

SVERIGES GEOLOGISKA UNDERSÖKNING

SERIE C NR 752 AVHANDLINGAR OCH UPPSATSER ARSBOK 72 NR 14

JAN LUNDQVIST

NEW INFORMATION
ABOUT EARLY AND MIDDLE
WEICHSELIAN INTERSTADIALS
IN NORTHERN SWEDEN



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EARLY AND MIDDLE WEICHSELIAN INTERSTADIALS

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ABSTRACT

The author describes a new discovery of a till-covered deposit of organic sediments at Tåsjö, Ångermanland. Insect and plant fossils and a pollen diagram indicate mountain heath or tundra conditions rather far from the birch forest zone. Radiocarbon dating has given $> 50\,000$ BP. The deposit is correlated with the Jämtland Interstadial of northern Sweden.

Other sites in the interior of northern Sweden are briefly mentioned. They contain till-covered organic sediments dated at about $40\,000$ – $30\,000$ BP and indicate that at this time at least parts of northern Sweden were deglaciated.

INTRODUCTION

The province of Ångermanland, central Sweden, forms part of the County of Västernorrland which is now being mapped by the Geological Survey of Sweden. The mapping of the Quaternary deposits is carried out under the leadership of the present author. Also northern Ångermanland, which now belongs to the County of Jämtland, is included in the mapping.

Within the southern parts of the County of Västernorrland a few deposits of till-covered sediments have been found, more or less certainly dating from an early Weichselian interstadial. The northern part of the province of Ångermanland crosses the zone in the interior of northern—central Sweden where such deposits are numerous (J. Lundqvist 1967, Fig. 58). However, within the province itself no deposit is known for sure within that zone.

For this reason special attention was paid to the possibility of finding till-covered deposits when mapping of this area began in 1976. Some interesting facts

were discovered, most important among which was a site with organic deposits covered with gravel and till. This site, from here on named Tåsjö, was found in 1976 by Miss Britt-Marie Ek, working as a field assistant. The following article mainly constitutes a description and interpretation of this site.

In the investigation of the deposit in question a number of specialists within and outside the Survey have taken part: The fauna of beetles has been investigated by Dr G. R. Coope, University of Birmingham, using his special technique of preparation. Dr Coope has also written the text dealing with the fauna, and corrected the language of the entire text. Plant fossils have been studied at the University of Lund by courtesy of Docent G. Digerfeldt. Moss fragments were determined by Prof. M. Sonesson and wood remains by Mr Th. Bartholin. Pollen analysis was carried out at the Micropaleontological laboratory of the Geological Survey by Mrs Karin Hedin and diatom determinations by Dr Urve Miller at the same laboratory. The petrographic investigation of till and gravel beds was carried out by Mr S. Björnbom of the Survey. Radiocarbon dating was made at the Laboratory of isotope geology in Stockholm. To these persons and institutions it is the pleasant duty of the author to direct his most sincere thanks.

The author is also indebted to Mr Gunnar Gustafson, VIAK, Falun, and to the Swedish State Power Board for permission to use unpublished material from their investigations.

GENERAL TOPOGRAPHICAL AND GEOLOGICAL CONDITIONS AT THE TÅSJÖ SITE

The northernmost part of Ångermanland is situated within the broken country just outside the Scandinavian mountain range. The area is hilly, with smooth mountains reaching about 600—700 m above the present sea-level. This means that they just reach the timber line of the mountains. 20—30 km northwest of the area in question are the easternmost mountains of the range itself, reaching more than 1 100 m a.s.l.

The area is dissected by deep valleys, in general running from the mountains southeastwards. The valley bottoms are between 200 and 300 m a.s.l., although the deeper parts are covered by lakes. The relief of the country is roughly 300 m (M. Lundqvist 1953).

One of the valleys mentioned runs straight through the area in about NNW—SSE. Its greater part within the area is occupied by Lake Tåsjön. This lake belongs to the series of deep, long and narrow piedmont lakes along the eastern edge of the mountain range. Parallel valleys west and east of the Tåsjö valley are occupied by similar lakes: Lake Flåsjön to the west and Lakes Ormsjön—Rörströmssjön to the east. Lake Tåsjön belongs to the water system of the River

Fjällsjöälven. It is fed from the north by the River Saxån and from the north-west by the River Sjoutälven.

The bedrock of the area is very complicated in detail. From east to west we can distinguish between three main units: the Precambrian crystalline basement, the Eocambrian to Ordovician sedimentary rocks, and the Caledonian Seve-Köli nappe complex. The boundaries between these units in outline run NE—SW.

The Precambrian crystalline basement mainly consists of granites and gneisses (e.g. Magnusson *et al.* 1960). Its western boundary is located about 20 km east of the Tåsjö site.

In the area under consideration a series of sedimentary rocks makes up the bedrock. According to Gee (1972) the lowermost strata is the Eocambrian Arkose group, mainly feldspathic sandstones, arkoses and quartzites, the so-called sparagmites. Upon this follows the Quartzite-Shale group of Varangian tillites, shales and quartzites. Then we have the Shale-Greywacke group of Cambrian alum shale and other sediments and the Ordovician greywackes and shales. This whole series of sedimentary rocks is thrust and folded (see Gee 1972, Pl. I). Because the broken land surface cuts this thrust and folded series the local distribution of rocks around the Tåsjö site is very complicated. Through the folding the crystalline basement is also exposed in vast areas in the western parts of the area of sedimentary rocks.

Some 10 km west of the site is the eastern boundary of the main Caledonian nappes, the Seve-Köli Nappe Complex. The rocks are highly metamorphic, mainly mica schists, mica gneisses and amphibolites.

Upon this generally rather old bedrock follow directly the Quaternary deposits. The general conditions of Quaternary geology are those of the supra-aquatic areas of the inland of Sweden. Till is the main deposit, and glaciofluvial outwash, eskers and kames form narrow courses through the country. Thin peat deposits cover the till in many places, particularly on flat ground.

Ice movements have altered widely in the region, partly because it is situated between the main ice divides of the last glaciation. Two main directions of movement have been identified not far from the site. At the power plant of Korselbränna, 5 km to the south, an older movement from N80°E and a younger one from N50°W can be traced with good sets of striae. If we consider the observations from the province of Jämtland, only a few kilometers to the west, we can infer the following changes in ice movements (cf. J. Lundqvist 1969, Figs. 77—80).

An oldest ice movement came from the northwest (or west; cf. J. Lundqvist 1974) and dates from the initial stage of the last glaciation (Weichsel II and III), probably also from an older part of the glaciation (Weichsel I). The main movements from the last glaciation came from the east to northeast. After this the ice came from a northwesterly direction and within this movement a clock-wise rotation could be noticed. Finally, again more westerly, very local

movements might have affected the area (J. Lundqvist 1969, Fig. 80) although the results from the mapping in progress so far have indicated that this was not the case.

Deposits of sediments below the general till cover, older than the last glaciation, are known from the surroundings of northern Ångermanland. In the province of Jämtland such deposits are particularly common (J. Lundqvist 1967). Most of them are not fossil-bearing and do not allow radiometric dating. In some cases, however, they are organic. Then it has been possible to make radiocarbon datings and pollen analyses. On the basis of such investigations the author has earlier drawn the conclusion that the deposits in question derive from an early Weichselian interstadial, older than 40 000 BP (J. Lundqvist 1967). The non-organic deposits most probably derive from the same interstadial, although it is not out of question that they may belong to different early interstadials or that some of them are even late-glacial.

