The Nature and Tectonic Setting of Mélange Deposits in Soknedal, near Støren, Central Norwegian Caledonides

ODD NILSEN

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A sedimentary mélange occurs as a mega-lens just east of the disjunctive boundary between the Støren Nappe and the Gula Nappe within the Trondheim Nappe Complex in the Soknedal–Støren area. Packets, blocks and shreds of pervasively sheared Gula and Støren lithologies occur as fragments within a virtually undeformed siltstone-greywacke matrix. The lithology is considered to represent an olistostrome with matrix material chiefly derived from the volcanic and volcanoclastic units of the Hovin and Horg Groups, but also from the Støren and Gula Groups. Evidence points to deposition after obduction, folding, thrusting and gravitational sagging with small-scale renewed thrusting of the Støren Nappe. The petrology of the mélange and the tectonic evolution of the adjacent nappe units suggest a late Silurian age for the olistostrome.

O. Nilsen, Department of Geology, University of Oslo, P.O.Box 1047, Oslo 3, Norway

Introduction

The Trondheim Nappe Complex (Wolff 1967, Guezou 1978) covers a large part of the central Norwegian Caledonides and constitutes the upper allochthonous nappe complex within the Caledonian tectonostratigraphy (Roberts 1978, Wolff & Roberts 1980, Roberts & Wolff 1981). The stratigraphy of the Støren–Hølonda–Horg area within the west-central part of the Trondheim Region was established by Vogt (1945) and comprises a series of metavolcanic and metasedimentary units spanning an age range from probable late Precambrian/Cambrian (Gula Group) to assumed early Silurian (Horg Group).

The Støren Group, of presumed Cambrian to earliest Ordovician age, constitutes the main volcanogenic unit of the western Trondheim Region. The group forms the basal part of a separate nappe, the Støren Nappe (Gale & Roberts 1974), within the upper allochthon, together with the succeeding metasedimentary and metavolcanic assemblages of the Hovin and Horg Groups (Vogt 1945, Chaloupsky 1970) (Table 1).

A study of the trace element geochemistry of the basaltic greenstones of the Støren Group has revealed ocean-floor tholeiitic affinities. Eastward translation or obduction of the metavolcanics upon the underlying Gula Group was postulated by Gale & Roberts (1974) and Roberts & Gale (1974); evidence favouring an obduction in pre-Middle Arenig time has been forwarded by Furnes et al. (1980).

In view of the earlier scanty evidence for a tectonic break between the Gula and Støren units (Roberts 1967, Guezou et al. 1972) and their overall conjunctive and apparantly gradational boundary relations in the Innset–Oppdal area of the south-western part of the Trondheim Nappe (Rohr-Torp 1972), some doubts were initially cast on the obducted nature of the Støren volcanites by the present author

Table 1. Nappe succession of the Central Trondheim region (after Wolff & Roberts, 1980 and Roberts & Wolff, 1981) with subdivisions and equivalent Swedish tectonic units. The column Singsås Formation to Sandå Formation refers to the present author's subdivisions

UPPER ALLOCHTHONOUS COMPLEX	Trondheim Nappe Complex	Støren Nappe	Horg Gr.	Sandå Fm.	Køli
			U. Hovin Gr.	Hovin ss.	
			L. Hovin Gr.	Dicranograptus shale Fm.	
				Krokstad Fm.	
			Støren Gr.	Ilfjell Fm.	
				Elgsjø Fm.	
		Gula Nappe	Gula Gr.	Undal Fm.	Seve (?)
				Singsås Fm.	
LOWER ALLOCHTHONOUS COMPLEX	Levanger Nappe				Køli
	Skjøtingen Nappe				Seve
	Leksdal Nappe	Leksdalsvatn Nappe Hærvola Nappe			Särv Offerdal
AUTOCHTHON	Precambrian Basement				

(Nilsen 1978). However, with the present recognition of a structural break between the two units the tectonic emplacement of the Støren Group upon the Gula now seems evident.

The present paper gives an account of the geology of the area immediately south of Støren where the nature of the disjunctive Gula/Støren contact has been investigated and where the occurrence of a local mélange unit immediately below the Støren Nappe has been mapped in some detail (Figs. 1 & 2).

General Geology

The boundary between the Gula complex or nappe (Roberts 1978) and the Støren Nappe trends NE-SW, more or less parallel with the Soknedal valley from Støren to Rennebu (Fig. 1). Near Støren, the valley bottom is heavily covered with glacial

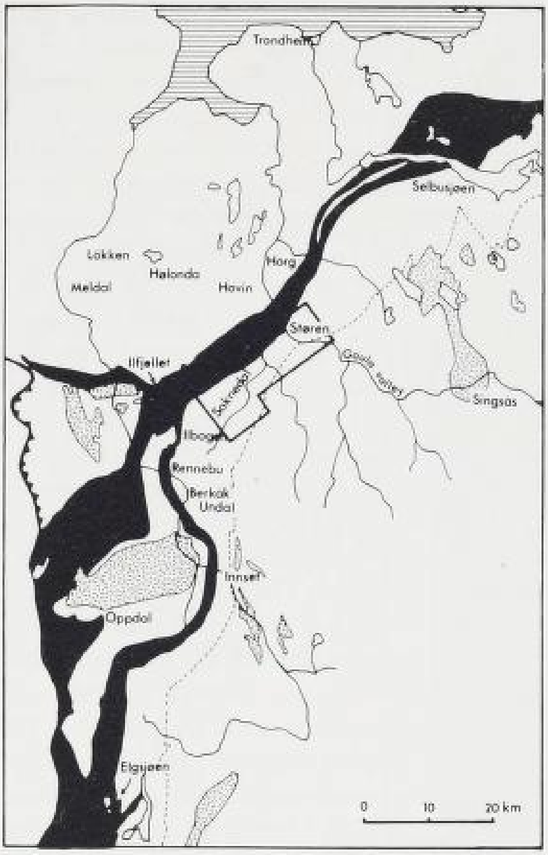

Fig. 1. Key map of the western Trondheim area showing localities mentioned in the text. Støren Group in black; the boundary between the Undal Formation and the Singsås Formation of the Gula Group is stippled. Major intrusions are cross-hatched. The boxed area is that of Fig. 2.

and alluvial deposits which tend to obscure the boundary relations. Detailed mapping through the years 1977 and 1980–1981, however, has revealed the nature of the boundary between these two tectonostratigraphic units (Nilsen 1980) in this particular area.

