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Lithofacies and palaeoenvironmental interpretation of the Early Jurassic Höör Sandstone, Southern Sweden

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Sedimentological analysis of the Early Jurassic Höör Sandstone in Central Scania, Sweden shows that two units representing different lithofacies may be distinguished. The lower Stanstorp Member is characterised by texturally and mineralogically heterogeneous sediments. Mature arenites and immature quartz and subarkosic wackes form two clearly separated groups, interpreted as fluvial channel and alluvial plain deposits respectively. The fluvial character of this member is supported by a dominance of unidirectionally oriented trough sets, abundant plant detritus, the presence of plant roots and palaeosols and a lack of marine body fossils and trace fossils. An intercalated composite polymict conglomerate layer is interpreted as the result of an extraordinary flood. The overlying Vittseröd Member is characterised by mature quartz arenites and large-scale tabular sets with multidirectional orientations. The Vittseröd Member arenites are of storm- and possibly tide-dominated shoreface origin. Bidirectional wave and tide-induced longshore currents and unidirectional onshore migration of sand ridges were the chief depositional processes. Longshore currents towards the NNW prevailed. Upper flow regime features, and erosion and reworking of sediments are attributed to the storm-induced rip currents. Lithofacies characteristics are used to define the following lithostratigraphical units: the Stanstorp and the Vittseröd members, as well as the Höör Sandstone (Fm) above. Lithofacies and palaeoenvironmental characteristics of the Vittseröd Member and their comparison with the facies of the Helsingborg and Döshult members in Western Scania suggest a Sinemurian age for the Vittseröd Member.

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Key words: Höör Sandstone (Fm), Early Liassic, Stanstorp Member, Vittseröd Member, sedimentology, fluvial lithofacies, storm- and tide-dominated facies, formal lithostratigraphy.

INTRODUCTION

The Höör Sandstone occurs in Central Scania at a few isolated exposures, both *in situ* and as boulders. Nilsson (1819) distinguished the Höör Sandstone within the succession of sandstones, conglomerates and mudstones lying on the weathered crystalline basement in Central Scania. Traditionally, it was subdivided into the lower "millstone" ("kvarnstenen") and the upper "buildingstone" ("byggnadsstenen") units, named after the main uses of the rocks. Brogniart (1826) classified the lower "millstone" unit as an arkose. Nathorst (1880) and Antevs (1919) described flora from the Höör Sandstone. Hadding (1929) and Troedsson (1940) reported the occurrence of marine and brackish-marine bivalves (*Avicula inaequivalvis*, *Liostrea* sp., *Pecten* sp., *Cardinia follini* Lungren) in the Höör Sandstone and Tullberg (1880) found trace fossils (*Monocraterion* sp.) in the "buildingstone". Troedsson (1940) subdivided the Höör Sandstone into a lower Rhaetic and an upper Liassic part. The Triassic-Jurassic boundary was placed by him at the top of an organic-rich clay bed a few metres thick. Recently, the term Höör Sandstone has referred to the Liassic (possibly also the Rhaetian) part of the section (Lund, 1977; Warnock, 1983, unpubl.; Sivhed, 1984; Norling *et al*., 1993; Grigelis and Norling, 1999). The Triassic part of the section, particularly its lower part developed as red beds, was provisionally named the Hörby Formation (Clarke, 1983, unpubl.; Warnock, 1983, unpubl.)

Today the Höör Sandstone is accessible only in two areas: between Höör and Stanstorp, and to the north of Vittseröd (Figs. 1 and 2). All the exposures are abandoned quarries. In the past the exposures were considerably bigger, therefore some archive photographs can still provide valuable information (Fig. 3). Several exposures are large enough to permit sedimentological observations. Most important are the Stanstorpsgraven quarry near Höör (Fig. 3) and the Rugerup quarry to the north of Vittseröd (Fig. 1). Several small exposures in the Vittseröd area have yielded some petrographic data

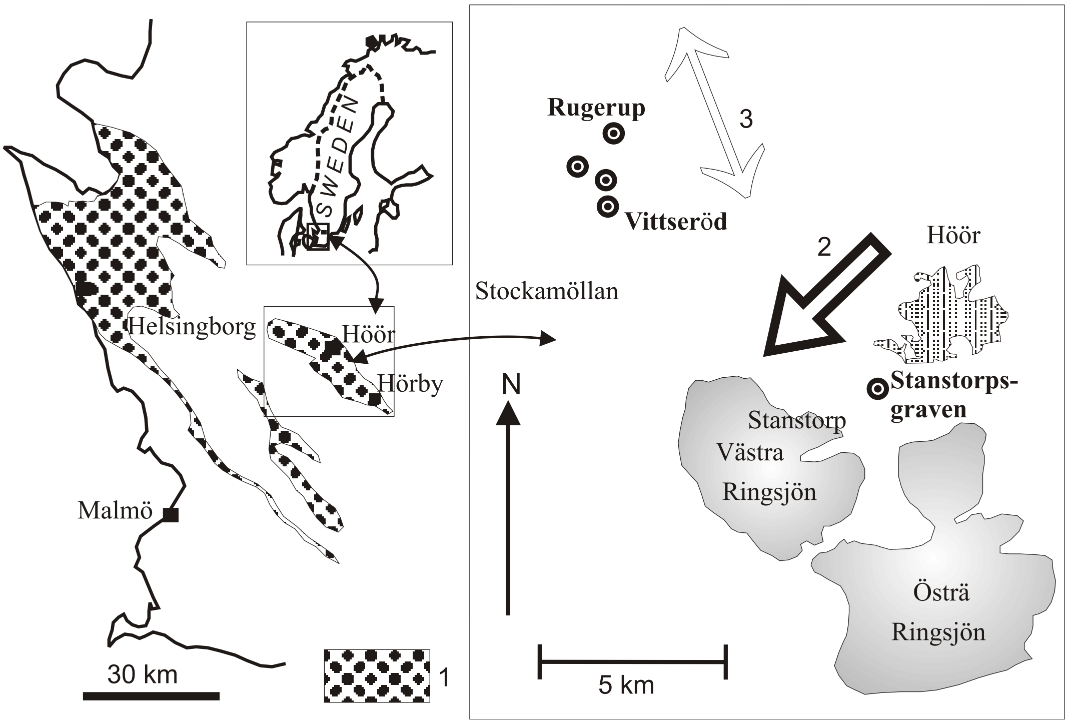

Fig. 1. Map of the area studied

1 — occurrence of Lower Jurassic deposits at the surface or below Quaternary deposits; 2 — transport of material in the Stanstorp Member (sum of vectors); 3 — general alignment of shoreline during sedimentation of the Vittseröd Member and directions of longshore currents

and additional measurements of palaeocurrent directions. The general geological profile (Fig. 2) is based on archival data (Warnock, 1983, unpubl. — profile of the Hörby borehole), literature (Troedsson, 1940) and my own observations. Despite limited data, it was possible to study the lithofacies, propose a palaeoenvironmental interpretation and define a lithostratigraphical subdivision of the Höör Sandstone. The distinguishing of the Höör Sandstone as a formal lithostratigraphical unit (formation), which should be subdivided into the Stanstorp and Vittseröd members was originally suggested by Clarke (1983, unpubl.), Warnock (1983, unpubl.), and adopted by Norling *et al.* (1993) and Grigelis and Norling (1999).

LITHOFACIES OF THE HÖÖR SANDSTONE

17 thin sections were examined in total: eleven from the Stanstorp Member and six from the Vittseröd Member (Ahlberg and Pieńkowski, unpubl.).

STANSTORP MEMBER

PETROGRAPHICAL CHARACTERISTICS

This lower unit (Fig. 2) is exposed in the old, abandoned Stanstorpsgraven quarry (Fig. 3) and in one small exposure in the Vittseröd area. Only the uppermost part of the Stanstorp Member is exposed (Figs. 2 and 3). The member consists of sandstones which are relatively coarse-grained and heterogeneous with respect to sorting and clay matrix content (Figs. 4–6). In places they contain numerous impressions of plant fragments. Both allochthonous plant fragments and plant roots indicating vegetation *in situ* (palaeosol) have been found (Figs. 3 and 7). Intercalations of conglomerates are common.

