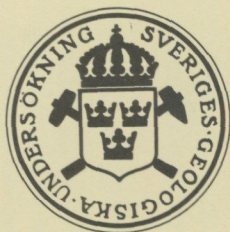


MICHAEL G. BASSETT, LESLEY CHERNS
AND
LARS KARIS

THE RÖDE FORMATION

EARLY OLD RED SANDSTONE FACIES
IN THE SILURIAN OF JÄMTLAND
SWEDEN



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ABSTRACT

Bassett, M.G., Chers, L., and Karis, L., 1982: The Röde Formation: early Old Red Sandstone facies in the Silurian of Jämtland, Sweden. *Sveriges geologiska undersökning, Serie C, No. 793*, pp. 1-24. Uppsala 1982.

The youngest Palaeozoic rocks preserved in the Swedish Caledonian mountain belt occur to the north of Alsensjön in Jämtland County. Defined here as the Röde Formation, these beds comprise fluvial sediments deposited in a meandering stream environment, with a source area some distance away and probably in a westerly to northerly quadrant. The recent suggestion of a possible Ludlow age for the underlying marine beds of the Ekeberg Greywacke Formation is shown to be unfounded on the basis of new faunal data, which include Wenlock graptolites. A Wenlock age is also deduced for the Röde Formation. The recognition for the first time of continental facies in the Silurian of Jämtland supports previous interpretations based on wider structural/stratigraphical evidence of a climactic phase of orogenic uplift in the Caledonides as early as Wenlock times.

INTRODUCTION

The pre-Pleistocene rocks of the area immediately to the north-west of Storsjön in Jämtland County, central Sweden (Fig. 1) consist mainly of Lower Palaeozoic sediments that have been subjected to Caledonian folding and thrusting. As part of the mapping to be incorporated within the Geological Survey of Sweden's bedrock map of Jämtland, particular attention has been focussed on some stratigraphical problems which have been interpreted in different ways in the past, including the tectonostratigraphical position and age of the youngest beds preserved in the Lower Palaeozoic sequence. The purpose of this paper is to review the structural setting of these beds, to demonstrate the evidence available for their dating and correlation, and to describe for the first

