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TILL STUDIES IN THE GUDBRANDSDAL AREA, EASTERN CENTRAL NORWAY

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Abstract. A number of localities with sub-till sediments have recently been found in the Gudbrandsdal area. The sediments are mostly of glacio-lacustrine origin and of an assumed Middle Weichselian age. Only a few of the findings have been described hitherto (Bergersen and Garnes, 1971). The author has succeeded in establishing a preliminary stratigraphy in the overlying, often thick, till deposits. The different tills are correlated to four ice-movement phases. The lower till shows certain characteristic textures, and has re-transported sediments incorporated. This till often has the surface morphology of a terrace or of a stoss-side moraine. These tills are assumed to have been deposited from valley glaciers during the initial stage of the last glaciation (phase A). The most widespread and thickest tills in the area are correlated to the succeeding, predominant, inland-ice stage (phase B). During this stage, the ice had a movement more or less obliquely to the side valleys, and the tills were very often deposited as lee-side moraines. From the later inland-ice stage, phase C, as well as from the deglaciation period, phase D, there are relatively few glacial deposits in the investigated area. This is presumably due to the fact that the area was situated in the reconstructed ice culmination zone during these phases.

Although till is by far the most widespread type of sediment in Norway, surprisingly few sedimentological studies have been carried out on till deposits. Attempts to establish a till stratigraphy are especially lacking. This is probably due to the traditional concept that Norwegian sediments were largely deposited during the last phase of the last glacial period. Usually a distinction is only made between lodgement till and ablation till (for example, G. Holmsen, 1965, p. 155).

However, many recent findings of sub-till sediments in the investigated area, show that older deposits have a widespread existence, even in greatly ice-eroded areas in central Norway. The locations at which sub-till sediments have been found to date are shown in Fig. 1. These sediments are mostly of glacio-lacustrine origin. They were presumably deposited during an ice-free period during the Middle Weichselian, a period referred to as the "Gudbrandsdalen Interstadial" (Bergersen and Garnes, 1971). The existence of sub-till sediments indicates the possibility of studying the till stratigraphy of the last ice age.

TILLS IN SIDE VALLEYS

Most of the side valleys in Gudbrandsdal are deep, narrow and primarily fluvially eroded. The majority contain a thick till blanket, unusually thick for Norway. In some localities, the sediments are exposed in recently formed ravines (Fig. 2). The question is how the huge till concentrations in the narrow side valleys were accumulated. In order to shed light on this question, the conditions in the side valleys carrying the Tromsa, the Veikla and the Våla rivers (see Fig. 1), in addition to Gudbrandsdal itself, will be described.

Tromsdal

This valley is a very deep and narrow one on the eastern side of Gudbrandsdal. As shown in Fig. 3, thick till deposits are located in a zone on the northern side of the valley with the lowest parts 200–300 m above the valley floor and stretching some hundred of metres up the slope. The southern valley slope and the valley floor are almost lacking in till. Till-fabric analysis of the thick deposits on the northern slope shows a well-defined maximum in the direction of the *a*-axis southeast and northwest (cf. Fig. 3). The dip of the stones' *a*-axes almost conforms to the slope of the valley side.

Studies of the roundness of pebbles in different tills presented as morphograms show distinct differences. The method used for roundness analysis is the same as that used by Bergersen (1973). The stone material in the thick till deposits is more abraded than the stones in

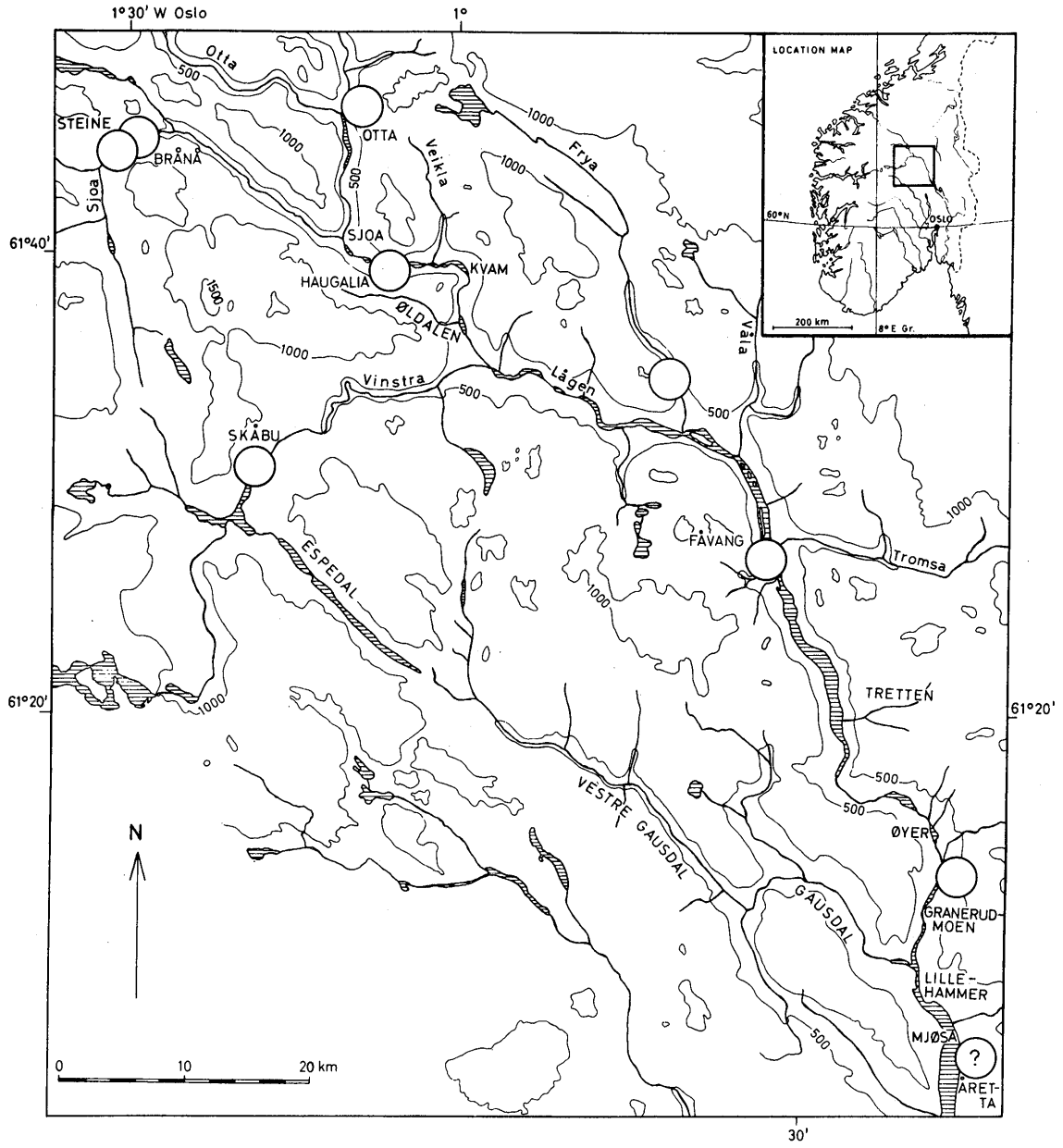

Fig. 1. The localities with sub-till sediments in the Gudbrandsdal area hitherto known. Two more finds were made in 1972, one in Vinstradal and one in Ottadal.

tills elsewhere in the Tromsdal area (cf. Fig. 3). The till in the thick blanket in this valley is unsorted, with a clay content (< 2 μ) of between 5 and 10 %.