This interstadial was called the Jämtland Interstadial. The term has been questioned (Mörner 1972), and Kulling (1967) preferred the name Pilgrimstad Interstadial. The reason for the choice is, however, that the picture of the interstadial outlined was based on the accumulated information from a large number of sites within Jämtland and not on the site Pilgrimstad itself. Because future research might well suggest that the bulk of the sites and the Pilgrimstad site derive from different interstadials it is preferable to retain the possibility of separating a Pilgrimstad Interstadial from the Jämtland Interstadial. It is not out of question that the results presented in this paper will lead to such a revision of our opinion about interstadials in central Scandinavia. Besides, the name Jämtland Interstadial is no more illogical or less correct than many other stratigraphic names (e.g. Holstein, Peräpohjola). In the following discussion the name Jämtland Interstadial is retained.

It was also shown (J. Lundqvist 1967) that the earlier known sites or isolated finds from the southern parts of Ångermanland should — or in some cases could — be correlated with the Jämtland Interstadial. This applies to the sites Långsele (Sundius & Sandegren 1948) and Härnön (Munthe 1890, 1904 and others) and a few mammoth finds (see J. Lundqvist & C. Pleijel 1976). Also the non-fossiliferous deposits from the adjacent Vilhelmina region in Lapland described by Granlund (1943) should possibly be referred to the same interstadial.

From northern Ångermanland itself, however, it is not clear if interstadial deposits have been observed earlier. There is some confusion in this respect. G. Lundqvist (1943, p. 129) mentioned 28 m thick sediments under till in this area. This observation was quoted by J. Lundqvist (1967, p. 249) with a personal communication by G. Lundqvist that it probably referred to the eastern side of Lake Flåsjön (5–10 km west of Lake Tåsjön). However, observations from the mapping in progress have made it less probable that deposits of that

thickness should occur at Lake Flåsjön within the province of Ångermanland. The till cover is rather thin, resting directly upon the bedrock. It also seems, from G. Lundqvist's text, as if he had his own information from p. 123 in mind, which refers to Lake Ormsjön (about 15 km east of Lake Tåsjön). On G. Lundqvist's (1943) map Fig. 37 a sign for the observation is, however, shown at a position which agrees best with Lake Tåsjön. Bearing this confusion in mind, special interest was paid to the Tåsjö area when mapping began there in 1976.

It has earlier been stated that there is no evidence of a younger interstadial than the Jämtland Interstadial in the northern parts of Sweden (J. Lundqvist 1974). Only on the west coast and in Scania, southernmost Sweden, deposits have been found that could be referred to a younger interstadial or complex of interstadials. Radiocarbon dates range from 22 000 BP to 37 000 BP. Recently, however, Gustafson (1976) has reported finds of wood with a radiocarbon age of about 30 000 BP in the province of Dalarna. This is the first indication of a Middle Weichselian interstadial in central Sweden, although it is true that some of the older radiocarbon dates of infinite age, for methodical reasons, have given rather low age limits. Thus they leave a theoretical possibility open for such a younger interstadial even in northern Sweden.

The Tåsjö area has not yet been completely mapped, but so far the following information has been obtained. Around the northern part of the lake the till seems to be rather thin or forming thicker hummocks of ablation till. Southwards, however, the deposits seem to be much thicker. Partly the "till" is of a very peculiar type (Fig. 1) somewhat reminiscent of Kalix till (Beskow 1935) or Sveg till (J. Lundqvist 1969, p. 57). It can be described as a rather fine and well-sorted sand with numerous stone clasts. This material is not an ordinary product of the ice disintegrating the bedrock. Rather it looks like water-laid sediments partly reworked by ice. The deposit can be an indication that the lake basin has contained thick sandy sediments before the last glacial phase.

After this manuscript was completed numerous sites with till-covered sediments have been found around the southeastern end of Lake Tåsjön, and south of it.

DEPOSITS FROM A MIDDLE WEICHSELIAN INTERSTADIAL

As was mentioned above, Gustafson (1976) has reported the first evidence of a Middle Weichselian interstadial north of the southern parts of Sweden. This report concerned wood fragments found in late-glacial sediments at Borlänge, Dalarna, some 400 km south of the Tåsjö site. The age reported was about 30 000 BP.

By courtesy of mr G. Gustafson, VIAK, Falun, the author is now permitted

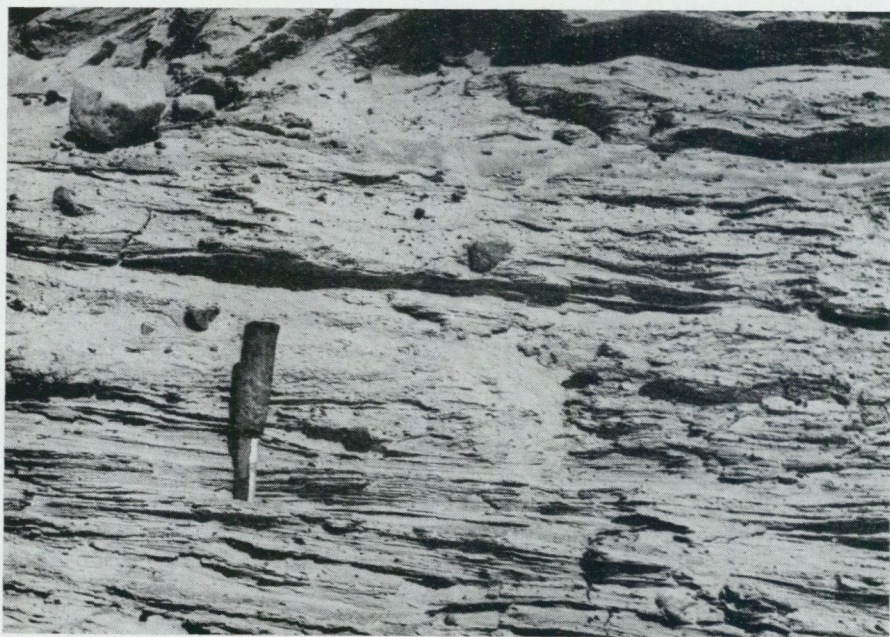


Fig. 1. Two details from the beds of sorted till at Lövvik, Lake Tåsjön, Ångermanland. This till probably consists of redeposited water-laid sediments. — Photo J. Lundqvist 1976.

to publish more complete information from the Borlänge site, obtained in borings made by VIAK.

The site is situated just northwest of the town of Borlänge, Dalarna (Fig. 6). Borings have shown the following stratigraphy: a) 21 m late-glacial silt, b) 45 m sand, and c) 22 m gravelly sand resting on d) till. 62—63 m below the surface, that is, in the lower part of the sand, wood fragments of *Picea*, *Juniperus* and *Salix* were found. They are obviously redeposited. Radiocarbon dating

(U-4 000) has given $32\,200 \begin{matrix} + 1\,700 \\ - 1\,400 \end{matrix}$ BP. Somewhat higher up in the sand (c. 45—48 m below the surface) in a nearby boring *Juniperus* wood was found. Radiocarbon dating (U-2 667) gave $41\,800 \begin{matrix} + 4\,100 \\ - 2\,800 \end{matrix}$ BP. In these and the following

datings from the Uppsala laboratory the value 5 570 yr for the half-life of ^{14}C was used for the calculation. Also in other borings in the same area wood fragments have been found at corresponding levels. Kulling (in Kulling & Hjelmqvist 1948) has made a pollen analysis of these sediments. He found 48 per cent *Pinus*, 32 per cent *Picea*, 18 per cent *Betula*, and 2 per cent *Alnus* beside compressed fragments of pine wood between 33 and 36 metres below the surface, that is, at the bottom of the fine-grained late-glacial sediments. The pollen flora immediately shows that the material is redeposited, interstadial or interglacial. The flora, if any, during the time of deposition of the late-glacial sediments must have been of a more subarctic type and lacking *Picea*.

