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WEICHSEL IN CENTRAL SOUTH NORWAY. A general view of the deposits from the Gudbrandsdalen Interstadial and from the following glaciation.

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Bergersen, O.F. & Garnes, K.: Weichsel in central South Norway. A general view of the deposits from the Gudbrandsdalen Interstadial and from the following ice age. Boreas

Present knowledge of sub-till sediments found in the valleys in the Mid-Gudbrandsdal area and the stratigraphy of the overlying basal tills is summarized. The existence of widespread waterlain sediments which are thought to have been deposited in a cold ice-free period of Middle/ Early Weichselian age, the Gudbrandsdalen Interstadial, gives evidence of surprisingly modest ice erosion during the last ice age, even in valleys close to the highest mountains. Judging by the nearly total evacuation of older deposits from the tributaries, the ice-free period seems to have lasted for a long time, with very strong slope processes. Huge quantities of proglacial sandur sediments accumulated in the main valleys indicate that the last inland ice sheet grew slowly. By comprehensive analyses the authors have succeeded in correlating the overlying tills with four regional glacial phases of the last ice age reconstructed mainly through analyses of striae. It is found that the conservation of the sediments, as well as the distribution of different tills, was dependent on the relative location of the ice divide.

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In 1971 the authors introduced the term Gudbrandsdalen Interstadial covering a presumed ice-free period of Middle Weichselian age (Bergersen & Garnes 1971). The paper was based on a reinterpretation of the stratigraphic position of two glacio-fluvial units containing mammoth fragments, namely Haugalia and Fåvang. Further evidence of an interstadial period was provided by several new discoveries where basal tills capped waterlaid sediments. Some of these localities are described in recent papers, e.g. Garnes & Bergersen (1977), Garnes (1978, 1979). The assumption of an ice-free period during the last ice age, in areas close to the highest mountains in Norway, generated a new understanding of the last ice age. Until then, it was generally accepted that most of Norway has been capped by the inland ice during the whole Weichselian since the last interglacial time. From central parts of Sweden and Finland, however,evidence already existed of ice-free period(s) during the Weichselian, i.e. Jämtland Interstadial (Lundqvist 1967), Peräphojola Interstadial (Korpela 1969), cf. also Hillefors (1968). Recently, several localities with sub-till sediments of assumed Middle/Early Weichselian age have been reported from different parts of central South Norway (Roaldset 1973, Rosenqvist 1973, Vorren & Roaldset 1977, Helle et al. in print.). In addition, many localities are also known from the coastal areas, see Mangerud et al.(in print.). New information about Weichselian interstadials in central part of Sweden is discussed by Lundqvist (1978).

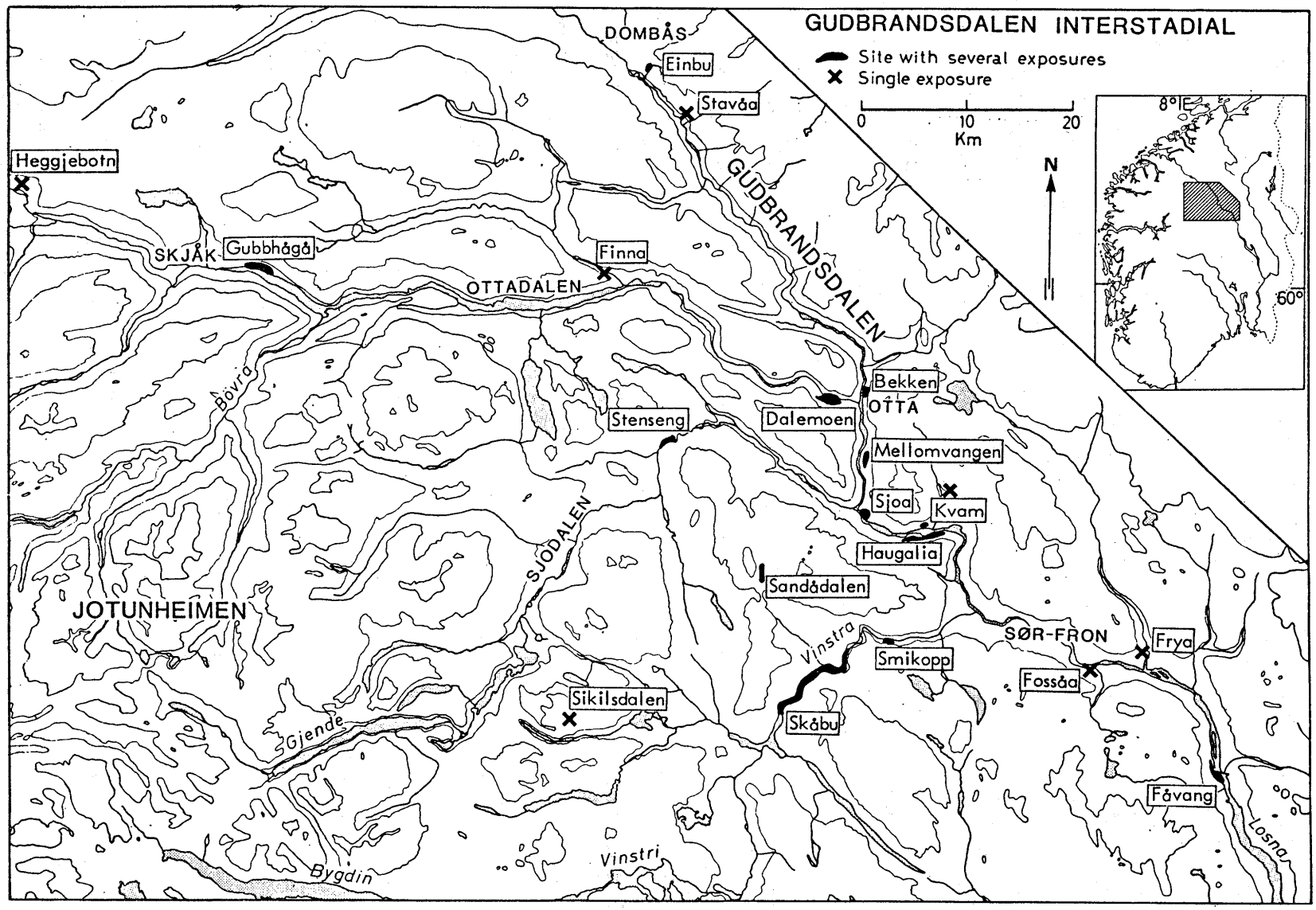

Fig. 1. *Localities with waterlaid sediments thought to have been deposited during the Gudbrandsdalen interstadial. The sediment remnants are concentrated in Mid-Gudbrandsdalen and in its tributaries. In the southern and northern part of the Gudbrandsdalen area we have found no locality with sediments of this age.*

At present, the Gudbrandsdalen area is the district in Norway, except for Jæren, where by far the most sites with pre-Late-Weichselian sediments are exposed (Fig. 1). Furthermore, in this area 16 of a total 18 Norwegian mammoth finds have been discovered (Fig. 2). As pointed out by Garnes in Heintz, Garnes & Nydal (1979), most of the fragments have been found in or close to localities with sub-till sediments. The most recent ^{14}C datings of the remnants have all given infinite age, more than 40,000 years B.P. (op.cit. Tab. 1).

