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Seismically deformed sediments in the Lansjärv area, Northern Sweden

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1991-05-15

ABSTRACT

Many fault scarps, interpreted as post- or late-glacial in age, occur in northern Sweden and adjacent parts of Finland and Norway. The dimensions of the fault scarps, extending up to about 150 km and with vertical displacements between 5 and 30 m, suggest that the faulting may have been associated with violent seismic activity. This assumption is supported by numerous landslides occuring in the vicinity of the fault scarps. The conception of strong seismic activity connected with the faulting is also strongly supported by the fact that different types of sediment deformation, interpreted as being seismically induced, were found in the Lansjärv area in northern Sweden when actively sought after. The types of deformation observed occur mainly in layered sandy and silty sediments but are also recorded in glacial till. Deformation is thought to be due to vibration, liquefaction and compaction of unconsolidated and saturated deposits. Extensive deformation proved to be very common in sediments deposited, or already in existence, during the deglaciation phase or shortly after whilst almost no deformation was found in younger deposits. This agrees fully with the concept of a short-lived early postglacial co-seismic faulting. The report presents an exposition of the different types of sediment deformation found in the Lansjärv area and aims to serve as reference material when studying possible seismites in other areas.

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1 INTRODUCTION

Fault scarps, interpreted as post- or late-glacial in age, occur in northern Sweden and adjacent parts of Finland and Norway (Figs. 1 and 2). The presumed Late Quaternary age of the fault scarps is based mainly on their remarkably fresh appearance in the glacially smoothed terrain and it is assumed that these features would not have survived the impact of the most recent continental ice sheet. Furthermore, at many localities, the relation between fault scarps and different late-glacial features, e.g. eskers, melt-water channels and shore-lines, suggests that faulting occurred subsequent to, or in close connection with, local deglaciation.

The dimensions of the fault scarps, extending up to about 150 km and with vertical displacements between 5 and 30 m, suggest that the faulting may have been associated with violent seismic activity. This assumption is supported by the presence of numerous landslide scars, developed in glacial till and occuring in the vicinity of the fault scarps (Fig. 2).

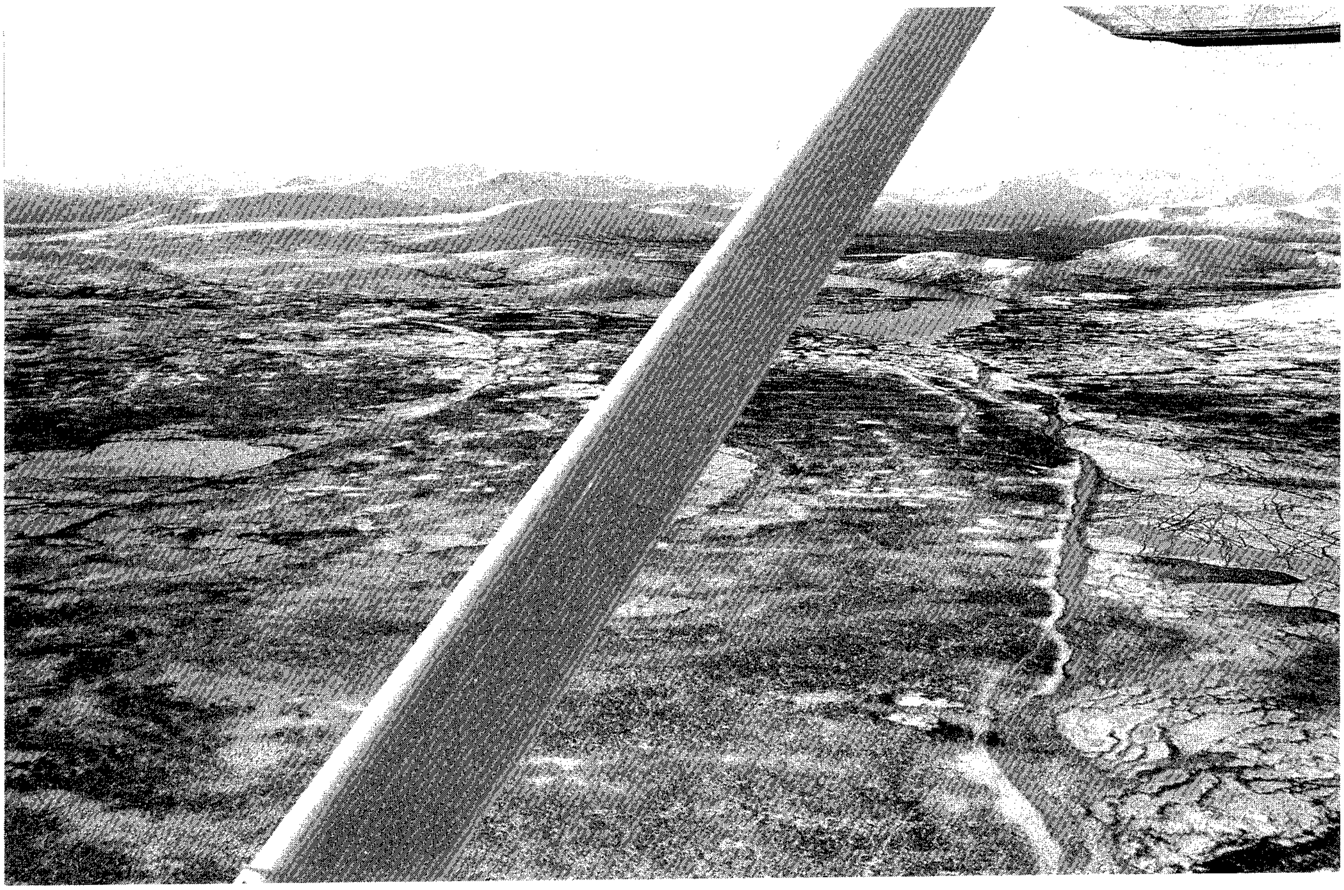


Figure 1. The Pärvie fault at lake Kamasjaure (in the background) some 70 km north of Kiruna. The main fault scarp (to the right) is up to about 10 m high and cuts the drumlinoid features reflecting the latest ice-flow direction during the last glaciation (from left to right). Although only one or two metres high the minor fault scarp to the left is very prominent. The photograph looks west. Photo: R. Lagerbäck 1981. Approved for publication.

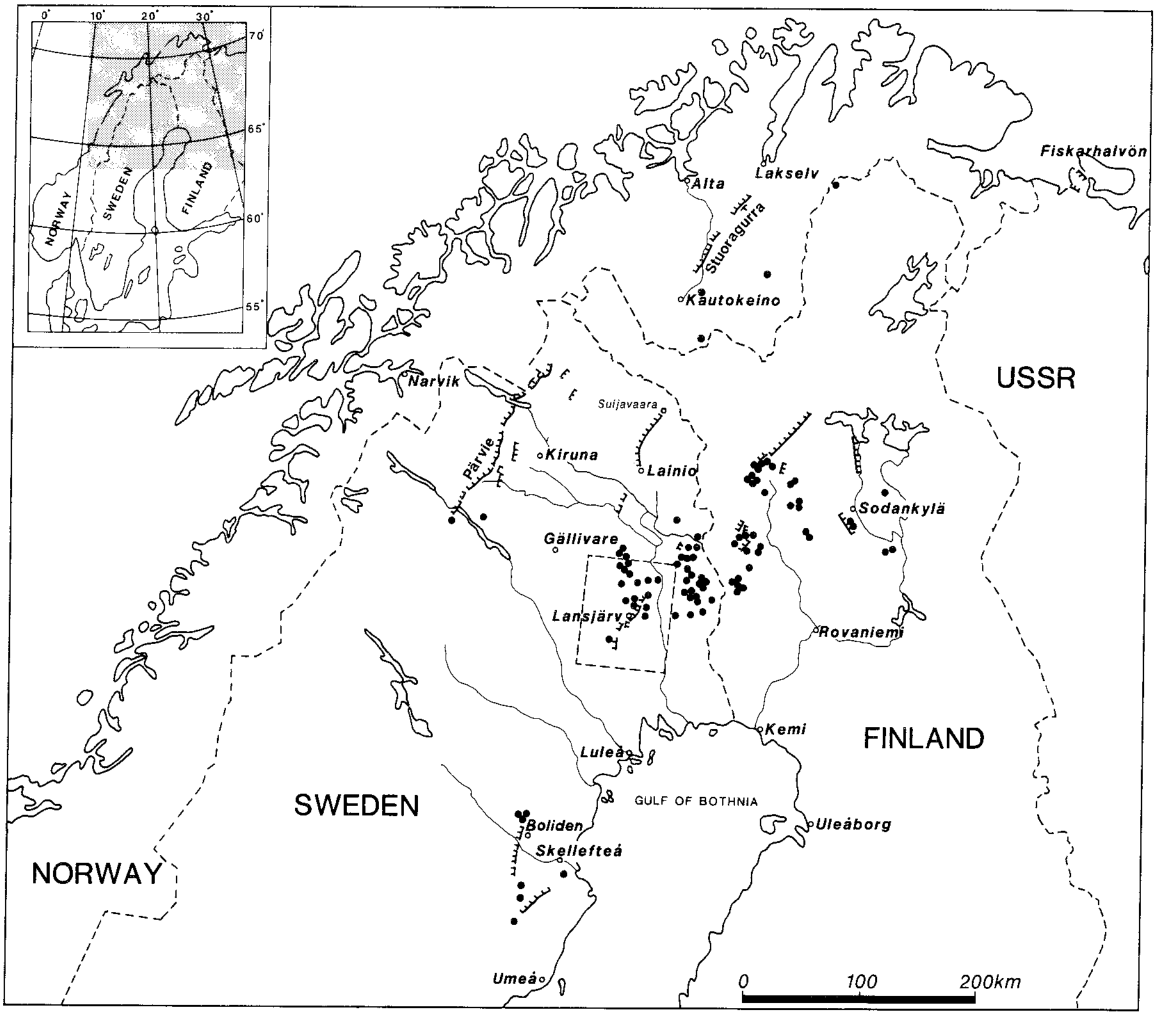


Figure 2. Location of landslides (black dots) and fault scarps interpreted to be of late- or postglacial age in northern Fennoscandia. Barbs along fault lines are turned towards the lower block. The Lansjärv area is framed. Information is obtained from: Tanner 1930 (faults at Fiskarhalvön), Kujansuu 1964, 1972 and pers. comm. (faults and landslides in Finland), Lagerbäck 1979 and unpubl., Lagerbäck & Witschard 1983 (faults and landslides in Sweden), Olesen 1988 (the Stuoragurra fault in Norway), L. Olsen, Geological Survey of Norway, pers. comm. (landslides in northernmost Norway), Svedlund 1985, Rodhe et al. 1990 (additional information about faults and landslides in the Boliden-Skellefteå district in Sweden)

In the Lansjärv area in northern Sweden (Figs. 2 and 3) attempts have been made to date fault displacement relative to the glacial and postglacial stratigraphy by trenching across the fault scarps (Lagerbäck 1988a and 1990). It is shown that the faulting occurred soon after the local deglaciation some 9 000 years ago and there are no signs of movement since that time.

Previous investigations have indicated that extensive deformation of primary sedimentary structures occur in different types of deposits within the Lansjärv area and it is concluded that these deformations probably to a large extent are caused by high magnitude earthquakes in connection with early postglacial faulting in the area (Lagerbäck 1988a and 1990). The faulting constitutes an obvious source of seismic energy generation and there is a reasonable causal relationship between sediment deformation and earthquakes associated with this faulting.

As the concept of extensive postglacial co-seismic faulting in Sweden is fairly new, and as seismically deformed glacial or postglacial sediments have not been previously studied here, it was considered important to build up knowledge cocerning the paleoseismic features. The Lansjärv area is well suited to paleoseismic research; the fault scarps are clearly defined, the time of faulting is well known in relation to deglaciation and the fact that the area was largely covered by the postglacial sea after deglaciation theoretically offers good opportunities for finding seismically induced liquefaction structures in sediment which were saturated at the time of faulting. Furthermore, the area is accessible by a rather extensive road network. Because of these arguments it was decided to continue and extend the research on the paleoseismic indicators in the Lansjärv area.

The present study aims to widen the knowledge of the character, variation and extension of the seismically induced deformations occuring in different types of deposits in the Lansjärv area. The study was carried out during August 1990. Trenches or minor pits were dug in different types of sediments and environments and at varying distances from the fault-scarp set. Included in the report are also some sites examined during previous investigations.The report presents an exposition of different sediment deformations met with and attempts to assess which of these are of seismic origin. The optimistic view is that the variety of deformational features found in the Lansjärv area, a selection of which is presented here, may serve as a reference in connection with studies of possible seismites in other areas of Sweden and elsewhere.

2 THE LANSJÄRV AREA

The Lansjärv area (Fig. 3) is situated in the forested part of northernmost Sweden and it is crossed by the Arctic Circle. The topography is gently undulating with scattered hills. The area lies between about 50 and 450 m above sea level and the terrain generally rises from the east towards the west. The southern, eastern and central parts of the area are largely located below the Holocene highest coastline which varies from about 205 m in the south-eastern part to 175 m in the north-west.

Bedrock is exposed in only a small percentage of the area and generally the outcrops are extensively frost-shattered. Glacial till is the predominant Quaternary deposit. The tills in general have a sandy composition and often constitute morphologically prominent features such as hummocky moraines and drumlins. The drumlinoid features mainly belong to a north-westerly directed ice-flow system deriving from the first Weichselian glaciation (Lagerbäck & Robertsson 1988). Features belonging to this system are spread over the entire area and they are generally very well preserved despite being exposed to younger glaciations.

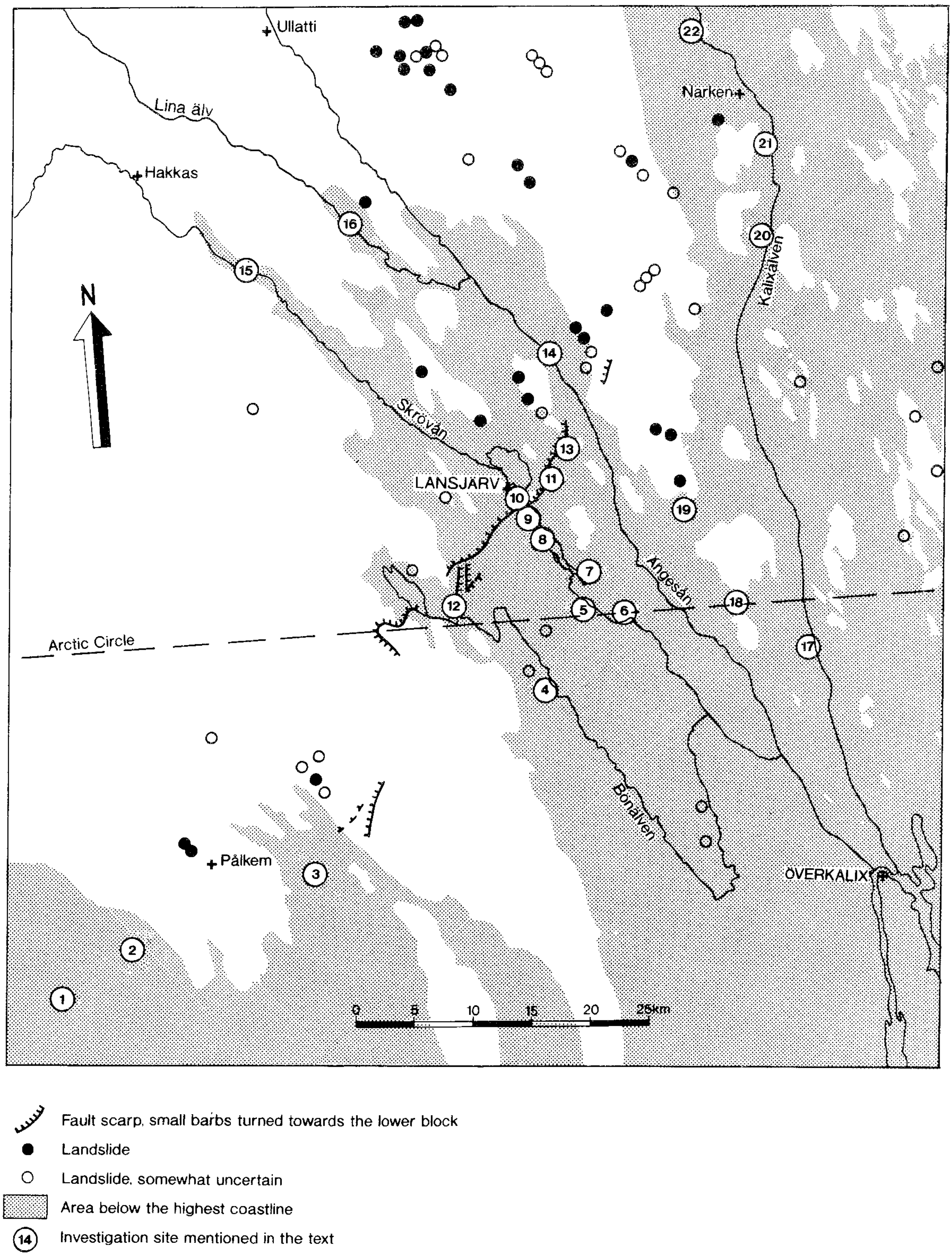


Figure 3. Map of the Lansjärv area showing the location of fault scarps, landslides, areas below the highest coastline and investigation sites mentioned in the text. Sites: 1. Lillåfors 2. Slättheden 3. Vuolpolandet-Svanamyran 4. Rotheden 5. Furuholmsbäcken 6. Sockberget 7. Svanaträsket 8. Kallvikmyran 9. Lillsundet 10. Storsundet 11. Missesberget 12. Pokölen 13. Furuträsket 14. Ängeså 15. Mäntyvaara 16. Lina älv 17. Storbäcken 18. Lilla Furuberget 19. Svartbergsbäcken 20. Torisevanmännikkö 21. Vuopionsuanto 22. Mestoskangas

The Quaternary stratigraphy is complex. Two or more till beds appear to be the rule rather than the exception down to 4-6 m below ground surface. The typical sequence is one, or occasionally two, brown or greyish brown fairly thin till beds resting on a thick grey till. These tills date from different stades of the Weichselian glaciation. Sometimes a brown, very compact till bed, interpreted to be of Saalian age, is encountered under the grey till. The different till beds are often intercalated by water-lain sediments, representing ice-free periods. Sometimes these older sediments occur on the surface without any till cover or covered only by scattered boulders and stones. In these cases it is often difficult without doing a more thorough examination to determine whether the sediments are "young" or "old".

According to traditional opinion (e.g. Lundqvist 1961, Fromm 1965) the area was deglaciated around 9000-8500 B.P. Late- and postglacial sediments of different geneses are fairly common below the highest coastline but sediments deriving from the deglaciation of the most recent ice sheet occur surprisingly sparsely and the beds are often thin.

