SVERIGES GEOLOGISKA UNDERSÖKNING

SERIE C NR 742 AVHANDLINGAR OCH UPPSATSER ÅRSBOK 72 NR 4

D. G. GEE R. KUMPULAINEN T. THELANDER

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WITH 1 PLATE

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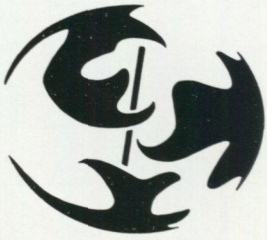
INTERNATIONAL GEODYNAMICS PROJECT



SWEDISH GEODYNAMICS PROJECT
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ABSTRACT

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Caledonian Front tectonics in northern Jämtland and southern Västerbotten are reassessed on the basis of new drillhole information, remapping of existing drillcores and some new field data, both geological and geophysical. The area considered here is composed of late Precambrian and Lower Palaeozoic sediments of the Jämtland Supergroup which are folded and thrust eastwards over the Baltoscandian Platform. It can be shown that the complex fold and thrust structures of the allochthonous Sjoutälven and Tåsjön Groups override a passive basement overlain by a thin veneer of autochthonous Gärdsjön and Fjällbränna Formation sediments. The granitic basement, along with these autochthonous sediments, dips c. 1° WNW, from the thrust front in the east as far west as Norråker (c. 30 km). Thus, décollement (detachment) clearly dominates the Caledonian Front tectonics. Further west (Fånsjön), the Risbäck Group units are allochthonous (above the Bygdvattnet Thrust) on the basement of the Sjoutälven Anticline, with its veneer of Gärdsjön (and Långmarkberg) Formation sediments.

Movement on the sole thrust of the Tåsjön Décollement is thus probably taken up, at least in part, on the Bygdvattnet Thrust. The extent to which the basement massif in the Sjoutälven Anticline is autochthonous or allochthonous is not assessable in the Tåsjön area on the basis of existing data. Fold and thrust structures similar to those above the Tåsjön sole thrust can be traced northwards to Malgomaj and southwards at least into central Jämtland. It is thus probable that décollement dominates the tectonics over a much greater area than that treated in this paper.

INTRODUCTION

The eastern front of the North Atlantic Caledonides (Fig. 1) is exposed in Scandinavia over a distance of some 1,800 km. In common with other well documented frontal-zones of orogens, the Scandinavian Caledonian Front is characterized by a passive basement (Precambrian c. 1,800—1,000 Ma) covered by a veneer of autochthonous sediments dipping very gently (c. 1—2° W) towards the centre of the orogen and overridden by an extensive allochthon. Décollement (detachment) dominates the frontal tectonics. As in most other orogenic belts, the distance of displacement of the nappes, the extent of the décollement-style, and the relationship of the latter to the evidence of basement thrusting nearer the centre of the orogen is controversial (Fig. 2).

In Scandinavia, basement-cover relationships are repeatedly exposed through the orogen from the thrust front, via the windows to the North Atlantic coast of Norway, providing an excellent opportunity for studying the extent and character of basement involvement in the tectonics.

The 1:1,000,000 geological maps of Norway (Norges geologiske undersøkelse 1960) and Sweden (Sveriges geologiska undersökning* 1958) provide good evidence for the general character of the décollement-style in the outermost (easternmost) parts of the front. The major transverse valleys eroded through the front, Lakselv in northernmost Norway, Torneträsk, Rautasjaure, St. Luleälven, Vindelälven, Storuman and Vojmsjön (in Sweden, north of the Tåsjön—Ormsjön area described here) show the décollement surface to extend at least 20—40 km westwards from the thrust front. In the Tåsjön—Ormsjön area and to the south, tectonic units (the Ström Quartzite Nappe of previous authors) shown as klippes on the 1:1,000,000 map are now known (Kulling 1961, Strand & Kulling 1972, Gee 1972) to have thrust contacts only on their eastern front, these dislocations passing down into a sole thrust (the main décollement surface). South of Östersund in the Bingsta, Klövsjön, Vemdalen, Råndalen, and Vassbo areas of Sweden a similar interpretation is applicable to that in the Tåsjön—Ormsjön area and again ESE—SE displacement is in the order of at least 40 km. In southern Norway, Permain faulting provides particularly good exposure of the

* Geological Survey of Sweden, henceforth referred to as SGU.

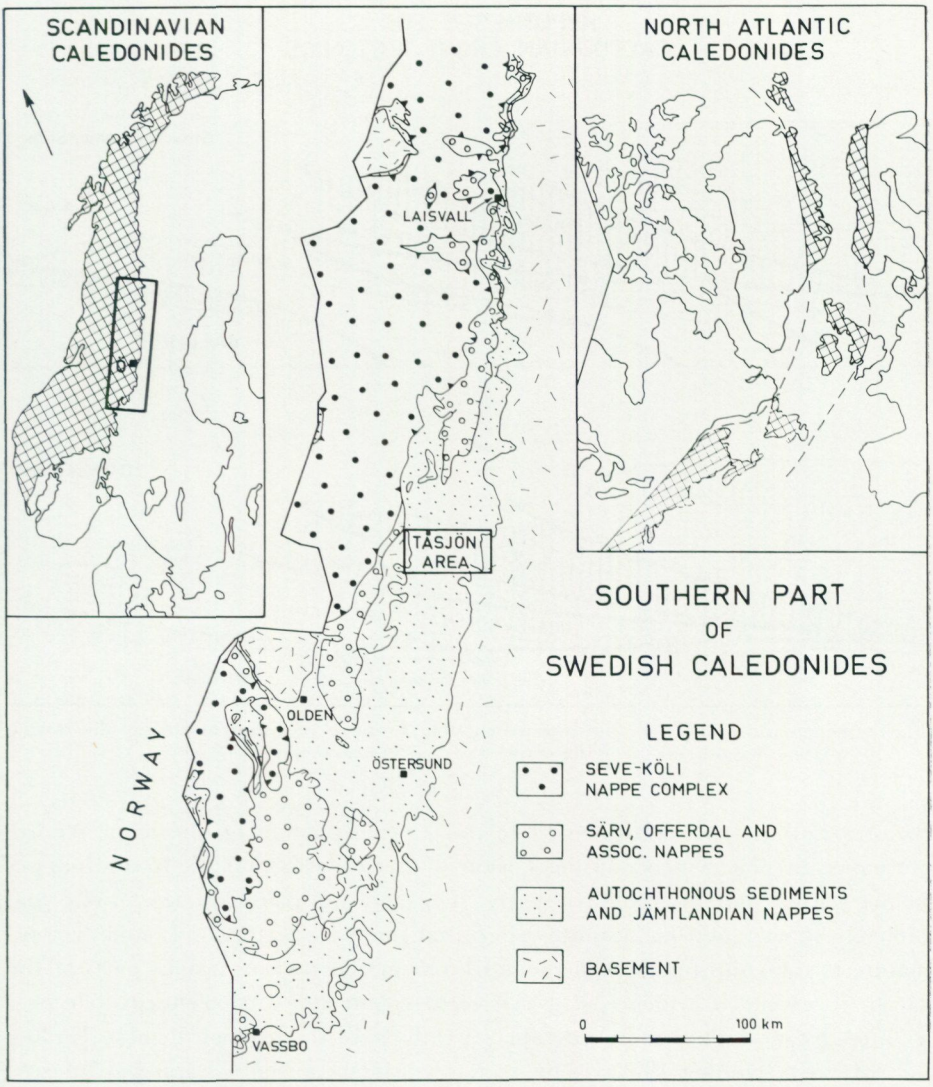

Fig. 1. Location of the Tåsjön area.

décollement surface in the Storsjøen valley and a minimum displacement of 70 km is apparent. This décollement-style can be traced further south into the Oslo area, where the Lower Palaeozoic sequence is folded above a passive basement.

The displacement distances quoted here are all minimum figures. Some authors believe these distances to be approximately representative of the amount of nappe displacement. In one area, Storsjøen (southern Norway), Nystuen (1975) has suggested that the nappe movement might be oblique to the dip of the sole

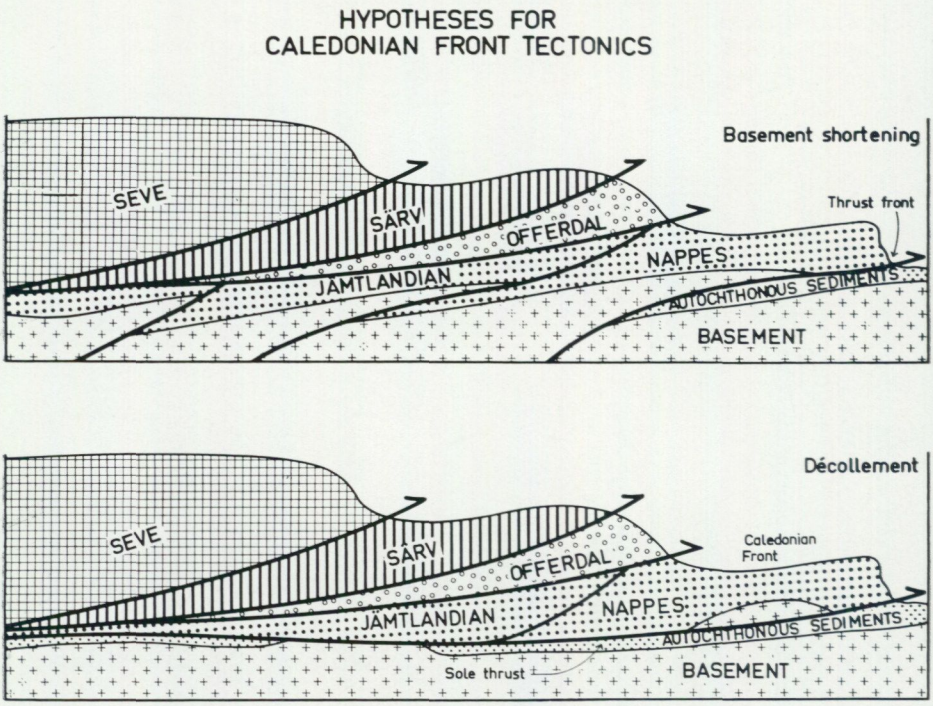

Fig. 2. Schematic profiles through the Caledonian Front in central Scandinavia illustrating tectonic hypotheses involving active and passive basement.

thrust and thus substantially less than the 70 km apparent on the map. We are persuaded by new evidence in the Tåsjön—Ormsjön area that the frontal nappes in the central part of Scandinavia are, in general, displaced at least twice and probably three times the distance recognized for the sole thrust. It may be premature to infer this for the Caledonian Front in general but various parts of the latter have yielded evidence of a passive basement and a décollement-style over greater distances than those inferable directly from the geological map. Kulling (*in* Strand & Kulling 1972) in his sections through northern Lappland inferred a décollement-style extending over 80 km west of the front. Åm (1975) on the basis of an analysis of flight magnetic anomalies, was able to define the gentle, westerly dip of the basement-surface for 50 km west of the front in the Finnmarksvidda area of northern Norway. Oftedahl (1943) outlined evidence for the allochthonous character of the "Sparagmite basins" in southern Norway.

Interpretation of the amount of displacement involved in the décollement is much dependent on stratigraphic correlation of autochthonous and allochthonous sedimentary units; this paper concentrates on this evidence in the Tåsjön area. The results were presented at the XII Winter-Meeting of Nordic geologists in Göteborg (Gee et al. 1976).