Due to the limited space given for this article, there is no room for detailed description of any locality. In this paper the authors will therefore summarize present knowledge of the sub-till sediments and the stratigraphy of the overlying tills in the Gudbrandsdalen area. The investigations, a part of the Norwegian IGCP-project "Glaciations in the Northern Hemisphere", have been assisted by the following persons, then students under the supervision of the authors: I. Alstadsæter, J. Hole, H. Hollund, E. Lien, L. Olsen, J. Skjerven, and M. Thoresen.

DISTRIBUTION OF SUB-TILL SEDIMENTS

It is often difficult to distinguish interstadial sediments from younger deposits. Especially complicated conditions occur where overlying tills are missing, or where the sediments have a blanket of unsorted material which might be the result of slope processes. Thick, sorted, melt-out layers of till or waterlain tills may also be misinterpreted

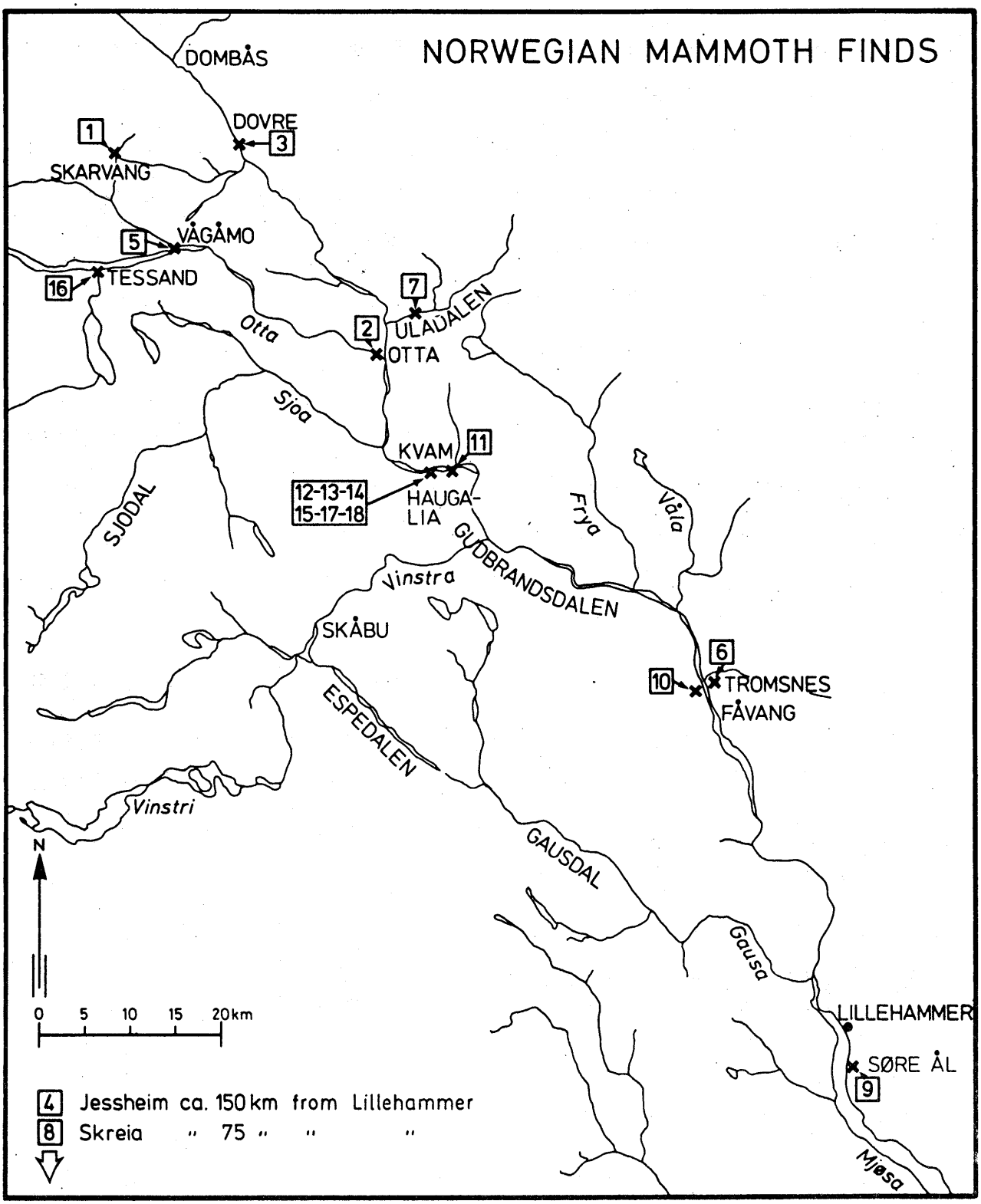

Fig. 2. Map showing the sites of all Norwegian mammoth finds numbered in chronological order after date of find (after Garnes in Heintz, Garnes & Nydal 1979).

as sub-till sediments. It cannot be excluded that till-capped sediments in some cases could have a subglacial or lateral origin, but such sediments normally show more complexity in texture and structure. Even if we eliminate the most uncertain localities, there are still many sites where exposures give clear stratigraphic evidence of interstadial sediments.

The geographical position of the known localities is remarkable (Fig. 1). All exposures have been found in valleys, none in the vast interfluve areas. Probably the most important reason for this is the lack of larger exposures outside the valleys. Most of the localities have been found in natural section where slope processes and fluvial erosion have exposed the sediments on steep valley slopes. The localities have been found at different altitudes, the highest ca. 1250 m a.s.l. in east Jotunheimen, the lowest in the bottom of Gudbrandsdalen, ca. 200 m a.s.l.