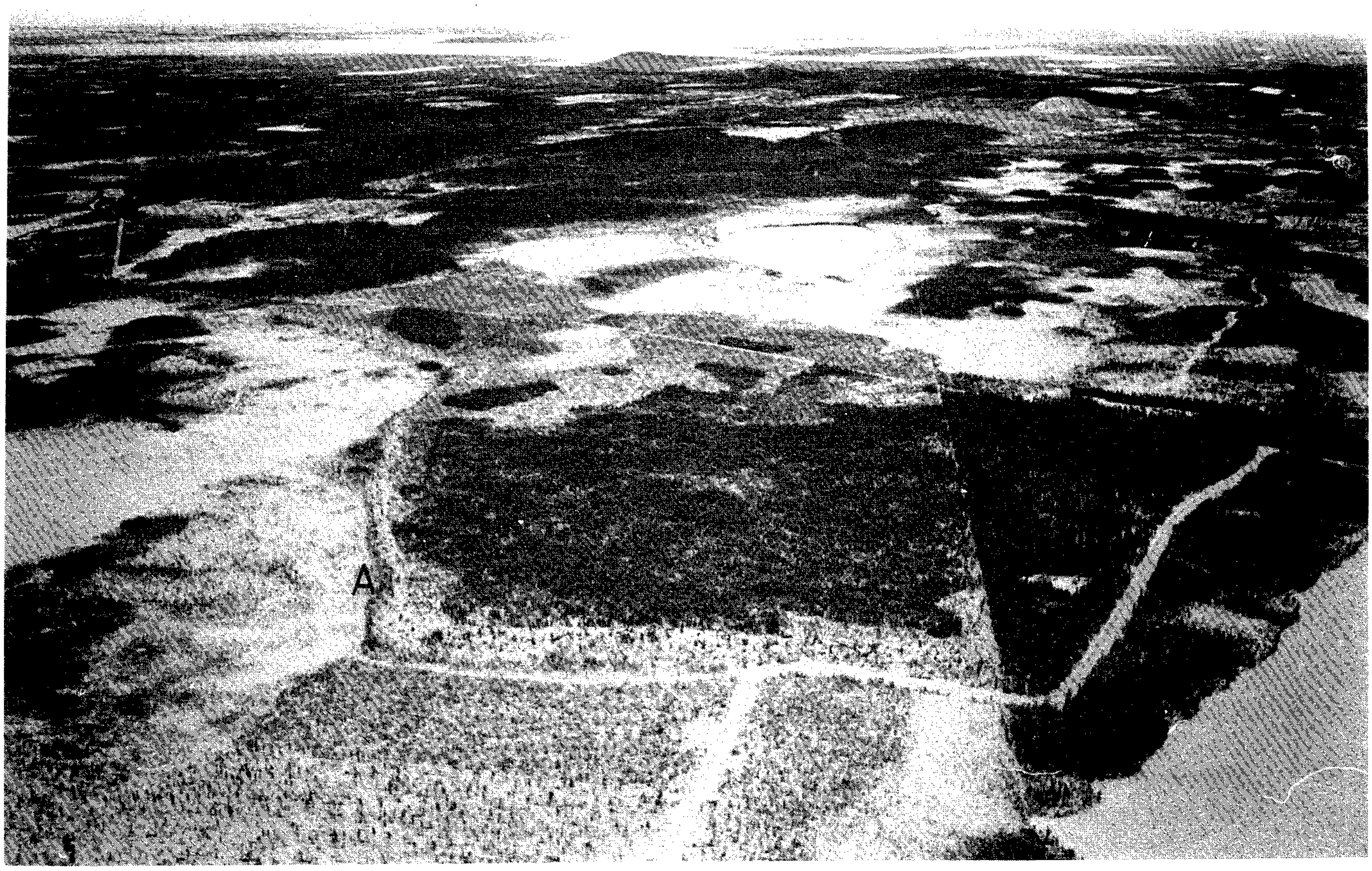


Figure 4. The highly deviant fault scarp line at Risträskkölen some 15 km to the SW of Lansjärv. The scarp in the foreground is about 20 m high and bedrock outcrops occur at A. The photograph looks east. Photo: R.L. 1976. Approved for publication.

The Lansjärv fault complex is composed of four major and several minor fault scarp lines which together form a 50 km long fault set with a SSW-NNE orientation (Fig. 3). The longest continuous fault-scarp segment is 17 km. The identified fault scarps generally range in height from between 5 to 10 m, with slightly more than 20 m as a single exception (Fig. 4). Most of the scarps down-throw to the west but some segments in the central and northern parts of the fault set show an eastward down-throw. The bedrock along the fault scarps is almost entirely covered by Quaternary deposits, mainly glacial till. Repose angles generally vary between 20 and 30 degrees.

A large number of landslide scars occur in the area (Figs. 3 and 5). There are some twenty five well identified scars representing major slides (>c. 100 000 m^3 in volume) and in addition to these some thirty somewhat uncertain scars are registered. The landslide scars are all stabilized and vegetated and peat formed inside one of the scars has been radiocarbon dated to older than 8000 years.

Several slides demonstrably moved in direct connection with local deglaciation as the mobilized material obviously slid over remaining glacier ice.

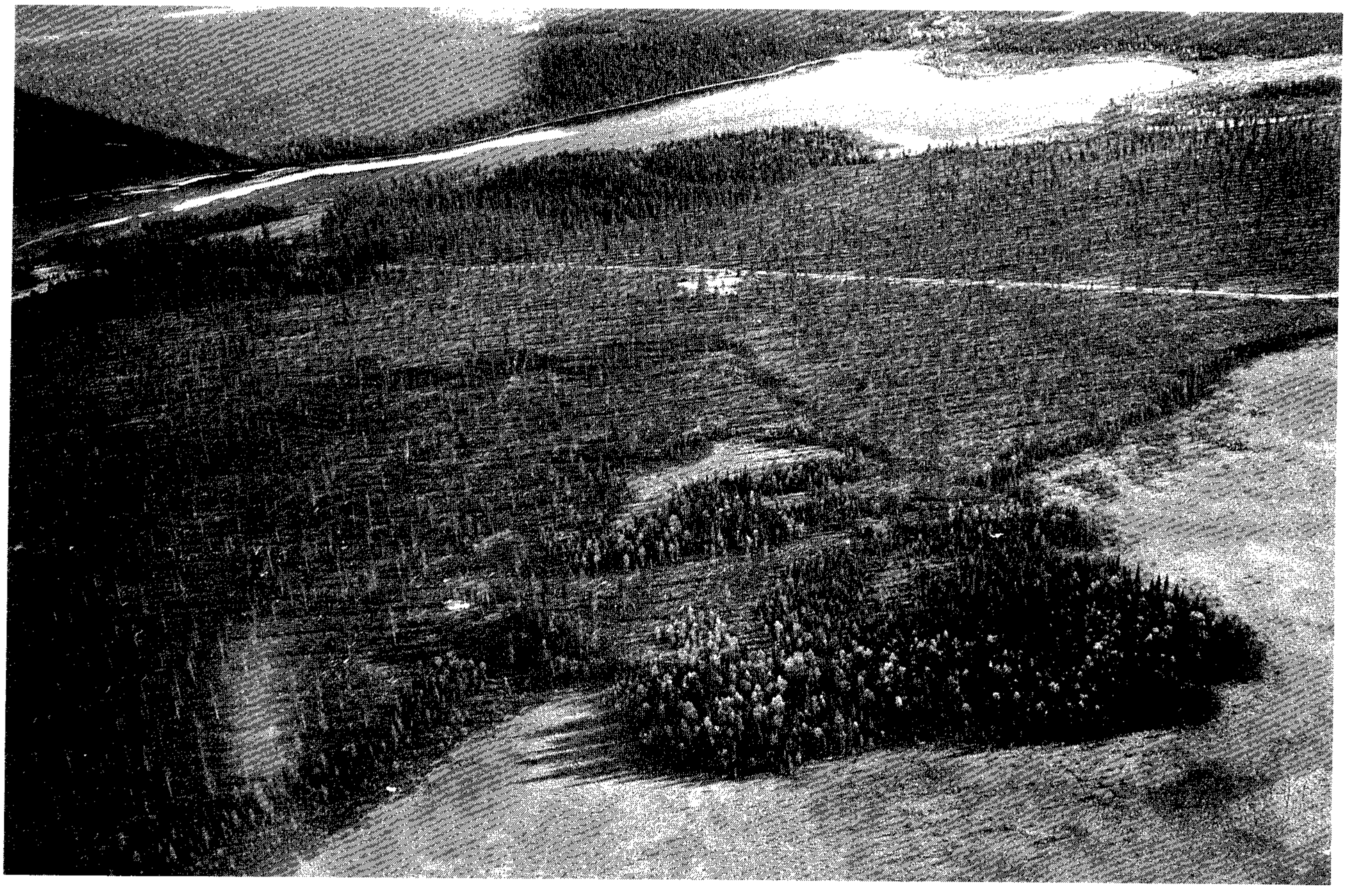


Figure 5. Landslide in glacial till at Elmaberget some 20 km to the NNE of Lansjärv. The landslide developed in a slope with an inclination of only 3-4 degrees. Radiocarbon dating of peat formed inside the scar has given the slide a minimum age of 8140±180 B.P. and it was probably triggered in close connection to the deglaciation of the area. Photo: R.L. 1981. Approved for publication.

3 METHODS

The investigations have been carried out mainly in machine-dug pits or longer machine-dug trenches. The pits or trenches normally reached depths of 2-4 m while the length varied between some 5 and 50 m, most of them no longer than 10 m. The sections were carefully cleaned and deformational structures of importance were documented by sketches and photographs. A number of samples were collected from heavily disturbed sequences for grain-size analysis of the sediments involved in the deformation. In all, some eighty pits or trenches were excavated in August 1990. In addition to these, five sections in naturally developed ravines or steep river banks, and two sections in sand-pits were examined. The report also includes six previously examined sites.

The location of the excavation sites was largely determined by practical considerations as, for instance, accessibility from roads, vegetation, ground moistness and, not least, land ownership. Most excavations took place on State-owned properties or land possessed by forestry companies.

The excavations concentrated on sediments derived from the time of local deglaciation, or shortly after, as previous investigations in the area have shown that it is in sediments of this age that deformations of any significance occur. However, for reference, some ten trenches were cut in thick sandy-silty deposits significantly younger than the deglaciation phase. The positions of all these sites are shown in Fig. 3.

On the whole the investigations have been carried out in accordance with the original plans. However, it was necessary to make minor adjustments to the original excavation programme because it was unexpectedly difficult to find appropriate sediments in some parts of the area. In some cases, mapped sediments proved to be of interstadial age, compacted by the load of the inland ice and thus not very sensitive to disturbing agents, such as, seismic shock. In other places the sediments were very thin, often only a few decimetres, and strongly disturbed by pedological processes. For these reasons the investigated sites were not as evenly distributed over the area as was desired. On the other hand there were far more pits dug than was originally planned.

There was also another problem of more technical nature. Due to very dry and windy weather during the excavation period, blowing sand and silt penetrated into the cameras. Two cameras were used, one for black and white and one for colour slides. After development of the films it became evident that a great number of exposures had failed, especially on the black and white film camera, and is one reason for the extensive use of colour prints in the report. The often very weak contrast between the different sediment units involved in the deformed sequences is another reason for using colour prints even though black and white are available. For technical reasons all colour prints occur in a separate appendix at the end of the report.

4 DESCRIPTION OF SITES

22 sites are described below. Their positions are shown in Fig. 3. The coordinates given for each site refer to the National grid system and the altitude above present sea level is also given. At some sites only one single section has been examined while others represent two or more sections in a restricted area, e.g. a delta terrace. Some sections, especially those which did not show any significant distortions, are only mentioned very briefly while others are documented by several photographs. An attempt to interpret the cause of different deformations met with is given for each site.

Site 1. **Lillåfors** (7365-7366 N / 1744-1745 E, 160-180 m). The site is situated about 30 km SW of the southernmost part of the fault--scarp set and about 50 km SW of its center. Excavations were carried out on a glaciofluvial delta terrace, built up more or less to the level of the highest coastline. Six pits, or trenches, were dug at somewhat different altitudes on the delta surface, which is gently lowered stepwise towards the delta front. The sandy and silty deposits found in the pits displayed a great variety of topset and foreset bedding.

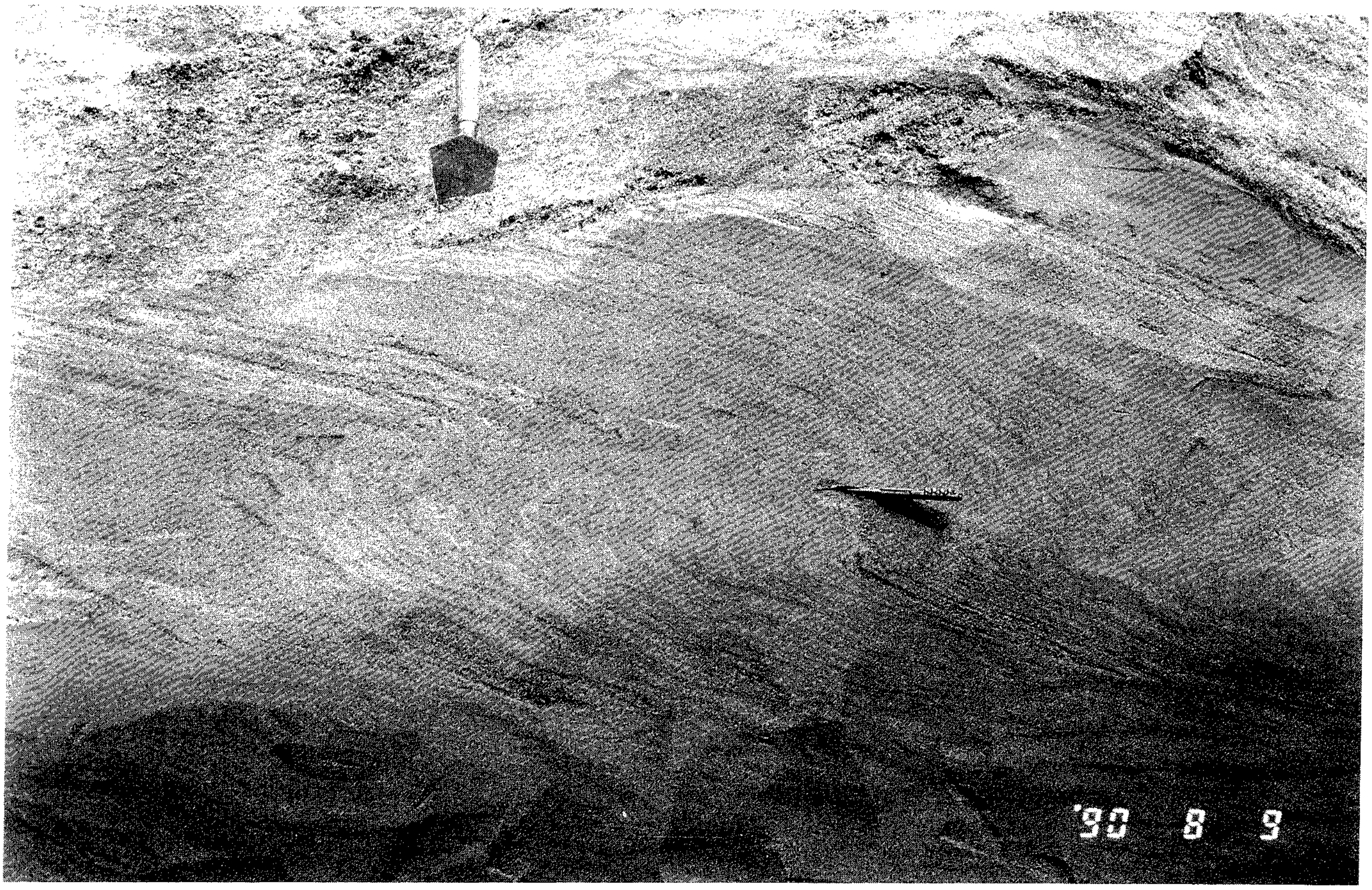


Figure 6. Differential movement along a horizontal zone (at the knife) in sandy deltaic sediments at Lillåfors (site 1). Photo: R.L. 1990.