In thin sections one may observe the following features (Figs. 4–6):

1. The amount of matrix (clay and grains below 0.03 mm in diameter) of the 6 samples is higher than 15% (Fig. 5), placing these samples in the group of quartz or subarkosic wackes according to Dott (1964), as modified by Pettijohn *et al.* (1972). Five other samples represent arenites, i.e. quartz arenites and subarkoses (Fig. 5). Thus, the texture of the sandstones is very heterogeneous and two clearly separated groups of samples can be recognised (Fig. 5).
2. The sorting of the grains varies from poor (Fig. 6A) to good (Fig. 6B).
3. The grains even the large ones are frequently angular in shape (Fig. 6A).
4. The amount of feldspar varies considerably. In majority of the samples it exceeds 5%, which defines those samples as subarkoses.
5. The intercalated conglomerates contain pebbles of different composition, size and roundness (Fig. 8).
6. Quartz overgrowths are abundant in many places rendering some of the Stanstorp Member arenites well indurated (Fig. 10).

Combined data from two diagrams (Figs. 4 and 5) show that the Stanstorp Member sandstones are both texturally and mineralogically diverse. About half of the samples represent

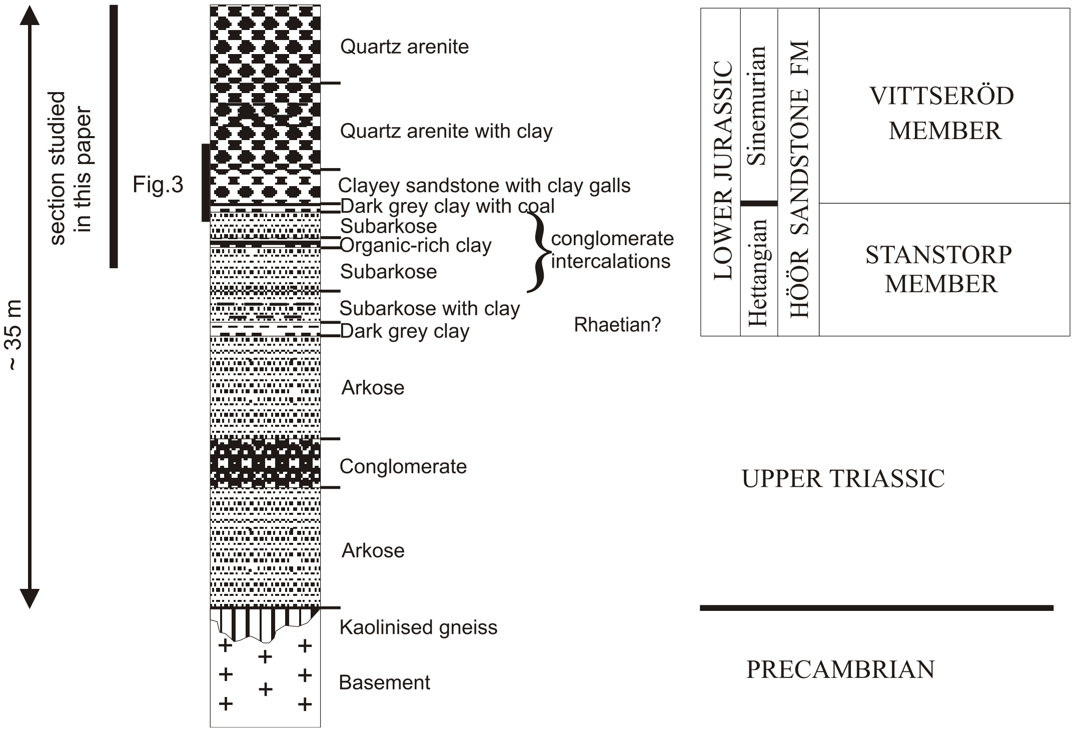

Fig. 2. Generalised lithological profile showing stratigraphical position of the Höör Sandstone, Stanstorp Member and Vittseröd Member

The profile is based on the archive description of the Hörby borehole, after Warnock (1983, unpubl.); stratigraphy and lithostratigraphy after Norling *et al*. (1993), Grigelis and Norling (1999) and my own observations

immature sediments, i.e. subarkosic wackes (Folk, 1968). The rest represent subarkoses and submature quartz arenites (Folk, 1968; Pettijohn *et al*., 1972).

One sample shows textural inversion (Fig. 6A, i.e. abnormal relationship between the sizes of the grains and their roundness). Large, angular grains of feldspar and quartz occur together with better rounded, smaller quartz grains. This "third type of inversion" (according to Folk, 1968) is connected with conglomerates intercalated in the profile of the Stanstorp Member (Figs. 3, 7 and 8). Such mixing of different sediments may have taken place during a rapid, powerful event (see the next chapters for further interpretation).

Intercalations of mudstones and siltstones rich in flora were also observed (Figs. 3 and 7).

SEDIMENTARY STRUCTURES

Large-scale trough sets are the dominating sedimentary structures (Figs. 3, 7 and 8). Two types of bed sets were observed. The first shows clearly inclined foresets (the dune migration type), while the second is composed of nearly flat, sub-parallel foresets (the scour-and-fill type). Palaeocurrent directions were measured directly from the dip of foresets (in the dune migration type), or were reconstructed from the sides of the troughs as the dips of the trough axes (in the case of the scour-and-fill type). The palaeocurrent directions (Fig. 9) are fairly consistent and in total at Stanstorpsgraven the transport of sediment was generally from the north-east to the south-west (Fig. 1), though this interpretation is based on limited data. In the lowermost part of the Stanstorp Member at outcrop (Figs. 3 and 7) there is a sandstone layer with plant roots at the top, covered with the coal-bearing shale, which has yielded abundant plant fossils (Nathorst, 1880; Antevs, 1919). The level with plant roots and overlying coal-bearing shale represents a palaeosol.

Higher in the section (Figs. 3 and 7), there is a remarkable composite layer, a coset of conglomerate and sandstone (Fig. 8), which consists of polymict conglomerates, pebbly sandstones and sandstones (subarkosic wacke — Fig. 6A). The layer rests on erosional base and is composed of two upwards-fining bedset units separated by another erosional surface. The upper unit is capped by rippled sandstone at the top (Fig. 8), which indicate a rapid waning of the current. The conglomerates comprise two different units. The lower of these contains vein quartz pebbles, large mudstone fragments (in places up to 30 cm in diameter) and ferruginous mudstone fragments. It shows clast-supported, massive gravel facies with little or no grading: lithofacies **Gcm** of Miall (1996, table 4.1). In the upper unit the conglomerate consists of vein quartz pebbles, scattered small and flattened mud clasts and one granite fragment (Fig. 8). The upper conglomerate is finer-grained. Its pebbles are better rounded, sandy matrix is abundant, and trough cross-beds are present. It represents the **Gt-St** lithofacies of Miall (1996, table 4.1). Notably, the lower conglomerate unit contains locally-derived, deformed mud fragments, while the upper one is composed of material from a more distant source. Fragments of drift-wood occur in these units, some being large (up to 20 cm in diameter). The base of the lower unit cuts down some 50 cm into the underlying deposit over a distance of 8 m visible in the exposure (Fig. 7).

The currents that formed the two units within the intercalated layer were directed approximately N–S, but their direc-

