The conglomerates of the Sel Group, Otta-Vågå area, Central Norway: an example of a terrane-linking succession.

REIDULV BØE, BRIAN A. STURT & DONALD M. RAMSAY

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The conglomerates at or near the base of the Sel Group in the Otta-Vågå area have a special significance in the interpretation of the palaeogeographical and geotectonic development of the Scandinavian Caledonides. They overlie a stratigraphic unconformity of Arenig-Llanvirn age, which separates them from a substrate of already obducted, forward-thrusted and folded ophiolitic rocks, which repose on a basement-cover couplet possibly of Fennoscandian Shield type. The conglomerates vary from the well known near-monomict serpentine conglomerate (Otta conglomerate facies) through polymict conglomerates containing clasts of the underlying substrate (To conglomerate facies) to mature conglomerates containing clasts of essentially vein quartz and quartz in a quartzitic matrix (Skardshøi conglomerate facies).

The conglomerate-bearing successions show considerable lateral and vertical variation through the region, and although certain areas are dominated by a particular clast population implying a special source-depositional system, the various conglomeratic and non-conglomeratic lithologies show interdigitating relationships. The conglomerate petrology shows that the basal part of the Sel Group is a terrane-linking succession, indicating that the Vågåmo ophiolite complex had already been emplaced, prior to the Arenig/Llanvirn, onto rocks of continental affinity. These latter possibly represented a western (relative to the present) extension of the Baltoscandian continental margin miogeocline, or part of a microcontinent. It also shows that the Vågåmo ophiolite complex and its substrate had been uplifted and deeply eroded before the deposition of a major clastic wedge which includes fan delta, littoral and deeper marine sediments. The Sel Group was apparently deposited in an extensional basin developed as a response to back-arc spreading in Middle Ordovician times.

Reidulv Bøe, Brian A. Sturt, Norges geologiske undersøkelse, Postboks 3006 - Lade, 7002 Trondheim, Norway.
Donald M. Ramsay, Geology Department, University of Glasgow, GL82 8QQ Glasgow, Scotland.

Introduction

The Otta Nappe, as defined by Strand (1951), comprises four groups, the Rudihøi Complex at the base succeeded by the Heidal (Gjelsvik 1946), Greenstone and Sel Groups. Recent revisions of this nappe succession (Sturt et al. 1991) have demonstrated that the volcanic Greenstone Group is really a fragment of ophiolite, the Vågåmo ophiolite complex (Fig. 1). Although disrupted by pre-Arenig/Llanvirn deformation, typical members of an opholite pseudostratigraphy are still recognised. The base of the nappe is a surface of thrusting marked by a prominent mylonite. This zone of high strain extends into the underlying Heidal Group, so that competent quartzites close to the thrust are actually quartz mylonites. The mylonitisation is superimposed on an already complex structural-metamorphic fabric in the rocks of the Heidal Group.

The contact between the Sel Group and the ophiolite and its substrate is a major unconformity, representing a period of uplift and erosion. This major break partitions the tectonothermal history of the region into two discrete orogenies (Sturt et al. 1991).

The lower horizons of the Sel Group are characterised by the development of various conglomerates (Fig. 1). Originally these were identified as three discrete members (Strand 1951), the Greenstone, Otta and Skardshø Conglomerates, each at a different stratigraphic level. The Greenstone Conglomerate was placed at the top of the Greenstone Group (later incorporated into a new Svartkampen Group (Strand 1964)), the Otta Conglomerate marked the base of the Sel Group and the Skardshø member was viewed as a younger member within the Sel Group. In a later revision, however, Strand (1964) tentatively correlated the

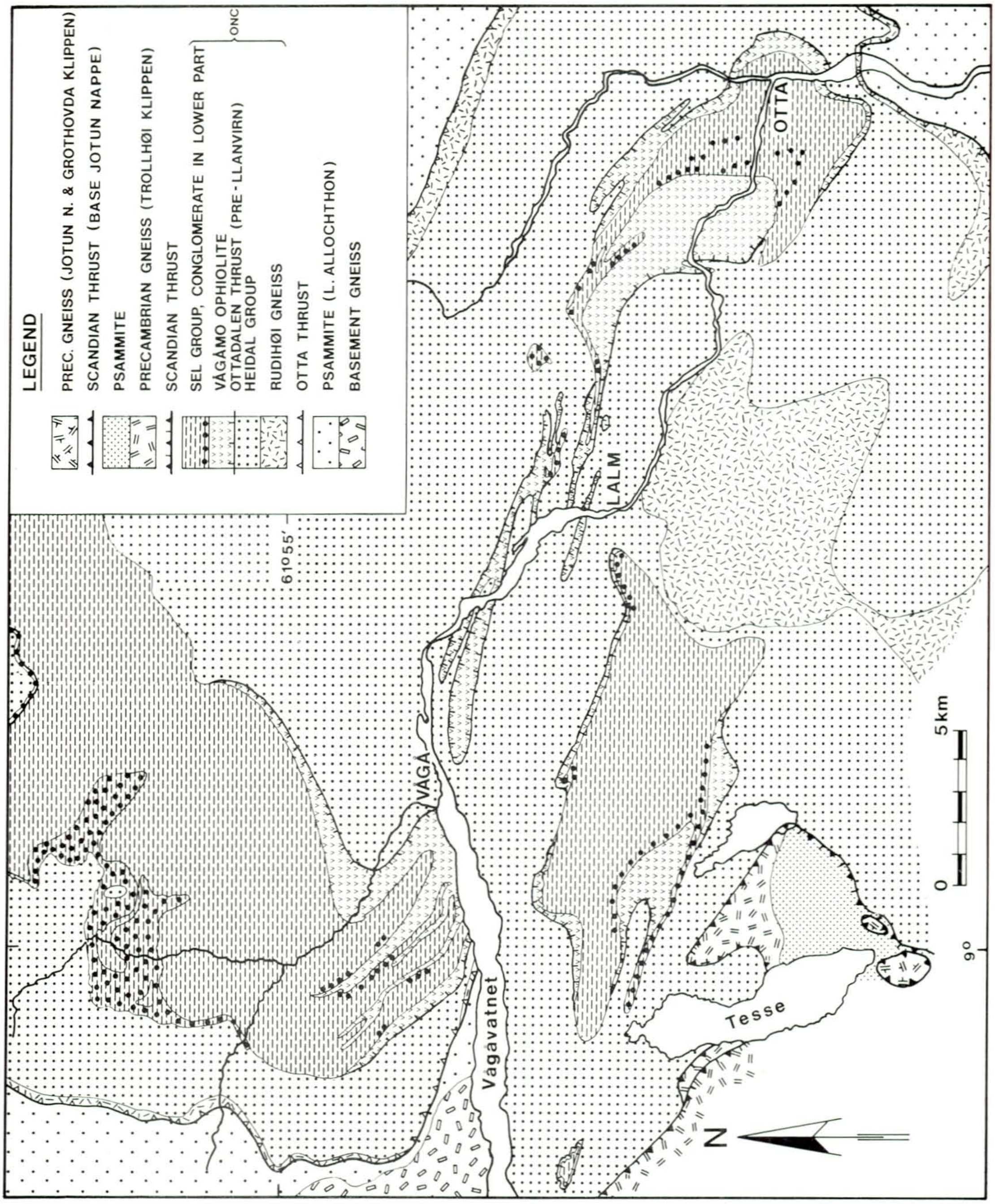

Fig. 1. Generalised geological map of the Vågå-Otta area. ONC: Otta Nappe Complex. See Fig. 2 for location of map area.

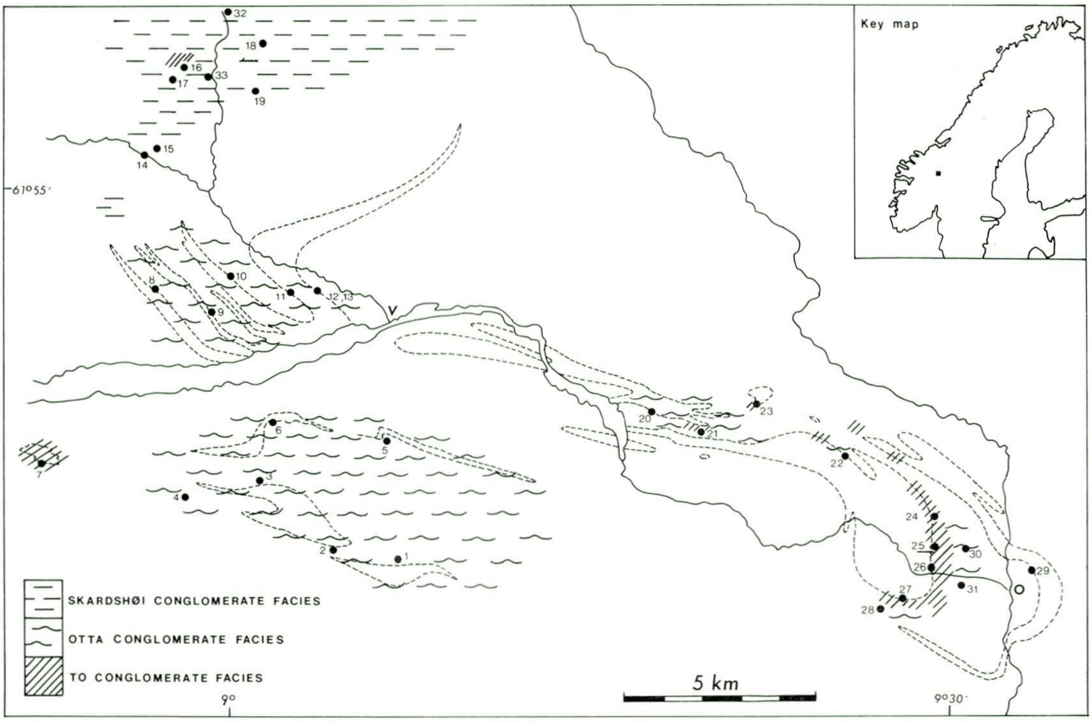

Fig. 2. Generalised map showing the distribution of the various conglomerate facies in the lowermost part of the Sel Group. The boundaries of the Vågåmo ophiolite complex are shown by dashed lines. Numbers 1–29 refer to key localities summarised in Table 1 and described in the text. Number 30 is Kleiverudtjern, 31 is To Farm, 32 is Ådalen, 33 is Skarvangsætrin. V: Vågåmo; O: Otta.