Geological maps have been published by Bugge (1910), Lindberg (1971), Nilsen (1978) and Rohr-Torp & Nilsen (1979) from the southern (Soknedal) parts of the area, while the northern part is covered by the 1:250,000 map-sheet 'Trondheim' (Wolff 1976).

Gula Group. A twofold division of the Gula complex in its western parts was proposed by Nilsen (1978). To the east, a lower, psammitic unit, the *Singsås Formation,* which occupies the central part of the extensive outcrop of the Gula, is exposed in the hills in the easternmost part of the present map area (Fig. 2). Lithologies range from low-grade calcite-bearing chlorite-quartz schists in the Soknedal–Hauka area to banded calc-silicate biotite schists and gneisses further south and in the Gaula valley where transitions into high-grade diopside-microcline rocks are associated with dioritic plutons in the Singsås district (Fig. 1). The formation is deformed by tight to isoclinal folds with steep, N–S-striking axial planes.

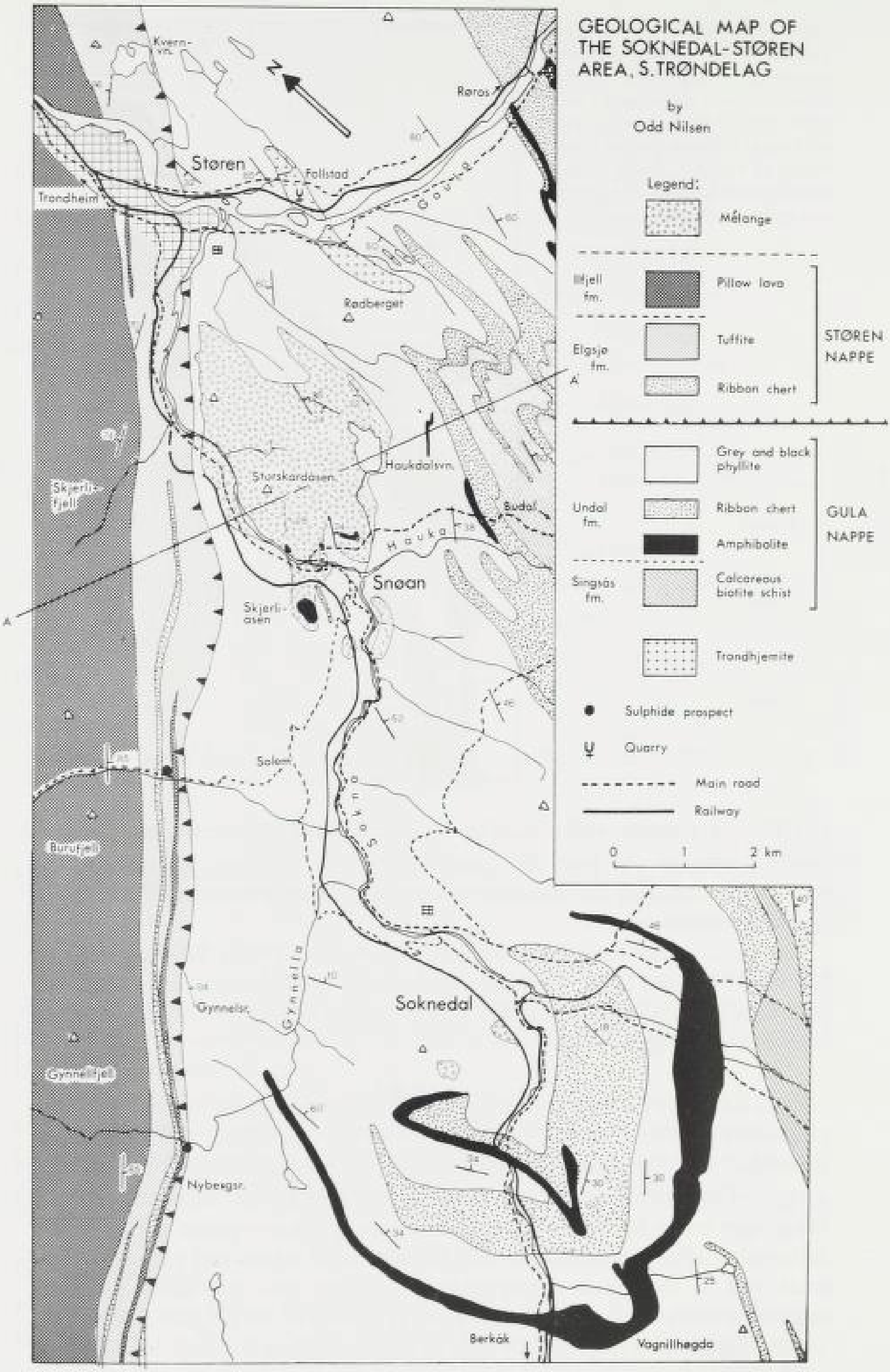

Fig. 2. Geological map of the Soknedal–Støren area.

An extensive zone of ribbon chert, grading into graphitic quartzites, marks the transition into an overlying unit, the *Undal Formation*, to the west. The Undal Formation consists mainly of graphitic metapelites with a variable carbonate content. They are chiefly developed as fine-grained, grey and black chlorite-sericite phyllites, often with thin intercalations of ribbon chert. Sulphide mineralizations, chiefly of pyrite with subordinate pyrrhotite, are ubiquitous constituents within the metapelites and occur as thin laminae and schlieren parallel to the prevailing schistotisy (Nilsen 1978).