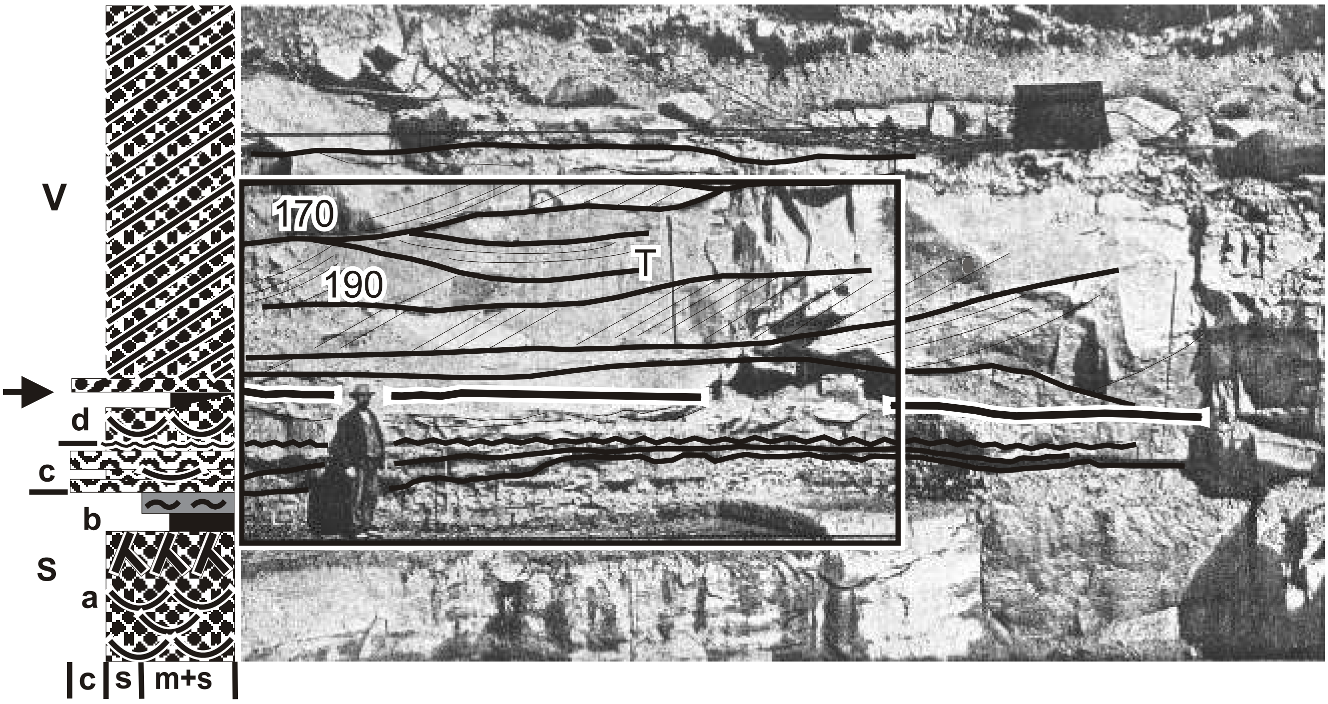

Fig. 3. Profile of the Stanstorpsgraven exposure compared to the archival photograph taken by *Cederquists Graf. A.-B.*, Stockholm, in 1904; the recent exposure is framed

Profile: **c** — conglomerate, **s** — sandstone, **m**+**s** — mudstone and siltstone; **sedimentary units and lithofacies**: **S** — Stanstorp Member: **a** — arkosic wackes, subarkoses and quartz arenites with trough cross-bedding sets and plant roots at the top, **b** — coal-rich mudstone and laminated siltstone with floral remains, **c** — channelised composite/conglomeratic layer with erosional bottom, mid-layer erosional surface and rippled top (see also Figs. 7 and 8), **d** — arkosic wackes, subarkoses and quartz arenites with trough cross-bedding sets (repetition of lithofacies **a**); **V** — Vittseröd Member, quartz arenites with large-scale tabular cross-bedding sets; two measured sets are shown with the dip azimuths; bounding surfaces are shown with continuous lines; interbedded trough cross-bedding set is marked with **T**; arrow — contact between Stanstorp Member and Vittseröd Member

tion remains unclear due to the limited exposure and lack of imbrication.

There are several other poorly exposed conglomeratic intercalations in the Stanstorpsgraven area, whose spatial relationships remain unclear.

VITTSERÖD MEMBER

PETROGRAPHIC CHARACTERISTICS

The overlying sandstones of the Vittseröd Member are generally finer-grained and much better sorted. Mudstones are rare and they occur only in the lowermost part of the member. Imprints of plant fragments are rare and small and limited to a few horizons.

Microscopic studies of 6 thin sections revealed the following features:

1. The amount of matrix does not exceed 15% (except for one sample from the Vittseröd area — Fig. 5).
2. The sorting is moderate to good. In five samples it is lower than 0.5 (Folk, 1951) (Fig. 10).
3. The roundness is notable (subrounded to well rounded on the Power's scale) (Fig. 10).
4. The amount of feldspars never exceeds 5% (Fig. 4). Feldspars are always strongly altered.
5. Quartz overgrowths are abundant (Fig. 10).
6. The amount of clay cement or "authigenic quartz minerals" (clay minerals covering the quartz overgrowths) varies and may reach 30 vol. % of the space between the grains.
7. Conglomerates are rare and the pebbles are composed of weathering-resistant rocks or locally-derived mud clasts.

Generally, the Vittseröd Member represents mature quartz arenites characterised by well sorted and fairly well rounded grains. Only in a few levels do submature sediments occur. The clayey substance observed in thin sections represents clay cement which apparently was derived from the strongly altered feldspars. Silt is almost absent from the Vittseröd Member. All these features show that the grains were systematically reworked, winnowed and sorted in a high-energy environment.

Both the Stanstorp and Vittseröd member sandstones were strongly influenced by diagenetic processes, which were described by Ahlberg (1994). Accordingly, the abundance of quartz cement in the Höör Sandstone by far outweighs any potential intraformational dissolution and reprecipitation. The microquartz cements are further evidence of this (Ahlberg, 2002, pers. comm.). The cementation was caused by flushing of hot brines through the strata, associated with penecontemporaneous volcanism, probably of late Early or early Middle Jurassic age.

SEDIMENTARY STRUCTURES

Exposures in the upper part of the Höör Sandstone (Vittseröd Member) are more abundant than those in the Stanstorp Member. At Stanstorpsgraven, the Vittseröd Member constitutes the major part of the exposure (Fig. 3). Additionally, in the Vittseröd area there are several larger and smaller exposures (Fig. 11). Large-scale tabular cross-bedded bedsets are the most common sedimentary structures (Figs. 3 and 11). The tabular foresets show multidirectional orientations (Figs. 11 and 12), but at Stanstorpsgraven they are almost unidirectional. Azimuths of the palaeocurrent directions range from 170 to 190°, indicating sediment transport to the SSW (Fig. 3 and 12). Conversely, in the Vittseröd area, 325–345° azimuths of transport to the NNW dominate (Fig. 12). Large-scale tabular sets also show a 40° azimuth, i.e. transport to the NE. There are also internal trough and tabular foreset migration directions from E to W (from 255 to 285°). Additionally, one can observe flat bounding surfaces between the bedsets (Fig. 3). In the Rugerup quarry near Vittseröd nearly bipolar tabular sets occur (Fig. 11). In the coset “2” (Fig. 11), flat trough sets with numerous redeposited ferruginous mud clasts dominate. Ferruginous mud clasts occur also at the bases of cosets “3” and “5” (Fig. 11). In the Vittseröd area conglomerates composed of quartz pebbles and rock fragments were found. Parting lineation indicating strong currents is common. Small-scale sedimentary structures are rare.

In the Vittseröd area a 30 cm thick, horizontally laminated bed with numerous plant detritus occurs. Except for this plant-rich bed, the plant remains are scarce elsewhere in the Vittseröd Member.

I did not find any biogenic structures. However, Tullberg (1880) described *Monocraterion* burrows from the “buildingstone”.

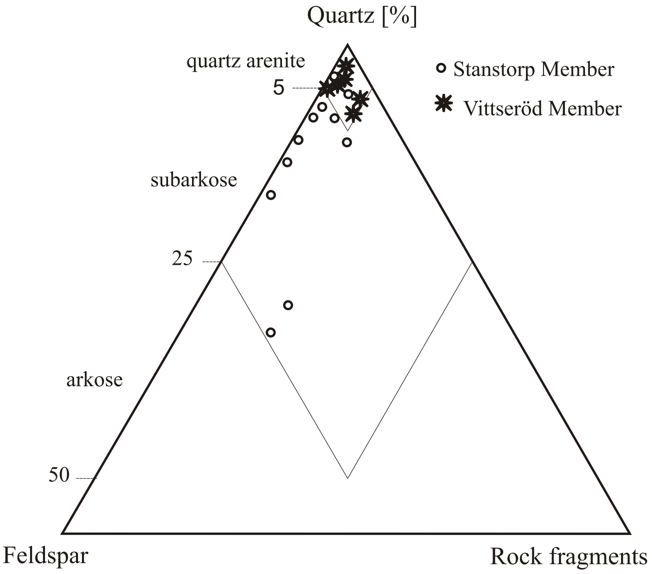

Fig. 4. Quartz-feldspar-rock fragments ternary diagram showing the mineral maturity of the Höör Sandstone

Note scattered Stanstorp Member samples (mostly subarkoses and some quartz arenites) and Vittseröd Member samples grouped within the quartz arenites field

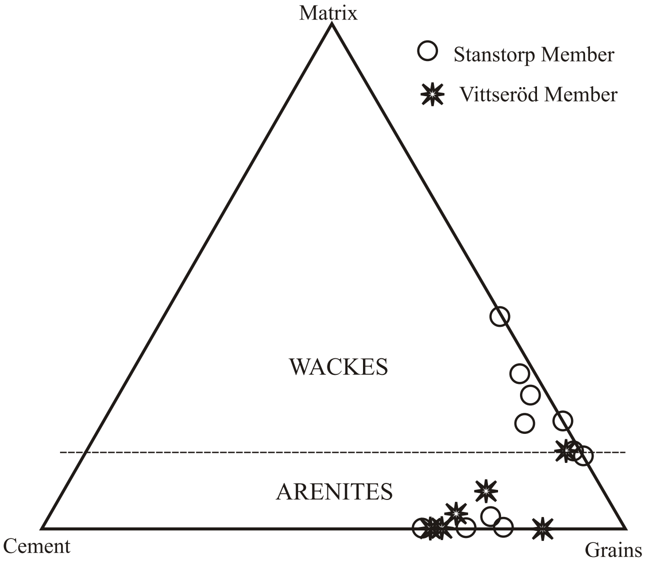

Fig. 5. Matrix-cement-grains ternary diagram showing the textural maturity of the Höör Sandstone

