the type two wedges are in fact no real wedges. Some of them are wedge-shaped though (Fig. 5) and at first sight their filling looks like the filling of the type one wedges. Because of this they are presented here as a separate type of wedge.

Type three: Description

Wedges of type three were only observed in the Treiten gravel pit (Fig. 7). Contrary to the other two types they are not laminated, but they consist of till. They are straight or curved, their curvature following the boundary between till and gravel. The dip of these wedges is NW-NNW and varies from 40° to 26°. All these wedges are extensions of the overlying till and seem to be intrusions in the underlying gravel. Near the end of some of the wedges several till "balls" occur. No clear connection between wedges and "balls" or between overlying till and "balls" could be observed. The "balls" might be the end of wedges though which have been cut off by dredging. The right-hand part of the wedges seems to have been deformed after their formation. The drag features in the underside of the till as well as the disturbed bedding in the upper part of the gravel point to the fact that deformation did occur.

2. Pollen analysis

From clay laminae in several type one and type two wedges samples have been taken for pollen analysis. Each sample weighed about 8 g and all the pollen in each sample were counted. The results are presented in the table.

From this table it is clear that all the samples taken from type one wedges do contain pollen, though their number varies from 2 to 47. The samples from a type two wedge did not contain any pollen, and neither did the sands surrounding the wedges, with the exception of one corroded *Alnus* pollen in sample 5. Conditions for pollen preservation being the same in type one and type two wedges the latter probably did not contain any pollen from the start. The absence of pollen in the surrounding sands can be due to corrosion as well as to nondeposition.

It is remarkable that there is a high number of indeterminable pollen (52 out of 228) and that the determination of another 10 pollen is questionable. This can be due either to reworking, the pollen might stem from older deposits, or to corrosion. *Pinus* makes up, by far the largest number of pollen (58). With the exception of the last eight species of the table all are mentioned by WELTEN (1978). So there is nothing curious about finding these pollen in this environment. It is very curious

Table: *Pollen analysis of wedge fillings and of the surrounding sands.*

SAMPLE NO	LOCALITY	SAMPLED FROM	TOTAL COUNT	INDETERMINABLE	ABIES	ALNUS	BETULA	CORYLUS	PINUS	QUERCUS	TILIA	ARTEMISIA	CHENOPODIACEAE	COMP. LIGULIFLORAE	COMP. TUBULIFLORAE	CRUCIFERAE	CYPERACEAE	ERICACEAE	GRAMINEAE	HELIANTHEMUM	LILIACEAE	PLANTAGO	RANUNCULACEAE	RUMEX	SAXIFRAGACEAE	MONOLEET PSIL	BOTRYOCOCCUS	ANALYSED BY
37H	MUNTSCHEMIER	VARVES	2						2																			II Y CASTEL
37M		TYPE ONE WEDGE	19	1		1?	3	3	4		2							2	2								1	
37N		–	15	4		1	1	1?	4				2						1			1						
37P		–	27	5		1?	1	4	11	1		1	1					1								1		
37R		–	6	4					2																			
37T		–	20	3	1	1 + 1?		1	5				1								1					6		
37U		–	7	1		2		1?	3																			
37V		–	16	4		1		2	4						1				2					2				
1		SAND	0																									RT SLOTBOOM
2		–	0																									
3		–	0																									
4		–	0																									
5		–	1			1																						
6		TYPE TWO WEDGE	0																									
7		–	0																									
8		–	0																									
8K	DONATYRE	TYPE ONE WEDGE	25	5		1	1		2					10				2	2	1?			1					II Y CASTEL
8L		–	7	4		1					1							1										
8M		–	7	1					4			1					1											
8N		–	48	11			1	1	17	1		2	1			2	1	3	4				1?		2	1		
8O		–	10			2	2								1			5										
15J	TREITEN	–	12	6								1	2?						3									
5K		–	2	2																								
5L		–	4	1								1					1		1?									

though that *Picea* was not found in the wedge fillings, because WELTEN (1978) showed its occurrence in Early and Middle Würm deposits. The lack of *Picea* was also observed by WEIDMANN (1962) in clay deposits, older than the Würm II glaciation.