Discontinuous, thin horizons of mafic metavolcanics occur within the Undal Formation. These are the *Gula greenstones* (Nilsen 1974) which occur mainly near the Singsås/Undal Formation boundary, but also within the central part of the Singsås Formation where they are associated with horizons of black schists and thin manganiferous iron-formations, usually in conjunction with minor cupriferous stratabound sulphide horizons (Nilsen 1978). In the Soknedal area the Gula greenstones are developed as strongly sheared and schistose, calcareous chlorite-bearing amphibolites and are intimately associated with graphitic ribbon cherts. Ultramafic pods, developed as fine-grained talc-chlorite-tremolite rocks or as medium-grained biotite hornblendites, occur within the Gula greenstones in the Hauka valley and in the Vagnillhøgda area. They were interpreted by Nilsen (1974) as cognate, cumulate, meganodules within the Gula greenstone.

The rocks of the Undal Formation show a strong axial-plane foliation, the regional S_2 schistosity, with a N–S to NNE–SSW strike and a moderate to steep eastward dip. The Undal Formation is folded into a tight, post–S_2, recumbent, SE-verging synform in the Soknedal area (the Soknedal synform), as revealed by the outcrop of the prominent amphibolite horizon (Figs. 2 & 3).

Støren Group. This major unit can be divided into two main formations in the southern Trondheim Region – the *Elgsjø Formation* (Nilsen 1978) and the *Ilfjell Formation* (new name) after the summit Ilfjellet, 8 km SW of Gynnelfjell. These have been traced more or less continuously from Støren southwards to the Elgsjøen area (Fig. 1). The *Elgsjø Formation* comprises a series of pelitic to semipelitic volcanoclastics and are chiefly developed as pastel-green, fine-grained quartz-sericite-chlorite phyllites which include thin intercalations of magnetite-bearing cherts, greyish green metagreywackes, felsic tuffs, ribbon cherts and thin (50–100 m) horizons of greenstone. A correlation of these rocks with the 'Quartz-schist/Upper phyllite unit' of the 'Lower Sedimentary Unit' of Torske (1965), bordering the Støren Group pillow lavas in the Selbusjøen area, seems reasonable.

In the Soknedal–Støren area the different units of the Elgsjø Formation have a wide lateral extent and dip steeply (75–90°) to the northwest. This pervasive (S_2) foliation (Fig. 3C) becomes overprinted by a subhorizontal (S_3) foliation towards the Gula/Støren boundary (Figs. 3E & 4) with the progressive development from a crenulation cleavage into a zone of cataclasites and mylonites (Fig. 5), approximately 1 km wide, which has been traced from Støren along the Støren/Gula boundary to the Berkåk area. Here the thermal influence of the Oppdal–Innset intrusive complex (Rohr–Torp 1974), internal thrusts and a higher

