Late Proterozoic (Vendian) to Early Cambrian sedimentation in the Hedmark Group, southwestern part of the Sparagmite Region, southern Norway

TOM DREYER

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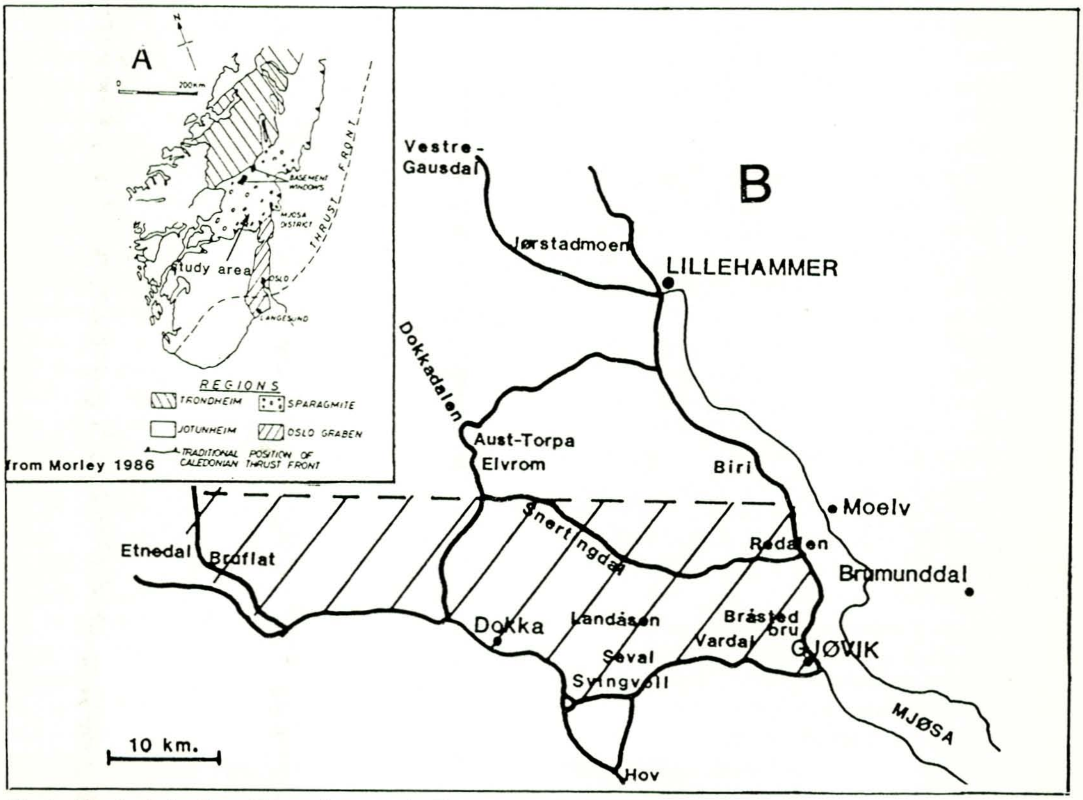
Field studies of the allochthonous Ekre Shale and Vangsås Formation (uppermost Hedmark Group) were undertaken in order to develop a sedimentary model for the final stages of infilling of the Hedmark rift basin. The Ekre Shale accumulated as a prodeltaic deposit following a quick eustatic sea-level rise caused by melting of Varangerian ice-sheets. It is conformably or erosively overlain by the Vardal Sandstone Member of the Vangsås Formation, which in its lower and middle parts represents a transition from a fan-deltaic to a braid-plain environment. Towards the top, the Vardal Sandstone Member is dominated by high-energy (wave-dominated) shallow-marine deposits, and a widening of the basin is documented. The Ringsaker Quartzite Member of the Vangsås Formation reflects the mature stages in this shallow-marine (epicontinental) sedimentation phase. Proximal (south) to distal (north) relationships can be demonstrated throughout the sequence.

Tom Dreyer, Norsk Hydro Research Centre, Postbox 4313, 5028 Nygårdstangen, Bergen, Norway.

Introduction

The Sparagmite region in southeastern Norway (Fig. 1) consists of sediments belonging to the Upper Proterozoic / Lower Cambrian Hedmark Group (Table 1). For more than a century the information obtained from these



from Morley 1986

Fig. 1. a) Geological setting of the study area in the SW corner of the Sparagmite region in southern Norway.
b) Map of the main study area (cross-hatched) and its surroundings.

AGE (m.a.)	FORMATION		THICKNESS (m)
CAMBRIAN —— ?570 ——	VANGSÅS FM.	RINGSAKER QTZ. MBR.	40—60
		VARDAL SST. MBR.	200—300
VENDIAN	EKRE SHALE		20—50
	MOELV TILLITE		1—20
	RING FORMATION		0—200
	BIRI FORMATION		100
	BISKOPÅSEN CONGLOMERATE		0—200
	BIRI FORMATION (LOWER)		0—10
UPPER RIPHEAN	BRØTTUM FORMATION		2000 (min.)

Table 1. The stratigraphy of the Hedmark Group in the studied area.

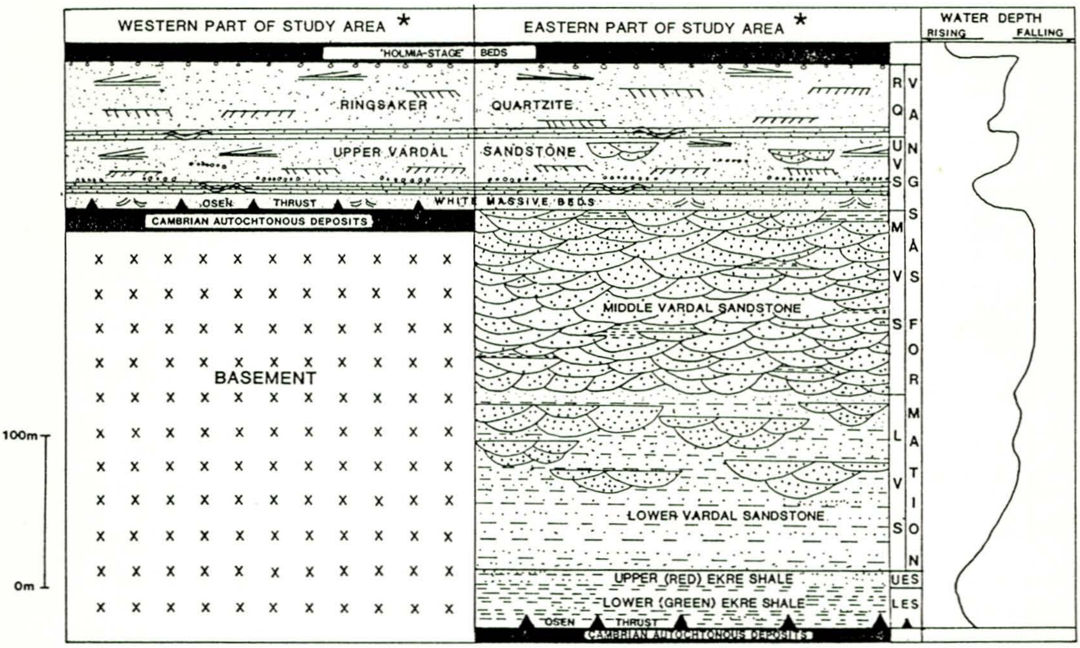
rocks has been vital in deciphering the early geological history of the Baltoscandian craton (Kumpulainen & Nystuen 1985). This study focuses on the sedimentological development of the two uppermost formations in the Hedmark Group; the Ekre Shale and the Vangsås Formation (Fig. 2). These formations were laid down during the last depositional period in the basin, from the end of the Varangerian ice-age (c.650 Ma ago) until Early Cambrian (? 570 Ma) time. It is important to note that the Vangsås Formation, which was previously regarded as entirely Precambrian (e.g. Vogt 1924), has lately been shown to be partly Cambrian in age (e.g. Vidal 1985). The Cambrian-Precambrian boundary is probably located beneath the upper member (Table 1) of the Vangsås Formation (J.P. Nystuen, pers.comm. 1987).

A broad sedimentological outline of the formations in question has been given by Bjørlykke et al. (1976) and Nystuen (1982). It is the aim of this paper to describe the depositional history of these sediments in greater detail. M.Sc. degree theses by Dreyer (1985) and Hostad (1985) form the basis of this investigation.

It is generally accepted that the Hedmark Group accumulated in a failed-rift basin (the Hedmark Basin) where, after a period of rapid basin floor subsidence, pulses of tectonic activity alternated with periods of relative quiescence. This resulted in the accumulation of a diverse suite of fault-controlled, coarse, clastic fan deposits and more 'stable-condition' sediments (e.g. Nystuen 1982). By mid Vendian times (Table 1) the tectonic activity in this area had gradually ceased (Bjørlykke 1983, Bockelie & Nystuen 1985, Kumpulainen & Nystuen 1985), and the youngest formations in the Hedmark Group may thus be regarded as deposits formed during the last-stage infilling phase of the now completely failed rift.

It is important to realize that the studied formations occur in an allochthonous position in the frontal part of the Osen—Røa Nappe Complex (e.g. Nystuen 1981, Morley 1986; Fig. 1A). The studied area is contained within a major duplex (Morley op.cit.; see his Fig. 5), where the sequence is broken up into hinterland-dipping imbricate units. This naturally puts serious constraints on the detailed investigation of lateral sedimentological development. Comparisons of vertical sequences in different parts of the study area have thus been emphasized. The exact distance of thrusting of the frontal part of the Osen-Røa nappe complex is still not fully agreed upon (Skjeseth 1963, Nystuen 1981, 1982, Bjørlykke 1983, Hossack et al. 1985; see review of discussions in Morley 1986). Most workers, however, favour thrust-distances of 130-200 km from a position NNW of where the rocks are now situated. Morley (1986) estimated the thrust-distance to 135 km by balanced cross-sections and a minimum of 130 km from palinspastic restoration. As will be evident from the following, the results of this study do not conflict with such estimates.

Since the Hedmark Basin is now in an allochthonous position, it is obvious that its present-



* FOR LOCATION OF WESTERN AND EASTERN PARTS, SEE FIG. 6

Fig. 2. Vendian to Lower Cambrian stratigraphy in the studied area (Fig. 1), with a summary curve for the variations in water depth (transgressions and regressions) through time. Symbols as in Figs. 5 and 11. Abbreviations refer to stratigraphic subdivision (see text).

day basin-margins do not correspond to the original ones. In this paper, focus will be placed upon the original western rift-basin margin (Fig. 6). Thus, it must be emphasized that all references to this margin herein are made with regard to the *present-day expression of this important feature, which during deposition was located some 135 km to the NNW.*

The Ekre Shale

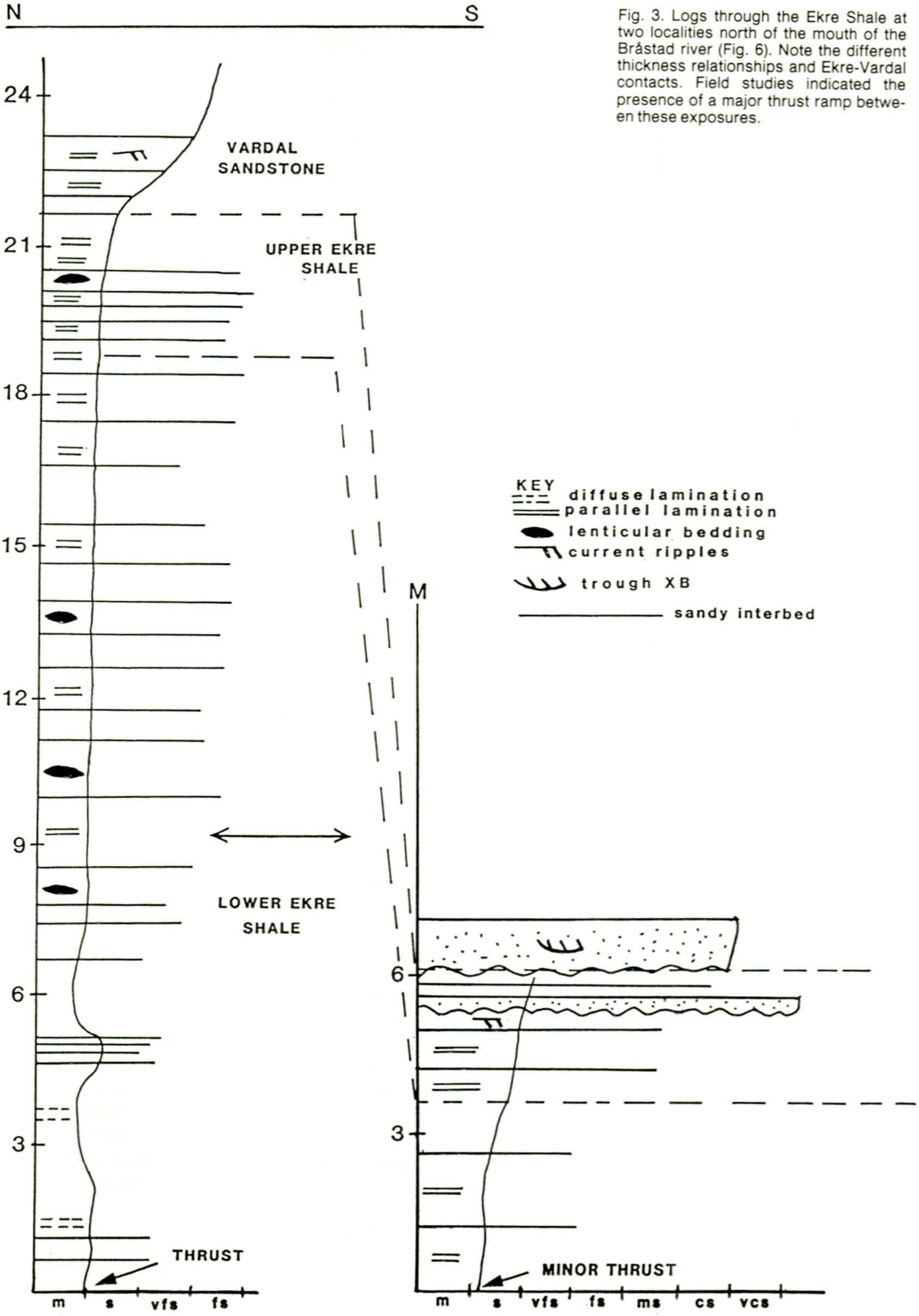
Description

Within the studied area, this fine-grained unit either conformably overlies the Moelv Tillite, or forms the base of the Osen—Røa Nappe Complex (Fig. 2, Bjørlykke 1979). The Ekre Shale is overlain by the Vardal Sandstone Member of the Vangsås Formation (see Fig. 3 and below). The formation has been Rb-dated by Welin (in Rankama 1973) to 612 ± 18 Ma, which presumably is a minimum age in view of the age of the subjacent Moelv Tillite (ca. 650 Ma).