SUB-TILL SEDIMENTS AND STRATIGRAPHY IN GUDBRANDSDALEN

Most of the sub-till sediments in Gudbrandsdalen proper consist of coarse glacio-fluvial material, mainly sand, gravel and pebbles. The most important localites are Fåvang, Haugalia, Sjoa, Bekken, and Dalemoen. The latter is situated in Ottadalen, but very close to the main valley (Fig. 1). Judging from overdeepening and other glacial erosion phenomena, Ottadalen, rather than the upper part of Gudbrandsdalen itself, may be called a main valley. The stratigraphy in three of these localites is

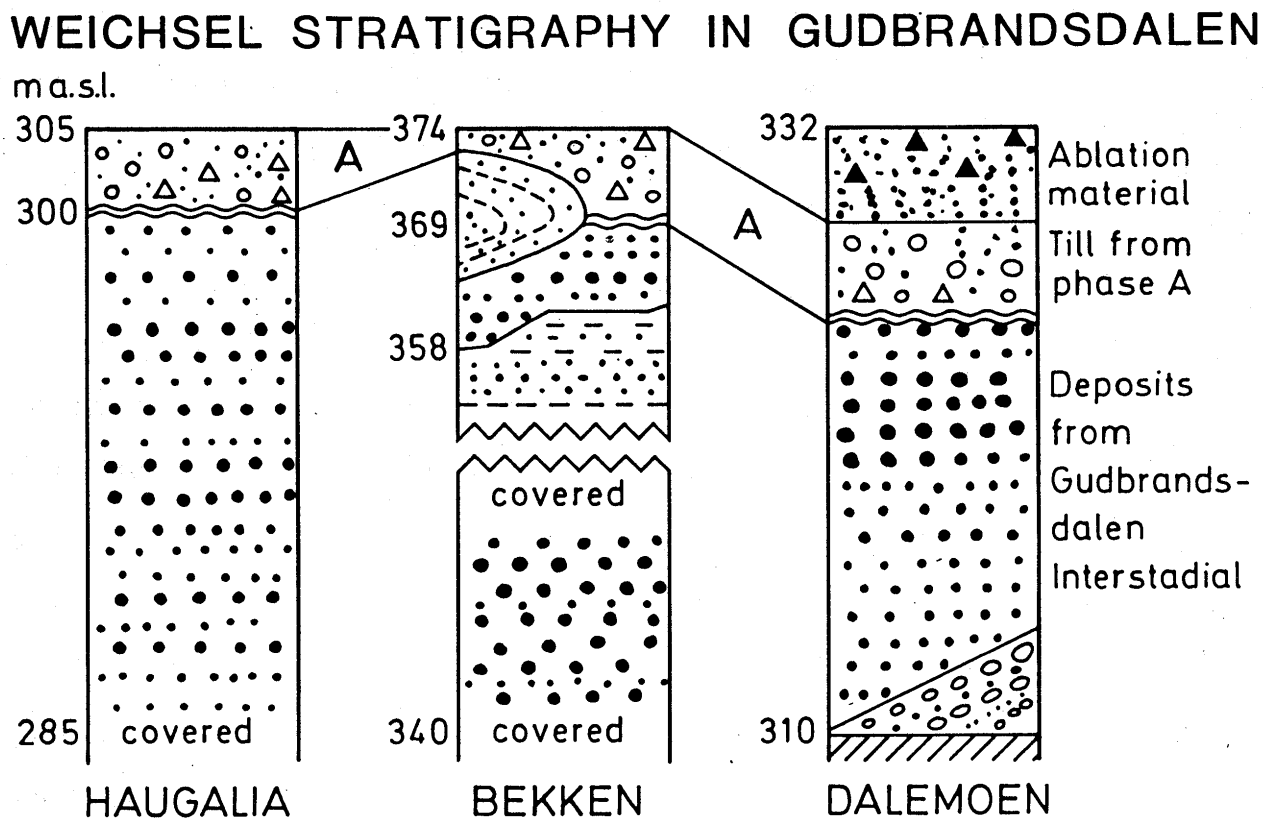

Fig. 3. *The Weichselian stratigraphy at three important localities in the main valley. As can be seen, the sub-till sediments are covered by only one basal till, and in addition, deposited from the deglaciation period are missing at two of the localities. The basal tills in all sections are interpreted as having been deposited at the beginning of the last ice age, in phase A, cf. Fig. 8. Notice the large overturned fold in the sediments in Bekken. This is most probably due to glacio tectonics (Lie 1974). At Dalemoen there is situated a local river fan (open rings) below the sandur sediments.*

shown schematically on Fig. 3.

The pebble fraction in the sediments is very well rounded and far-transported, the roundness index being higher than found in any other deposits in the area (Bergersen & Garnes 1971, Lie 1974). From petrographic and structural studies, there is convincing evidence that the sediments are of glaciofluvial origin, transported and deposited along the main valley. The composition indicates that a large bulk of the sediments originated in east Jotunheimen, mainly from the catchment area of the present rivers Otta and Sjoa. It is striking that the content of so-called Jotun-rocks, which cover large areas of Jotunheimen, in nearly all sub-till sediments in Gudbrandsdalen is higher than 20 %, often much higher. In sediments deposited from other tributaries than Otta, Sjoa and Vinstra rivers, the content of Jotun rocks is very low, normally less than 5 %. In Gudbrandsdalen Bergersen (1964) used the content of Jotun rocks, and the degree roundness of the pebble fraction, to distinguish between autochthonous and allochthonous sediments and tills. Along the valley bottom and on the lower part of the valley slopes an allochthonous basal till exists which earlier was hard to explain in respect to distribution as well as to genesis (Bergersen 1964, 58-61). More recent studies have indicated that all allochthonous basal tills are chiefly derived from underlying coarse sub-till sediments (e.g. Bergersen & Garnes 1971, Garnes & Bergersen 1977). Therefore, where allochthonous till is widespread, sediments are often hidden below. Based on this assumption, some new localites