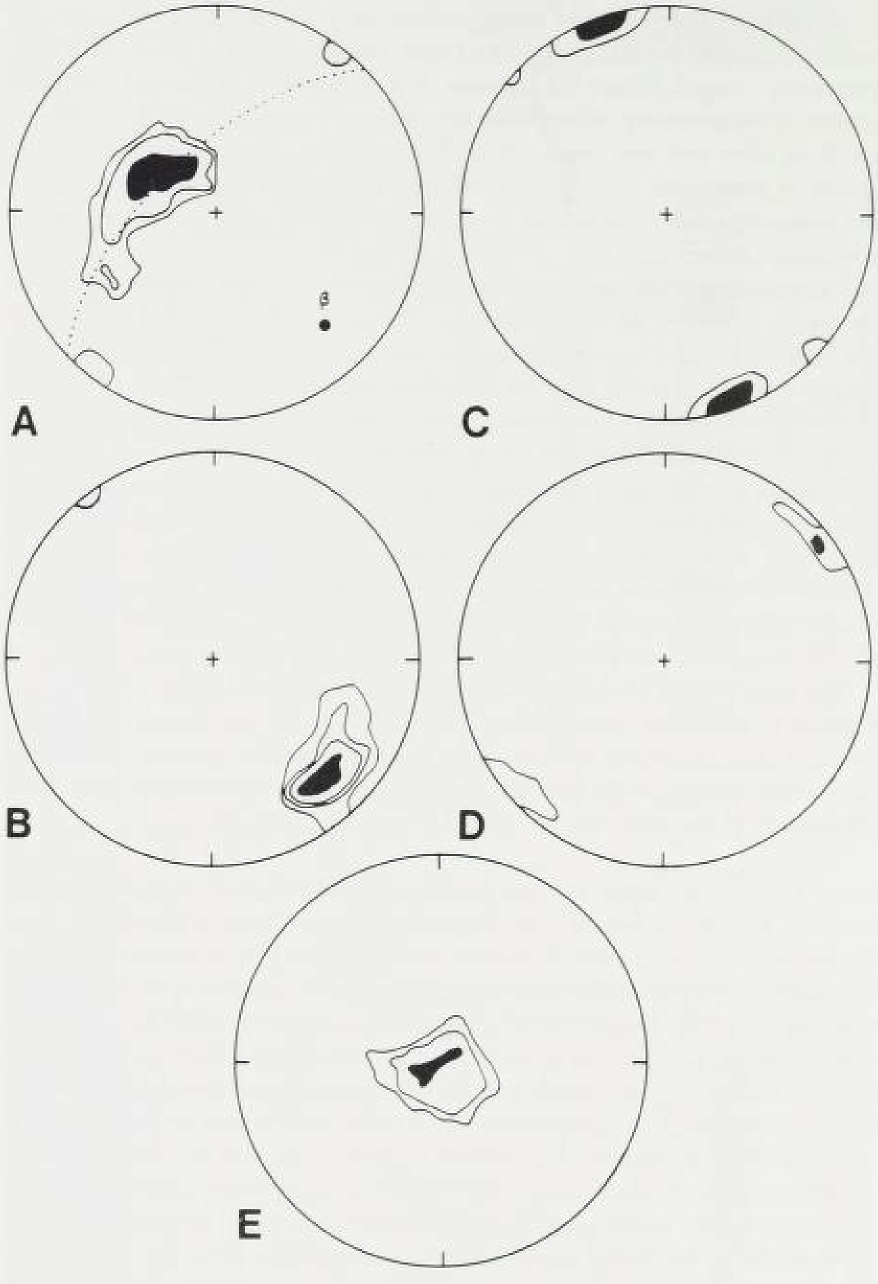

Fig. 3. Stereographic contour diagrams of structures from the Soknedal–Støren area. Equal area projection; lower hemisphere. (A) Pi diagram of S_2 foliation from the Soknedal synform (80 obs.). Contours: 10–5–3% per 1% area. Point ß denotes the statistical (F_3) fold axies of the synform. (B) Fold axes (crenulations and puckerings) of the Soknedal synform (42 obs.). Contours: 25–15–10–5% per 1% area. (C) Pi diagram of S_2 foliation in the Støren Nappe (30 obs.). Contours: 20–10% per 1% area. (D) Fold axes (F_3) in the Støren Nappe (20 obs.). Contours: 20–10% per 1% area. (E) Pi diagram of S_3 foliation from the Støren–Gula boundary zone (40 obs.). Contours: 20–10–5% per 1% area.

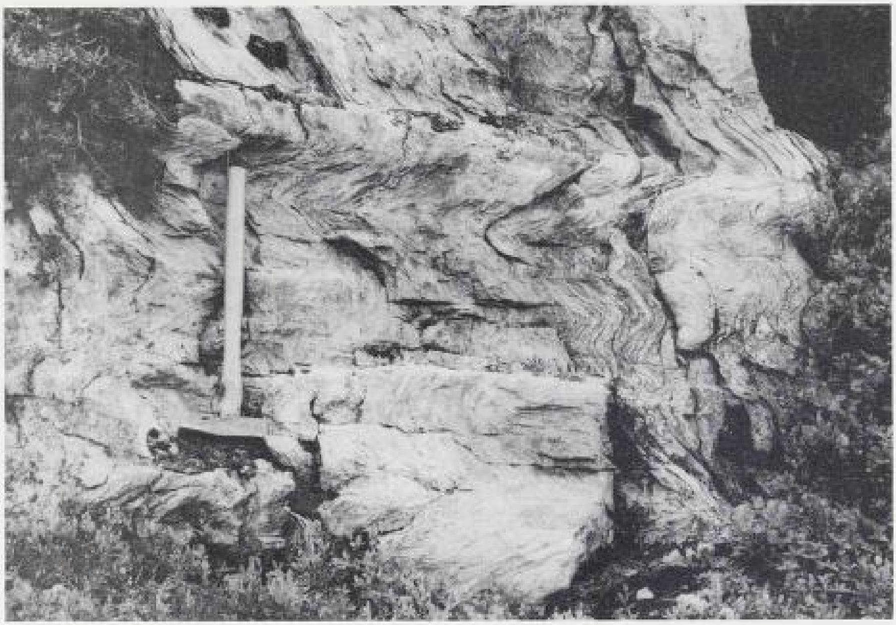

Fig. 4. A sub-horizontal (S_3) crenulation cleavage overprinting the steep (S_2) regional schistosity in tuffite from the Elgsjø Formation (sericite–chlorite–quartz phyllite) from W. Burufjell.

grade Barrovian-type regional metamorphism has obscured the disjunctive, cataclastic nature of the boundary zone. The sub-horizontal (S_3) shear-zones have affected the upper part of the Undal Formation, as revealed by the imbrication of minor stratabound sulphide horizons in the Ilbogen district (Nilsen 1978), but the effect of the locally penetrative S_3 foliation rapidly decreases to the south-east.

The *Ilfjell Formation* constitutes the major part of the Støren Group and has been the subject of much geological research over the years (Bugge 1910, Goldschmidt 1916, Carstens 1920, 1924, Oftedahl 1968, Gale & Roberts 1972, 1974, Loeschke 1976, 1977, Loeschke & Schock 1980). The name Ifjell Formation is here introduced as an informal term for a rather heterogeneous sequence of mafic pillow lavas and pillow breccias with minor intercalations of chert and a few disrupted sulphide horizons. In the upper, western part of the formation, near the border to the overlying Lower Hovin Group, there are some distinct horizons of coarse volcanoclastics. The formation also contains some small lensoid bodies of gabbro and ultramafite.

The pillow lavas of the formation in the map-area are developed mainly as massive, fine-grained, pastel-green chlorite-epidote-amphibole rocks, locally with variolitic structures as first described by Bugge (1910). In the Soknedal–Støren area the formation attains its maximum thickness of ca. 4 km, which was attributed to the existence of a local 'Soknedal volcano' by Oftedahl (1968). To the south, the pillow-lava horizon wedges out into the volcanoclastics of the Elgsjø Formation in the Oppdal area (Nilsen 1978).

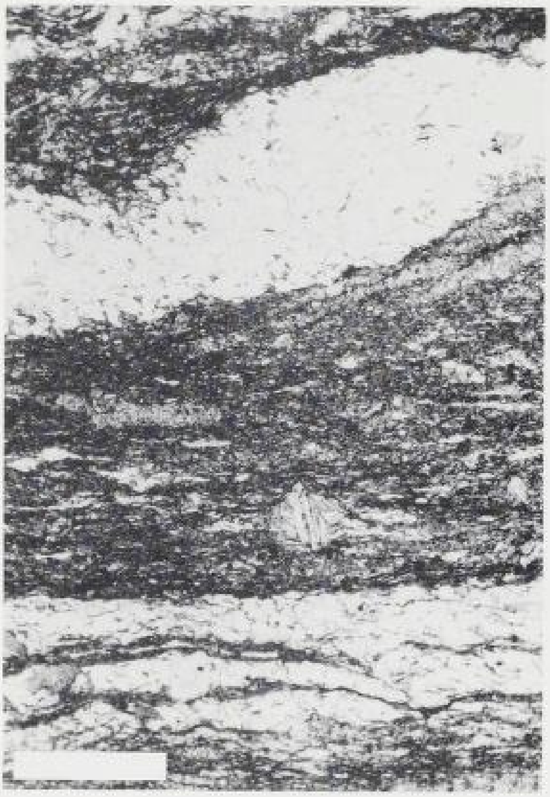

Fig. 5. Mylonite from Øverøyan, 1 km NW of Storskardåsen (UTM grid ref. 623 875). Plane polarised light. Scale bar: 0.5 mm.