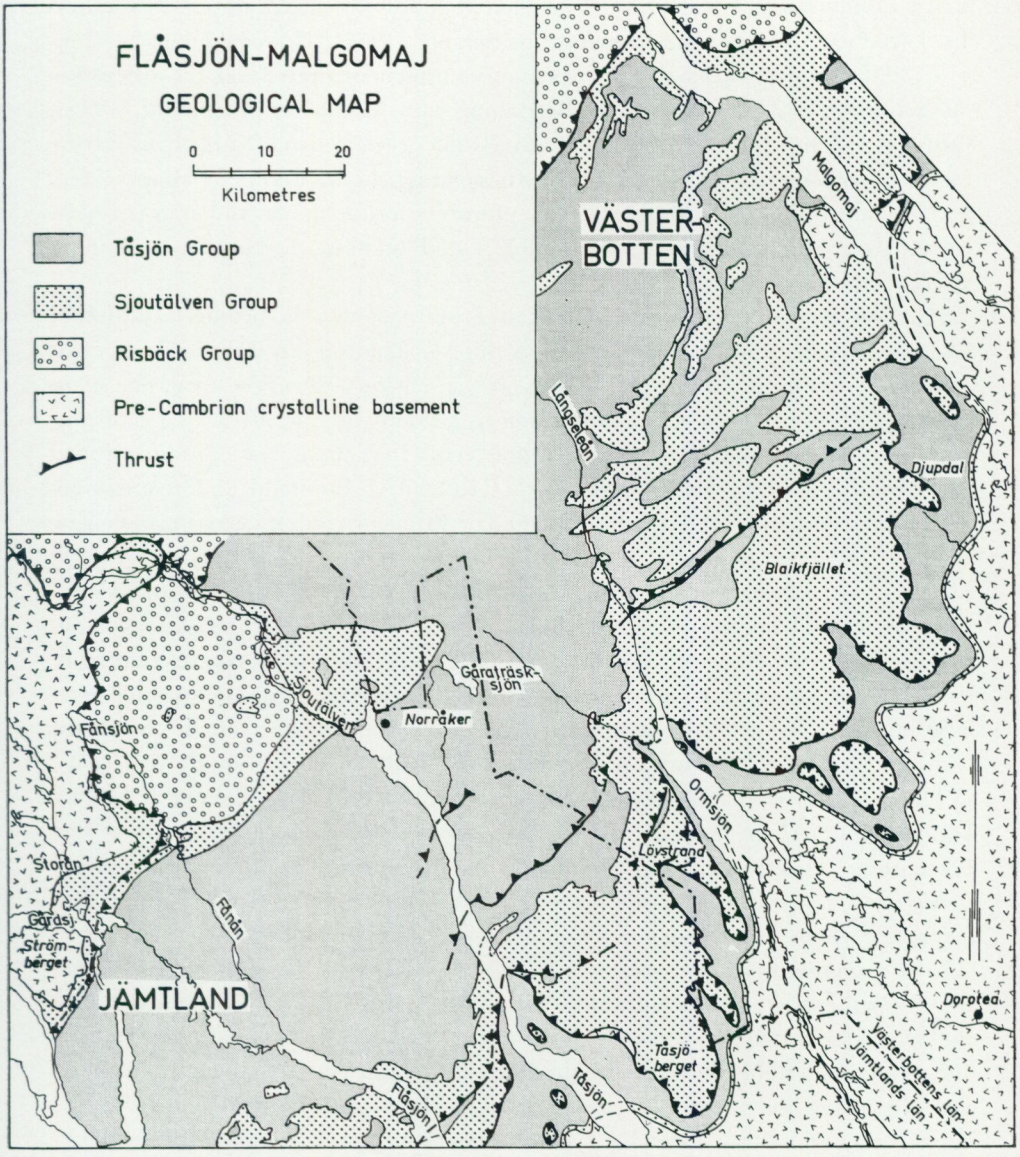

Fig. 3. General geological map of the Caledonian Front from Flåsjön to Malgomaj.

The first regional evidence of the subsurface extension of the décollement in the central Scandinavian Caledonides (southern Västerbotten and northern Jämtland, Fig. 3) was provided by Du Rietz (1960) on the basis of Boliden Company drillhole data. Du Rietz's evidence supported the interpretation that the unfossiliferous quartzite units (Gärdsjön Formation) overlying the Cambrian black

shales (Fjällbränna Formation) were allochthonous, an interpretation introduced by Törnebohm (1896) and supported by Schiøtz (1902), Holtedahl (1915), Zenzén (1932), and Asklund (1933) despite a conspicuous opposition (cf. discussion in Gee 1972, p. 7). However, Du Rietz along with Asklund & Thorslund (1935), Grip (1941) and Kulling (1941, 1942 and 1955) regarded the basal thrust of the allochthonous quartzites to rise westwards isolating the quartzites as klippes (Fig. 4). Not until Kulling (1961) was this interpretation in doubt and it was finally rejected by Armands (1972), Gee (1972), and Kulling (*in* Strand & Kulling 1972).

Previous interpretations of Caledonian Front tectonics in northern Jämtland and southern Västerbotten are shown in Fig. 4. There is no direct evidence for basement rooting of the frontal thrusts in the Tåsjön—Ormsjön area; one of us (Gee 1972) introduced this construction to account for the involvement of granitic basement in the Tåsjöberget Nappe. This hypothesis was also mentioned by Strömberg (1971) and applied (1974) to central Jämtland and requires general basement shortening in the Caledonian Front of central Scandinavia. New drillhole evidence from the vicinity of Norråker (Långviken drillhole) requires rejection of the basement shortening hypothesis for northern Jämtland and acceptance of a décollement surface extending at least as far west as the basement antiforms ("horsts" of Asklund *in* Magnusson et al. 1960) of northern Jämtland. It strongly suggests that an extensive detachment-surface is to be expected over large areas of the central and southern Jämtland Caledonian west of the thrust front and probably elsewhere to the north and south in the mountain belt.

The term Caledonian Front is used here to refer to the development of folding and thrusting in the eastern part of the orogen where the nappes override the autochthon. This front can be identified unambigously throughout the mountain belt. It is a narrow zone in the northern and southern parts of the Swedish Caledonides where it coincides more or less with the thrust front. In the central part it composes a broader zone extending from the thrust front in the east, westwards to the front of the Offerdal Nappe. It does not in any way suggest that the décollement deformation ceased at or near the present erosional front; indeed the extension of the décollement deformation in southern Norway from Mjøsa into the Oslo area, where it is preserved in the Permian graben, suggests that the nappes may once have extended many kilometres east of the present front elsewhere in the mountain belt. This definition of the front does not involve Strömberg's (1974) requirement of a hypothetical zone of basement shortening, trending NE—SW through the Östersund area.

Another hypothesis exists for Caledonian Front structure in the Tåsjön area. Armands (1972), in his summary of Atomenergi AB's geological synthesis of the Tåsjön area, states (p. 333) "The quartzites, including the Ström quartzite, which have previously been considered to be nappes, have, . . ., been found to belong to the autochthon". He regarded the granites outcropping on the top of

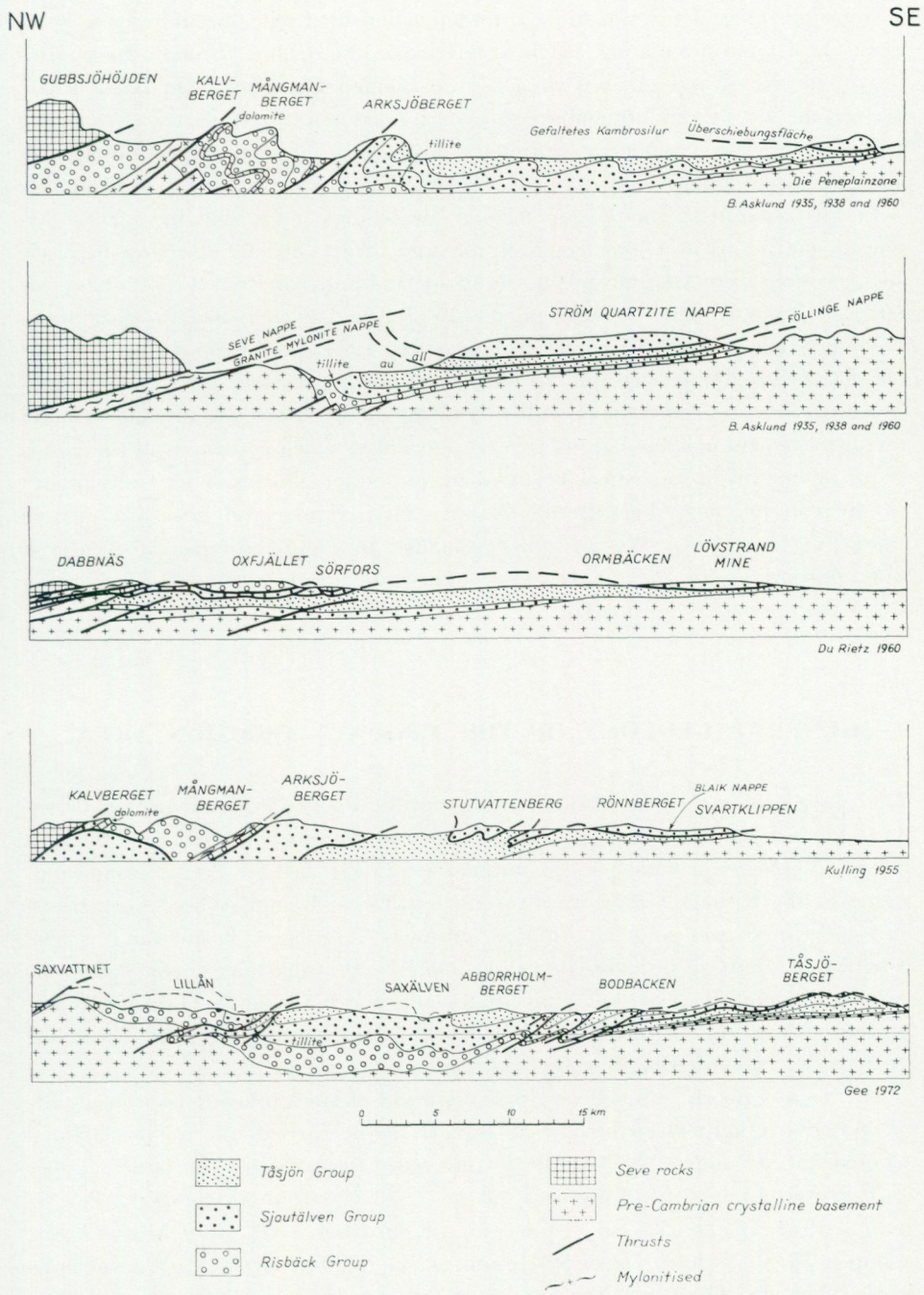

Fig. 4. Previously published sections through the Caledonian Front in the Tåsjön—Ormsjön area. (Redrawn from Asklund 1935, 1938, 1960; Du Rietz 1960; Gee 1972, and Kulling *in* Gavelin and Kulling 1955.)

Tåsjöberget (Fig. 3) as monadnocks directly connected with the underlying basement. The outcrop mapping, taken in relation to the drilling through the quartzites in the Lövstrand—Bellvik area by the Boliden Company (Du Rietz 1960) render the hypothesis untenable. SGU has measured three electrical sounding profiles over the Tåsjöberget granites. An average thickness of 30 m (K. Johansson, pers. comm.) was defined overlying the highly conductive black shales.

In this account of the Tåsjön tectonics we discuss units that have been displaced many tens of kilometres over the sole thrust. Strictly speaking they are allochthonous and Asklund & Thorslund (1935) and Du Rietz (1960) have referred to them as such. We have previously preferred to treat them as parautochthonous (Gee 1972, 1975 a and b, Gee et al. 1974, Strömberg 1974) for two reasons. Firstly, the stratigraphy in the autochthon throughout the front is directly comparable and correlatable with that in these lowermost nappes, and secondly the displacement of these nappes is very subordinate when compared to the hundres of kilometres of movement required by the major allochthonous units higher in the tectonic pile, the Offerdal Nappe, Särv Nappe, and Seve-Köli Nappe Complex (Gee 1975). We are now persuaded that the term parautochthon is not appropriate for these lowermost nappes, the displacement distances being larger than previously estimated.