At ground investigations for the power stations of Vojmån and Juktan in the county of Västerbotten (Fig. 6) deposits have been found that seem to derive from such an interstadial. These deposits have been observed by the Swedish State Power Board but the results have not yet been published. With the permission of the Power Board brief descriptions of the sites can be included in this article.

The Vojmån power station is situated on the river Vojmån at the village Volgsele, 13 km NNE of Vilhelmina. This is about 60 km NE of the Tåsjö site. A boring there has shown the following stratigraphy: a) an uppermost complex, 18 m thick bed of till with thin strata of sand; b) about 2 m of silt with some organic content, downwards grading into a thin sand layer; c) 1—2 m boulder-rich till or extremely fractured bedrock, resting on the homogeneous bedrock. Samples suitable for microfossil investigations were not taken, but part of the core was dated by radiocarbon at $32\,685 \pm 4\,200$ BP (St-5178).

The boring which constitutes the Juktan site was made 1 km south of the eastern end of the lake Blaiksjön 22 km NNE of the community Storuman. This is about 120 km NE of the Tåsjö site. The boring showed the following stratigraphy: a) an upper, 6 m thick till bed; b) about 60 cm sand and silt with some organic content; c) 1.5 m greyish blue till; d) 0.5 m silt and clay; e) 0.3 m gravel, resting on the bedrock. The stratigraphy could include two intersta-

dials, although further details are unknown. Radiocarbon dating of the organic material in the upper silt gave $32\ 060 \pm 5\ 135$ BP (St-4814). Even if the limit of error (1σ) is great there seems to be a close correspondence between the Vojmå and Juktan dates.

Two other sites should be considered in this connection. Near Gällivare, northern Lapland, some 400 km north of Tåsjö, organic material in till has been radiocarbon dated to $41\ 655 \pm 4\ 350$ BP (St-5405). This site will be described by mr R. Lagerbäck at the Geological Survey.

Finally there may be reason to reconsider Kulling's (1945) observation of an upper organic layer at the Pilgrimstad site. Kulling mentioned the possibility that this layer represented an ice-free period separated from the period represented by the main Pilgrimstad deposit. This hypothesis has not been verified, and the author (J. Lundqvist 1967) has so far interpreted the layer in question as a redeposited part of the main bed. Because there is nothing left of the upper layer we can not come to a final conclusion, but the possibility should be borne in mind.

Together the five sites mentioned are, if the radiocarbon dates are correct, clear evidence of at least one ice-free period around 40 000—30 000 BP in the central and northern parts of Sweden. We must, however, consider the fact that the dates refer to redeposited material and thus can be incorrect.

So far an interstadial of this age is known only from southernmost and southwesternmost Sweden (Brotzen 1961, Hillefors 1969, Nilsson 1973, J. Lundqvist 1974, Miller 1977). From Norway the observations are more frequent (Bergeresen & Garnes 1971, Mangerud 1972). The new finds in Sweden all occur not far from the mountain range, that is, rather far to the west (Fig. 6). In the more eastern parts of Sweden as well as in Finland observations of a similar interstadial are lacking. All interstadial deposits there, which are not late-glacial, give infinite or very high age and can more or less certainly be referred to the Jämtland—Peräpohjola Interstadial.

There could be three different explanations of the absence of corresponding interstadial deposits in the east. The most probable is — perhaps — that such deposits do occur but have not yet been found. Actually, observations of interstadial deposits of any kind are comparatively few. The second possibility is that deposits from the younger interstadial have occurred, but have been completely removed during the following glaciation. It is hard to see why the older interstadial deposits should have been preserved, but the explanation could simply be their lower stratigraphic position. The third explanation implies that the distribution really reflects the original distribution of younger interstadial sediments. In this case the reason must be that only the western parts of Scandinavia were deglaciated in this time. Ice could have remained — probably stagnant — in the Baltic basin and on the lowlands east of the mountain range. The idea does not appear likely but would explain some features of ancient

ice movements and the distribution of interglacial ice-dammed lakes. On the contrary, the fragmentary information about the flora contradicts this possibility. However, the observations so far do not justify further speculations. Future investigations will provide the answer to this problem.

Whether the sites in question represent one or more interstadials the evidence is insufficient for a reconstruction of the climate and environment. The scattered information available, however, does not indicate any considerable difference from the Jämtland Interstadial. The southern site (Borlänge) indicates coniferous forest with *Picea*, while the northern sites have not been investigated in this respect.

The result will make new investigations of the old, supposed Jämtland Interstadial sites necessary. In some cases radiocarbon datings have given infinite values of a rather low age. With modern dating technique it is possible that some of them should get a finite age within the range of the period treated here.

DESCRIPTION OF THE TÅSJÖ SITE

TOPOGRAPHICAL SITUATION

The site Tåsjö is situated on lat. $64^{\circ}30'N$, long. $15^{\circ}33'E$, 8 km north of the northern end of Lake Tåsjön (Fig. 2). This is very close to the northern end of the province of Ångermanland and only 50 m inside its border.

Topographically the situation is in the flat valley of the River Saxån and only some 20 m from the right (western) bank of the river. The valley bottom is covered with till with a slightly undulating surface, locally more or less kame-like. The thickness of the till is unknown, but the river has formed an erosion valley with a depth of 10–20 m in the till. Because there is not a sharp and well-defined erosion channel, but a more diffuse and irregular depression, it is reasonable to assume that the erosion took place subglacially. The valley bottom is partly covered with outwash of coarse, stony gravel.

In the side of this erosion valley on the southeastern end of Mt. Långmarkberget a gravel pit has been opened in the till slope. The reason was probably that glaciofluvial gravel had been found locally there. This gravel pit forms the site, which has been named Tåsjö (pronounced *tɔ:ʃɔ:*) after the parish in which it is situated, since there is no suitable local name in the vicinity.

The height above the present sea-level is about 300 m. Thus the situation is well above the highest position of the late- and post-glacial sea-level, which was about 224 m where it reached closest to the site (Lindström 1973, p. 318).