INTRUSIVE ROCKS

Swarms of medium- to fine-grained trondhjemite dykes intrude the rocks of the Soknedal–Støren area. They occur as more or less composite, conformable sheets, less than 10 m in thickness, and as a few larger, lenticular bodies within the Undal Formation. Trondhjemite dykes also occur sporadically within the Ilfjell Formation, but are quantitatively much less prominent than within the Gula Group outcrop. Cross-cutting relationships as revealed by apophyses are common. Dykes of trondhjemitic type also cut the mélange described below.

A large lensoid body of trondhjemite occurs in the Follstad–Rødberget area in the Gaula valley, and has been the object of extensive quarrying at Follstad for more than a century. The Follstad locality (Fig. 2) is the type locality of trondhjemite as described by Goldschmidt (1916) and its petrology and geochemistry have recently been re-examined by Size (1979).

MÉLANGE

Weakly metamorphosed sedimentary rocks of pelitic to psammitic composition occur locally adjacent to the Gula–Støren boundary in the western Trondheim region. These have been described by Torske (1965) from the Selbusjøen area and were included as members of his Lower Sedimentary Unit (Gula Group). These

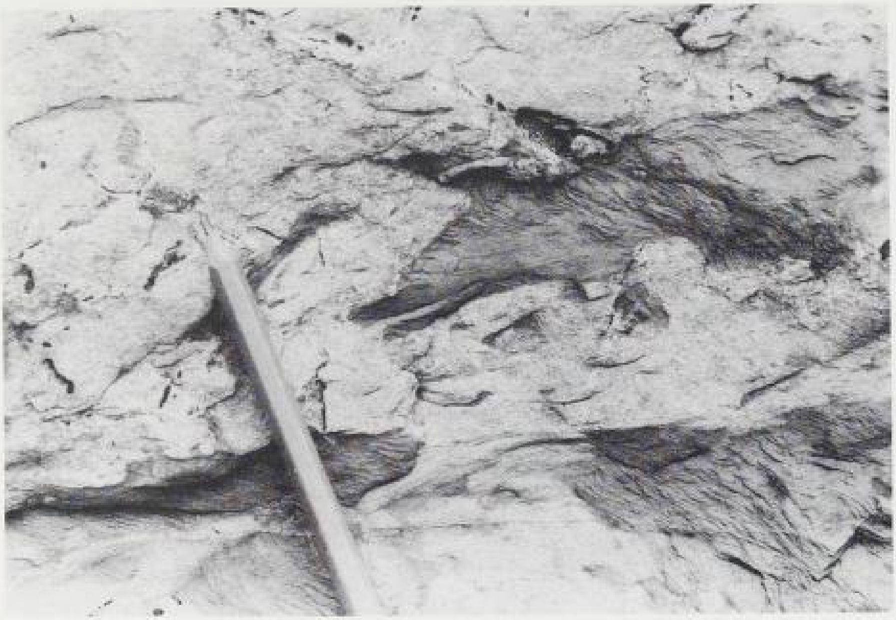

Fig. 6. Fragments of black phyllite (Undal Formation) in greywacke, Storskardåsen.

rocks have recently been reinvestigated by Horne (1979) and described as part of a mélange. Horne interpreted the mélange unit as being associated with the development of a forearc accretionary prism. Particular attention will be given in the following to the apparently corresponding deposits in the Støren–Soknedal area.

The deposits in question occur as a mega-lens of sedimentary rocks deposited upon and locally intermixed with the strongly tectonized rocks of the adjacent Undal Formation. Laterally the sedimentary rocks occur as irregular pockets and lenticles, filling in space between rotated fragments of strongly sheared and fragmented phyllite and ribbon chert of the Undal Formation (Figs. 6 & 7). Virtually undeformed, poorly sorted siltstones and greywackes constitute the main rock types in the central Storskardåsen area. They occur as massive, fine-grained rocks of greenish-grey colour. Well preserved intraformational slumps with internal bedding are present in some places, but in general the sedimentary rocks are devoid of stratification. Due to the extensive glacial and alluvial cover in the Soknedal area the boundary between the polymict sedimentary unit under consideration and the Undal Formation is not exposed. Locally, a bedded structure of the sediments is revealed by indiscrete horizons of coarser material. Where observed, bedding surfaces have in general a N–S strike and a moderate dip of 15–30° to the east and the west revealing an apparent discordant nature of the sediments in relation to the steeply dipping (60–85°) phyllites of the adjacent Undal Formation.

Near the boundary of the sedimentary complex the presence of a great variety of mega-clasts reveals a chaotic mixed lithology. Large blocks, boulders and