GENERAL GEOLOGY OF THE TÅSJÖN — ORMSJÖN AREA

The geology of the Caledonian Front in northernmost Jämtland and southernmost Västerbotten is shown on Plate I. The stratigraphy of the area has been described (Gee et al. 1974) and is summarized in Fig. 5. Late Precambrian sandstones of the Risbäck Group are overlain by tillites (Långmarkberg Formation) and then quartzites and subordinate siltstones (Gärdsjön Formation) of the Sjoutälven Group. The overlying black shales with stinkstone lenses (generally known in Scandinavia as the "alum shales") of the Fjällbränna Formation compose the lower unit of the Tåsjön Group, which in its upper part is dominated by shales and greywackes (Norråker Formation).

The area is poorly exposed and interpretation of the geology has been greatly facilitated by flight electro-magnetic measurements carried out by the Boliden Company (Armands 1972, Gee 1972) and by examination of the large number of drillcores obtained from the area, 68 (c. 2,130 m) from Atomenergi AB (Armands 1972), 7 (c. 525 m) from Stora Kopparberg AB (E. Carlsson, pers. comm.), 38 (c. 3,120 m) from SGU, and 41 (c. 2,230 m) from Vattenbyggnadsbyrån (Fig. 6). These are largely located in central Tåsjön and adjacent areas and northwestwards to Åsjön. Most of the Atomenergi, SGU and Stora Kopparberg holes were drilled to investigate the character of the Tåsjön uraniferous

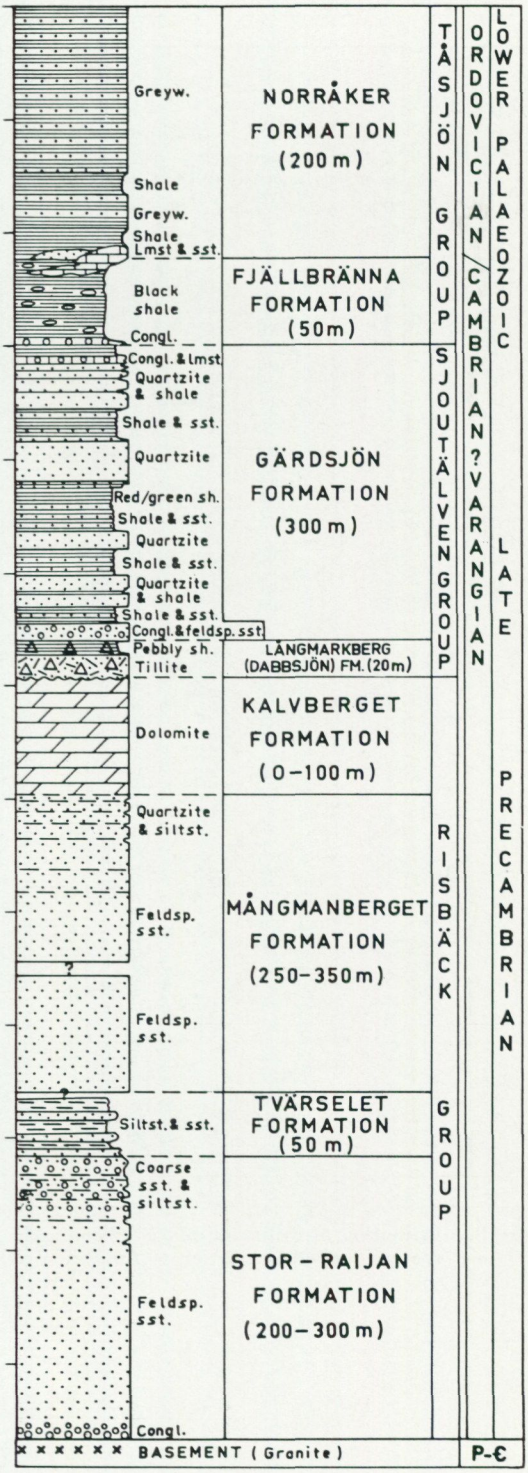

Fig. 5. Stratigraphy in the Tåsjön area (based on Gee et al. 1974). Scale on left side of diagram is marked at 100 m intervals.

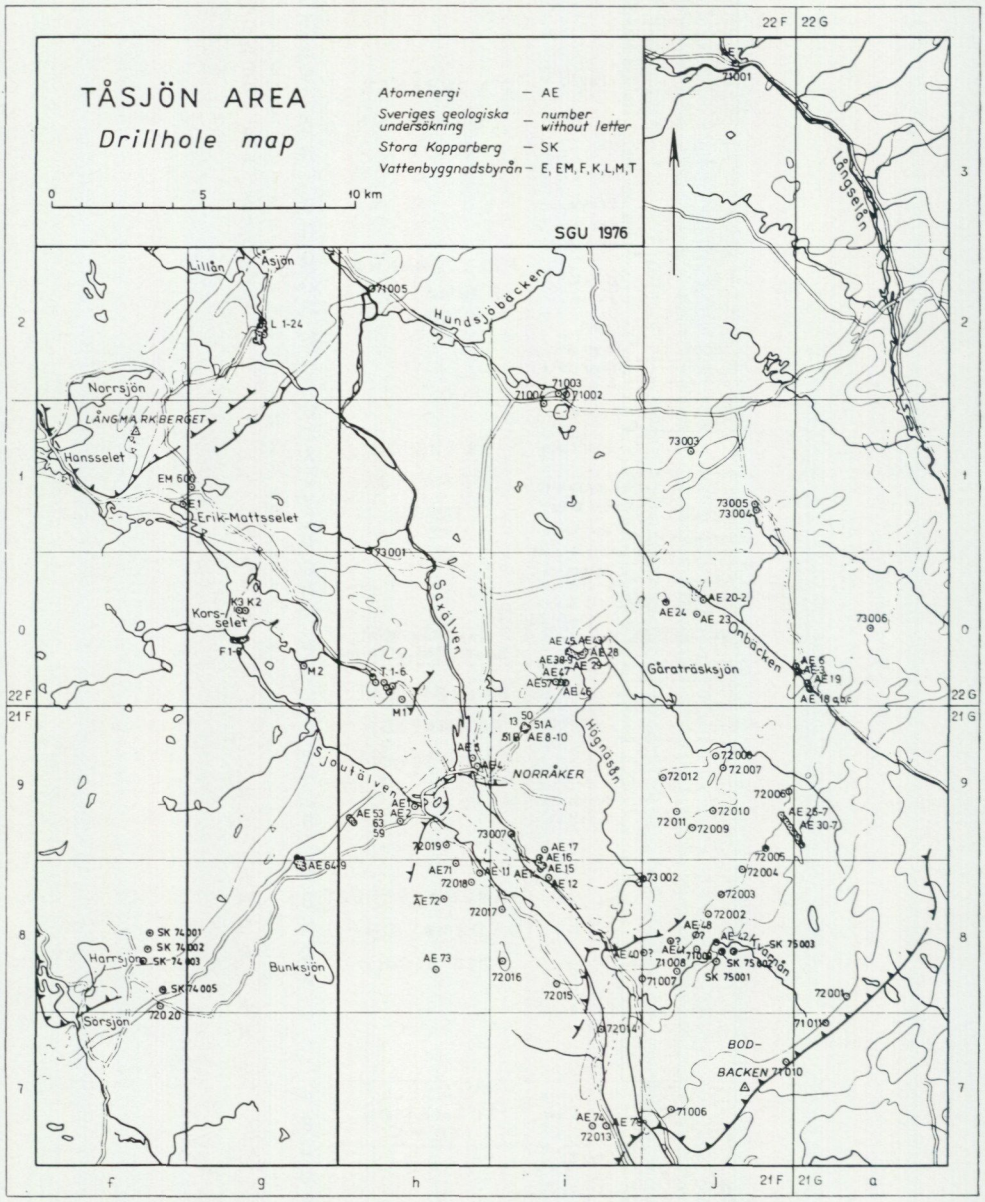

Fig. 6. Map showing the distribution of drillholes in the Tåsjön area. (Geological boundaries, as on Plate I, are not revised in relation to this new drillhole data.)

unit (Andersson 1971) — the basal member of the Norråker Formation (Gee et al. 1974). In addition, a few of the Boliden Company's several hundred holes from the Lövstrand—Bellvik area of galena mineralizations (Du Rietz 1960) have been re-examined, particularly those penetrating the sole thrust and reaching basement.

A general description of the geology is to be found in Gee (1972). West of the thrust front in Tåsjöberget the structure is dominated by the Fånån Syncline, the Sjoutälven Anticline and the Hundsjöbäcken Syncline. Basement is involved in the Sjoutälven Anticline and the structure folds a detachment-surface — the Bygdvattnet Thrust. The subordinate anticlines and synclines east of the Sjoutälven Anticline occur in the sedimentary cover above the passive basement being related to subordinate, low angle reverse faults which curve back into the sole thrust of the main detachment (décollement) surface. The folding and thrusting above the passive basement are referred to here as the Tåsjön Décollement.

BASEMENT

LITHOLOGY

The crystalline basement below the autochthonous sediments is largely composed of coarse granites and adamellites correlated with comparable units of Svecokarelian age (1,750—1,800 Ma, Revsund granite). Gneisses have been reported in the Lövstrand area (drillholes B 415 and B 642). About 10 km east of the Tåsjön thrust front, a major gabbro mass occurs in the vicinity of Dorotea (Åhman 1967). Basement units in the west appearing in the core of the antiform at Bergvattnet contain a large number of minor greenstone and gabbro intrusions.

SURFACE

Within the Tåsjön—Ormsjön area, the interpretation of the sub-surface configuration of the basement is based on nine drillholes. Seven of these were documented by Du Rietz (1960) and we have had the opportunity to re-examine them (Fig. 7). One, in Djupdal, was drilled by Atomenergi AB in 1965 and another by SGU, at Långviken, in 1973 (Fig. 8). This data, taken in relation to the outcrop evidence in Tjocknäsbäcken (referred to as Sågbäcken in previous literature) has allowed the construction of Fig. 9 — a structure contour map on the upper surface of the basement. It is worth noting that the regular orientation of the basement surface (dipping c. 1° WNW) obtained from the SGU and Boliden drillhole data alone is in complete agreement with the configuration obtained when outcrop data at Tjocknäsbäcken are taken into account.

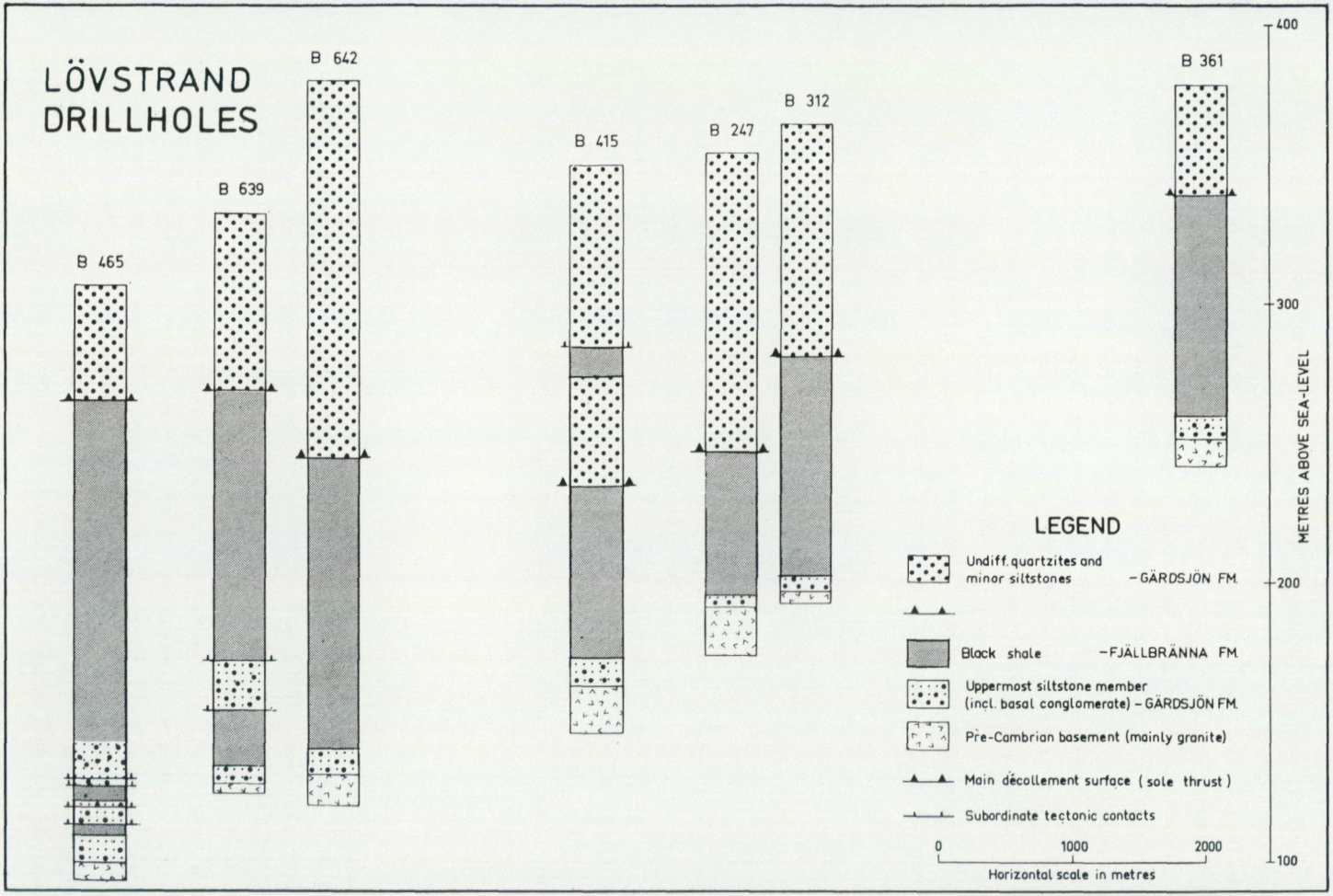

Fig. 7. Illustrations of the seven Lövstrand drillholes that reach basement, the locations being shown on Fig. 9. (These have been illustrated previously by Du Rietz 1960, Plate 3.)