BASEMENT AND BASAL SEL GROUP LITHOLOGIES

LOCALITY	BASEMENT LITHOLOGY	BASAL SEL GROUP LITHOLOGY	
1 Raggehaugen	Gabbro/ultramafics	Otta Conglomerate	
2 Megårdsåsen	Gabbro with dykes	Otta Conglomerate	
3 Skytningen	Gabbro with dykes	OttaConglomerate	
4 Tristeinen	Heidal quartzite	Otta Conglomerate	
5 Åmhaugen	Serpentinite and gabbro	Otta Conglomerate	
6 Strondsæterhøi	Gabbro with dykes	Sel schist	
7 Kleppdalen	Gabbro	Gabbro/Greenstone Congl.	
8 Eastern Sæterhøi	Gabbro	Otta Conglomerate	
9 Svarthåmårbekken	Gabbro with dykes	Sel schist	
10 Bukkehaugen	Gabbro with dykes	Sel schist/Otta Conglomerate	
11 Finna	Greenstone	Sel garbenschiefer	*
12 Dalen	Heidal quartzite/calcsilicate	To Conglomerate	
13 Dalen	Greenstone	Otta Conglomerate	
14 Grønlii	Heidal quartzite	Otta Conglomerate	*
15 Hovda	Ultramafics	Otta Conglomerate	*
16 Svarthovda	Heidal quartzite/calcsilicate	To Conglomerate	*
17 Svarthovda south	Heidal quartzite/calcsilicate	Skardshøi Conglomerate	*
18 Raudbergshøi	Heidal garbenschiefer	Skardshøi Conglomerate	
19 Fjelltithøi	Heidal quartzite/calcsilicate	Skardshøi Conglomerate	
20 Bolstad	Serpentinite	Otta Conglomerate	*
21 Svarttjern	Heidal quartzite/schist	Otta Conglomerate/To Congl.	*
22 Åsåren	Serpentinite	Otta Conglomerate	*
23 Geithornet	Heidal quartzite	To Conglomerate	*
24 Søre Josten sæter	Gabbro	To Conglomerate	
25 Gauklihaugen	Greenstone	To Conglomerate/Sel phyllite	
26 Dale	Greenstone	Sel phyllite	
27 Myromsætri	Greenstone	To Conglomerate/Sel phyllite	*
28 Rondasætri	Gabbro	Sel conglomeratic sandstone	*
29 Rusti	Gabbro	Sel phyllite	*

Table 1. Basement and basal Sel Group litholgies at key localities in the Otto-Vågå area. Asterikes show where the contact is exposed. The localities are shown Fig. 2.

Skardshø and Greenstone Conglomerates and renamed them the To Conglomerate, still within the Svartkampen Group.

Sturt et al. (1991) demonstrated that the conglomerates are all facies of a major development within the Sel Group, which pass laterally and vertically into one another. The tectonic fabrics within pebbles of the polymict To conglomerate facies, together with its interbedded relations within the Sel Group, indicate that it cannot belong to the pre-Sel succession.

The basal Sel Group, in places conglomeratic, locally oversteps the ophiolite on to the subjacent Heidal Group (Sturt et al. 1991) (Fig. 1). The low strain state in conglomerates when juxtaposed against quartz mylonites in the upper Heidal Group provides an age constraint on the thrusting of the ophiolite and confirms the primary nature of the Sel overstep. This indicates that the Otta Nappe is a composite structure, comprising a pre-Arenig/Llanvirn nappe of ophiolite within a younger Otta Nappe. This scenario is confirmed by the varied composition of the To conglomerate facies which reflects an ophiolitic and metasedimentary provenance.

The present account further develops previous findings and focuses on the sedimentology of the Sel conglomerates. The work is based to large extent on the complete remapping (by the authors) of 1:50,000 map-sheet Vågå, substantial parts of 1:50,000 map-sheet Otta and neighbouring parts of adjacent map-sheets. Fig. 1 represents a simplified compilation of the results of this mapping.

Conglomerates of the Sel Group

The various conglomerates occurring at the base of the Sel Group have previously been mapped, described and interpreted by a number of authors (Bjørlykke 1905, Vogt 1915, 1945, 1947, Goldschmidt 1916, Carstens 1928, Strand 1951, 1964, Oftedahl 1969, Bruton & Harper 1981, Siedlecka et al. 1987). Until recently, lack of knowledge concerning the general statigraphy has hampered detailed correlation of the conglomerates (Sturt et al. 1991).

The lower part of the Sel Group comprises polymict and monomict metaconglomerates, separated by intervening garbenschiefer phyllites, slates, mica schists, metasandstones, metasiltstones and thin metamorphosed limestone horizons. In the following, the sedimentary terms conglomerate, sandstone, siltstone and limestone will be employed for rocks in the Sel Group, instead of the metamorphic terms metaconglomerate, metasandstone, metasiltstone and metalimestone.

The thickness of the lowermost, conglomerate-bearing part of the Sel Group varies from almost zero to several hundred metres. The conglomerates may locally represent the base of the Sel Group, though in other instances first appear at higher levels, while sandstones and various phyllites occur at the base. There are considerable variations in texture, internal structures and composition from one area to another, and different names have been applied to the different conglomerate lithologies. These included Otta Serpentine Conglomerate (Vogt 1945), Serpentine Conglomerate (Bjørlykke 1905, Strand 1951), Otta Conglomerate (Bruton & Harper 1981), Gabbro Conglomerate (Goldschmidt 1916), Greenstone Conglomerate (Strand 1951), Hornblende Conglomerate (Bjørlykke 1905), Skardshø Conglomerate (Strand 1951) and To Conglomerate (Strand 1964).

In the following we will continue the use of the names Otta, Skardshøi (Skardshøi is a modern form of Skardshø) and To. However, the conglomerates are treated as facies types describing composition: Otta conglomerate facies (monomict to near monomict conglomerate with serpentine clasts in a talc-chlorite-magnesite matrix), Skardshøi conglomerate facies (conglomerate dominated by clasts of quartzite and/or vein quartz in a matrix of micaceous or massive quartzite) and To conglomerate facies (polymict conglomerate with varying proportions of ophiolitic rocks, quartzite, calc-silicate, granite and trondhjemite clasts in a matrix of quartz and greenstone materials). These conglomerate facies will be characterised by reference to a number of key localities.

The Otta conglomerate facies is most prominently developed in the western and southwestern part of the investigated area (Fig. 2, Table 1). It predominates in the ESE-WNW trending synformal structures of the Flatningen area to the south of Vågå (localities 1-6), in the Bukkehaugen area (localities 8-11), at Grønlii-Øyagarden (locality 14) and at Hovda (locality 15), but also occurs at Svarttjern (locality 21) and Åsåren (locality 22) (Fig. 2, Table 1). The Skardshøi conglomerate facies predominates in the northern part of the investigated area, to the east of Svarthovda (localities 16-19), but it also occurs on Gauklihaugen (locality 25). The To conglomerate facies occurs in the northern and eastern parts of the area, from Svarthovda (locality 16) to Otta, and in the Kleppdalen synform (locality 7) in the west (Fig. 2).

Locality (conglomerate facies)	Thickness of conglomerate bearing succession	Degree of deformation	Conglomerate bed thickness	Sandstone/ siltstone bed thickness	Maximum (average) clast diameter	Grain support/ roundness of conglomerate clasts	Sedimentary structures in the conglomerates	Sedimentary structures in the interbedded sandstones and siltstones
Bukkehaugen (10) (Otta)	10-100 m	Moderate, increasing upwards	5-200 cm	1-100 cm 1-40 cm	20 (7) cm	M, C/ Subrounded to well rounded	Erosional scours, plane parallel stratification and trough cross-stratification are common.	Sandstones often show upward-fining trends, plane parallel stratification and trough cross-stratification; siltstones show plane parallel lamination, trough cross-lamination and flaser bedding.
Raggehaugen (1) (Otta)	ca. 200 m	Weak to moderate	10-200 cm	1-60 cm	50 (12) cm	M, C/ Subrounded to well rounded	Conglomerate beds amalgamated or separated by erosional scours. Upward fining is common. Clast-supported beds <1 m thick may be ungraded or inverse-to-normally graded. Imbrication occurs.	Plane parallel stratification and trough cross-stratification. Cross-stratified sets up to 40 cm thick. Trough cross-stratified intervals usually occur on top of plane parallel stratified intervals, indicating palaeocurrents towards the east. 1-2 cm thick, red, plane parallel laminated and trough cross-laminated siltstone may occur on top of sandstone beds.
Tristeinen (4) (Otta)	ca. 50 m	Moderate	10-200 cm	1-30 cm	40 (10) cm	C/ Subrounded to well rounded	Poorly sorted, generally massive and amalgamated, matrix-supported lenses occur.	Some structureless, conglomeratic sandstone beds occur. They wedge out laterally due to erosional truncation.
Svarthovda (16) (To)	ca. 400 m	Moderate	10-1000 cm		150 cm	C, (M)	Generally structureless. See details in main text.	See details in main text.
Fjelltithøi (19) (To)	ca. 400 m	Moderate	10-100 cm	1-50 cm	50 (7) cm	M/ Subrounded to well rounded	Relatively well sorted. Size fractions within beds typically 1-5, 5-10 and 5-15 cm.	
Øyagarden-Grønlii (14) (Otta)	ca. 50 m	Weak	5-100 cm	1-50 cm	10 (2) cm	M, (C)/ Rounded to well rounded	May grade up into sandstone. Imbrication occurs. Trough cross-stratification. Palaeocurrents towards the east.	Sandstones and conglomeratic sandstones show plane parallel and trough cross-stratification. Undulating and erosive lower contacts. Erosional scours are common.
Svarttjern (21) (To)	ca. 150 m	Moderate	5-150 cm	1-20 cm	25 (8) cm	M, (C)/ Subrounded to well rounded	Usually normally graded or structureless.	Structureless or normally graded.
Gauklihaugen (25) (To)	ca. 150 m	Moderate	5-100 cm	1-10 cm	70 (7) cm	M/ Subangular to well rounded	Laterally discontinuous beds. Frequent upward-fining from boulder/cobble to pebble size. Basal scours common. Bimodal size distribution common.	Pebbly sandstones show plane parallel stratification and cross-stratification. Sandstones on top of conglomerates may grade up into thin schists.
Pit at Åsåren (22) (Otta)	? ca. 100 m	Weak	2-35 cm	1-15 cm	3 (1) cm	C/ Rounded to well rounded	Upward fining. Undulating, erosive lower surfaces. Well sorted.	Well-sorted. Overlie conglomerates with erosional or sharp gradational contacts. Plane parallel lamination, trough cross-lamination and trough cross-stratification (0.5-3 cm thick foresets.

Table 2. Characteristics of the Sel conglomerate at various key localities in the Otta-Vågå area. The localities are shown in Fig. 2.

Description and interpretation of key localities

Bukkehaugen area

Description

At Bukkehaugen (Fig. 2, locality 10), the basal part of the Sel Group is a succession of garbenschiefer phyllites (2-20 m thick), succeeded by ultramafic conglomerates and sandstones of the Otta conglomerate facies (Table 2). The Otta conglomerate facies overlies greenstones of the Vågåmo ophiolite complex (Table 1) in a series of NE-SW-trending synforms and antiforms. This is followed by slates and phyllites alternating with thin sandstone beds.

