A pre-Devonian pediment in the lowermost Old Red Sandstone Hitra Group, Western Norway

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The ORS Hitra Group on the island of Hitra rests unconformably on igneous and metamorphic rocks of Ordovician age, and the surface of unconformity shows considerable palaeo-relief. In some topographic depressions thick regoliths have been developed and preserved, whilst on palaeo-hills such are rarely present or very thin. The basal sediments of the Hitra Group are interpreted as weathering remnants and as scree and flood deposits developed in an alluvial piedmont setting. Vertical variation in the succession is consistent with the unconformity having formed contemporaneously with sedimentation as a pediment at the foot of a retreating elevated source area.

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The Lower Devonian (Reusch 1914; Størmer 1935; Siedlecka & Siedlecki 1972) Hitra Group (Bøe 1988) occurs along the southeastern shore on the island of Hitra, Western Norway (Fig. 1). Along the northern margin of the Hitra Group the sequence commences with a basal conglomerate (Member A) resting unconformably upon a dioritic to granitic basement. Above this there is a passage into red, grey or locally green sandstones and siltstones (Member B). The latter are interpreted as the deposits of ephemeral streams on the distal reaches of alluvial fans (Bøe 1986). These two members constitute the Aune Formation. The present account will concentrate on this lowermost unit and its unconformable relationship to the basement. The Aune For-

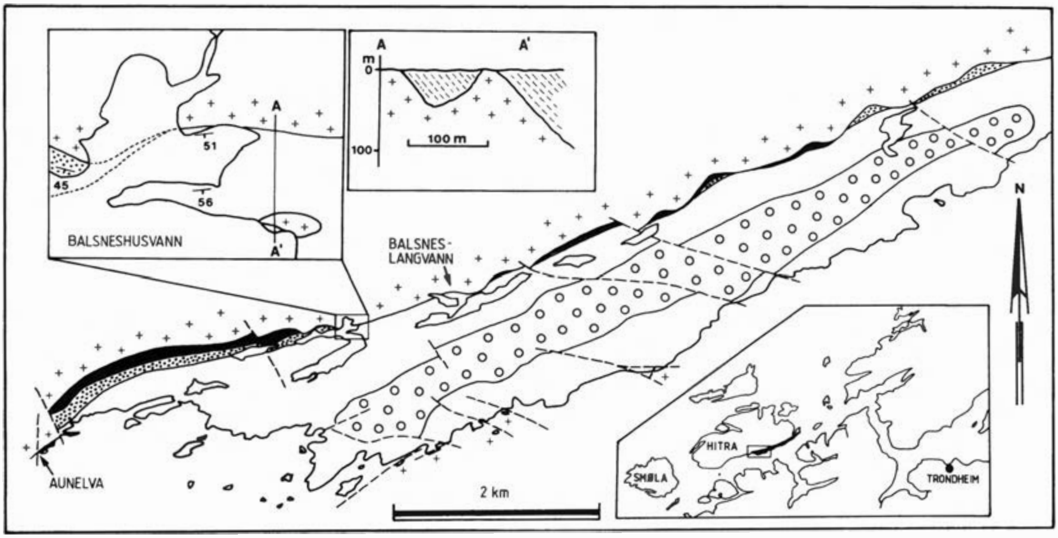

Fig. 1. Geological map of the westernmost part of the Hitra Group. Inset map (lower right corner) shows the location of the Devonian rocks on Hitra (black). Exaggerated area shows the unconformity and a basement high (cross-section) piercing the Vollan Formation at the eastern end of Balsneshusvann. Black: Member A; Dots: Member B; Unornamented: Vollan Formation; Circles: Balsnes Formation; Crosses: Basement rocks.

mation is succeeded by the Vollan Formation and the Balsnes Formation (Bøe 1988).

It is well established that deposition of the Hitra Group occurred in a continental environment (Siedlecka & Sidlecki 1972; Bøe 1986, 1988). However, previous research concentrated mainly on the broader aspects of deposition, and little detailed sedimentological work has been published. An exception to this is the basal conglomerate (Member A), which has been described and discussed by a number of authors over the past 75 years. It was first mentioned in the literature by Schetelig (1913), who concluded that the underlying diorite was intrusive into, and thus younger than, Member A. Reusch (1914) demonstrated that this was incorrect, and illustrated an upward transition from unaltered and unweathered basement to regolith, then basal conglomerate and finally into stratified, finer-grained sediments.

Peacock (1965) re-examined Reusch's localities and a number of previously undescribed examples where Member A and its relationship to the basement could be studied in detail. Later Siedlecka & Siedlecki (1972) mapped the area and described Member A as a 'basal weathering breccia'.