Note that the Stanstorp Member samples are divided into two fields — one within the arenite field, and second within the wacke field; such division into mature and immature sandstones probably reflects the primary difference between fluvial channel and fluvial overbank deposits (Folk, 1951); the Vittseröd Member samples represent arenites and are more consistent in their textural maturity

INTERPRETATION OF SEDIMENTARY PROCESSES AND DISCUSSION

STANSTORP MEMBER

A dominance of unidirectionally oriented trough foresets (Fig. 9), abundant plant detritus, a lack of marine body fossils and trace fossils, the presence of plant roots and palaeosols and frequently immature sediments (Figs. 4 and 5), are characteristic of fluvial environments (Allen, 1970; Jackson, 1978; Collinson, 1978; Walker and Cant, 1984; Miall, 1996). Fining-upward units are present, though their frequency and geometry remain unclear due to the limited exposures. Clear contrast and separation of the samples into two groups — texturally mature and texturally immature — probably reflects fluvial channel and fluvial overbank deposits respectively (Folk, 1951). Trough cross-bedding was produced both by migration of bedforms with curved crests and by cut-and-fill processes. The latter case one can also explain by migration of ripples and dunes with low height/length ratios, which are not capable of producing well defined cross-bedding.

It is difficult to judge whether the fluvial system was dominated by meandering or braided streams; again, very limited exposure makes such a discrimination impossible. One may note, however, that both sandy channel facies and muddy alluvial plain (fluvial overbank) facies are present (Figs. 3 and 7). This may broadly point to a meandering fluvial system, as overbank lithofacies are more frequent on meandering river alluvial plains (Allen, 1970; Miall, 1996).

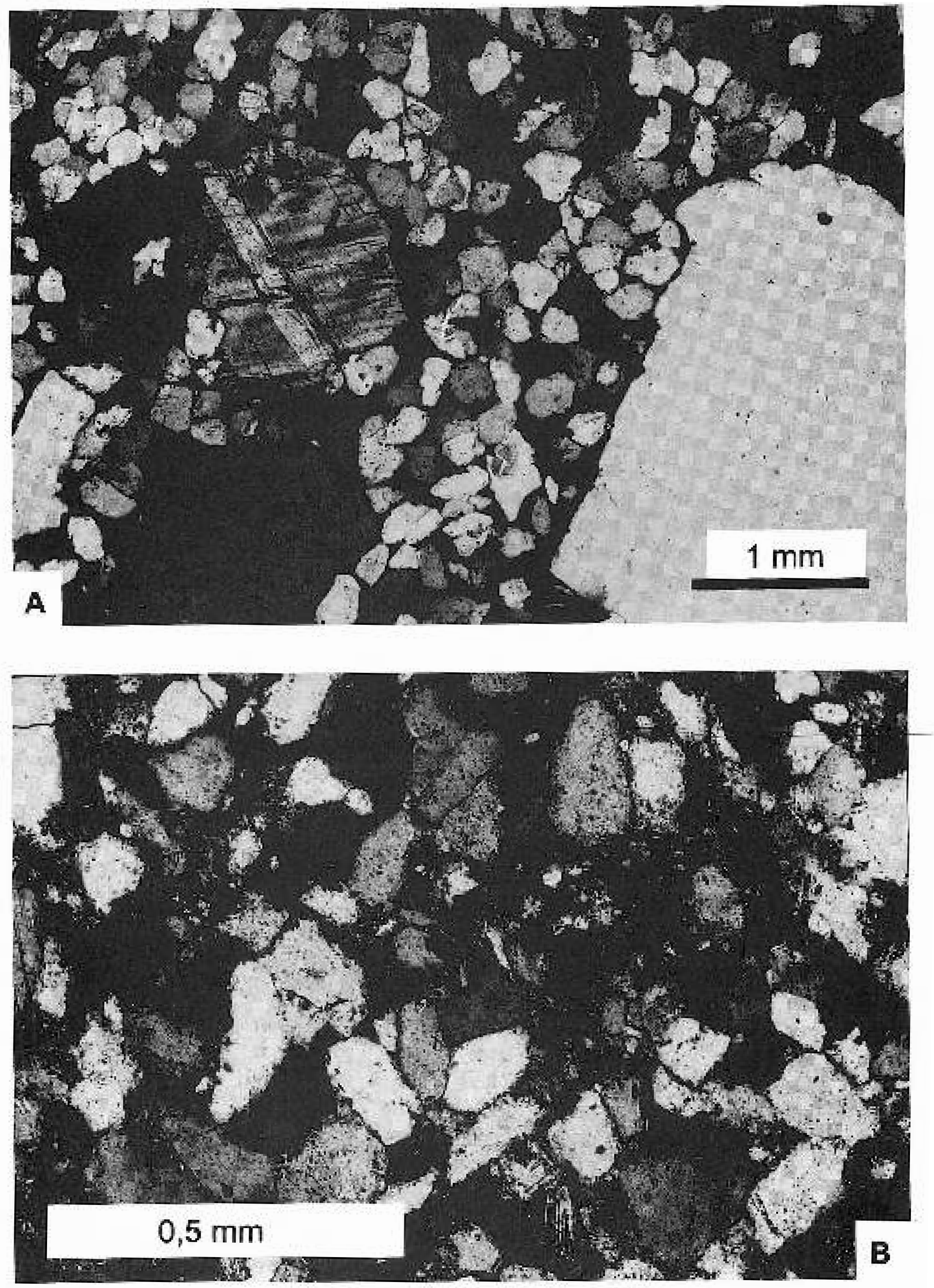

Fig. 6. Photomicrographs of sandstones from the Stanstorp Member

Sample **A** is taken from unit **c** (Fig. 3) and represents a medium-grained arenite with granules of quartz and feldspar (microcline); note the bimodality and textural inversion — large grains are angular, while the fine grains are rounded; such bimodality and inversion occurred due to turbulent mixing of two different types of sediment during a violent sedimentary event; crossed polars. Sample **B** is taken from unit **d** (Fig. 3) and represents fine-grained quartz arenites with little or no matrix admixture; sorting is good, grains are rounded; such sandstones are interpreted as fluvial channel facies; crossed polars

Measurements of transport directions are few (Fig. 8), but they are consistent with the overall palaeogeography (Bertelsen, 1978; Pieńkowski, 1991*b*), with material carried by rivers from the adjacent hights situated to the north-east, while the sea was situated generally to the west.

The intercalated conglomerate layer (Figs. 7 and 8) throws light on sedimentary processes active during formation of the Stanstorp Member. This layer, composed of two bedsets, suggests the effect of a short-duration and powerful event, because it shows distinctly marked bottom and top surfaces, conspicu-