MANGERUD & SKREDEN (1972) also studied the pollen content of a laminated wedge (similar to type one wedges). They found that the wedge filling contained more pollen (also with a high number of indeterminable pollen) than the other sediments studied. They also found that the pollen indicated an arctic type of vegetation. Pollen analysis of a laminated joint filling by STEPHANSSON & ERICSSON (1975) only revealed tree pollen, which, they concluded, were redeposited from older sediments.

3. Thin sections

Two samples for thin sections of the filling of type one wedges were taken in pits 3 and 4 (Fig. 2). For comparison thin sections of a type two wedge (pit 5) and of varves from another gravel pit were taken.

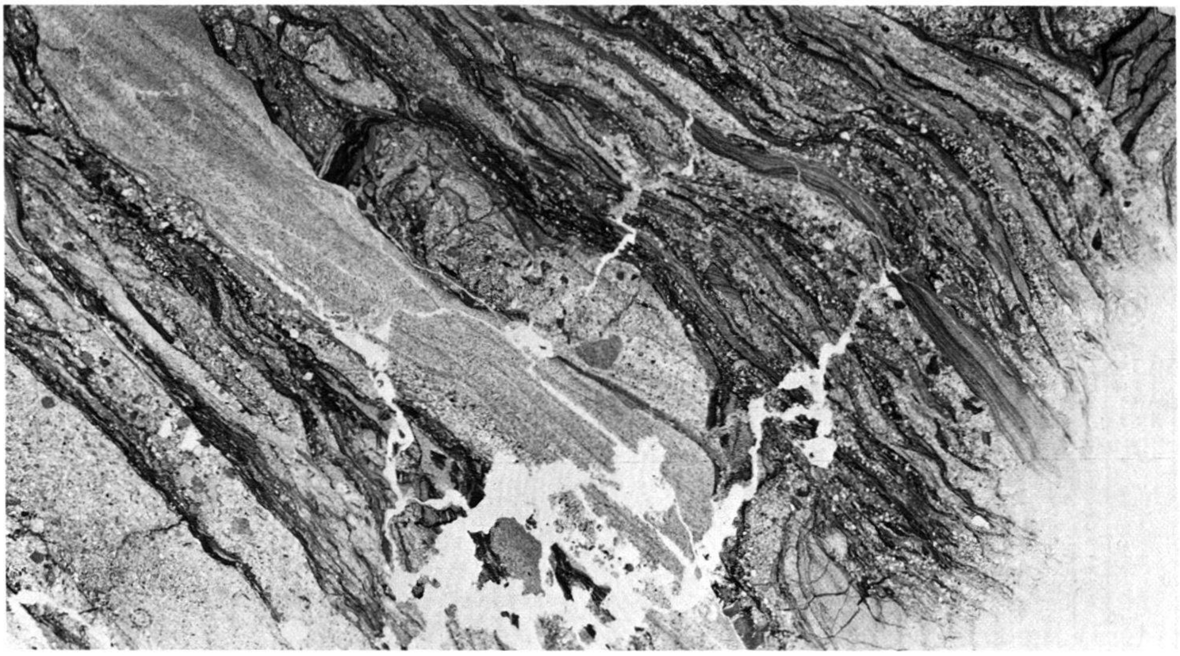

Fig. 8. Gravel pit 4; west of Müntschemier: thin section of type one wedge filling. Actual size. For location see figure 2.

Especially the filling of the type one wedge in pit 4 showed many laminae (Fig. 8), the clay laminae of which can be very thin. Though at first sight the laminae seem to show a graded bedding, this could not be seen under the microscope. Instead most of the laminae appear to be very homogeneous in texture. Each lamina is characterized by a specific texture. As was already observed macroscopically the laminae cut each other regularly, and as a matter of fact very few of them were continuous when observed under the microscope. It was also found that many laminae contained parts of older ones, dragged along and slightly deformed. In the filling of the type one wedge from pit 4 also very thin cracks were observed, most of which were oriented perpendicular to the general trend of the laminae. All of these cracks showed a filling of fine textured material on both sides bordered by a distinct transition to a clay lining. The filling of the type one wedge in gravel pit 3, as observed in thin section, was much coarser. Also here no graded bedding was found in the laminae. Where this appeared to be the case macroscopically, observation under the microscope showed this to be due to a lack of clay matrix in some parts of the laminae. The laminae were also much thicker in this thin section and some of the laminae contained many coarse (up to 1 cm) subangular "papules" of older clay laminae. Drag features were very common here, while no cracks were observed.