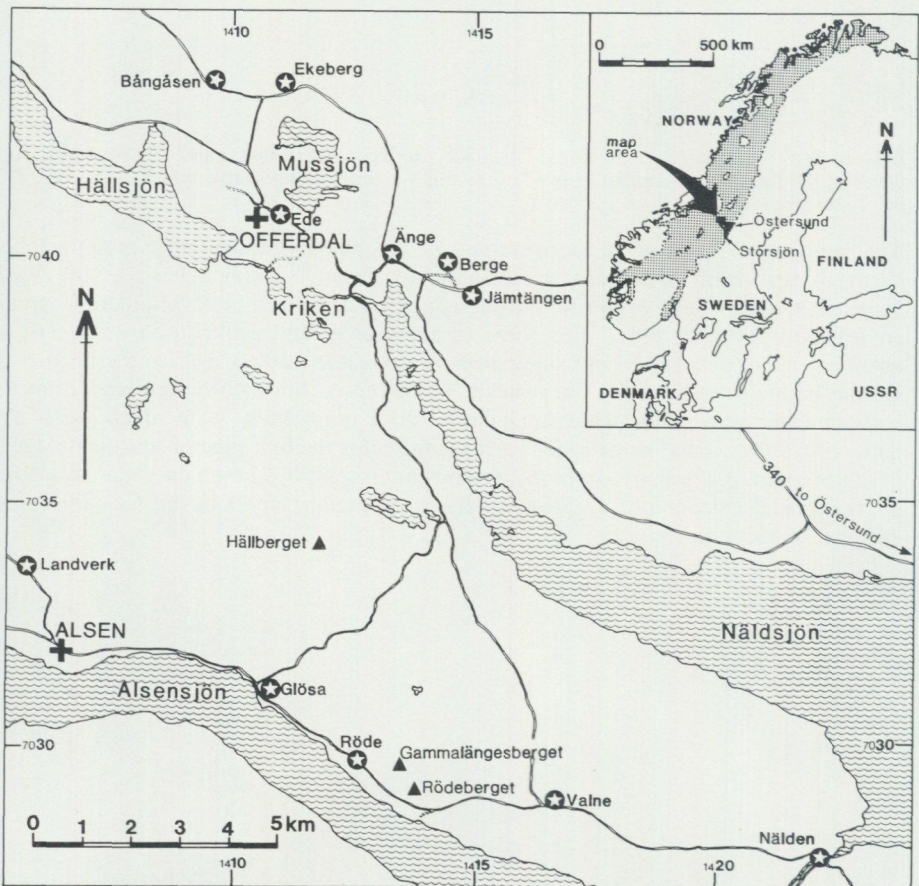


Fig. 1. Locality map of the area discussed in the text; inset map shows the setting of the area within the Scandinavian Caledonide cover (stippled).

time from Jämtland a Silurian lithostratigraphical unit formed in fluvial environments that represent an early introduction of Old Red Sandstone continental facies in direct response to Caledonian orogenic activity further to the west; the regional implications of this related sedimentary/tectonic pattern are also assessed.

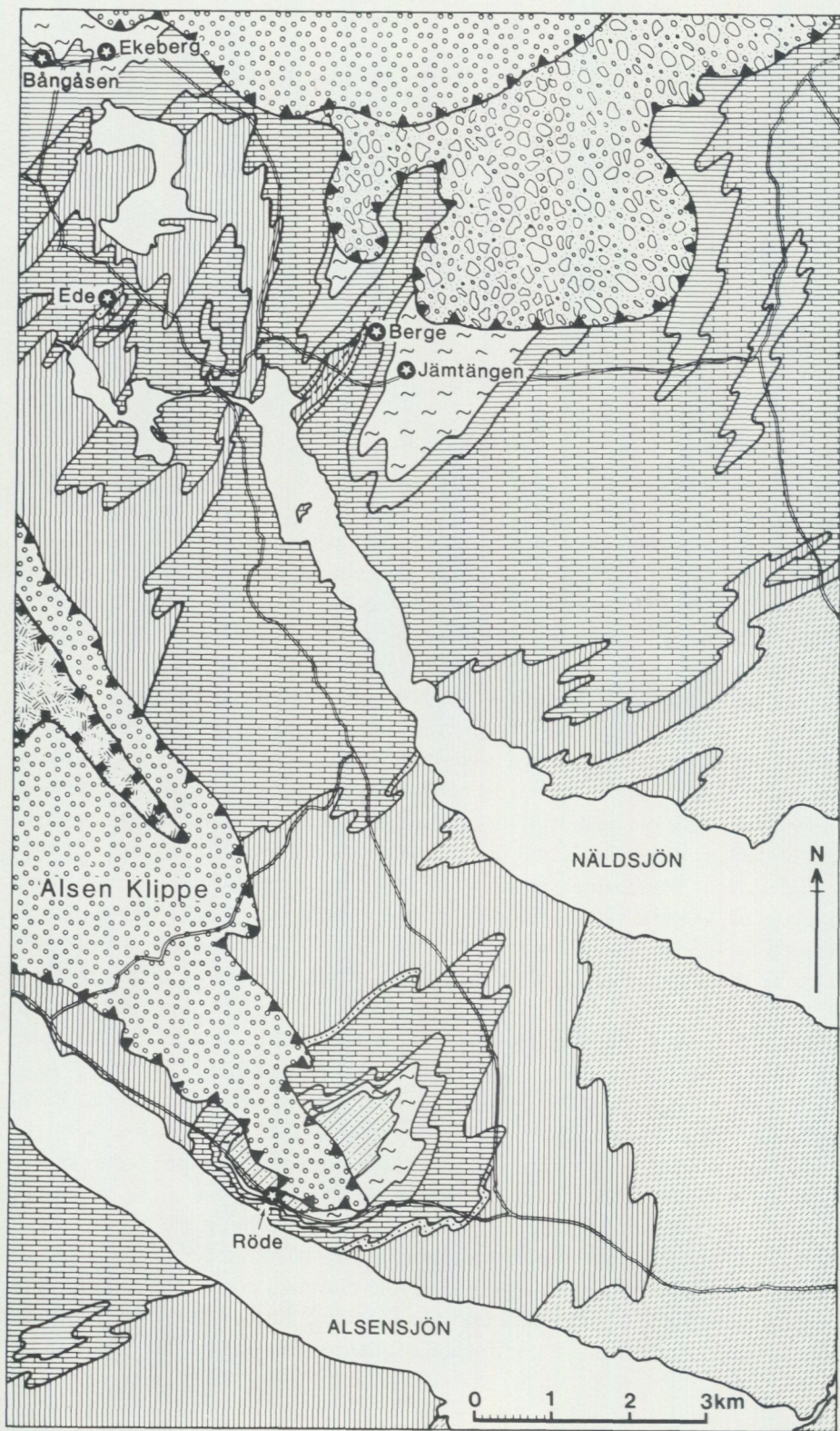
All eight figure Grid References quoted in this paper refer to the Swedish National Grid (Rikets Nät) on the 1:50 000 topographical map sheet 19 E Östersund NV (1975), within the 100 km grid square 70 14.