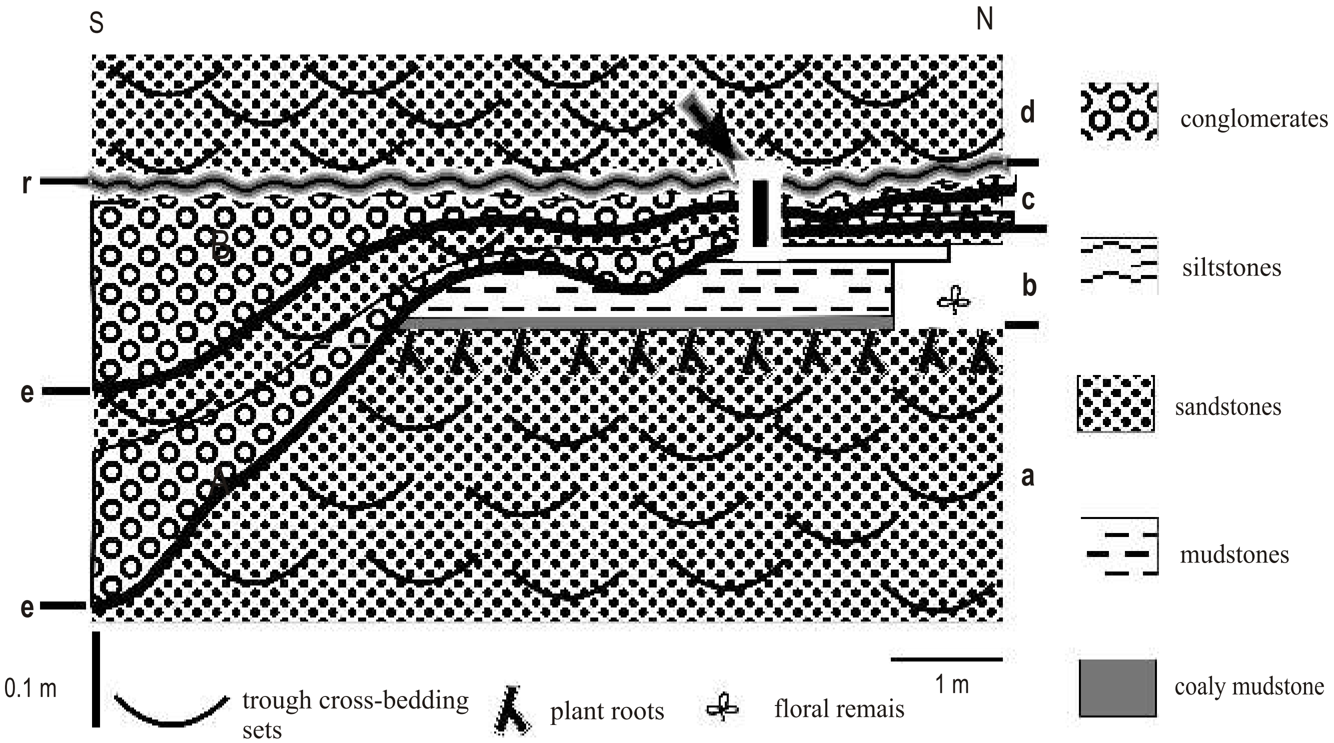

Fig. 7. Sketch showing facies relationships within the upper part of the Stanstorp Member in the Stanstorpsgraven exposure

Units **a–d** correspond to Fig. 3; **e** — erosional surface; **r** — rippled surface; note composite **c** layer with two erosional surfaces generally representing a composite graded bedding with a rippled top; the **c** layer fills the erosional channel, incised into the host fluvial channel and alluvial plain deposits; unit **b** is locally wholly removed by erosion; the detail shown on Fig. 8 is arrowed

ous lateral changes in thickness (Fig. 7), varied grain-size and composition, and textural inversion. The simultaneous occurrence of rounded quartz pebbles, large mud clasts in the lower conglomerate unit, and remarkable granite fragments in the upper conglomerate unit indicates mixing of various materials (Fig. 8). Lithofacies **Gcm** of the lower conglomerate unit can be interpreted as a product of inertial bedload with turbulent flow (Miall, 1996, table 4.1). The **Gt-St** lithofacies of the upper conglomerate unit could represent either minor channel-fill or sinuous-crested/linguoid dunes of a waning event (Miall, 1996, table 4.1). The initial current was able to erode local depressions, which were deep enough to protect the event deposits from subsequent fluvial reworking.

The profile of the bed clearly reflects waning current energy. The fining-upward texture, sharp erosional base and sedimentary structures (poorly preserved in the conglomeratic part, wave ripples at the top) point toward rapid deposition from episodic, waning flow: the current, initially carrying large fragments of rocks and plants, was rapidly replaced by wave action. The event clearly formed during two peak discharges, of which the first was much the stronger, and the whole event terminated by waning discharge deposition (Figs. 7 and 8). The first event eroded the fluvial plain (host) sediments and left behind a chaotic mixture of quartz pebbles, clay and wood fragments and sand interpreted as a product of turbulent flow. The second event was less violent and it deposited channel-fill and/or sinuous dunes. This wave quickly lost energy leaving behind sandy sediment in the form of wave ripples. It would be possible to interpret the event beds as a product of two separate events, but the general consistency of the two units suggests that it was actually one event with two stages (Fig. 7). Similar sequences produced by aqueous flows were described by Blair (1987) from an alluvial fan formed by a catastrophic flood that was generated by a dam failure — particularly, in respect of the rechannelised flow resulting in sharply bounded, interstratified sand and pebble-gravel couplets. Consequently, the origin of this conglomeratic layer can be explained as an extraordinary flood event. As far as concerns the source area, the adjacent hills were likely built of crystalline rocks which could deliver granite fragments, mud, trees *etc*. during discharge peaks. These hills were probably deeply weathered and prone to release material.

VITTSERÖD MEMBER

Observations at Stanstorpsgraven and in the Vittseröd area predominantly show large-scale tabular cross-sets with a multidirectional palaeocurrent pattern (Figs. 11 and 12) throughout the whole Vittseröd Member (Figs. 3 and 11). The tabular cross-sets represent multidirectional migration of sand waves. One may expect bidirectional longshore currents (with dominance of one direction in a given place) and unidirectonal onshore sand ridge migration as processes responsible for the

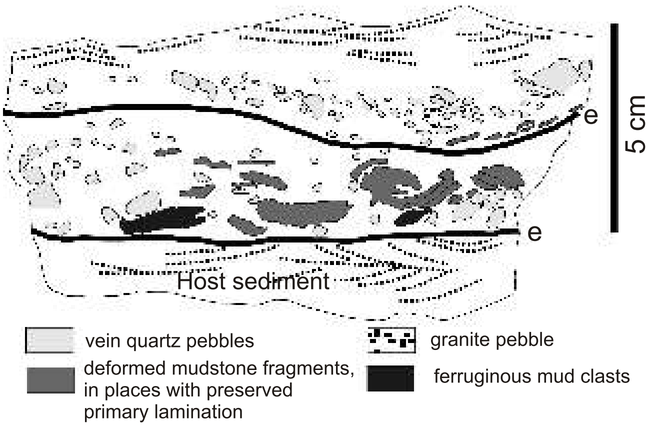

Fig. 8. Sketch showing a detail of the composite layer arrowed in Fig. 7

Note two sharply bounded sand and pebble couplets (units) reflecting rechannelised flooding with two peak discharges and rapid waning of the event reflected by wave ripples at the top; **e** — erosional surface

forming of those structures. The foreshore and shoreface zones are almost continuously subject to a variety of currents, which owe their origin to waves, wind and tides (Davis and Fox, 1972). The constantly changing nature of these driving forces dictates that the currents vary in speed and direction in both space and time (Swift *et al.*, 1979). Bipolar foreset migration producing bidirectional herringbone cross-bebdding (as in the exposure at Rugerup — Fig. 11) is very common in tidal environments (Reineck, 1972; Sellwood, 1972; Terwindt, 1988; Murakoshi *et al.*, 1995). Such bipolar foreset migration may also occur due to reversal of long-shore currents by wind, although this is less likely as geostrophic shore-parallel currents tend to be rather unidirectional (Hobday, 1974). The presence of sequences intersected by runnels and channels (Figs. 3 and 11) may also support the tidal interpretation. The presence of a facies of wave-built sand ridges implies that the tidal range must have been at most mesotidal, as macrotidal conditions are not favourable for formation of such sand ridges parallel to coastlines (Elliott, 1986).

Due to the dominance of high-energy conditions, specific features defining the tidal environment such as vertically accreted tidal bundles (Kreisa and Moiola, 1986; Tessier and Gigot, 1989; Murakoshi *et al.*, 1995) and mud drapes are absent. Troughs are mostly of scour-and fill type. In most cases, conglomeratic lags occur at the bottoms of troughs (Fig. 11). The trough axes show mostly SW–NE orientation, and the transport of material was towards the SW (Fig. 12). This means that the currents were probably running towards an open basin, taking into account the general the palaeogeography and coastline alignment (Fig. 1). The sediment grading alone indicates rapid deposition from suspension, but the presence of cross-stratification also points to deposition dominated by migrating bedforms with low high/length ratios. The fining-upwards successions, sharp erosional bases, and lack of distinct sedimentary structures within the sediments filling the "troughs" point to rapid deposition from episodic, waning flows. Rip currents or longshore currents associated with storms in a shoreface environment were probably significant (Ingle, 1966). Davidson-Arnott and Greenwood (1976) suggested that rip currents expand seawards of a breaker zone, which causes a sudden decrease in flow velocity, and results in the deposition of large volumes of sediment offshore.