Within the Lövstrand area the seven drillholes penetrating to the basement illustrate the degree of regularity of the basement surface. It is evident that over a distance of about ten kilometres the surface of the basement does not vary more than ten metres above or below the mean inclination. These small variations are considerably less than the relative irregularity of the sole thrust. Those drillholes penetrating a basement high (e.g. B 639 and B 247) have a thinner and less sandy member of the Gärdsjön Formation than elsewhere. Thus it is probable that the minor variations in basement surface in the Lövstrand area reflect primary variations in basement topography during deposition of the uppermost member of the Gärdsjön Formation.

Subsequent to the preparation of this paper, we have received information on two other holes drilled by the Boliden Company (shown on Fig. 9). Both holes (B. Bellviksberg 99, B. Sotbränna 1) reach basement and have yielded data fully compatible with the previous information.

The Djupdal drillhole located near the southern end of Malgomaj penetrated basement at c. 350 m a.s.l. which is c. 40 m below the projected data from the Tåsjön—Ormsjön area. Further north (Vojmsjön), U. Svensson has inferred (pers. comm.) the presence of transverse (NW) faults transecting the front. It is thus possible that comparable faults, trending NW—SE, have downthrown the basement northwards c. 40 m.

Du Rietz (1943) described a drillhole from northwest Ormsjön (B. Ormsjö 1) which did not reach the base of the quartzites in the nappes. Nevertheless, the base of the hole (184 m a.s.l.) reached to c. 20 m above the projected depth to the basement based on the structural contour data south of Ormsjön. None of the Lövstrand drillholes have a sequence of sediments less than 50—60 m thick below the sole thrust. Thus, these drillcore data are in conflict with those at Sotbränna, suggesting that the basement may be in the order of at least 40—50 m deeper northeast of Ormsjön than on the southwest side. New data are needed to resolve this conflict.

The westerly extent of this gently dipping basement surface is conjectural, there being no deep drillhole data west of Långviken. In 1969, flight magnetic and radiometric profiles through the area were measured and a distinct magnetic anomaly was located (Fig. 10). This curvilinear anomaly, extending approximately E—W, is clearly not influenced by the cover structures, it being related to a magnetite-rich unit in the basement. Hesselbom (in prep.) has calculated the depths to this anomaly and, in the Ormsjön area, these coincide with the depth of the basement surface. This suggests that the unit causing the anomaly sub-outcrops in the basement below the autochthonous sediments. The gentle, westerly dip of this anomaly and its extension over 15 km WNW of the Långviken drillhole suggest that the basement continues to dip gently WNW for at least that distance (Hesselbom in prep.). Seismic refraction experiments (Lund 1978) in the

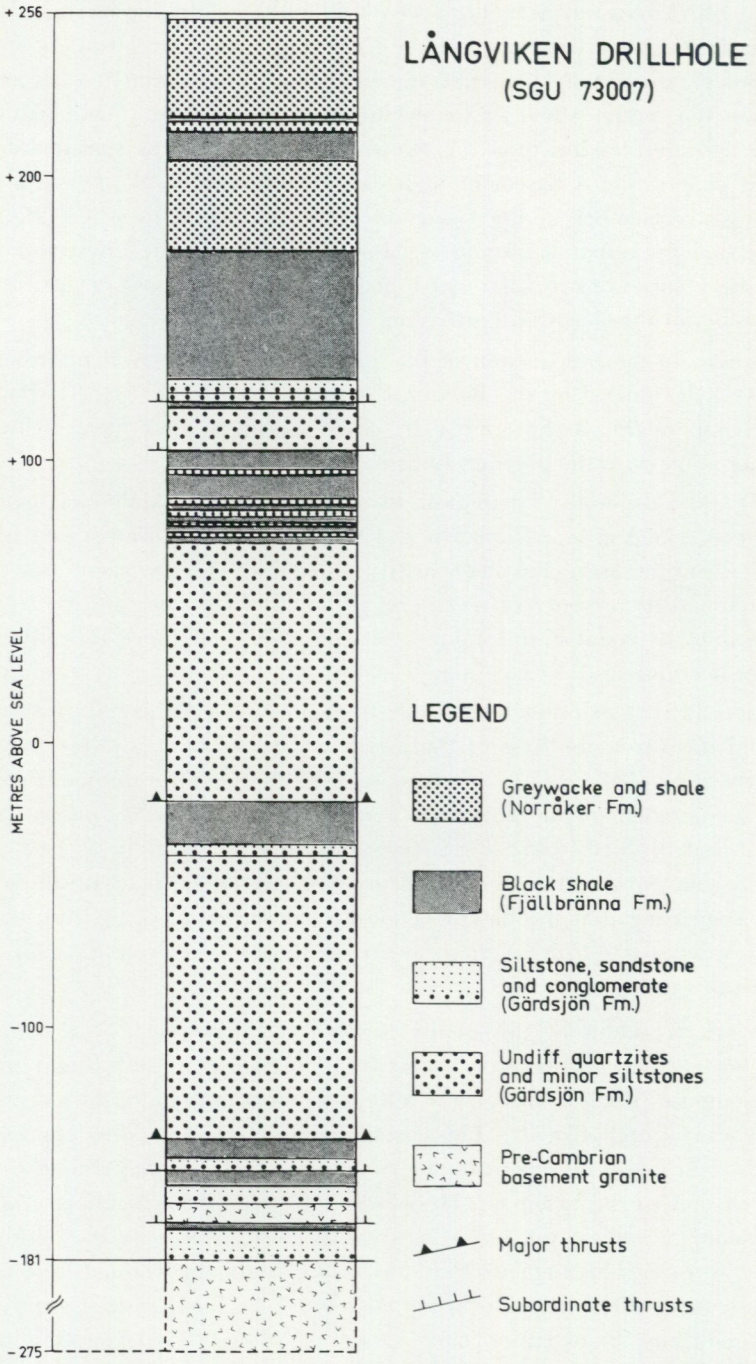

Fig. 8. Illustration of the Långviken drillhole, located (see Fig. 9) 1.8 km south of Norråker.

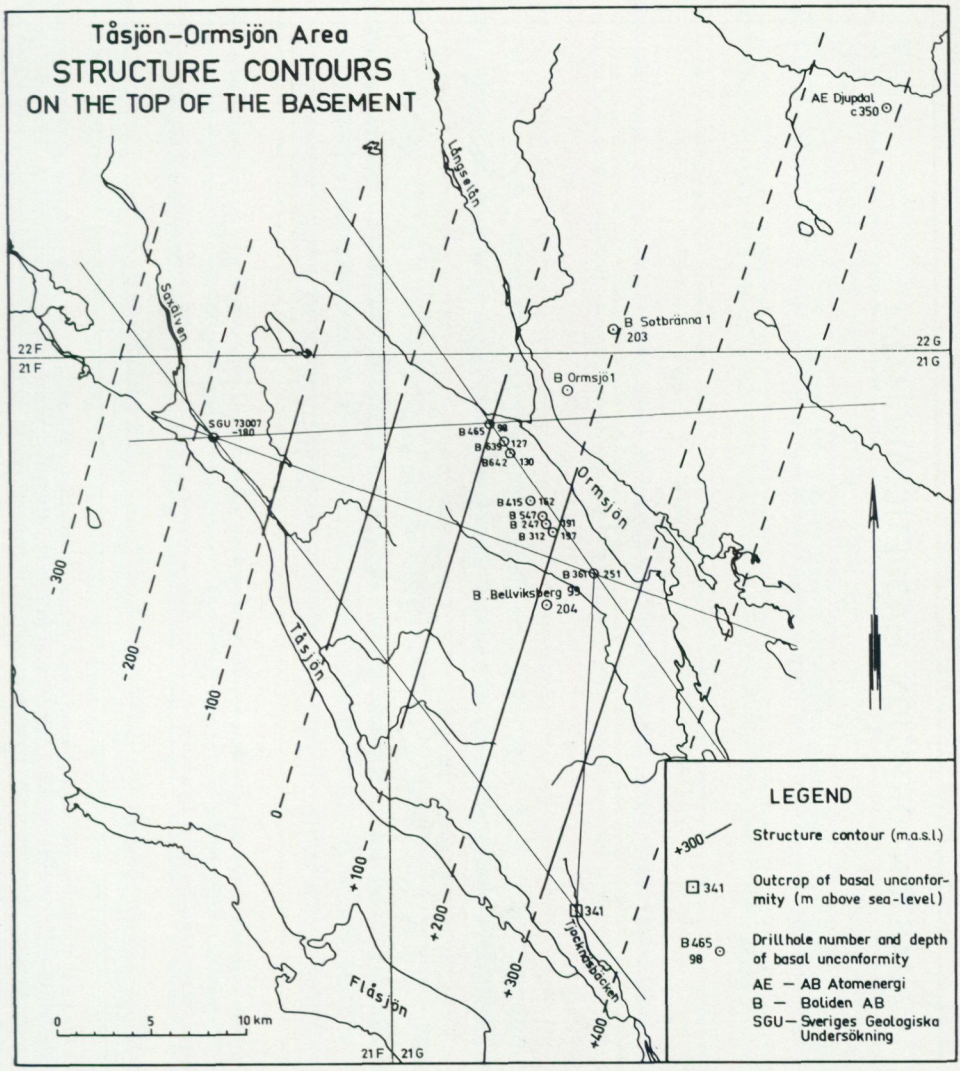

Fig. 9. Structure Contour map for the surface of the Precambrian crystalline basement beneath the autochthonous sediments (based on Boliden Company and SGU drillhole data). Drillhole B. Ormsjö 1 (Du Rietz 1943) was drilled to +184 m a.s.l. and did not reach basement. Two drillholes (B. Sotbränna 1 and B. Bellviksberg 99) have been added later (see p. 15).

area of northern Tåsjön and to the northwest likewise suggest that the basement continues to dip gently WNW within the area treated here. Our new profile through the area takes into account this evidence and the preliminary calculations of basement depth west of Tåsjön.