The Ekre Shale can be divided into an upper and a lower part (Fig. 3), based mainly on colour variation. Except for thickness the unit is uniformly developed throughout the study area (see below). It is mostly a parallel-laminated to massive silty mudstone, with minor amounts of sand intercalations. The massive nature is best developed near the base of the formation. The laminations are caused by slight grain-size variations or subtle colour changes. All laminae are on the mm-scale. Sand interbeds ranging in thickness from 2 mm to 3 cm also occur. Common for all the sandy interbeds is a high lateral continuity (sand-sheets), though some may be observed to pinch out and reappear regularly when traced laterally (lenticular bedding). They are mostly ungraded, and no internal structures have been preserved. Their bases and tops are usually sharp and planar; erosional features were only observed in the upper Ekre Shale at the most proximal exposure (Fig. 3).

Careful studies of the laminations revealed the following features:

Fig. 3. Logs through the Ekre Shale at two localities north of the mouth of the Bråstad river (Fig. 6). Note the different thickness relationships and Ekre-Vardal contacts. Field studies indicated the presence of a major thrust ramp between these exposures.



1) The *clay thickness* is always greater than the *silt/fine-grained sand thickness*, especially in the lower half of the Ekre Shale.
2) There is no regularity to the thickness of either the silty or the clayey laminae.
3) The frequency and thickness of silty and sandy laminae increase stratigraphically upwards.
4) The boundaries between the two laminae types are sharp and planar.
5) The coarsest laminae are light to red in colour, while the finest laminae are usually green.
6) No grading within the laminae has been observed.
7) The laminae do not form well-defined couplets, but are best described as a fine-grained groundmass with randomly interspersed coarser layers.

The transition from the lower Ekre Shale into the thinner upper Ekre Shale (Fig. 3) is mainly a change in colour. Over a thin transition zone the greenish colour of the lower part gives way to the reddish colour which characterizes the upper part. However, a slight coarsening upwards also takes place over this transition zone (silty mud to muddy silt).

Although the distance between the southernmost and northernmost Ekre Shale exposures in the Mjøsa district is less than 15 km, the thickness of this unit varies considerably over this area (6 m just north of the mouth of the Bråstad river, 23 m only slightly further north, and 40 m at Lundehøgda). Apart from this thickness variation and the slightly coarser grain-size in the south, the sedimentological characteristics of the Ekre Shale remain uniform throughout the study area. However, the Ekre-Vardal transition is differently developed in the two exposure types (Fig. 3). In the southern (from now on referred to as proximal) exposure, the lower Vardal Sandstone Member erodes into the shale, while in the northern (hereafter termed distal) exposures, the transition is a very gradual coarsening upwards (Fig. 4). Finally, it should be noted that phosphorite bands have been found in the westernmost Ekre Shale outcrops (Bjørlykke 1979). Field studies indicate that the thickness of the Ekre Shale decreases to zero when approaching the western basin-margin line in Fig. 6.

Interpretation

It is assumed that the Ekre Shale, which almost exclusively consists of fine-grained material, accumulated under low-energy conditions. A basinal (probably marine) setting is suggested for this unit, based on the gradational contacts to underlying marine shales (belonging to the Moelv Tillite, Nystuen 1976) and overlying marginal marine deposits of the lower Vardal Sandstone Member (distal exposures, see later). The onlap to the south, the presence of phosphorite bands, and the absence of traction-formed structures also indicate a low-energy marine depositional setting. Other factors, such as the uniform development, the great lateral continuity of beds and laminae, and the absence of any erosional features, also support this interpretation.

The coarsening, both stratigraphically upwards and to the south, suggests an overall *northward progradation of the depositional* system. The most obvious indication of this is the presence of *delta front and delta plain* deposits directly on the top of this basinal marine (?) shale unit (see below). In accordance with Nystuen (1982) I believe that the Ekre Shale may have accumulated as *prodelta* deposits in relatively deep, quiet water during and after the post-Varangerian transgression. The western basin margin seems to have been largely inactive, as witnessed by the drastic thinning of the Ekre Shale in this direction.

The proximal-distal relationships displayed in the southernmost and more northerly exposures (Fig. 3) may be explained by different positions in the nappe hierarchy. Bjørlykke (1979) and Morley (1986) illustrated the complex thrust-sheet relationships in this region, and as mentioned in the caption to Fig. 3, my own field studies indicate the presence of a major thrust ramp just north of the 'proximal' exposure. Thus, it might be argued that the great sedimentological changes over short present-day distances are due to superimposition of two sequences which originally were far apart. In this context, the sediments in the proximal exposure have been thrusted the shortest distance. The thinness of the Ekre Shale and its erosional upper boundary in this exposure may be due to southward onlapping, erosion by overlying fluvial channels (see below and Fig. 11 A), and a lower accomodation-potential (Posamentier & Vail, 1987) toward the southerly source area.

In earlier literature, the genetic term *varve*

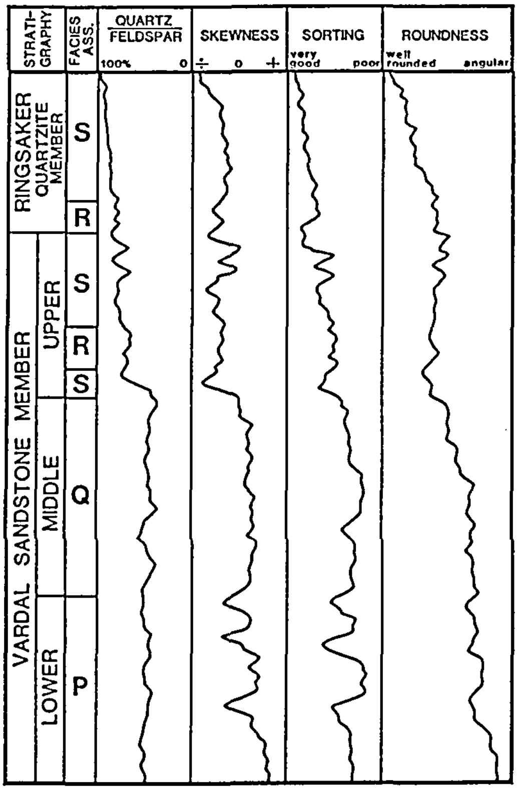


Fig. 4. Diagram showing textural and mineralogical variations in the Vangsås Formation. The stratigraphic subdivisions shown here are those proposed for the studied area.

has been applied to the fine-grained couplets of the Ekre Shale (e.g. Løberg 1970, Englund 1973, Bjørlykke et al. 1976). Investigations of laminations in this study, however, have not been able to confirm the existence of such annual winter/summer (seasonal) couplets within the present study area.

The Vangsås Formation

General

This formation is the youngest one in the Hedmark Group (Table 1). It is a 150—350 m thick, mainly coarse-grained unit which everywhere is superseded by fossiliferous 'Holmia-stage' shales and thinly bedded sandstones of probable shelf-origin.

The formation has traditionally been subdivided into two members (Fig. 2), the Vardal Sandstone Member and the Ringsaker Quartzite Member. This subdivision was originally erected on petrological evidence (Vogt 1924), based on a gradual upward decrease in feldspar content. In this study, however, a more refined subdivision is suggested. It has been discovered that the formation contains four facies associations which show considerable differences both in macroscopic and microscopic sedimentary characteristics (see below and Figs. 4, 5, 6 and 13). Based on feldspar content only (Q/F-ratio in Fig. 4), it is difficult to locate accurately the boundary between the Vardal Sandstone Member and Ringsaker Quartzite Members. The Q/F-ratio increases in two "cycles', corresponding to the upper Vardal Sandstone Member and the Ringsaker Quartzite Member. Comparison between the vertical facies sequence documented here and the positioning of the Vardal—Ringsaker boundary in earlier publications shows that this boundary usually has been placed above a level corresponding to the upper 'feldspar-peak' in the upper Vardal Sandstone Member (Fig. 4) (e.g. Vogt 1924, Skjeseth 1963, Løberg 1970, Bjørlykke 1979). With this in mind, I suggest that the boundary should be placed at the abrupt upper transition from facies association S to facies association R (Fig. 4). In the studied area, this transition is everywhere marked by the change from subhorizontally laminated well-sorted sandstones to alternating thin sandstones and shales. A 2 m thick shale bed forms the base of facies association R in some areas (e.g. Dalsjordet near Gjøvik). This boundary is kept informal, since it has as yet not been documented elsewhere in the Sparagmite Region. The Vardal Sandstone Member is (informally) divided into three parts (Figs. 4 and 6). The boundary between the lower and middle parts is placed above the uppermost distinct coarsening upwards sequence in the member. The boundary between the middle and upper parts is placed where grey, lenticular cross-bedded sandstones are replaced vertically by a sequence of white, sheet-like and mostly structureless sandstones.

Facies association P: 5—50 m thick coarsening upwards sequences

Description

This facies association consists of laterally continuous shale and sandstone beds, in intervals of variable thickness (5—50 m, Fig. 5). A well-defined coarsening upwards is usually seen.

Most commonly, thin (5—15 cm), parallel-laminated and wave- or current-rippled beds occur, the grain-size of these changing upwards from silt to medium-grained sand. A few cm-thick, normally graded massive beds of coarse-grained sand erode into the CU-intervals. Near the boundaries to facies association Q (Fig. 5), beds containing subhorizontal lamination and low-angle cross-bedding dominate. Concentrations of heavy minerals in laminae exhibiting normal density grading and inverse size grading are quite common here. The degree of rounding and sorting is improved in these somewhat coarser sediments (Fig. 4), and the bed thickness is 20-30 cm.

Facies association Q intervals always seem to erode into facies association P. The reverse transitions (Q to P) are usually sharp (fine-grained sand resting upon very coarse-grained sand). However, in a few cases gradational contacts have been found, displaying fining upwards throughout a few meters of subhorizontally laminated sand. Ripples and cross-beds mostly have foresets dipping to the north, but some low-angle cross-bedding associated with the subhorizontal lamination may dip southwards. Regionally, the sequence becomes more shaly to the north, where wave-rippled silt and very fine sand (often in lenticular bedding) dominate. To the south, facies association P intervals become thinner, more coarse-grained, and are subordinate to facies association Q in the lower Vardal Sandstone Member (e.g. Skonhovd, Fig. 6).

Interpretation

This facies association is thought to represent *delta-front* deposits. The main indicators of this are the coarsening-upward character, the abundance of wave and current ripples, the interbedding with beds of fluvial origin (facies association Q, see below), and the presence of laterally continuous beds containing subhorizontal lamination with heavy-mineral enrichments. This latter feature can be related to beach processes (see facies S4).

The upper parts of the CU units probably formed in shallow-water parts of the deltaic system, where waves and wave-induced currents reworked and redistributed sand along the shoreline.

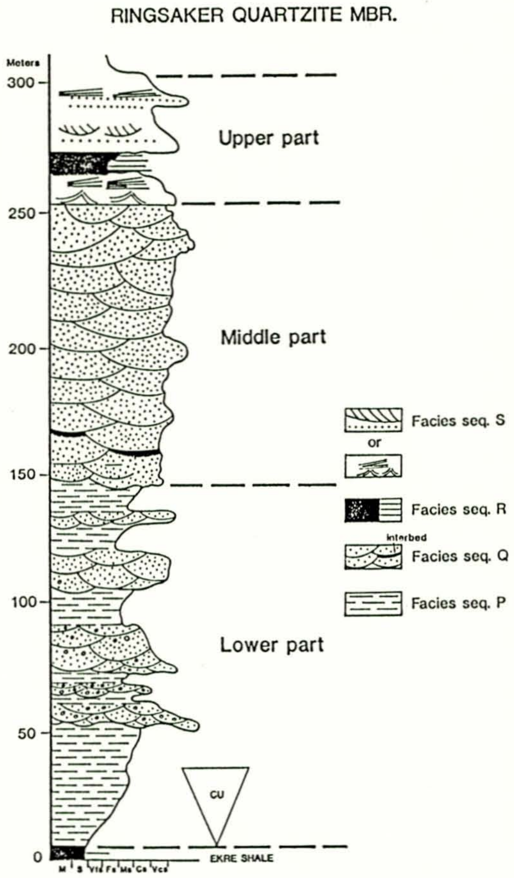


Fig. 5. Vertical log through the Vardal Sandstone Member, incorporating data mainly from the Bråstad/Skulhus areas. The four facies associations in the Vardal Sandstone Member are shown.

The lower parts of the CU sequences are thought to contain more distal delta-front sediments that were formed by suspension fallout in an area influenced by symmetrical wave orbital motions (deeper water or protected bays).