In the Vittseröd Member, horizontal bedding with parting lineation is common. Such structures are indicative of strong currents (upper flow regime) — Allen (1984). Another type of horizontal bedding was observed in one abandoned quarry in the Vittseröd area. This was a horizontally stratified, *ca*. 30 cm thick sandstone bed with abundant plant detritus (elsewhere in this member plant detritus is absent or very scarce). Most likely, these laminated sandstones were deposited by flooding rivers and rapidly reworked by waves and currents. Such plant-rich beds represent periods of relatively higher river discharge in the adjacent source area or may represent regressive periods during the deposition of the Vittseröd Member.

A scarcity of small-scale cross-lamination, wave ripples, and structures indicating weak currents are characteristic for the Vittseröd Member. Also biogenic structures are very rare. Large-scale cross-bedding and high-energy structures certainly had higher preservational potential than small-scale structures formed by waves or weak currents. Complete storm sequences with the features presented by Dott and Bourgeois (1982) or Aigner (1985) were not observed, again probably due to preservational factors. All that could be preserved from the storm deposits in the sediment record here were conglomeratic lags and high energy, massive or parallel-laminated sandstones. Such prominent storm beds are characteristic features of a lower shoreface that is protected from fair-weather reworking (Galloway and Hobday, 1996). Therefore, the Vittseröd Member likely represent amalgamated, high energy deposits.

The environment of deposition of the Vittseröd Member was strongly dominated by nearshore currents. Although data

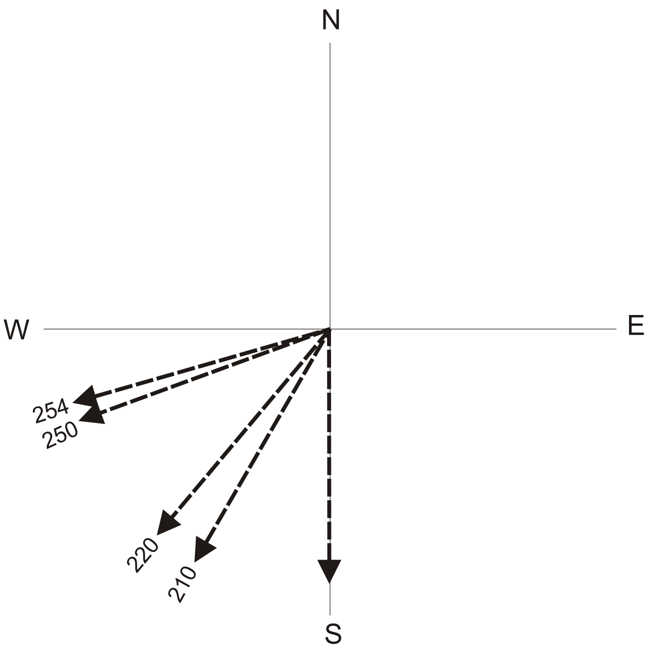

Fig. 9. Palaeocurrent directions of the Stanstorp Member;
all measurements were taken from trough cross-bedded foresets

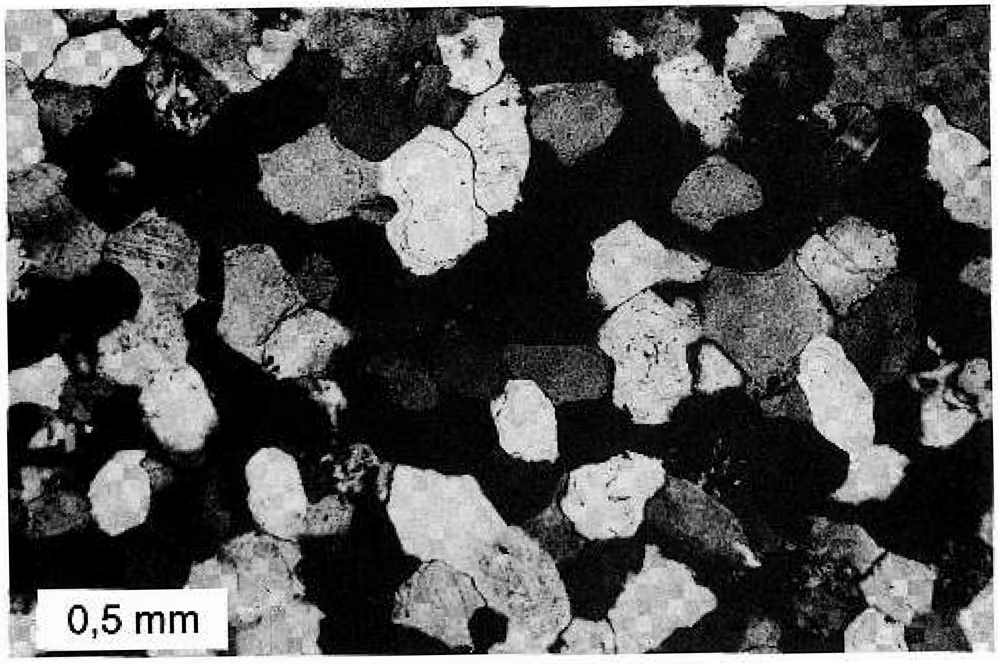

Fig. 10. Photomicrograph of a typical quartz arenite (Vittseröd Member)

Note mature, very well sorted and rounded grains with abundant quartz overgrowths; crossed polars

is scarce, the cross-bedding measurements and general palaeogeographical setting suggest that the ancient shore was probably situated generally along a NW–SE to N–S trend; the foreset migration with orientations ranging from NW–SE to N–S represent both the tide- and wave-induced longshore currents. Persistent geostrophic currents flow more or less parallel to the shoreline and such currents cause the greatest amount of sediment transport in recent nearshore zones (Davis, 1978). Other large-scale tabular sets should be related to onshore migration of longshore bars (Davidson-Arnott and Greenwood, 1976). Offshore-oriented scours and gutters observed in the Vittseröd Member (Fig. 12) may be due to storm-amplified rip currents transporting sediments from the surf zone onto the shoreface zone (Shepard *et al*., 1941; Ingle, 1966). Some of the very flatly inclined and offshore-inclined tabular sets also may represent the inclination of a welded beach face (Clifton, 1969; Davis *et al*., 1972).

The general succession of the Vittseröd Member dominated by longhore-oriented large-scale tabular cross-bedding with internal troughs, the presence of landward-oriented sets deposited by wave-driven ridges and a lack of hummocky cross-bedding sets in the profile, point to balanced accumulation on a storm- and tide- (of a micro- to meso-scale) -dominated shoreface zone (Galloway and Hobday, 1996). The presence of bidirectional herringbone cross-bedding suggests tidal activity.

A simplified palaeoenvironmental reconstruction of the Vittseröd Member is shown in Figure 13. The marine character of the Vittseröd Member is confirmed by finds of the bivalves *Avicula inaequivalvis*, *Liostrea* sp., *Pecten* sp., *Cardinia follini* Lungren (Hadding, 1929; Troedsson, 1940) and trace fossils (*Monocraterion* sp.) (Tullberg, 1880).

LITHOSTRATIGRAPHY AND AGE OF THE HÖÖR SANDSTONE

The data given above allow improved definitions of the formal lithostratigraphical subdivision of the Höör Sandstone. Within the Höör Sandstone two clearly defined and mappable units are present: the Stanstorp Member and the Vittseröd Member (Fig. 2). These differ significantly concerning their lithofacies/palaeoenvironmental characteristics.

The first task, though, is the formal definition of the formation as the primary lithostratigraphical unit (*International Subcommission on Stratigraphic Classification of IUGS Commission on Stratigraphy*, 1976). Norling *et al.* (1993) and Grigelis and Norling (1999) proposed the Höör Sandstone as a new formation, but with incomplete definition. It would also embrace an unnamed member representing partly Rhaetian rocks known only from archive descriptions. The boundaries of the Höör Sandstone cannot be clearly defined due to a poor exposure. Despite that, the term Höör Sandstone should be accepted as a formal lithostratigraphical unit for historical reasons, because its general lithology is known and because the whole formation represent a mappable unit (Norling *et al.*, 1993). The *International Subcommission on Stratigraphic Classification of IUGS Commission on Stratigraphy* (1976) recommended that lithology should not be included in a formation name, unless kept for historical reason, which is the case here.