Veikledal

Veikledal is covered by a very thick till blanket. This valley also has substantial till depsits along the valley floor. An earlier till cover almost 50 m above the valley floor is indicated by a ledge on both sides of the valley. It is also noteworthy that there is a thick blanket of till above the ledge, especially on the western side of the valley. Many fresh gullies indicate that recent slope processes are active on the steep slopes (cf. Fig. 4).

Till-fabric analysis shows that the till is oriented parallel to the valley near the valley floor. On the western side of the valley, above the ledge, the orien-

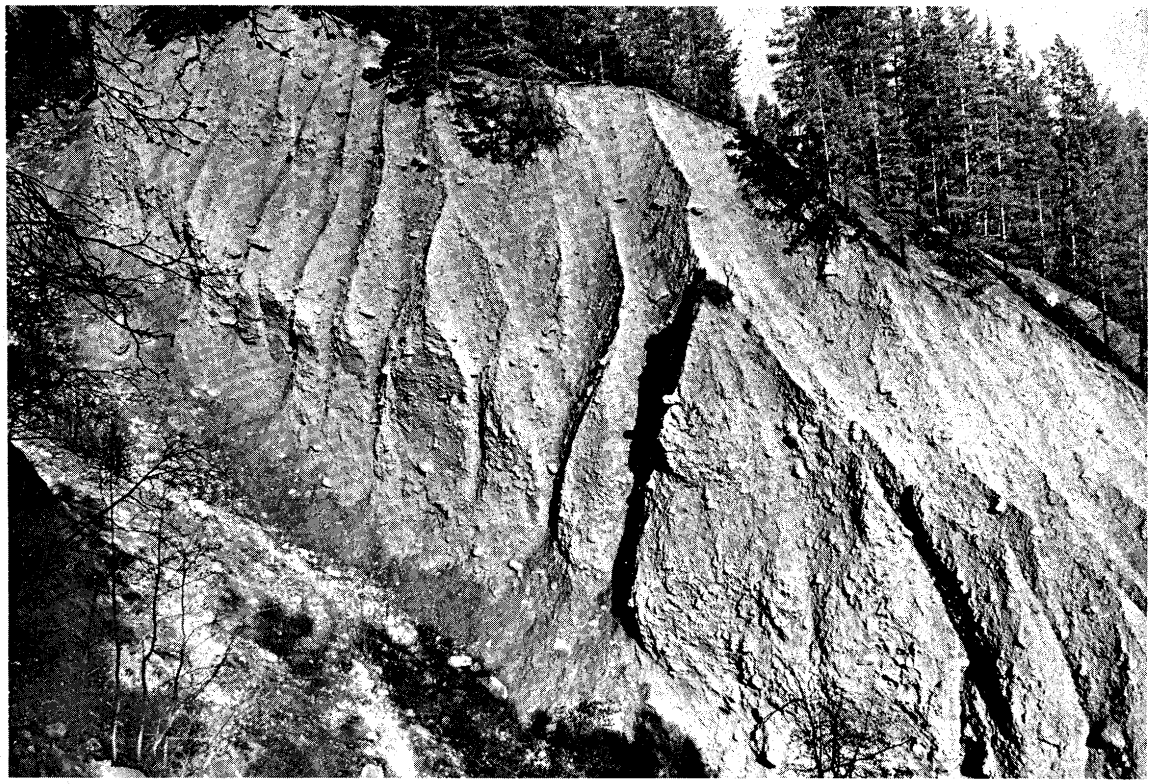

Fig. 2. Gully in till in Sjodal, a side valley of Gudbrandsdal, looking towards the northeast. In the area at the right-hand edge of the picture, sub-till clay-silt sediments are exposed.

tation is more easterly. The *a*-axis dip also shows caracteristic variations. Where the orientation is parallel to the strike of the valley, the dip is almost zero or slightly towards the north, opposite the slope of the valley profile. Where the orientation cuts obliquely across the valley, the dip approximates to that of the valley side. The stone counts show that local bedrocks predominate in the till. As will be seen in Fig. 5, the content of quartzite is very low in the inner part of the valley. At the mouth of the valley, as well as in the main valley, there are outcrops of quartzite. The north-south till orientation must therefore be assumed to be due to an ice movement towards the south, leading out of the side valley.

The morphograms of roundness from Veikledal also show caracterstic differences (cf. Fig. 6). The till on the western side of the valley contains stones significantly more angular than the till nearer the valley floor. The morphograms from the western side of the valley are nearly identical to those from till in the same position in Tromsdal.

Våladal

Våladal, with the Nordåa branch, has a rich cover of till (cf. Fig. 7), with caracteristics similar to the till blanket in the Veikla valley. It is assumed to have been deposited in the same manner as that in Veikledal.

Near the mouth of the Våla valley, there occurs a till which is completely different from the other tills in the valley. Morphological distinctions, however, cannot be made among the types of till. As will be seen from Fig. 7, the orientation of the *a*-axis in this till is relatively poor in the mouth of the valley, but the northeast-southwest direction predominates. The till is sandy and lacking in distinct structures.

The composition of the material is the predominant distinction of this till. The content of Jotun-type rocks, transported for long distances, is much higher than in other glacial deposits in the area. The morphograms of roundness of the till are also distinctly different from those of other tills in Våladal (cf. Fig. 7). Tills with similar roundness and rock-type composition are only found in Gudbrandsdal itself.