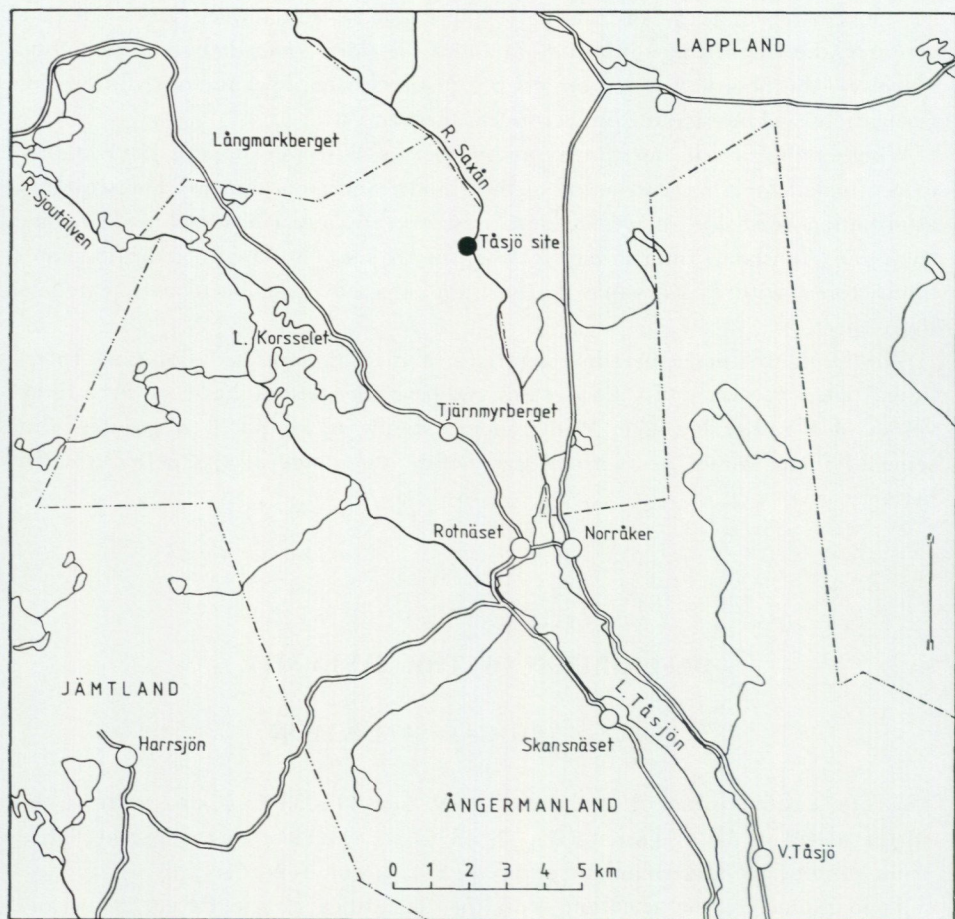


Fig. 2. Location map. The black dot denotes the Tåsjo site.

STRATIGRAPHY

In the Tåsjo gravel pit the stratigraphy changes from one part to the other. Most important is the easternmost part of a west—easterly, north-facing wall, that is, the part of the pit nearest to the river Saxån (Fig. 3). The stratigraphy along the steep slope towards the erosion valley of the river is very simple, consisting only of material, probably both till and gravel, that has slumped down immediately after the erosive phase. This material cuts the following stratigraphy with a steep discordance.

A. The uppermost bed is a till, the thickness of which varies from about 1 m closest to the scarp (the till has there been removed) to about 3 m some tens



Fig. 3. The Tåsjö site, section with the organic bed (F). This bed is seen as a dark band just above the slumped material at the foot of the section. Above the organic bed follow the gravel beds E—B. In the gravel the thin sand layer (D) is seen as a light band cut by a large dark spot to the right. Above the sand layer follow the gravel C and the more stony, somewhat lighter, poorly sorted gravel B. The covering till is the light bed at the surface, above a rather distinct boundary (exaggerated through the excavating method). — Photo J. Lundqvist 1976.

of metres from the scarp. The till in this place is stony, with rounded boulders and stones. The contact with the gravel, B, is gradational and one gets the impression that the till consists of gravel reworked by the ice. The beds A + B could be interpreted as an ice-advance deposit.

B. Below the till follows a gravel bed with a thickness of about 3 m. The gravel is similar to the sediments in many glaciofluvial deposits in this region of non-resistant sedimentary rocks. Thus, although it is well rounded and with a good sorting in the coarse fractions, it contains a considerable amount of silt, which makes it rather hard and somewhat cemented. The bedding is not well developed. These features vary between different strata.

C. For the reason mentioned above we may distinguish beneath bed B a layer of less stony gravel, with a thickness of 1.5 m but in other respects very similar to B.

D. Below this gravel follows a consistent, 10 cm thick bed of pure fine sand.

E. The lower part of the gravel series is a 3 m thick bed very similar to B, but with a more distinct horizontal bedding.

All the strata B—E show in general a glaciofluvial appearance. From them we can clearly separate the strata F (below, thickness c. 25 cm), which have a non-glacial appearance.

- F 1. 9 cm fine sand
- F 2. 3 cm fine sand with a content of organic stuff
- F 3. 2 cm sandy peat
- F 4. 1 cm peat with some sand
- F 5. 2 cm silty peat
- F 6. 2 cm silt with a content of organic stuff
- F 7. 1 cm silt
- F 8. 2 cm sand
- F 9. 0.5 cm silt
- F 10. 2 cm sand
- F 11. 1 cm silty gravel.

The whole bed F seems to be compressed and is rather hard. The organic content seen in the section itself is not high but blocks from this bed remaining on the floor of the pit often show a higher peat content. Wood remnants, twigs and leaves have been observed in these blocks. The variations seem to be very rapid in a horizontal direction as well as vertically (Fig. 4). This accounts for

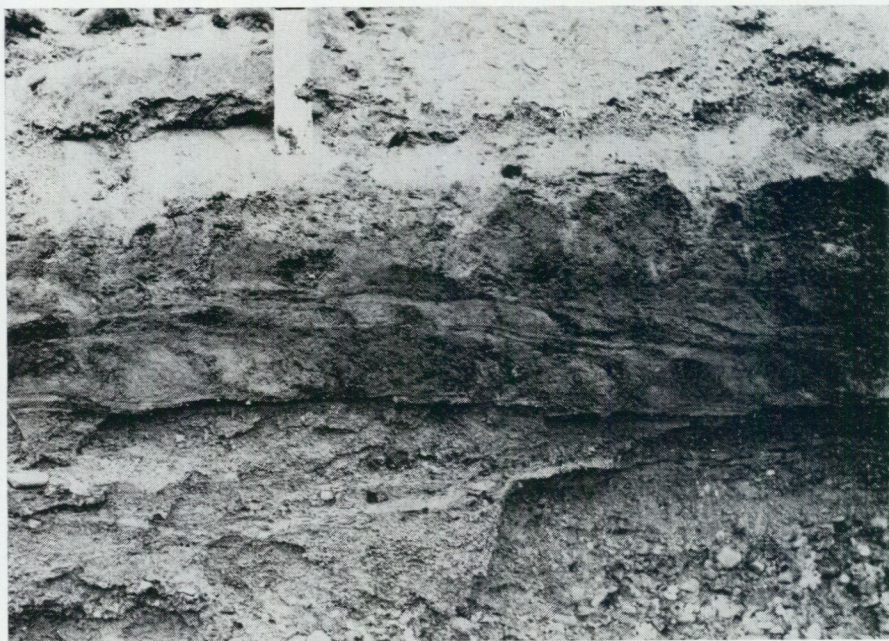


Fig. 4. Close-up of the organic bed F. The thickness between the gravel beds is here about 20 cm. The picture shows the wavy appearance of the bed, explaining the rapid horizontal changes of the composition. Possibly the bed is also somewhat disturbed by glaciotectionics or for other reasons. — Photo J. Lundqvist 1976.

the difference between the stratigraphy F1—F11 and the one shown in the pollen diagram, Fig. 5, taken a few dm from the point where layers F1—F11 were measured. These rapid variations might to some extent be caused by glaciotectonics, but probably they merely reflect the changes within a small stream over a considerable time.