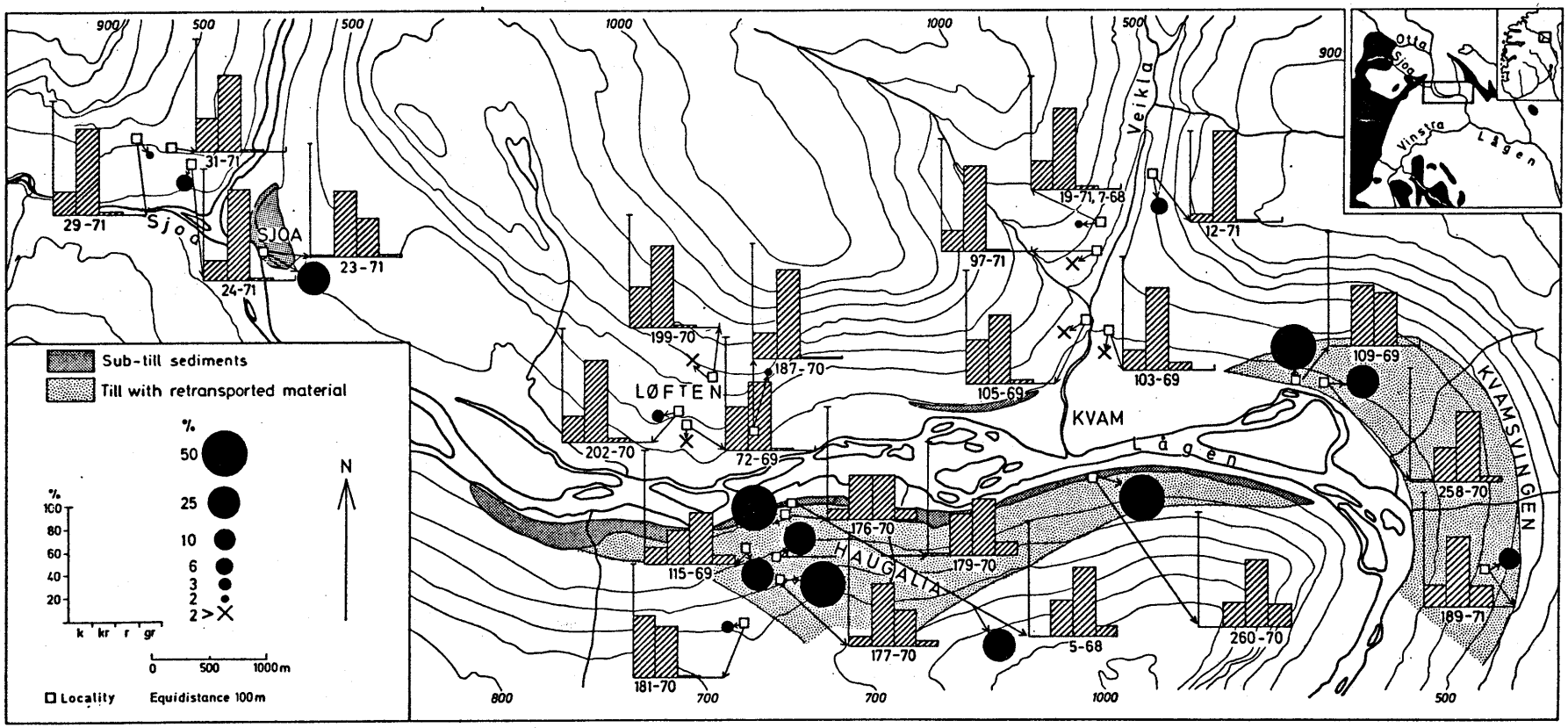

Fig. 4. *Distribution of sub-till sediments and till with retransported material in Kvam - Sjoa area. Both types of sediments show a high content of Jotun rocks (black) and a high degree of roundness in the stone fraction compared with the local till and glacio-fluvial deposits from the deglaciation. (Modified after Garnes 1973).*

with sub-till sediments have been discovered. Fig. 4 shows the widespread occurrence of till with retransported sediments in the Kvam - Sjoa area. In the same area coarse sediments interpreted as deposited during an interstadial period, have been found at Haugalia, Kvam, and Sjoa.

Another interesting fact is that the allochthonous till often shows a terrace-shaped surface. In some places, e.g. the Kvam - Sjoa area, the terrace-shape turns into a stoss-side moraine down the valley slope.

In the lower part of Gudbrandsdalen large deposits occur at the mouth of the tributaries where the main valley widens. These deposits have been much debated, but in the last decades they have been assumed to be subglacial fans accumulated from the tributaries (Mangerud 1963, Bergersen 1964). Judging from sections in the deposits at the mouth of the rivers Frya and Fossåa, we interpret the stratigraphy as shown in Fig. 5. This means that we presume that the bulk of the deposits at the mouth of other tributaries also, may be built up from old sediments and/or allochthonous till. On the top, deglaciation sediments camouflaging the deposits below, give the whole deposit a fan-like appearance. These fan-like deposits, often continuing into terrace-shaped deposits with presumably the same stratigraphy, strech up to approximately the same altitude. Plotting these heights in a longitudinal profile along the valley, together with the heights of the terrace-shaped moraines and the upper limit of the old

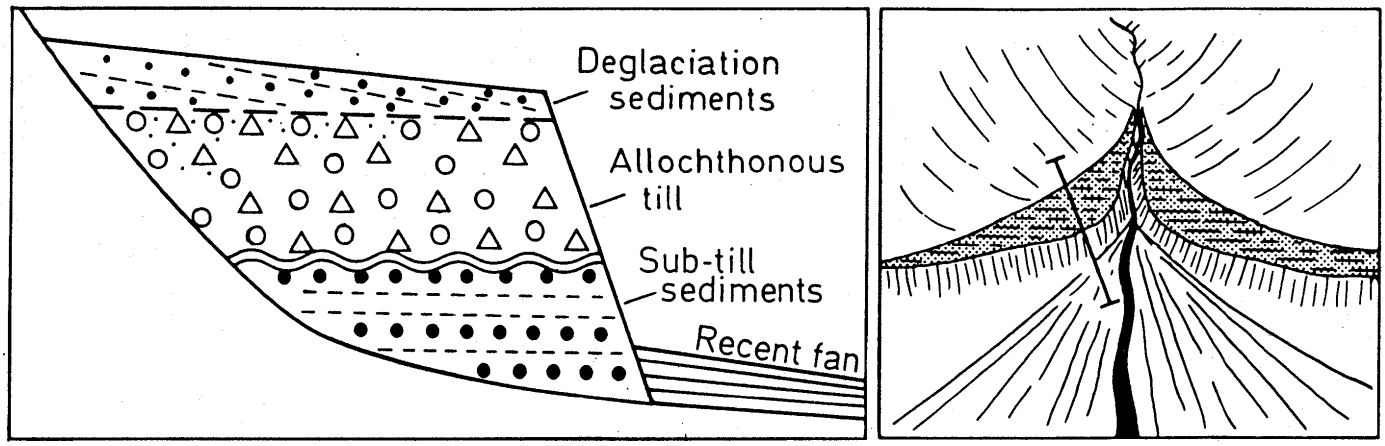

Fig. 5. *Schematic section through the deposits situated at the mouth of several tributaries in Gudbrandsdalen. Where the cover of deglaciation sediments is thick, there occur a hummocky terrain due to dead ice melting. Elsewhere the surface of the deposits is terrace-shaped.*