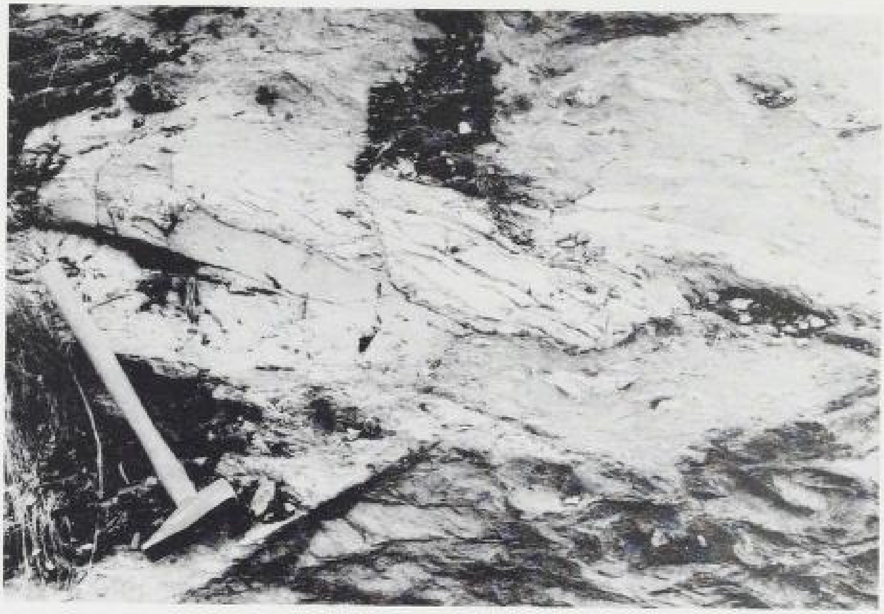

Fig. 7. Fragment of ribbon quartzite in greywacke, Snøan.

packets of strongly sheared phyllite, ribbon chert and greenstone occurring within the undeformed greywacke matrix constitute a mélange fabric which is exposed in roadcuts along the Hauka valley near Snøan (Fig. 7). The mega-clasts range from fist size to blocks hundreds of metres in maximum dimensions. A greenstone mega-block exposed at the hillock Skjetliåsen covers approximately 400 m^2, but usually the fragments occur as slightly rounded and rotated elongate bodies 2–200 m in thickness with fragmented margins. Internally the mega-clasts show a complex history of deformation displaying a sheared and in part mylonitic fabric.

PETROLOGY

The greywackes and siltstones of the mélange matrix are composed of a fine-grained heterogranular quartzo-feldspathic material with a grain-size of 0.03–0.1 mm. Chlorite, sericite, clinozoisite and sphene occur in minor amounts and magnetite, pyrite, sphalerite, limonite and zircon are accessory clastic constituents. Coarser grit deposits contain subangular clasts with a grain-size of 0.6–2 mm in the fine-grained quartzo-feldspatic matrix, with a low clast/matrix ratio (Fig. 8). The clasts display no preferred orientation and reveal a polymict assemblage of the following rock-types and minerals: quartz, plagioclase, albite-quartz symplectite, quartzite, rhyolite, rhyodacite, biotite-chlorite rock, greenstone, chlorite-sericite phyllite (tuffite) and graphitic phyllite.

Quartz occurs as clear, generally strained single grains. Glomeroclasts composed for two or three subgrains usually show amoeboidal grain boundaries. Medium-grained heteroblastic calcite-quartz glomeroclasts are probably derived from quartz-calcite veins intersecting the Gula Group assemblages.

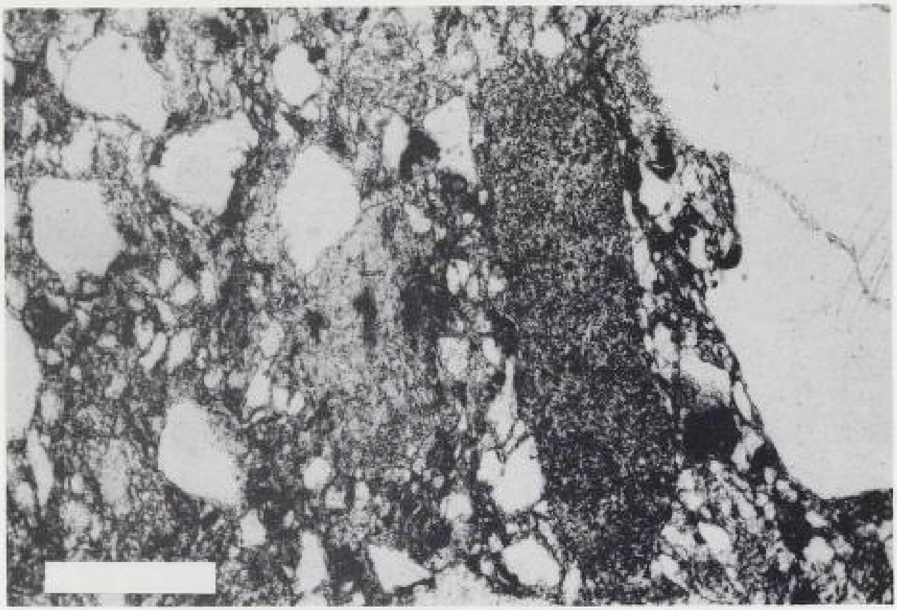

Fig. 8. Greywacke, Haukdalsmyra, NW Haukdalsvatn, (UTM grid ref. 640 876). Fragments of quartz, quartzite and tuffite (the large, grey fragment) embedded in a fine-grained chlorite-sericite-quartz groundmass. Plane polarised light. Scale bar: 0.5 mm.

Plagioclase occurs either as single grains with well developed albite twinning or, less commonly, in a symplectite intergrowth with quartz (Fig. 9). Chess-board twins are common (Fig. 10), and some grains show incipient sericitization and saussuritization.

Quartzite occurs in two different varieties: 1. As a microgranular recrystallized chert with accessory magnetite and chlorite; 2. as granoblastic equigranular orthoquartzite, probably representing clasts of the Undal Formation ribbon cherts.

The clasts of the felsic metavolcanics comprise at least three different varieties, based on textural and compositional features: 1. A porphyritic variety with resorbed and shattered phenocrysts of chess-board albite in a microgranophyric albite-quartz groundmass. 2. An aphyric albititic variety composed of a decussate, interlocking mosaic of lath-shaped albite (Fig. 11). Some varieties may contain interstitial chlorite and clinozoisite in an intersertal texture. 3. Equigranular rhyolite with an interlocking anhedral mosaic of micropoikilitic albite/quartz symplectite ('snowflake' texture).