Basement

The Devonian succession on Hitra is underlain by igneous and metamorphic rocks of Ordovician age (Kollung 1964; Siedlecka & Siedlecki 1972; Sundvoll & Roberts 1977; Tucker et al. 1987; Gautneb 1987; Tucker 1988). The intrusives can be correlated with similar rocks on Smøla which have been dated at 436 ± 7 Ma (Sundvoll & Roberts 1977) and 428 ± 3 Ma (Gautneb 1987).

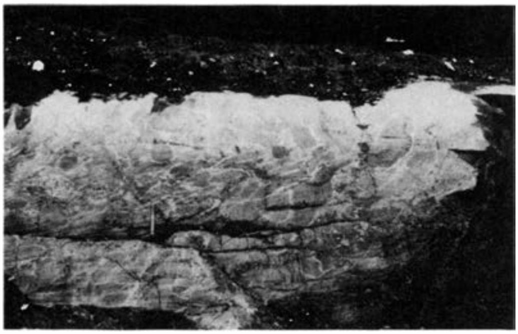

Fig. 2. Typical appearance of the dioritic basement. Dark, round fragments are xenoliths. Hammer shaft is 35 cm long.

The intrusive rocks on which the Hitra Group rests vary from granite through granodiorite to diorite in different areas; diorite, however, appears to be the predominant lithology of the undeformed basement. The diorite is rich in xenoliths, which may represent as much as 50% of the total rock mass. These are also of dioritic composition, but are darker and finer grained than the host. They have rounded shapes (Fig. 2) and, in areas with strong regolith development at the unconformity, it may be difficult to distinguish between basement and the overlying sedimentary sequence.

Occurrence and outcrop of Member A

Member A occurs as scattered outcrops along the northern margin of the ORS; traced from the west it occurs between Aunelva (610900 20200) and Balsneshusvann (611250 22800) and Balsneslangvann (612250 24700) to the west of Aksethusvann (213700 28200). It reappears 1 km east of Terningvann (615500 33300) and continues to the south of Storvågen (618000 36900). A thin development is also found southwest of Litlvågen (619000 38500). It is obvious that the member does not form a continuous unit (Siedlecka & Siedlecki 1972; Bøe 1986) (Fig. 1).

Description

The thickness of Member A varies from zero to a maximum of 114 m at Strandavann in the eastern part of the Devonian area. At the type locality at the mouth of Aunelva (Fig. 1) it is 45 m thick.

Prior to deposition of the Hitra Group the area was deeply eroded, and the terrain was characterized by an undulating surface, with valleys at least 100–200 m deep and up to several kilometers wide. The type locality is situated in one of these palaeo-valleys, where residual breccias (regoliths) were more liable to preservation, due to coverage of transported material, than they were on palaeohills. The sedimentary sequence at Aunelva rests on a highly irregular and fissured, weathered dioritic surface (Fig. 3). Due to the nature of this surface, and the poorly sorted and very angular material of the regolith above, it is difficult to differentiate between the basement and the residual breccia.

Fig. 3. Weathered basement west of Balsneshusvann. The picture is taken approximately 30 m beneath the unconformity. The material at the hammer shaft (35 cm long) is a weathering product from the diorite, now mainly epidote and chlorite.

On palaeo-hills it is easier to observe the precise diorite-sediment contract, as finer grained sediments of higher members rest directly on practically unweathered basement rocks. Sandstone-filled fissures in the old diorite surface are preserved, e.g. at the eastern end of Balsneshusvann (611650 23300; Fig. 1; Peacock 1965; Bøe 1986). At this locality an ancient hill pierces the Vollan Formation, the size of exposed basement outcrop being approximately 75 × 40 m. On the southern side the unconfirmity shows undulating palaeo-relief of less than 1 m, and 10–30 cm of conglomerate occur in the topographic depressions. Upwards this passes into horizontally and cross-stratified sandstone (Fig. 4). At the northern side of the fossil hill in the westernmost part of the outcrop, 3 m of residual breccia is preserved. The zone of fissured basement rocks is thickest on the northern side of the hill.

Fig. 4. The unconformity between the diorite and the Vollan Formation at the eastern end of Balsneshusvann. Note the occurrence of conglomerate in topographic depressions and of horizontal bedding in the sandstones.

Fig. 5. Basal conglomerate of Member A about 10 m above the regolith at the mouth of Aunelva. Hammer shaft is 35 cm long.