The filling of the type two wedges appeared to be much more regular than that of the type one wedges. The laminae were much more regular in width, they did not cut each other and also no drag features were observed. Also here, the laminae were found to be ungraded. Most of them appeared to be of a very homogeneous texture while the coarser laminae are separated from each other by clay laminae.

The thin sections of the varves were completely different from type one and two wedges. Most laminae show graded bedding. Drag features were not observed, but some distinct faults were observed. No such faults have been found in the type one and two wedge fillings.

MANIL (1958, 1960) described thin sections from the laminated wedges studied by MACAR (1969). He also found different laminae, cutting each other. While part of the laminae were ascribed to periglacial processes, he considers some of them to be of "interglacial or postglacial" nature. From this description it appears that he consideres them as illuviation cutans (argillans). The clay laminae observed in the thin sections described here cannot be explained this way.

As a conclusion it can be said that the different laminae filling the type one wedges are of a homogeneous texture. This and the fact that the material filling a crack was able to erode parts from older laminae, points to the fact that this filling was not hampered in any way.

4. Interpretation of wedge types

Type one wedges

As the type one wedges do not consist of till and so cannot be till wedges (DREIMANIS 1969) another explanation has to be given. Thought has been given to the following possibilities:

1. clastic dikes,
2. injection wedges,
3. frost wedges.

Ad 1. Clastic dike is, according to DIONNE & SHILTS (1974), "a general expression for any wedge-shaped feature, usually in a vertical or in a nearly vertical position, filled with clastic materials, and cutting through different layered consolidated or unconsolidated sedimentary rocks"; "generally two things must be considered in the formation of any clastic dikes: first the formation of fissures or cracks, and second their filling". In case of the type one wedges it is the formation of fissures or cracks that creates problems when one tries to explain them simply as clastic dikes. Only in the Müntschemier gravel pit a direct contact between till and wedge was observed. In the other cases this contact either could not be observed or the wedges clearly made no contact with the till. So it is not possible to relate the fissuring to an overriding glacier. In fissures created by glaciers only till fillings (till dikes) occur (DIONNE & SHILTS 1974, Table 2). They only mention one case of "filling from above of fissures most resulting from melting of buried ice". Only in the Treiten gravel pit faults have been observed together with wedges. These faults might be the result of melting of buried ice, but then one wonders why only two out of so many faults have been filled from above. So we can conclude that neither the formation of the fissures nor their fillings has any resemblance with known clastic dikes. From northern Norway WORSLEY & ALEXANDER (1975) described clastic dikes occurring in a comparable situation to that of the Swiss wedges. Of four clastic dikes only one consisted of clay-silt laminae, a feature the authors found difficult to account for. They considered the dikes to be formed through glacier overriding.

Ad 2. Recently, BROSTER et al. (1979) described a special kind of laminated wedge. These occur in fractures in bed-rock, which had been widened by an overriding glacier. All the wedges dip down glacier and the laminated silt portions of the wedges occur mainly along their base. From Sweden laminated "joint fillings" have been described by STEPHANSSON & ERICSSON (1975). In this case the widening of the original joints was thought to be the result of the freezing of water in a cold climate. The filling of the joints was the result of deposition from water streaming through the still open joints during ice recession. As our type one wedges are older than the last glaciation (in most cases no connection to the till above was observed) they cannot be explained this way.

Ad 3. From the start these wedges have been thought to be fossil frost wedges despite the fact that only one or two of them have been found in any gravel pit. Also the absence of up- or downwarping of the host is not very positive in identifiying these wedges as frost wedges.