The gradual transition from the brackish (?)marine Ekre Shale, and the scarcity of eroding high-energy events also support a marine origin for facies association P. The dominant northward dip of ripple-lamination and cross-bedding indicates transport to the north. The reversals seen near the top of some CU units may reflect shoaling waves which drive sand back towards the shore (e.g. Clifton et al. 1971). Progradation to the north is also indica-

Facies ass.	*Vertical occurrence*	*Facies*	*Main characteristics*	*Depositional environment*
P: 5—50 m thick CU-sequences	Lower part of Vardal Sst. Mbr.	No subdivision	Cu-intervals, wave-ripples, subhor. lamination, thins sourcewards, laterally continuous beds, medium to fine grained sand.	Deposits of a prograding distal to proximal delta front.
Q: Lenticular coarse-grained sandbodies with fine-grained interbeds.	Common in lower to middle parts of the Vardal Sst. Mbr., rare in upper Vardal Sst. Mbr.	Q1	Erosively based conglomeratic beds, dominant sourcewards (south), ordered fabric, mostly massive, normal grading.	BRAIDED STREAMS Infills of proximal channels, and/or longitudinal bars.
		Q2	Erosively based poorly sorted sandbeds. Crossbedded, rip-up clasts, lenticular, usually 30-60 cm thick. Unidirectional XB-dip.	Interlocking channel-fills, dominated by migrating dunes and sandwaves.
		Q3	Finer grained, mostly flat based sandbeds. Normal grading, parallel-lam./current ripples. Usually 10.25 cm thick.	Sheetfloods/ephemeral stream deposits. Distal end member.
		Q4	Very thin and discontinuous shaly beds, micaceous, current ripples.	Floodplain/abandoned channel fines.
R. Thinly-bedded sandstones with fine grained interbeds.	Near the base of upper Vardal Sandstone Mbr. and at the base of Ringsaker Qtz. Mbr.	No subdivision.	Overall CU. Heterogenous appearance. Wave-ripples at bedtops, undulating lamination near some bed bases. Pinch-and-swell beds. Shale drapes. Variable grain size and bed continuity. Beds often massive, sometimes graded.	Distal parts of shallow-marine system (mainly lower shoreface). Storm generated sandbeds.
S: Cross-stratified, sub-horizontally laminated or massive coarse-grained quartz sandstones.	At the base and in upper 2/3 of upper Vardal Sst. Mbr. Forming most (upper 5/6) of the ringsaker Quartzite Mbr.	S1	Mostly white, massive beds. Amalgamated. Some dishes & pillars. Transgressive lag at base. Negative skewness.	"Transgressive' deposits formed by fluvial discharge into a "rising' sea (reworking of minor lobes).
		S2	Sandbeds of high lateral continuity, containing pebbly foresets, pebble stringers & pebbly scour pockets.	Storm-dominated shallow-marine beds deposited between outer breaker zone & lower shoreface.
		S3	Mature quartzite, laterally continuous sandbeds. Multidir. XB. Small-scale cyclicity (Fig. 22). Mostly flat bases.	Longshore bars & troughs, rip channels (upper shoreface).
		S4	Very mature quartzite. Subhor. lamination. Heavy minerals. Capping the sequences.	Beach face.

Table 2. Facies associations, facies and their characteristics in the Vangsås Formation.

ted by the presence of thinner, coarser and more ill-defined facies association P-intervals in the south. In the 'proximal' southern exposure, this facies association has apparently pinched out. The cause of the cyclic alternations between facies associations P and Q will be trated in the section on basin evolution.

Facies association Q: Lenticular coarse-grained sand bodies with thin fine-grained interbeds. Description

General

This facies association constitutes all of the middle Vardal Sandstone Member, 25—75%

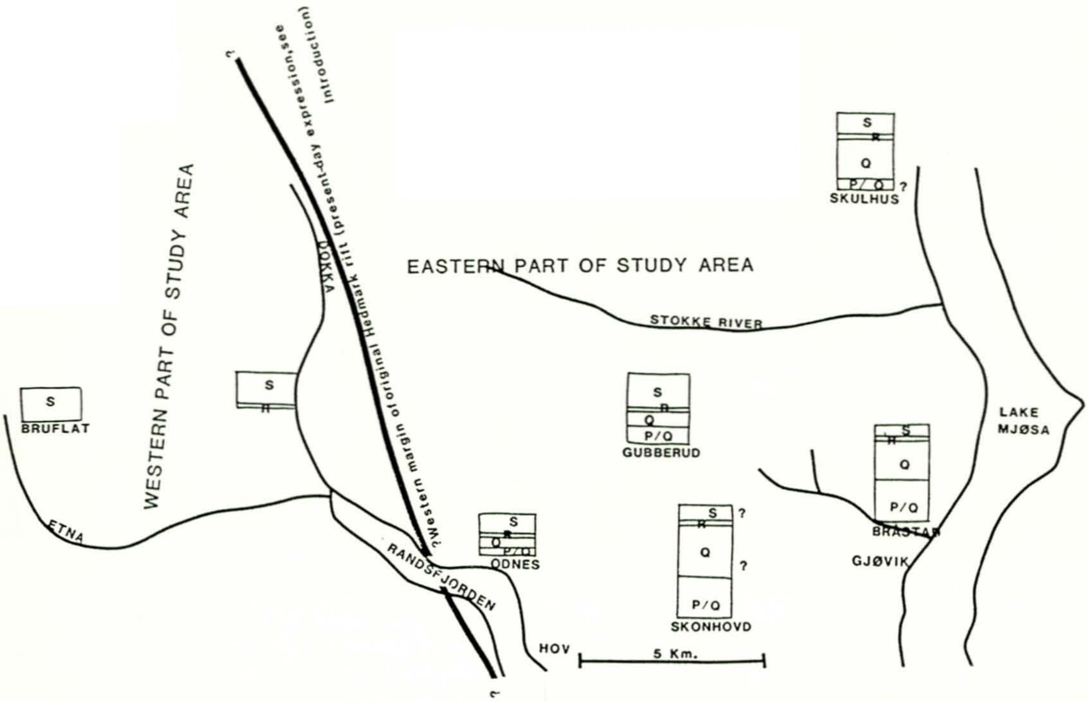


Fig. 6. Distribution of facies associations P, Q, R and S (Vardal Sandstone Member) within the study area. The NNW-trending line indicates the suggested post-thrust position of the ancient western margin of the rift-basin (see introduction). In the vertical column, 7 mm equals 100 m of sediments.

of the lower Vardal Sandstone Member (most prominent in the south), and 5–10% of the upper Vardal Sandstone Member. It can be subdivided into four facies (Table 2). Facies Q1, Q2 and Q3 may collectively be referred to as the coarse member, while facies Q4 may be termed the fine member. Note that this facies association contains 98% coarse member beds. These beds are poorly to moderately sorted, as well as texturally and mineralogically immature (Fig. 4). The sorting is poorest and the beds coarsest and most feldspar/rock fragment-rich towards the south. Beds vary in average thickness from 3 m (southern parts) to 25 cm (extreme north or west). Usually they are vertically stacked (mutually erosive, Fig. 7), though in some cases discontinuous fine-member beds are present in between. Sometimes the lower bounding surfaces may be strewn with mud rip-up clasts, or rarely, well-rounded quartz pebbles.

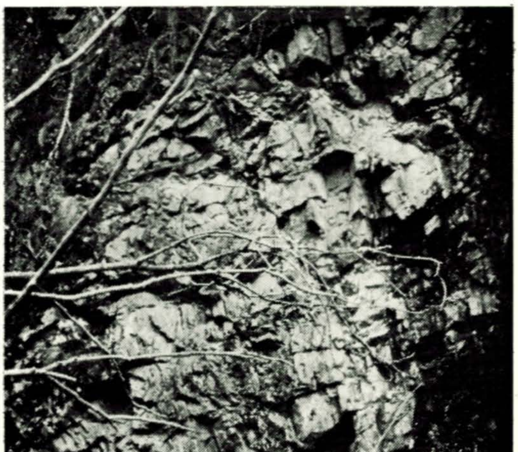


Fig. 7. View (normal to paleoflow direction) of a 10 m high section through the coarse member beds in facies association Q. Note the erosional lower bases, and the lenticularity of the beds. From the Bråstad river.

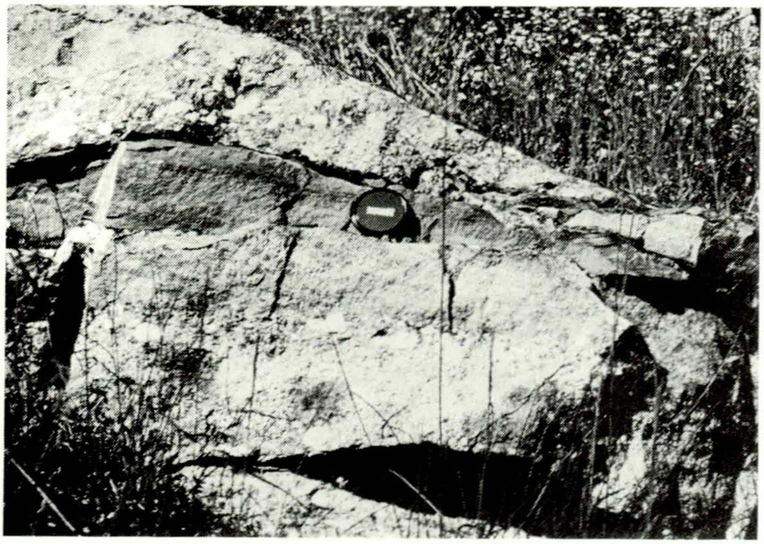


Fig. 8. The Vardal conglomerate (facies Q 1), exposed near Mæhlum, map-sheet "Gjøvik'. Note the mostly clast-supported nature of the conglomerates, and the alternations with cross-bedded to massive coarse-grained sand (facies Q 2).

Facies Q1: Conglomeratic beds (Fig. 8)

These beds dominate in the south, especially at Skonhovd and Hov (Fig. 6, the "Vardal conglomerate' of Skjeseth, 1963). Sandstone interbeds between the conglomerates become more numerous northwards. The conglomerates occur in erosively based lenticular bodies with a maximum clast size of about 10 cm, but all clast sizes between this and coarse-grained sand seem to be present. The conglomeratic beds appear to be of the *ordered fabric type* (Steel & Thompson, 1983). They are usually

Fig. 9. Deformed tabular cross-bed (facies Q 2). Note also the presence of a dark, lenticular fine member bed (facies Q 4), and the unidirectional dip of the cross-bedding. The vertical distance from bottom to top in this picture is 2.20 m. From the Skulhus locality.

clast-supported. The clasts are commonly imbricated, with the intermediate axis plunging towards the south or southeast. Most conglomeratic beds are massive, but crude horizontal stratification can sometimes be seen (Fig. 8). Coarse-tail normal grading is common in these beds. The amount of sandy matrix rarely exceeds 20%.

Facies Q2: Poorly sorted cross-bedded sandstones (Fig. 9)

The sandstone beds have grain-sizes varying from fine- to very coarse-grained. They are commonly arranged in thickening and thinning sequences some five to fifteen metres thick, generally accompanied by subtle coarsening and fining trends in grain size (usually in the form of CU-FU or FU-CU sequences). Internally, the interdigitating network of lenticular beds are rich in sedimentary structures. Medium- to large-scale trough and tabular cross-bedding (Fig. 10) dominates, especially in proximal (southern) to middle areas (e.g. Skulhus section, Fig. 6). The cross-beds are usually of the high-angle type, with dips towards north and northwest (low paleocurrent spread). The largest ones (50 cm—1.20 m thick) commonly exhibit variation in grain size from foreset to foreset. Parallel-laminated and massive intervals also occur, and current ripples are present near the top of some beds. Detailed logs through this facies are given in Fig. 11 (A and B).

Facies Q3: Fine- to medium—grained thinly bedded sandstones (Fig. 10)

These beds become increasingly more common northwards, and dominate in the Bratteng section (Fig. 10). The beds are characterized by their thin-bedded nature. Other distinctive features are the low-relief basal contacts, the ubiquituous normal grading, the common parallel-lamination to ripple-transitions, and the increased amount of fine-grained interbeds.

Facies Q4: Shaly interbeds

These occur as very thin (usually between 3 mm — 3 cm) intercalations between the coarse member beds. The shale beds can rarely be traced laterally for more than a few metres (a maximum extent of 100 m has been observed). They are dark-coloured, and locally mica-rich. Som lenses of fine-grained current-rippled sand occur in the thicker interbeds.

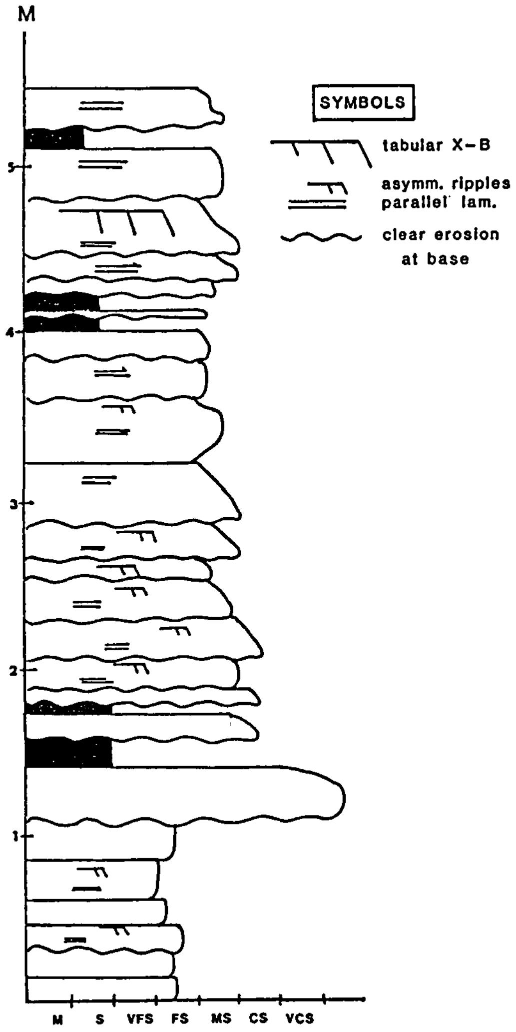


Fig. 10. Detailed log through facies Q 3, Vardal Sandstone Member. Locality: Bratteng, about 3 km north of Redalen (map-sheet "Gjøvik'). See text for discussion.