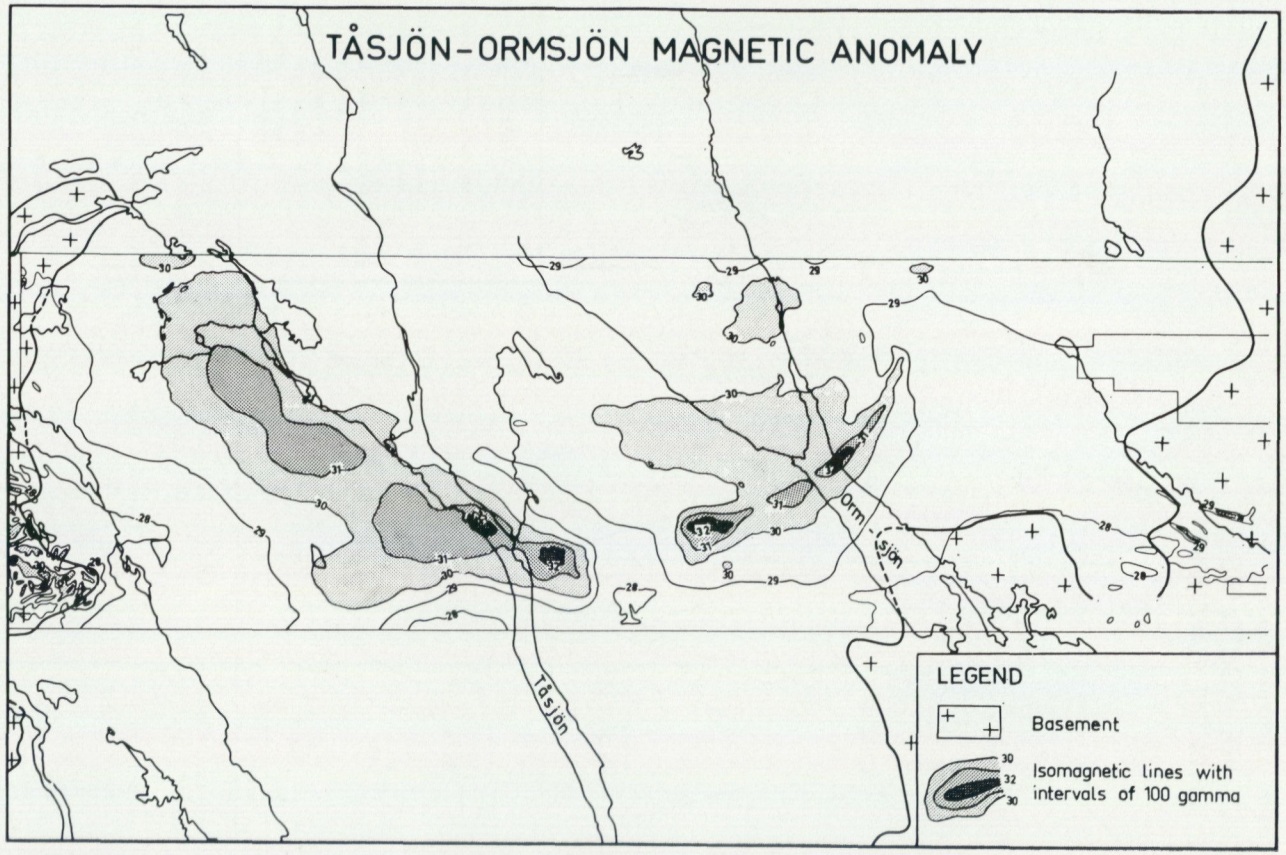

Fig. 10. Magnetic anomalies in the Tåsjön—Ormsjön area based on SGU flight measurements 1969 (flight altitude 30 m, line spacing 200 m and line orientation E—W). Contacts are shown between Precambrian basement and sedimentary cover in autochthon of the Caledonian Front and in the core of the Sjoutälven Anticline.

COVER SEQUENCES

Short summaries of the deep drillholes are presented here. These are followed by a more detailed treatment of the stratigraphy, largely of the Gärdsjön Formation, below and above the sole thrust of the Tåsjön Décollement and within the Sjoutälven Anticline.

DEEP DRILLHOLES

Djupdal

About 25—30 cm of granite were penetrated in the bottom of the Djupdal drillhole, overlain by 12.6 m of conglomerates, sandstones and siltstones. The basal part of this unit is a coarse, poorly sorted breccia, passing up into well-stratified siltstones and sandstones with scattered pebbles. The contact to the overlying Fjällbränna Formation is sharp, the basal unit in this formation being a 2 cm thick shale-pebble conglomerate comparable to that described by Du Rietz (1960, Fig. 1) from the Lövstrand area. The Fjällbränna Formation in this drillhole is unusually thick (nearly 80 m) and contains a substantial component of siltstones and calcareous sandstones. The hole started in Ordovician limestones described by Kulling (1942).

Lövstrand

The seven holes (Fig. 7) reaching basement in the Lövstrand area have been described by Du Rietz (1960) and illustrated in his Plates 3 and 4. They establish the local, regular dip of the granitic basement overlain by autochthonous conglomerates, sandstones and siltstones and black shales below the sole thrust. The latter is less regular than the basement surface. The overriding nappes contain up to c. 150 m of imbricated quartzites with minor shale/siltstone units and crushed black shales.

Långviken

The Långviken drillhole (Fig. 8) was drilled in the eastern limb of the Fånån Syncline, c. 1.8 km south of Norråker, on the shore of Tåsjön. It penetrated nearly 437 m of sediments (and one thin slice of basement) before reaching autochthonous basement granites, 181 m below sea level. The hole was continued to a depth of 532 m. The autochthonous sediments immediately overlying basement, composed of sandstones, siltstones and conglomerates, are very similar in facies and thickness to those recorded in the Lövstrand holes. They are overlain by a few metres of Fjällbränna black shales, followed by two minor

repetitions of the underlying sediments and including a thin (7 m) slice of granite. Two major tectonic units each including about 100 m of Gärdsjön Formation quartzites and minor siltstones, overlie the autochthonous and parautochthonous sediments. Both these quartzite units are overlain by Fjällbränna black shales, the upper passing up with subordinate repetitions into the Norråker greywackes and shales.

GÄRDSJÖN FORMATION STRATIGRAPHY

INTRODUCTION

The Gärdsjön Formation is dominated by quartzites, quartzitic sandstones and siltstones. Deposition occurred in fluviatile, marginal and shallow marine environments. Regressive cycles seem to dominate the sedimentary record, although an overall eastward transgression is evident. In the Tåsjön—Ormsjön area, the basement has been shown to be regular and passive. The stratigraphy below the sole thrust is similar in the nine drillholes, being dominated by Fjällbränna Formation black shales and a few metres of Gärdsjön Formation. Further west the basement-cover relationships are exposed in the Sjoutälven Anticline below the Bygdvattnet Thrust. The granitic basement in the Sjoutälven Anticline is overlain by Gärdsjön Formation quartzites and shales and, in the extreme west (Fånsjön), by Långmarkberg (Dabbsjön) Formation tillites. The Bygdvattnet Thrust cuts back westwards into deeper levels of the Sjoutälven Group stratigraphy and the sequence preserved above the basement and below the tectonic discontinuity varies in thickness from a few metres in the west to c. 130 metres in the east (e.g. on Strömberget). Above the Bygdvattnet Thrust, the Gärdsjön Formation overlies tillites (Långmarkberg Formation) and Risbäck Group arkoses and sandstones, being well exposed in the Sjoutälven section.

As discussed below (p. 31), it is thought probable that the Bygdvattnet Thrust originally passed east into the sole thrust below Tåsjön. The Sjoutälven Anticline is a later structure superimposed on the displaced nappe units and involving subsequent eastwards thrusting of the basement. Thus, stratigraphy is treated here in four parts, below and above the Tåsjön sole thrust and within the Sjoutälven Anticline below and above the Bygdvattnet Thrust.

AUTOCHTHON IN THE TÅSJÖN—ORMSJÖN AREA

The stratigraphy described here from below the sole thrust in the Tåsjön—Ormsjön area is based on drillhole data and an interrupted section in Tjocknäsbäcken. Du Rietz (1960, p. 14—16) described this stratigraphy based on drillholes

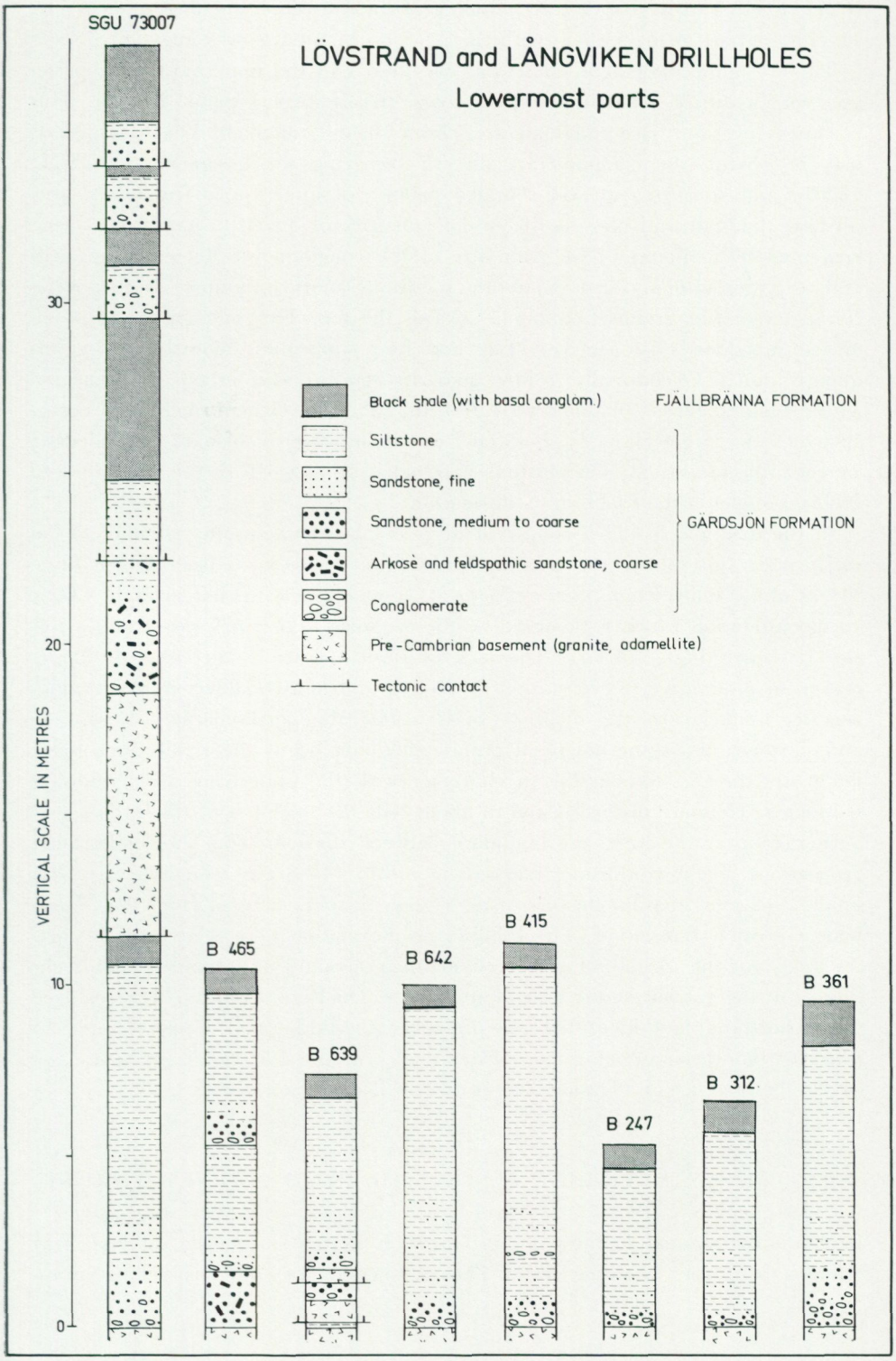

Fig. 11. Stratigraphy of the autochthonous (and parautochthonous) Gärdsjön and Fjällbränna Formation sediments below the Tåsjön Décollement, from Lövstrand to Långviken.

B 247, B 415 and B 465. Our re-mapping of these drillholes is illustrated in Fig. 11 (summarized below) along with the new information from Långviken.