In describing several kinds of wedges indicative of permafrost BLACK (1976) mentions a deep wedge from Poland, where the sand filling in upper and lower parts is vertically stratified and in the lower part crack fillings are commonly less than 1 cm in width. Besides, stratification of the host carries through between cracks without offset and only very slight settling or downwarp has occurred. Supposedly this is a primary sand wedge. As a matter of fact GALLWITZ (1949, p. 13) especially mentions the fact that the stratification of the host, of an ice wedge from Germany, did not show any up- or downwarping, with the exception of one bed. Similarly, figures 2 and 4 in ZECH & GROTTENTHALER (1975) and figures 1 and 6 in MAYR (1968) show wedges that are not bordered by any offset of the host. Also MACAR (1969) mentions the fact that out of more than 70 fossil ice fissures only on three cases a bending of the layers cut by the fissures could be found. As a matter of fact offset of the host hardly shows if the filling of a crack is thin or if the host is homogeneous or coarse gravel. So it is not amazing in this case, where the wedges occur in homogeneous sand and gravel beds, that no offset was found.

It should also be noted that our wedges are by no means the first of their kind to be interpreted as fossil frost wedges. Wedges which resemble the features very much, in outline as well as in the laminated fillings, are provided by MANGERUD & SKREDEN (1972) from Norway, SERET (1965) from France, MACAR (1969), MACAR & VAN LECKWIJCK (1958) from Belgium and ZECH & GROTTENTHALER (1975) from Germany. Especially figure 13*b* in MANGERUD & SKREDEN (1972) and figure 3 in MACAR (1969) do resemble the laminated filling of the wedges described here (Fig. 3). Offshoots are also shown by the examples in ZECH & GROTTENTHALER (1975), MANGERUD & SKREDEN (1972) and also resemble recent examples described by RAPP & CLARK (1971, Fig. 9), PISSART (1968, Fig. 1*b*) and PAEPE & PAULISSEN (1974). The type one wedges are thus considered to be fossil frost wedges, and especially as primary sand wedges (BLACK 1976). The length of the type one wedges excludes the possibility that they are seasonal frost cracks. According to WASHBURN (1979) they should be named fossil permafrost soil wedges. Interpretation as primary sand wedges means that they indicate permafrost, with a mean annual ground temperature of at least -5 °C (WASHBURN 1979) with a mean annual air temperature of at least −6 °C for this area. As the mean annual air temperature at Fribourg is 8 °C nowadays, this means a minimal lowering of about 14 °C for the Würm maximum. This is in accordance with the examples cited by WASHBURN (1979, Fig. 14, 24) for Central Europe.

Observation of the thin sections indicated that the infilling of the cracks was not hampered. It is difficult to explain why the material flowing into the cracks did not immediately freeze when entering the cracks. Examination by binocular of sand grains from the filling and of the host did not show any difference, no indication of eolian sand was found.

Type two wedges

Macroscopically the filling of the type two wedges resembles the varve-like deposits that can be observed in almost every gravel pit. These are not only found intercalated in the sandur deposits, but also as a transition from the gravelly and sandy sandur deposits to the overlying till.

In the Müntschemier gravel pit the till contains in its lower part pockets of sand and gravel from the underlying deposits. This shows that the glacier actually reworked the top of these deposits. Also the top of the type one wedge in this pit has been slightly faulted by the glacier.

The upturning of all the type two wedges in the W–E wall occurs near their western ends (Fig. 5, 6), the type two wedge in the N–S oriented gully was complexely deformed (Fig. 4) and more or less incorporated in the till. This can only be the result of the overriding glacier, which moved northeast in this area. And so the deformation is considered to be glacitectonic in origin. One can then visualize the following sequence:

- Deposition of varve-like deposits in shallow pools not far from the glacier.
- Slight erosion by meltwater, which deposited flat mudballs.
- Compression and distortion by the glacier that overrode these deposits, coming from the Lake Neuchâtel basin.