Lateral and vertical relationships

Fig. 12 summarizes the salient features of large-scale lateral variability in this facies association.

Regarding the vertical sequences, a remarkable uniformity is present within any single exposure. The implications of this will be discussed below.

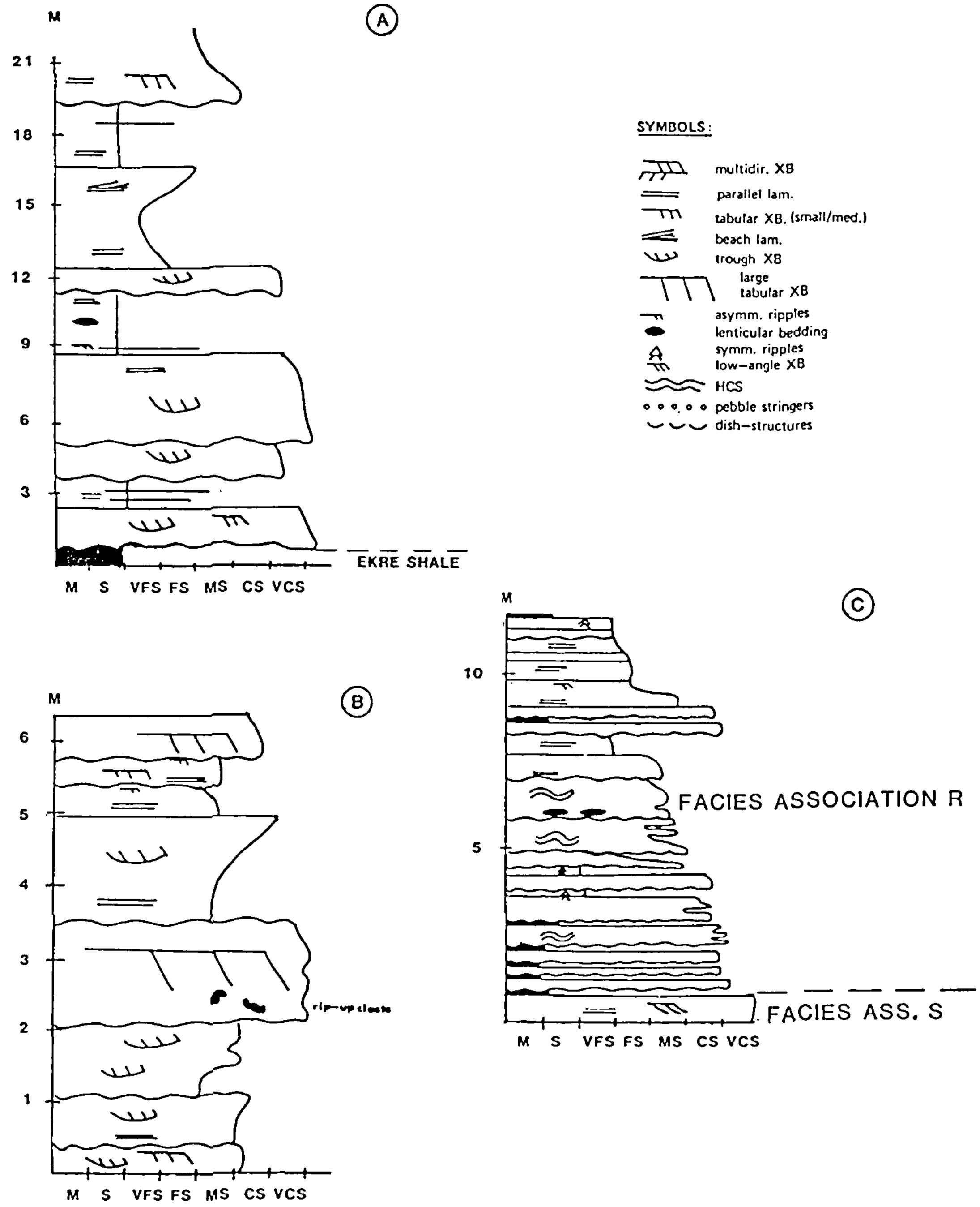


Fig. 11. Detailed logs from various sedimentary sequences in the Vardal Sandstone.
A) The erosive transition between the Ekre Shale and the Vardal sandstone at the southern outcrop by Lake Mjøsa. The sediments are interpreted as interdistributary bay deposits (fine-grained parts) and delta plain channel deposits (facies Q 2). B) Stacked braided channels with evidence of fluctuating discharge (Skulhus section, facies association Q). C) Lower half of storm-bed assemblage, facies association R, upper Vardal Sandstone Member at Skulhus.

Facies association Q: Interpretations

General

It has been suggested by previous workers in the Sparagmite Region that sediments corresponding to facies association Q of the Vardal sandstone accumulated in proximal to distal alluvial fans (easternmost Sparagmite area) or in a fluvial setting (Bjørlykke et al. 1976, Bjørlykke 1979, Nystuen 1982). The data presented here seem to conform well to such an overall fluvial/alluvial fan-depositional model.

Many of the observed features indicate deposition by northward-flowing unidirectional currents in a subaerial setting:

1) Low divergence of paleocurrent data.
2) Textural and mineralogical immaturity (Fig. 4).
3) Well-developed lateral fining and thinning trends away from an inferred southern source area.
4) An assemblage of sedimentary structures that indicates varations in discharge and depth of flow through time.
5) Closely spaced erosional surfaces.
6) Lenticular sedimentary bodies.
7) Coarse-grained nature of the deposit.
8) Absence of any clear marine or aeolian indicators.

The mutually cross-cutting sand-bodies with mostly random structural and grain-size variations are thought to represent channel deposits. These are dominated by unidirectional (northwards-dipping) medium-scale trough or tabular cross-bedding, indicating deposition in an ancient fluvial system containing a complicated network of braided channels. In these depositional tracts, a fluctuating discharge regime produced repeated CU and FU cycles as well as the downcurrent migration of various types and scales of bedforms. A comparison with similar modern and ancient fluvial deposits strongly suggests a *braidplain* setting for these sediments, perhaps with a transition to alluvial fan at the proximal (southern) end (Harms et al. 1982, Miall 1977, Williams 1971). Long (1978) showed that an overwhelmingly large part of Precambrian fluvial systems were braided in nature.

Facies Q1

In the *proximal* end of the spectrum, the coarse member beds consist mainly of ordered-fabric conglomerates. This facies type is thought to represent waterlain, multistorey longitudinal bar accumulations and conglomeratic channel-fill deposits (e.g. Nemec & Muszynski 1983, Miall 1977). This is indicated by the elongation of these sedimentary bodies parallel to the transport direction, and by their lenticular shape in a direction normal to this. Further, the many erosion surfaces, the upstream-dipping imbrication, the crude normal grading and the diffuse stratification or massive clast-supported appearance strengthen this theory. The alternation between conglomerates and sandstones is characteristic of proximal braided rivers with a "flashy' discharge. The detailed origin of longitudinal bars has been reviewed by Miall (1977) and Hein & Walker (1977).

Facies Q2

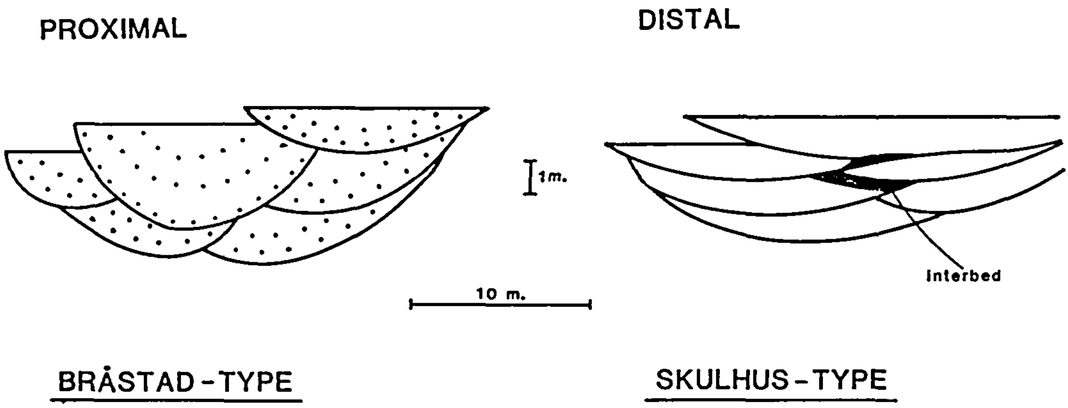
These broadly lenticular erosive beds reflect deposition in the channelized parts of the braided stream system. The largest tabular cross-beds with rapid grain-size variations on foresets are interpreted as transverse bars (e.g. Smith 1972). The ubiquitous smaller cross-beds probably represent migrating dunes and sandwaves (Harms et al. 1982). Where fining-upwards is seen, this may be related to waning flow-power. Coarsening-upwards intervals might indicate increasing flow-power through time, or the migration of in-channel bars.

Facies Q3

The erosively based, thin-bedded, parallel-laminated to rippled sandstones found in the northern parts of the study area (Fig. 10) are interpreted as the *distal* end-member of this braided system. These deposits are so strikingly similar to the *sheet-flood and ephemeral flow-deposits* of Tunbrigde (1982) and McKee et al. (1967) that a similar origin must be envisaged here. The normal grading, sheet-like bed geometry and parallel lamination to ripple transitions suggest deposition from non-channelized flows which experienced a quick loss of energy. The fine-grained interbeds and drapes probably represent suspension fallout between floods (see below).

Facies Q4

The discontinuous nature of these fine member beds, together with their structural assemblage and infrequent occurrence between lenticular sand-bodies, suggest that they accumulated in abandoned channel reaches, floodplain ponds or simply as overbank material in interchannel areas (e.g. Williams 1971, Cant &



BRÅSTAD - TYPE	SKULHUS - TYPE
1) Lenticularity moderately to well developed.	1) More sheetlike sandbodies.
2) Very coarse sand mean grain size.	2) Coarse sand mean grain size.
3) Conglomeratic beds moderately common.	3) Conglomerates rare.
4) Beds usually thicker than 0.5m.	4) Beds usually thinner than 0.5m.
5) Few fine-grained interbeds.	5) Fine-grained interbeds moderately common.
6) Trough XB dominant bedding type.	6) Trough XB only slightly dominant over tabular XB.

Fig. 12. Lateral variations in facies association Q fluvial sandbodies. The terms proximal and distal refer to the positions of these exposures (types) relative to each other and not to the entire basin.

Walker 1976). The scarcity of these interbeds may indicate a lack of fine-grained material (insufficient weathering in the source area?) or a low preservation potential for these deposits, or probably both. Their discontinuous nature may also have two causes; first, they may have accumulated in a laterally restricted area (ponds on floodplains, abandoned channels), or second, they may have been subjected to erosion during the next channelized sedimentation episode.

Interpretation of lateral and vertical trends

The lateral trends described earlier (Fig. 12) indicate that the source area for these sediments lay to the south. The transition from proximal (conglomeratic, facies Q1) braided stream sediments, via braidplain sediments (facies Q2) into sheetflood deposits (facies Q3) suggests a quite rapid reduction of slope to the north. The system became systematically less channelized as flow-power diminished distally. As can be seen from Fig. 6, facies association Q is absent from the areas west of the "rift-margin' line (see Introduction and Basin evolution).

As mentioned, most facies association Q intervals exhibit a uniform vertical development, contrasting with their notable lateral variability. Together, the vertical and lateral relationships reflect vertical stacking in facies belts which for long periods appear to have been in a more or less fixed position with respect to the source area. This requires some kind of long-term equilibrium between sediment supply, subsidence and sea-level changes.