G. Below the non-glacial series follows again a clearly glaciofluvial gravel. It is very coarse like beds B and E but lacks the content of fines. Thus it is much looser, but the uppermost part is cemented by iron hydroxide. The thickness is at least 4 m, but its bottom or substratum has not been observed.

The stratigraphy A—G can be followed about 15 m westwards. The thickness of the strata is principally the same, but shows some variations. Due to the undulating land surface the thickness of A and even B varies greatly. The bed F seems to be somewhat disturbed and more or less broken in some places, but its main units have the same thickness.

In the western part of the gravel pit, some 25 m west of the section described, the conditions are more irregular. The surface is much more undulating and the thickness of the upper beds is very variable. The till may be locally absent but elsewhere it may be at least 2 m thick, both on hill tops and in depressions. It is here much more stony and rich in boulders than in the main section. The appearance is chaotic, reminiscent of more typical ablation till.

The sedimentary strata below the till are similar to those in the main section with a few exceptions. Irregular sandy or silty layers occur in the upper gravel. The sand bed D is present and a little thicker. On the other hand, the non-glacial bed F is absent.

PETROGRAPHY

Because of the very complicated bedrock in relation to the ice movements one cannot expect petrographic analyses of the different beds to be very informative. In spite of this a few samples of the till and gravel beds have been studied in this respect. According to the author's old method (J. Lundqvist 1952) the gravel fractions 2—6 and 6—20 mm have been studied under binocular microscope. This investigation was carried out by mr Sven Björnbom. The following rock types have been identified.

Granites: To this category have also been added quartz and feldspar grains of more uncertain origin. The latter minerals most probably were derived from granitic rocks or very coarse-grained gneisses, but also minerals from pegmatitic dykes in other rocks may have been included. This group may have westerly or easterly origin, but the association with other rock types makes a westerly origin more probable. There is no clear evidence for an easterly origin.

Dolerites: These are very easily identified. They may have been derived from

TABLE 1. Petrographic composition

Sample	Fraction	Granite	Dolerite	Gabbro	Diorite	Amphibolite	Micaschist
18 till	F	—	1	—	+	—	—
18 till	C	—	—	—	—	—	—
17 gravel	F	—	—	—	—	2	—
17 gravel	C	2	1	+	—	4	—
16 gravel	F	8	1	—	—	3	—
16 gravel	C	3	—	—	—	2	—
15 gravel	F	7	3	—	—	1	1
15 gravel	C	7	1	4	—	+	1
19 gravel	F	12	6	1	—	2	+
19 gravel	C	3	6	2	+	—	2

the east or west, but the observations from Jämtland (J. Lundqvist 1969, Fig. 18) makes a westerly origin probable.

Gabbros, diorites and amphibolites: These rocks may occur in the granites in the east or north (Gee 1972, Pl. I) but most probably all the types, not only those which have been called amphibolites, come from the western nappes.

Mica schists: They also most probably originate in the western nappes.

Gneisses in general: Gneisses occur in the crystalline basement in the east but are also exposed in the west. Possibly also some coarse-grained schists and other metamorphic rocks from the nappes may have been referred to this group.

Meta-arenitic gneisses: This term refers to fine-grained clastic sedimentary gneisses. According to Björnbom, the main part of the group should probably be combined with the greywackes, but the separation is very difficult to make. Non-metamorphic greywackes are of local origin, but slightly metamorphic types also occur in the crystalline basement.

Greywackes: As mentioned above the non-metamorphic greywackes can not in the fractions used be separated from somewhat metamorphic types. The non-metamorphic types are all of local origin.

Alum shale: This rock is very easily identified and of local origin.

Sparagmites: This term here refers to the local arkoses, earlier described as the "sparagmite formation" (cf. the review by Gee 1972).

Quartzites: These are easily identified and of local origin.

Besides these rock types there is a small percentage (0—5 per cent) of rocks that have not been identified.

Five samples were investigated in this way. They had the following stratigraphic position.

No. 18 from the till cover in a position where the till is still in situ. This is not exactly above the organic bed.

(per cent; F = fine gravel, C = coarse gravel)

Gneiss	Meta-arenitic gneiss	Grey-wacke	Alum shale	"Spargmite"	Quartzite	?	Grains counted
7	27	63	—	—	2	—	332
5	46	49	—	—	+	—	258
7	18	37	—	3	31	1	405
9	29	28	—	3	23	1	261
5	25	32	—	2	23	1	300
11	25	34	—	7	18	—	263
32	—	32	—	6	17	1	370
23	—	30	1	8	22	4	306
6	1	18	5	8	39	1	265
12	9	18	5	12	25	5	241

No. 17 from the gravel below sample 18. The gravel bed can be followed directly between points 16 and 17.

No. 16 from the upper part of the gravel above the organic bed (bed B in the stratigraphy).

No. 15 from the gravel bed just above the organic bed and below 16 (bed E in the stratigraphy).

No. 19 from the gravel bed below the organic bed and points 15 and 16 (bed G in the stratigraphy).

The complete result of the petrographic investigation is shown in Table 1. As is obvious there are some differences between the samples and fractions but these variations seem to be somewhat irregular and are probably not significant. At least they do not permit any detailed conclusions except that there seems to be no material of undoubtedly easterly origin. The rock types are either local or can be of westerly (or northwesterly) origin. The associations as a whole make this interpretation probable.

The variations are more clear if we group the rock types together. If we separate the local rocks from those that have been transported from further afield (from W or NW) we find the variations shown in Table 2. Here also the two gravel fractions have been grouped together. The variations imply that the lower gravel bed and the gravel deposited first after the interstadial has the highest percentage of originally distant material. A possible explanation could be that the gravel consists of reworked till that is not of entirely local origin.

In the upper beds the amount of local rocks is higher. Particularly this applies to the till, which is of pronouncedly local origin. The gravel immediately underlying it is a little richer in long-distance material, probably derived by erosion of the older strata or due to the fact that the direction of transport has been different for the till and gravel. The till was deposited by ice moving from

TABLE 2. Percentage of local and distant rocks

Sample	Local rocks	Distant rocks
18 till	93	7
17 gravel	84	15
16 gravel	87	12
15 gravel	59	40
19 gravel	71	28

the northwest, while the meltwater depositing the gravel must have followed the valley from a more northerly direction.

Thus the petrographic composition of the different strata has some importance for the local stratigraphy. It cannot be used, however, for a more regional correlation with other interstadial sites or till stratigraphies.

FAUNA

by G. R. Coope, Department of Geological Sciences, University of Birmingham

The only animal fossils from this site were insect remains extracted from the organic stratum bed 7. Firstly insect fossils were recovered from the same series of eleven samples that were used for pollen analysis but it was found that insects only occurred in the middle part of the bed and that insects were absent from the upper four and lower two samples. The result of this first investigation is shown in Table 3. There seems to be little significance in the stratigraphic positioning of the various species, probably because of the smallness of the samples used. A second investigation was therefore made using a bulk sample (about

TABLE 3. Insect fossils in the different layers within the organic bed

FAMILIES & SPECIES NAMES	LAYER F5	LAYER F6	LAYER F7	LAYER F8	LAYER F9
CARABIDAE					
<i>Diacheila polita</i> Fald.	1	—	—	1	—
<i>Dyschirius globosus</i> Hbst.	—	—	—	—	1
<i>Amara alpina</i> Payk.	—	1	—	—	—
DYTISCIDAE					
<i>Hydroporus acutangulus</i> Thoms.	—	1	—	—	—
STAPHYLINIDAE					
<i>Olophrum boreale</i> Payk.	—	—	2	1	1
Subfamily Aleocharinae <i>gen. et spec. indet.</i>	—	1	—	—	1
BYRRHIDAE					
<i>Simplocharia metallica</i> Sturm	—	—	—	1	—
<i>Byrrhus arietinus</i> Steph.	—	—	1	1	—

2 kg) of the whole organic bed and from this a larger faunal list was obtained shown in Table 4. The environmental significance of these insect species will be considered here as if they all had lived together at the same time.