A representative section of the Otta conglomerate facies, on the northeastern side of Bukkehaugen (UTM 998617), is summarised in Table 2 and shown in Fig. 3. The clasts in the conglomerates are of serpentine, soapstone and greenstone, whereas the coarse- to very coarse-grained sandstone matrix has a similar composition. Between the levels of conglomerate there are beds of siltstone and very fine- to very coarse-grained serpentinitic sandstone (Table 2). A well-preserved, coarsely ribbed brachiopod was recovered from one of the plane parallel-laminated siltstones.

A similar sequence occurs on the southwestern flank of the Bukkehaugen antiformal core. Along the strike, towards the northwest, there is a change to coarser-grained deposits, with serpentinitic conglomerates and sandstones in approximately equal proportions. At UTM 989618 this is a well-bedded sequence of erosively based and normally-graded conglomerates and conglomeratic, very coarse-grained sandstones, in beds up to 1 m thick. These are usually massive, but trough cross-stratification and clast imbrication sometimes occurs, indicating sediment transport in an easterly direction. The conglomerates are overlain by very fine-grained, plane parallel-laminated and trough cross-laminated sandstone beds up to 10 cm thick.

Towards the northwest (UTM 986622) the succession is dominated by medium- to very coarse-grained sandstones, conglomeratic sandstones and conglomerates with pebbles generally not exceeding 5 cm in

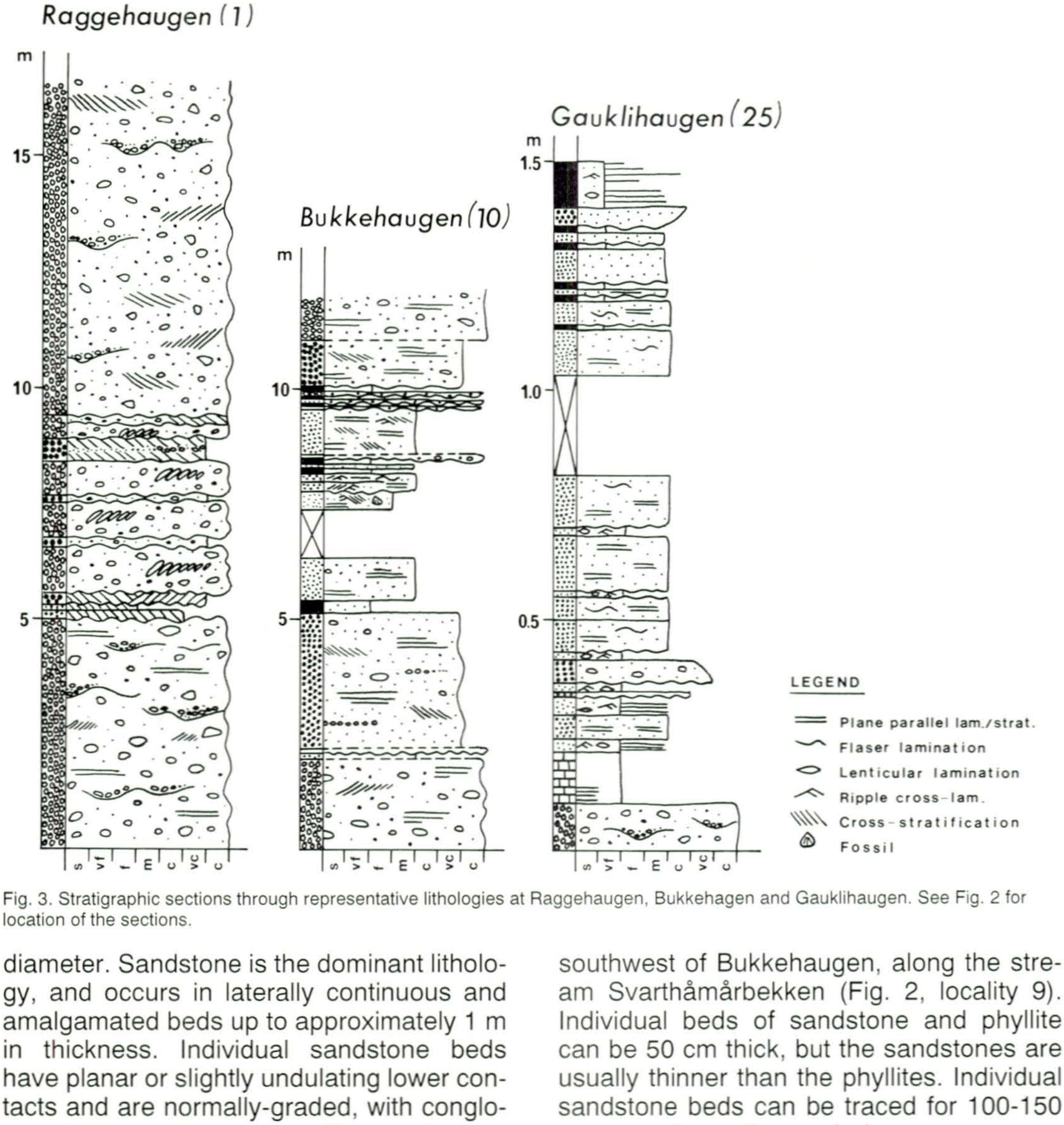

Fig. 3. Stratigraphic sections through representative lithologies at Raggehaugen, Bukkehagen and Gauklihaugen. See Fig. 2 for location of the sections.

diameter. Sandstone is the dominant lithology, and occurs in laterally continuous and amalgamated beds up to approximately 1 m in thickness. Individual sandstone beds have planar or slightly undulating lower contacts and are normally-graded, with conglomeratic lags at their bases. The sandstones commonly appear to be structureless, but several beds show plane parallel stratification and trough cross-stratification in their upper parts. Beneath this sandstone interval there are poorly exposed massive greenstone conglomerates, which overlie garbenschiefer phyllites, on top of the ophiolite. Above the sandstone interval there is a rapid transition to phyllites with thin sandstone beds.

Well-bedded ultramafic sandstones and phyllites of the Sel Group occur to the southwest of Bukkehaugen, along the stream Svarthåmårbekken (Fig. 2, locality 9). Individual beds of sandstone and phyllite can be 50 cm thick, but the sandstones are usually thinner than the phyllites. Individual sandstone beds can be traced for 100-150 m along the strike, and show a very constant thickness (Fig. 4). The sandstone beds tend to show an upward- fining trend, but otherwise appear to be structureless. These are separated from the ophiolite by 20-30 m of garbenschiefer phyllites, phyllites and thin, pebbly, quartzose sandstones containing clastic quartz grains.

Interpretation

A possible interpretation of the Bukkehaugen succession could be that it represents submarine fan or sheet system deposits (e.g. Ethridge & Wescott 1984, McDougall

Fig. 4. Well bedded sandstones and phyllites of the Sel Group at Svarthåmårbekken. Hammer is 30 cm long. See Fig. 2 for location.

et al. 1987, Pickering et al. 1989), with sediment input from a coastal or subaerially exposed source area composed of mafic and ultramafic rocks. Well-rounded clasts in the conglomerates indicate thorough reworking prior to deposition, probably on a shoreline or in a fluvial environment. An interpretation of the sediments as submarine (possibly proximal) gravity flow deposits is supported by the predominance of massive beds and matrix-supported texture in the conglomerates. The well preserved brachiopod found in serpentinitic sandstone could be either a marine or a brackish water species, transported into deeper water by mass flow.

The relatively thick, laterally continuous, well sorted, erosively based and normally graded sandstone and conglomerate beds occurring on the southwestern part of Bukkehaugen were probably deposited as high-density turbidites (Lowe 1982). Shanmugam & Moiola (1991) and Mutti & Normark (1987) have described similar deposits and interpreted them as channel fill and proximal fan lobe deposits. Plane parallel and trough cross-stratification occurs in the upper part of many of the sandstones. This interval may be overlain by laminated, very fine-grained sandstone, and several examples of almost complete Bouma sequences occur. The well-bedded serpentinitic sandstones and phyllites at Svarthåmårbekken were probably deposited as high- to low-density turbidites, possibly in a mid-fan to distal fan setting or on a sheet system.

An alternative interpretation of the sediments in the Bukkehaugen area could be that they were deposited in a fan delta environment; however, the complete lack of structures indicating wave reworking makes such an interpretation uncertain. The sedimentary processes depositing sediments on fan deltas and submarine fans may be very

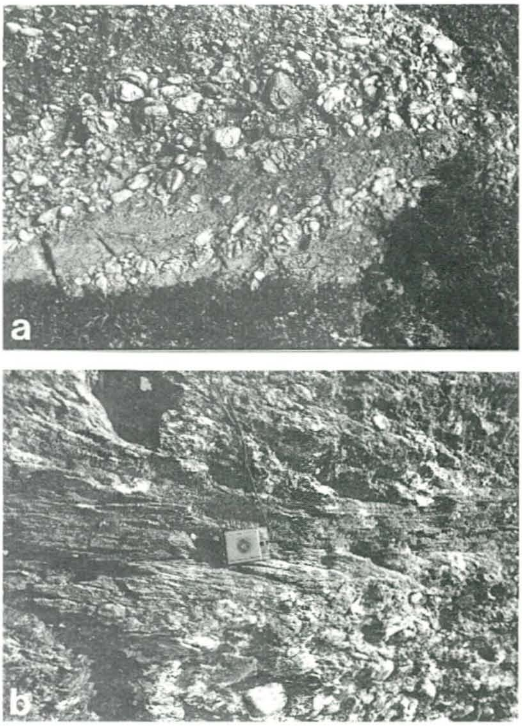

Fig. 5. Otta conglomerate facies at Raggehaugen. a) Conglomerate with beds of conglomeratic sandstone. Lens cap in lower right corner is 6 cm in diameter. b) Conglomerate with beds of plane parallel stratified and through cross-stratified sandstone. Compass is 10 cm long. See Fig. 2 for location.