The residual breccias are dominated by poorly sorted material. At the type locality maximum boulder size is approximately 1.5 m across, which is the largest observed anywhere (Fig. 5). Commonly there is a complete size range from boulders through coarse-grained sandstone to clay size material. The largest fragments occur near the base of the member, and there is a gradual upwards decrease in the size and number of cobbles and boulders (Fig. 6).

Sand-supported conglomerate predominates in the upper part of Member A, where the largest cobbles are about 15 cm in diameter. In the lower part of the basal conglomerate (Fig. 6) fragments are subangular to subrounded, while at higher levels they are subrounded to rounded. Member A is generally matrix supported, and except for upward fining and increased rounding upwards, the only sedimentary structures present are some horizontal laminations near the top.

Over a vertical thickness of about 1 m there is a change to very coarse grained sandstones with scattered pebbles and vaguely defined, pebbly horizons of Member B. Within the lower levels of this member there is an upward increase in the number and thickness of mudstone beds, whereas sandstone beds become thinner and finer grained. There is also a decrease in the size of rip-up mudstone clasts, which may reach 1 m in diameter near the base.

The size of fragments and degree of rounding within Member A varies throughout the area. Clast lithology of the lower part, however, usually reflects the composition of local basement. This applies also for the highly epidotized, coarse,

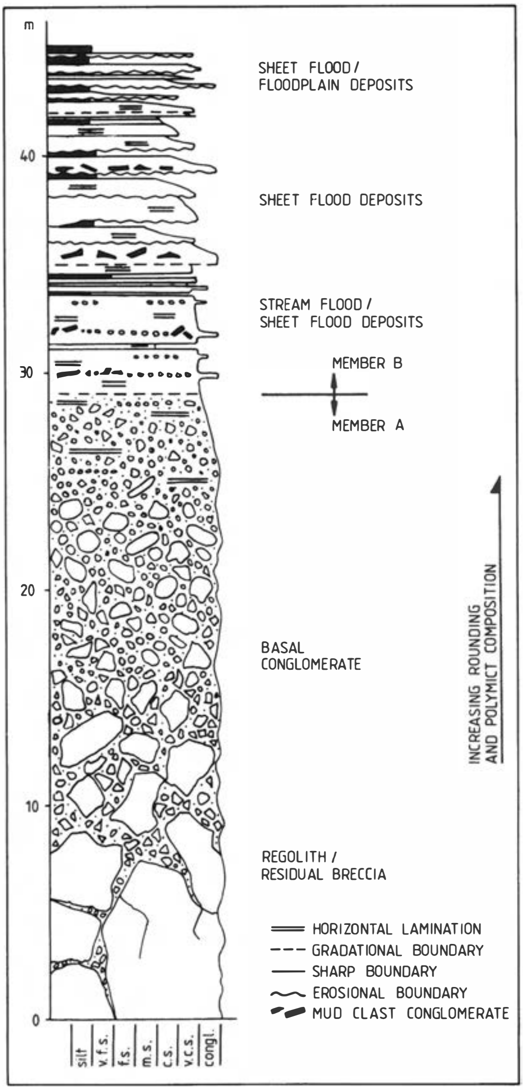

Fig. 6. Vertical section through the exposed sequence at the type locality at Aunelva.

lithic sandstones and grits in the matrix. Upwards, through the basal conglomerate (Fig. 6), more exotic rock fragments appear, e.g. jasper, limestone and volcanoclastics.

Discussion of sedimentary environment

Overthrusting and nappe emplacement in the Scandian phase of the Caledonian Orogeny in latest Silurian times produced a greatly overthickened crust, regional uplift and strong denudation of the highly elevated land surface. This led to deposition of thick sedimentary successions over extensive land areas, i.e. the Old Red Sandstone molasse. Some of the thickest successions were deposited in more local basinal areas, resultant from extensional 'collapse' of the most elevated regions (Bryhni 1982; Steel et al. 1985), while others, such as the Hitra Group, accumulated in wide sedimentary basins in front of or between highland source areas.

In the area of deposition which is now preserved, palaeo-relief is of the order of 100–200 m (Fig. 1). Prior to the onset of deposition relief differences were probably larger, but as deflation and sedimentation progressed, landforms were smoothed out and relief differences diminished. Palaeo-relief of 200–300 m was sufficient for erosion of weathered material from hills and its deposition in the valleys between the hills. Regoliths in the palaeo-valleys were by this process protected from further erosion. A similar relationship between basement relief and regolith preservation was observed at the unconformity beneath the Torridonian in NW Scotland (Williams 1969).