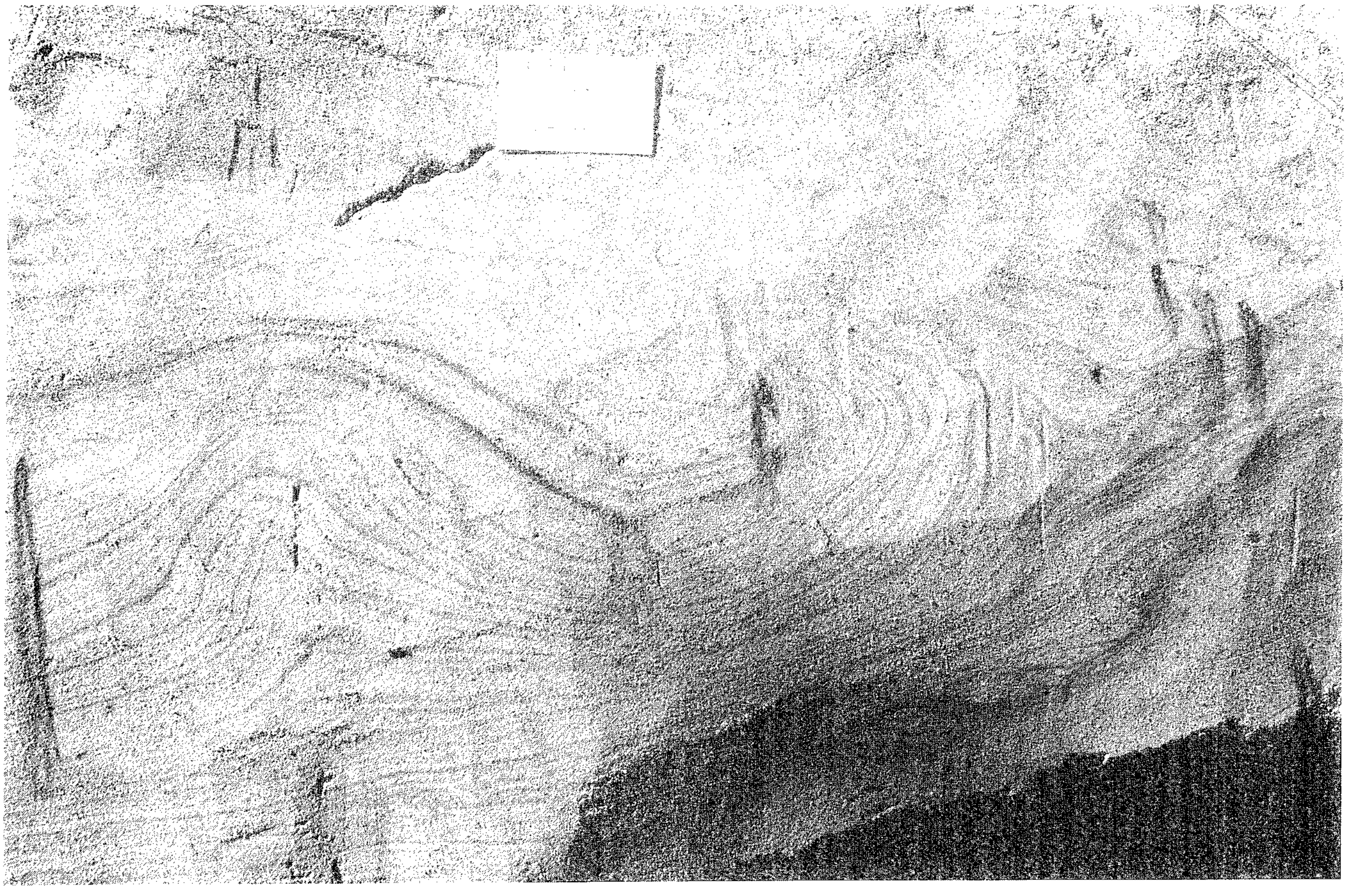
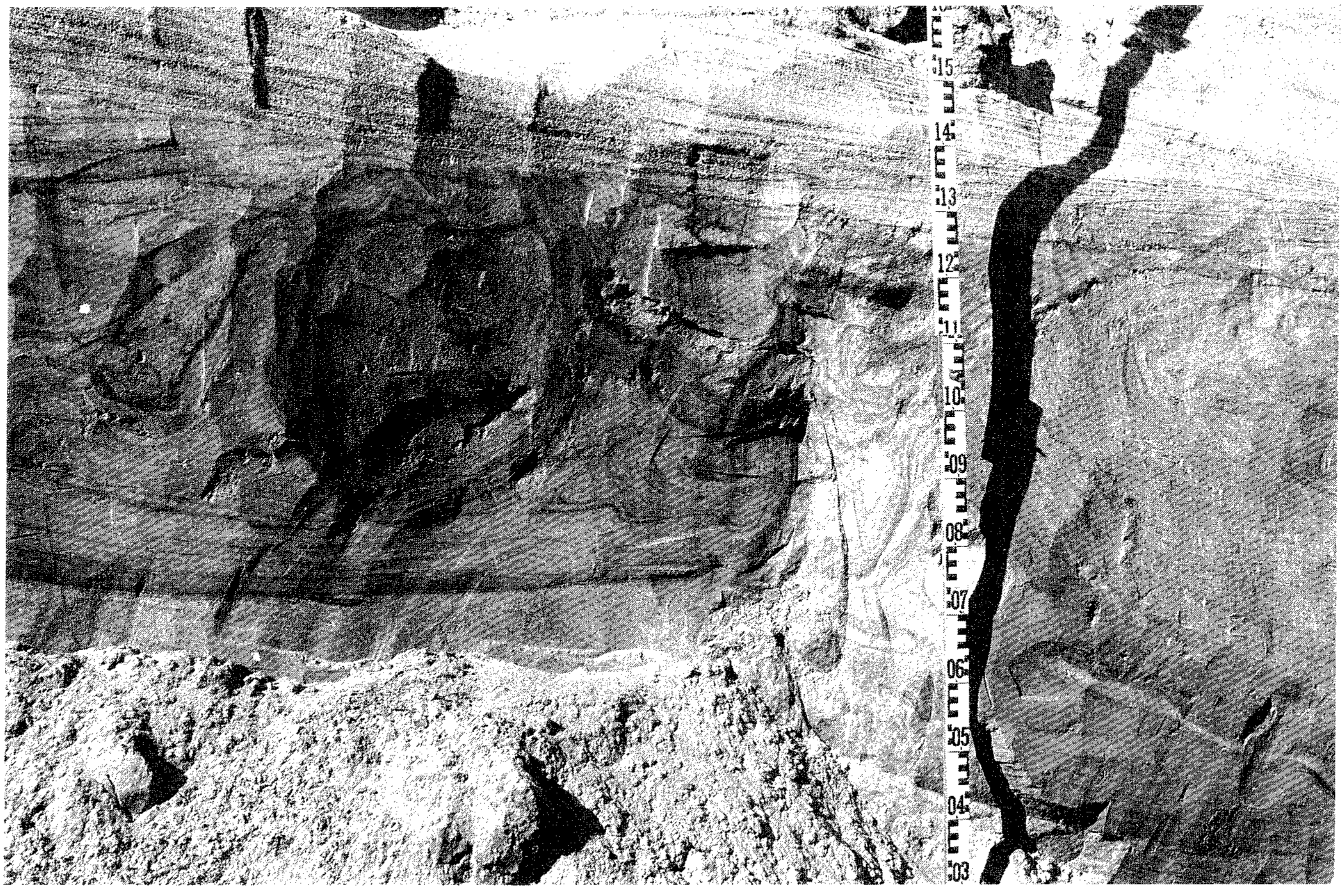
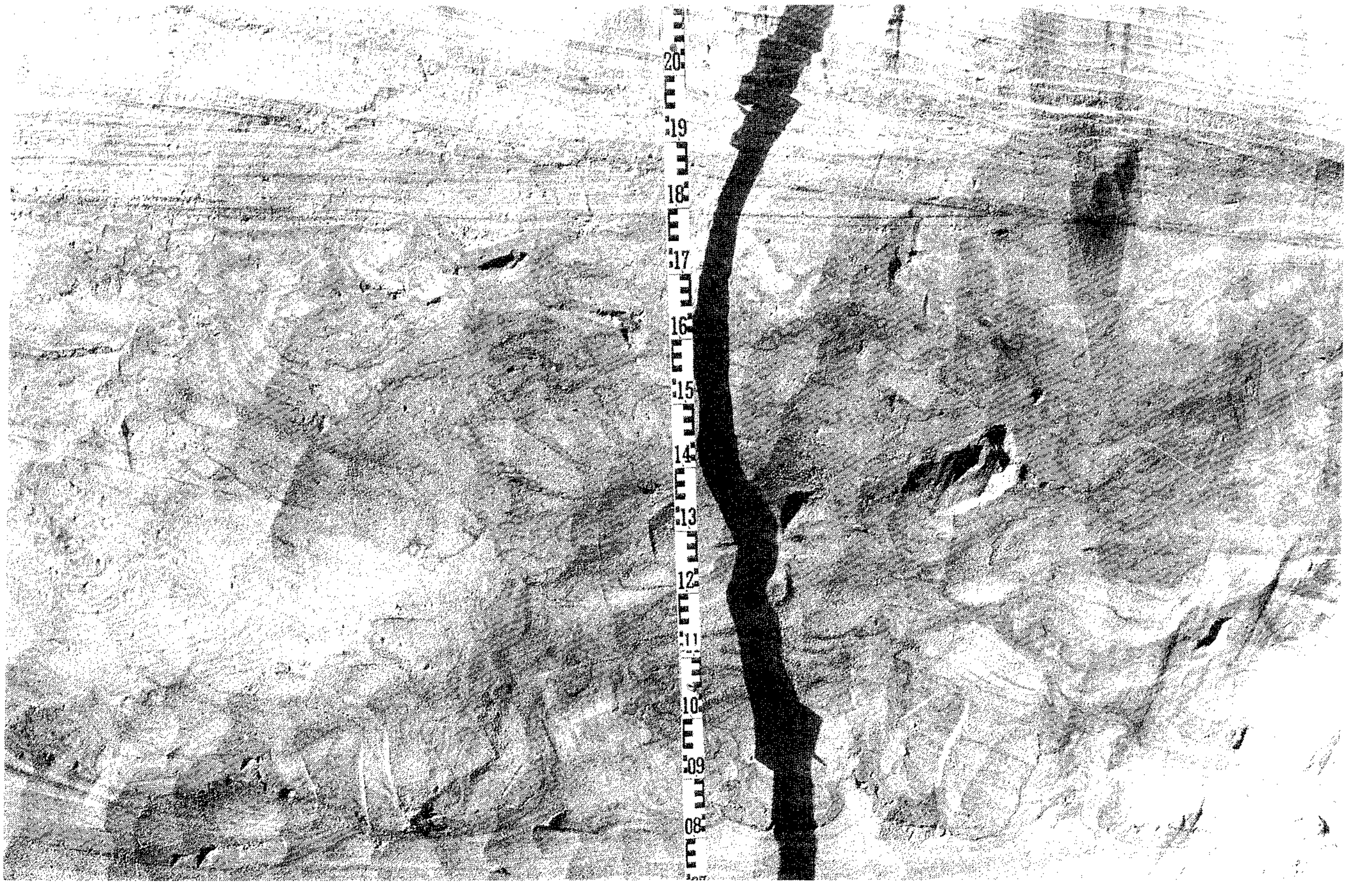


Figure 7. Weak folding in sandy deltaic sediment at Lillåfors (site 1). Photo: R.L. 1990.

Moderate deformations, such as weak folding, small-scale convolutions or minor shearing, occured in several pits (Figs. 6 and 7). More intense deformations were found in a longer trench. A 0.8-1.2 m thick and slightly inclined bed of sand and silt showed strongly convoluted bedding and upward injection of sand from the deposits beneath (Figs. 8 a and b). The deformed sequence has been eroded by running water after deformation and the covering layers showed even bedding without any deformations. Obviously the deformations occured during the build up of the delta terrace.

The fact that the deformed sequence was partly produced by injection of water from below, but still occur in a clearly defined bed, demonstrates that the deformation was associated with compaction of the underlying deposits. The injection structures, and the fact that the folds and convolutions have no preferred lateral orientation, indicate that no significant lateral movements have occurred during deformation. Further, as the deposits are grain-supported and the inclination of the bed is only a few degrees from the horizontal, it is difficult to see how gravity alone could have produced deformation by slumping or sliding. Seismic shock causing liquefaction of what were the uppermost, less consolidated strata, is a probable candidate for the explanation of the extensive deformations.





Site 2. Slättheden (7368-7372 N / 1750-1752 E, 170-185 m). Slättheden is another major delta terrace, built up to the level of the highest coastline. It is situated some 7-8 km NE of the Lillåfors delta and thus nearer to the fault set. Eleven pits or trenches were examined during 1990 and four others have been dug earlier (Lagerbäck 1988a).

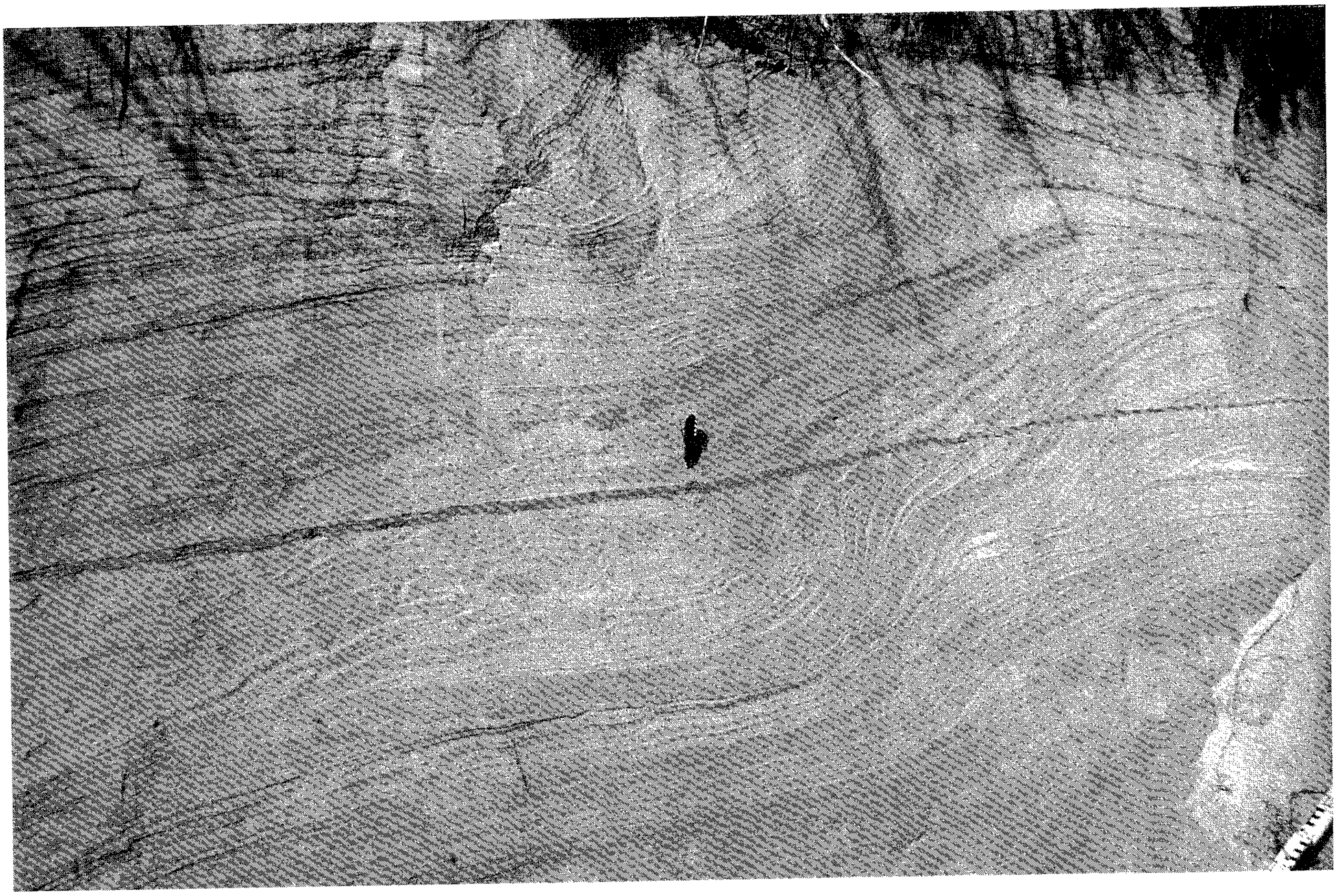


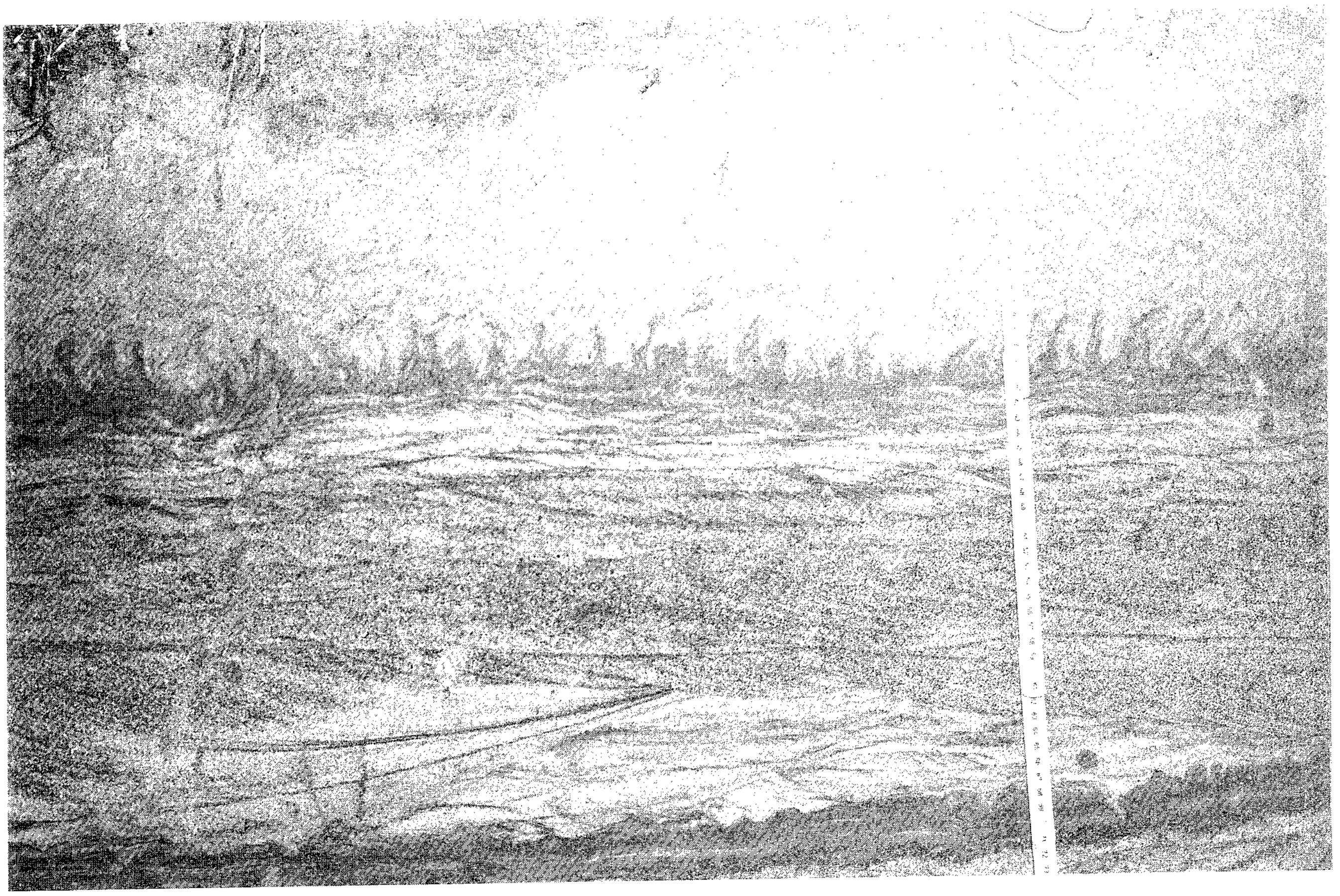
Figure 9. Horizontal layer of structureless silty sand discordantly cutting through evenly bedded deltaic sand at Slättheden (site 2). The deformation is one of the very few examples on brittle deformation encountered during the excavation programme. The process of deformation is not understood. Glaciotectonic shearing may explain the phenomenon but there is nothing else indicating a glacial readvance after sediment deposition (cf. Fig. 43). The delta surface is horizontal which therefore excludes sliding due to gravitational forces. The section is situated at 180-185 m above sea level and thus some 10 m higher than most of the other deformed sequences found at Slättheden. 8 cm long knife shaft for scale. Photo: R.L. 1990.

Figures 8 a (upper left) and b (lower left). Strongly convoluted bed of deltaic sand and silt at Lillåfors (site 1). Undeformed upward sand-injection features and lack of structures indicating lateral movements exclude sliding as a cause of deformation. The fact that the bed is eroded by running water and ovelain by sand with undeformed layering demonstrates that the deformation took place during the build-up of the sequence. Extensive injection of sand from below indicate a significant compaction of the underlying deposits. Photo: R.L. 1990.

Deformational structures were encountered in many of the pits (Figs. 9 to 15. Note that Figs. 15 a and b are colour photographs at the end of the report) and chiefly at altitudes below 175 m in the southern part of the delta terrace where the sandy fore- and topset beds showed different types of convolutions, ripples and flames. Most convincing as indicators of earthquakes are the different types of deformation implying liquefaction of the often fairly coarse sand. A considerable compaction was noticed at many places and a rough estimation indicated that the volume of the sediments was reduced by as much as 15-20 % compared with the undisturbed beds.

Figure 10. Convoluted sandy and silty deposits at Slättheden. The bedding above the 15 cm long knife is undisturbed and indicates that deformation occurred during the build-up of the sequence. Photo: R.L. 1990.

Figures 11 a (upper right) and b (lower right). "Earthquake sheet"? The small-scale corrugations occur in fine sandy to silty layers in current-stratified deltaic sand at Slättheden (site 2). The layers are laterally persistent for at least tens of metres and occur at the same stratigraphical level as the features shown in Figs. 12, 13 and 14). Features very similar to these "flames" are produced experimentally by shaking of sand overlying mud (Dzulynski & Walton 1963, plate XXIIB). Photo: R.L. 1987 (a) and 1990 (b).