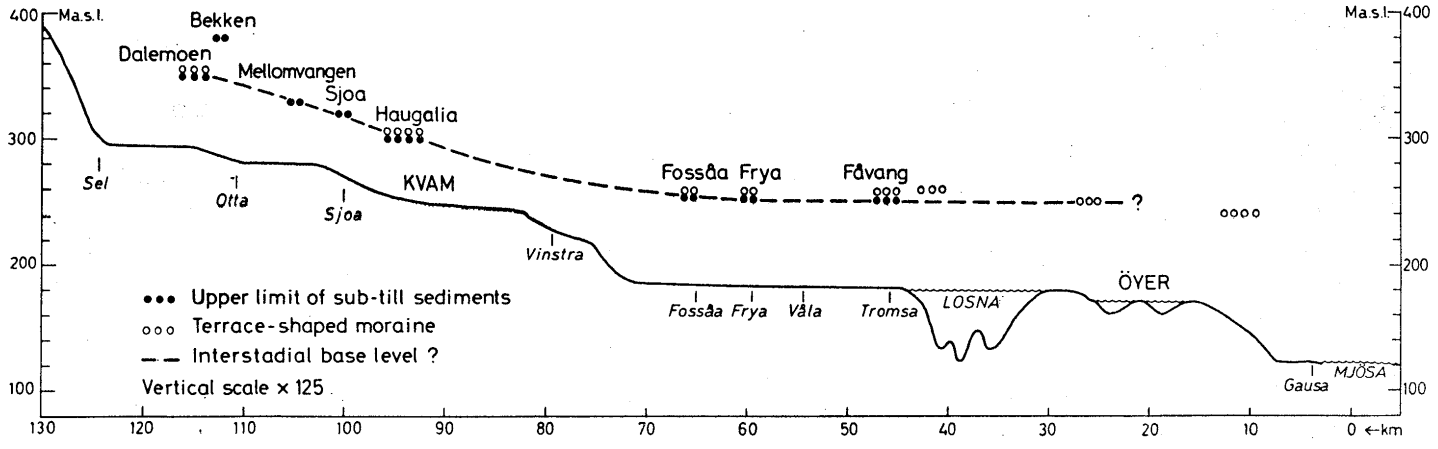

Fig. 6. *A longitudinal profile along the lower part of Gudbrandsdalen with reconstruction of a possible interstadial base level.*

sediments, we find that the heights fit well together (Fig. 6). The level which can be reconstructed, indicates that the sub-till sediments which formerly had a widespread distribution, are the main cause of the characteristic moraine terraces down the valley.

The assumed interstadial sediments along Gudbrandsdalen have all been interpreted as proglacial sediments deposited from advancing valley glaciers (Bergersen & Garnes 1971, Lie 1974, Garnes 1978) (Fig. 7). Even with sparce knowledge of the former extension of the sandurs which in parts of Lower Gudbrandsdalen could have been lateral terraces, it is evident from the remnants that the deposits have been huge compared with the cover today. Also the last deglaciation sediments are tiny compared with the former interstadial sandur sediments. Most probably the advancing glaciers at the beginning of the last ice age eroded deep U-formed valleys into the sediments. The sediments are mostly preserved in the outer bends of the valley, cf. Fig. 4, and in leeside positions.

Although information is incomplete, the authors suggest that the former sandurs filled the main valley bottom to a regional level of 350 m a.s.l. in the Otta district, sinking to ca. 250 m a.s.l. in the lower part of Gudbrandsdalen. This level is most easily explained by a marine transgression deep into the valley, due to glacial downpressing of the central part of the country. Higher sea levels than the Late- and Post-Glacial marine limit are known from different coastal areas of Norway, cf. Andersen et al. (in print.). In a recent paper dealing with sub-till

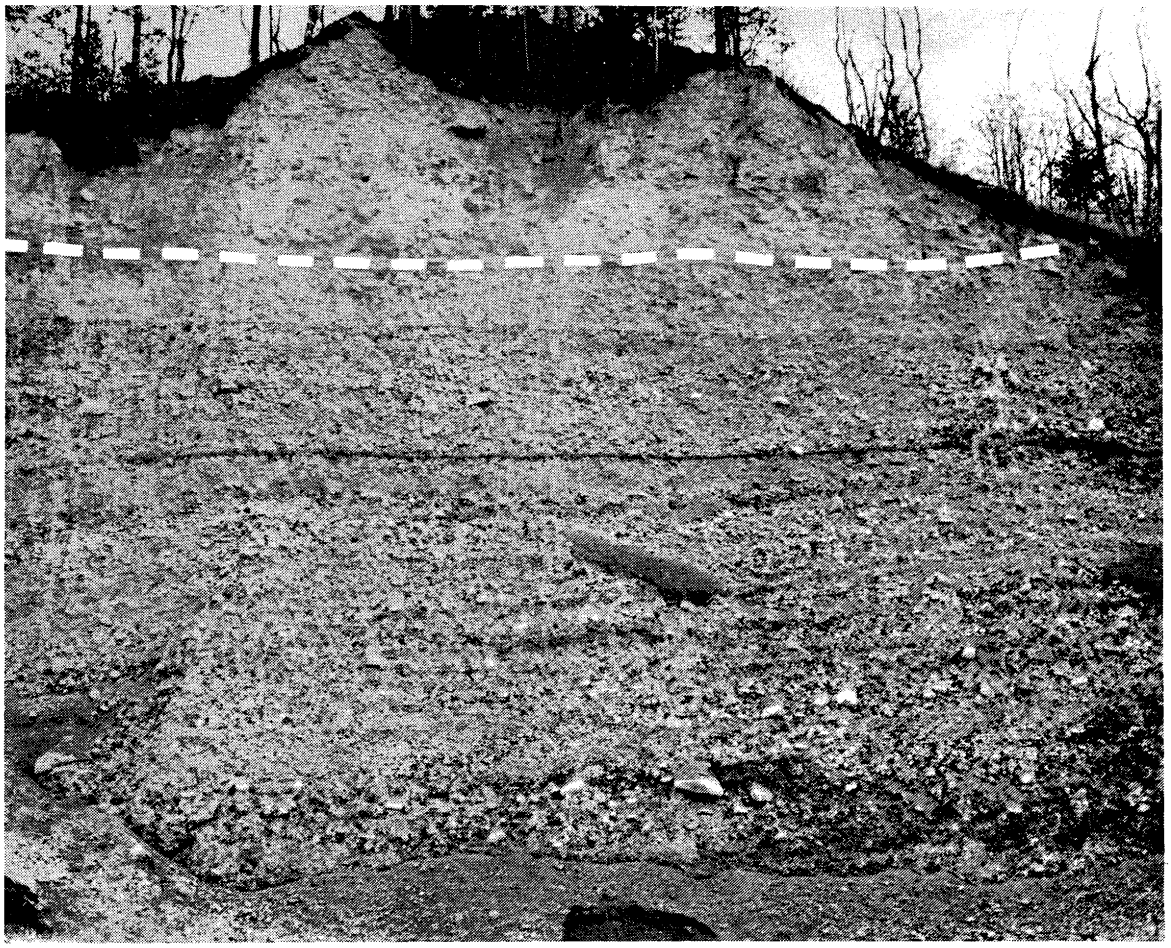

Fig.7. *Section at Haugalia showing coarse proglacial sediments below basal till. In this section 6 of a total of 18 Norwegian mammoth finds have been made in the sub-till sediments or in the transition zone to the till (broken line). Most localities with sub-till sediments in the main valley have the same stratigraphy and types of sediments. The two units were deposited from the right. The total height of the section is measured to 19 m.*

clays, situated 90 m above the local marine limit of the last deglaciation in the Numedal valley, Roaldset (1980) concluded that the clays most probably were deposited in marine environment during Middle Weichselian age.