Biotite-chlorite rock occurs as irregular fragments, with the biotite occurring as discrete flakes in a felty chlorite matrix together with clinozoisite. Greenstone clasts are composed of a fine-grained aggregate of chlorite, albite and sphene with accessory biotite. Tuffites possibly deriving from the Elgsjø Formation (chlorite-sericite phyllite) are less common clastic components (Fig. 8). Black phyllitic fragments are composed of sericite and chlorite with abundant graphite and sulphide ore minerals. Scattered, rounded grains of magnetite and zircon may be present in some of the greywackes.

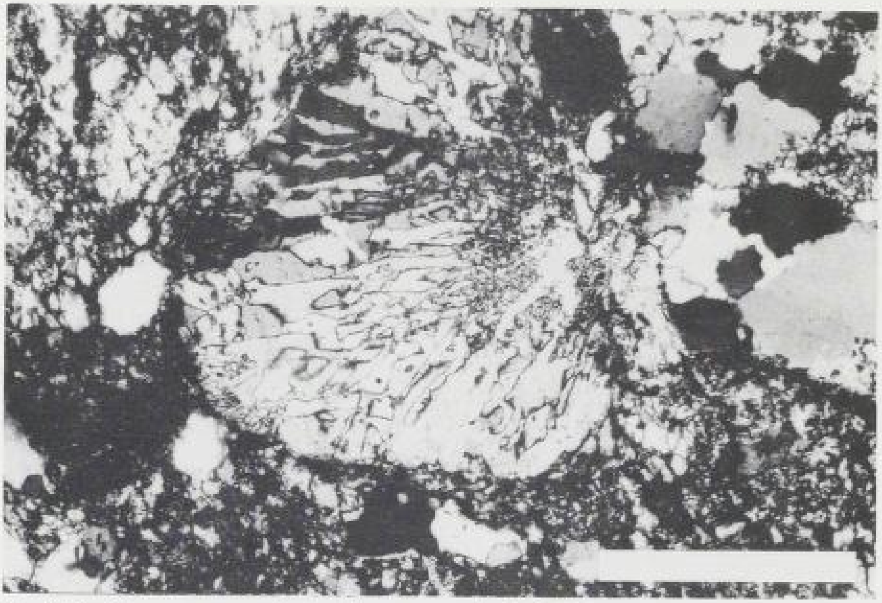

Fig. 9. Plagioclase-quartz symplectite. From greywacke, Haukdalsmyra, same locality as in Fig. 8. Crossed nicols. Scale bar: 0.5 mm.

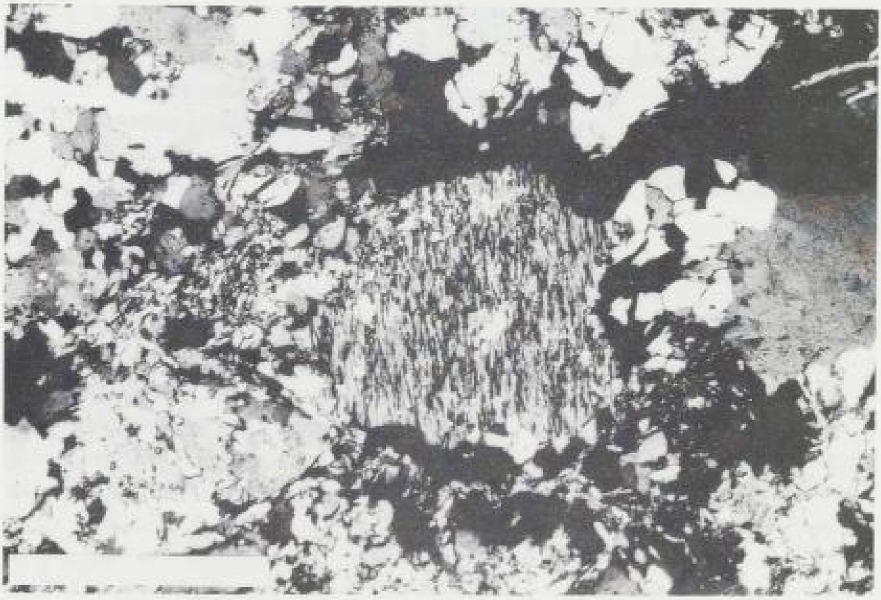

Fig. 10. Chess-borad albite. Clast in greywacke, Snøan (UTM grid ref. 865 631). Crossed nicols. Scale bar: 0.5 mm.

The lithology of the sedimentary clasts in the greywacke matrix corresponds fairly closely with those of the Lower Hovin Group metasediments as described by Vogt (1945) and Chaloupsky (1975). The clasts of the coarser, gritty greywackes reveal a great similarity to the clasts encountered in the lowermost

Fig. 11. Clast of aphyric rhyolite (albititic) in greywacke, Snøan. Same locality as in fig. 10. Crossed nicols. Scale bar: 0.5 mm.

psammitic and psephitic members of the Lower Hovin Group (i.e. the Krokstad beds, as described by Chaloupsky (1963)), with abundant recrystallized jasper and fragments of chess-board albite and micropegmatite. Chess-board albite has also been described as a constituent of quartz-dioritic pebbles in the Lyngestein conglomerate of the Horg Group (Vogt 1945).

The petrology of the felsic fragments corresponds well with the composition and texture of the many units of acidic to intermediate lavas and pyroclastics in the Hovin Groups, e.g. the Grimsås rhyolite and the Hølonda porphyrite in particular, and clasts of the porphyritic granophyres resemble the quartz keratophyres intercalated within the Støren Group equivalents in the Meldal (Rutter et al. 1968) and Selbu (Torske 1965) areas. Here, the observed myrmekitic rims around phenocrysts appear to be a characteristic textural feature. However, a more detailed petrography of the felsic metavolcanics and hypabyssal rocks of the Støren Nappe is essential in order to reveal the true palaeogeographical and stratigraphical position of the source rocks for the Soknedal mélange.