The crystalline basement, sometimes weathered in the uppermost part, passes up (with a diffuse boundary) into a coarse arkose (e.g. Fig. 11, B 465). This is sharply overlain by a conglomerate, about 10—50 cm thick. The basal arkose may be absent, the conglomerate directly overlying the basement (e.g. SGU 73007) and consisting of well-rounded pebbles of quartz, quartzite, dark grey siltstone, feldspar and phosphorite in a framework of quartzitic sandstone, often cemented by carbonate. The grain size of the conglomerate decreases upwards and it passes into a coarse quartzitic sandstone unit containing an increasing frequency of fine-grained sediments towards the top. This unit gradually passes into interbedded siltstones, very fine and fine sandstones; bioturbation is frequently noted. Occasionally, coarse quartzitic sandstone interbeds are repeated within the sequence. Conglomerate interbeds, (about 5—10 cm thick) also occur, in which the larger clasts (c. 2—3 cm) dominantly consist of dark grey siltstone or very fine sandstone. The siltstone-dominated unit, 4—10 m thick, is followed by black shales of the Fjällbränna Formation.

In the drillhole B 639 a couple of units of basement granite, 60 and 30 cm thick, occur just above the basal unconformity. These have been shown (Fig. 11) as minor imbrications of the basement, comparable with that in SGU 73007, an interpretation which is favoured by the evidence that B 639 penetrates a minor basement high (p. 15). The lack of similar units in the other drillholes makes an alternative interpretation of these granites, as boulders in the conglomerate, unlikely. In the drillhole SGU 73007 the conglomerates, sandstones and siltstones above the basement granite slice and below the Fjällbränna black shales are directly comparable in character with the underlying autochthonous sediments. They are disturbed and of about half the thickness of the latter.

In the Lövstrand area, the boundary between the Gärdsjön and Fjällbränna Formations is a disconformity marked by a thin (4—8 cm) conglomerate with small (< 2 cm) angular pebbles of dark grey siltstones derived from the underlying Gärdsjön Formation. The Fjällbränna Formation here is at least 50 metres thick but the top is not preserved in the Lövstrand and Långviken autochthon, it being cut out at the base of the nappe. Du Rietz (1960, p. 13) reported that Thorslund had identified the presence of Middle and Upper Cambrian zones within these autochthonous black shales in the Lövstrand drillholes and locally the presence of Tremadocian units with Dictyonema species.

SJOUTÄLVEN ANTICLINE BELOW THE BYGDVATTNET THRUST

Basal quartzite conglomerates of the Gärdsjön Formation overlie the basement granitic rocks from localities west of Fånsjön over Storån and Gärdsjön to Ström-

berget. Asklund (1960, p. 54) described these and overlying units of his "autochthonous sandstone formation" or "Varegian formation" from the Storån profile. This section is complicated by faulting and is less complete than that on Strömberget, south of Gärdsjön, from where the type section has been described. No section has been found where the formation is complete and Gärdsjön Formation stratigraphy is based (Gee et al. 1974) on a composite section near Gärdsjön and in Sjoutälven.

THE STRÖMBERGET SECTION

In the eastern slope of Strömberget, south of Gärdsjön, the Gärdsjön Formation occurs in the locally overturned, western limb of the Fånån Syncline. The Gärdsjön sediments were deposited directly on a coarse-grained granite (Frödin 1922, Grip 1941) which now overlies the section.

The stratigraphy of the lower part of the Gärdsjön Formation has been established (about 130—150 metres) by combining three sections in the eastern slope of Strömberget (Fig. 12). The upper rock units of the Gärdsjön Formation recorded in the Sjoutälven section (above the Bygdvattnet Thrust) have not been identified in the Strömberget section.

The basement is overlain by conglomerates, feldspathic sandstones and quartzites. This basal unit (c. 10—35 m thick) is separated by a thin conglomerate bed (20 cm) from overlying interbedded siltstones, very fine and fine sandstones. Another thin conglomerate bed occurs within the middle of these, c. 15 m thick, fine-grained sediments, which coarsen upwards and pass gradually into quartzites, coarse feldspathic sandstones and conglomerates (c. 9 m). These are sharply overlain by interbedded siltstones and sandstones (3 m) passing into another quartzite-dominated unit (12 m), followed by siltstones, very fine and fine sandstones (c. 20 m, partly covered). Thin quartzite interbeds occur within the uppermost part of the unit passing gradually into massive quartzites (10 m). A characteristic red and green siltstone unit (at least 16 m and probably less than 30 m) follows abruptly, containing interbeds of coarse quartzitic sandstone in the uppermost c. 3 m. This unit is overlain by quartzites, coarse quartzitic sandstones and conglomerates (c. 35 m). Finally, the sequence is terminated by interbedded siltstones and sandstones.

The section on Strömberget yields the highest units and the thickest development of the Gärdsjön Formation below the Bygdvattnet Thrust.

SJOUTÄLVEN ANTICLINE ABOVE THE BYGDVATTNET THRUST

THE SJOUTÄLVEN SECTION

The stratigraphy above the Bygdvattnet Thrust is best known in Sjoutälven between Klingerselet and Tåsjön. This river section has previously been described

by Asklund & Thorslund (1935). The Sjoutälven sequence (Fig. 12) occurs within the southeastern limb of the Sjoutälven Anticline, which here has a regional sheet-dip at a low angle to the southeast. Minor folds repeat parts of the succession (Gee et al. 1974).

All major rock units known in the Tåsjön area are represented in the Sjoutälven river section: the Risbäck Group, the Långmarkberg (Dabbsjön) Formation, the Gärdsjön Formation, the Fjällbränna Formation, and the Norråker Formation. In this context only the Gärdsjön Formation and its relationship to underlying and overlying sequences are described.

The Långmarkberg Formation (about 10—25 m thick) separates an underlying thick sequence of the Risbäck Group (c. 1,000 m) from the Gärdsjön Formation. The basal unit of the Gärdsjön Formation consists of quartzites, quartzitic sandstones and conglomerates (17 m). Rare, very thin interbeds of siltstone or fine sandstone are present. The frequency of these increases within the uppermost part of the unit passing gradually into interbedded siltstones and very fine and fine sandstones (4 m). No outcrops were discovered further along the river section for a distance of almost one kilometre, which is estimated to correspond to a stratigraphic thickness of c. 100—200 m (extrapolated from fold pattern). The quartzites (11 m) overlying this covered part of the section are followed by alternating siltstones, very fine and fine sandstones (c. 30 m), passing upwards into red and green siltstones (6 m). The contact to the overlying interbedded quartzites, quartzitic sandstones and conglomerates (13 m), has not been observed by us. However, a sharp contact was reported by Asklund (*in* Asklund & Thorslund 1935, p. 37). The quartzite and quartzitic sandstone unit above the red and green siltstones is overlain by interbedded siltstones and sandstones. The unit is not entirely exposed, but it is at least 20—30 m thick. The basal 6 metres contain interbeds of quartzite, coarse and very coarse quartzitic sandstones which fine upwards into siltstones and fine sandstones. The frequency of sandstone interbeds increases again in the uppermost part. Cross-bedded quartzites and quartzitic sandstones (c. 35—40 m), with a basal conglomerate (c. 0.5 m) containing shale fragments, follow abruptly. A few, about half a metre thick interbeds of siltstone occur. The uppermost 6—8 metres are composed of very thinly and thinly cross-bedded, coarse and very coarse quartzitic sandstones separated by laminae of siltstone. A characteristic unit with phosphorite-bearing conglomerates and limestone (c. 1.5 m) underlies the uppermost siltstone unit of the Gärdsjön Formation. The siltstone unit is about 7 metres thick.

Limestones, comparable with those mentioned above in the Sjoutälven section, have been described from Högnäsån (Thorslund *in* Asklund & Thorslund 1935) to contain early Middle Cambrian fossils. Recently, Larsson (1976) suggested a somewhat older age for similar lithologies at the Sörsjön locality (younger Early Cambrian). The upper part of the Gärdsjön Formation contains trace fossils.

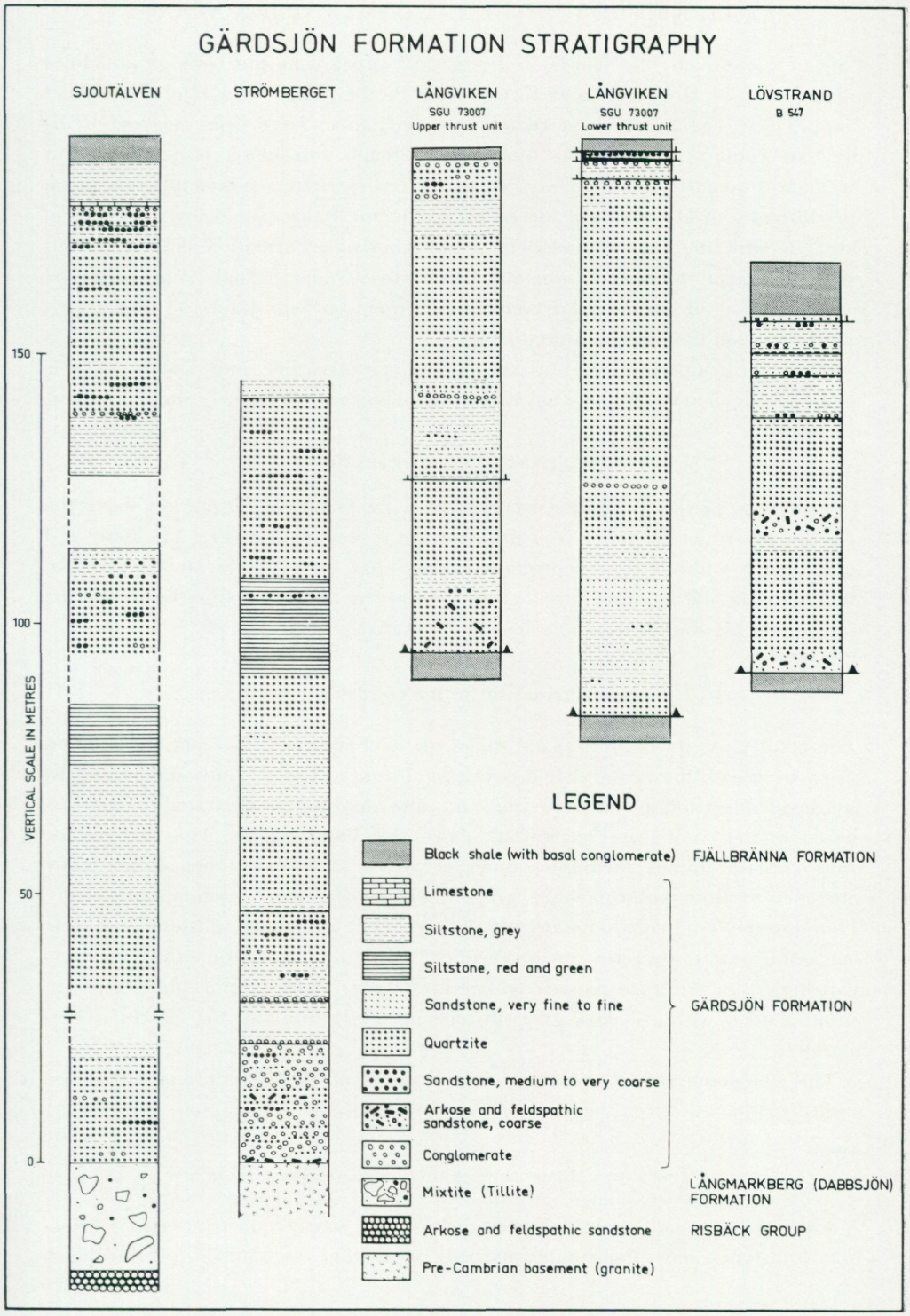

Fig. 12. Comparison of the Gärdsjön Formation stratigraphy above the Tåsjön sole thrust in the east (Lövstrand and Långviken) with that within the Sjoutälven Anticline in the west, deposited on basement (Strömberget) and on the Långmarkberg Formation and Risbäck Group allochthon (Sjoutälven).