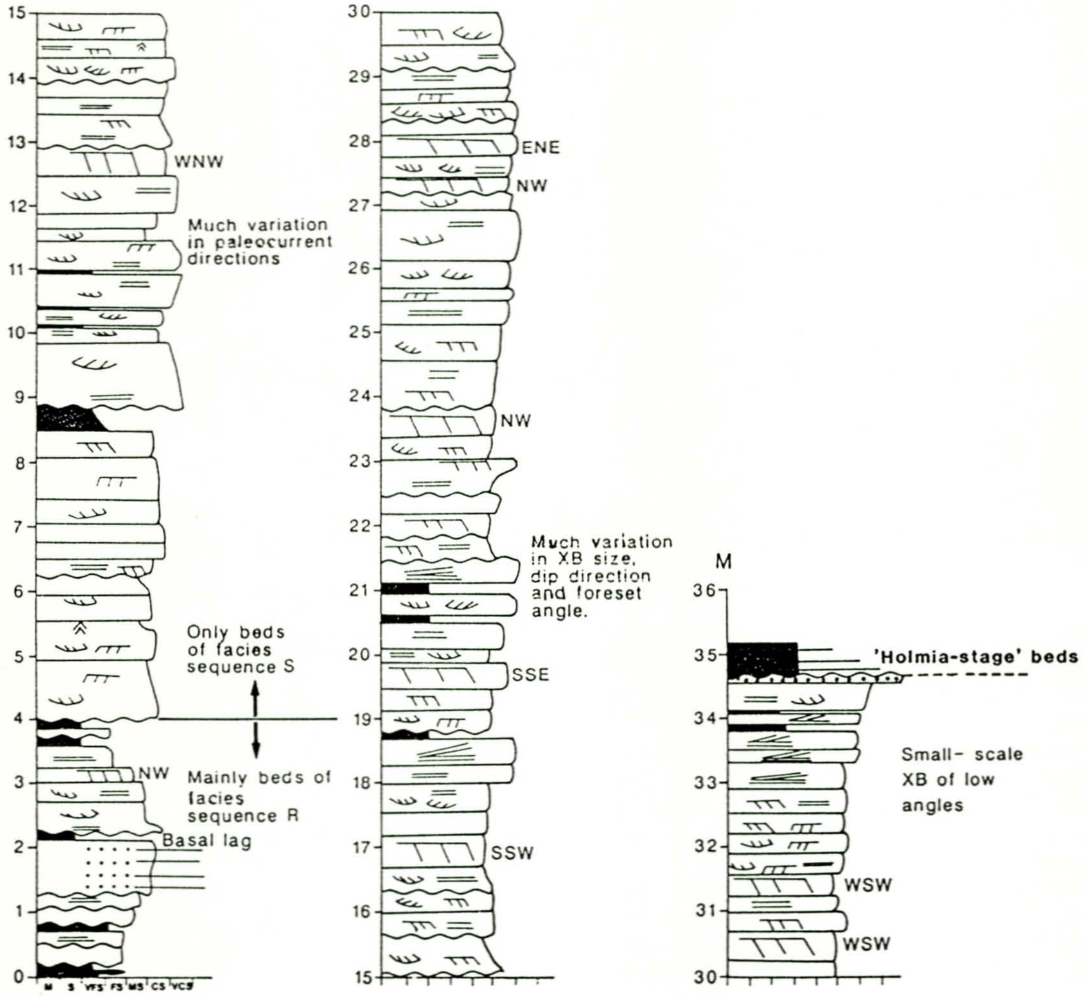


Fig. 13. Log through the Ringsaker Quartzite Member, from Dalsjordet (north of Gjøvik, Fig. 1). See text and Fig. 21 for interpretations of the complex structural assemblages, and Fig. 11 for symbols.

Facies association R: Thinly bedded sandstones with fine-grained interbeds. Description

This facies association occurs in two separate intervals, one near the base of the upper Vardal Sandstone (Figs. 5 and 11 C), the other at the base of the Ringsaker Quartzite Member (Fig. 13). Both intervals are present over most of the studied area (Fig. 6). An overall coarsening-upwards is evident in both intervals, facilitated by the disappearance of shaly interbeds and an increase in pebbly material. The sandstone beds are between 5 and 40 cm thick, and are commonly amalgamated. The grain size ranges from fine-grained sand (very rare) to granules, with coarse-grained sand being most common. The sand-beds have low-relief erosional bases. The structureless to symmetrically rippled muddy or silty *interbeds* are rarely more than 3 cm thick, but near the base of the Ringsaker Quartzite these interbeds become thicker and more numerous. The maximum thickness of shale here is 2 m. The interbeds commonly drape the topography of underlying sand beds (Fig. 14).

Three types of sand-beds can be recognized. Lowest in the facies association, beds with parallel or gently undulating lamination in mostly medium-grained sand (Fig. 11 C) are numerous. In some cases, these beds have a top of fine-grained, wave- or current-rippled

Fig. 14. Section through beds of facies association R present in the upper Vardal Sandstone Member at Skulhus. Note the two pinch-and-swell beds (one by the 30 cm-long hammer), the shale-drapes above these (conforming to their shape), the gently undulating lamination in other beds (see inked line), and the mainly symmetrical ripples in some of the interbeds.

sand. The undulations only occur in the basal part of these beds, which otherwise appear to be massive. They resemble the undulating parallel laminations described by Duke (1983).

Another bed type, normally occurring slightly higher in the association, contains coarse-grained sand with a strongly undulating (pinch-and-swell) *upper surface* and a nearly flat erosive base (Fig. 14). These beds lack visible internal structures. Outcrop studies indicate that the pinches-and-swells are 3-dimensional in shape, and that their "topography' is always covered by a shale drape. Dips on the flanks of ridges may reach 20°. The third bed type is the most coarse-grained (containing some pebbles), and dominates in the upper half of facies association R. These beds are ungraded, massive or diffusely parallel-laminated, and have notable erosional features at their base.

The beds of facies association R display a lateral continuity that varies from 25 m to more than 200 m in all directions.

Facies association S: Cross-stratified, subhorizontally laminated or massive coarse-grained quartz sandstones. Description

General

This facies association comprises most of the Ringsaker Quartzite and upper Vardal Sandsto-

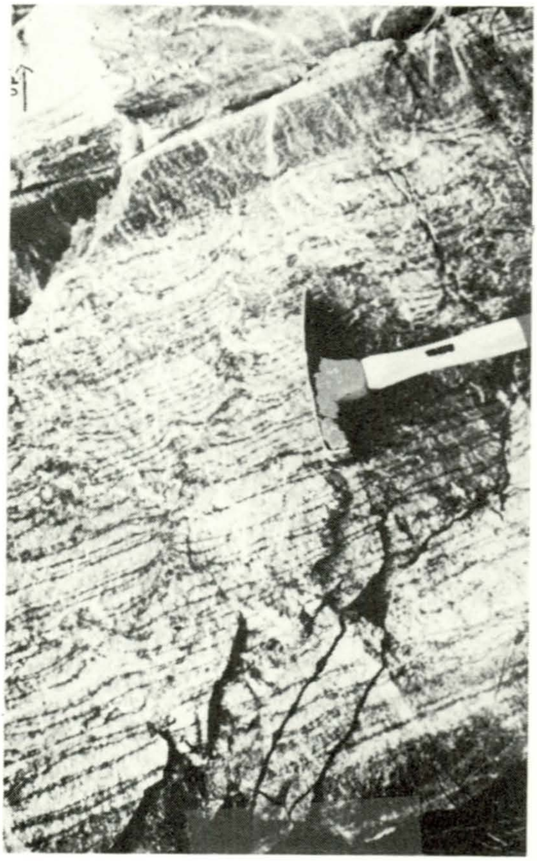


Fig. 15. Bed in facies S1, at Skulhus, displaying dishes and pillars. The dark material outlining the dishes is clay/silt.

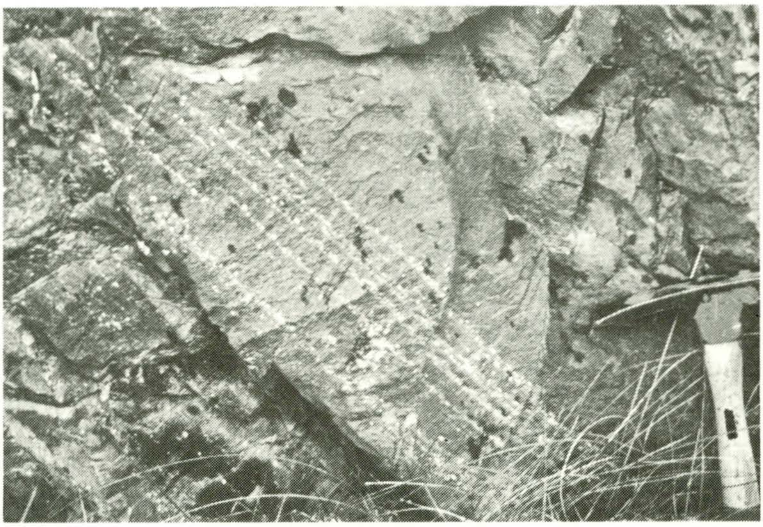


Fig. 16. Thin pebble-stringers in laterally continuous beds (facies S2). Note well-segregated and sheet-like nature of these thin stringers. From the Skulhus section.

ne Members (Figs 5 and 13). The relationships to surrounding facies associations can be seen from these figures. The amount of fines in this facies association is remarkably low, about 1% (grey, laterally continuous shale beds). The facies association is divided into four facies (Table 2). Common to all of these are lateral bed continuity, dominance of quartz grains, a fairly constant bed thickness (usually 30—50 cm, maximum 2 m), a decrease in mean grain-size northwards, and sharp bed boundaries which usually lack erosional relief.

Facies S1: White, mostly massive beds (Fig. 15)
This facies is only present at the base of the upper Vardal Sandstone Member (Figs. 2 and 5), where it overlies facies association Q. At the base, a 3 cm-thick laterally persistent layer of conglomeratic clasts is present. Another lag-deposit (15 cm thick) occurs in the middle of this facies. In western parts of the study area, where the lower and middle parts of the Vardal Sandstone Member are absent, this facies forms the base of the Osen-Røa Nappe Complex (Fig. 2). Individual beds are sheet-like with low-relief erosional bases, and their thickness varies from 50 cm to 2 m. In the field, their clean white appearance makes them into something of a marker horizon. Internal structures are scarce in these very coarse-grained beds, although well-defined dish- and pillar-structures (Fig. 15) and some subhorizontal lamination occasionally disturb their monotonous massiveness. The white colour is mostly due to calcite dementation and light-coloured grains of quartz and plagioclase feldspar.

Well-rounded, 1—3 cm large, vein-quartz fragments have been observed floating in a sandy matrix in several facies S1 beds. Texturally, the white massive beds are distinctly negatively skewed (Fig. 4).

Facies S2: Pebbly beds (Fig. 16)
This facies overlies facies association R with a gradational contact in both the upper Vardal Sandstone Member and the Ringsaker Quartzite Member, the former occurrence being the most notable (e.g. Skulhus section, Fig. 6, where these beds are 20 m thick). The pebbles (mostly vein quartz) sit in beds of mostly medium-grained sandstone. A distinct vertical structural sequence is seen in these beds (Fig. 20). Lowest in this facies, well-rounded pebbles form 1-layer thick bands that have a wide lateral extent (pebble stringers, Fig. 16). These stringers lack signs of basal erosion, and stand out from the sand beds in which they lie. Vertically, they are replaced by pebble-filled scour-pockets which erode into the stringers (Fig. 20). The pebbles are densely packed and form a massive fabric. The scours are 10—25 cm deep and asymmetrically spoon-shaped. Stratigraphically upwards, these scours are overlain by low-angle tangential cross-beds in which pebbles and coarse to very coarse-grained sand alternate on the foresets. In several cases cross-beds can be seen to merge laterally into parallel-laminated or massive

Fig. 17. Large-scale tabular cross-bedding (facies S3, Ringsaker quartzite), overlain and eroded by parallel-laminated coarse-grained sand. Note the high angle of foreset dip (towards the north, allowing for tectonic tilt), planar foreset base, and lack of reactivation surfaces. From the Dalsjordet road-cut.

sand. These beds usually have a southward dip.

Facies S3: Quartzites with multidirectional cross-bedding (Fig. 17)

These texturally and mineralogically mature beds dominate in the Ringsaker Quartzite Member (Fig. 13), but play a subordinate role to facies S4 in the upper Vardal Sandstone Member. The most common sedimentary structure is that of cosets of multidirectional, low- to medium-angle cross-bedding. Trough cross-bedding is slightly more common than small- to medium-scale tabular cross-bedding. The height of these cross-beds usually varies from 10 to 20 cm, and as can be seen from the paleocurrent summary (Fig. 18), sand transport was multidirectional, although the dominant flow was towards N to NE or W to SW. In extreme cases, five to ten successive beds may display almost as many different foreset migration directions.

Though volumetrically much less important, large-scale high- to medium-angle tabular cross-beds (Fig. 17) are perhaps the most distinctive single feature of this facies. These cross-beds have mostly planar bases, and are usually present as simple sets. They may be up to 1.1 m in height, though 50 cm is a more common figure. Along an E-W trend the cross-beds may continue for more than 100 m. E-W trending cross-beds are normally smaller than ones with N-S trends and may occur as superimposed tabular sets. The large-scale, high-angle cross-beds are commonly mixed with smaller cross-beds or parallel-laminated beds.

Beds with *erosional* lower bed boundaries are a rare but conspicuous feature of facies S3. These beds contain mostly massive, coarse- to very coarse-grained sand, sometimes with a pebbly bottom layer. In the upper parts of these beds, trough and tabular cross-beds with mostly northward dips are present. These quartzite beds may be over 1 m thick, and are lenticular along an E-W trend. A fining-upward tendency is seen in most of these beds.