CONGLOMERATE CLAST LITHOLOGIES

LITHOLOGY/ MINERAL	SVARTHOVDA 1	2	3	4	5	SKARVANGSÆTRIN 1	2	3	TO 1	2	GAUKLI-HAUGEN	SVART-TJERN	TRI-STEINEN	Å-DALEN	FJELLTITHØI 1	2
GABBRO	10	6	7	15		3	2	*	8	17	5	3	3		5	5
GREENSTONE	15	40	27	29		1		*	42	35	5		2		20	5
TRONDHJEMITE		2	1						16	14	9					
DIABASE		6	5	9							16					
GREENSCHIST		5	3	6												
ULTRAMAFICS			*			*	1					10	95			
EPIDOTE									1	1						
QUARTZITE/ PSAMMITE	30	29	38	27	28	81	64	66	11	18	12	63		60	15	40
MICA SCHIST/ QUARTZ MICA SCHIST			*			*	1				2	4				
MYLONITIC QUARTZITE						*	1									
CALCSILICATE	45	8	10	4		13	21	32	1	2		3				25
LIMESTONE			2	1											45	10
AMPHIBOLITE				2												
VEIN QUARTZ		3	7	6	72	2	9	2	18	7	6	17		40	15	15
GRANITE		1		1					2	5	37					
GNEISS	*								1		2					
PEGMATITE										1	4					
FELDSPAR									*	*						
RHYOLITE											2					

Table 3. Conglomerate clast lithologies (percentages). Asteriks denote less than 1 percent of a lithology. Svarthovda analysis 1 is in the basal breccia, 10 m above Heidal basement; Svarthovda analysis 2 is in the To conglomerate facies, 25 m above Heidal basement; Svarthovda analysis 3 is in the talc-magnesite matrix, mass-flow conglomerate; Svarthovda analysis 4 is in the To conglomerate facies 20 m above the mass-flow; Svarthovda analysis 5 is in the Skardshøi conglomerate facies 150 m above Heidal basement; Skarvangsætrin analyses 1–3 are in the To conglomerate facies; To analyses 1–2 are in the To conglomerate facies; Gauklihaugen is in the To conglomerate facies; Svarttjern is in the To conglomerate facies; Tristeinen is in the Otta conglomerate facies; Ådalen is in the Skardshøi conglomerate facies north of Svarthovda; Fjelltithøi localities 1–2 are in the To conglomerate facies. See Fig. 2 for location of the different sites.

similar (Nemec 1990, Prior & Bornhold 1990).

Raggehaugen and Tristeinen

Description

The Otta conglomerate facies is well exposed on the small hill Raggehaugen (UTM 052508) (Fig. 2, locality 1), where it occurs above metagabbros and serpentinitic ultramafics of the ophiolite complex (Tables 1 and 2). The conglomerate has a monomict composition of serpentine clasts, variably altered to talc and magnesite, in a matrix of coarse- to very coarse-grained serpentine/talc sandstone. Conglomerates usually show an upward fining trend into conglomeratic serpentinitic sandstones (Figs. 3 and 5a) in their uppermost parts (Table 2). The sandstone beds typically wedge out over 5-30 m, and frequently show plane parallel-stratification and trough cross-stratification (Fig. 5b) (Table 2).

On Tristeinen (UTM 980534) (Fig. 2, locality 4) the Otta conglomerate facies (Table 2) is a near monomict serpentine conglomerate with sporadic gabbro and greenstone clasts (Fig. 6, Table 3). The conglomerate directly overlies mylonitic quartzite and psammite of the Heidal Group (Table 1).

Interpretation

The conglomerates at Raggehaugen and Tristeinen are thought to be lateral equiva-

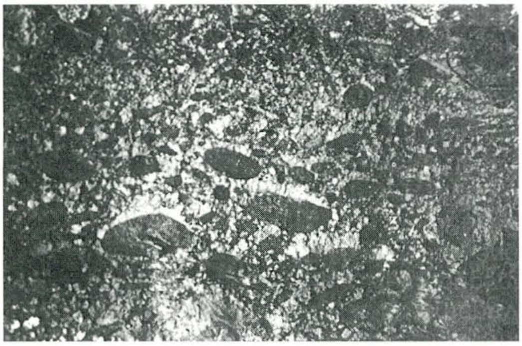

Fig. 6. Massive Otta conglomerate facies at Tristeinen. Vertical side of photograph is 0.6 m. See Fig. 2 for location.

lents of one another, deposited on top of previously eroded ophiolitic rocks and psammites, respectively. The composition of the conglomerates indicates derivation from a nearby source area with abundant ultramafic rocks in the basement. The coarseness of the detritus suggests a relatively short distance of transport from the source area, although the rounding of the clasts reflects a thorough reworking. This may have been achieved on a shoreline or in an alluvial environment, prior to deposition.

The conglomerates at Tristeinen and many of the conglomerates at Raggehaugen were probably emplaced by debris flows. Because of the relatively common occurrence of normal, inverse-to-normal and inverse-graded conglomerate beds, clast imbrication, the presence of mud/silt cappings and a common upward increase in matrix content (features typical for subaqueous debris flow deposits (Nemec & Steel 1984)), we prefer to interpret these deposits as subaqueous. Erosional scours, planar stratification and trough cross-stratification, as observed at Raggehaugen, and clast-supported texture, as observed at Tristeinen, are common in fluvial/alluvial fan deposits (Jolley et al. 1990). However, these features are also common on fan deltas and in submarine gravity flow deposits, e.g. on submarine fans (Nemec & Steel 1984).

Thick sequences of conglomerate in shallow-marine settings are likely to be the product of a pronounced fluvial flooding out from fan-deltaic or deltaic systems (Nemec & Steel 1984, Prior & Bornhold 1990). Typical reworked beachface or shoreface conglomerates (Nemec & Steel 1984) were not observed; however, a fan-delta (Kleinspehn et al. 1984, Nemec 1990, Prior & Bornhold 1990) interpretation of the sediments at Raggehaugen and Tristeinen is a possibility. Another possible interpretation of the sediments at Raggehaugen and Tristeinen could be that they represent proximal submarine fan channel deposits. Ineson (1989) has described coarse-grained submarine fan and slope apron deposits similar to the conglomerates at Raggehaugen and Tristeinen, and ascribes these to deposition from debris flows and high-density turbidity currents. Because of the lack of sedimentary structures indicating wave reworking we prefer to interpret these sediments as submarine fan deposits. The decrease in grainsize from Tristeinen eastwards towards Raggehaugen may be interpreted as a change from proximal to more distal deposition, but the change may also be related to local topography and sediment dispersal patterns at the time of deposition.

Svarthovda area

Description

Remapping has demonstrated that the conglomerates on Svarthovda occupy the same structural and stratigraphic level as the Otta conglomerate facies and can be correlated with it. These conglomerates are well exposed on the mountain Svarthovda and on the eastern slopes towards the river Skjerva (Fig. 2, localities 16 and 17). The best exposures occur at UTM 982702, where a sedimentary breccia rests unconformably on banded calc-silicate rocks of the Heidal Group (Table 1). This unconformity can be traced southwards, where it is very well exposed despite strong folding (Fig. 7). At UTM 982702 the lowermost part of the Sel Group consists of a 10 m thick, clast-supported, polymict breccia (Table 3, Svarthovde analysis 1). Angular and subangular slabs of calc-silicate rocks, up to 1.5 m long and identical to the rocks of the immediately underlying substrate, dominate in the lowermost part of the breccia.

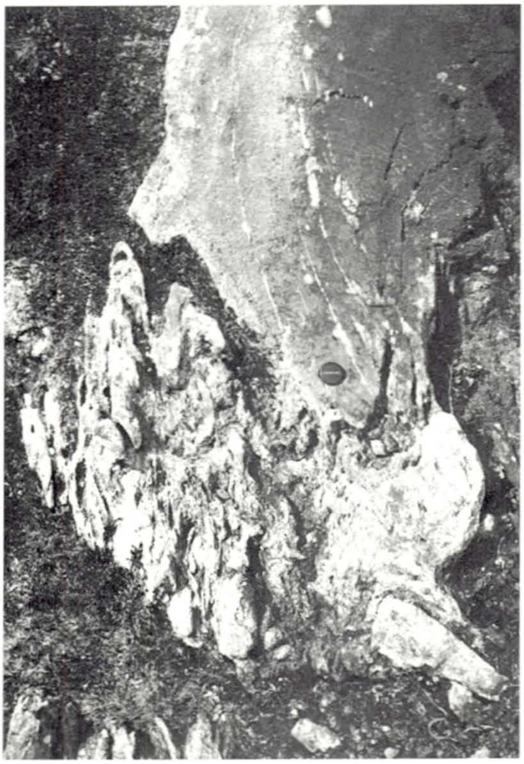

Fig. 7. Folded unconformity between Heidal Group calc-silicate rocks (upper part of photograph) and To conglomerate facies at Svarthovda. Lens cap is 6 cm in diameter. See Fig. 2 for location.

The breccia is succeeded by approximately 20 m of clast-supported, polymict conglomerate (To conglomerate facies), with greenstone and psammite as the dominating clast lithologies (Table 3, Svarthovde analysis 2). This has a quartz-mica schist matrix with cobbles and boulders up to 50 cm in diameter. The boulders are commonly rounded, although generally they are subangular to subrounded. Upwards through the conglomerate there is an increasing proportion of talc in the matrix.

This conglomerate is abruptly overlain by a 10 m thick, matrix-supported, polymict conglomerate (Table 3, Svarthovde analysis 3). Psammite and greenstone dominate the clast population, and the clasts are up to 50 cm long. Pebbles, cobbles and boulders are evenly distributed in a talc-magnesite matrix (Fig. 8a). There is an almost bimodal size distribution with cobbles in a very coarse-grained sandstone matrix. This unit is succeeded abruptly by a mafic-matrix, green conglomerate with clasts of predominantly quartzite, greenstone and gabbro (Table 3, Svarthovde analysis 4) (To conglomerate facies). The matrix contains a high proportion of talc, becoming more amphibolitic upwards. Clasts in the conglomerate reach 75 cm in diameter, but rarely exceed 50 cm.

There is a gradual transition from the To conglomerate facies into a conglomerate with matrix varying from quartz-schist to schistose quartz sandstone, and with pebbles of quartzite and vein quartz (Table 3, Svarthovde analysis 5) up to 10 cm in diameter (Skardshøi conglomerate facies) (Fig. 8b).

Eastwards, towards the Skjerva River, these two facies alternate. At Skarvangsætrin (Fig. 2, locality 33) (UTM 992693) the To conglomerate facies is clast-supported, with a quartzitic matrix and subangular to subrounded clasts up to 50 cm long (Fig. 8c). The clast composition of the To conglomerate facies at Skarvangsætrin is shown in Table 3.The clasts at this locality dramatically illustrate pre-pebble tectono-metamorphic fabrics, indicating derivation from an earlier metamorphic complex. These features include pre-pebble foliations, folds, quartz veins and metamorphic minerals cut by pebble margins.

In Krossdalen, 500 m north of Skarvangsætrin, the Skardshøi conglomerate facies contains beds of yellowish limestone and calcareous sandstone. The succession shows well preserved sedimentary structures, in particular channels and erosional scours, planar and trough cross-stratification and thin, intraformational mud-clast conglomerates.