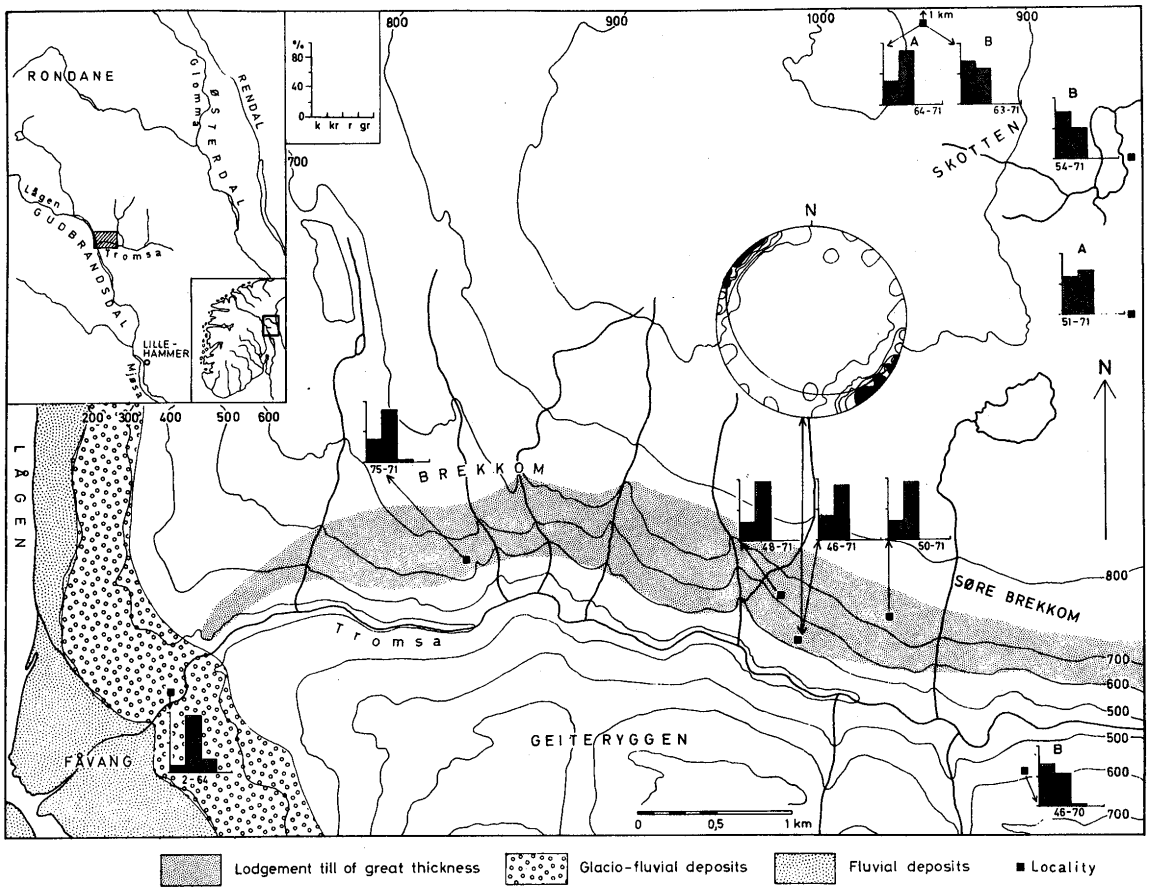

Fig. 3. Sketch of Tromsdal. The result of the till-fabric analysis of stones is plotted in Schmidt's net. Histograms show roundness of pebbles in the sediments. Classes of roundness: angular (k), abraded angles (kr), rounded (r) and well rounded (gr). A = ablation till, B = lodgement till.

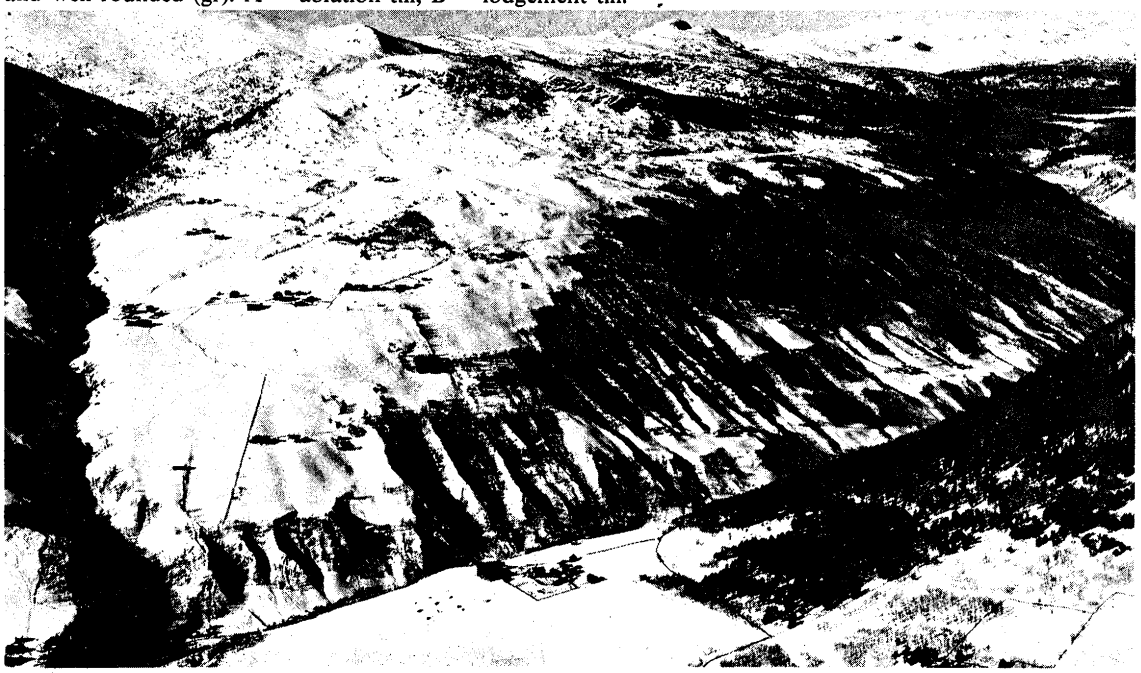

Fig. 4. Veikledal looking towards the northwest. The ledge in the lower part of the valley side is interpreted as a remnant from an infill in the lower reaches of the valley. Copyright by Wideröe.