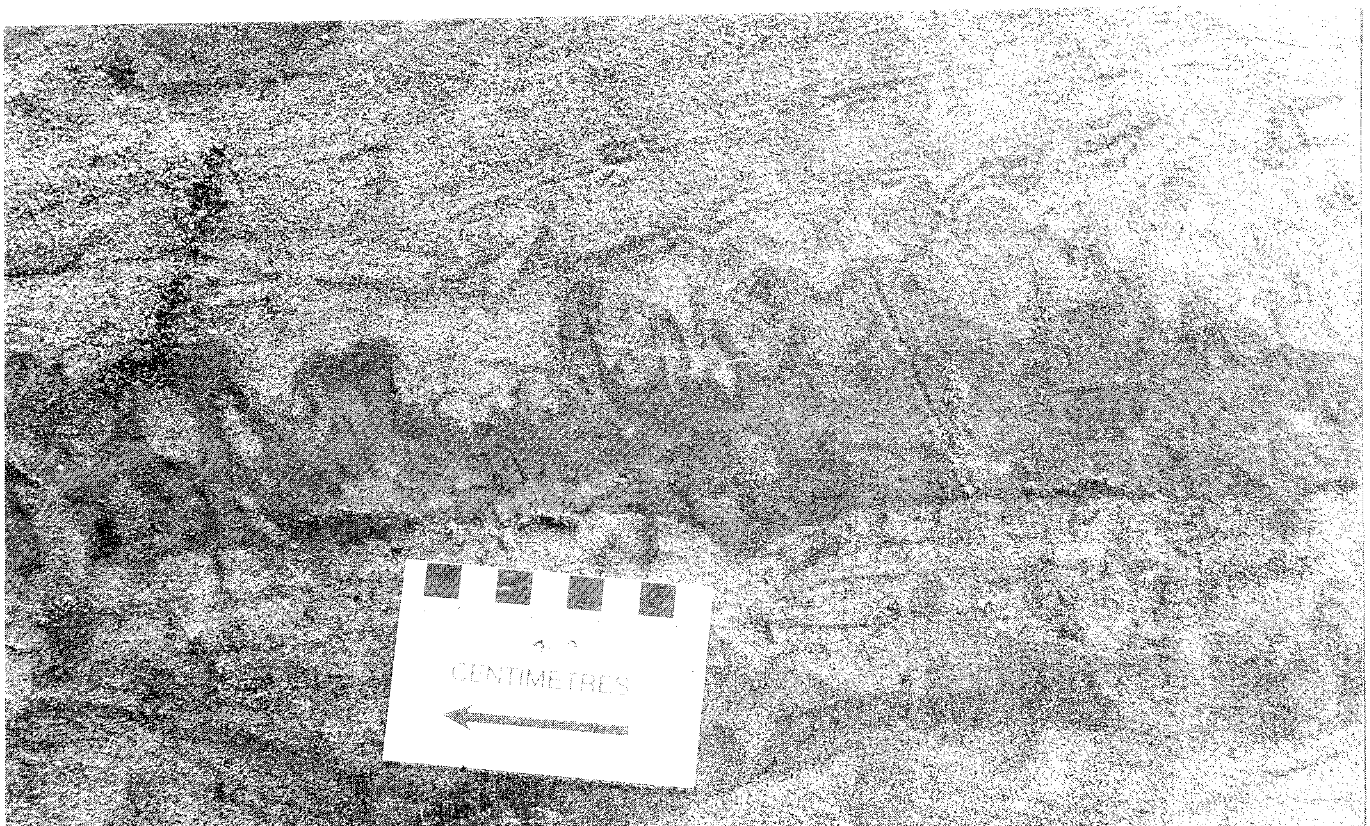

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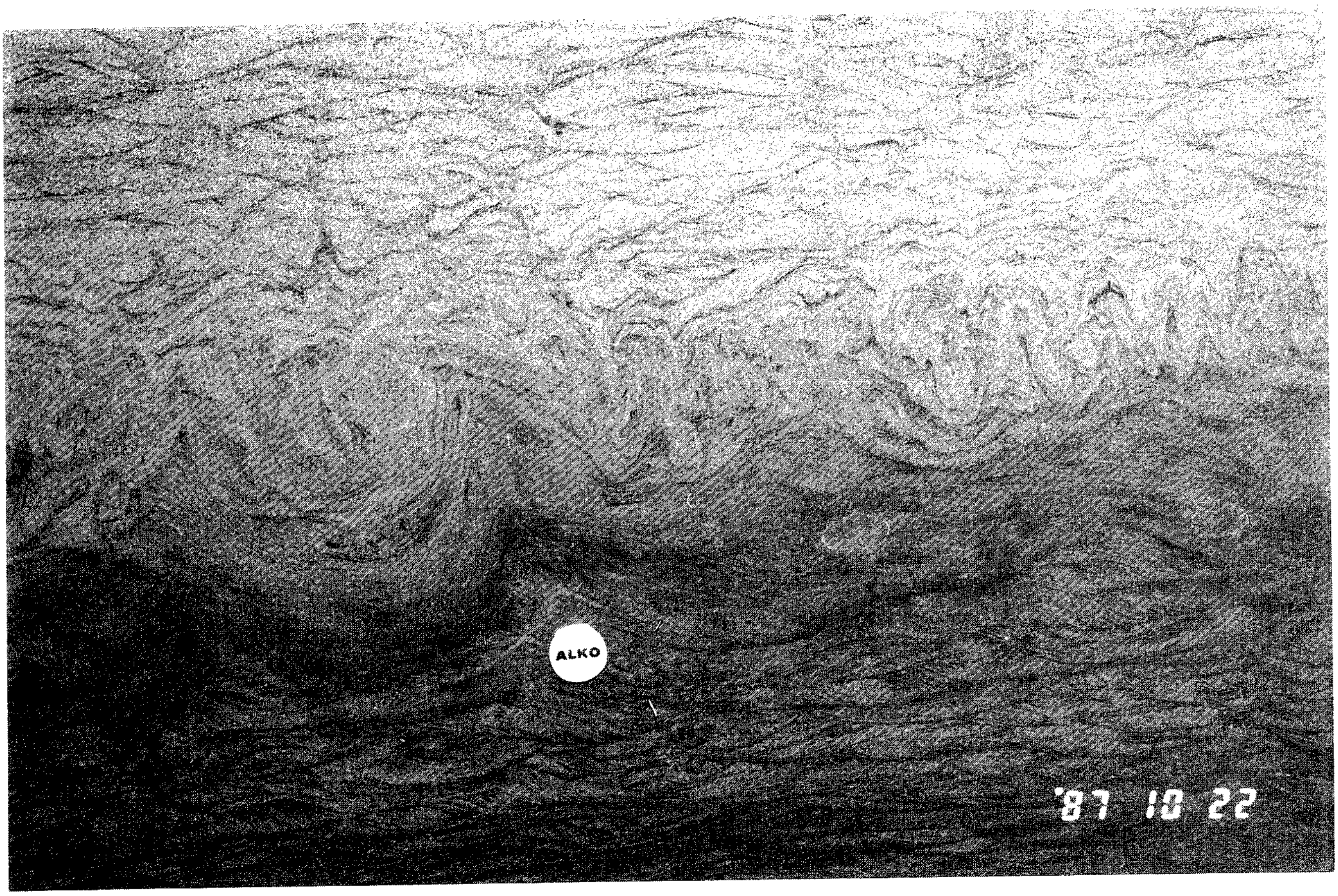
Figure 12. Distortions in cross-stratified deltaic sand at Slättheden (site 2). The features are interpreted as being caused by earthquake induced liquefaction and dewatering during the build-up of the sequence. Note grading of particle-size in the flame-shaped bulges. The grading is thought to be gravitational and provides evidence for liquefaction or elutriation during deformation. The picture measures about 1.5 m across. Photo: R.L. 1987.

Figure 13 (upper right). Deformations in cross-stratified sand at Slättheden (site 2), close to the sequence shown in Fig. 12. The corrugations are restricted to a 0.1 m thick, laterally persistent bed. Diameter of scale is about 3 cm. Photo: R.L. 1987.

Figure 14 (lower right). Upward injection of sandy gravel into highly deformed and extremely compact sandy and silty deposits at Slättheden (site 2). The deformation is interpreted as being due to earthquake induced liquefaction of the sandy silty sediments and rapid compaction and dewatering of the gravel below. The deformations occur at the same stratigraphical level as the features shown in Figs. 11, 12 and 13. The knife is about 20 cm long. Photo: R.L. 1990.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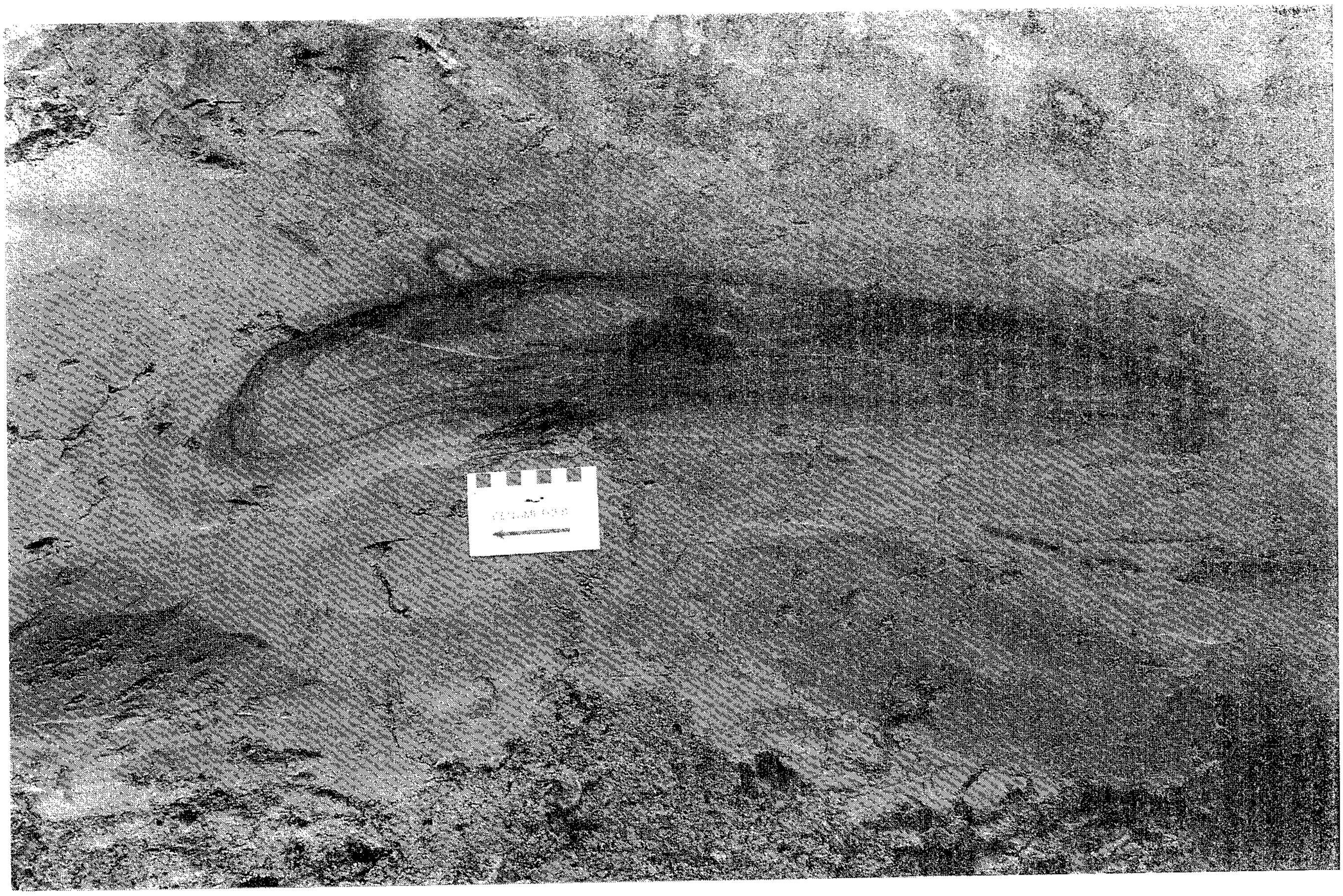
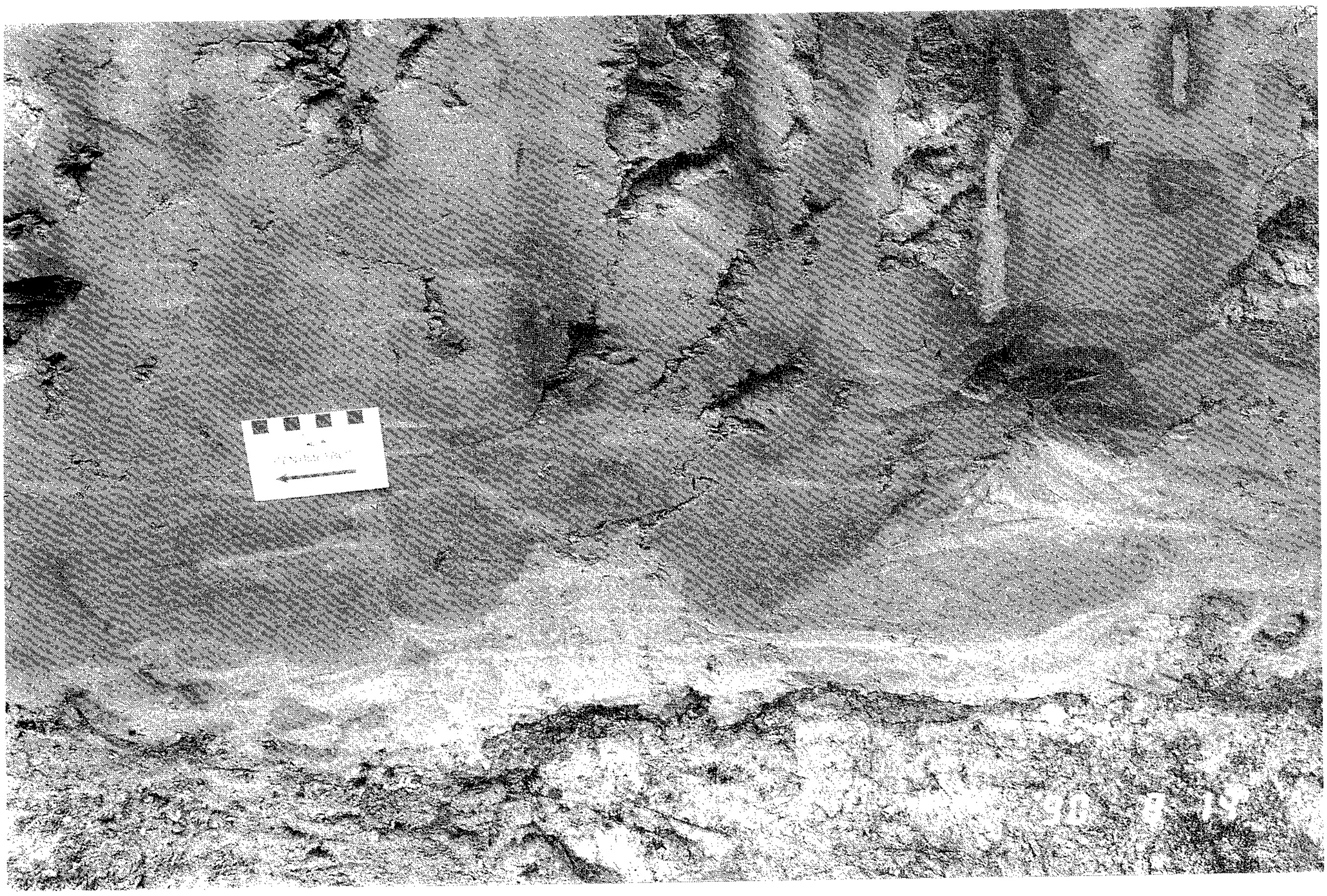
Site 3. Vuolpolandet-Svanamyran (7374-7377 N / 1764-1767 E, 160--185 m). The locality is another glaciofluvial delta formation, situated some 5 km SW of the southernmost fault scarp segment. The delta terrace reaches up to the level of the highest coastline where glaciofluvial kames and a feeding esker connect. In all, some twenty pits or trenches were dug. Almost no deformations were found in the higher (above 180 m), proximal parts of the delta where fairly coarse, crossbedded sand dominated.

In the eastern part of the delta terrace, at about 170 m, a strongly deformed, 0.3-0.4 m thick bed of fine-sand and silt was encountered in two pits situated some 100 m apart (Fig. 16, colour). The deformed bed, as well as the deposits beneath, were extremely compact. The deformations in the two pits were very similar and there is no doubt that they represent one and the same bed and deformational event. At this place the delta surface, as well as the deformed bed, were perfectly horizontal and deformation due to sliding or the like appears to be excluded. This circumstance, and the very regular appearance of the convolutions, without any indication towards sideward motion, strongly suggest a seismic origin of liquefaction and deformation.

Figures 17 a, b and c. Deformed sediment sequence at the distal part of the delta deposits at Svanamyran (site 3). The silty and fine-sandy deposits below the light-coloured silt layer in the middle of the sequence (Fig. a, above) are extremely compact and the primary layering is totally disordered with sausage-shaped lumps of sand (Fig. b, upper right) floating in a matrix of gray silt marbled with thin veins of light-coloured silt (Fig. c, lower right). Photo: R.L. 1990.





Extensive deformation of fine-sandy and silty sediments was also found in a pit on the southern, distal part of the delta at an altitude of about 160 m (Figs. 17 a,b and c). In this pit two metres of silt and fine-sand rested on glacial till. In the middle of the sequence, a distinct and undisturbed layer of light-coloured silt occurred. Above this layer the laminar bedding was undisturbed and not significantly compacted. Below the silt layer the bedding was totally disordered and extraordinally compact. Sausage shaped lumps of fine-sand were floating in a mass of grey silt, marbled with thin and crumpled veins of more light-coloured silt.

As the ground surface (Fig. 18) and the sediment - till contact are horizontal there is no reasons to speculate on either sliding or any other lateral movement as a cause of deformation. The entire sediment bed below the silt layer must obviously have been liquefied during deformation and a sudden breakdown of internal sediment framework due to violent earth tremor may explain the phenomenon. The light-coloured silt layer may represent the suspended load of turbulent water during earthquake. Similar and often much thicker layers of sand or silt, delimiting deformed sequences upwards, have been found at many localities in the Lansjärv area (cf. sites 5, 7, 8 and 10).

Figure 18. The southern, distal part of the delta terrace at Svanamyran (site 3). The ground surface, as well as the internal bedding and contact to underlying glacial till, is horizontal. Consequently, the extensive deformations found in the silty-sandy sediments (Figs. 17 a,b,c) cannot be explained by any sliding processes or the like. Photo: R.L. 1990.

In another pit, a kilometer away from the last mentioned, the sediments were coarser and displayed more large scale and regular convolutions which had been eroded by running water and covered by cross-stratified sand (Fig. 19, colour).

As the pits showing disturbed sequences at Svanamyran are situated kilometres apart it is, of course, not possible to claim that they represent the same stratigraphical level and deformational event. However, this is not unlikely as the deformation probably took place in rather shallow water in the more elevated sequences (Fig. 16) while at the more low lying sequence (Fig. 17) the deformation occurred in deeper water, long before the upheaval above the sea and cessation of sedimentation.

Site 4. Rotheden (7391-7392 N / 1786-1787 E, 95-100 m). Three pits were dug in fine-sandy and silty sediments, assumed to date from the deglaciation of the latest inland ice. However, scattered boulders occur on the ground surface and the excavations revealed that the sediments are covered by a thin sheet of sandy-silty diamicton, interpreted as a deformation till. Cryoturbations and ice-wedge casts, probably dating from the Tärendö interstadial (Lagerbäck 1988b), occurred in two of the pits (Fig. 20, colour). In the third pit the sediments contained organic matter and will be radiocarbon dated and analyzed for microfossils in order to confirm the interstadial age. No deformations interpreted as being seismically induced were found. The sediments are probably too consolidated by the load of the inland ice and by cementation of iron oxides to be sensitive for seismic deformation.

Site 5. Furuholmsbäcken (7399 N / 1789 E, 85 m). Several small pits were dug in clay covering a rather thin bed of glacial silt and sand, resting on "deformation till". The primary layering in the silty and sandy bed was strongly deformed and compacted in all of the pits (Fig. 21, colour). The lowermost part of the glacial clay was often broken, sometimes into small pieces, and was covered by a thin layer of sand. The clay above the sand layer was undeformed. Principally the same sequence has been found at several places in the Lansjärv area (cf. Figs. 24, 28 and 30) and is interpreted to reflect a major earthquake shortly after deglaciation and during the first sedimentation of glacial clay. This is in agreement with the concept of major fault movements in the area shortly after deglaciation.