Northwest of the mountain Fjelltithøi (UTM 012686) (Fig. 2, locality 19) there is a well exposed succession of conglomerates (Table 2), with clasts in a quartz-mica schist or phyllitic matrix. The conglomerates have a polymict composition (Table 3) reminiscent of the To conglomerate facies, although the clast population is usually domi-

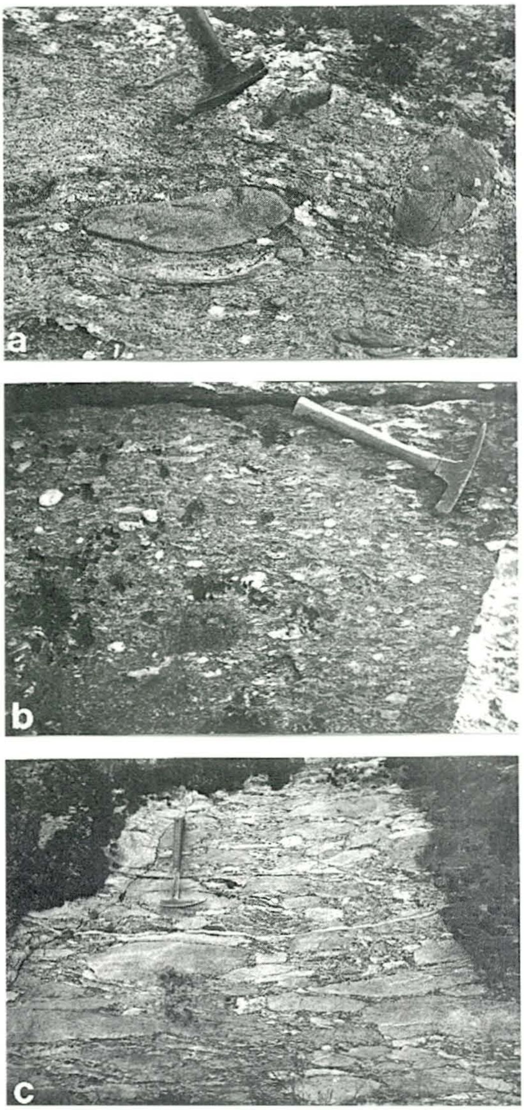

Fig. 8. a) Mass-flow conglomerate (To conglomerate facies) at Svarthovda. Visible part of hammer is 20 cm long. b) Skardshøi conglomerate facies at Svarthovda. Hammer is 30 cm long. c) To conglomerate facies at Skarvangsætrin. Hammer is 30 cm long. See Fig 2. for location.

nated by quartzite and vein quartz. Some conglomerate beds have a yellowish colour, and contain a high percentage of limestone clasts (Table 3), up to 10 cm long. The matrix of these conglomerates is generally enriched in carbonate.

Interpretation

The lowermost part of the succession at Svarthovda is interpreted as a basal breccia. The predominance of very angular clasts of rocks of local basement affinity indicates only a short distance of transport, prior to deposition. The overlying clast-supported To conglomerate facies contains more rounded clasts, interpreted as reflecting greater reworking and greater distance of transport prior to deposition. The upward increase in talc content of the matrix suggests an influx of material from a more distant location and downward erosion into ultramafic rocks in the source area. The lack of sedimentary structures and fine-grained sediments in the breccia and the conglomerate indicates a sedimentary environment dominated by rapid mass-flow deposition. The depositional environment could have been either subaerial (alluvial fan) or subaqueous (fan-delta or submarine fan) (see below).

The overlying 10 m thick, matrix-supported conglomerate is interpreted as a mass-flow deposit (Sturt et al. 1991). The homogeneous appearance suggests that this unit was deposited as a debris flow (e.g. Nemec 1990), although it could alternatively be classified as a mudflow deposit (Curry 1966).

The decrease in matrix-serpentine upwards through the succeeding To conglomerate facies may reflect a decreasing sediment supply from ultramafic source rocks, either because ultramafic rocks were no longer available for erosion or because of a shift in the sediment dispersal pattern. This decrease could also be a result of more thorough reworking of the sediments, with removal of the softer components, prior to deposition. The latter suggestion is supported by the occurrence of mature, well sorted Skardshøi conglomerate facies, enriched in vein quartz (Table 3), on top of the To conglomerate facies. The main source rock of the Skardshøi conglomerate facies is interpreted to have been Heidal quartzite. These sediments were probably extensively reworked, possibly in a shore environment, prior to deposition in a marine setting.

It is possible that the lowermost part of the succession at Svarthovda was deposited in a subaerial setting, but no marine flooding surface or transgressive lag has been identified to support this suggestion. Our inability to identify a marine flooding surface may, however, be due to the relatively strong deformation of these deposits. Alternatively, the lowermost part of the succession at Svarthovda may have been deposited in a fan delta environment or as channel fill on the proximal part of a submarine fan. Coarse-grained fan delta sediments, very similar to the deposits at Svarthovda and deposited by debris avalanching and inertia flows, have been described by Prior & Bornhold (1990). During high-energy river floods, coarse-textured debris may plunge directly into the sea to be deposited on the subaqueous fan.

The gradual transition from Skardshøi conglomerate facies to quartzitic sandstones, calcareous sandstones and, in some cases, limestones probably reflects a transgression and gradual transition to deeper marine conditions, dominated by turbidite deposition. The limestones may represent calcarenite turbidites, with calcareous material transported from a shallow shelf area, or calcareous oozes deposited between the turbidites. Limestone clasts in the conglomerates at Fjelltithøi were probably eroded from a shallow shelf, where deposition of calcareous sediments occurred.

Øyagarden - Grønlii

Description

The Otta conglomerate facies is well exposed in an approximately E-W striking syncline at Øyagarden and Grønlii, along the river Finna (UTM 965665) (Fig. 2, locality 14) (Table 2). At this locality the local basement comprises black schists and psammites of the Heidal Group (Table 1). The succession is composed principally of conglomerates, but there are also many intervals of sandstone and conglomeratic sandstone (Fig. 9). The conglomerate has an almost monomict composition, with serpentine clasts in a matrix of serpentine/talc sandstone.

A 2-3 m thick horizon of coarsely crystalline limestone is present in the lowermost part of the succession at Øyagarden. Its upper, sharp and undulating surface is well exposed. Numerous rounded serpentine clasts up to 10 cm in diameter are embedded in the uppermost 20 cm of the limestone. These clasts have a composition similar to those in the overlying conglomerate.

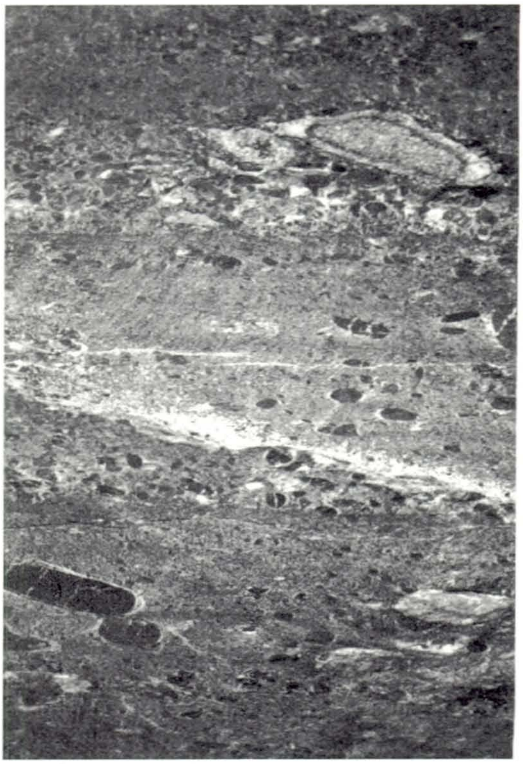

Fig. 9. Well bedded Otta conglomerate facies at Grønlii. Note stratification an imbrication of serpentine clasts indicating palaeocurrents towards the left (east). Vertical side of photograph is 75 cm. See Fig. 2 for location.

Interpretation

The sedimentary rocks at Øyagarden-Grønlii are derived from ultramafic source rocks. The well rounded nature of clasts show that these were subject to transport and reworking prior to deposition in their present stratigraphic position. The relatively well sorted nature of the deposits, and the presence of scours, clast imbrication, plane parallel and trough cross-stratification, indicate deposition in an environment with strong currents. The sediments can possibly be interpreted as submarine fan braided channel deposits. Surlyk (1984) and Ineson (1989) have described deposits very similar to the deposits at Øyagarden-Grønlii, showing complex multiple scouring, laterally discontinuous bedding, scarcity of fines and lack of systematic internal organisation, and ascribe them to deposition in braided, axial distributary channels of submarine fans. Shanmugam & Moiola (1991) described similar deposits, composed of conglomerate and pebbly sandstone, and interpreted them as braided channel deposits on mid-fan lobes.

The sediments at Øyagarden-Grønlii could alternatively be interpreted as the deposits of a braided fluviatile system dominated by stream flow and stream flood (Flint & Turner 1988, Bøe & Sturt 1991) processes. However, the presence of upward-fining gravel beds (interpreted as small mass-flows) and the general predominance of matrix-supported texture point towards subaqueous deposition.

Svarttjern

Description

On the northern face of the ridge north of Svarttjern (Fig. 2, locality 21), coarse-grained garbenschiefer with bands of quartzite and quartz schist of the upper Heidal Group is overlain with angular unconformity by dark green To conglomerate facies (Tables 1, 2 and 3) (Fig. 10). The contact is exposed at only one locality (Fig. 10b), but elsewhere the gap in outcrop is only centimetric in scale. Despite moderate deformation in the To conglomerate facies it is not high enough to explain the absence of ophiolite as a consequence of tectonic excision

The green matrix of the conglomerate is rich in amphibolite, talc and chlorite. Immediately above the unconformity, conglomerate beds are interbedded with medium-grained green sand to conglomeratic sand (Fig. 10a) (Table 2). This conglomerate has a crescentic outcrop, overlapped to the east and west by a thick development of monomict Otta conglomerate facies in the core of the Svarttjern synform (Sturt et al. 1991). The Otta conglomerate facies is typically massive, matrix-supported and poorly sorted. Clasts are well-rounded to sub-rounded with maximum diameters up to 30 cm but averaging 10 cm.

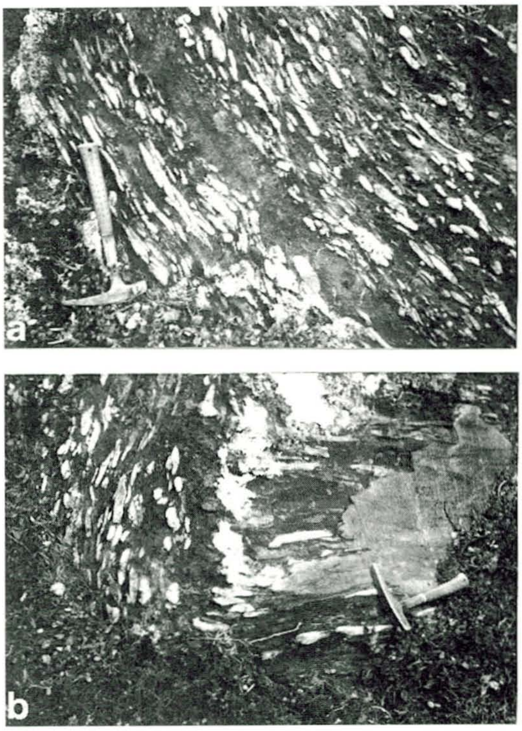

Fig. 10. a) To conglomerate facies with beds of laminated sandstone at Svarttjern. b) Unconformity between To conglomerate facies (left) an Heidal Group (right) at Svarttjern. Hammer is 30 cm long. See Fig. 2 for locatiion.