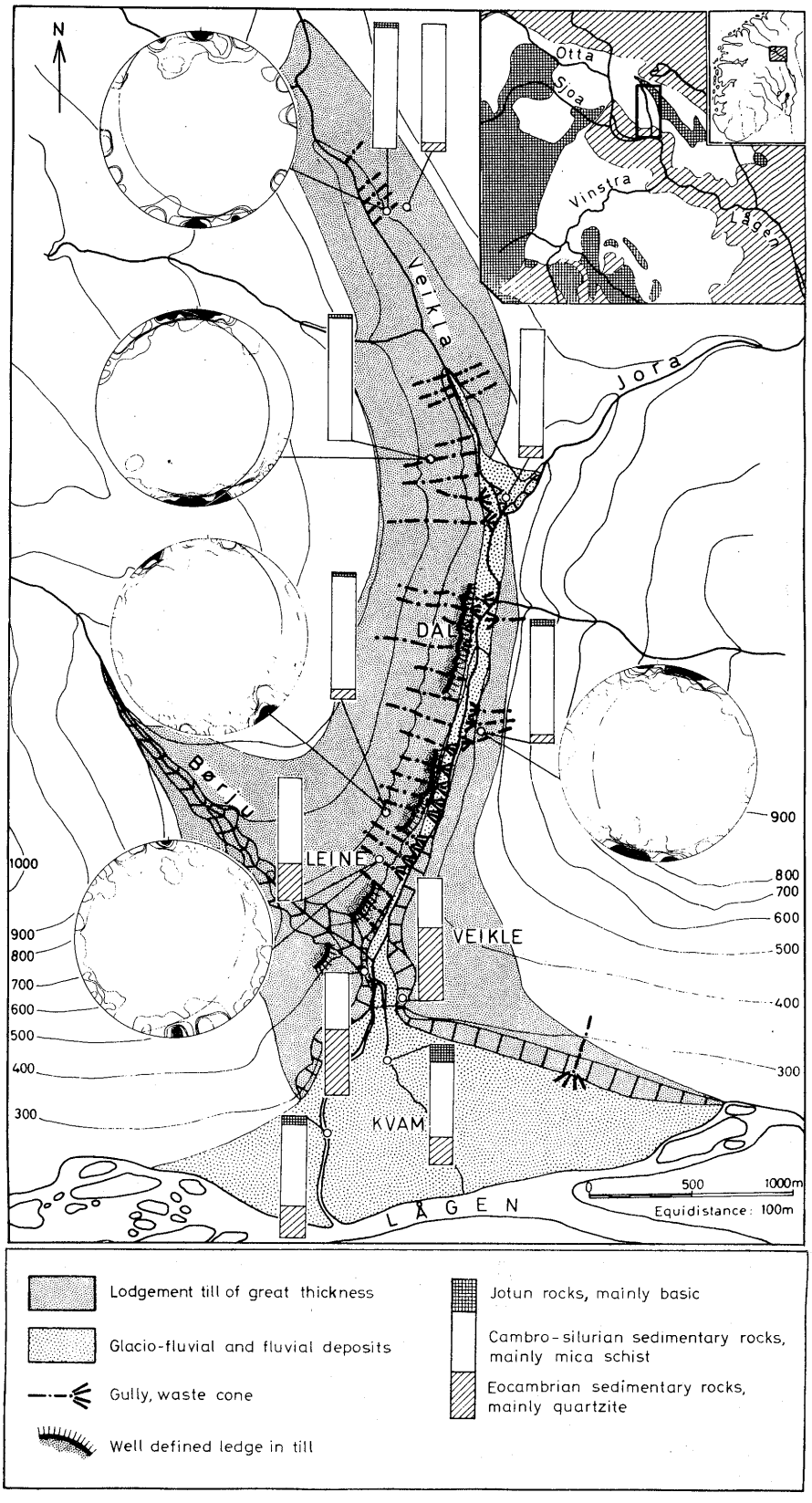

Fig. 5. Sketch of Veikledal. Data from till-fabric analysis and stone counts are presented. The geological map has been simplified from O. Holtedahl (1960).

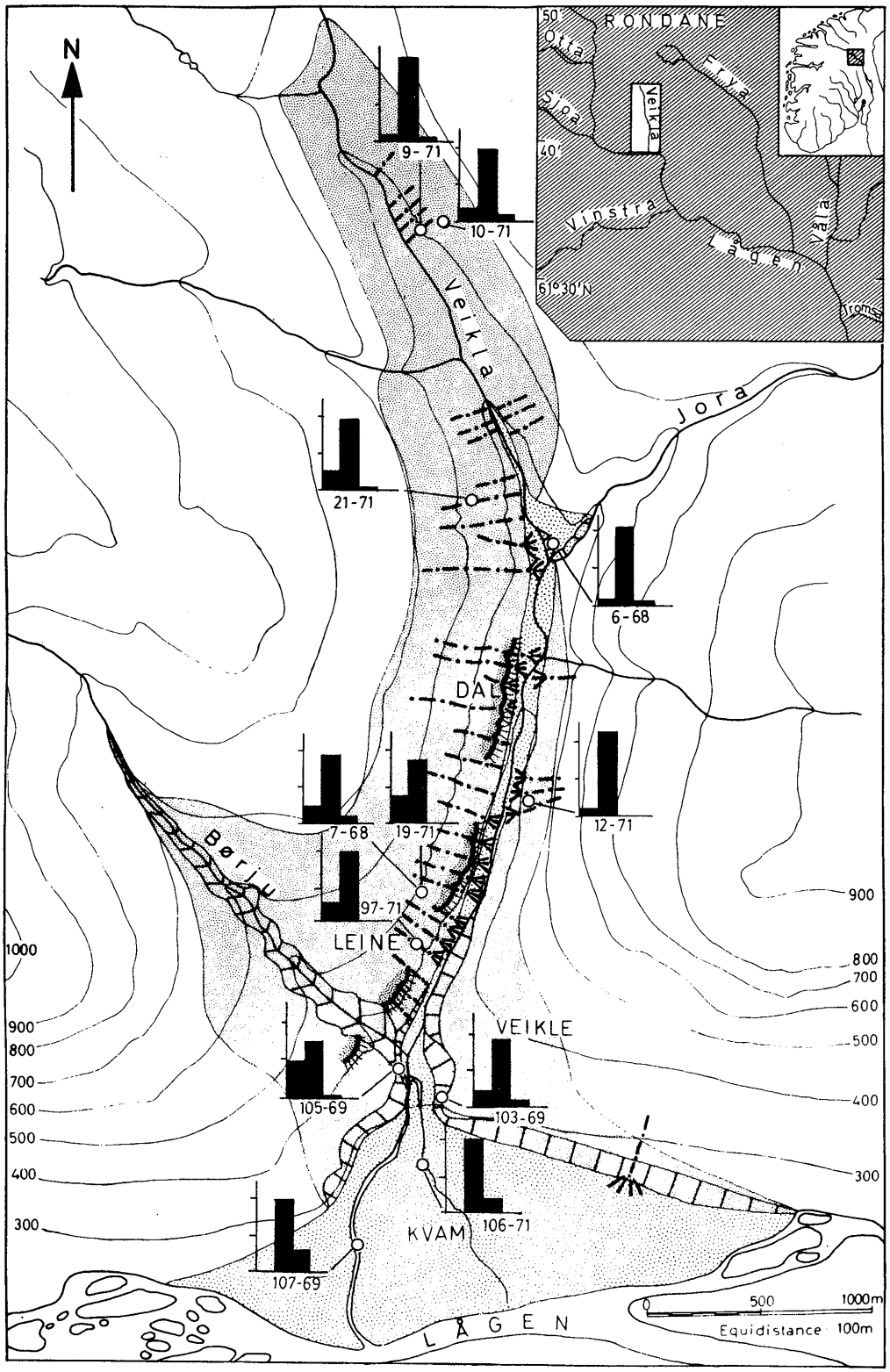

Fig. 6. Morphograms showing roundness of pebbles in the various sediments in Veikledal. The legend is given in Fig. 3.