STRATIGRAPHY IN THE TRIBUTARY VALLEYS

Due to the well developed till stratigraphy, the localities with sub-till sediments in the tributary valleys give important information about the development of the last ice age. In the three largest tributaries, the valleys of Otta, Sjoa, and Vinstra, as well as in some of the smaller ones, waterlaid sediments have been found below different types of basal tills. By comprehensive analyses of tills, we have succeeded in correlating different tills with regional glacial phases reconstructed mainly through detailed analyses of striae (Fig. 8). The stratigraphy at Stenseng (Garnes & Bergersen 1977), Einbu (Garnes 1979) and Gubbhågå (Hole & Bergersen in print) is recently published (Fig. 1). In addition, recent investigations of several exposures in Skåbu, earlier described by Mangerud (1965), have been undertaken under the guidance of the authors (e.g. Alstadsæter 1979). The general stratigraphy at these four localities is shown on Fig. 9.

Skåbu. In the Vinstra valley at Skåbu eight large, and a number of small exposures can be seen showing glaciolacustrine sediments of up to 100 m thickness below tills. In addition, coarse, short-transported fan deposits have

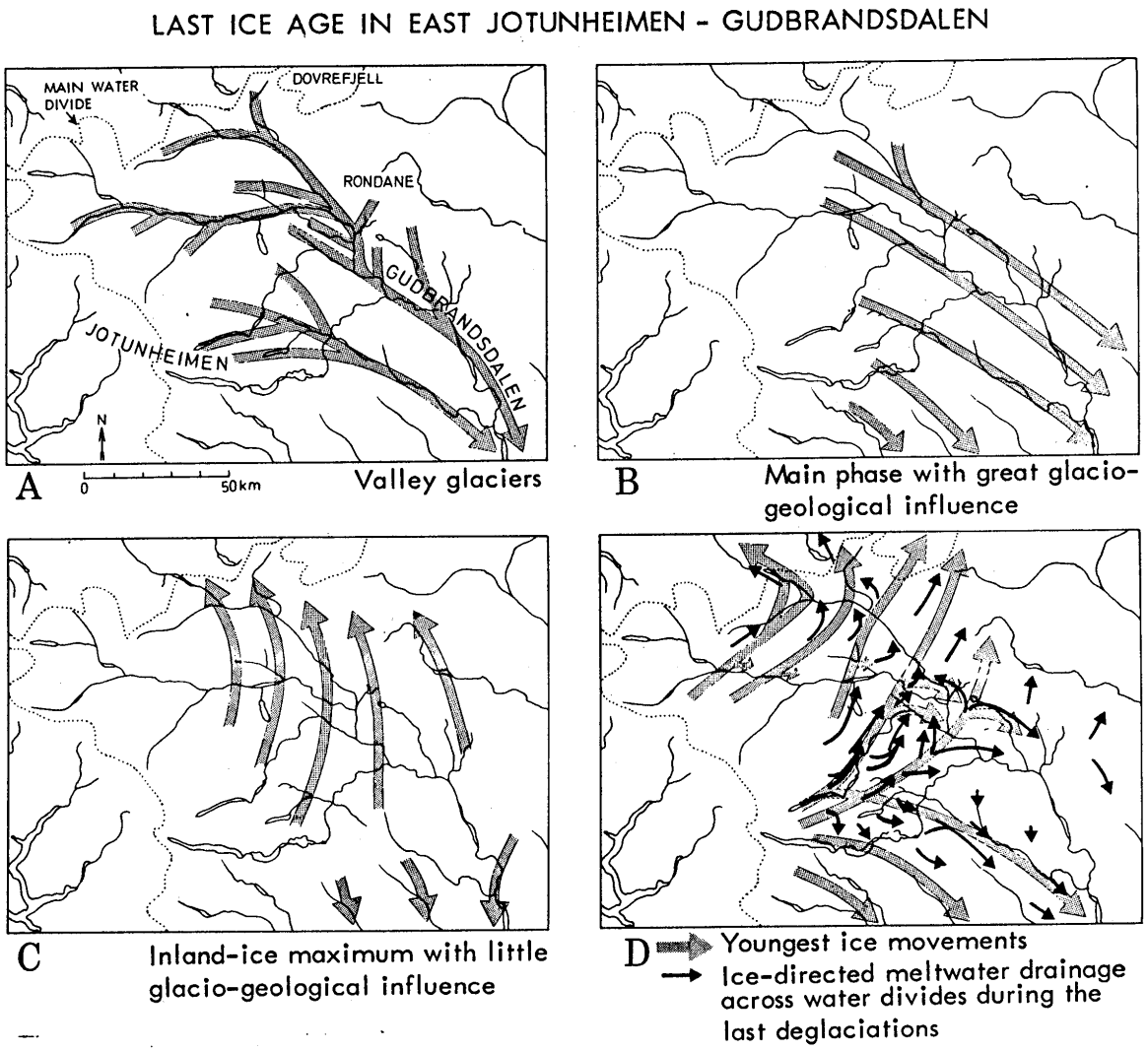

Fig. 8. *Reconstruction of four phases of ice movements during the last ice age. As can be seen, there occured an ice divide over Mid-Gudbrandsdalen during phase C and D. (After Garnes 1975).*