Type three wedges

Since the type three wedges consist of till and not of laminated sediments it is rather obvious that they are looked upon as till wedges. DREIMANIS (1969, 1973) defined till wedges as "downward intrusions of till, wedge-shaped, 5–100 cm long, trending approximately at a right angle to the direction of that glacial movement which had deposited the overlying till, and dipping mostly at 45 degrees downglacier". MÖRNER (1972, 1973) and HUMLUM (1978) showed till wedges as spoonshaped injections of till dipping downglacier. Especially the one described by HUMLUM (1978) was parallel to the lower till boundary, while the one shown by MÖRNER is much steeper. The type three wedges are obviously wedge-shaped downward intrusions of till. Their length varies between 20 cm and 2 m. The till wedges described by MÖRNER (1972) varied from 0.5 to 2 m in length, while the one described by HUMLUM (1978) was much larger. As the three-dimensional figures of MÖRNER and HUMLUM show, the apparent dip and trend of a section of a till wedge as shown in a gravel pit wall may differ considerably from the actual trend and dip of the till wedge. The fact that the type three wedges dip to the NW-NNW, while the overall glacier movement in this area was northeast cannot be considered an objection to their interpretation as till wedges. Neither can the fact that the observed dips vary from 26 to 40°.

The till-"balls" that are found together with the type three wedges can very well be the extension of till wedges, which have been cut off by dredging operations. It is also possible that some deformation occurred after the formation of the till wedges. The drag features in the till, to the right of the wedges (Fig. 7) as well as the irregular shape of part of the wedges points to this.

5. Conclusion

As for the genesis of the three types of wedges described here we come to the following conclusions:

— type one wedges are primary sand wedges,
— type two wedges are glaci-tectonically deformed varve-like deposits,
— type three wedges are till wedges.

The fact that the type one wedges are considered to be primary sand wedges, leads to the conclusion that permafrost occurred in this area at some time before the final glaciation. The area under consideration is within the limits of the main region of fossil frost fissures in Europe (Dylik & Maarleveld 1967) and also within the area with permafrost (Maarleveld 1976).

It is not the first time fossil frost fissures are described from Switzerland. Furrer (1955, 1966) and Bachmann (1966) mentioned frost fissures from the area, just outside the Würm maximum, while Wick (1973) described younger fissures from the canton Graubünden. As for the age of the type one wedges, a date of 55,100 (+4500-2900) BP (GrN - 8105) on wood found in sandur deposits under till in a gravel pit near pit 3, gives a maximum age (van der Meer 1979). Since the wedges occur under till they are older than the last ice cover. The glacier fluctuation curve (for the Aare glacier) (Welten 1978) points to the time between 30,000 and 25,000 BP as the possible time of formation of these wedges. This would also be in agreement with the age of a large fossil frost wedge in Belgium, which was dated between 26,220 and 24,760 BP by Vandenberghe & Gullentops (1977). These dates were obtained on peat layers, one cut by the frost wedge, the other one on top of it.

The curve of Welten (1978) indicates an age of about 23,000 BP for the type two and three wedges. It is not sure if permafrost (still) occurred at that time. The fact that the flat mudballs associated with and derived from the type two wedges were not deformed during transport, points to transport in a frozen state. But this needs not indicate permafrost. The occurrence of the till wedges (type three wedges) in this area is not contradictory to the occurrence of permafrost nor does it prove it. Humlum (1978) discusses the temperature regime during the formation of his till wedge. He considers the occurrence of an intense folding of the sand bordering the till wedge as well as the existence of a mixing zone in the margins of the till wedge as some support for his supposition that the sediments were unfrozen at the time of till wedge formation. In the type three wedges neither a deformation of the surrounding sediments, nor the existence of a mixing zone was observed.

Acknowledgments

Throughout the preparation of this paper Prof. Dr. G.C. Maarleveld greatly contributed in its completion. Not only through stimulating discussions but also through his remarks on the first draft. Discussion in the field with Prof. Dr. J.P. Portmann (Neuchâtel) and Dr. Ch. Schlüchter (Zürich) and general discussions on the character of fossil frost wedges with Prof. Dr. G. Furrer (Zürich) and Prof. Dr. K.H. Kaiser (Berlin) are gratefully acknowledged. The author wishes to express his thanks to Dr. R.T. Slotboom and Mrs. I.I.Y. Castel who kindly performed the pollen analysis. Mr. C. Zeegers prepared the thin sections, Mr. A. Eikeboom the reproductions, while Mr. Ch. Snabilié assisted with the figures, Mrs. M.C.G. Keijzer-v. d. Lubbe and Mrs. G.J.M. Scholts did the typing. Mr's. H. Wolfert and D. Molenaar are thanked for their enthusiastic support during the fieldwork.

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