Site 6. Sockberget (7398 N / 1792 E, 80-85 m). One trench was dug in glacial sand and silt covered by clay and resting on a bed of deformation till, underlain by sandy gravel. That is, in principal, the same sequence as was found at Furuholmsbäcken (site 5, above). Similar to that sequence, the sandy-silty bed here was very compact and deformed. Sand veins emanating from the sandy gravel injected upwards through the deformation till and into the sandy-silty bed (Fig. 22, colour) indicating considerable compaction of the gravel. This compaction is remarkable when considering that the gravel had already undergone compression by an inland-ice sheet. Earth tremor, causing a breakdown of the gravel framework and resulting in compaction and expulsion of sand and water, is a reasonable explanation of the phenomenon and also explains the deformation of the sandy-silty deposits. Another deformed sediment sequence, with principally the same stratigraphy, was observed in a road cutting a few hundreds of metres away (Fig. 23, colour).

Figure 24. Sediment sequence showing part of the general stratigraphy at Svanaträsket (site 7). The stratigraphy from the bottom of the picture is; deformed and very compact glaciofluvial sand with thin veins and lenses of silt (0.20-1.05 m), glacial clay (1.05-1.10 m), layer of dark sand (1.10-1.16 m), clay, mainly of "glacial" origin (varved), possibly postglacial in the upper parts (1.16-1.55 m) and littoral sand (1.55-). The sand layer intercalating the clay is believed to represent the fall-out from sediment-loaded turbulent water in connection with faulting and earth tremor shortly after deglaciation. The clay below the sand layer is deformed and in another part of the trench even broken into pieces (cf. Figs. 26 and 27). Photo: R.L. 1990.

Site 7. Svanaträsket (7402-7403 N / 1788-1790 E, 85-95 m). Ten pits or shorter trenches were dug in gently undulating terrain, with a surficial bed of littoral sand. A great variety of stratigraphies and deformations were encountered. The most instructive section included a sequence of glacial clay resting on glaciofluvial sand and silt (Fig. 24). The sandy-silty sediment was strongly deformed and extremely compact (Fig. 25). The lower part of the clay was intercalated by a 5-15 cm thick sand layer and the clay beneath this layer was deformed and even broken into pieces and mixed into the sand layer (Figs. 24, 26 and 27). The clay above the sand layer showed an undisturbed horizontal layering with distinct varves. Thus, the sequence strongly resembled the one recorded at Furuholmsbäcken (site 5, above) and supports the concept of a major seismic event shortly after deglaciation.

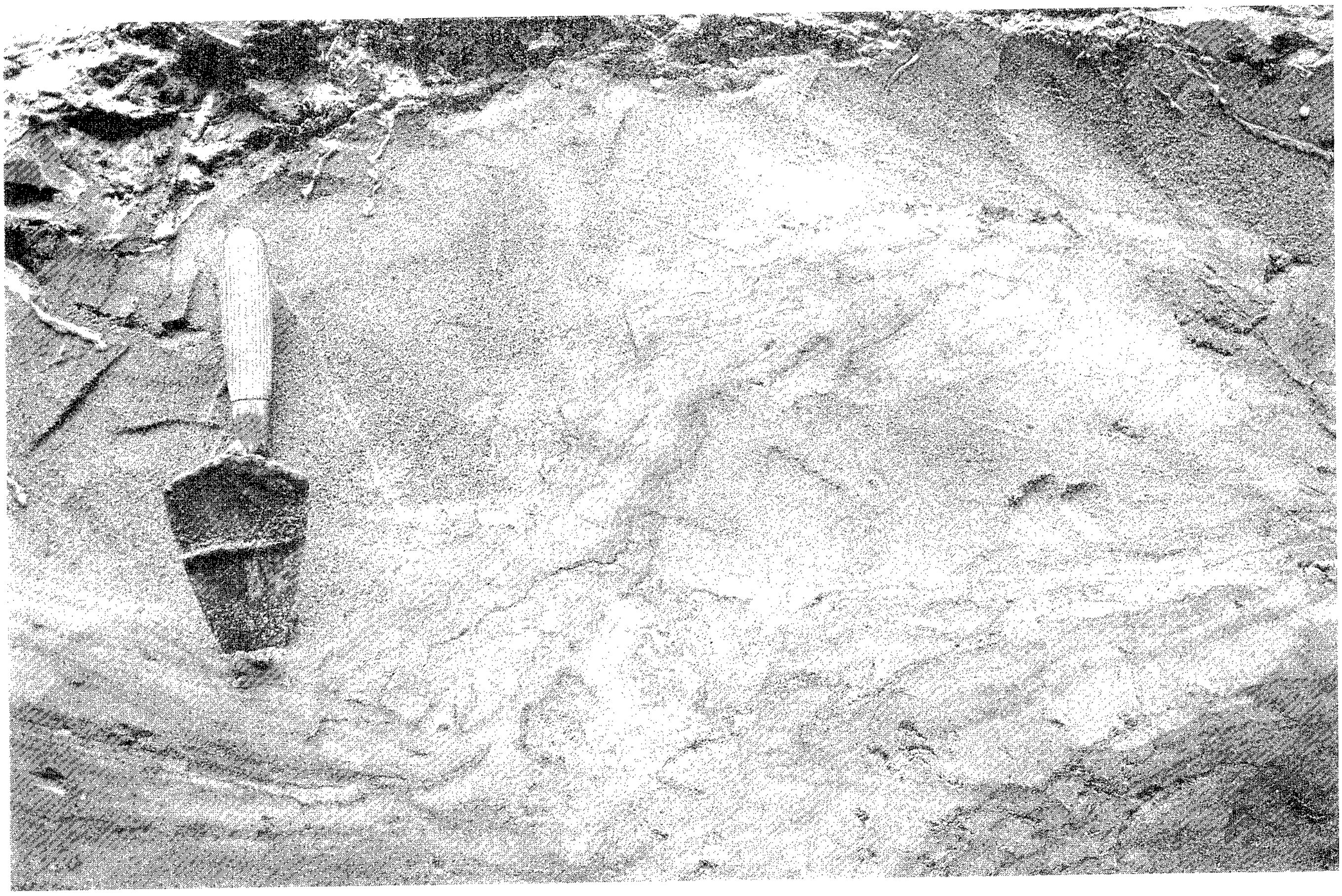
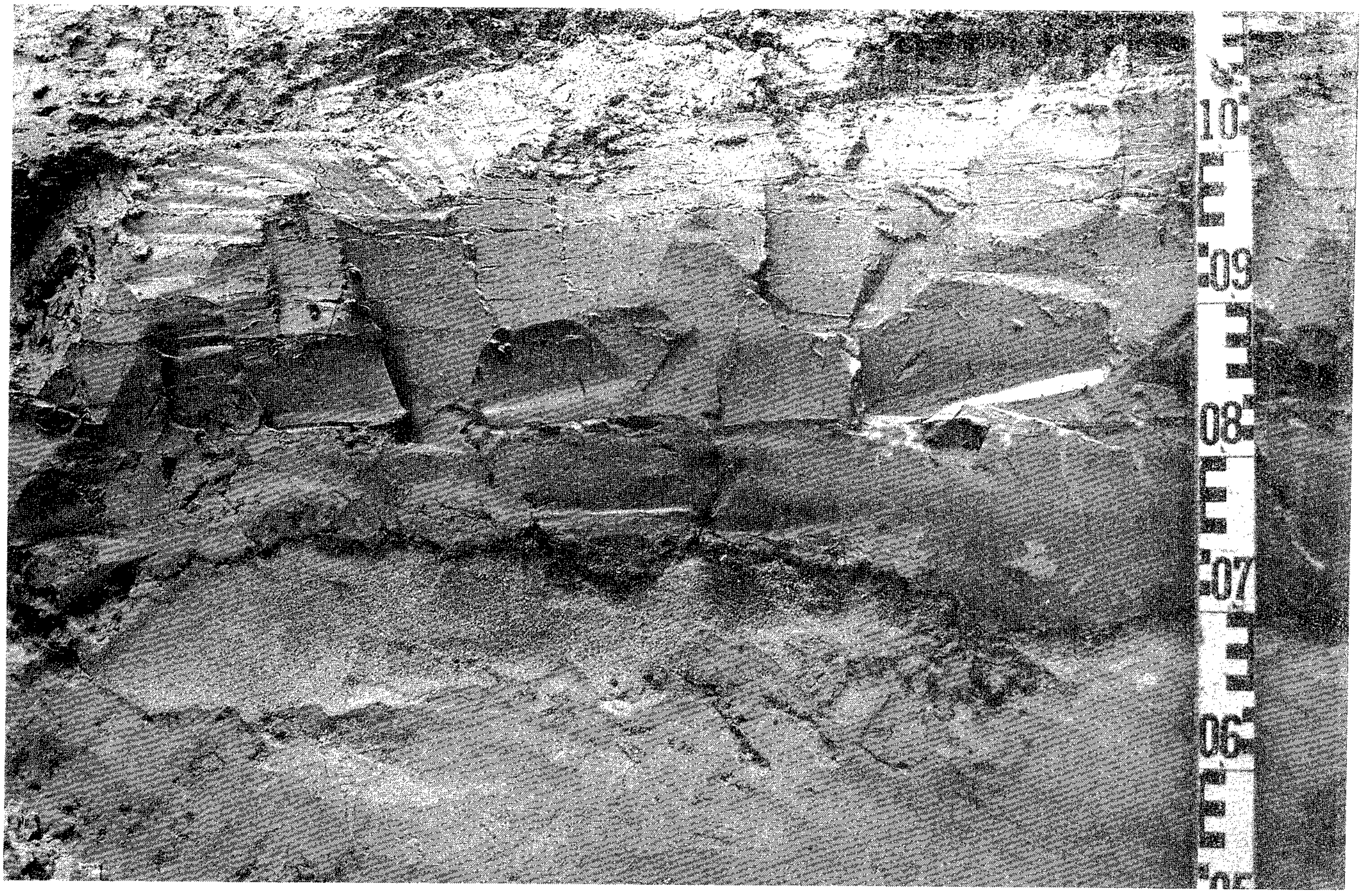
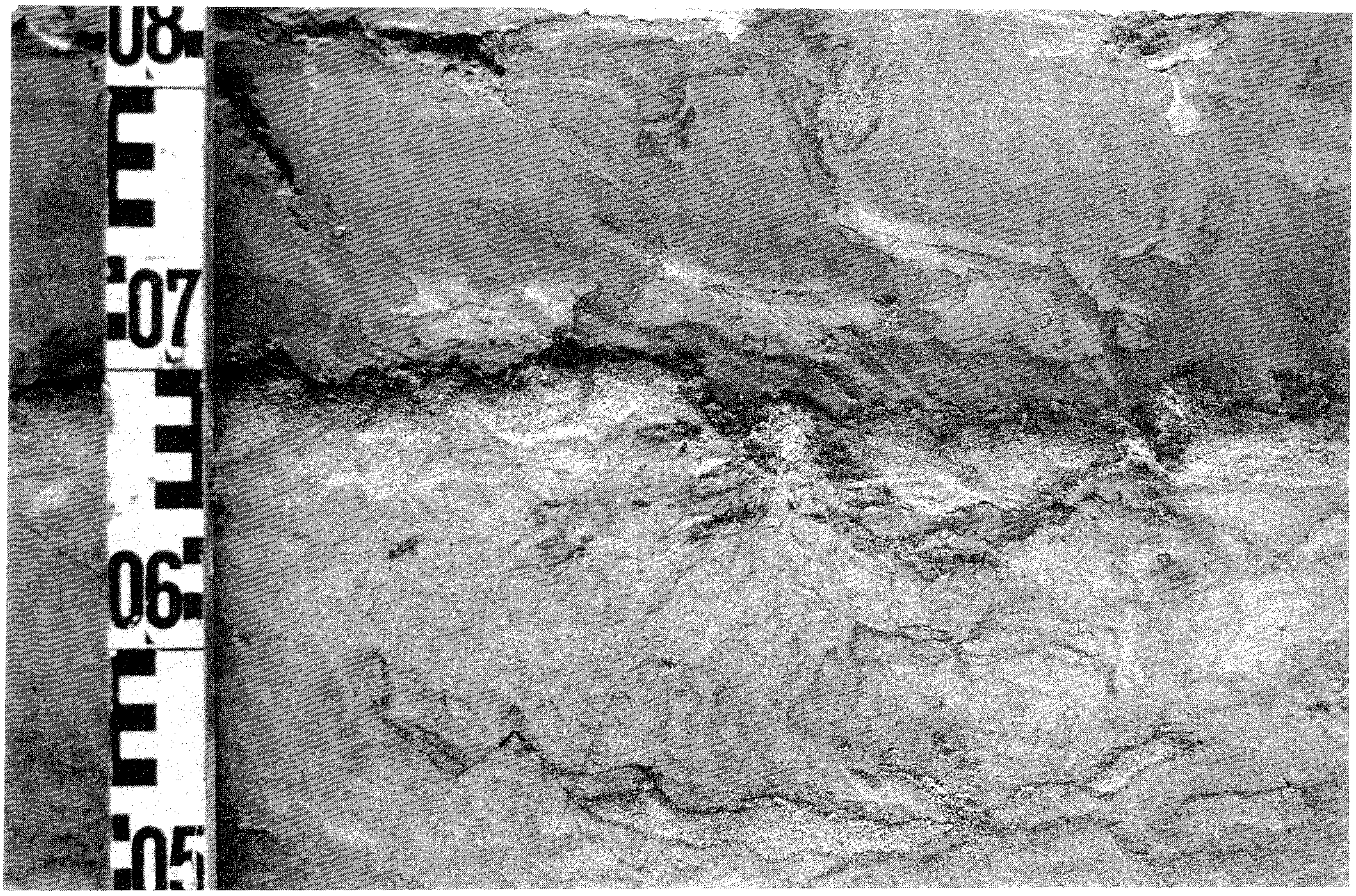


Figure 25. Deformed and very compact glaciofluvial sand and silt below clay at Svanaträsket (cf. Figs. 24, 26 and 27). Photo: R.L. 1990.





Site 8. **Kallvikmyran** (74049 N / 17856 E, 90 m). Two small pits were dug exposing a stratigraphy principally very similar those of Furuholmsbäcken (site 5) and Svanaträsket (site 7). A clay sequence, intercalated at the bottom by a sand layer, rested on a thin bed of deformed coarse sand. The bottommost part of the clay, below the sand layer, is truncated by sand veins (Fig. 28 a, colour) and small lumps of clay are floating in the sand (Fig. 28 b, colour). The sand layer is assumed to be deposited from suspended matter in turbulent water in connection with faulting, earth tremor and regional deformation of sediments. Graded bedding and lumps of clay in the sand layer support the concept of a short-lived, violent event and the circumstance that principally the same stratigraphy is repeated from place to place indicates that this event was of regional extent.

Site 9. **Lillsundet** (74064 N / 17845 E, 95 m). This site was studied in 1983 and 1984 and was one of the first sections with deformed sediments found as a result of active search for seismites in the Lansjärv area. The deformations occur in fine-sand and silt of glacial origin, covered by clay and resting on deformation till, in its turn probably resting on glaciofluvial sediments. All sections studied showed intricate deformational structures in a zone between two beds of somewhat different composition (Figs. 29 a and b, colour). The upper layer has a higher content of fines and a slightly higher density (in a water-saturated and agitated state) compared with the lower, better sorted and more sandy layer. The disturbed sequence was also remarkably compact. No significant deformations were found in the covering silty clay. The deformation is interpreted as being sesmically induced.

Site 10. **Storsundet** (74081 N / 17836 E, 90 m). Two pits were dug in clay covering glaciofluvial sand. One of the pits was dug in very wet ground and it was not possible to study the section very thoroughly as the walls continually collapsed. No significant deformations were indicated here. In the other pit the bottommost part of the clay was broken and injected by sand (Fig. 30, colour). The sand veins ceased upwards in a sand layer, significantly thinner and less distinct if compared with the sections at Furuholmsbäcken, Svanaträsket and Kallvikmyran, but, in principle it is the same phenomenon. The locality is situated to the northwest of the fault scarp set (Fig. 3) and, as it was the eastern fault block that was raised, less turbulent water probably would be expected as a result of faulting.

Figure 26 (upper left). Undisturbed glacial (varved) clay (0.82-) resting on deformed and very compact sand and silt (-0.70) at Svanaträsket. The dark sand layer (0.70-0.82) contains lumps of clay, corresponding to the clay beneath the sand layer in Fig. 24. Photo: R.L. 1990.

Figure 27 (lower left). Close-up of sand layer and upper part of deformed sand and silt in Fig. 26. Note lumps of clay in the dark sand. Photo: R.L. 1990.

The sand beneath the clay is rather compact but the primary layering show only minor deformations . The chronostratigraphical position of this sand is uncertain but possibly it is related to an esker situated nearby, covered by scattered boulders and interpreted to date from a previous glaciation. A thin layer of more diamict material between the sand and clay is the only, but very weak, indication of a possible former ice sheet.

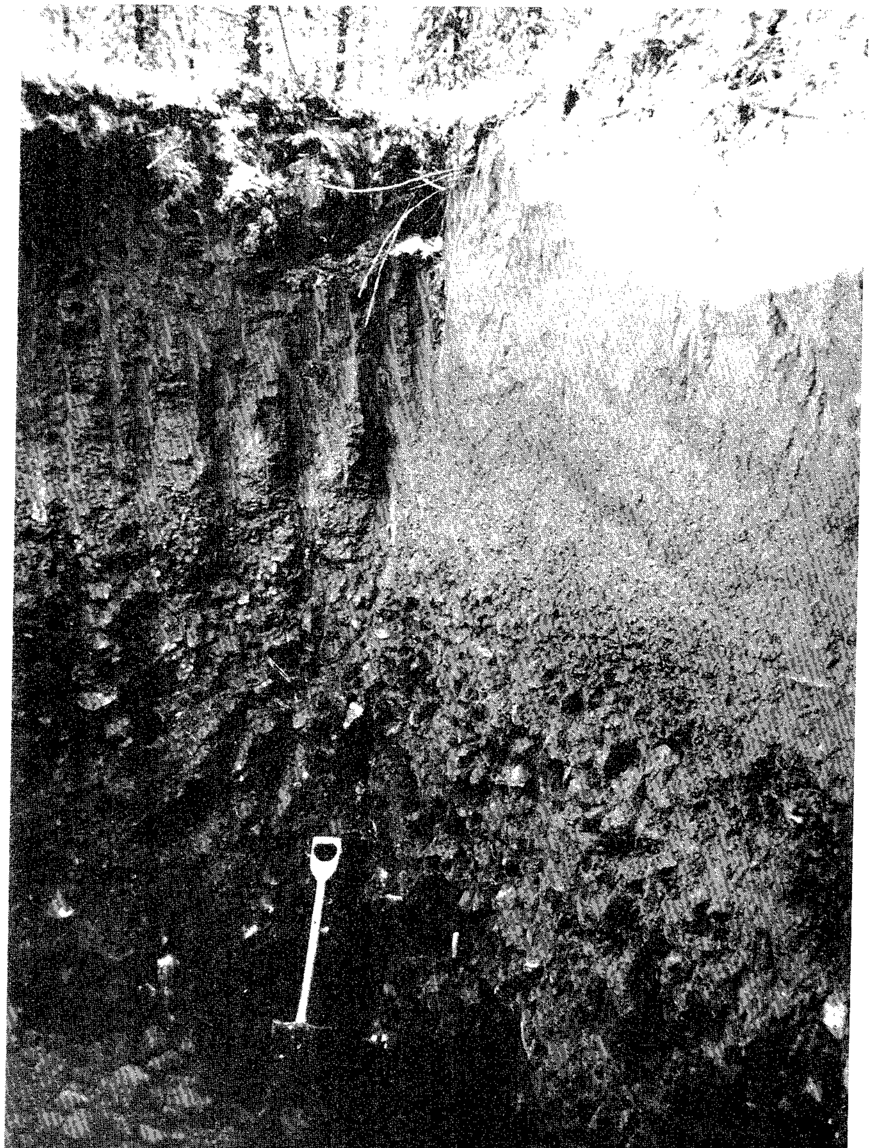


Figure 31. "Graded till" at Pokölen (site 12). The size of the clasts, from small pebbles to boulders, successively increases downwards and the biggest boulders (>0.5 m) do not occur until a depth of about 4.5 m below ground surface. The sediment was extremely compact and the excavator had great difficulty in penetrating the ground. The primary stratigraphy as shown by excavations in the surrounding, consisting of two different till beds, is destroyed and the clasts from the two till beds are totally mixed. The matrix between the clasts consists of a mixture of the sand and silt fractions, that is, the residue of the original till. The grading is interpreted to be caused by violent seismic vibration in connection with faulting. Photo: R.L. 1983.