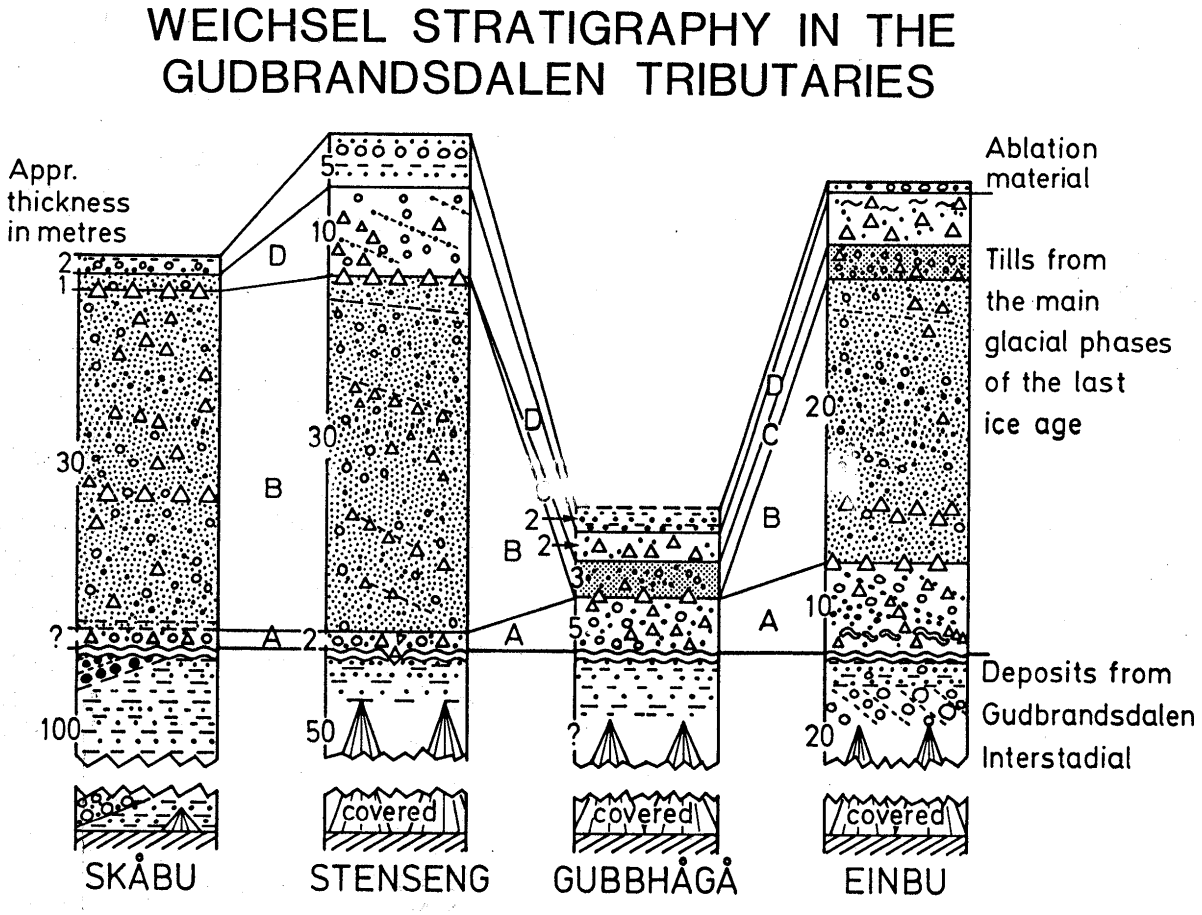

Fig. 9. *Correlation of the till stratigraphy in four sections in four different tributaries, from the south (left) to the north (Garnes 1980). The distribution of the tills from different phases seems to vary with the distance from the ice divide. In the sub-till glacio-lacustrine sediments at Skåbu there occur both glacio-fluvial units of local origin (open rings) and far-transported deposits (filled rings). The latter are interpreted to be of proglacial deposits. The till units A - D correspond to the four phases in Fig.8.*

been observed below the silt-sand layers. Above the glacio-lacustrine sediments a glacio-fluvial sequence occurs. The fine-grained sediments, deposited in a lake probably dammed between two glacier tongues, are found to have been deposited without break in the sedimentation and overridden by the inland ice without any subaeril exposure. Therefore, the sediments probably belong to the starting phase of the last ice age. The same conclusion was also suggested by Mangerud (1965).

The bulk of the tills, which are found up to 30 m thick, have evidently been deposited during the first part of the last ice age, from glaciers flowing to the east - south-east, as also pointed out by Mangerud (1965). As a result of detailed field work, using different methods, the authors have identified also a younger covering basal till being deposited from northflowing glaciers. This till, having a fabric which corresponds very well with a number of striae observations in the vicinity of Skåbu, is thought to belong to phase D. The upper till is separated from the lower till by a block layer, which the authors believe represents the change in the direction of the glacier-flow, from ca 160° to ca 20°. The till stratigraphy at Skåbu is thus found to be similar to that of Stenseng, see below. The reason for the lack of tills from phase C at these localities could be that the localities are found in an area which was located just below the inland-ice culmination zone during this phase. In Sandådalen, situated between Skåbu and Stenseng, cf. Fig. 1, coarse glacio-fluvial sediments are overlaid by basal till deposited

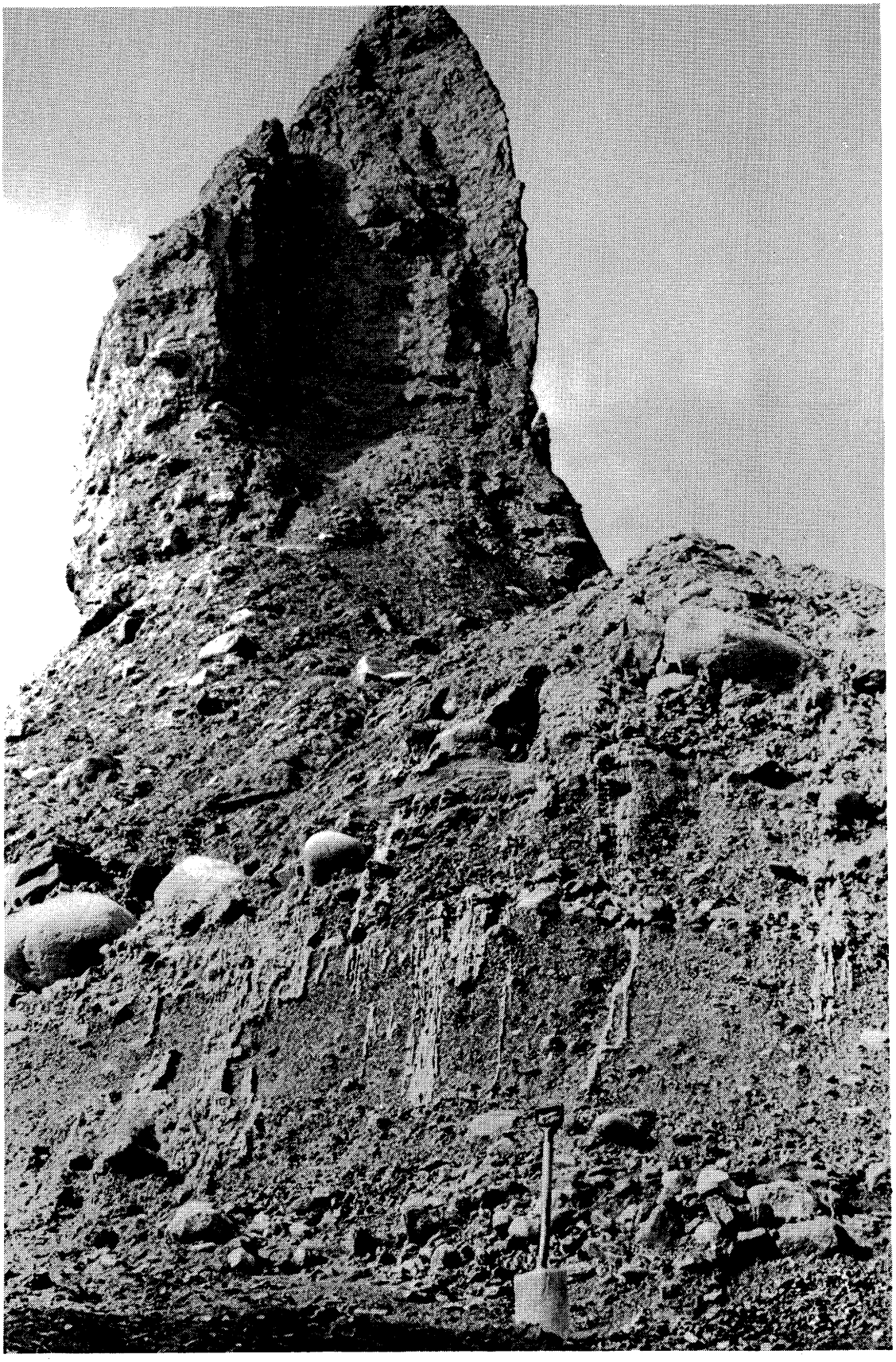

Fig.10. *Sub-till deltaic sediments at Einbu, cf. Figs.1 and 9, viewed to the north. The sediments are thought to have been deposited in a local ice-dammed lake.*

by northflowing glaciers. This till can most probably also be correlated with phase D.