The presence of an igneous basement probably did not favour rapid denudation. Fissures and joints, however, which promote decomposition because they present routes for water infiltration, are present in the basement rocks beneath the Hitra Group, and decomposition and denudation probably started along these.

The regolith and weathering style at Aunelva resemble examples described by Clement & Kimpe (1977), Roaldset et al. (1982) and Went et al. (1988). There is an upward transition from unweathered basement into a weathered zone, where relatively fresh core-stones occur in a decomposed rock penetrated by fissures and joints infilled by clastic material. The jigsaw fit of many clasts (Fig. 6) provides clear evidence of *in situ* fissuring and brecciation (Wright & Wilson 1987).

The lowermost part of Member A with its angular rock fragments and a monomict, local basement composition represents a residual breccia (Siedlecka & Siedlecki 1972; Birkeland 1974; Retallach 1986; Bøe 1986). The thickness of this deposit varies throughout the area, from being absent to being a few metres thick. Where it is present, e.g. at Aunelva, there is commonly an upward (and probably lateral) transition to local talus deposits which can be recognized by containing slightly better rounded rock fragments than the regolith beneath. A similar relationship was observed by Went et al. (1988) from the Lower Palaeozoic of Jersey. Large-scale, downslope mass movement of weathered material, e.g. by landsliding, presently occurs in New Zealand (McSaveney & Griffiths 1987), but such processes were probably not important at the onset of Hitra Group deposition.

The thickness of the regolith at Aunelva is not exceptional. Ollier (1965) describes granitic rocks from Australia, which are weathered to depths of 100–200 m. It is usually assumed, however, that this happens under near-peneplain conditions, as otherwise erosion would more easily keep pace with weathering (Ollier 1965). No peneplain existed prior to deposition of the Hitra Group. The unconformity probably rather represents a landform developed during sedimentation, and the regolith is therefore not a remnant of a formerly much thicker regolith zone.

On the islands to the southeast of Smøla (Fig. 1) the unconformity between basement rocks and the ORS can be observed at several localities (Atakan 1988). As on Hitra there was an undulating land surface prior to deposition, and palaeo-relief of the order of 50–100 m can be observed. The basement is penetrated by fissures and joints several meters deep but, in contrast to the situation on Hitra, it is everywhere easy to pinpoint the exact basement surface. Zones of decomposed basement rocks comparable in thickness to those occurring beneath the Hitra Group are nowhere observed, probably because of more rapid erosion and less exposure time for deep chemical weathering. A similar zone of fissured basement rocks with neptunian dykes penetrating more than 20 m below the basement surface was observed at the unconformity beneath the Hornelen Devonian in Western Norway (Bryhni 1962, 1978).

The upward increase in rounding and polymict composition of clasts within Member A probably reflects the influx of river-transported material from more distant source areas. Periodic floods in proximal ephemeral streams and small debris flows on minor alluvial fans were probably the main transporting agents. Stream currents must have been relatively strong to transport boulders 1 m in diameter, as also indicated by the occasional presence of upper flow regime horizontal lamination and thin conglomeratic lags (Fig. 6).

Deposits of the transition zone are clearly stream transported. The horizontally stratified, pebbly sandstones alternating with conglomeratic beds reflect a sedimentary environment dominated by sheetfloods (Laming 1966; Bull 1972; Picard & High 1973). Each flood event deposited an erosive-based, conglomeratic lag. As the current strength decreased parallel-laminated sand was deposited, and on top rippled and parallel-laminated very fine sandstones and siltstones occur. The next sheetflood again eroded underlying beds, thus the uppermost part of the sheetflood deposits may not be present.

These processes of sedimentation probably continued to play an important role during deposition of Member B, but on a less frequent and violent scale. The abundance of rippled and parallel-laminated siltstones and very fine sandstones reflects a change to a quieter environment on distal alluvial fans and wide floodplains (Bryhni 1978; Steel & Aasheim 1978; Tunbridge 1981; Parkash et al. 1983). The upward fining from Member A to Member B may have resulted from a climatic change, a reduction in the relief of the source area or a decline in coarseness of available detritus. The most important cause was probably a reduction in local relief combined with retreat of the elevated source area. A schematic block diagram (Fig. 7) illustrates the main features during deposition of Members A and B of the Hitra Group. No well-defined sediment dispersal pattern was established at this early stage of deposition, though the presence of exotic pebbles in the upper part of Member A and in Member B may reflect longitudinal, long-distance transport from the SW and/or the NE (Bryhni 1977; Steel et al. 1985).