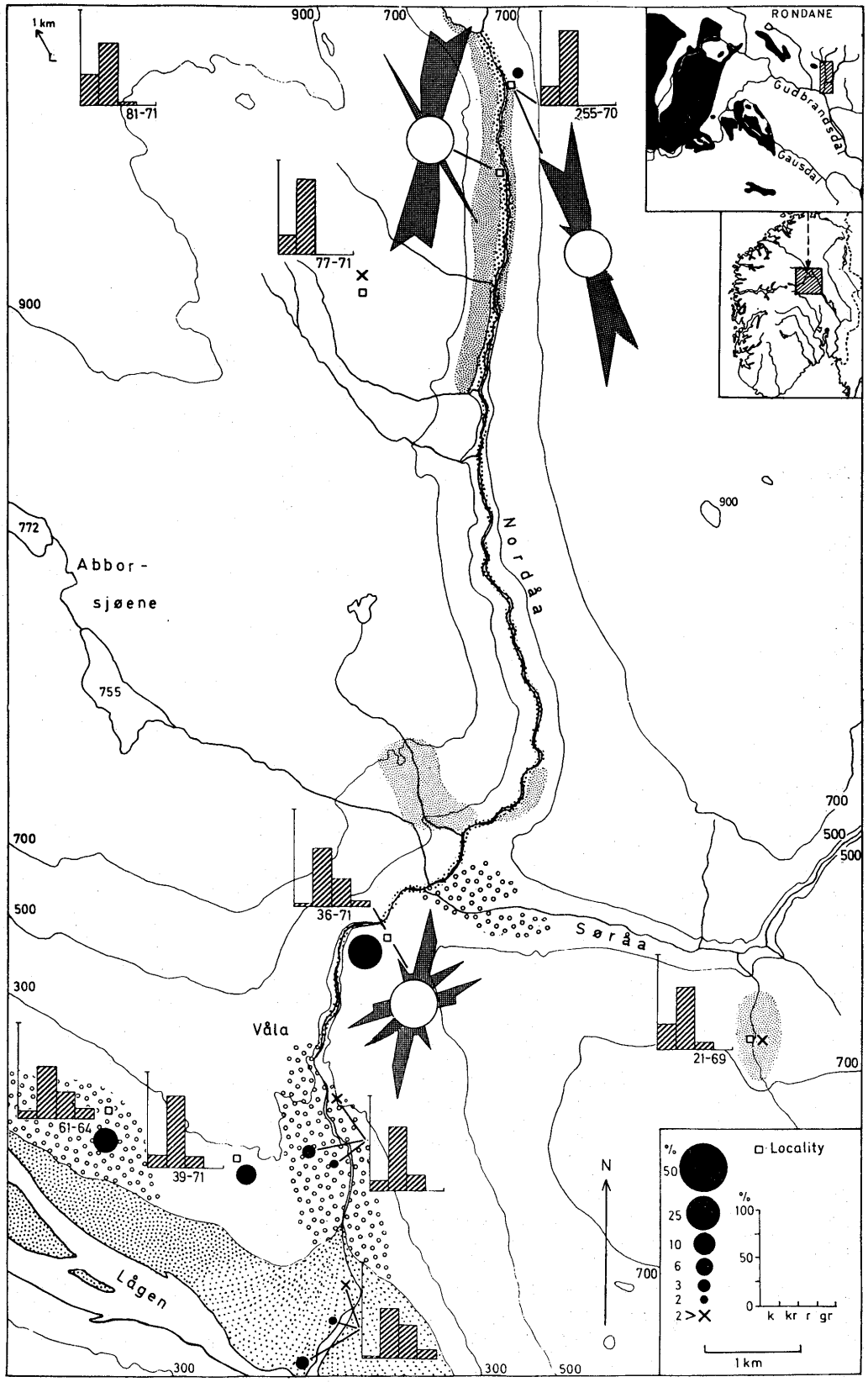

Fig. 7. Occurrence of thick till deposits, glaciofluvial and fluvial sediments in Våladal with the Nordåa branch. The legend is given in Fig. 3. The solid circles show the content of gabbroid Jotun rocks in different sediments. Dark areas on the key map indicate the sources of Jotun rocks. The geological map has been simplified from O. Holtedahl (1960).

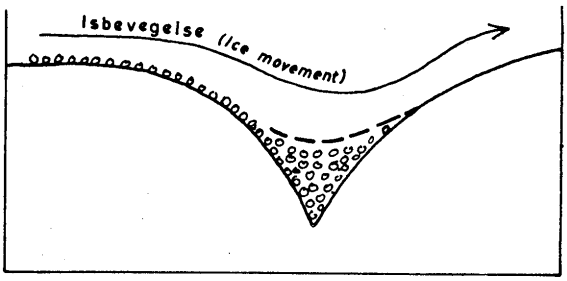

Fig. 8. Sketch showing infills in side valleys in Gudbrandsdalen, as interpreted by Mangerud (1965).

Discussion and conclusion regarding the tills in the side valleys

Valley infills of till in valleys tributary to Gudbrandsdal, for example, those of Veikledal, have been discussed by Mangerud (1965, pp. 201–221). He assumed that there was only one direction of ice movement in the area, the predominant one to the southeast. Consequently, he concluded that the movement in this direction, cutting obliquely across most of the side valleys, had accumulated the till. He thought that the accumulation of till started at the valley floor and built up along the valley slopes (Fig. 8).

Tromsdal lies more at right angles to the direction of ice movements than the other side valleys. No ice movements have been found along this valley. It is therefore especially suitable for the study of the influence of ice movements across a narrow valley on the distribution and accumulation of till.

In order to discuss the formation of the tills of the side valleys, it is necessary to have some knowledge of the ice movements during the last glaciation period of the area. A reconstruction of these has recently been made by Bergersen and Garnes (1972) (cf. Fig. 9). The introductory phase is designated as phase A (cf. Fig. 10). Gudbrandsdal is the confluence area for valley glaciers from the high mountain regions to the west and north.

Phase B is clearly the main one, with a direction of movement diagonally across the side valleys. The till, both in the side and in the main valleys, was primarily deposited during these movements.

Phase C is a later stage of an inland ice with an east-west ice divide across the middle of Gudbrandsdal with shifting culminations. During this stage, very little glacial erosion and accumulation are apparent. This ice divide is found considerably further to the south than the earlier known culmination zone (cf., for example, the "Glacial Map of Norway" (O. Holtedahl, 1960). On the other hand, P. Holmsen (1951) has established the existence of boulder transport in a northerly direction in the lodgement till south of this main divide in Österdal, east of Gudbrandsdal. It is not yet known whether this corresponds to phase C or is part of an older phase.

Phase D is the deglaciation phase, showing a transition from active through stagnant to dynamically dead ice.