Interpretation

Although tectonically distorted, the pebble shapes of the To conglomerate facies suggest a well-rounded, pre-deformation shape. This, together with the dominance of quartzite, suggests greater reworking and greater distance of transport prior to deposition. The general absence of sedimentary structures suggests deposition as mass-flows, possibly in a submarine fan or fan delta setting. The overlying Otta conglomerate facies has a coarse clast size suggestive of a short distance of transport.

Gauklihaugen

Description

On the ridge Gauklihaugen, to the north-west of Otta (UTM 258508 to 259506) (Fig. 2, locality 25), the To conglomerate facies is present above rocks of the ophiolite complex (Table 1). The sedimentary succession starts with a 1-2 m thick, black phyllitic schist that can be traced southwards

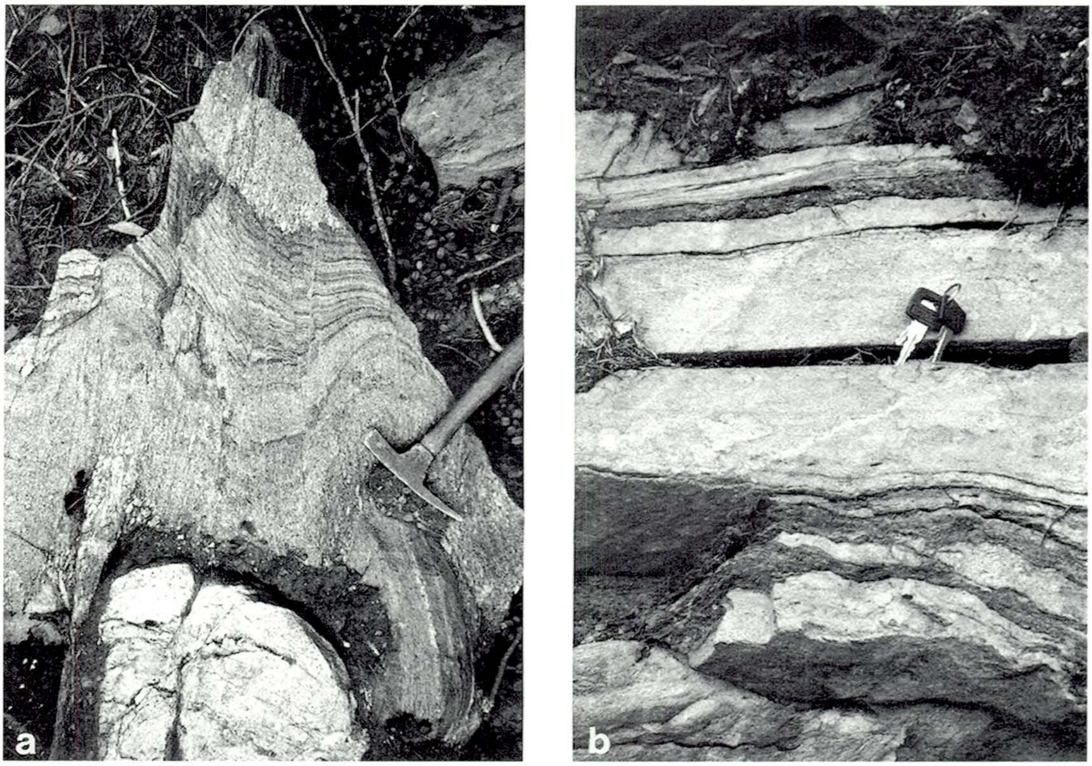

Fig. 11. a) To conglomerate facies with beds of laminated sandstone and graded pebble-size conglomerate on top of granite gneiss boulders at Gauklihaugen. Right way up. Visible part of hammer is 20 cm long. b) Beds of calcareous sandstone, limestone and phyllite at Gauklihaugen. Note plane parallel lamination and trough cross-lamination. Key is 5 cm long. See Fig. 2 for location.

towards Nedre Josten. On top of the phyllitic schist there is an approximately 60 m thick interval of talc schist, sandstone and pebble-size To conglomerate facies.

These sediments are succeeded by approximately 35 m of fine and coarse To conglomerate facies with minor sandstones and schists (Table 2) (Fig. 11a). The coarse conglomerates are usually poorly sorted, while the pebbly conglomerates (clasts typically 1-2 cm in diameter) may be well sorted and have a bimodal size distribution, with clasts embedded in coarse- to very coarse-grained sandstone. A typical clast composition is indicated in Table 3.

The interval of fine and coarse conglomerates is succeeded by 8 m of conglomeratic sandstone and fine conglomerate. This is followed by approximately 30 m of fine conglomerates (Skardshøi and To conglomerate facies) which alternate with sandstones, phyllitic schists (often with talc) and thin limestones. The sandstone beds are typically 2-15 cm thick (Fig. 3) and well bedded. The sandstones are pale grey, medium- to coarse-grained and well sorted, and show upward-fining motifs, as well as plane parallel lamination and trough cross-lamination. Their lower surfaces are sharp and undulating. The boundaries with the overlying brown schists are usually abrupt (Fig. 11b). Individual beds in these schists are typically up to 5 cm thick and laterally continuous. Brown limestones are up to 15 cm thick and contain thin layers of darker brown schist.

Interpretation

The composition of the clasts in the conglomerates of Gauklihaugen indicates a source for these sediments in the ophiolite, rocks of the Heidal Group and the granitic basement gneisses. The fine-grained sediments at the base of the succession were probably originally clays, silts and sands deposited relatively slowly in a sheltered part of a sedimentation basin.

The overlying coarse deposits may have been deposited on submarine fans that built out into the sedimentation basin. The coarse grain-size, poor sorting, complex multiple scouring, laterally discontinuous bedding, scarcity of fines and lack of systematical internal organisation probably reflects deposition in braided distributary channels on the proximal part of submarine fans. Many of the conglomerates were probably deposited from mass-flows as high-density turbidites, while bimodal size distribution and normal grading show that sediment transport by debris flow was also common. Mud-matrix conglomerates, with gabbro clasts, at Søre Josten sæter, to the north of Gauklihaugen (Fig. 2, locality 24), were probably deposited as debris flows within this system.

The upward fining of the conglomerate succession, above the coarse interval, reflects a gradual termination of coarse-grained sediment input. This could be due to an overall reduction in the amount of conglomeratic sediment input due to levelling of the topography, or to a relative rise in sea level, putting the location of deposition landwards. The well sorted and normally graded sandstones in the uppermost conglomeratic interval probably represent lower density turbidites (Lowe 1982) deposited in relatively deep water. Limestones and fine-grained, clastic sediments may represent pelagic and hemipelagic deposits.

Åsåren

Description

In the soapstone quarry at Åsåren (UTM 230537) (Fig. 2, locality 22) the unconformable contact between foliated ultramafic rocks (soapstone) of the ophiolite complex and the Otta conglomerate facies is exposed (Fig. 12; Table 1). The conglomerate is clast-supported in its lower part, and contains rounded clasts up to 20 cm in diameter of variably steatitised serpentine in a matrix of talc, chlorite and magnesite. Above the quarry the conglomerate passes transitionally upwards into garbenschiefer and sandy phyllites of the Sel Group.

Fig. 12. Sheared unconformity between serpentinite (upper part of photograph) and Otta conglomerate facies at Åsåren. Lens cap for scale is 6 cm in diameter. See Fig. 2 for location.

A unit of serpentine fine conglomerates and fine-grained sandstones occurs some 500 m to the northwest of the quarry, at UTM 225540 (Table 2). The rocks are poorly exposed in a small pit (only 1 m of stratigraphic thickness can be observed) but are critically important on account of the large number of well preserved fossils which have been recovered. Brachiopods, gastropods, trilobites, cephalopods and bivalves dominate the fauna (Bruton & Harper 1981). According to Bruton & Harper (1981) the brachiopods show strong North American affinities while the trilobites are a mixture of North American and Baltoscandian types. The fossils occur only in the conglomerate beds, which are very poorly cemented.

Interpretation

The contact in the quarry, between the soapstone and the soapstone conglomerate, is interpreted as a subaerially eroded unconformity. The overlying garbenschiefer and sandy phyllites probably represent shallow-marine sediments deposited after a transgression. The abundance of fossils in the small pit to the northwest of the quarry is evidence of a marine environment. From the mixed Laurentian-Baltic affinity of the fauna and the petrology/geochemistry of the conglomerate clasts (Stigh 1979), Bruton & Harper (1981) concluded that the serpentine conglomerate originally formed in an oceanic island setting, far removed from a land-derived source of sediment, during an early closing of the Iapetus Ocean (see discussion below).

From the excellent preservation of internal features and the broken and abraded exteriors of the brachiopods, Bruton & Harper (1981) suggested that the shells were infilled with fine sediment during a period of exposure on the seafloor, and from the taphonomy of the fossils they suggested gross sorting and possibly transport of the assemblage. The mixture of benthos and nekton indicates that much of the shell material may be derived from a nearby shore area, with high biogenic productivity (Bruton & Harper 1981).

The mixture of whole shells and large shell fragments can possibly be interpreted as indicating reworking above storm wave base. Similar features have been described by Banerjee & Kidwell (1991). However, the well preserved nature of many fossils suggests only restricted reworking prior to final deposition. A possible interpretation of the sediments could be that they were deposited as near-shore or inner shelf, storm-induced tempestites (see Einsele & Seilacher 1991), with concentration of fossils primarily in the conglomeratic, lower part of the beds (corresponding to the Bouma A division) (Bouma 1962). Well developed plane parallel lamination, trough cross-lamination and trough cross-stratification in the overlying sandstones indicate traction currents.

The fossiliferous conglomerate beds could alternatively be interpreted as a marine transgressive lag. This could have formed as a result of marine flooding across a sequence boundary, with winnowing of the underlying beds and concentration of shells in conglomeratic lags. Because of the poor exposures this is an uncertain interpretation. It is also possible that the shell debris represents populations indigenous to the shelf, deposited during a sea level rise, with low sedimentation rates (Van Wagoner et al. 1990). Such marine surfaces can be located on top of sequence boundaries or ravinement surfaces. One possible interpretation of the fossiliferous interval is therefore that it may represent a condensed section. Although there is no conclusive evidence in the sediments, e.g. increased cementation, to indicate prolonged exposure on the sea floor, the succession at Åsåren was probably deposited during a marine transgression.