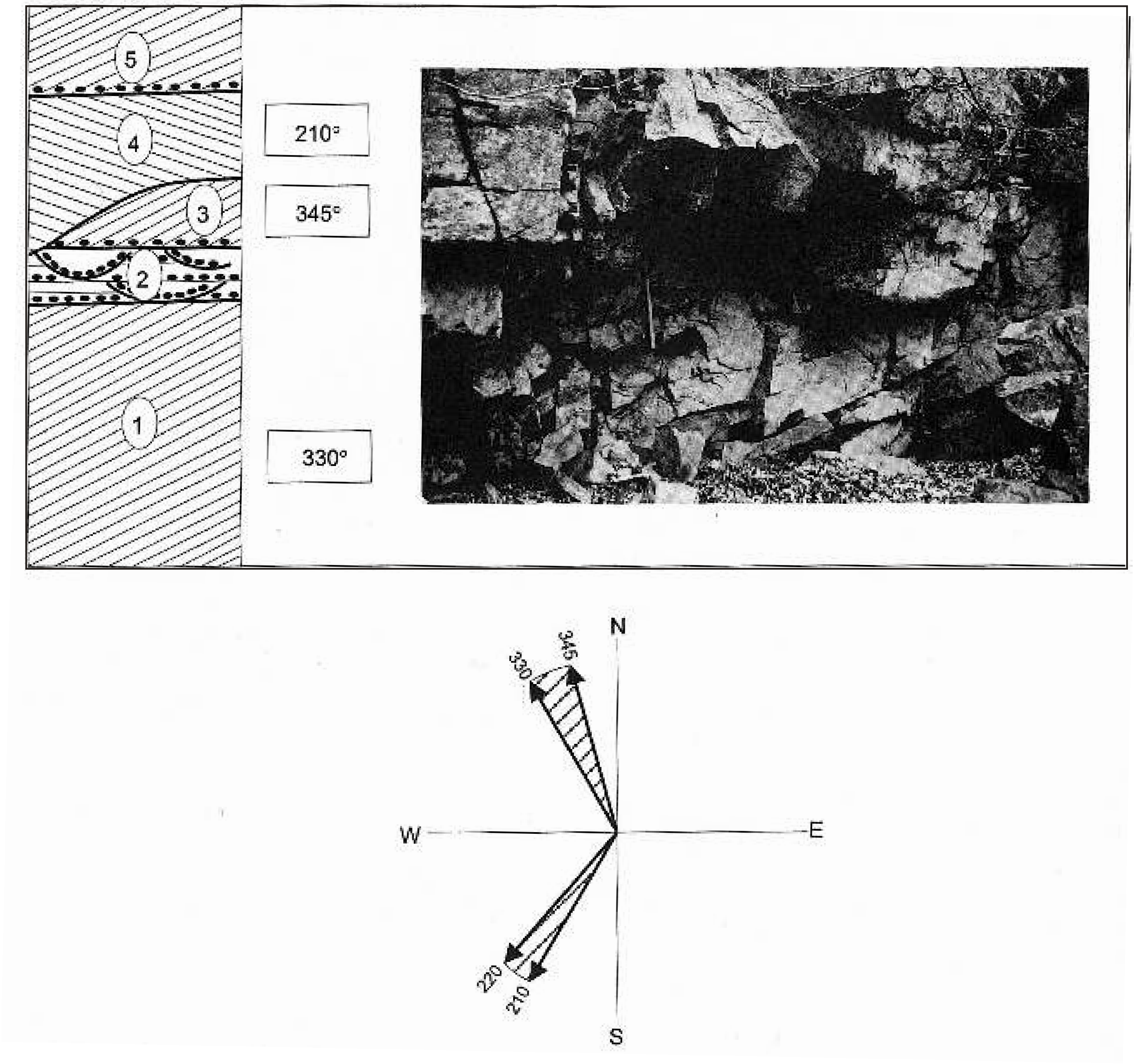

Fig. 11. Rugerup abandoned quarry

Note bidirectionally oriented tabular foresets (1, 3– 5); bedsets 1 and 3 are separated by an intercalated trough cross-bedded coset with mud clasts; sets 3–5 represent "herringbone" orientation and are separated by erosional bounding surfaces (with mud clasts between sets 4 and 5); palaeocurrent azimuths are shown in the diagram

HÖÖR SANDSTONE (FORMATION)

Name: Used since the Middle Ages after the small town of Höör in Scania (Sweden), around which the sandstone has been quarried.

Type locality: Stanstorpsgraven abandoned quarry near Stanstorp, south of Höör, map 1:50 000 (issued by Rikets Allmanna Kartverk, Stockholm), map 3D NV, coordinates 620 060, 135 665.

Thickness: Maximum about 55 m (according to archive materials in: Clarke, 1983, unpubl.; Warnock, 1983, unpubl.; Grigelis and Norling, 1999).

Dominant lithofacies: Grey and white-grey sandstones (subarkosic wackes, quartz wackes, subarkoses and quartz arenites), subordinate conglomerates and dark grey, organic-rich mudstones. Variously cross-bedded. Origin of lithofacies: fluvial and nearshore. Mature and coarser sediments often strongly indurated by silica cement.

Boundaries: The lower boundary is not exposed. Archive materials suggest that it should be placed at the top of the upper kaolinitic/bituminous horizon, which is approximately the traditional boundary of the Höör Sandstone. It should be emphasised that the Höör Sandstone represents only the "grey coloured" deposits: the underlying red bed deposits (probably of Norian age; Clarke, 1983, unpubl.; Warnock, 1983, unpubl.) are not included in the Höör Sandstone (Fm) and represent the underlying Kågeröd Formation. The upper boundary is undefined, it should be placed below the Brandsberga and Kolleberga sandstones of Pliensbachian age known only from boulders (Sivhed, 1984).

Age: Rhaetian, Hettangian and Sinemurian.

Distribution: Central Scania (Fig. 1).

Equivalents: Höganäs Formation (Helsingborg Member and Döshult Member) of north-west Scania (Sivhed, 1984).

STANSTORP MEMBER

Name: After the small village Stanstorp on the northern bank of the Västra Ringsjön, in the vicinity of which the type locality is situated.

Type locality: Stanstorpsgraven near Stanstorp, south of Höör, map 1:50 000 (issued by Rikets Allmanna Kartverk, Stockholm), map 3D NV, coordinates 620 060, 135 665.

Thickness: Maximum about 15 m (according to Sivhed, 1984).

Dominant lithofacies: Sandstones (subarkosic wackes, subarkoses and quartz arenites), subordinate organic-rich mudstones and conglomerates. Plant deritus and plant roots are abundant. Trough cross-sets dominate. Origin of lithofacies fluvial. Mature and coarser sediments often strongly indurated by silica cement.

Boundaries: The lower boundary is not exposed. Archive materials (Clarke, 1983, unpubl.; Warnock, 1983, unpubl.) suggest that it should be placed at the top of the upper kaolinitic/bituminous horizon, which is approximately equal to the traditional boundary of the Höör Sandstone. The upper boundary is moved up (Fig. 3) to the top of clay horizon (the "second" or "upper" clay), overlain by a conglomerate composed of clay intraclasts and rare quartz pebbles which commences the domination of quartz arenites. The new boundary separates different deposits; in the earlier one the uppermost "millstone" subarkosic wackes, subarkoses and quartz arenites were conflated with the "buildingstone" quartz arenites.

Age: According to Lund (1977), who examined the sample taken probably from the organic-rich clay in the Stanstorp Member (previously regarded as the top of the "millstone"), the age of the member is Hettangian, possibly also Rhaetian in its unexposed, lowermost part.

Distribution: Central Scania (Fig. 1).

Equivalents: Helsingborg Member and possibly Bjuv Member of north-west Scania (Sivhed, 1984).

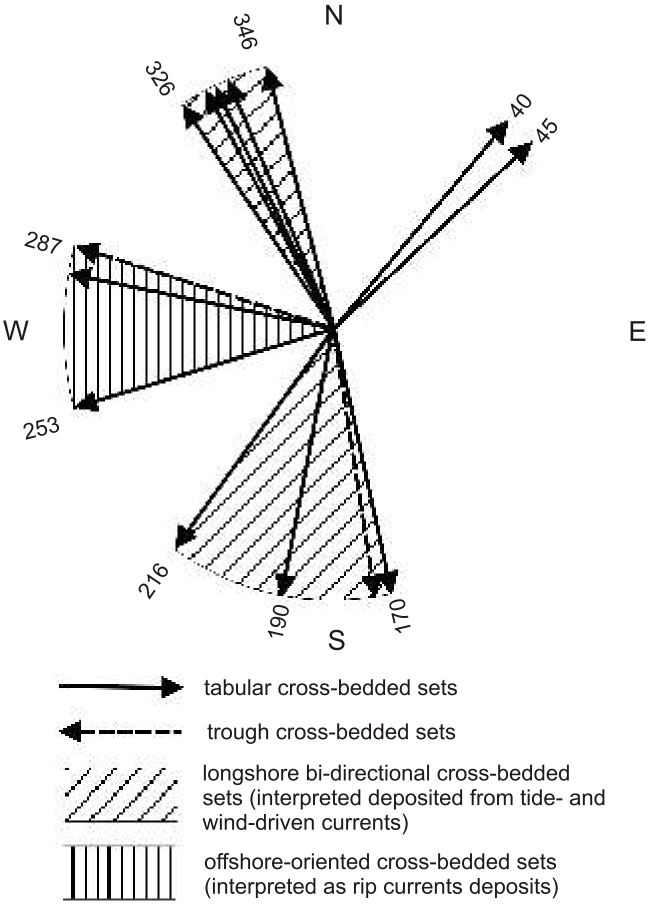

Fig. 12. Palaeocurrent azimuths in the Vittseröd Member

40 and 45 degree azimuths — tabular cross-bedded sets interpreted as the result of onshore, sand ridge migration

VITTSERÖD MEMBER

Name: After the village Vittseröd, where the sandstone ("buildingstone") has been mined for several hundred years.