Facies S4: Subhorizontally laminated quartzites (Fig. 19)

Beds in this facies display the highest textural and mineralogical maturity, and the highest lateral continuity, of all beds in the Vangsås Formation (Fig. 4). They cap both the upper Vardal Sandstone and Ringsaker Quartzite Members (Figs 5 and 13). In the upper Vardal Sandstone Member, 5—15 m-thick intervals containing beds of facies association Q occur intermixed with these mature beds (Fig. 20). The subhorizontally laminated beds (Fig. 19) dip at very low angles (2-5°) towards the north. The laminations are defined either by alternating layers of varying grain size, by alternating

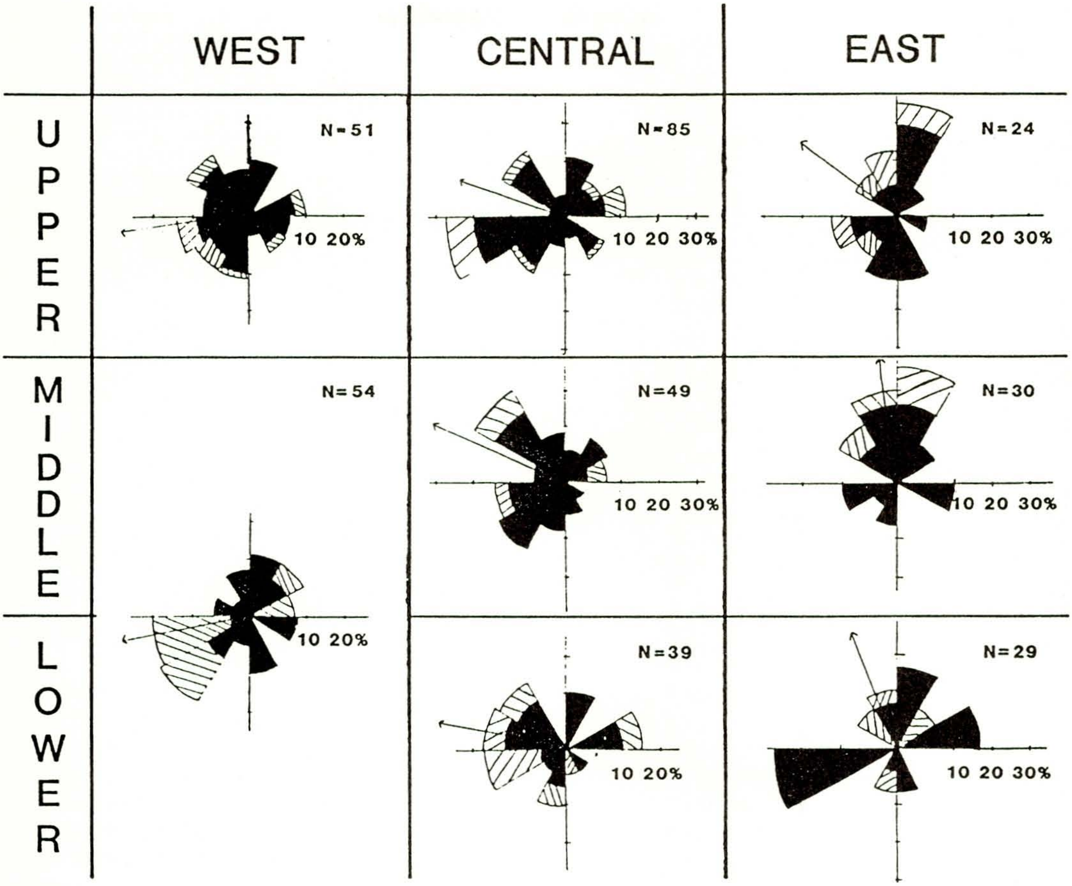


Fig. 18. Paleocurrent rose diagrams for various intervals of the Ringsaker Quartzite Member in the eastern, middle and western parts of the study area. The data are plotted at 30° intervals. The arrow indicates the vector mean (which has little meaning for these beds, Dreyer 1985).
The black areas represent trough cross-bedding and the cross-hatched areas tabular cross-bedding. Both cross-bedding and rib-and-furrow structures were measured.

lighter and darker layers, or by a combination of the two. As shown in Fig. 19, these laminae display inverse size grading, whereas the density grading is normal (Clifton 1969). At the top of the Ringsaker Quartzite Member, beds of this facies are capped by a 2–20 cm-thick pebbly lag-deposit, before "Holmia-stage' shales take over. The upper few centimetres of this lag-deposit are commonly phosphorite-cemented. Several smaller top-surface lags occur within facies S4.

Facies association R and S: Interpretations

General

The Ringsaker Quartzite Member has for a long time been regarded as a shallow-marine deposit (Vogt 1924, Skjeseth 1963, Bjørlykke et al. 1976, Nystuen 1982). As yet, no convincing interpretation has been made of the depositional environment of the similar upper Vardal Sandstone Member. Generally, these latter beds have been grouped with the fluviodeltaic middle and lower Vardal Sandstone Member, but the possibility of marine influence has been raised at least once (Bjørlykke 1979, commenting upon phosphorite bands in these beds). Results of the present study strongly suggest that facies sequence R and S beds in both the upper Vardal Sandstone and the Ringsaker Quartzite Members were deposited in a shallow-marine setting. The main points of evidence in favour of this are:

1) High lateral continuity of beds.
2) Dominance of planar bed boundaries.

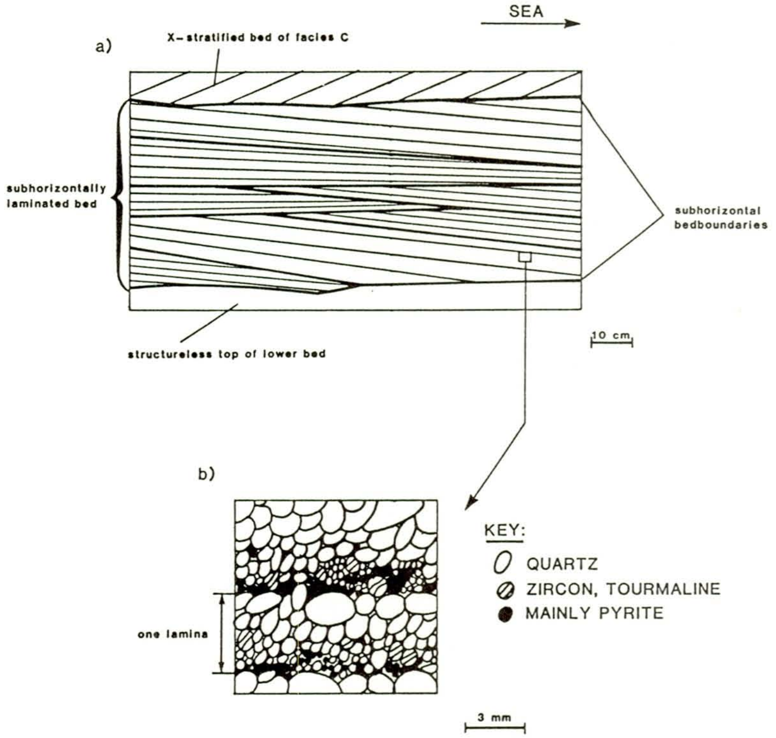


Fig. 19. A) Field-sketch of facies S4 bed containing subhorizontal lamination, formed in the swash zone. Note the seaward dip of the lamina, and the generally low-angle truncations.
B) Detail of lamination, drawn from observations with the petrographic microscope. Notice the rather sharp boundary between the lamina, and the normal density grading and inverse grain-size (quartz) grading.

3) Multimodal paleocurrents.
4) Mature mineralogy and high textural maturity, despite source rocks being rich in unstable minerals.
5) Top-surface lags.
6) Marine trace fossils and phosphorite bands (Skjeseth 1963, Bjørlykke 1979).
7) Large areal extent of facies associations.
8) Inverse grading (grainsize) and normal grading (density) within laminae.
9) Dominance of low-angle cross-bedding.
10) Scarcity of channelling.

The total dominance of coarse-grained material and the large areal extent of these members suggest deposition under high-energy conditions in an extensive shallow-marine sea.

Detailed discussions about how a laterally extensive marine sequence can become so totally dominated by very coarse material is outside the scope of this paper. It should however be pointed out that any model which seeks to explain this must incorporate processes which enable either tides, waves, or wave-induced currents to keep the water-masses agitated. Either this agitation persisted "constantly' over large areas, or a mechanism existed which allowed quick back-and-forth sweeps of a high-energy zone (in both cases preventing the settling of fines; see Gjelberg et al. 1987). In the present case, waves and wave-induced currents seem the most likely candidates for providing the required energy, as no signs of tidal activity have been observed (compare with DeRaaf & Boersma 1971, Anderton 1976 and Johnson 1978). All features of facies associations R and S can in fact be satisfactorily explained by considering a *storm-dominated barred near-shore system* as the depositional setting for these sediments (Davidson-Arnott & Greenwood 1976, Hunter et al. 1979, Shipp 1984, Greenwood & Mittler 1985).

The vertical sequence of structural assemblages, textural variations and lithology types (Figs. 5, 13 and 20) indicate that facies associations R and S together form two major upward-shallowing near-shore marine cycles. The lower cycle comprises the upper Vardal Sandstone Member, while the upper cycle contains the Ringsaker Quartzite Member. The facies will be interpreted according to this shallowing trend, starting with the presumable most deep-water facies.

A summary of this shallowing is given in Fig. 20.

Facies association R

Several factors indicate that the beds of this facies association were deposited in distal parts of the shallow-marine, barred setting. Briefly, these are: their basal position in the overall prograding sequences (Fig. 20), the increasing dominance of these beds away from the inferred southern source area, and the greater percentage of clay or silt interbeds in this facies association compared to facies association S. Further, the thinly bedded nature and lower textural and mineralogical maturity of these beds, along with their higher frequency of wave ripples and finer mean grain size, support a more distal setting. The high percentage and frequent amalgamation of coarse-grained sand-beds convincingly demonstrate that storm events dominated over fair-weather processes, or at least that the deposits of these high-energy events had by far the highest preservation potential. The most likely depositional agent for the facies sequence R sand beds seems to have been storm-generated surges or geostrophic currents (see reviews in Dott & Bourgeois 1982, Swift & Rice 1984). These currents carried material eroded from the foreshore or upper shoreface into deeper water.

The three bed types mentioned in the description are interpreted in terms of deposition from waning storm-flows in progressively deeper water. The massive and ungraded coarsest-grained beds (Fig. 11 C) probably formed in relatively shallow water by very quick dumping of only the coarsest part of the load (storm beds type II, Fig. 20). Slightly more offshore, the remaining coarsest fraction fell out as internally massive but externally hummocky-shaped *(pinch-and-swell)* beds (Fig. 20, lower drawing). Here, gravitational pull still forced the released load to fall out more or less as one thick "lamina', but since the water particles near the bottom now approached a more elliptical orbit, the depositing sand was moulded into the observed ridges and mounds. Fair-weather (post-storm) mud beds were preserved at this depth, draping the pinch-and-swell topography. In an even more offshore position, beds with normal grading, wave ripples and undulating to parallel lamination may have formed. The sedimentary load had by then lost its coarser fractions, and the remaining sand grains settled out incrementally from the waning flow. This enabled the basinal processes to shape the individual laminae into a forerunner of hummocky cross-stratification (Dott & Bourgeois 1982). These latter bed types are collectively called storm beds type I in Fig. 20.

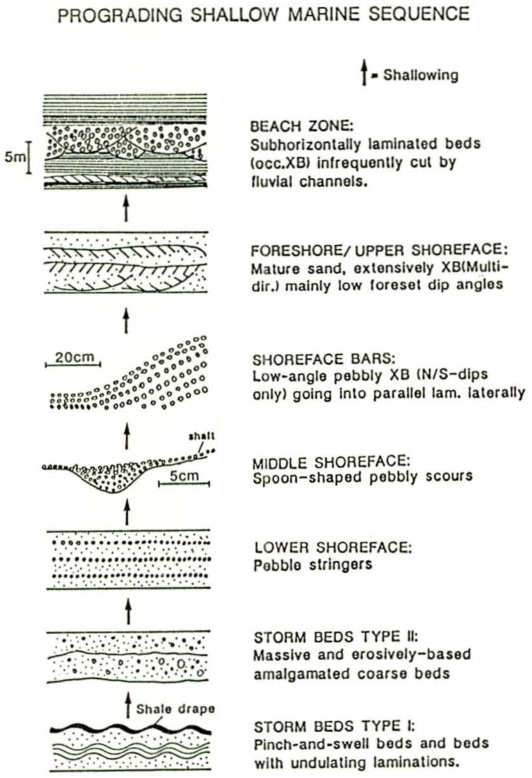


Fig. 20. Presentation of the main sedimentary characteristics in a vertical sequence through facies associations R and S. Microenvironmental interpretations of this sequence (text on figure) indicates an overall upwards shallowing (regression).

Facies S1

These postulated marine beds are either directly overlying the fluvial sediments of facies association Q, or they form the base of the Osen-Røa Nappe Complex in the west (fig. 2). The laterally continuous conglomeratic lags at the base and in the middle of this facies are thought to be winnowed deposits (Levell 1980) formed as the sea transgressed these areas. The sheet-like, texturally mature and negatively skewed nature of these beds imply that they may represent near-shore (beach?) deposits (see facies S4). This is supported

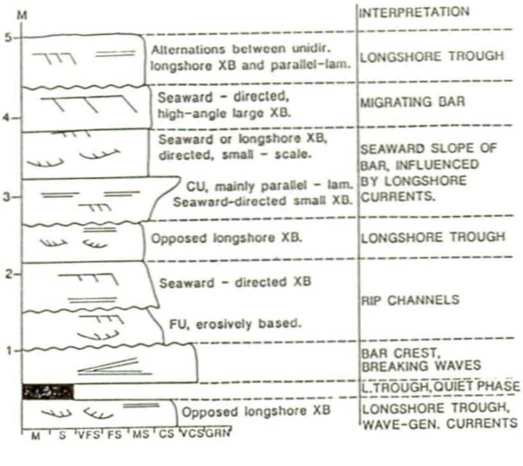


Fig. 21. Detailed interpretation of part of Fig. 13, highlighting the barred nature of this shallow-marine sea. This sequence is thought to have formed by the seaward migration of a bar/trough couplet (e.g. Greenwood & Mittler 1985). Symbols as in Fig. 11.

by the presence of subhorizontal lamination (Fig. 19). A fluvial influence is indicated by the high feldspar content, the generally massive nature (suggesting rapid deposition) and the very coarse grain size (including large floating pebbles). The most likely depositional scenario for these beds is illustrated in Fig. 23. Here, flashfloods in a marginal marine setting led to short-lived progradations of sheetflood-dominated lobes into the sea. After the progradational pulse had ended, the lobes were reworked by wave processes, which spread the lobe-accumulations out into sheets (e.g. Hine & Boothroyd 1978). The final deposit is thus characterized by combined fluvial and marine processes.