Rusti

Description

A well exposed contact between fine-grained black phyllites of the Sel Group and ophiolite can be observed at and around the Rusti Mines (Fig. 2, locality 29) (Table 1). Here, the surface of unconformity is slightly irregular, truncating several members of the Vågåmo ophiolite complex from pillow lava to gabbro. A thin regolith is preserved at one locality at North Rusti Mine (UTM 298493) where sand and silt have penetrated into cracks in the underlying gabbro. A basal breccia up to 5 cm thick, with small angular gabbro fragments, is intermittently present at this locality filling hollows in the irregular surface. The black phyllites pass up into an interlayered succession of garbenschiefer and mica schist.

Interpretation

The black phyllites at Rusti are interpreted as turbidites and pelagic/hemipelagic sediments deposited in a marine setting, after a transgression of the unconformity.

Kleiverudtjern

Description

The deposits of the Sel Group succeeding the conglomerates comprise phyllites, garbenschiefer, sandy psyllites, slates, mica schists, sandstones, thin limestones and a few thin conglomerates. Kleiverudtjern (Fig. 2, locality 30) (UTM 268507) is located in the central development of the classic 'Sel schiefer' which in the Otta area is the highest unit in the Sel Group. The 'Sel schiefer' is quarried as a cladding and ornamental 'slab' and is, in fact, a thinly interbedded succession of fine-grained sandstones and siltstones with phyllitic partings wich may preserve sedimentary lamination. The Otta conglomerate facies occurs within this succession, and is near monomict, approximately 3 metres thick, an carries rounded serpentinite clasts up to 30 cm in diameter. The matrix-supported conglomerate has a serpentinite (talcose) and paartly chloritic matrix and can be traced for some 1.5 km towards the south.

Interpretation

The conglomerate at Kleiverudtjern in its lithological context of quartz-rich siltstones is remarkable and represent an unusual event horizon. Because of the sediments beneath the conglomerate horizon, it is unlikely that this represents reworking of an older conglomerate deposit.

A possible interpretation of the unusual event horizon could be that it resulted from a drop in relative sea level, with the formation of a sequence boundary, overlain by coarse-grained deposits. Such type-1 sequence boundaries may be overlain by fluvial and estuarine deposits or submarine fan deposits of the lowstand systems tract (Van Wagoner et al. 1990). Because of the poor exposures it is, however, impossible to observe the lower and upper surfaces of the conglomerate to determine whether they are of erosional of depositional character.

An alternative interpretation could be like that of the coast of northern Oman today (Skelton et al. 1990, Nolan et al. 1990) where a relatively flat-lying coastal plain separates the shore line. In such an evironment, flash floods transport ophiolite-derived coarse debris along wadis to coastal and near-coastal localities. A particularly catastrophic flash flood would bring such material into the marine environment where it could then be transported and emplaced as a debris flow. The implications are that the sediments of the 'Sel schiefer' were not deposited at any great distance offshore.

Discussion

In the foregoing section it has been demonstrated that the composition, thickness, texture and structure of the conglomerates in the lowermost part of the Sel Group vary considerably from area to area. The most notable feature, however, is their lithological variation (Table 3).

The distribution of the different clast types commonly reflects the composition of the local basement, particularly in the case of the Skardshøy conglomerate facies. This is not invariably the case; for example, the Otta conglomerate facies can be deposited on top of rocks of the Heidal Group (Table 1). In the basal part of the cover sequence to the Oman ophiolite complex, Nolan et al. (1990) also observed that the clast composition is generally different from the underlying rock; this is not an unusual feature.

The various conglomerate facies in the lower part of the Sel Group are commonly interbedded, and transitional into one antother both laterally and vertically (Figs. 2 and 13). This applies also to the serpentine conglomerates, although these have previously been interpreted as deposits of an isolated evironment, far emoved from a land-derived source of sediment (Bruton & Harper 1981, see above). The serpentine conglomerates are commonly located at the base of the Sel Group, above the ophiolite, but may also occur higher up, e.g. in the Bukkehaugen area and at Kleiverudtjern.

A good example of the lateral transition from one conglomerate type to another occurs where the serpentine conglomerates of Åsåren pass southeastwards into polymict conglomerates, with numerous clasts of continental affinity, e.g. granite, on Gauklihaugen (Table 3). This To conglomerate facies on Gauklihaugen is overlain by horizons of Skardshøi conglomerate facies. In the ground between Gauklihaugen and To farm (Fig 2, locality 31), there are also many talc schist horizons interbredded with the To conglomerate facies (Bjørlykke 1905). Another example of lateral transition is provided by the Otta conglomerate facies at Grønlii-Øyagarden norhwards into To conglomerate facies on Svarthovda. In the eastern slopes of Svarthovda there are many examples of To conglomerate facies passing both laterally and vertically into Skardshøi conglomerate facies.

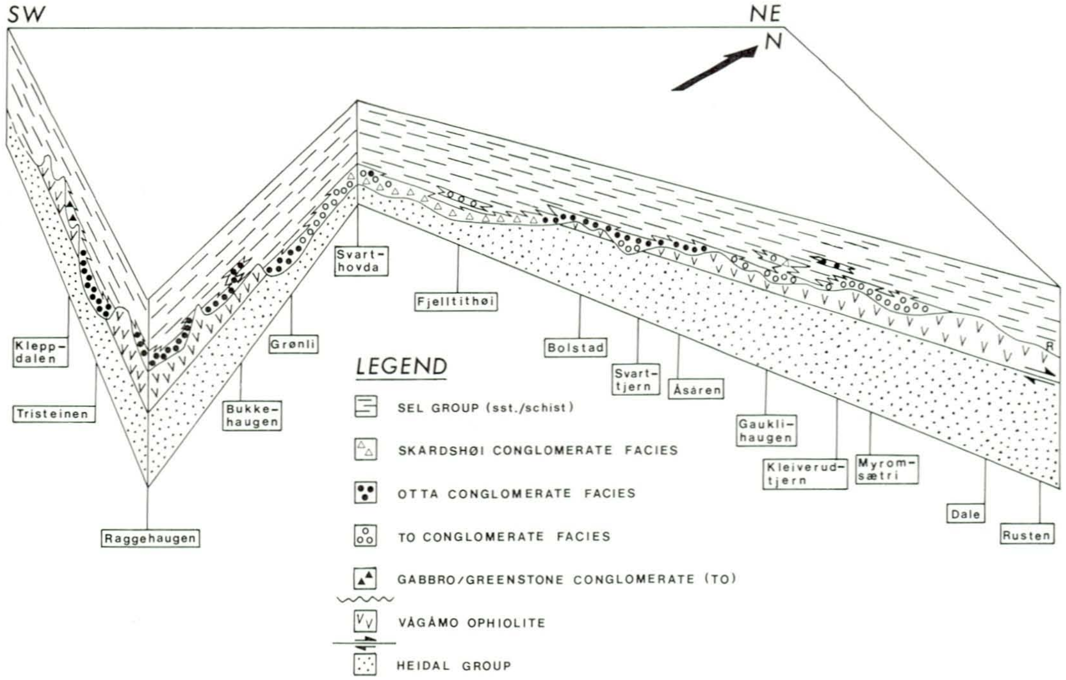

Fig. 13. Block diagram (not to scale) illustrating the lateral relationship between different conglomerate types after deposition of the Sel Group, prior to folding and thrusting of the Otta Nappe Complex. Note pronounced palaeotopography and interfingering relationship between various conglomerate types. The situation of some key localities (see Fig. 2 for location) are shown. R: regolith.

At some localities, the conglomerates at the base of the Sel Group can be strongly deformed, and variation in thickness is therefore partly tectonically induced. However, this variation is also a primary feature, interpreted as reflecting topography (Fig. 13) and sediment dispersal patterns at the time of deposition.

The unconformity at the base of the Sel Group is interpreted as a subaerially eroded surface (sequence boundary), and indeed at North Rusti Mine a partially preserved regolith is present. This unconformity was progressively drowned and sedimented during a regional marine transgression, leading to marine conditions being established over much of the former land area. The transgression was accompanied by the formation of a marine sedimentary basin. The texture and structure of the sediments overlying the unconformity reflect a variety of depositional environments, varying from relatively deep marine to shallow marine, littoral, fan-deltaic and possibly even subaerial. Much of this has similarities to the Arenig transgression described from western Iberia (McDougall et al. 1987).

Shallow-marine conditions locally existed along the margins of the basin and around emergent topographic highs. In this shallow shelf area local high biogenic productivity prevailed, and deposition of sands and shallow-water carbonates occurred. These sediments were transported into deeper water by turbidity currents.

In other areas sandstone and coarser-grained sediments were shed directly into the sea with the formation of fan deltas and submarine fans. The 'Sel transgression' across a land area with a rugged topography, maybe with a relief up to several hundred metres and possibly still undergoing post-orogenic fault movements, would have resulted in steeply sloping submarine surfaces. As erosion penetrated through the still emergent hilly hinterland of overthrust, ophiolitic rocks to expose quartzites and psammites of the subjacent Heidal Group and granitic basement gneisses, transport of

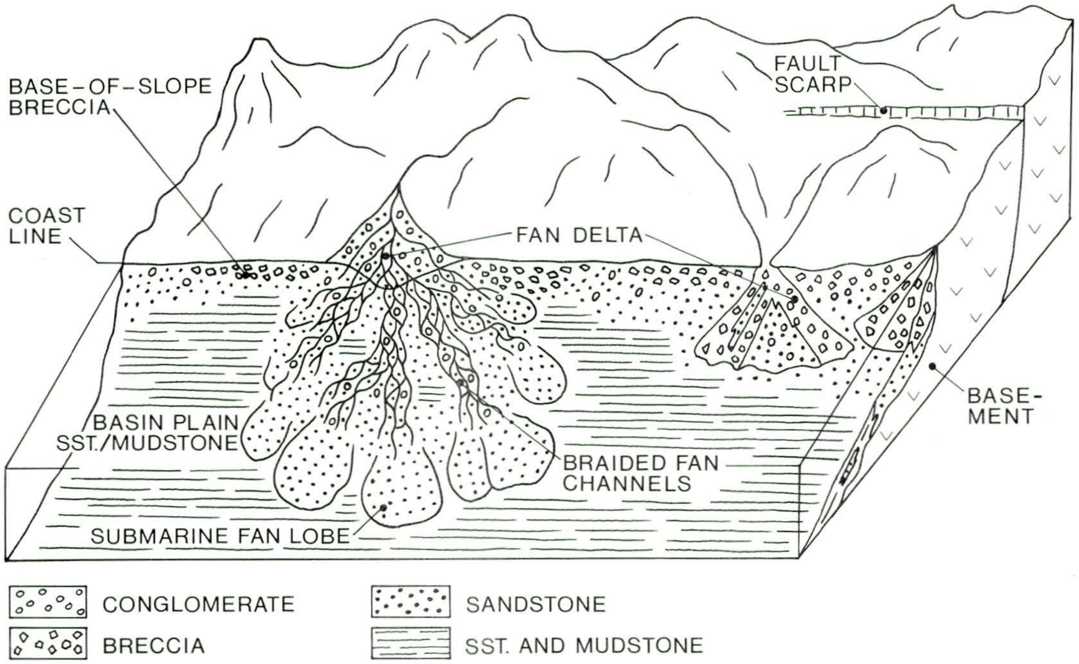

Fig. 14. Schematic block diagram (not to scale) illustrating possible palaeogeographical setting and sedimentary environment during deposition of the lower part of the Sel Group.

debris would have been very rapid. The clastic material would have been dumped into the sea more or less directly. Such a situation would be the ideal for the formation of fan deltas and submarine fans (Fig. 14). The geomorphology and drainage pattern in the hinterland would have controlled whether the basal beds consisted of conglomerate, sandstone or mudstone.