Type locality: Rugerup abandoned quarry in the Vittseröd area (Fig. 9), map 1:50 000 3C (issued by Rikets Allmanna Kartverk, Stockholm), coordinates 620 680, 134 910.

Thickness: Maximum about 40 m.

Dominant lithology: Quartz arenites. Intercalations of mudstones and conglomerates are rare. Plant detritus is rare. Characteristic sedimentary structures are large-scale tabular cross-sets. Origin — shallow marine, tide- and wave-dominated nearshore/shoreface zone. Significantly hardened by diagenetic silification.

Boundaries: The lower boundary is placed on top of the last significant mudstone intercalation of the Stanstorp Member. The upper boundary is unknown, but it should be

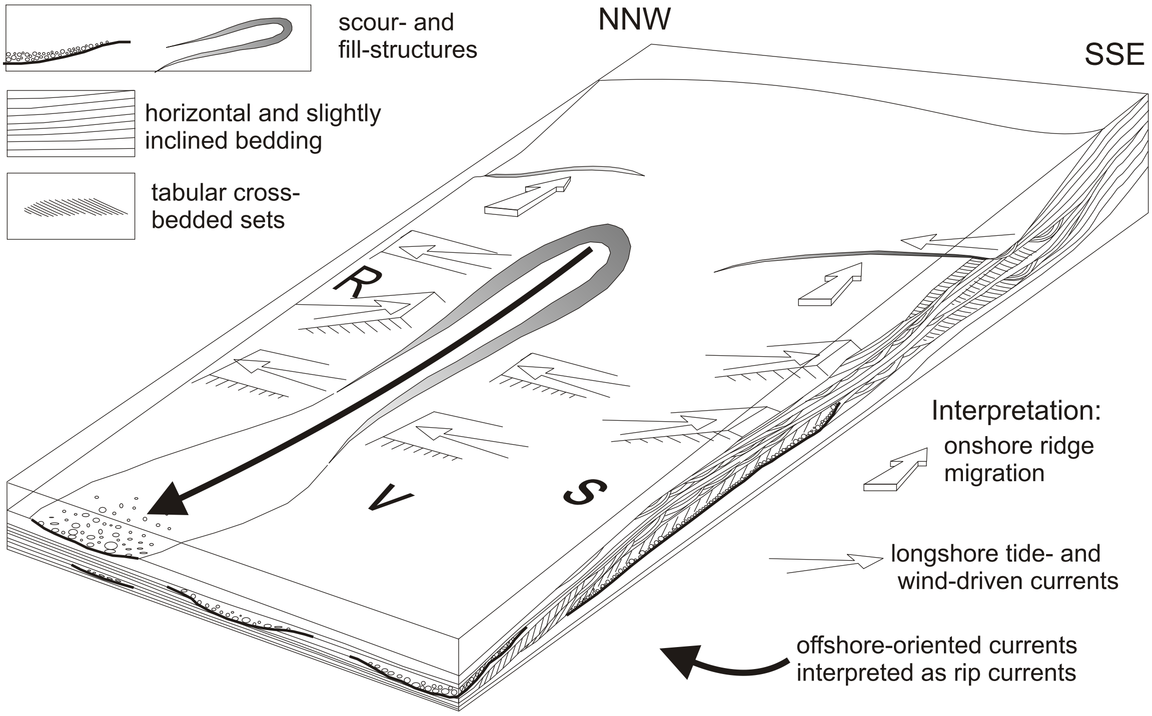

Fig. 13. Palaeoenvironmental interpretation of the Vittseröd Member

R — Rugerup, **V** — Vittseröd, **S** — Stanstorpsgraven

placed below the Brandsberga and Kolleberga sandstones of Pliensbachian age known only from boulders (Sivhed, 1984)

Discussion on the age: The “buildingstone”, which is approximately an equivalent of the Vittseröd Member, was referred to the Hettangian (Troedsson, 1940). This view was based on some finds of *Cardinia follini* Lungren in the “buildingstone”. Because this bivalve is characteristic of the Helsingborg beds (= Helsingborg Member) in north-west Scania, the “buildingstone” was considered by Troedsson as Hettangian in age. However, it is doubtful that such a facies-dependent fossil of poorly established stratigraphical range and distribution may serve as a reliable biostratigraphical indicator. Because fossils in the Vittseröd Member are so few, other methods of stratigraphical correlation may provide more stratigraphic precision. Possible methods may include regional facies/basin analysis.

As noted earlier, the Vittseröd Member is composed of nearshore, high energy, current-dominated deposits, possibly also of tidal origin. More fully marine sediments may be expected to the seaward, offshore direction, i.e. generally to the WNW (such a general palaeoslope tilt for the whole Liassic of Scania is indicated by many authors) (Larsen, 1966; Bertelsen, 1978; Pieńkowski, 1991*a, b*). Therefore, the key to the problem is the palaeoenvironmental character of the Helsingborg Member. Some brackish-marine, lower shoreface/offshore deposits (Pieńkowski, 1991*a*, *b*), or deposits showing some tidal features (Ahlberg, 1990, 1994) are known from the Helsingborg Member, but significant part of the Helsingborg Member is developed as deltaic or lagoonal deposits (Vossmerbäumer, 1970; Ahlberg, 1990; Pieńkowski, 1991*b*). In the lower part of the Helsingborg Member, in the Bjuv area, fluvial deposits are dominant (Pieńkowski, 1991*b*). However, fluvial or deltaic deposits are unknown in the Vittseröd Member, while they should be expected there, if they were continental counterparts of the Helsingborg Member. Moreover, the tidal origin of the Vittseröd Member does not find a proper counterpart in the Helsingborg Member (Hettangian), where the tides were less significant depositional processes (Pieńkowski, 1991*b*).

There are two possible answers to this dilemma:

— the entire Vittseröd Member represents the counterpart of only those sublittoral/offshore or tidal-influenced parts of the Helsingborg Member; or alternatively:

— the Vittseröd Member is not a time equivalent of the Helsingborg Member, but should be considered as a consistently nearshore equivalent of the marine Döshult Member.

I consider the latter to be more likely. It is unlikely that fluvial or deltaic facies would be absent from landward equivalents of the Helsingborg Member, in which deltaic facies are frequent. The Vittseröd Member thus most likely constitutes a high energy, shoreface-storm/tidal influenced facies equivalent of the shallow marine/tidal Döshult Member. The prominent component of tidal deposits in both the Döshult Member (Pieńkowski, 1991*b*; Norling *et al.*, 1993) and the Vittseröd Member (this paper) provides a strong argument for correlating them. The Döshult Member from north-west Scania is of Sinemurian age, and I thus suggest the same age for the Vittseröd Member (Fig. 2).

Distribution: Central Scania, southern Sweden.

Equivalents: Döshult Member (Sinemurian), north-west Scania.

CONCLUSIONS

Despite limited exposure, lithofacies/sedimentological analysis of the Höör Sandstone allows interpretation of the palaeoenvironmental characteristics of this formation. The Höör Sandstone shows clear lithofacies subdivision into two units: the Stanstorp and Vittseröd members, generally corresponding to a traditional subdivision into "millstone" and "buildingstone" units.

The Stanstorp Member represents fluvial sediments composed of both dominant fluvial channel and subordinate fluvial overbank (= alluvial plain) deposits. The sediment was transported generally from NE to SW. In intercalated conglomeratic layer represents an extraordinary flood event with two discharge peaks.

The superimposed Vittseröd Member was deposited on a storm- and tide-dominated marine shelf (shoreface zone).

Lithofacies characteristics suggest a more precise definition of the two lithostratigraphical members. Palaeoenvironmental characteristics of the Vittseröd Member suggests that this member is a correlative of the Döshult Member of SW Scania, and therefore is likely of Sinemurian age.

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