Diacheila polita is characteristic of the northern tundras and also occurs on the high cold steppes of central Asia. Its nearest modern locality is on the eastern extremity of the Kola Peninsula. This species lives on peaty soils in open country.

Bembidion mckinleyi is a high northern species in Scandinavia, known also from northwest Canada and Alaska. This species is confined to completely barren places often by temporary banks of streams with very cold water.

Amara alpina is one of the most characteristic animals of the tundra and of the alpine zones of the mountains occurring in many places in Scandinavia but almost invariably above the tree line. It is a species of open rather dry habitats with sandy or gravelly soil.

Pterostichus brevicornis is a high northern species that lives on rather dry, meadow-like places on both the tundra and in the uppermost parts of the forest zones. It has a circumpolar distribution as far west as the Kola Peninsula.

Agonum exaratum is one of the most arctic species of this genus almost always occurring above the tree line. It has an almost circumpolar distribution reaching as far west as the eastern extremity of the Kola Peninsula. This is a species of soft marshy ground at the margins of pools with *Carex* and *Eriophorum*.

Hydroporus acutangulus is a small water beetle that inhabits peaty ponds. Though it is widespread on the tundra its distribution extends down into the coniferous forests.

Helophorus sibiricus is widespread in the mountains and north of Fennoscandia and eastwards into northern Siberia and Mongolia. This is a species of sandy river banks where it is found in shallow ponds sometimes at the edge of melting snow.

Helophorus khnzoriani is the most unexpected member of this fauna because it is only known today from the Altai and Mongolian Altai mountains where it is abundant in water on the tundra-alpine zones about 2500—2600 m. The only other species with which the Tåsjö fossils could be confused is *H. niger* J. Sahlb., a northern asiatic species whose range extends westwards to the arctic Urals and which would have been the more expected species in a Swedish fossil assemblage. Yet the fossils clearly resemble *H. khnzoriani* rather than *H. niger* in their very e-faced sculpture of the head and pronotum, their uniform maroon colour of the head and pronotum and in the weakness of the intercalary striae.

Boreaphilus nordenskiöldi is typically a tundra species with an almost circumpolar distribution that extends westwards as far as Novaya Zemlya.

TABLE 4. Insect fossils from the layers in Tab. 3 and a bulk sample

CARABIDAE

- Diacheila polita* Fald. (2)
Dyschirius globosus Hbst. (1)
Bembidion ?mckinleyi Fall. (3)
Amara alpina Payk. (1)
Pterostichus ?brevicornis Kby. (1)
Agonum exaratum Mnh. (1)

DYTISCIDAE

- Hydroporus acutangulus* Sturm (3)
Hydroporus arcticus Gyll. (1)
Agabus spp (2)

HYDROPHILIDAE

- Helophorus sibiricus* Mtsch (2)
Helophorus khnzoriani Angus (5)

STAPHYLINIDAE

- Pycnoglypta lurida* Gyll. (1)
Olophrum boreale Payk. (5)
Boreaphilus nordenskiöldi Makl. (5)
Stenus sp? (2)
Aleocharinae gen. et sp. indet (7)

BYRRHIDAE

- Simplocaria metallica* Sturm (1)
Byrrhus arietinus Steff. (1)

CHRYSOMELIDAE

- Donacia* sp. (1)
Melasoma collaris L. (1)

CURCULIONIDAE

- Apion* sp? (2)
Phytobius quadrituberculatus Fab. (1)

Diptera misc. TIPULIDAE and CHIRONOMIDAE.
 Hymenoptera parasitica.

Simplocaria metallica is a boreo-alpine species whose distribution extends down into the coniferous forest only in southern Finland. It lives on open habitats with moss upon which it feeds.

The local environment suggested by the Tåsjo insect fauna is of an open tundra-like landscape with occasional small pools. The local vegetation appears to have been restricted, hence the small number of phytophagous insect species. Moss is indicated by *Simplocaria metallica* and *Byrrhus arietinus*. *Melasoma collaris* lives on *Salix* and the small weevil *Phytobius quadrituberculatus* feeds upon *Polygonum*.

remnants are in most cases slow-growing small twigs of the types occurring above the tree-line and on tundras. There is no indication that the other fragments could have come from species belonging to a different floristic environment.

Selaginella selaginoides, occurring as macro-spores, is a species common in the alpine and subarctic environment. However, it is found over a large part of Sweden today. As to the climate and environment during the time of deposition it is not very informative.

Cenococcum graniforme, represented by sclerotia, is a systematically problematic fungus found in the temperate and arctic regions. Most commonly it occurs in mor soils, in different types of forest vegetation as well as heaths and bogs (Ferdinandson & Winge 1925). Thus it is not very informative but could nevertheless be considered typical for the environment indicated by the plant remnants.

The three mosses that have been named to species all occur in most of Sweden today. They belong to fens and shores and could thus be an indication of the local environment at the deposition of bed F. As to the climatic conditions they are not informative.

The palynology has been carried out by Mrs Karin Hedin. Concentration of the pollen was by sedimentation separation (Påsse 1976) and the acetolysis method of Erdtman (Fægri & Iversen 1964). The determination offered some problems because almost all pollen and spores were strongly corroded. The diagram (Fig. 5) is composed of three main components: pollen of trees (mainly *Betula* and *Pinus*), a considerable amount of shrub pollen (*Salix* and *Juniperus*) and the dominant part of the diagram — pollen of herbs. Among the herbs, pollen of Gramineae and Cyperaceae generally make up the main part. Dominant among pollen of herbs are the Caryophyllaceae, especially in the upper part of the diagram.

The component of tree pollen is most common in the upper and lower part of the stratigraphy, in the entirely mineral sediments. There is a clear development from conditions characterized by a relatively dominant amount of tree pollen through conditions where the group of tree pollen plays a more insignificant role and back to conditions similar to the first. Evidently the tree pollen has undergone long-distance transportation. At a time when there is a relatively rich production of pollen from the local tree-less flora the tree pollen is proportionally suppressed, but when there is no local vegetation the percentage of the more or less long-transported tree pollen increases.

The shrubs and herbs represent the local flora. As far as can be estimated from the few taxa identified, the local pollen flora corresponds to a light and open environment, probably mountain heath — or tundra — and fens. The fact that the amount of Cyperaceae pollen decreases in the upper part of the diagram, to some extent being replaced by Caryophyllaceae pollen, can be an indication that a dry and cold climate follows upon moister conditions. In the

composition of the pollen spectra the relatively high percentages of shrub pollen is most characteristic. It is rather different even from the conditions in the present-day mountain heaths (cf. a postglacial pollen diagram from the same region, e.g. J. Lundqvist 1969, Fig. 99). In this respect the pollen diagram is much more similar to interstadial diagrams, e.g. the Pilgrimstad diagram (J. Lundqvist 1967, Fig. 46). Particularly the content of *Juniperus* pollen is characteristic.