Site 11. Missesberget (74099 N / 17864 E, 105 m). One trench was cut in pebbly and partly organic-bearing sand covered by sandy diamicton and littoral sand. The origin of the sand is uncertain but the covering diamicton and scattered boulders on the ground surface in the surrounding area indicate that it predates the last inland ice-sheet. The sand was rather compact but no significant deformation were found in the even but somewhat curved lamination. The compaction is assumed to be due to compression by inland ice and may have protected the deposits from seismically induced deformation.

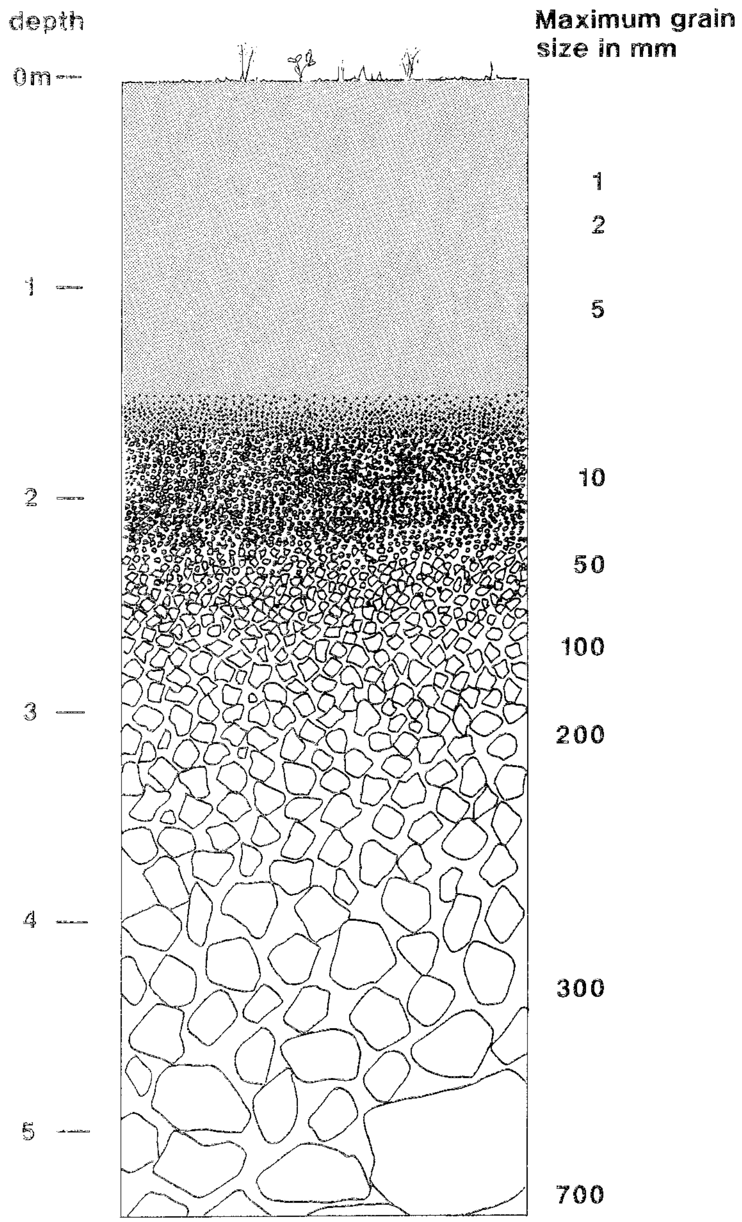


Figure 32. Idealized drawing of the section at Pokölen (site 12) showing the successive increase in particle size downwards (cf. Fig. 31).

Site 12. **Pokölen** (73991 N / 74032 E, 155 m). The site is located at the central, east-facing fault segment, immediately behind the scarp on the raised block. It was examined in 1982 and 1983 and is one of the first sites found in the Lansjärv area with deformations interpreted to be of seismic origin. It represents one of the most spectacular types of deformed deposits found, namely the "graded tills" (Fig. 31).

In the graded till all clasts coarser than sand are perfectly size-sorted so that the coarseness of the ballast material successively increases downwards. The matrix between the clasts, and the material in the uppermost parts of the sequence, consist of an unsorted mixture of the remaining sand, silt and clay fractions of the original till. The material is extremely compact and proves difficult to excavate as it is almost as solid as a sedimentary rock. Deformation reaches to a depth of at least 5.5 m. The upper 1.0-1.5 m of the sequence is more or less free from grains coarser than c. 2 mm. Below 1.0-1.5 m from ground surface the coarse material has been size-sorted such that clasts of a given size do not occur above a given level (Fig. 32).

Figure 33. Part of a major depression with graded till at Furuträsket (site 13). The photograph is taken from the inside of the depression towards the surrounding rim. The level bottom of the depression is situated some 1-2 m below the surroundings. This subsidence can probably be explained mainly by a much tighter packing in the graded till compared with the undeformed beds outside. Note the boulder-strewn surface of the rim in contrast to the boulder-free surface in the foreground. Photo: R.L. 1990.

Site 13. **Furuträsket** (7413 N / 1788 E, 165-175 m). The site constitutes a small area located on the eastern side of the fault scarp some 6-7 km NE of Lansjärv. A large number of pits and trenches have been dug there in graded till since 1983. The type of deformation, the same phenomenon as was described from Pokölen (site 12, above), occur as subcircular patches. These are often tens or even hundreds of metres across, and are indicated by the absence of boulders or stones on ground surface (which is usually boulder-strewn) and by the fact that the ground surface is noticeably depressed (Fig. 33). This subsidence is assumed to be mainly due to the much tighter packing of the graded till compared to the undeformed till-beds outside, but a minor loss of fines in connection with deformation (in turbulent water) may also have made a contribution.

The size-sorting of clasts reaches to depths between two and at least five metres (the excavator failed to dig deeper in the extremely compact and bouldery mass) and generally the deformation is clearly defined laterally (Figs. 35 a and b, colour). At least two till-beds are affected by the deformation and the materials from the tills are mixed.

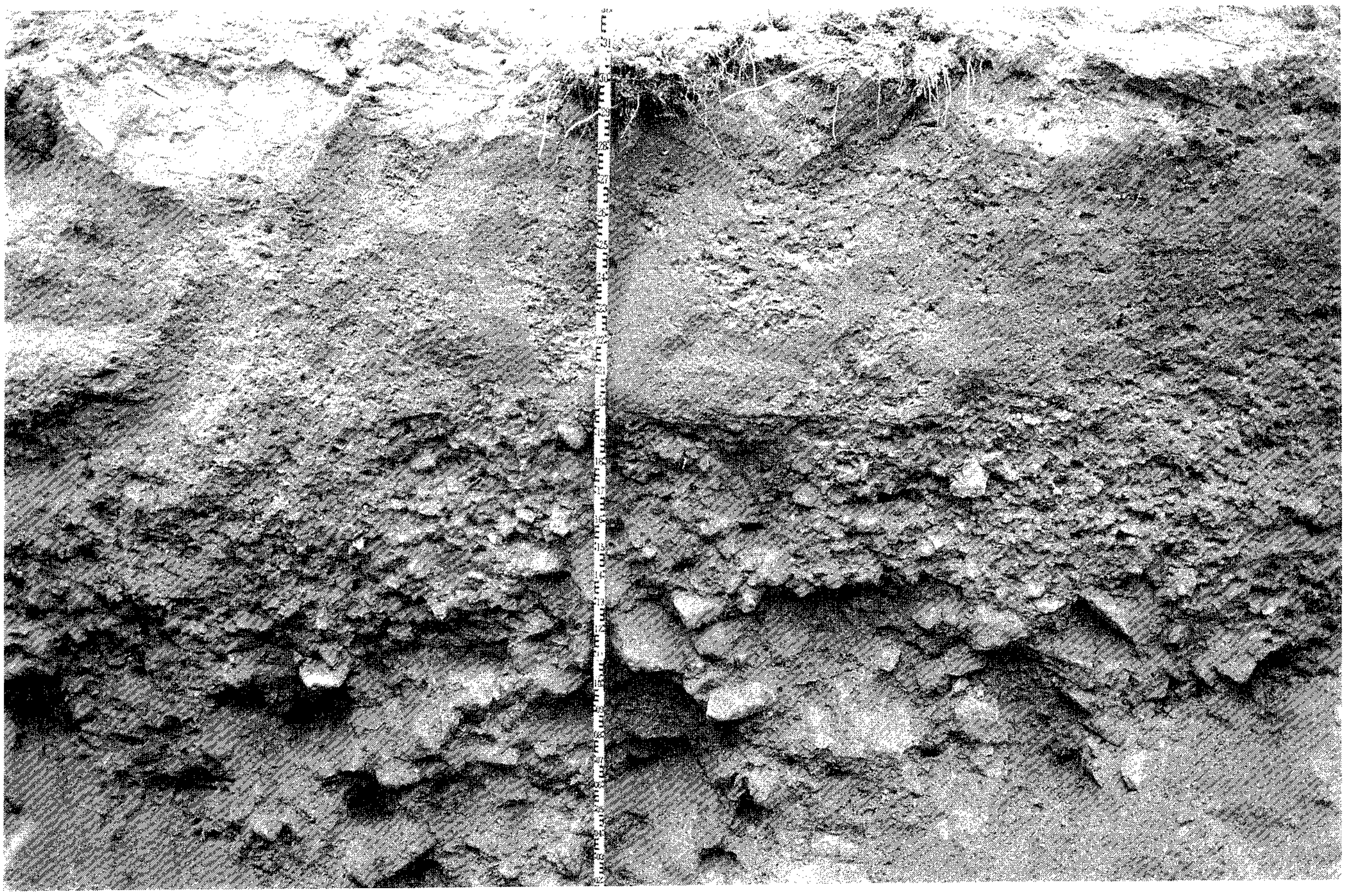


Figure 37. Section through graded till at Furuträsket (site 13). The grading in the upper part of the sequence here is incomplete or, rather, disturbed by deformational processes in connection with grading (turbulent flow of liquefied, semi-graded till-material?). Photo: R.L. 1990.

In all, some fifteen pits or trenches have been dug in this type of deposit. Almost all of the sections studied showed a very uniform structure with a successively increasing grain-size downwards (Fig. 34, colour). A more complex stratigraphy was recorded in two trenches cut in a major (c. 125 x 300 m, 1-2 m deep) depression. Parts of these trenches displayed a less uniformly developed size-sorting. At one spot, the uppermost one metre thick bed contained irregular layers or bodies of coarser, but still sorted, material mixed with the typical fine-grained residue of the graded till (Fig. 37). A few boulders were also present on the ground surface at this place (Fig. 38). The precence of boulders may possibly be explained by post--deformational sea-ice rafting or transportation by ice-bergs (faulting occurred soon after local deglaciation). The processes involved in the less uniform size-sorting, or rather, the deformation of an already size-sorted sequence, are not understood. Hypothetically it may be due to turbulent flowage of liquefied and partly size-sorted till material during ground collapse.

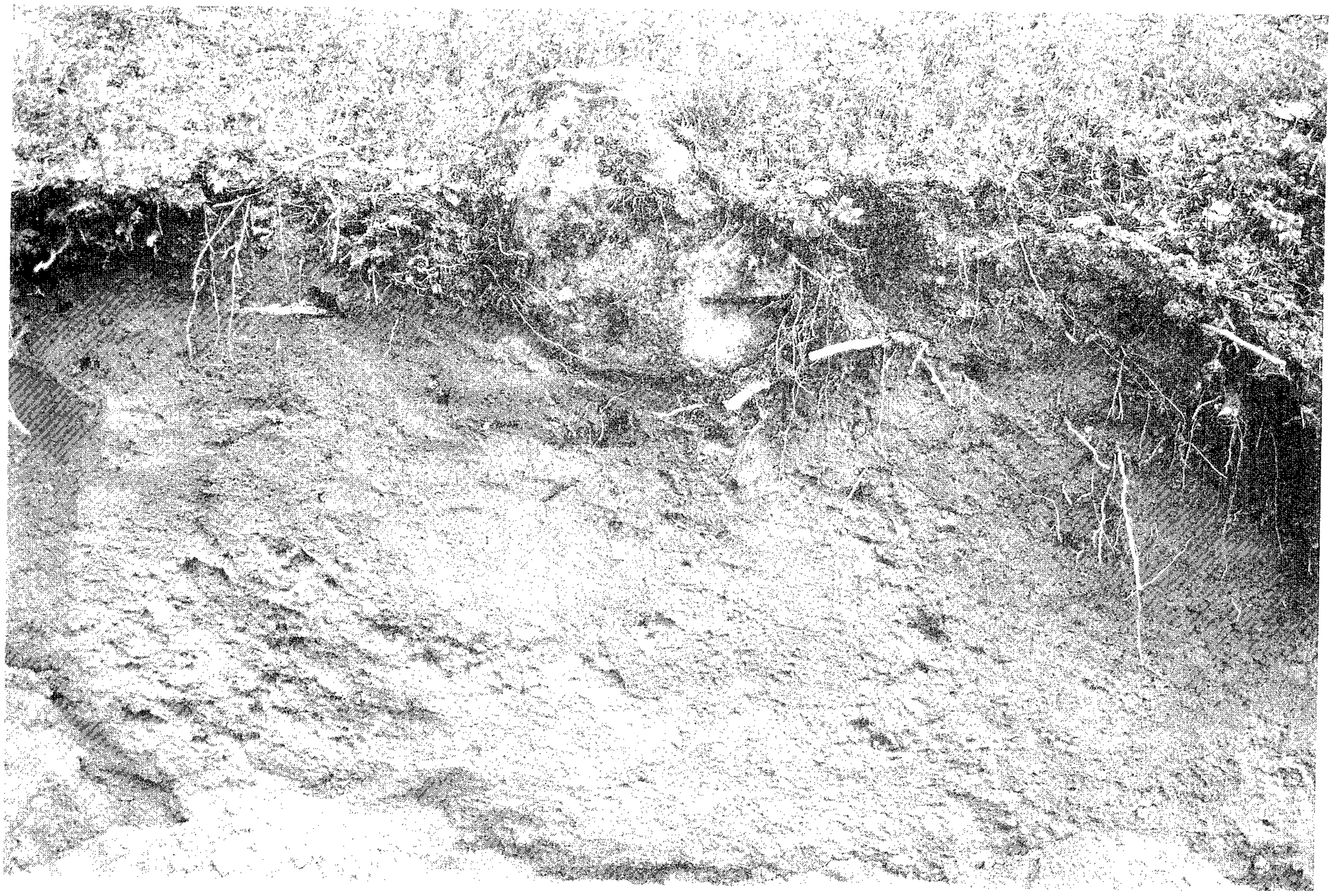


Figure 38. Section through the upper part of a graded-till sequence at Furuträsket, close to the section shown in Fig. 37. The boulder, measuring some 0.3 m, may have been transported to the place by sea-ice or icebergs after the deformation of the till. Similar to the section shown in Fig. 37. the grading here is incomplete or disturbed. Photo: R.L. 1990.

The other section with a differing stratigraphy displayed two beds of graded material within the northwestern border of the depression (Figs. 39 a and b). Some 12-15 m away from the rim, towards the center of the depression, the two beds merge to form one single bed with the more typical appearance (Fig. 39 b). The process of formation for this sequence is not understood either. Possibly it is a matter of stepwise collapse of the till stratigraphy at the margin of a sidewards expanding area of collapsed ground, resulting in repeated slips and flowage of liquefied till and forming separate beds. Once consolidated, a graded sequence is probably resistant to further deformation and another bed of liquefied till, produced by successive collapse, may flow to cover and "grade" upon it.

Another puzzling phenomenon in this sequence is the occurrence of rounded lumps of sandy-silty sediments floating in the more fine-grained material in the upper parts of the sequence (Fig. 40). The origin of these lumps, and the explanation as to why they remained resistant to complete disintegration and became mixed into the graded till, is not understood.

A number of questions concerning abnormal features and different aspects of the graded till remain unanswered (see e.g. Fig. 41, colour) and others probably await discovery, but there is no doubt that this spectacular phenomenon must reflect an extreme deformational impact on the ground. The grading is interpreted to be seismically induced and it represents the most violent deformation of loose deposits found in the Lansjärv area. It is assumed that an extremely strong (probably exceeding 1 g) and probably also long-lasting earthquake is a prerequisit for this type of deformation.

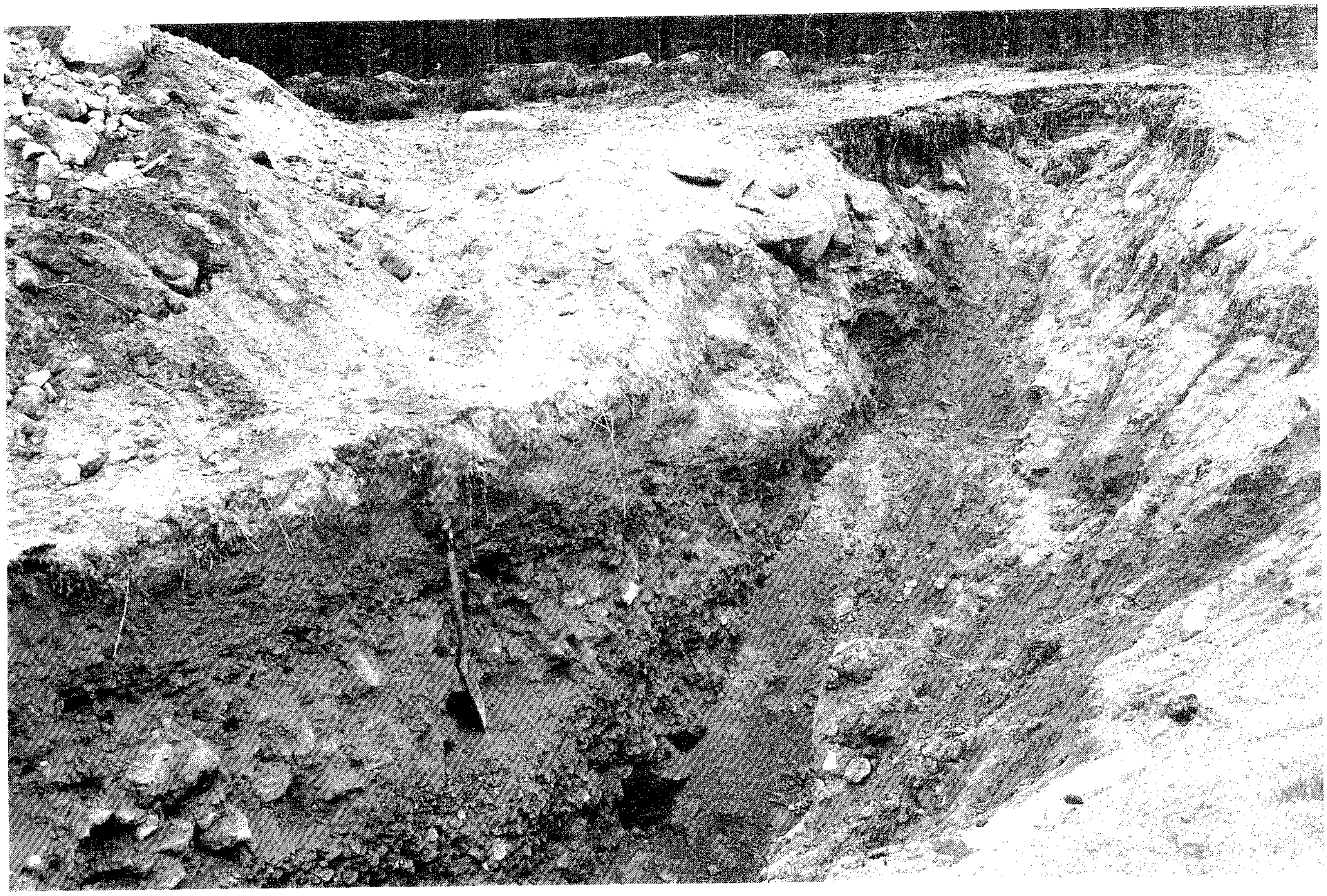
Site 14. <u>Ängeså</u> (7420-7421 N / 1785-1786 E, 110 m). The locality is situated some 5 km to the west of the northernmost fault-scarp segment. Ten trenches were dug in 1987, four of them to the north of the river Ängesån and six to the south of it. The sediments found were fluvial sand and glacial as well as postglacial clay. No deformation of any kind was observed. The fluvial sand was of an adequate grain-size for liquefaction and would probably have demonstrated extensive deformation if deposited when faulting occurred. However, at this altitude (some 60 m below the highest shore-line) the age of the sand is probably at least some 2 000 years younger than the deglaciation. Therefore, the lack of deformation is in agreement with the conception that co-seismic faulting was restricted to a very short period of time in connection with the deglaciation of the area. The clay on the other hand, if deposited when faulting occurred, was probably too fine-grained and cohesive to liquefy from seismic tremor.