ALLOCHTHON IN THE TÅSJÖN—ORMSJÖN AREA

East of Sjoutälven, the Gärdsjön Formation appears in the core of anticlines in and east of Högnäsån and further east in the Tåsjöberget and Blaikfjället Nappes (Gee 1972). The quartzites in these nappes have been referred to by previous authors as the Ström quartzites. Altough correlation of the Gärdsjön Formation quartzites and shales with the Ström quartzites is generally accepted, the difficulty in identifying a succession within the latter (see below) and correlating it with the various members of the Gärdsjön Formation, have persuaded us to accept the term Ström quartzites only as an informal name (comparable with that of the Vemdal quartzites further south in Jämtland) for Gärdsjön Formation units in the frontal nappes.

Gärdsjön stratigraphy east of the Sjoutälven Anticline and above the sole thrust is best known in the Långviken and Lövstrand drillholes; these are treated below.

THE LÅNGVIKEN DRILLHOLE

The lithology of the two major occurrences of the Gärdsjön Formation above the sole thrust within the Långviken drillhole are represented by Fig. 12. Folds and local thrusts within these occurrences suggest that the total thickness as well as thicknesses of the separate lithological units are uncertain; comparison with the units in the Sjoutälven section is therefore tentative.

The upper thrust unit of the Gärdsjön Formation

The basal part, thrust over black shales of the Fjällbränna Formation, is dominated by coarse arkoses and feldspathic sandstones. Three units dominated by interbedded siltstones and very fine and fine sandstones, separated by quartzite-dominated units, are recognized above this basal arkose. The fine-grained units contain minor, medium-grained to very coarse sandstones. Subordinate siltstones to fine sandstones are present within the quartzite-dominated units. Thin interbeds of conglomerate also occur. The uppermost siltstone and fine sandstone unit is overlain by interbedded quartzites, quartzitic sandstones and conglomerates. An uppermost conglomerate (9 cm), consisting of quartz and siltstone pebbles within a dark grey siltstone matrix, terminates the Gärdsjön Formation.

This conglomerate is overlain by black shales of the Fjällbränna Formation and the contact between the formations is disturbed.

The lower thrust unit of the Gärdsjön Formation

A lowermost unit of quartzites, medium to very coarse quartzitic and feldspathic sandstones and subordinate interbeds or siltstone, tectonically overlies black

shales of the Fjällbränna Formation. This lowermost unit is followed by interbedded siltstones and very fine and fine sandstones. Interbeds of medium sandstone to fine conglomerates are also present, in particular within the lower part.

The overlying unit is dominated by apparently massive quartzites and medium to coarse quartzitic sandstones. Occasional interbeds of conglomerate and coarse to very coarse feldspathic sandstones are recognized. This quartzite-dominated unit is separated from the overlying very fine sandstones and siltstones by a conglomerate, the larger fragments of which are dominated by quartz but well-rounded fragments of siltstone are also recognized; phosphorite may be present. Local tectonic disturbances are recognized above the conglomerates as indicated by the presence of black shale and brecciated quartzite (not shown on Fig. 12 due to their small thickness, 2 dm). Above this contact, there follow very fine sandstones overlain by silty limestone, containing fossil fragments. The lime content decreases upwards and the unit is terminated by siltstone.

The uppermost conglomerate (shown on Fig. 12) has a dark grey, fine-grained matrix with scattered quartz grains (coarse sand—granular). This conglomerate is separated from an overlying major black shale unit by a thrust-zone (c. 1 m thick), containing black shale and quartzitic sandstone.

THE LÖVSTRAND AREA

A short, general description of the allochthonous Gärdsjön Formation stratigraphy in the Lövstrand area is given by Du Rietz (1960). He did not refer to any particular drillhole and outlined the stratigraphy as follows. The basal part of the formation consists of arkoses, sometimes lying directly on a slice of basement. These arkoses grade into white and pale grey quartzitic sandstones (quartzites). A glauconitic, greenish grey siltstone—shale unit occurs on the top of this sandstone sequence. This uppermost unit of the Gärdsjön Formation is overlain conformably by thin (a few metres) black shales (Fjällbränna Formation) below another allochthonous Gärdsjön unit (Du Rietz 1960, pl. 3 and 4).

We have re-examined seven of the drillholes in the Lövstrand area, penetrating the whole sedimentary cover-sequence. In addition, a few were studied which only penetrate the quartzite nappe sequence. The stratigraphy recorded in the drillcore B 547, which only contains the nappe sequence, is described below (see Fig. 12). It agrees well with the type-stratigraphy of the allochthon described by Du Rietz (1960).

Thrust over the black shales (Fjällbränna Formation) there is a coarse to very coarse, pale grey arkose (4.5 m), passing into coarse quartzites (18 m). The quartzites are overlain by silty, grey shales (3.0 m). Another, very coarse grained arkose unit (5.5 m) overlies these shales, the arkoses grading upwards into quartzites (16.5 m), containing silt interbeds in the uppermost part. The

overlying uppermost unit of the Gärdsjön Formation is composed mainly of greenish (partly bioturbated) siltstones (16 m), occasionally interlayered with thin sandstones and conglomerates. The Gärdsjön Formation siltstones are overlain by black shales (11 m) of the Fjällbränna Formation. The total thickness of the Gärdsjön Formation in this drillhole is c. 65 m, which is thought to be representative of the thickness in the Lövstrand allochthon.

GÄRDSJÖN FORMATION CORRELATION

The stratigraphic evidence from below the sole thrust in the Tåsjön—Ormsjön area demonstrates that the (c. 5—10 m) Gärdsjön Formation siltstones with subordinate phosphoritic, glauconitic, calcareous sandstones and conglomerates, directly underlying the Fjällbränna shales, have a similar character over an area of at least 1,000 km^2 and extending from the thrust front to Norråker, a distance of about thirty kilometres. The Tåsjön—Ormsjön area was apparently subject to extreme peneplanation prior to late Lower and Middle Cambrian transgression. This development of the Gärdsjön Formation is directly comparable with the uppermost members of the formation in the allochthon above the sole thrust and above the Bygdvattnet Thrust as exposed in the Sjoutälven, Fånån (near Sörsjön) and Högnäsån sections. These uppermost members of the Gärdsjön Formation are not exposed in the type area in the eastern limb and hinge of the Sjoutälven Anticline being cut out below the Bygdvattnet Thrust.

Whereas the Gärdsjön Formation in the type area is in general comparable with its development in the overlying nappes (e.g. Sjoutälven), which have been derived from substantially further west, it contrasts markedly with that in the Tåsjön—Ormsjön autochthon some 25 km to the northeast. This change in development of the Gärdsjön Formation is considered further below in the tectonic interpretation.

Any attempt to establish the area of derivation of the Gärdsjön Formation in the nappes is dependent upon interpretation of nappe geometry and comparison of stratigraphy below and above the sole thrust and below the Bygdvattnet Thrust. These constraints clearly require that the most easterly Gärdsjön successions (Lövstrand) above the sole thrust must have been derived from west of Norråker. The data from the Lövstrand—Tåsjöberget area is fragmentary but there is good evidence that the Gärdsjön Formation was deposited directly on a granitic basement, and is composed of basal arkoses and quartzites and contains only very subordinate, thin (1—3 m) siltstone beds. The total thickness is certainly less than 100 m and is estimated to about 65 m. Red and green siltstones are absent. Comparison of this Lövstrand succession with that of the Gärdsjön Formation in the Strömberget area leads to the conclusion that the former was deposited either east or west of the east limb of the Sjoutälven An-

ticline. The similarity between the Gärdsjön stratigraphy deposited on the granitic basement of the anticline and that deposited on the Risbäck Group units in the overlying nappes above the Bygdvattnet Thrust, strongly suggests that the Lövstrand allochthonous successions were deposited between the Norråker (Långviken) autochthon and the Strömberget area. The allochthonous Gärdsjön units in the Norråker—Högnäsån area may represent the higher units in the formation that have been displaced eastwards from the Gärdsjön—Strömberget area.

INTERPRETATION OF STRUCTURE

The drillholes in the area between Tåsjön and Ormsjön unambiguously demonstrate the geometry of the passive basement and the sole thrust. These extend nearly 30 km from the Caledonian thrust front to Norråker, dipping c. 1° WNW. Interpretation of geophysical (magnetic and seismic) data suggests that the basement continues to dip gently WNW for at least a further 15 km. The Gärdsjön stratigraphic sequences are markedly dissimilar above and below the sole thrust, requiring that displacement over the latter exceeds 45 km. If stretching of the allochthon is neglected (compensated perhaps by small-scale imbrication in the nappes, as shown in Du Rietz 1960) and account is taken of the folding and major thrusting above the sole thrust as shown in the profile (Plate I), then displacement of the Risbäck Group and overlying units northwest of Tåsjön exceeds 70 km.

Interpretation of structural geometry of the Tåsjön Décollement is based on the outcrop mapping, the drillhole data and the electro-magnetic anomalies, both flight (Gee 1972) and ground measurements (Fig. 13). The geological map (Plate I) differs from that published earlier (Gee 1972) in some important details, particularly, in the thrust front where examination of the Boliden Company drillholes provided new data. Apart from the electrical measurements over Tåsjöberget (referred to on p. 10), deep electrical soundings were made in profiles (marked on Fig. 13) over the Fånån Syncline north of Norråker in the neighbourhood of Gåraträsksjön. This experiment defined the orientation of the different Cambro-Ordovician units down to a depth of c. 300 m (K. Johansson, pers. comm.). It showed that the highly conductive black shales are down-folded to a depth greater than 300 m and probably to about 400 m below the lake level (376 m a.s.l.). This evidence has influenced the construction of the profile (Plate I).

In this paper little account has been taken of the detailed biostratigraphic data. Tectonic repetition of the main lithostratigraphic units is easily recognized; repetition within formations is more difficult to identify. The great thickness (up to 400 m) of black shales beneath Tåsjöberget is unambiguously the result of tectonic repetition and this has been clearly substantiated by Thorslund