Stenseng. Also in parts of the Sjoa valley, thick glacio-lacustrine sediments below tills have been demonstrated. The strongly deformed upper zone of the sediments gives no indication of whether they were overridden by the inland ice just after their deposition or whether they survived a subareal period. Above the sediments, till units have been identified corresponding to the main glacial phases of the last ice age, with the exception of phase C.

Gubbhågå. In the uppermost part of Ottadalen, in a large glacial through close to the highest mountains in Norway, several localities with glacio-lacustrine sediments below till have been observed near the valley bottom. The most complete stratigraphy is shown at Gubbhågå where basal tills corresponding to the phases A, C and D, have been found. The reason why a till deposit from the phase B (the main phase elsewhere) is missing, could be that the main ice divide crossed the area during that period.

Einbu. The most complete till stratigraphy above waterlaid sediments has been reconstructed at Einbu in Hjellådalen, a small tributary close to Dombås. At this place basal tills from all four main glacial phases of the last ice age are found. The sub-till sediments are thought to have been deposited in a lateral lake dammed by the advancing ice at the beginning of the last ice age, (Fig. 10).

X-ray analyses of material from all till units show no traces of fossil soils or weathering products as smectite and kaolinite (Garnes in prep.).

OTHER LOCALITIES WITH SUB-TILL SEDIMENTS

In addition to the localities chiefly described, a number of sites with sub-till sediments are known. Some of these are uncertain concerning their stratigraphic position, and they may be mixed up with sorted melt-out till layers. Furthermore, in Jotunheimen we have seen sub-till sediments which have obviously been deposited during the last deglaciation period and overridden by local ice advances. Both of these types of localities are excluded from Fig. 1.

Most interesting is the highest situated locality, 1250 m a.s.l., in Sikilsdalen in Jotunheimen. Glacio-lacustrine sediments more than 4 m thick can be found here below thick tills which are considered to have been deposited during the first part of the last ice age.

SUMMARY AND CONCLUSIONS

No organic matter has been found in the sediments investigated, except for mammoth fragments and pollen. The pollen content is extremely low, but all localities seem to show the same picture. Betula and Graminae account for almost all of it (Garnes 1978, Alstadsæter 1979). All observations indicate that the sediments were deposited in a cold

interstadial environment, cf. Bergersen & Garnes (1971). No argument has been found for an interglacial age for the deposits. The stratigraphic position of the sediments shows that they are older than the last inland-ice period and that most of them, if not all, were deposited in the same ice-free period. All investigations on structure and texture point to this conclusion. In the Brumunddal area, ca. 100 km southeast of Mid-Gudbrandsdalen, recent finds of sub-till layers with bog and lake sediments are supposed to represent a Weichselian interstadial called Brumunddal Interstadial (Helle et al. in print). Two ^{14}C datings of the bog, which was overlying several older tills, gave infinite age, one of them > 50,300 B.P. (T-3222), (op.cit.). Judging by the geographic and stratigraphic position, the datings, and the pollen content of the sub-till layers, the Gudbrandsdalen and the Brumunddal Interstadial probably represent the same ice-free period. The authors have focused the present investigation on the development and course of the last ice age. Therefore, in this review we will not give a further discussion of the possible correlation of the Gudbrandsdalen Interstadial period with ice-free periods in other areas.

In many localities it has been proved that the sub-till sediments rest on bare rock, which sometimes is striated. During the ice-free period before the last ice age, there must have been an extensive evacuation of older deposits from the tributaries. From calculations based on the rate of slope processes, Garnes (1979) suggested that the conditions in Hjellådalen, a tributary in upper Gudbrandsdalen,

show that the period could have been longer than the post-glacial period, i.e. more than 9000 years.

The large, sub-till, sandur sediments in Gudbrandsdalen may indicate that the last inland ice sheet grew slowly. The snouts of glaciers from Jotunheimen seem to have remained in Gudbrandsdalen for a long time, transporting enormous quantities of glacial material into the valley. There are indications of a strong glacio-isostatic down-pressing of the area allowing the sea to transgress farther into the valleys than during the last deglaciation period.

The most plausible explanation for most of the sediments is that they are deposited at the beginning of the last ice age. This is not proved, however, and it cannot be excluded that some of the sediments were deposited in a deglaciation environment. Most of the sub-till sediments in the tributaries are situated in the same areas where large ice lake sediments were deposited during the last deglaciation. Furthermore, the two lake sediments, different in age and stratigraphy, show many similarities in texture, structure, and distribution pattern. It may also be pointed out that there are some glaciological difficulties in reconstructing the position of the damming glaciers. The authors suggest that some of the sediments could have been deposited between downwasting ice masses in the main valleys and advancing valley glaciers from the western tributaries.

The most important conclusions from the present study of Weichsel deposits are:

1. Till studies have appeared to throw more light upon the development of the last ice age than studies of the sub-till sediments have done (Figs. 8 and 9). The sub-till sediments, however, have been a useful basis for the establishment of the Weichselian till stratigraphy.

2. The widespread existence of sub-till sediments gives evidence for surprisingly modest ice erosion during the last ice age, even in valleys close to the highest mountains in Norway. The glacial sculpture of these valleys must therefore be older than Weichsel.

3. The sub-till sediments give little information about the period in which they were deposited, namely the Gudbrandsdalen Interstadial. Evidence has been found for an arctic/subarctic environment during the deposition of the sediments. Judging by the nearly total evacuation of older deposits from the tributaries, the ice-free period seems to have lasted for a long time, with very strong slope processes.

4. Most of the remnants from the Gudbrandsdalen Interstadial have been found in Mid-Gudbrandsdalen. This is presumably due to the fact that the main ice divide was situated over this area for a long time, conserving the sediments from ice erosion. It is also found that the intensity of ice erosion, as well as the magnitude

of till deposition, was dependant on the ice divide's position in relation to the location of the areas.

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