It appears that the various till types described for the side valleys can be correlated with the ice phases. In *Veikledal* the lower till was deposited during phase A by glaciers flowing out through the valley. During phase B, with glacial movements more independent of the valleys, the upper till was accumulated.

In *Tromsdal,* only deposits from phase B have been found. This shows that the till could not have been deposited from the bottom upward when the ice moved across the valley, which was Mangerud's (1965) interpretation (cf. Fig. 8). On the contrary, the present author's investigation points to the conclusion that the largest till deposits are to be interpreted as lee-side moraines. First the till is deposited uppermost on the valley side, then the till of the valley sides are gradually deposited. Accumulations on the valley floor and the opposite side of the valley are deposited last, if the deposit is sufficient in size.

In *Våladal* there is, in addition to the two types of till mentioned previously, also a third type which consists of till transported in from the main valley. This type is presumed to belong to the deglaciation phase (phase D).

Except for the Våla type of infilling, only a few till deposits were found in the above-mentioned side-valleys from phases C and D. The interpretation of valley infills of till is shown in Fig. 11.

TILLS IN GUDBRANDSDAL

The stratigraphy of the Quaternary deposits in the Gudbrandsdal area is very complex. In this paper, only some of the characteristics of the Kvam area will be discussed, namely, the so-called terrace-shaped moraines. An example of these is shown in Fig. 12. Such formations are found at many locations in Gudbrandsdal.

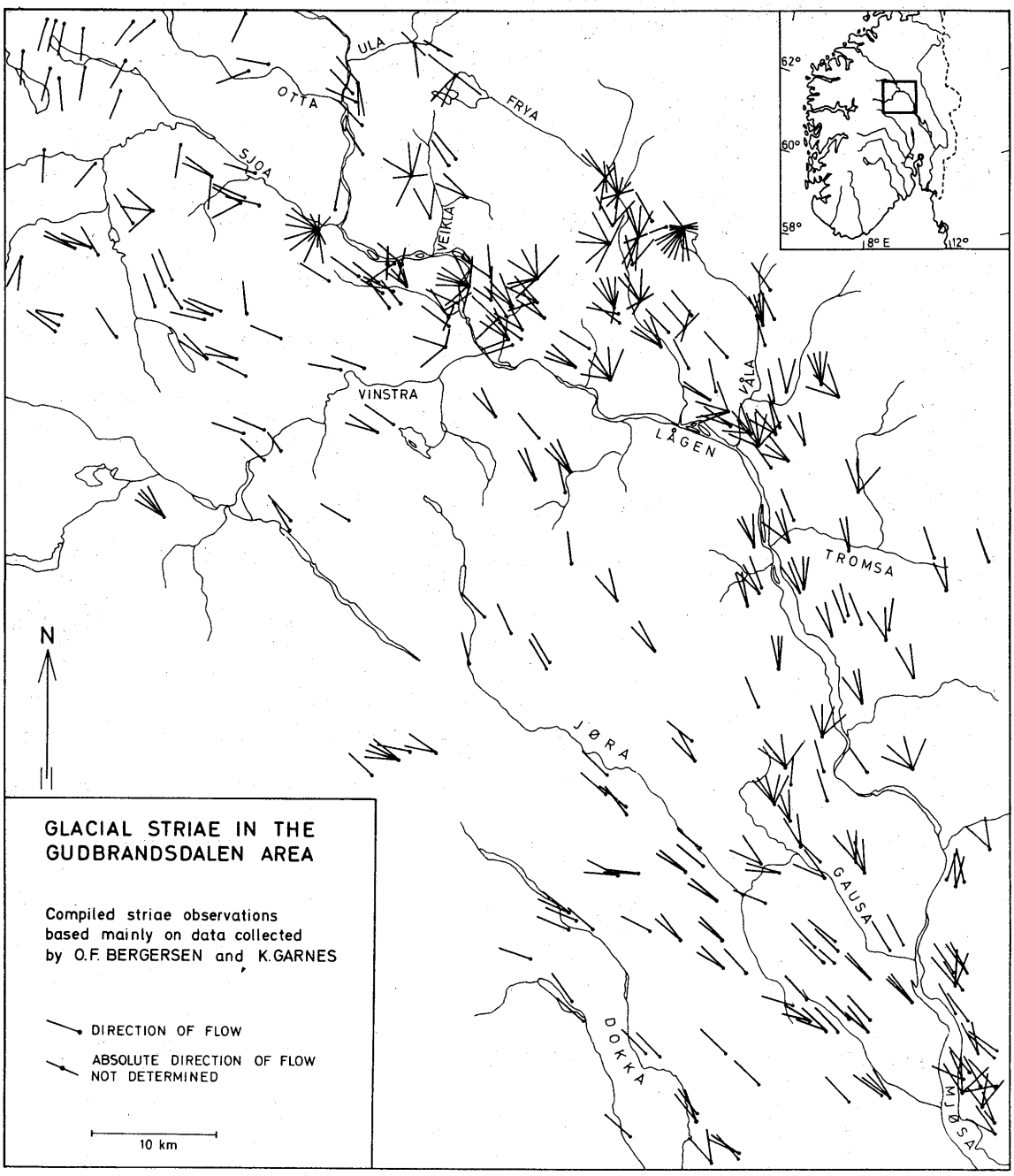

Fig. 9. Glacial striations in the Gudbrandsdal area. After Bergersen and Garnes (1972).

In the Haugalia-Feten area, the terrace-shaped moraine is transformed into a stoss-side one (cf. Fig. 12). Thick alluvial deposits underlie lodgement till at Haugalia-Feten (Fig. 13). Four of the 15 Norwegian mammoth finds were made in the Skardsanden gravel pit and another find has been made in similar sediments further east.

Stone counts and roundness analysis show that the till material in the terrace-shaped and the stoss-side moraines at Haugalia-Feten are primarily derived from