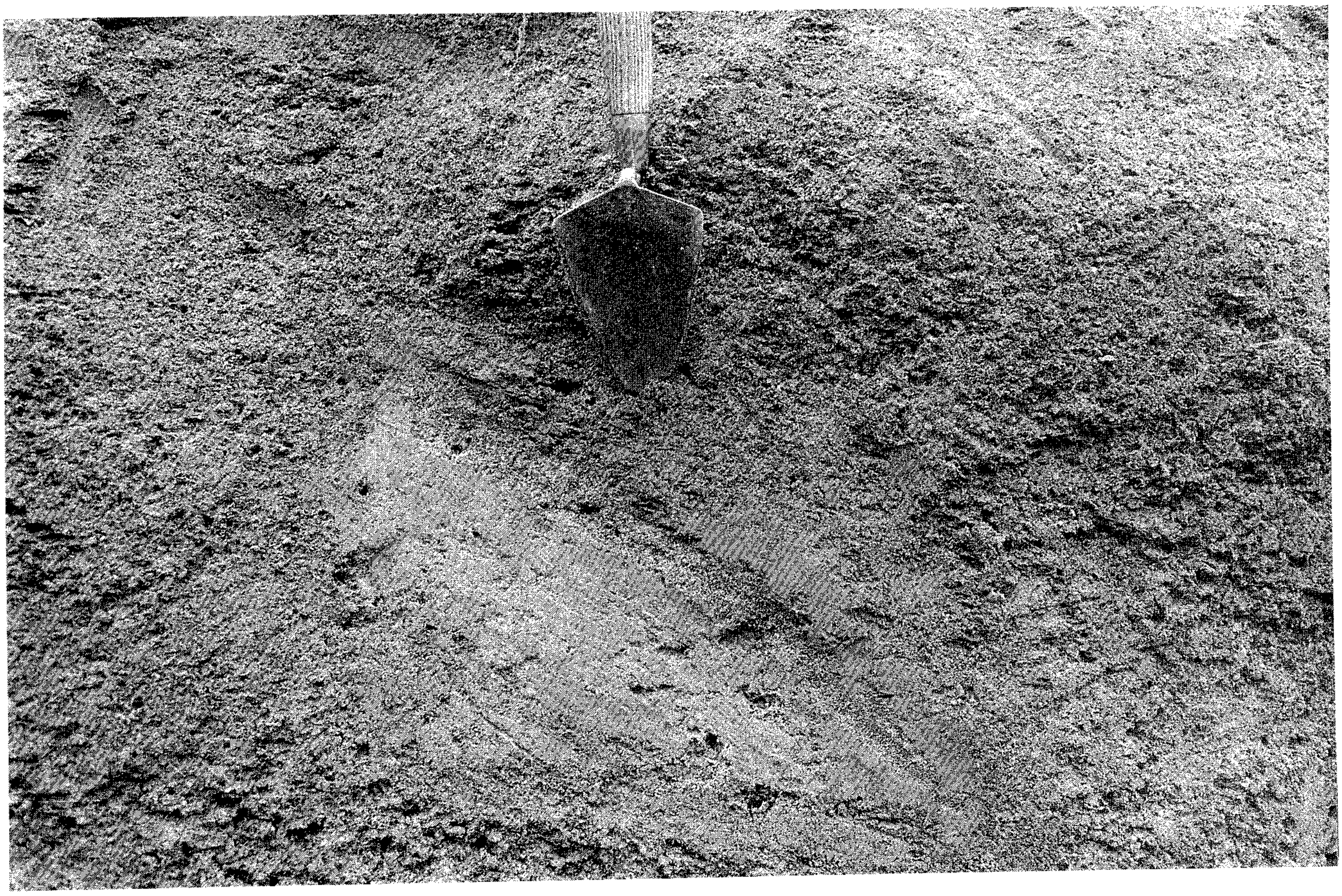
Site 15. <u>Mäntyvaara</u> (7428-7429 N / 1758-1762 E, 140-165 m). Three sections in deltaic sediments along the river Skrövån were studied. Two sections were cleaned up in sand-pits and a third one in a gully carved out by a small brook in thick (more than 30 m) silty and fine-sandy sediments. The sediments were loosely packed and no deformation was found except in the form of minor (a few centimetres) faults and insignificant water escape structures (Fig. 42).

Figures 39 a (above) and b (upper right). Trench cut in graded till at Furuträsket. The 50 m long trench starts at the margin of the subsided area with a deformed stratigraphy (Fig. b) and runs towards its center (Fig. a). The undeformed stratigraphy beneath the boulder-strewn surface outside the depression (Fig. b) contains two separate till beds (cf. Figs. 35 a and b). Nearest to the margin of the depression the section displays a double-bedded graded till. The two beds merge to a single bed some 12-15 m inside the margin (Fig. a). The process of formation for the repeated bedding is not understood but may possibly be a gradual collapse of the till stratigraphy or a sidewards flowage and repeated grading of liquefied till. Photo: R.L. 1990.

Figure 40 (lower right). Lump of fine-grained sediments in the upper part of a graded till section at Furuträsket. Possibly the sediment was mixed into the derived till material in a frozen state which may explain how it could remain undeformed in the completely altered till material. Two other lumps of the same type of sediment were found a few metres away. Photo: R.L. 1990

The sections studied are situated some 30 km to the northwest of the Lansjärv fault-set and probably the sediments were not yet deposited at the time of faulting. It is worth noting that no landslides have been found this far west in the area and very likely the site was still covered by inland-ice when faulting occurred.





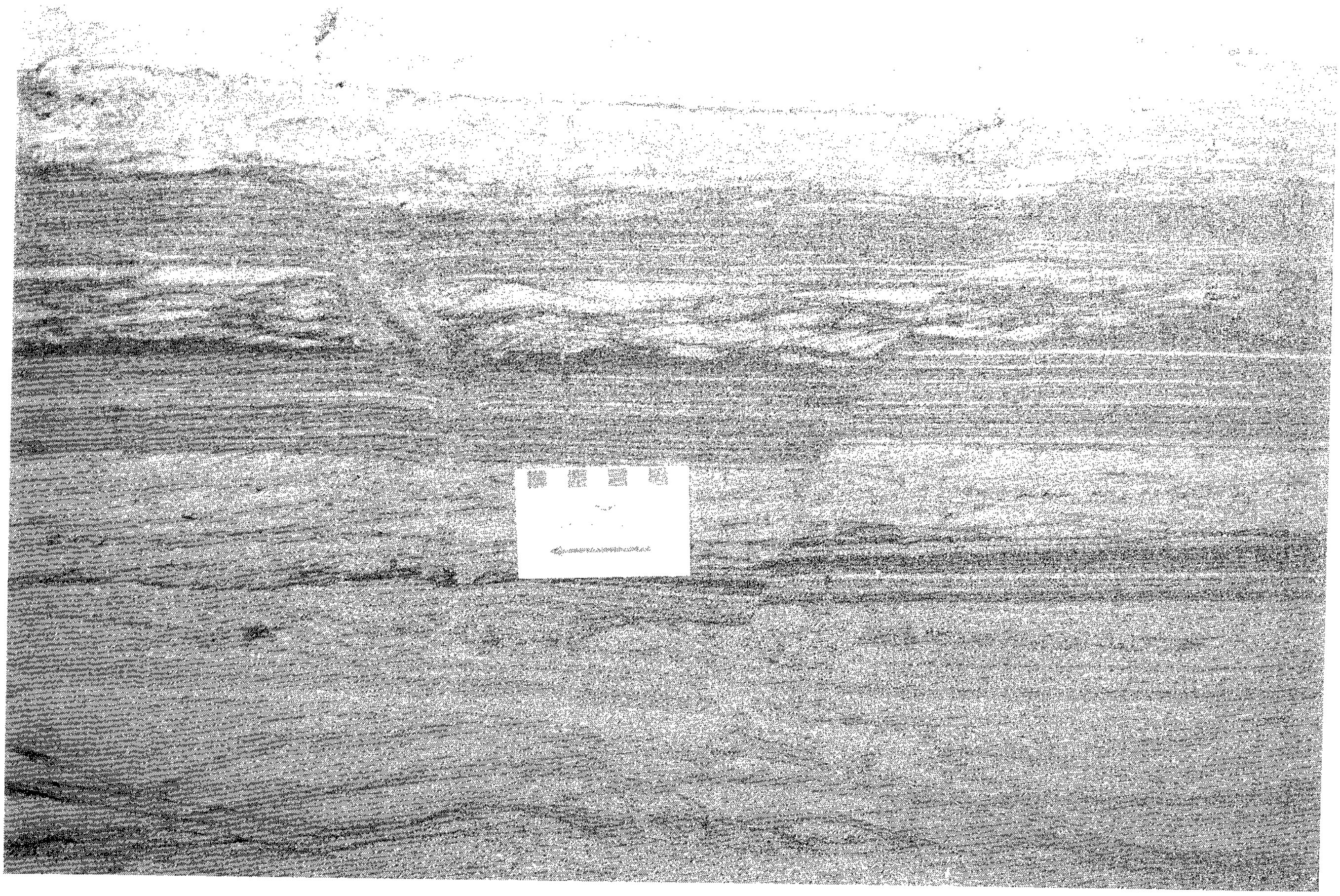


Figure 42. Minor fault (to the right of the scale) and water escape structure (to the left) in deltaic sand along river Skrövån at Mäntyvaara (site 15). The sediments are loosely packed and no major deformations were found at this site or at other sites studied nearby. The sediments are probably deposited after the movement in the Lansjärv fault set, situated some 30 km to the southeast. Photo: R.L. 1990.

Site 16. Linaälven (150-160 m). The stratigraphy of several steep river-banks and small road-cuttings in deltaic sediments along river Linaälven were studied. The loosely packed sandy and silty sediments displayed minor faults in the river banks but these faults may well be the result of settling in connection with the erosion by the river. No features indicating liquefaction or sudden dewatering were observed and the sediments are loosely packed. Similar to Mäntyvaara (site 15, above), the sediments were probably not yet deposited when faulting occurred some 25 km to the southeast. A minor landslide scar is noticed on a small hill a few kilometres to the north of the river but since this place is situated at a higher altitude it may well have been deglaciated while an ice-lobe still occurred in the river valley.

Site 17. Storbäcken (73962 N / 18086 E, 55 m). Till-covered sandy and silty sediments were studied in a steep river-bank by river Kalixälven some 20 km north of Överkalix. The sediments, probably of interstadial age, are deformed by weak folding and shearing along sub-horizontal fault-planes (Fig. 43). The sediments are also significantly compacted. The deformations are, with all certainity, the result of glaciotectonic stress and load of the inland ice which covered the area after sediment deposition. No features indicating liquefaction or rapid dewatering were observed and are probably neither to be expected from early postglacial earthquakes since the sediments were already consolidated by the impact of the inland ice.

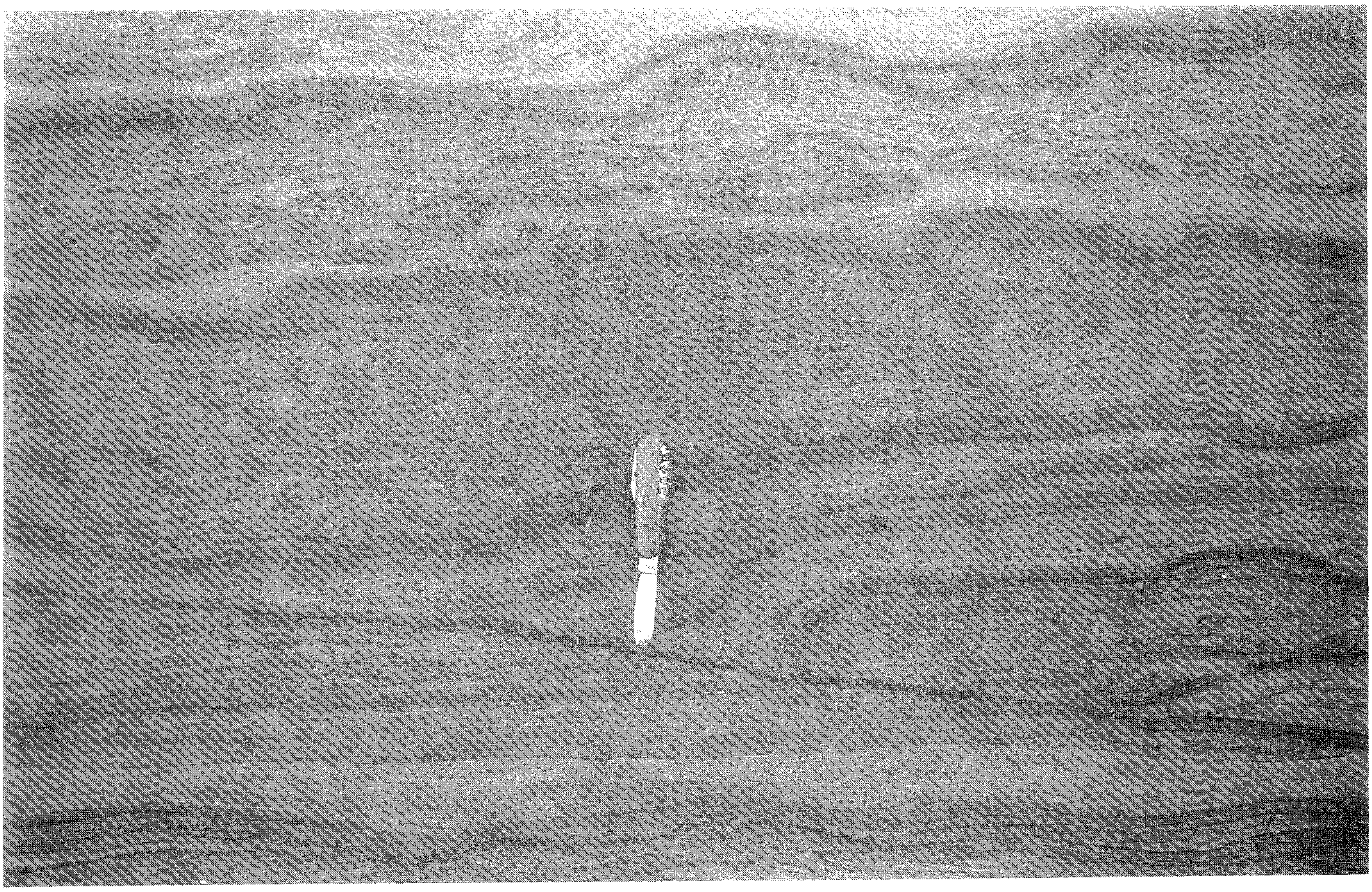


Figure 43. Till-covered fine-sandy and silty sediments at Storbäcken (site 17) showing weak folding and shearing along a sub-horizontal fault plane. The deformation is thought to be due to glaciotectonic stress caused by an ice-movement obliquely from the right, towards the viewer. Photo: R.L. 1990.

Site 18. Lilla Furuberget (73998 N / 18023 E, 130-140 m). In a gully, cut by meltwater during the spring of 1987, extensive deformation of the primary sedimentary structures was found in evenly bedded sand and silt, of glaciofluvial origin but reworked by littoral processes (Figs. 44, 45 and 46). Similar to other sites described above, the disturbed sequences were remarkably compacted. The deformations appeared to be restricted to a certain stratigraphical level and the uppermost parts of the sequences were unaffected, that is, the agents generating the distortions were acting only during a short period of time in the early postglacial period and before the locality emerged from the sea.

Figure 44. Convoluted sandy deposits at Lilla Furuberget (site 18). The material above the scale is artificial filling. Pseudo-nodules very similar to the one in the center are produced experimentally by simulating earthquake effects on sand overlying mud (Kuenen 1958). Scale in centimetres. Photo: R.L. 1987.

Figure 45. Convolutions in slightly inclined, evenly bedded littoral sand at Lilla Furuberget. The layering in the upper part of the section is undisturbed, demonstrating that the distortion took place before the locality emerged from the sea and the sedimentation ceased. The features occur at the same stratigraphical level as those in Figs. 44 and 46. Scale in centimetres. Photo: R.L. 1987.