As a whole the pollen diagram and its components agree well with the picture of the environment indicated by the other fossils. This means open conditions, probably a fen on a mountain heath. The distance to forests was considerable. The dominance of *Betula* pollen over the more easily transported *Pinus* — and a few *Picea* — pollen grains indicates that the pine forest was far more remote than the birch forest.

Diatoms, mainly fragmented, occur in samples 3, 4, 6, and 7 and particularly in no. 10. The taxa identified by Urve Miller are listed in Tab. 6. They belong to a fresh-water environment and indicate sedimentation conditions characteristic of a small water body or a fen with water of low pH (oligotrophic), mixed with more neutral.

INTERPRETATION OF THE TÅSJÖ SITE

GEOLOGICAL DEVELOPMENT

The geological development indicated by the Tåsjö site can be outlined in the following way.

1. At the time when sedimentation began at the Tåsjö site the region was probably covered with ice moving from the north or northwest though there is no conclusive evidence that the locality itself was covered with ice in this stage. The ice might theoretically have stopped before the ice front reached the place. However, the rich amount of gravel, which is most probably of glaciofluvial origin, is an indication that the ice was not far away.

2. After the glaciofluvial sedimentation had ceased there was a period with much weaker stream activity and less sedimentation. The area was barren and covered with heath or tundra vegetation. Probably there was still a stream in the valley. The fauna and flora give a picture of a stream with bare gravel banks flowing through a heath landscape with fens and probably small pools around the stream. The deposits of bed F accumulated in such a pool or possibly calm-water branch of the stream.

The temperature corresponded to that of the mountain region today. The tree-line must have been situated considerably more than 450 m lower than today. It is evident that the climate, even during the warmest part of the period,

TÅSJÖ: INTERSTADIAL

TABLE 6

LIST of DIATOM TAXA :					
+ = RARE					
++ = RATHER COMMON					
+++ = COMMON					
SAMPLE NO	3	4	6	7	10
<i>Achnanthes (Eucoconeis) flexella</i> (Kz) Grunow					+
<i>Anomoeoneis serians</i> (Bréb.) Cleve		+			
<i>Cymbella aequalis</i> Smith					+
<i>Cymbella aspera</i> (Ebg) Cleve	+				
<i>Cymbella borealis</i> Cleve					+
<i>Cymbella cf. norwegica</i> Grunow					+
<i>Cymbella perpusilla</i> A.Cleve					+
<i>Cymbella</i> spp.	+	+			+
<i>Diploneis ovalis</i> (Hilse) Cleve	+				+
<i>Eunotia arcus</i> Ebg	+			+	+
<i>Eunotia faba</i> (Ebg) Grunow					+
<i>Eunotia lunaris</i> (Ebg) Grunow	+				
<i>Eunotia pectinalis</i> (Kz) Rabenhorst					+
<i>Eunotia praerupta</i> Ebg	+				++
<i>Eunotia robusta</i> Ralfs				+	+
<i>Eunotia</i> spp.	+	+		+	+++
<i>Fragilaria pinnata</i> Ebg	+				+++
<i>Gomphonema intricatum</i> Kz				+	+
<i>Gomphonema olivaceum</i> (Lyngbye) Kz					+
<i>Melosira cf. italica</i> v. <i>alpigena</i> A.Cleve (<i>Melosira distans</i> v. <i>alpigena</i> Grunow) ?	+				+++
<i>Navicula pupula</i> v. <i>aquaeducta</i> (Kraske) Hust.					+
<i>Pinnularia microstauron</i> (Ebg) Cleve	+				
<i>Pinnularia molaris</i> Grunow					+
<i>Pinnularia</i> spp. ("Majores")	+				+
<i>Tabellaria fenestrata</i> (Lyngbye) Kz				+	+
<i>Tabellaria flocculosa</i> (Roth) Kz	+				++
FRAGMENTS, SMALL (mainly <i>Eunotia</i> , <i>Pinnularia</i> , <i>Tabellaria</i>)	++	+	+	+	+++

DETERMINATIONS: U. Miller 1978

was much cooler than it has been in postglacial time. The difference from a true interglacial is great (e.g. J. Lundqvist 1971) and obviously the period in question must correspond to an interstadial with cool continental conditions.

3. The stream through the valley later became a glaciofluvial character. This change corresponds to the approach of a glacier front in the northern part of the Saxå valley. The ice must have advanced from the mountains in the north or northwest, but details about the advance are unknown.

4. The advancing ice covered the Tåsjö site. Probably there were different movements within this ice, but it has not been possible to identify them in the Tåsjö stratigraphy.

5. Towards the end of the last glaciation the ice retreated from the site. The covering till bed was left behind. Already before the place became free of ice, subglacial meltwater erosion affected the area and a subglacial tunnel valley was formed through the older deposits. After deglaciation the meltwater from the ice and, later, the postglacial river Saxån followed the tunnel valley. The valley was partly further eroded, partly glaciofluvial and fluvial sediments accumulated. The older, glaciofluvial and interstadial, deposits were removed in the centre of the valley but were left behind in the terraces surrounding the tunnel valley.

6. Very soon after the deglaciation the climate was considerably milder than during the interstadial. The tree-line was even higher than today and the vegetation was richer and much more differentiated. This is clearly demonstrated by dates from fossil pine stumps above the present-day tree-line and several pollen diagrams (see J. Lundqvist 1969).

DATING

From the foregoing it is evident that there are at least two interstadials that should be considered for the correlation of the Tåsjö site. These are the Jämtland Interstadial and the interstadial complex around 40 000—30 000 BP. Because no site in northern Sweden from the younger period has been described thoroughly enough to define the interstadial there, there is no local name for the period in the region under consideration. However, it corresponds to the Upton Warren complex in Great Britain, the Denekamp and Hengelo interstadials on the European continent and the Göta Älv or Younger Dösebacka—Ellesbo Interstadial on the Swedish west coast.

The later period can immediately be excluded from the discussion by radiocarbon dating. The organic matter from the Tåsjö site has given "infinite age" and by means of extended counting time the value given is $> 50\ 000$ (St-5703). Therefore a comparison with the Jämtland Interstadial is necessary.

According to J. Lundqvist (1967) the Jämtland Interstadial was characte-

ized by a mean annual temperature 2–3°C lower than today. Such a lowering of the temperature would mean a displacement of the tree-line down into the interior of northern Sweden. It is appropriate here to consider the conditions shown in G. Lundqvist's (1964, Fig. 17) illustration of the vegetation zones in-