The massive nature of these beds may be ascribed to waves washing out much of the primary bedding and sedimentary structures. It may also have induced liquefaction processes (Fig. 15) by creating excess pore-pressures in the newly deposited grain framework (e.g. Lowe & LoPiccolo 1974).

Facies S2

The pebbly beds continue the shallowing-upwards trend which started with the distal stormbeds of facies association R. The stratigraphic position and character of these beds suggest that they accumulated in a lower shoreface environment. Laterally extensive pebble stringers (Fig. 16) are, in this context, probably related to winnowing and rolling along the bottom caused by storm surges (e.g. Bourgeois & Leithold 1984, Swift & Rice 1984).

The pebbly scours (Fig. 20), which in some cases erode into the stringers, possibly formed by storm-induced erosion seaward of the breaker zone (Bourgeois & Leithold 1984). The spoon-shaped depressions that were generated soon afterwards became infilled by the coarsest load set in motion by these currents. The final type of pebbly beds, the southward (landward) -dipping low-angle cross-beds, may represent low-amplitude longshore (swash) bars (Bourgeois & Leithold 1984, Roep et al. 1978). Due to the restricted lateral extent of the breaker zone, these quickly wedge out in a direction normal to the inferred shoreline. The lateral replacement of these crossbeds with parallel-laminated sand exemplify the pinch-out of these longshore gravel bars (Fig. 20).

Facies S3

These extensively cross-bedded sediments occur between lower shoreface (facies S2) and foreshore (facies S4) beds, and can be inferred to have accumulated in an upper shoreface setting. Independently, this is also suggested by the high textural and mineralogical maturity of these beds, by the scarcity of structures formed by lower flow-regime processes, by the lack of fine-grained material, and by the abundance of low-angle cross-bedding.

The complex suite of variously scaled cross-bed types mixed with parallel-laminated to massive beds resembles the sedimentary sequence which forms in modern longshore bar-dominated settings. Here, waves and wave-induced currents, (swash, backwash, longshore drift, rip-currents, storm surge ebbs) have a profound effect on sediment disperal (e.g. Hunter et al. 1979, Davidson-Arnott & Greenwood 1976). Shallow-marine "cycles', possibly generated by slow seaward progradation or aggradation of several bar-trough couplets (Hunter et al. 1979, Greenwood & Mittler 1985) have been recognized in the Ringsaker Quartzite Member (Fig. 21).

The variably directed trough cross-beds and the small- to medium-scale tabular cross-beds are thought to reflect migrating dunes and sandwaves, respectively (Harms et al. 1982). These bedforms developed in response to a variety of processes in the barred near-shore setting, such as coast-parallel flow in longshore troughs, shoaling waves, and seaward return flow in bar-flank and bar-crest areas. The details of this longshore bar environment are currently being investigated, and will be published in a forthcoming paper.

The large-scale tabular cross-beds (Fig. 17) commonly show dips to the north or south, perhaps resulting from the migration of an entire longshore bar into the adjacent trough (Hunter et al. 1979, Ly 1982). This interpretation is based on the scale of these cross-beds, their restricted lateral extent in the N-S direction and high lateral E-W extent, and their intimate association with structures believed to have formed in longshore troughs and on bar crests. The erosively based fining-upwards beds (Fig. 21) might represent rip current channel infills (Fig. 24).

Facies S4

At the top of both shallow-marine progradational sequences (Figs. 5 and 13), facies S4-beds dominated by subhorizontal lamination are found. These very mature sediments are thought to represent beach-related deposits which formed landwards of the breaker zone, behind the innermost bar (Fig. 24). The few low-angle cross-beds are very "event-like' in character, and are thought to have formed mainly by wave action in the inner and outer rough zones of Clifton et al. (1971). The subhorizontal, slightly seaward-dipping laminations with many internal discordances and inverse size grading/normal density grading are characteristic features of beach lamination (e.g. Clifton 1969). Facies association Q deposits which erode into these beds (Fig. 20) suggest the presence of channels cutting through the beaches. The top-surface lags found in this facies reflect storm winnowing (Levell 1980) and, in the case of the uppermost and thickest lag, transgressive winnowing. The phosphorite-cement associated with this lag indicates a low sediment supply.

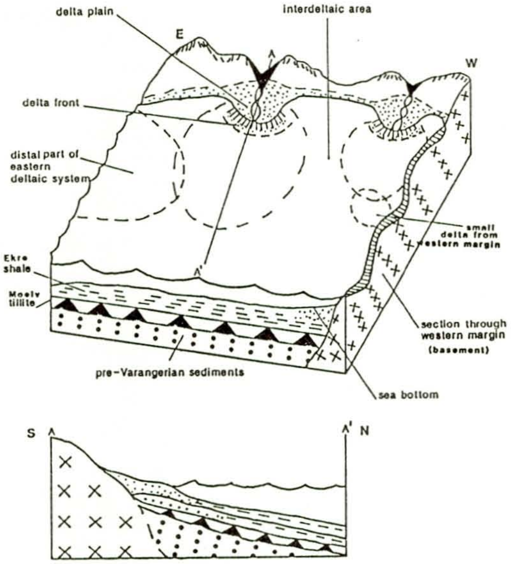


Fig. 22. Paleogeographic sketch (basement relief exaggerated) of the (fan)-deltaic system in which the Ekre Shale (prodelta deposits) and the lower and middle Vardal Sandstone Member (delta front and braidplain deposits) accumulated. A transverse section (A-A') illustrates the onlapping nature of the Ekre Shale. This and the following paleogeographic reconstructions represent the Hedmark Basin in a pre-thrust position.

Lateral trends

These shallow-marine sediments appear to be rather homogeneously developed in a direction normal to the ancient coastline, although some proximal to distal changes can be observed. As mentioned, bed thickness and mean grainsize decrease northwards, while the number of fine-grained interbeds increases. In terms of facies types, sediments deposited in deeper water (Fig. 20) become more dominant northwards. North of the Torpa area (Fig. 1), beach-related sediments are absent, and the basal conglomerate seems to disappear. The thicknesses of the upper Vardal Sandstone and Ringsaker Quartzite Members also decrease to the north (the upper Vardal Sandstone Member probably thins out north of the study area; Dreyer, unpublished data). These relationships suggest that the shallow-marine sequences prograded from south to north in late Precambrian to earliest Cambrian times. The fact that the fluvial sediments lower down in the Vangsås Formation were derived from the south strengthens this argument.

Concluding discussion: Vendian-Early Cambrian basin evolution

During post-Varangerian times, the region on the western Baltoscandian craton where the

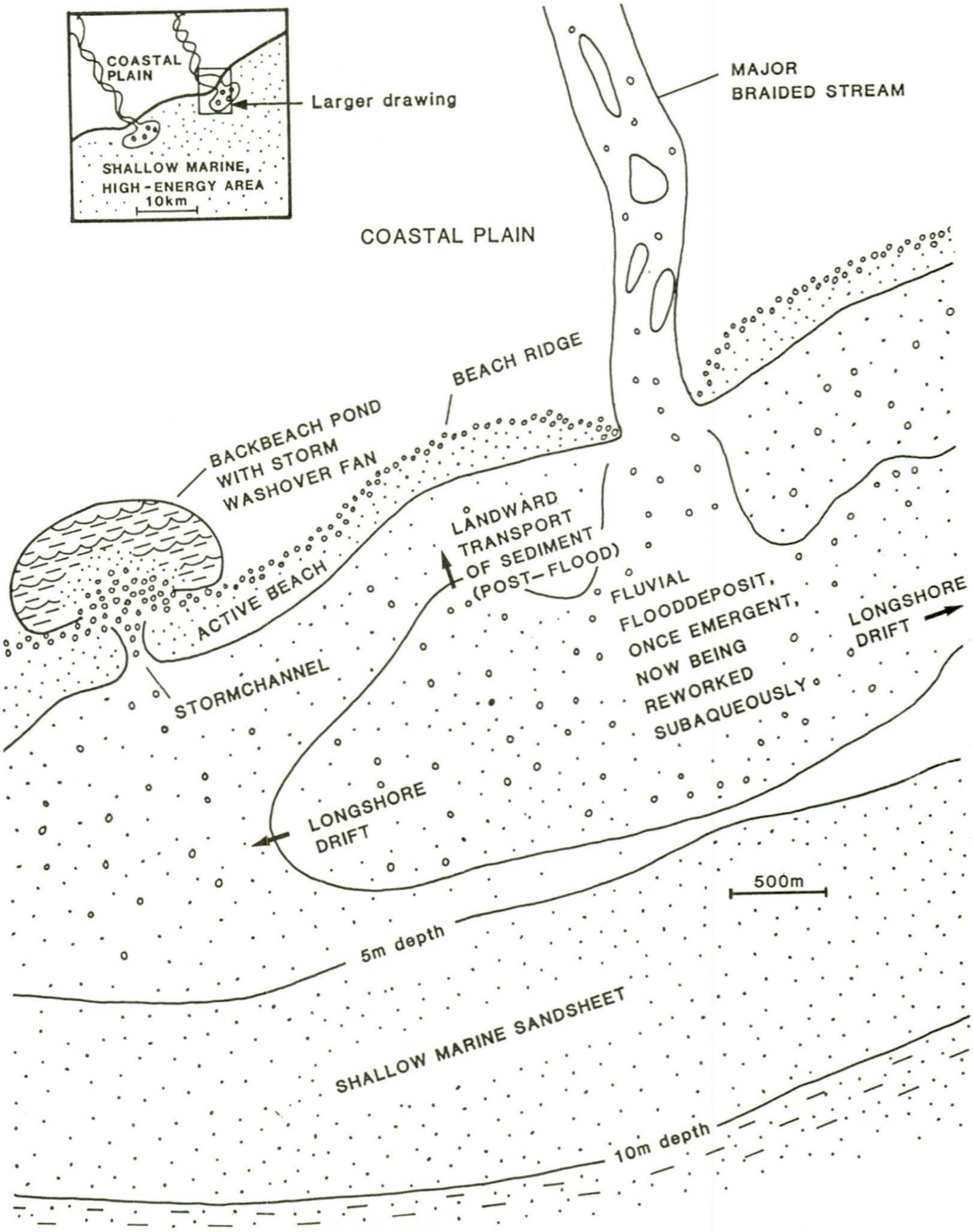


Fig. 23. Details of the deltaic coastline configuration during deposition of both the lower Vardal Sandstone Member and facies S1 of the upper Vardal Sandstone Member.

upper parts of the Hedmark Group accumulated was probably situated at a latitude of about 40-50° south (Piper 1985). After the cold climatic event associated with the deposition of the Varangerian Moelv Tillite, the climate that prevailed as the presently discussed sediments were deposited seems to have been temperate and moderately humid (e.g. Willden 1980).

The rifting phase which created the Hedmark Basin also generated similar basins elsewhere in the westernmost parts of the Baltoscandian craton. The characteristics of these are summarized in Kumpulainen & Nystuen (1985), Bockelie & Nystuen (1985) and Nickelsen et al. (1985). In all these basins, a post-Varangerian sedimentary sequence is present similar to the one discussed here. As in the Vangsås Formation, evidence for more than one late Vendian/early Cambrian shallow-marine progradation episode has been found in these basins (Nystuen 1980, Nickelsen et al. 1984).

The basin evolution, as deduced from vertical and lateral facies developments in the studied sequences, may be summarized in three phases.

PHASE 1:

After the end of the Varangerian ice-age (about 650 Ma ago), a eustatic rise in sea-level (probably caused by melting of ice) led to low-energy basinal conditions in large parts of the Hedmark Basin (Fig. 2). In this energetically quiet setting, the prodeltaic Ekre Shale was deposited. Signs of progradation are present only in the upper (red) part of this formation. The thickness relationships and facies development in this unit indicate that the sea onlapped southwards through time. The border to the Vardal Sandstone Member (Vangsås Formation) is diachronous.

PHASE 2:

A northward-prograding deltaic system infilled the basin mainly with delta-front-sediments (facies association P) (Figs. 22 and 23). If the thickness from the Ekre/Vardal boundary to the first fluvial beds (facies association Q) is taken as an indication of minimum water depth, this depth was at least 50 m (Fig. 5). In the lower Vardal Sandstone Member, facies associations P and Q (delta front — delta plain) alternate cyclically. The cyclicity may be due to shifting of delta lobes in response to local gradients (autocyclicity), or to allocyclic mechanisms such as changing rates of sediment supply or variation in relative sea-level. During deposition of the middle Vardal Sandstone Member, progradation had moved the coastline far north in the Hedmark rift-basin. The fluvial system was braided to the sea. Its large-scale morphology (fan-shaped or not?) is not known, thus making it impossible to say whether the deltaic system should be termed a fan-delta or a braid-delta (Nemec & Steel 1987). A period of vertical aggradation followed the progradation.

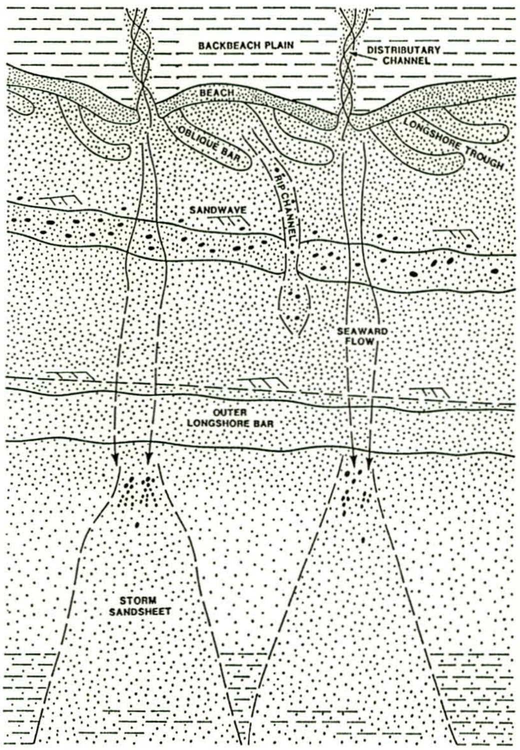


Fig. 24. Paleogeography of the barred nearshore system in which most of the upper Vardal Sandstone Member and the Ringsaker Quartzite Member sediments were deposited.