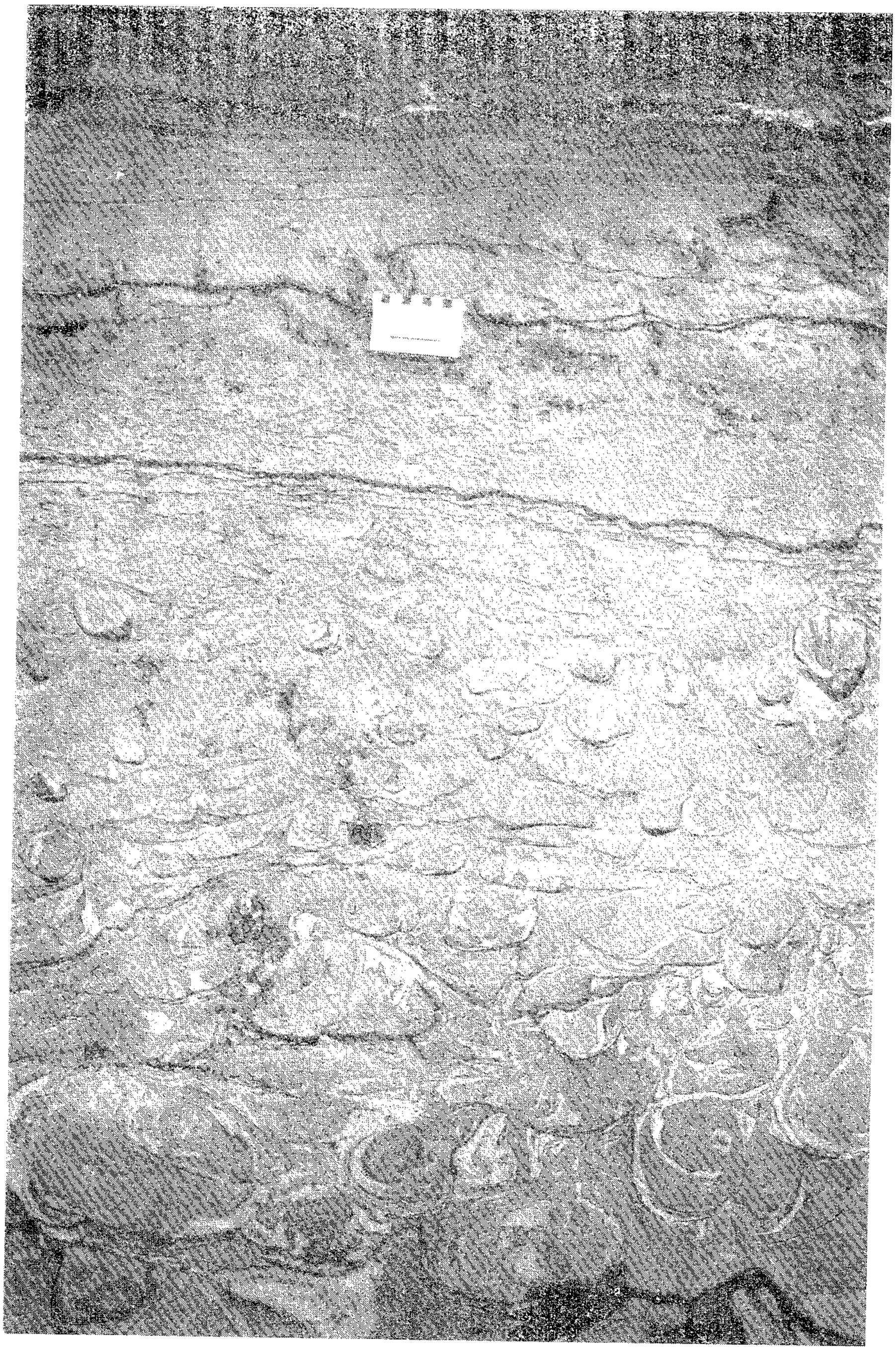


Figure 46. Strongly corrugated sandy and silty littoral deposits at Lilla Furuberget. The undeformed upper part of the sequence (above the scale) was deposited subsequent to deformation. The distortions are interpreted as being caused by seismically induced liquefaction, compaction and dewatering during the build-up of the sequence. Photo: R.L. 1987.

Site 19. Svartbergsbäcken (74074 N / 17977 E, 160 m). A 30 m long trench was dug in distal glaciofluvial sediments. These were fine-sandy and silty and had been reworked by wave activity and littoral currents in the upper parts. A great variety of deformations occurred in a 0.8-1.5 m thick bed. The original layering here was completely destroyed and replaced by a chaotic mass of convoluted and corrugated sand and silt layers, sand balls, water escape and injection structures etc. (Figs. 47 - 51, colour). Several sand pockets displayed gravitational sorting of heavy minerals, indicating intense shaking or possibly elutriation in connection with water escape (Fig. 49).

The deformed bed was sharply delimited upwards and replaced by sand with undisturbed planar bedding. Downwards the deformed sequence was likewise rather clearly defined and replaced by coarser sand. However, water-escape structures emanating from the sand and injecting into the highly deformed bed indicate that compaction of the sand, resulting in upward discharge of water, has contributed to the deformation of the more fine-grained deposits above. The strongly deformed bed, as well as the sand below, were both very tightly packed compared with the undisturbed strata above.

The deformations are believed to be due to intense seismic tremor, resulting in compaction, liquefaction and water-escape. Slumping, gliding or the like have probably not contributed to the deformation, at least not to any significant degree, since the bedding is almost horizontal and no directional structures indicating lateral movements in the deformed beds occur. The undeformed layering on top shows that the disturbance occurred before the place was raised above the sea and the sedimentation then ceased. Since the place is situated only some 20 m below the highest shoreline this means that the event occurred shortly after deglaciation.

Site 20. Torisevanmännikkö (74308 N / 18046 E, 90 m). Two pits were dug in four metres of silt and clay resting on glacial till. The sediments were very stiff and dark coloured and it was difficult to see the layering. A thin lamination, possibly glacial varves, occurred in the lowermost metre of the sediment sequence but no significant deformations could be observed. Probably the sediments are late-glacial in origin, and thus existed at the time of faulting in Lansjärv. Due to the stiffness, the sediments were probably not sensitive to liquefaction and deformation by the seismic impact.

Site 21. Vuopionsuanto (74386 N / 18046 E, 100 m). One excavation revealed a stratigraphy more or less identical with that of Torisevanmännikkö (site 20, above). Four metres of silt and clay rested on glacial till. Primary sedimentary structures were difficult to observe due to the effects of pedological processes and the dark colour of the sediment but at least the lowermost metre showed a thin lamination without any significant deformations. Similar to Torisevanmännikkö the sediments are probably glacial in origin but too stiff to deform by the fault induced seismicity.

Site 22. <u>Mestoskangas</u> (7447-7449 N / 1798-1799 E, 135-150 m). Eight pits were dug in thick sandy and silty postglacial fluvial sediments along the river Kalixälven. The pits were dug from different erosional surfaces, representing different stratigraphic levels in the deposits. The sediments proved more or less throughout to be built up of alternating beds of small-scale cross-stratified sand and laminated silt (Figs. 52 and 53).

In all pits but one, the primary structures were perfectly intact and not the tiniest fault or water-escape structure, indicating sudden subsidence, was found. In one pit, representing the bottommost part of the deposits, some deformations were found in a c. 0.5 m thick sandy silty sequence resting on one metre of silty clay over glacial till (Fig. 54). Since the deposition of the thick (at least 10-15 m) fluvial sediments may have started fairly closely in time to the deglaciation, and the deformed sediments are among the first deposited, the deformations may possibly be the result of seismic activity in connection with the faulting in the Lansjärv area. It is worth noting that the site is situated far to the NE and was probably deglaciated significantly earlier than the actual fault area.

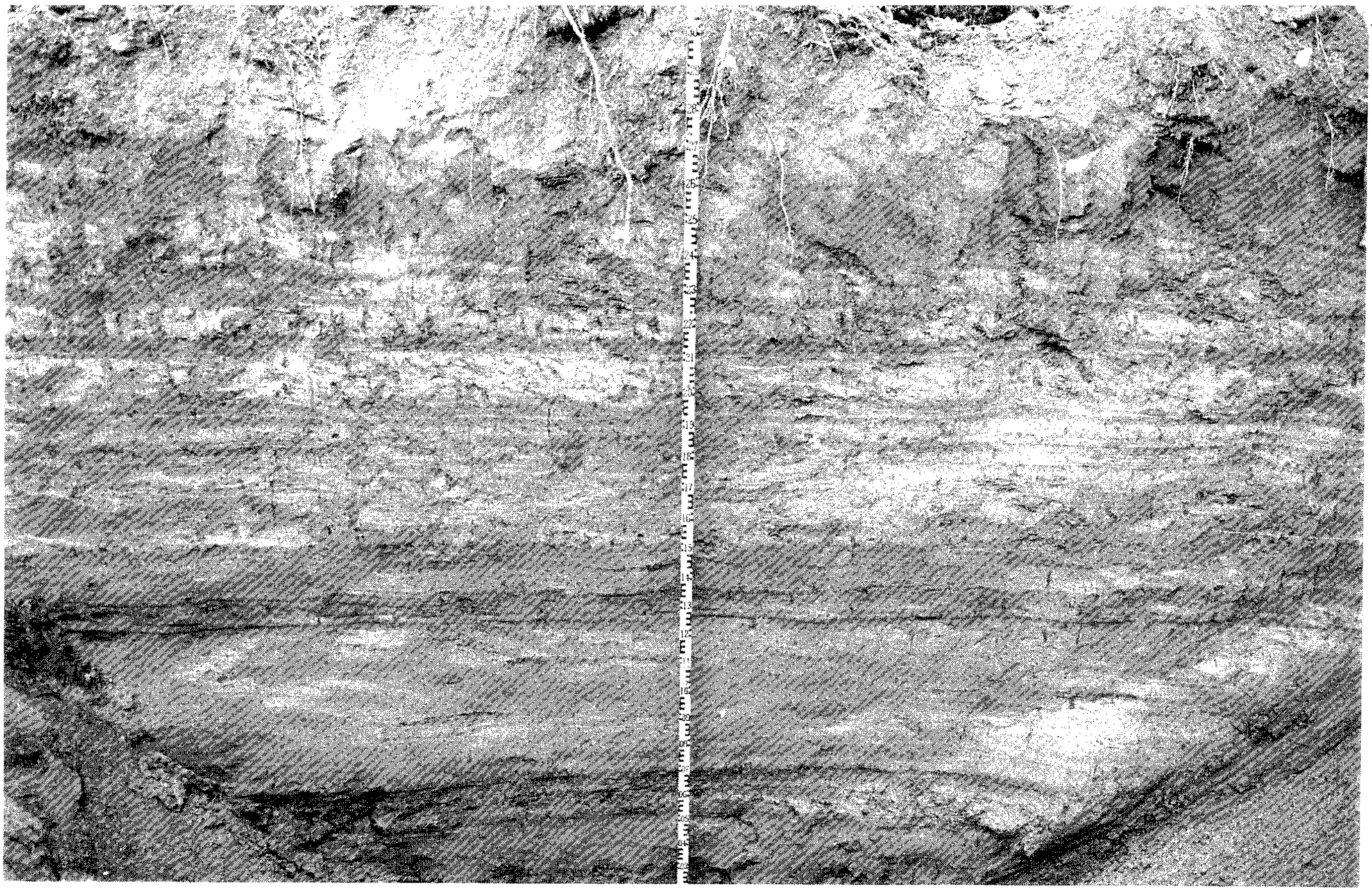


Figure 52. Sandy and silty postglacial fluvial sediments at Mestoskangas (site 22). The stratigraphy, with alternating sandy and silty beds, is typical of several pits dug in the vicinity. The sediments are loosely packed and the planar bedding shows no irregularities. Photo: R.L. 1990.

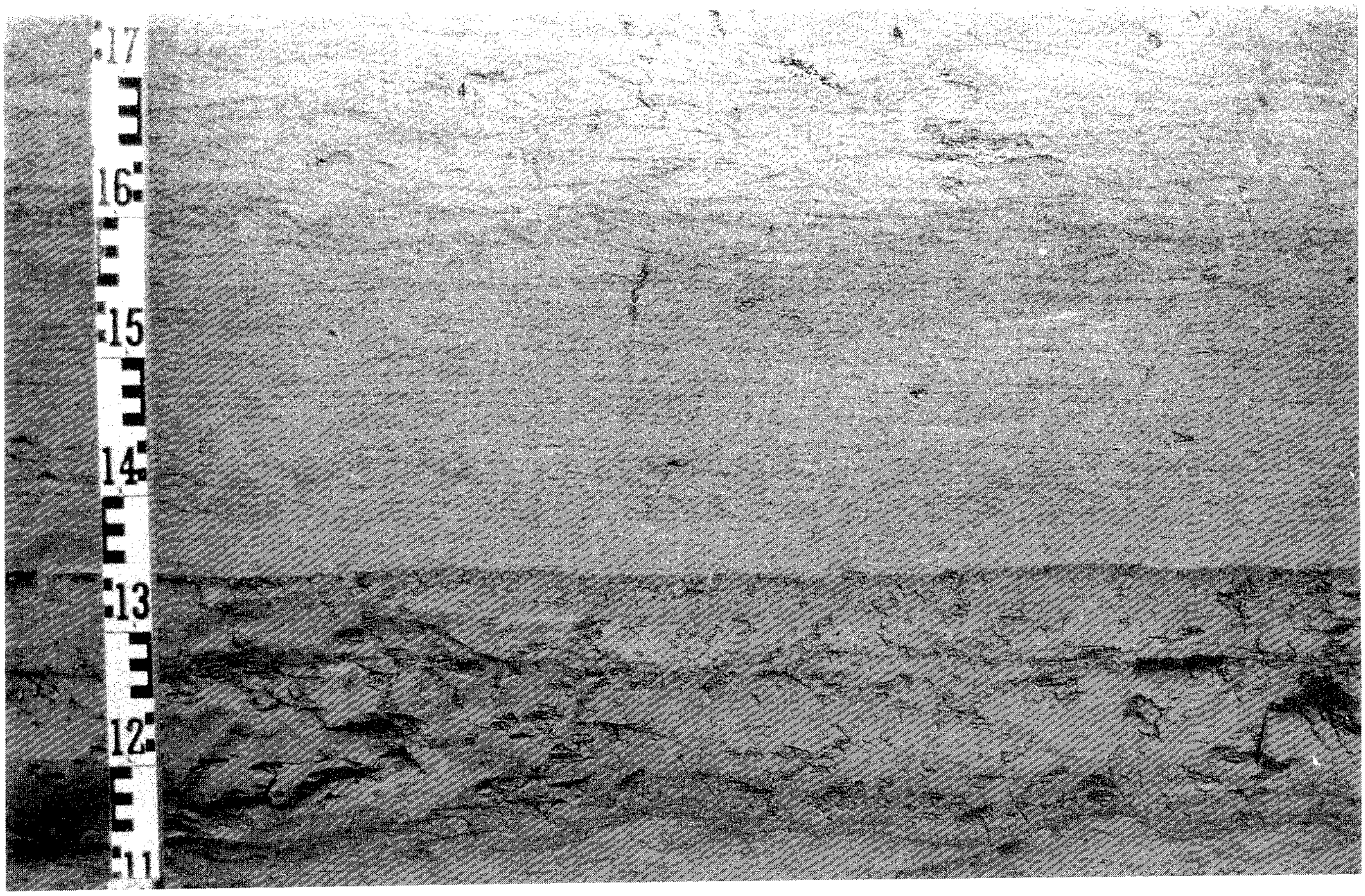


Figure 53. Small-scale cross-layered sand and laminated silt at Mestoskangas. The section represents a more elevated (younger) stratigraphy compared with the section shown in Fig. 52. Nothing indicating subsidence, faulting or rapid water escape was found in this or several other pits dug in the vicinity. Photo: R.L. 1990.

Figure 54. Deformed sand and silt at Mestoskangas. The primary layering in the lower half of the picture is broken, and fragments of sand layers are floating in a mass of silt, marbled with sand veins. The sediments rest on one metre of silty clay over glacial till and represent the bottommost part of the thick (at least 10-15 m) postglacial fluvial deposits. In the upper half of the picture the layering is more or less undisturbed (but miscoloured by iron precipitation). Photo: R.L. 1990.

5 FINAL REMARKS

It has previously been argued that the extensive occurrence of soft sediment deformation in the Lansjärv area can be explained by early postglacial co-seismic movements in the Lansjärv fault-set (Lagerbäck 1988a, 1990). The interpretation of the features as being seismically induced is supported by, amongst others, the following arguments:

- They occur in sediments with a grain size favourable for liquefaction when affected by earthquake vibration (see e.g. Lee & Fitton 1969).
- They occur in mainly grain-supported deposits, with similar grain-size throughout the section, not expected to develop load-cast structures if not liquefied.
- They occur in flat-lying or very gently sloping terrain which tends to exclude the possibility that slumping or sliding caused the deformation.
- They occur in sediments deposited during the early postglacial period contemporaneous with the faulting, but have not been found in younger sediments in the area.
- On each site they appear at a certain stratigraphical level and they are covered by undisturbed sediments. This demonstrates that the phenomenon was syndepositional, occurring over a short interval of time before the sites were raised above the sea. The distortions are developed in the uppermost, less consolidated strata, which must have been most sensitive to liquefaction at the time of deformation.
- The features fit well into a pattern of extensive faulting, accompanied by large earthquakes triggering a great number of landslides in the Lansjärv area.
- The features were found in deposits and environments where they were expected according to the theory of early postglacial seismogenic faulting in the Lansjärv area, based on other arguments.

The conception of violent seismic activity during the deglaciation phase has gained further support from the investigations carried out during 1990. It is, of course, not possible to claim that all major deformations were triggered by earthquakes associated with the early postglacial faulting, but, on the other hand, it is hardly accidental that extensive deformation has been encountered in practically all investigated deposits of deglaciation sediments whilst almost no deformation were found in thick younger sediments of a similar composition. Furthermore, the few examples of deformation met with in younger sediments consist mainly of minor faults, and resemble by no means the extensive compaction, liquefaction, load casting, water escape etc. indicated in the deglaciation sediments).

It is often argued that thick sediments easily deform under their own load. E.g. Lowe (1975) suggests that rapid deposition by itself, resulting in consolidation and dewatering of subjacent units, may lead to liquefaction, fluidization and associated distortion of sandy deposits, but also indicates that earthquakes or other disturbances are probably influential in some instances. The experiences from the Lansjärv area strongly suggest that a trigger is essential for the development of major deformation in sediments without any significant inclination. The faulting in the area is an obvious trigger in this context.

Some of the features examined in the Lansjärv area are so extreme that it is difficult, or impossible, to see any other source for the deformation than high-magnitude earthquakes. This is especially true for the graded tills which indicate extremely violent agitation. As far as is known to the author, only one sequence found in a similar deposit is described from outside the Lansjärv area, namely at Boliden some 200 km to the south of Lansjärv (Fig. 2).

The Boliden-section is described by Lundqvist (1946) who explains the phenomenon in terms of a slight reworking of a glacial till by the impact of wave-action and suggests the term "skvalpsediment" for this type of deposit. "Skvalp" is a swedish word for lapping, that is, water splashing to and fro in a rather quiet manner. However, it seems strange that small waves in a shallow bay of the ancient Gulf of Bothnia at Boliden could have produced an almost perfect size-sorting of till-boulders and -stones, with the matrix maintained, to a depth of several metres. Appropriately, the site is situated 4 km east of a prominent fault-scarp line (Fig. 2) interpreted as late- or postglacial in age (Lagerbäck 1979, Rodhe et al. 1990) and most probably this deposit also is the product of strong seismic impact on an ordinary till as is suggested for the sections described from Lansjärv. Similar to the Lansjärv area, strong paleoseismic activity in the Boliden area is supported by the occurrence of several landslide scars in the region (Fig. 2).

It is also worth noting that at the different sites in the Lansjärv area there is only one major deformational event indicated. On each site there is one deformed bed and no indications of a repeated deformation stratigraphy. This is also in agreement with the conclusion that the faulting in the Lansjärv area occurred within a very limited time period after local deglaciation and that the different fault scarps developed on one and the same occasion and as a one-step event.

Many of the deformed sequences encountered in the Lansjärv area resemble deformational features interpreted as seismically induced in other areas (e.g. Ringrose 1989) and environments (e.g. Sims 1975). They also resemble features produced experimentally with the intension to simulate earthquakes (Kuenen 1958, Dzulynski & Walton 1963). Recent investigations (unpublished) in the Skellefteå district, another area with young fault movements (Fig. 2), revealed a great variety of deformational structures, many of them very similar to those described in this report (Figs. 55 and 56, colour).

In order to elucidate the significance of paleoseismicity in connection with glacio-isostatic rebound, the search for seismites should be extended to comprise other and larger parts of Sweden and other glaciated areas with a low current seismicity. A systematic study of favourable sediments at strategically located sites would probably contribute to a much better understanding of the late- and postglacial seismotectonics.

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APPENDIX, COLOUR PHOTOGRAPHS