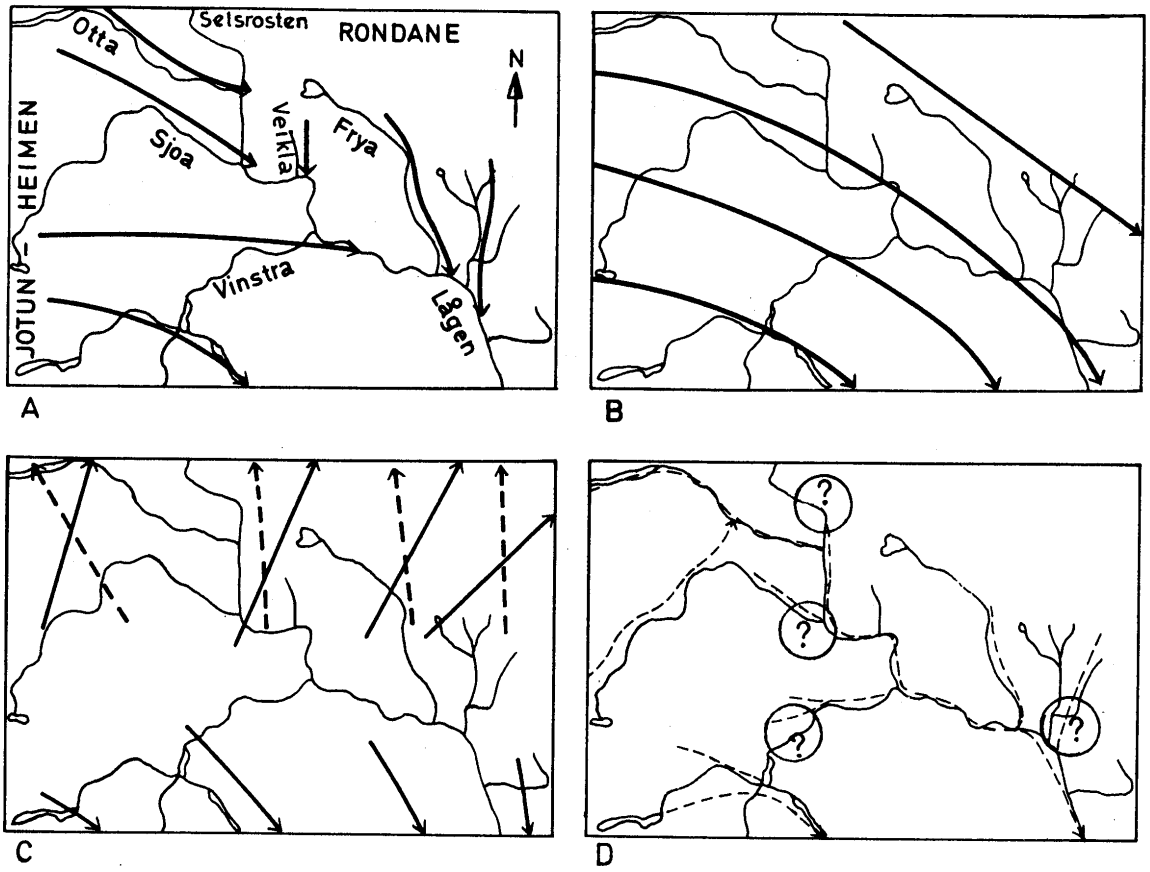

Fig. 10. A simplified reconstruction of four phases of ice movement during the last glaciations. After Bergersen and Garnes (1972).

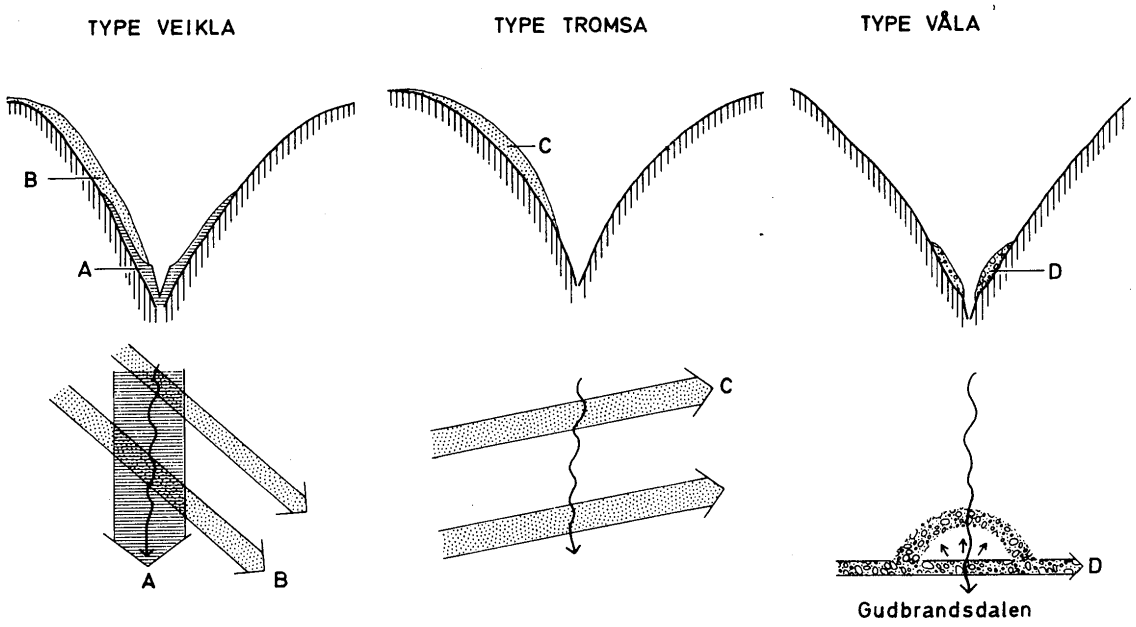

Fig. 11. Three modes of accumulation for large till deposits in some of the tributary valleys of Gudbrandsdal, as interpreted by the author. Most of the side valleys in Gudbrandsdal have a till blanket deposited in phase B as a lee-side moraine after ice flows obliquely across the valleys.

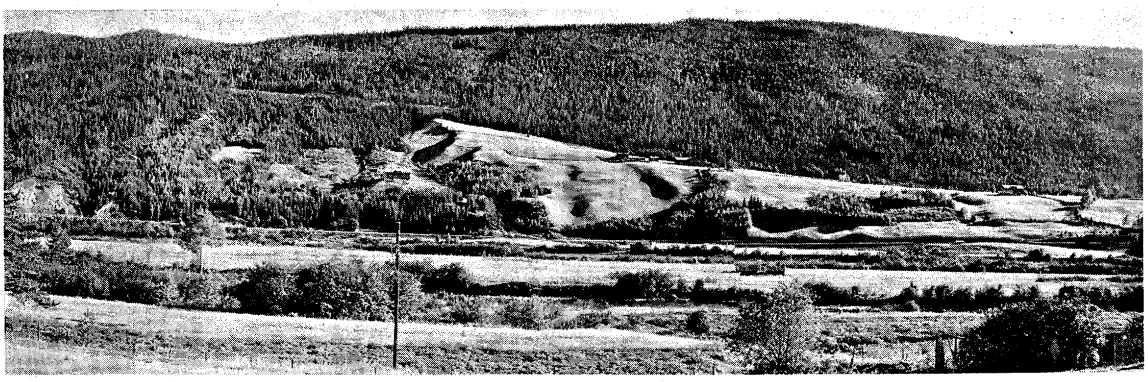

Fig. 12. The Feten area in Kvam looking towards the south-east. Cultivated fields show the upper limit of the terrace-shaped moraine, which continues into a stoss-side moraine.