The frequent occurrence of pedogenic carbonate horizons in Member B (Siedlecka 1977) implies a relatively dry sedimentary environment with deposition mainly from ephemeral streams during periods of heavy rainfall. This theory is supported by red coloration of mudstones. The presence of colour-mottling within the mudstones suggests, however, that soil conditions were not always well-drained (Wright & Wilson 1987). Mudcracks and raindrop imprints indicative of subaerile exposure were not observed. Desert pavements have not been identified in the Hitra Group, probably because of a more humid climate and a higher rate of erosion and deposition. Such

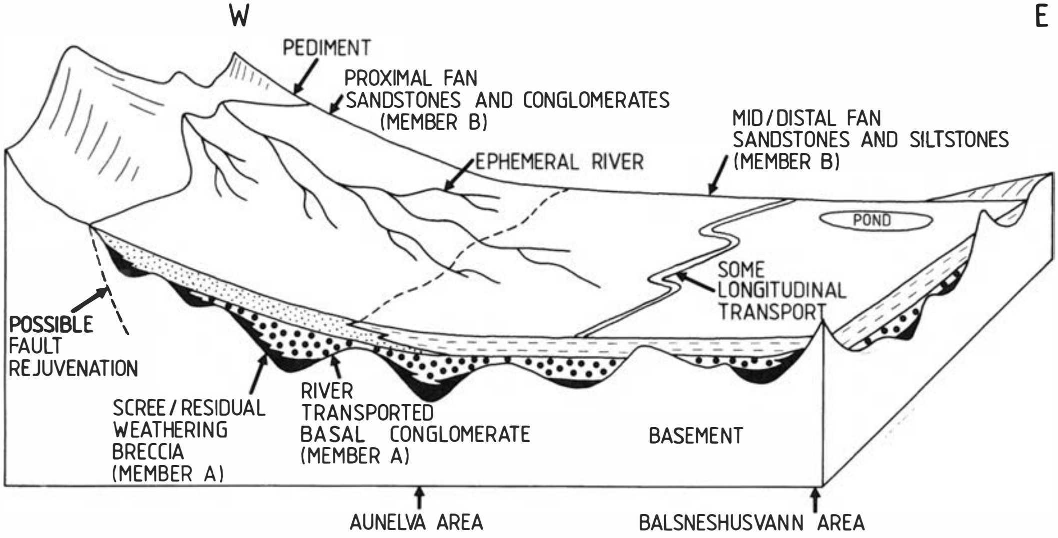

Fig. 7. Schematic block diagram showing the main topographic features during deposition of the Aune Group. The probable location of the Aunelva area during deposition of the Aune Group is indicated. Note the location of a highland source area to the west (possibly rejuvenated as a result of faulting).

pavements often need hundreds of thousands of years to develop (McFadden et al. 1987). Neither have true caliches nor soil profiles been observed.

From the Appalachian Piedmont, Pavic (1985) estimated that a typical saprolite profile can develop in one to two million years, and that the average chemical denudation rate varies from 7–40 m/million years. The lower figure is rather conservative (see also Wellman (1987)), and denudation probably took place at higher rates at the onset of Hitra Group deposition.

The best described ancient analogues to the Aune Formation of the Hitra Group are sediments at the base of the Stoer and Torridon Groups of the Torridonian in NW Scotland. Topographic relief was of the same order of magnitude, the palaeo-climate was probably comparable, and both areas were unvegetated during deposition. The Stoer Group overlies a hilly, fossil landsurface, with a relief of up to 400 m cut into the Lewisian gneiss. This surface was buried beneath residual breccias, and marginal screes deposited on hillslopes, small alluvial fans and in valleys. Outwards and upwards this locally derived detritus passes into fluvial (sheetflood and streamflood) and floodplain deposits, and then into shales and sandstones of marine or lacustrine origin. (Stewart 1969, 1975; Lawson 1976; Anderton et al. 1979). Another very similar ancient analogue is the basal Rozel Conglomerate Formation of Jersey (Went et al. 1988).

Conclusions

After the Scandian phase of the Caledonian Orogeny in latest Silurian times the lowermost Aune Formation of the Hitra Group was deposited. The unit starts at the lowermost level with a residual weathering breccia (regolith) developed on a basement surface penetrated by neptunian dykes. In palaeo-valleys the regolith was preserved beneath an accumulating sedimentary sequence, whereas in topographically elevated areas the regolith, if present, was eroded away. A pediment formed contemporaneously with sedimentation in front of a retreating elevated source area located to the W and N. This was covered by screes and progressively buried by encroaching piedmont alluvium. During retreat of the source area there was a change to finer-grained, long-distance transported material.

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