REGIONAL STRATIGRAPHY AND STRUCTURE

The geology of the area considered here is summarised in Fig. 2. As throughout much of the eastern marginal zone of the central Scandinavian Caledonides, the Lower Palaeozoic rocks of this Alsen-Offerdal region form part of an allochthonous sedimentary cover that is interpreted as riding on a décollement surface over a thin sedimentary autochthon and westerly dipping Precambrian crystalline basement (e.g. Gee & Zachrisson 1979; Gee 1978, 1981). The younger rocks of the Palaeozoic cover are preserved in a series of synforms aligned roughly NE-SW and thus parallel to the Caledonide front. Recent geophysical investigations suggest that the tectonic pattern may be modified by or related to irregularities in the underlying basement, and particularly to relatively large undulations that show up as marked magnetic anomalies (e.g. Dyrelis 1981). In general the western fold limbs are steep to overturned, with the eastern limbs more flat lying; both limbs incorporate two sets of earlier, minor folds and are frequently cut by small thrusts.

The Lower Palaeozoic sequence in the area comprises the 'Jemtlandian Nappes' of Askund (1960a, 1960b), included within the Lower Allochthon as defined by Gee & Zachrisson (1979, p. 9). In the north and west of the area (Fig. 2) these beds are overlain by metamorphosed rocks of higher tectonic units, the main Offerdal Nappe to the north of Offerdal itself, and the Offerdal and Särvi Nappes in the Alsen Klippe. The general setting and tectonostratigraphy have been described in detail in recent years by a number of authors (e.g. Strömberg 1974; Gee 1975a, 1975b; Gee & Zachrisson 1979; Gee & Kumpulainen 1980). Metamorphic grades throughout the area are low, with the Palaeozoic sediments in lowermost greenschist to subgreenschist facies (Kisch 1980; Andréasson & Gorbatshev 1981).