PHASE 3:

At the upper/middle Vardal sandstone junction, there is evidence for a change to a transgressive regime. This transgression was probably caused by a slow eustatic sea-level rise induced by the opening of the Iapetus Ocean (e.g. Anderton 1982). The sediment supply was sufficient to fill the space added by the base-level rise, resulting in periods characterized mostly by vertical aggradation. Shallow-marine conditions dominated from now on until the time of deposition of the Cambrian "Holmia-stage' beds. This epicontinental sea was dominated by wave processes. It is important to note that this epicontinental setting represents a significant departure from the graben-confined sedimentary setting that had previously characterized Hedmark Group sedimentation (Fig. 2). Now, the transgressive event initiated shallow-marine deposition in areas *outside* the original Hedmark rift (Fig. 2) (and outside other rifts on the western Baltoscandian craton; Bjørlykke 1979, Kumpulainen & Nystuen 1985, Nickelsen et al. 1985). As a result of this expansion, the basinal energy (wave power, etc.) was able to reach higher levels than would have been possible in a semi-enclosed rift-basin setting.

In this newly-formed epicontinental sea, two progradational/aggradational sequences formed, corresponding to the upper Vardal Sandstone Member and the Ringsaker Quartzite Member (Figs 4, 5, 13 and 20). The shallow-marine environment in this phase was barred and storm-dominated (Fig. 24). A major transgressive event terminated the progradational/-aggradational regime, forming a lag-deposit which marks the base of deeper-water sediments belonging to the fossiliferous "Holmia-stage' (Lower Cambrian).

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References

Anderton R. 1976: Tidal shelf sedimentation: an example from the Scottish Dalradian. *Sedimentology 23,* 429—458.

Anderton, R. 1982: Dalradian deposition and the late Precambrian — Cambrian history of the N. Atlantic region; a review of the early evolution of the Iapetus Ocean. *J. Geol. Soc. Lond. 139,* 421—431.

Bjørlykke, A. 1979: Gjøvik og Dokka. Beskrivelse til de berggrunnsgeologiske kartblad 1816 I og 1816 IV. *Nor. geol. unders. 344,* 1—48.

Bjørlykke, K. 1983: Subsidence and tectonics in late Precambrian and Paleozoic sedimentary basins of southern Norway. *Nor. geol. unders. 380,* 159—172.

Bjørlykke, K., Elvsborg, A. & Høy, T. 1976: Late Precambrian sedimentation in the central Sparagmite basin of southern Norway. *Nor. geol. Tidsskr. 56,* 233—290.

Bockelie, J.F. & Nystuen, J.P. 1985: The southern part of the Scandinavian Caledonides. *In:* Gee, D.G. & Sturt, B.A. (eds.), The Caledonide orogen-Scandinavia and related areas. J. Wiley & Sons, Chichester, 69—88.

Bourgeois, J. & Leithold, E.L. 1984: Wave-worked conglomerates — depositional processes and criteria for recognition. *In:* Koster, E.H. & Steel, R.J. (eds.), Sedimentology of gravels and conglomerates. Can. Soc. Petr. Geol. Mem. 10, 331—343.

Cant, D.J. & Walker, R.G. 1976: Development of a braided fluvial facies model for the Devonian Battery Point sandstone, Quebec. *Can. J. Earth Sci. 13,* 102—119.

Clifton, H.E. 1969: Beach-lamination, nature and origin. *Mar. Geol. 7,* 553—559.

Clifton, H.E., Hunter, R.E. & Phillips, R.L. 1971: Depositional structures and processes in the non-barred high-energy nearshore. *J. Sed. Petr. 41,* 651—670.

Davidson-Arnott, R.G.D. & Greenwood, B. 1976: Facies relationships on a barred coast, Kouchibougac bay, New Brunswick, Canada. *In:* Davis jr., R.A. & Ethington, R.L. (eds.), Beach and nearshore sedimentation. *SEPM. Spec. Publ. 24,* 149—168.

DeRaaf, J.F.M. & Boersma, J.R. 1971: Tidal deposits and their sedimentary structures. *Geol. en Mijnb. 50,* 479—504.

Dott, R.H. & Bourgeois, J. 1982: Hummocky stratification: Significance on its variable bedding sequences. *Geol. Soc. Am. Bull. 93,* 663—680.

Dreyer, T. 1985: *A sedimentological analysis of the Ekre Shale and Vangsås Formation (late Precambrian Hedmark Group) in the southwest Sparagmite area, southern Norway.* Cand. Scient. thesis, Univ. of Bergen, 330 pp.

Duke, W.L. 1983: The "type-locality' of hummocky cross-stratification: the storm-dominated Silurian Medina Formation in the Niagara gorge, New York and Ontario. *21st. Ann. Ont. Petr. Inst. Conf. Tech. Pap. 2,* 31 pp.

Elliot, T. 1978: Deltas and Clastic shorelines. *In:* Reading, H.G. (ed.), Sedimentary environments and facies, 97—177.

Englund, J.O. 1973: Geochemistry and mineralogy of pelitic rocks from the Hedmark Group and the Cambro-Ordovicium sequence, Southern Norway. *Nor. geol. unders. 286,* 60 pp.

Gjelberg, J., Dreyer, T., Høie, A., Tjelland, T. & Lilleng, T. 1987: Late Triassic to Mid Jurassic sandbody-development on the Barents and Mid-Norwegian Shelf. *In:* Glennie, K.W. (ed.), Petroleum Geology of NW Europe Vol. 3 (in press.)

Greenwood, B. & Mittler, P.R. 1985: Vertical sequence and lateral transitions in the facies of a barred nearshore environment. *J. Sed. Petr. 55,* 366—375.

Harms, J.D., Southard, J.B. & Walker, R.G. 1982: Structures and sequences in clastic rocks. *SEPM. Short Course no. 9.*

Hein, F.J. & Walker, R.G. 1977: Bar evolution and development of stratification in the gravelly, braided Kicking Horse river, British Columbia. *Can. J. Earth Sci. 14,* 562—570.

Hine, A.C. & Boothroyd, J.C. 1978: Morphology, processes and recent sedimentary history of a glacial outwash plain shoreline, Southern Iceland. *J. Sed. Petr. 48,* 901—920.

Hossack, J.R., Garton, M. and Nickelsen, R.P. 1985: The geological section from the foreland up to the Jotun sheet in the Valdres area. *In:* Gee, D.G. & Sturt, B.A. (eds.). The Caledonide Orogen: Scandinavia and related areas: John Wiley & Sons, Chichester.

Hostad, Ø.: 1985. *En sedimentologisk studie av Ekre-skiferen og Vangsåsformasjonen (Sein-prekambrium), Hedmark-gruppen) i Ringsaker og Rena området.* Cand. Scient. thesis, Univ. of Bergen, 150 pp.

Hunter, R.E., Clifton, H.E. & Phillips, R.L. 1979: Depositional processes, sedimentary structures, and predicted vertical sequence in barred nearshore systems, SE. Oregon coast. *J. Sed. Petr. 49,* 711—726.

Johnson, H.D. 1978: Shallow siliciclastic seas. *In:* Reading, H.G. (ed.), Sedimentary environments and facies, 207—258.

Kumpulainen, R. & Nystuen, J.P. 1985: Late Proterozoic basin evolution and sedimentation in the westernmost part of Baltoscandia. *In:* Gee, D.G. & Sturt, B.A. (eds.). The Caledonide orogen-Scandinavia and related areas, J. Wiley & Sons, Chichester, 213—232.

Levell, B.K. 1980: Evidence for currents associated with waves in late Precambrian shelf deposits from Finnmark, North Norway. *Sedimentology 27,* 153—166.

Long, D.G.F. 1978: Proterozoic stream-deposits: Some problems of recognition and intepretation of ancient sandy fluvial systems. *In:* Miall, A.D. (ed.), Fluvial sedimentology. *Can. Soc. Petr. Mem. 5,* 313—341.

Lowe, D.R. & LoPiccolo, R.D. 1974: The characteristics and origin of dish and pillar-structures. *J. Sed. Petr. 44,* 484—501.

Ly, C.K. 1982: Sedimentology of nearshore marine bar sequences from a Paleozoic depositional regressive shoreline deposit of the central coast of Ghana, West-Africa. *J. Sed. Petr. 52,* 199—208.

Løberg, B.E. 1970: Investigations at the southwestern border of the Sparagmite Basin (Gausdal Vestfjell and Fåberg Vestfjell), southern Norway. *Nor. geol. unders. 266,* 160—205.

McKee, E.D., Crosby, E.J. & Berryhill jr., H.L. 1967: Flood-deposits, Bijou creek, Colorado, June 1965. *J. Sed. Petr. 37,* 829—851.

Miall, A.D. 1977: A review of the braided river depositional environment. *E. Sci. Rev. 13,* 1—62.

Morley, C.K. 1986: The Caledonian thrust front and palinspatic restorations in the southern Norwegian Caledonides. *J. Struc. Geol. 8,* 753—765.

Nemec, W. & Steel, R.J. 1987: What is a fan-delta and how do we recognize it? *In:* Fan deltas-sedimentology and tectonic setting, Int. Symposium Bergen 1987 (abstract).

Nickelsen, R.P., Hossack, J.R. & Garton, M. 1984: Late Precambrian to Ordovician stratigraphy and correlations in the Valdres and Synnfjell thrust sheets of the Valdres area, South Norwegian Caledonides; with some comments on sedimentation. *In:* Gee, D.G. & Sturt, B.A. (eds.), The Caledonide orogen-Scandinavia and related areas, J. Wiley & Sons, Chichester.

Nystuen, J.P. 1976: Facies and sedimentation of the late Precambrian Moelv Tillite in the eastern part of the Sparagmite region, Southern Norway. *Nor. geol. unders. 329,* 70.

Nystuen, J.P. 1980: Stratigraphy of the Upper Proterozoic Engerdalen Group, Kvitvola nappe, southeastern Scandinavian Caledonides. *Geol. Føren. Stockh. Førh. 102,* 551—560.

Nystuen, J.P. 1981: The late Precambrian "sparagmites' of southern Norway: a major Caledonian allochthon, the Osen-Røa Nappe Complex. *Am. J. Sci. 281,* 69—94.

Nystuen, J.P. 1982: Late Proterozoic basin evolution on the Baltoscandian craton: the Hedmark Group, southern Norway. *Nor. geol. unders. 375,* 1—74.

Piper, J.D.A. 1984: Continental movement and break up in late Precambrian—Cambrian times: Prelude to Caledonian orogeny. *In:* Gee, D.G. & Sturt, B.A. (eds.), The Caledonide orogen-Scandinavia and related areas, J. Wiley & Sons, Chichester.

Posamentier, H. & Vail, P. 1987: Eustatic control on clastic deposition. *In:* Wilgus, C. (ed.), Sea-level changes — an integrated approcah. *SEPM Spec. Publ.* (in press).

Rankama, K. 1973: The late Precambrian glaciation, with reference to the southern hemisphere, *J. Roy Proc. New South Wales 106,* 89—97.

Roep, T.B., Beets, D.J., Dronkert, H. & Pagnier, H. 1979: A prograding coastal sequence of wave-built structures of Messinian age, Sorbas, Almeria, Spain. *Sed. Geol. 22,* 135—163.

Shipp, R.C. 1984: Bedforms and depositional sedimentary structures of a barred nearshore system, East Long Island, New York. *Mar. Geol. 60,* 235—259.

Skjeseth, S. 1963: Contributions to the geology of the Mjøsa districts and the classical Sparagmite area in southern Norway. *Nor. geol. unders. 220,* 126 pp.

Smith, N.D. 1972: Some sedimentological aspects of planar crossstratification in a sandy braided river. *J. Sed. Petr. 42,* 624—634.

Steel, R.J. & Thompson, D.B. 1983: Structure and texture in Triassic braided stream conglomerates ("Bunter' pebble beds) in the Sherwood sandstone Group, north Staffordshire, England. *Sedimentology 30,* 341—367.

Swift, D.J.P. & Rice, D.D. 1984: Sandbodies on a muddy shelf: a model for sedimentation in the Western Interior Cretaceous seaway, North America. *In:* Tillman, R.W. & Siemers, C.T. (eds.), Siliciclastic shelf deposits. *SEPM. Spec. Publ. 34,* 43—62.

Tunbridge, I.P. 1982: Sandy high-energy flood sedimentation, some criteria for recognition, with an example from the Devonian of southwest England. *Sed. Geol. 28,* 79—95.

Vidal, G. 1984: Biostratigraphic correlation of the Upper Proterozoic and Lower Cambrian of the Fennoscandian Shield and the Caledonides of east Greenland and Svalbard. *In:* Gee, D.G. & Sturt, B.A. (eds.), The Caledonide Orogen-Scandinavia and related area. John Wiley & Sons, Chichester, 331—338.

Vogt, T. 1924: Forholdet mellom Sparagmit-systemet og det marine underkambrium ved Mjøsen. *Nor. geol. Tidsskr. 7,* 281—384.

Willden, M.Y. 1980: Paleoenvironment of the autochthonous sedimentary rock sequence at Laisvall, Swedish Caledonides. *Stockh. Contr. Geol. 33,* 100 pp.

Williams, G.E. 1971: Flood-deposits of sand-bed ephemeral streams of Central Australia. *Sedimentology 17,* 1—40.