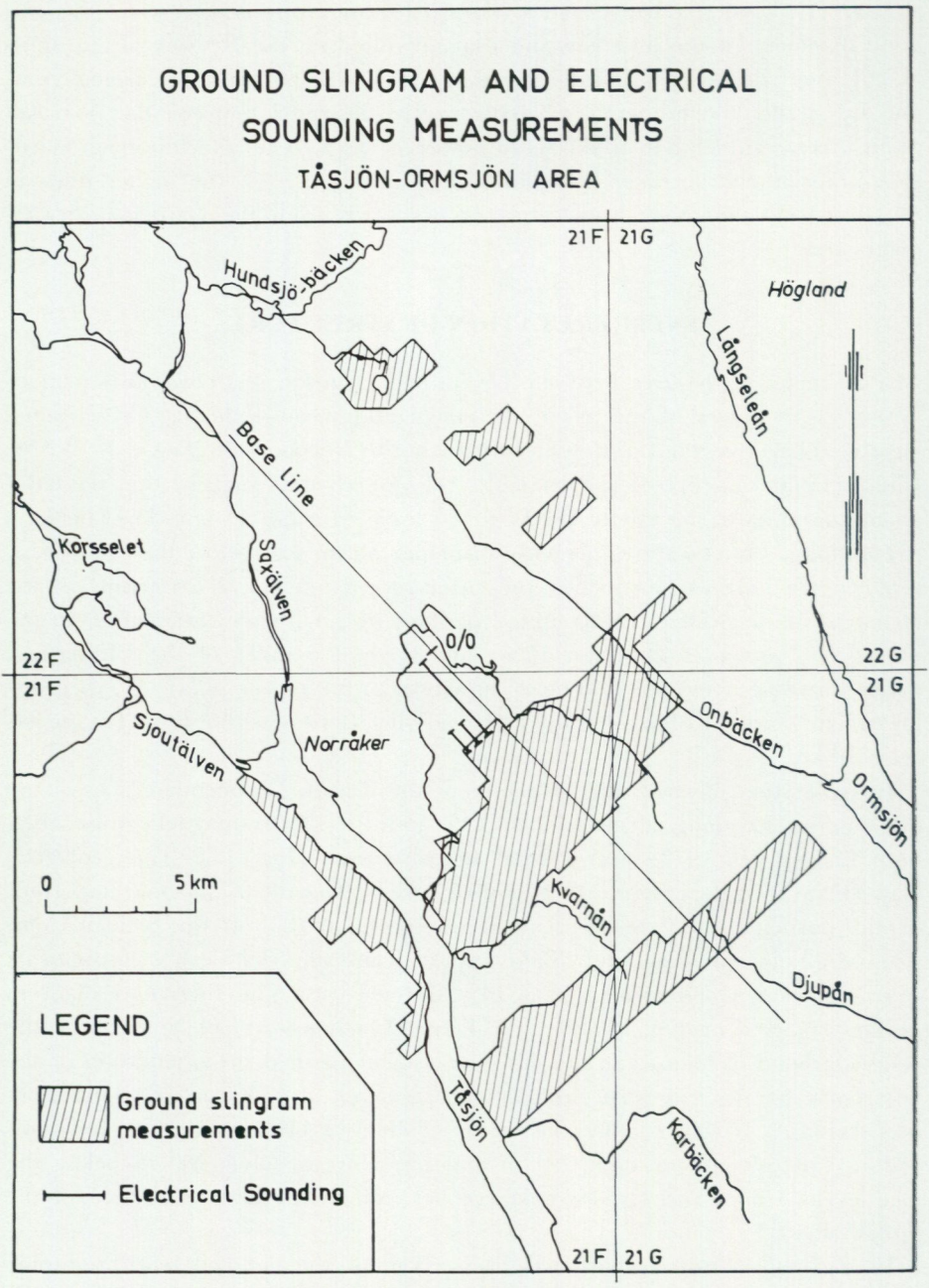

Fig. 13. Sketch map showing the extent of the SGU ground electro-magnetic (slingram) and electrical sounding measurements in the Tåsjön area.

(*in* Asklund & Thorslund 1935). A reassessment of the biostratigraphy of the Tåsjön area, taking into account the new drillhole data, is in progress (Karis, in prep.).

The movement on the Tåsjön Décollement can be taken up further west of Tåsjön either by eastward thrusting of the basement in the core of the Sjoutälven Anticline or by displacement on the Bygdvattnet Thrust or (more probably) by a combination of both. The character of the Bygdvattnet Thrust as a décollement phenomenon lying close above the basement surface and the evidence that it is folded in the Sjoutälven Anticline suggests that the Bygdvattnet Thrust once passed continuously eastwards into the Tåsjön Décollement. Nevertheless, the most conspicuous change in stratigraphy in the Gärdsjön Formation occurs between the Norråker (Långviken) autochthon and the Gärdsjön type area, i.e. between sequences below the Bygdvattnet Thrust. This requires either very rapid facies changes and westwards thickening of the Gärdsjön Formation from Norråker to Gärdsjön or substantial easterly thrusting of the basement in the Sjoutälven Anticline.

The extent of thrusting of the basement cannot be assessed in the area under discussion. Some light will be thrown on this aspect as progress is made with the re-mapping of basement-cover relationships further south towards Hotagen and the Grong—Olden Culmination. That facies changes in the Gärdsjön Formation may be rapid, with sandstone units several tens of metres thick appearing beneath the uppermost siltstone member, is documented in autochthonous areas further north along the Caledonian Front (e.g. Laisvall, Lilljequist 1973). Thus, although basement displacement may be considerable it need not be more than a few kilometres. In the section on Plate I the dilemma is illustrated with a question mark.

Assessment of the amount of movement on the Bygdvattnet Thrust is also problematical. Gee (1972) showed the thrust (then thought to be a continuation of the Sörsjön Thrust) to cut back westwards into basement. Subsequent mapping by Thelander has shown that this is not the case; the Bygdvattnet Thrust passes westwards, riding closely above the basement surface. It can be traced from c. 2.5 km southwest of Sörsjön to c. 1 km north-northwest of Bygdvattnet, folded by the Sjoutälven Anticline. Gärdsjön units thin out westwards below the thrust. An isolated occurrence of Långmarkberg Formation tillite occurs c. 1 km south of Fånsjön, outcropping close to the basement and separating the latter from the overthrust Risbäck Group. A few hundred metres further north the Risbäck Group occurs close to the basement but the contact is not exposed. Thus, the Bygdvattnet Thrust in the type area can be traced over a distance of about 8 km.

The continuation of the Bygdvattnet Thrust to the north and then northeast is poorly exposed. However, at Hansselet, the Risbäck Group (as well as a minor slice of granitic basement) is separated from the main basement by Långmark-

berg mixtites. Contact relationships above and below the mixtites are unexposed. Further north (Bergvattnet) the upper surface of the basement is mylonitized as are the overlying sediments. Thus, it is probable, but not as yet unambiguously demonstrated, that the Bygdvattnet Thrust continues westwards to pass below the overlying allochthon of the Seve-Köli Nappe Complex.

The Bygdvattnet Thrust has not been traced southwards from a position 2.5 km southwest of Sörsjön. Exposure is poor south of the area treated here and its extension in this direction is discussed elsewhere (Kumpulainen & Thelander, in prep.).

SUMMARY AND DISCUSSION

The evidence has been presented for the character and extent of the Tåsjön Décollement, defined in an area of c. 1,000 km^2 and over a distance stretching from the thrust front to Norråker and probably (on the basis of the interpretation of the magnetic anomaly data) at least 15 km further west. A recent seismic refraction study (Lund 1978) identified depths to basement in the Tåsjön area that approximately coincide with those obtained by the deep drilling. It is thus clear that the minor slices of granitic basement in the base of the allochthon above the Tåsjön sole thrust do not give evidence of basement rooting of this thrust in the western Tåsjön area (Gee 1972); they probably represent irregularities in the basement surface topography that were detached during displacement of the sediment-dominated allochthon. Drillhole evidence and interpretation of magnetic and seismic data favour a gently dipping (c. 1° WNW), regular basement surface below the décollement.

Within the autochthonous sequences below the Tåsjön Décollement, no important changes in lithofacies have been identified in the area from southwest Ormsjön to northwest Tåsjön. The Gärdsjön Formation is generally 5—10 m thick and is composed of basal conglomerates and sandstones (usually phosphoritic) passing up into bioturbated siltstones and fine sandstones. The easternmost allochthonous Gärdsjön units in the Lövstrand area must have been derived from west of northwest Tåsjön. Their thickness (c. 50—100 m), lithology (dominated by quartzites, conglomerates and arkoses with very little siltstone and no red and green shales), and the local evidence of deposition on granitic basement, requires that they were probably derived from areas between the Gärdsjön—Strömberget type area (in its pre-fold/thrust position) and northwest Tåsjön. Allochthonous units further west, appearing in the Högnäsån area and in the Långviken drillholes were derived from areas further west than those of the Lövstrand allochthon, possibly from the upper parts of the Gärdsjön Formation in the Gärdsjön—Strömberget type area and its extention northwestwards to Bygdvattnet and towards Fånsjön. V. Stejskal (pers. comm.) has reported red and green shales in these allochthonous units in the area c. 10 km west of Flåsjön. Gärdsjön sequences overlying the Risbäck Group above the

Bygdvattnet Thrust are clearly derived from substantially further west.

Although it is probable that the Tåsjön Décollement originally passed westwards into the Bygdvattnet Thrust it remains possible that much of the displacement on the former was taken up by movement of the basement in the core of the Sjoutälven Anticline. This aspect remains controversial.

Continuation of the Fånån Syncline and related structures southwards into Jämtland and comparability of related folds and thrusts in central and northern Jämtland suggest that the sole thrust of the Tåsjön Décollement underlies a substantial part, if not all of the Jämtland Caledonian Front. It remains to be seen whether it passes in central and southern Jämtland into a zone of greater basement activity (Strömberg 1974).

Further west in central Jämtland and in the vicinity of the Grong—Olden Culmination and Tømmerås area in Norway, it is apparent that the décollement structures pass westwards beneath Precambrian granites and rhyolites of the basement. These thrust sheets are up to at least two kilometres thick and were probably substantially thicker prior to Caledonian flattening. Nevertheless, it remains unclear whether these thrusts steepen into the deeper basement further west, as shown on the 1:1,000,000 geological map of Norway (Norges geologisge undersøkelse, 1960) and Gee (1977) or cut back westerwards (cf. Gee & Zachrisson 1974) isolating the basement allochthon as detached slices, "floating" above an autochthonous—parautochthonous basement.

There are very few mountain belts in the world that are so susceptible to analyses of the interplay of crystalline basement and sedimentary cover during orogenesis as the Scandinavian Caledonides. In most of the classical décollement terrains of the frontal zones of orogens (e.g. in the Jura, the Rocky Mountains, and the Appalachians) cover sequences are thick, drilling to basement involves holes of several kilometres depth and interpretation of the structure is often based on analyses of geophysical data, particularly seismics. In the Scandinavian Caledonides we are fortunate indeed to have an erosion level that allows many of the basement-cover controversies to be resolved by detailed geological mapping, supplemented by some drilling and shallow seismics.

ACKNOWLEDGEMENTS

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NGU = Norges geologiske undersøkelse
SGU = Sveriges geologiska undersökning

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GÄRDSJÖN-TÅSJÖN-ORMSJÖN, GEOLOGICAL MAP

NORTHERN JÄMTLAND AND SOUTHERN VÄSTERBOTTEN

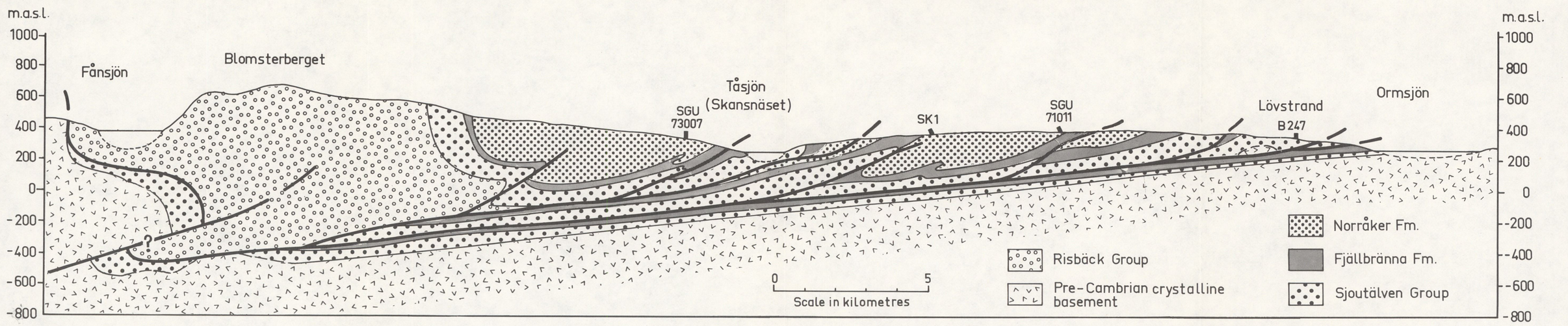
D.G.GEE, R.KUMPULAINEN AND T.THELANDER, 1975

Erik Mattsselet
Korsselet
Stensjön
Saxälven
Onbacken
Gåratråsksjön
Klingerselet
Sjoutälven
Högnäsån
NORRÅKER
Rönnberget
Fånsjön
A
Långviken
Bygdvattnet
Harrsjön
Bunksjön
Kvarnån
LÖVSTRAND
Ormsjön
Sörsjön
Djupån
B
Storån
Bodbacken
Gärdsjön
Tå-
sjön
Karbäcken
Ström-
berget
Fjällbrännan
Brattbäcken
BELLVIK
Övre
Gissmansvattnet
Yttre
Gärdviken
Täsjö-
berget
Rönnberget
Flåsjön
0
5
Scale in kilometres

LEGEND

- Norråker Fm.
- Fjällbränna Fm.
- Sjoutälven Group
- Risbäck Group
- Pre-Cambrian crystalline basement
- Thrusts

SECTION A-B, FÅNSJÖN-ORMSJÖN



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