DISCUSSION

The gravity data reported by Åm et al. (1973) from the Støren–Hovin area have been taken to indicate that the Støren Group extends vertically down to a depth of perhaps 10 km or more in the Støren area, forming the eastern, lowermost limb of a complex synformal structure (the Hovin synform) within the Støren Nappe (Vogt 1945, Chaloupsky 1963, 1970, Roberts 1968, Olesen et al. 1973, Oftedahl 1979). The low-angle thrusting of the Støren Group rocks as revealed by the development of a cataclasite zone at the Gula/Støren boundary in the Soknedal area can thus be considered as a local late (S_3) event with a minor low-temperature, sub-horizontal displacement of the earlier obducted, folded and weakly metamorphosed Støren Nappe. This late tectonic event corresponds in all probability with the post-thrusting gravitational collapse after the main, Silurian nappe emplacement recognized by Roberts (1971, 1978) both within and outside the Trondheim region. Late, low-temperature dislocation zones occur quite commonly within the Støren Nappe sequence between Støren and Oppdal and may be contemporaneous with this D_3 tectonic event.

As the greywacke matrix of the Soknedal mélange is devoid of any apparant imprints of the D_3 and earlier tectonic events, the deposition of the mélange in question apparently post-dates the Silurian folding and metamorphism of the Støren Nappe and adjacent nappe units. It seems therefore unlikely that the formation of the Soknedal mélange could have occurred in a tectonic-sedimentary setting related to a destructive plate boundary as a member of a fore-arc accretionary prism between the Gula and Støren Nappes as proposed by Horne (1979).

It is pertinent in this context to define the term 'mélange', as it has been applied with a genetic as well as non-genetic connotation in the literature. Following the recommendations of a Penrose Conference Report (Silver & Beutner 1980, p. 32) the term has a non-genetic meaning, referring to «. . . rock mixtures formed by tectonic movements, sedimentary sliding or any combination of such processes with no mixing process excluded». As such, the polymict sedimentary rock unit under consideration falls well within the concept of a mélange. However, one may distinguish between mélanges occurring as composite bodies of metamorphic tectonites and olistostromes (or 'sedimentary mélanges'). The former connotation has been applies to the pervasively tectonized members of the Undal Formation in general, according to the map by Horne (1979, p. 268); while the latter connotation can be applied to the rock unit considered here. The distinction between these different usages of the term 'mélange' has been discussed by Raymond (1975) who stresses the presence of exotic blocks in a fragmented matrix and not the presence of tectonites as a main criterion for distinguishing a mélange from other rock units. Horne's model for the development of the Trondheim Nappe Complex has been rejected by Roberts (1980) largely on grounds of the incompatibility of a fore-arc accretionary prism involving nappe units of great age ranges with the composition and derivation of a fore-arc subduction complex.

The disjunctive nature of the Gula–Støren boundary in the Soknedal–Støren area may be composite feature, attributed to a primary, destructive plate obduction/thrust contact subsequently folded, metamorphosed and then locally displaced along flat-lying (S_3) shear planes with the renewed development of cataclasites and mylonites along the contact (Fig. 12).

The mélange deposition must have taken place after the last major tectonic event (D_3), incorporating angular meta-clasts of the internally sheared and in part mylonitized fragments of the Undal Formation, the greywacke matrix filling in local depressions and fissures in the folded Gula Group basement. The occurrence of abundant mega-clasts of crenulated black phyllite and granoblastic ribbon chert

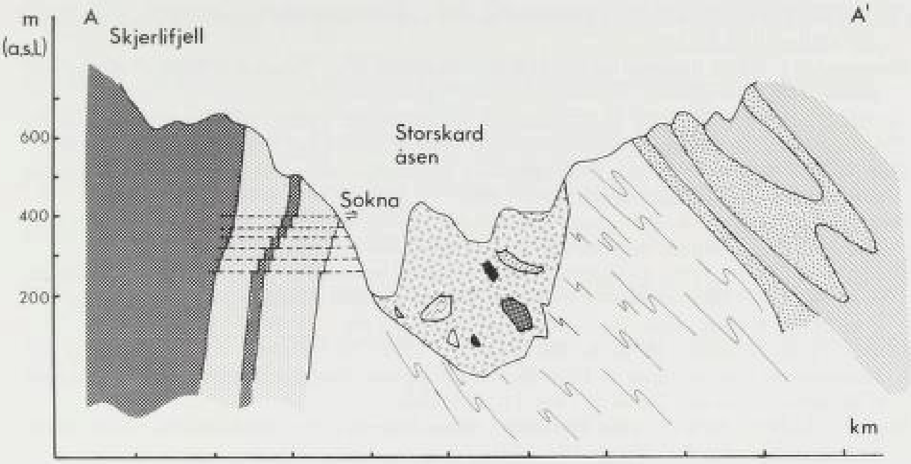

Fig. 12. Schematic section A – A' (Fig. 2) across the Soknedal valley through Storskardåsen. The ornament is the same as on the geological map, Fig. 2. Note that the vertical scale is exaggerated 5 times that of the horizontal.

within the greywacke points to a minor influx of lithified Gula Group material during deposition.

The Soknedal mélange may have been deposited as a debris flow or by sedimentary sliding of material dervied from the Støren and Hovin Group lithologies, incorporating mega-clasts or olistoliths derived from the adjacent Undal Formation which formed a highly fractured irregular floor to the local olistostrome basin. The olistoliths are mostly of local origin, being subjected to only a short-range transport during the deposition. The Soknedal mélange can thus be classified as an olistostrome formed by the mixing by submarine sliding of a variety of lithified rocks in an unlithified fluid sediment matrix forming a 'broken formation' or an 'endolistostrome' in the sense of Raymond (1978). The deposition of the Soknedal mélange was thus of a relatively young age, postdating the obductional event of the Støren Nappe, the main Silurian folding and metamorphic events, the thrusting of the Trondheim Nappe Complex, and the D_3 (or D_4) 'sagging' event. The evidence presented suggests a possible late Silurian age for the formation of the mélange.

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