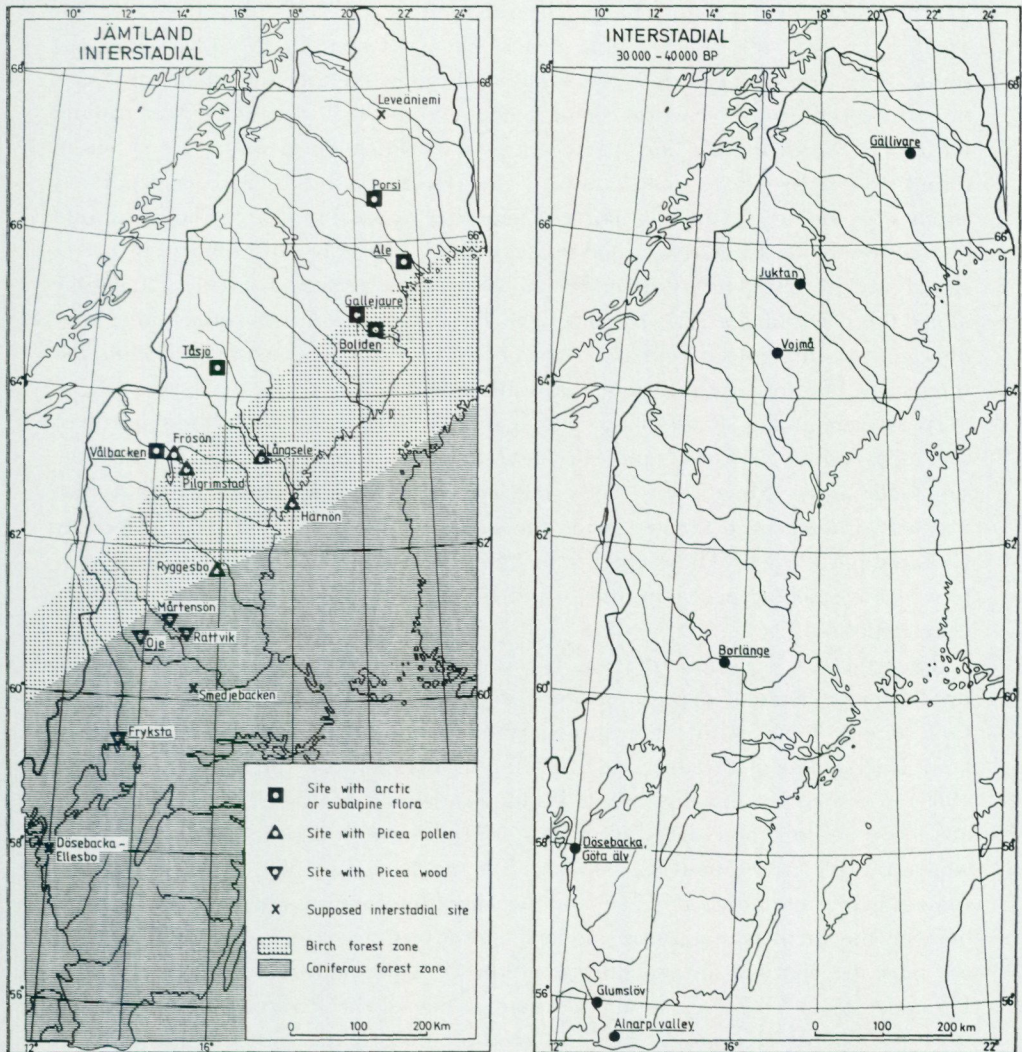


Fig. 6. The interstadial sites of central and northern Sweden. The left map shows the sites so far referred to the Jämtland Interstadial (redrawn after G. Lundqvist 1964 and J. Lundqvist 1967). The right map shows the younger interstadial deposits (40 000–30 000 BP) whether they belong to one or more interstadials. So far our information does not permit the indicating of vegetation zones like in the left map. There is no evidence, however, that the main conditions should have been very different during these periods.

In both maps underlined names represent radiocarbon dated sites.

licated by the interstadial sites together. According to the opinion of the present author this zonation corresponds well to the conditions during the Jämtland Interstadial.

The figure in question has been slightly modified (Fig. 6) according to the opinion presented by the author (J. Lundqvist 1967) and to some new finds. The modification does not change the zonation of the vegetation from the original figure. It still shows a zone where the sites contain *Picea* wood in the south. This zone, where the spruce obviously grew in the interstadial in question, traverses central Sweden in a southwest—northeasterly direction around lat. 61°N. North of this line there is a zone in which *Picea* wood has not been found, but where *Picea* pollen occurs, the result of long-distance transport. It reaches a second southwest—northeasterly line across central Sweden around lat. 64°N. Finds of *Betula* wood indicate that this zone approximately corresponds to the birch forest zone. Probably this forest reached north of the zone along the coast in the east. North of the *Picea* pollen limit the interstadial sites only contain microfossils of an arctic or alpine flora. Pollen of *Pinus* and *Betula* occur, but are most probably long-transported.

As is seen in Fig. 6 the Tåsjö site is one of those situated farthest north of the supposed birch forest limit. Because the birch forest probably reached the site Gallejaure (Magnusson 1962) but not Ale (Fromm 1960) we find that Tåsjö is situated even farther inside the subarctic zone than Porsi (described by G. Lundqvist 1960). These conditions agree very well with what has been proposed above about the environment and temperature when the Tåsjö sediments were deposited.

Thus there is no doubt that, as far as the general conditions are concerned, the Tåsjö interstadial deposit can be correlated with the Jämtland Interstadial. Only one fact makes this a little uncertain. The correlation between the Jämtland Interstadial in Sweden and the Finnish Peräpohjola Interstadial (Korpela 1969) seems to be obvious (see J. Lundqvist 1974 and others). However, there are some radiocarbon dates from this Finnish interstadial indicating a somewhat younger age (about 42—45 000 BP, see Korpela 1969, Kujansuu 1972) than the one obtained at Tåsjö but because the contamination of the sample by even the smallest amount of modern carbon can account for such differences, we must be cautious in the interpretation of such high radiocarbon ages (cf. Hirvas *et al.* 1976). There is also a recent dating of the Peräpohjola Interstadial to > 55 000 BP (Kujansuu 1975). Therefore the slightly different radiocarbon ages should not be taken as evidence against a correlation between the Tåsjö site and the Jämtland Interstadial. The conclusion of the present study must be that the Tåsjö organic deposits belong to the Jämtland Interstadial.

CONCLUSIONS

The new observations presented in this paper have given the following main results.

The Tåsjö site has a fauna and flora which provide a picture of a rather cold continental, subarctic or subalpine, climate throughout the whole period represented by the organic deposits. The climate might have been moister during the first and middle part of the period, then dryer. The local environment was an open country of tundra or mountain heath. The radiocarbon age of the deposit is $> 50\ 000$ BP. The deposit can be correlated with the Jämtland Interstadial.

Several new observations of organic material or deposits with radiocarbon ages between, roughly, 41 000 and 30 000 BP are an indication that the main part of the central area of glaciation may have been ice-free during one or more periods in Middle Weichselian time. This is important because it means a considerable revision of our former idea about the course of the Weichselian glaciation. As a matter of fact it means, together with older observations from southern and western Scandinavia, that the wide extension of the Weichselian ice sheets existed only during limited parts of the Weichselian glacial. The evidence so far available does not indicate that the conditions during this (or these) younger interstadial(s) differed much from those of the Jämtland Interstadial.

The fact that the ice extended outside the Scandinavian mountain range during so limited periods may lead to new consequences about the causes and dynamics of the glaciation. Maybe we have to imagine the advance of the ice outside the mountains as a kind of short-lived surges. This, however, seems less plausible. More likely is a hypothesis implying that when once the ice advanced into the foreland of the mountains large areas were brought close to the threshold of glaciation. The increased albedo and the chilling effect of snow remaining in the summers could then give a feedback effect resulting in a regional and instant glaciation of the lowlands. This means a counterpart to the regional vertical downwasting of the ice during the deglaciation in some areas. A climatic development that could have had this effect has been suggested by some authors (Lamb & Woodroffe 1970, Bradley & Miller 1972, and others). A discussion of this problem, the causes of glaciations, is, however, far beyond the scope of the present paper.

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