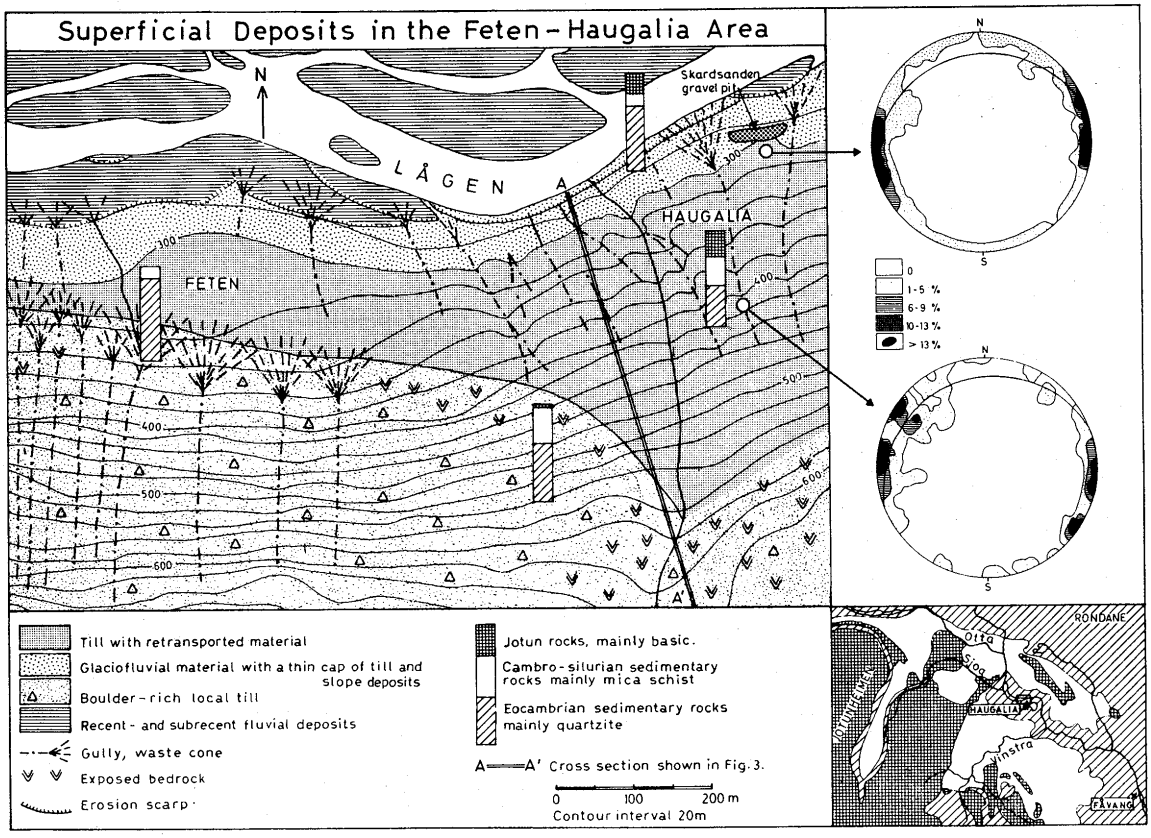

Fig. 13. The histograms show the average of the stone counts in the different sediments. The content of Jotun-type rocks transported from distant sources is far higher in the glaciofluvial deposits and the till above than in the local till and the slope deposits. The geological map has been simplified from O. Holtedahl (1960). After Bergersen and Garnes (1971).

the underlying sediments (cf. Fig. 13). The material is clearly that of a lodgement till, as is apparent from its structure, till-fabric analysis, and grain-distribution analysis. Striations on the valley side above the sediments have been measured strictly parallel to the orientation of the till.

In *Kvamsvingen* there are till deposits with exactly the same outline and composition as those at Haugalia-Feten (cf. Fig. 14).

It is an interesting fact that till with re-transported sediments seems to be found along the outside of the valley bend only, and frequently has the shape of a

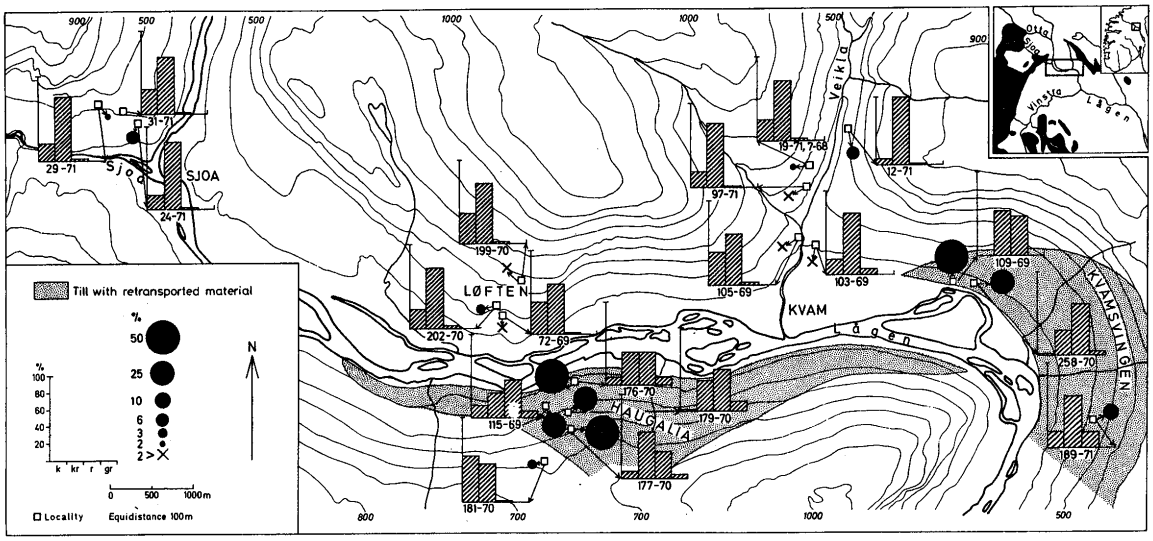

Fig. 14. Occurrence of till with re-transported sediments in the Kvam-Sjoa area. Far-travelled stones are numerous in these deposits. The legend is given in Fig. 3.

stoss-side moraine. These terrace-shaped moraines and stoss-side moraines are assumed to have been deposited during the first part of the last glaciation period by glaciers advancing over older sediments. The till therefore corresponds to phase A in Fig. 10.

While the till deposits in the region under investigation often have the form of stoss-side moraines in the main valley, typical lee-side moraines are less common. The few lee-side morains which occur clearly have a more local-rock-type composition and belong to another accumulation phase than that of the stoss-side moraine. The lee-side moraines, however, are common in side valleys and on the mountainous plains. Stoss-side moraines have not been found outside the main valley. Accumulations during the various ice phases are presumed to account for this condition. While valley glaciers in phase A formed stoss-side moraines, the till from the main phase of the glaciation, phase B, was often deposited as lee-side moraines.

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