Interfingering of fan lobes from different source areas and fan lobe switching may explain the interbedded relationship of the different conglomerate types (Fig. 13). Rocks of the Heidal Group and its basement were probably the main source rocks of the Skardshøi conglomerate facies. Palaeocurrent indicators such as imbrication and cross-bedding were observed in only a few localities, but show that the predominant sediment transport, referring to the present position of the rocks, was in an easterly direction.

The conglomerates gradually disappear upwards through the Sel Group and give way to finer-grained deposits. This can be considered to be a consequence of continued transgression and denudation of the land area, with the sediments higher in the succession being deposited in deeper water, farther from the source.

The deposits in the lower part of the Sel Group bear a striking resemblance to the cover sequence of the Oman ophiolite complex (Skelton et al. 1990), which also show an upward transition from marginal marine facies to deeper, open marine facies. A gradual transgression was interrupted by regressive phases, attributed to eustatic sea level fall or localised, tectonic activity. In the cover sequence to the Oman ophiolite complex, wide lateral variation in depositional environment and sediment type is recorded over relatively short distances (Nolan et al. 1990, Skelton et al. 1990). A similar pattern is evident in the lower part of the Sel Group, and in both areas this is very much attributed to the palaeotopography.

The sedimentary succession of the lower Sel Group has a distinct flavour of a transgressive-systems tract. The lower boundary of a transgressive-systems tract (Van Wagoner et al. 1990) is a transgressive surface. Retrogradational parasequences within a transgressive-systems tract onlap onto the sequence boundary in a landward direction and downlap onto the transgressive surface in a basinward direction. It is possible that some of the coarser grained intervals within the lower part of the Sel Group originated due to progradation of parasequences within a transgressive systems tract with retrogradational parasequence sets.

It is also possible that, within the Sel Group, several sequences may be present separated by sequence boundaries. One such example is at Kleiverudtjern, where the coarse conglomerate may mark a surface of subaerial erosion, formed during an intermittent relative drop in sea level.

Conclusions

The denudational history of the pre-Llanvirn Caledonide belt in the Otta area is one of uplift and progressive unroofing of an allochthonous ophiolite complex to expose the metamorphosed cratonic and miogeoclinal successions beneath. The products of this erosion were deposited unconformably over the dissected remains of the Early Ordovician orogenic belt. Where erosion breaches the ophiolite the unconformity oversteps on to the Heidal Group, thereby stitching the allochthonous ophiolite to the cratonic miogeoclinal sequences prior to the Arenig/Llanvirn.

The lower levels of this unconformable cover sequence have an extensive development of conglomerate, whose clast populations reflect the geology of the substrate, ranging from unimodal ultramafic or metasedimentary to bimodal assemblages of ophiolite, metasedimentary and metamorphic rocks. Many of the clasts of metasedimentary rocks (Heidal Group) bear evidence of pre-pebble deformation and metamorphic fabrics, attesting to the rocks of the Heidal Group having been involved in pre-Late Arenig orogenic activity. Similarly, many of the greenstone/gabbro clasts bear imprint of pre-pebble deformation and metamorphism.

The present study has confirmed the tripartite differentiation of the conglomerates but demonstrated considerable variability and the lateral and vertical transitions between them. In consequence the original names, Otta, To and Skardshøi conglomerate facies, have been retained.

The more restricted distribution of the Otta conglomerate facies compared with the other facies and the regional dominance of the Skardshøi conglomerate facies suggest that the source rocks for these conglomerates were in a cratonic setting. The contribution of the ophiolitic component is directly related to the availability of ophiolite as a sediment source. Progressive removal or blanketing of the ophiolite is reflected in its reduction in the clasts of the younger conglomerates.

Conglomerates may occur as basal conglomerates within the Sel Group, but more commonly they occur higher in the succession and slate, schist, siltstone and sandstone occur at the lowest levels. The development of the coarse clastic assemblage in an environment of essentially fine- to medium-grained sediments demands a strongly elevated (mountainous) hinterland, probably with active faulting, from which youthful rivers (possibly seasonal) debauch fans of coarse clastics. Indeed, ignoring the coarse clastics, the metasedimentary rocks of the Sel Group consist of garbenschiefer phyllites, various phyllites (in part graphitic), metasiltstones, metasandstones and less common metalimestones. These represent the metamorphosed products of an initially fine- to medium-grained assemblage of calcareous sediments, muds with varying clay mineral and graphite contents, silts and sands. The depositional milieu would have probably varied from shallow to relatively deep marine.

The depositional environment of the coarse clastics, on the other hand, has been indicated to vary from fan deltas, through littoral conditions to submarine fans. The depositional environment of the fine-grained sediments and the coarse clastics thus show considerable and significant differences, indicating input into an offshore marine basin of the coarse clastic wedge from the mountainous hinterland (probably situated to the west, relative to the present position) via youthful river systems (Fig. 14), whilst the finer-grained sediments were the result of possibly axial transport in the offshore marine basin. Such a set-up is highly reminiscent of the Maastrichtian succession of northwestern Oman (Skelton et al. 1990) and the Late Cretaceous and Early Tertiary sedimentation of eastern Oman (Filbrandt et al. 1990).

The provinciality of the Otta fauna, showing mixed Laurentian-Baltic affinity (Bruton & Harper 1981, Pedersen et al. 1992), has led to various interpretations of the sedimentary succession and the palaeogeography. Pedersen et al. (1992) interpret the fossil-bearing conglomerates to have been deposited in an intra-oceanic active arc position, somewhere in the Iapetus Ocean between Baltica and Laurentia, with the arc thereafter being accreted to the Laurentian margin prior to overthrusting associated with continental collision. The postulate of Pedersen et al. (1992) appears to have support from a recent article by Stephens et al. (1993) on the Storfjället Terrane of the Central Scandinavian Caledonides. Stephens et al. (1993) conclude that the Storfjället Terrane was not spatially coupled to Baltica during the Early to Mid Ordovician. Sturt & Roberts (1991), on the other hand, interpreted the fossil-bearing conglomerates to have been deposited on the Baltic side of a Finnmarkian orogenic belt, created after ophiolite obduction, and separated from Baltica by an epicontinental sea. They interpret the mixed fauna as a result of faunal interchange where the 'Finnmarkian landmass' was breeched by transverse marine channels.

The allochthonous nappes of the Scandinavian Caledonides have been consigned to Lower and Middle Allochthons, taken to represent tectonically disrupted parts of the Baltoscandian continental miogeocline, and Upper and Uppermost Allochthons in which rocks of outboard terranes make their first appearance (Roberts & Gee 1985). The nappes of the Uppermost Allochthon also contain continental crustal rocks assumed by many authors (e.g. Stephens & Gee 1985) to have been derived from Laurentia or an intervening microcontinental block.

The Otta Nappe rests directly on nappes of the Middle Allochthon and in common with these contains a couplet of continental basement and miogeoclinal cover. It differs in that it is a composite nappe containing an ophiolite complex thrust in before the Middle Ordovician on the Ottadalen Thrust. The Vågåmo ophiolite complex is overstepped by the metasedimentary rocks of the Sel Group onto the subjacent Heidal metasediments, showing that this oceanic outboard terrane had accreted onto the basement-cover couplet already in Early Ordovician times. As no nappe unit, containing rocks of an oceanic outboard terrane, has yet been identified to intervene between the Otta Nappe and the rocks of the Middle Allochthon it is tempting to assume that its basement-cover couplet represents a more distal part of the Baltoscandian continental miogeocline. That it could have represented part of a microcontinental block cannot, however, be ruled out.

Modern palaeomagnetic studies indicate that previous palaoegeographic models assuming a positioning of Baltica opposite Laurentia during the Early Ordovician are in doubt (Torsvik et al. 1991). Indeed, the most recent reconstruction of Torsvik et al. (1992) models Baltica opposite to the Siberian Block during this time period. If these palaeomagnetic results are confirmed, considerable revisions will have to be made to existing geodynamic/palaeogeographic models for the evolution of the northern part of the Appalachian-Caledonian Belt.

The sedimentation of the Sel Group may have occurred in an extensional basin consequent upon the off shore subduction systems operative at the time. Sturt & Roberts (1991) have modelled the western margin of palaeo-Baltoscandia for Llanvirn-Llandeilo times. This period may have been dominated by an eastward (relative to present position) directed subduction system relating to the calc-alkaline arc magmatism of the Smøla type in the central segment, and the plutonic calc-alkaline rocks of the West Karmøy Igneous Complex in the southern segment of the Norwegian Caledonides. Furnes et al. (1986) have shown that the lithologies and geochemistry of the Llanvirn-Llandeilo Siggjø volcanic complex of Bømlo are indicative of eruption and deposition in an extensional setting of 'Basin and Range' type. Similarly, it has been shown (Sturt & Roberts 1991, and references therein) that Mid Ordovician to Early Silurian spreading in ensialic extensional basins positioned eastward of the island arc system dominated the geological development of much of the Upper Allochthon of central and northern Norway.

There are many accounts of the palaeogeographical and palaeotectonic evolution of sedimentary successions in extensional basins, where the sedimentary basin is margined by an actively uplifted land area and where coarse clastics are brought in by river systems into a basin where fine-grained sediment is accumulating. We propose that the Sel Group sediments accumulated in the type of environment indicated in Fig. 14, and that the sedimentary basin was part of the general pattern of sedimentary basins formed by back-arc extensional tectonics, which has been indicated in other parts of western Baltoscandia during Middle Ordovician times. The terrane-linking nature of the unconformity beneath the Sel Group has consequences for the interpretation of successions in parts of the Trondheim Nappe Complex, to the north of the present area.

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