The Ordovician to Silurian age of the sediments forming the upper part of the Lower Allochthon in the Alsen-Offerdal area has long been established on the basis of good palaeontological control, although some age relationships have remained unclear in detail and are discussed further below (p. 15). The Silurian units of the lithostratigraphical sequence, comprising the Änge Group



of Strömberg (1974), have their type areas in the Offerdal-Änge region at the north-west end of Näldsjön (Figs. 1, 2); in ascending order this sequence comprises the Ede Quartzite Formation, Berge Limestone Formation, Bångåsen Shale Formation, and Ekeberg Greywacke Formation (nomenclature modified after Thorslund 1948, 1960a, 1960b). The folded pile of Ordovician-Silurian rocks north of Offerdal-Änge is cut by the basal thrust of the main

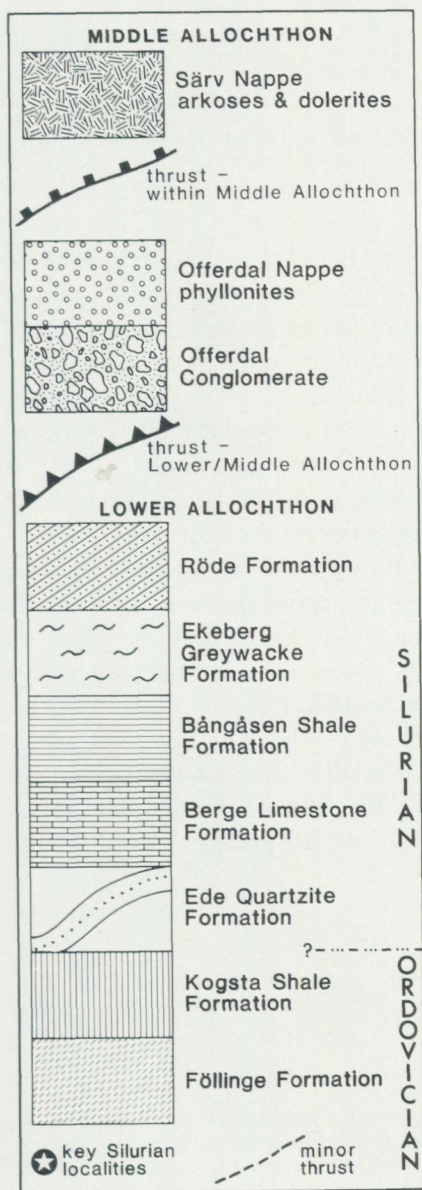


Fig. 2. Geological map (opposite) of the Alsen-Offerdal area indicating the regional setting and stratigraphical relationships of the Röde Formation; the Särv Nappe is included here in the Middle Allochthon following D.G. Gee (personal communication 1981).

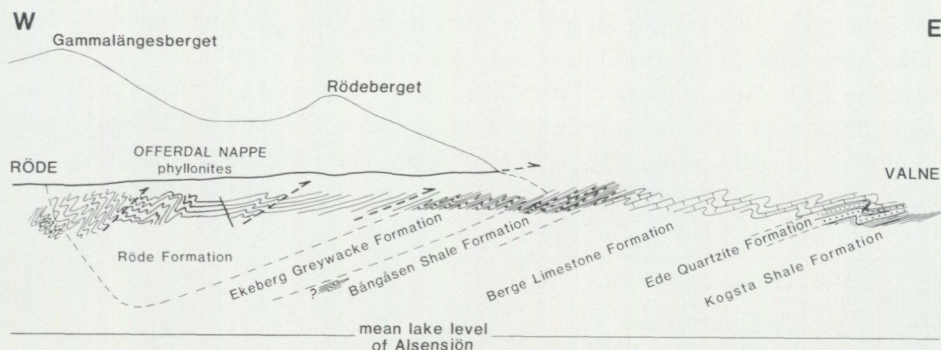


Fig. 3. Reconstruction of upper Ordovician-Silurian stratigraphy and structural relationships in the Röde-Valne area (see Figs. 1 and 2), and relationships between the Lower and Middle Allochthon; length of section 4 km; difference in elevation between Alsensjön and Gammalängesberget 142 m.

Offerdal Nappe, whose lower unit comprises late Precambrian (Strömberg 1975, p. 16; Gee & Zachrisson 1979, p. 24) conglomerates, sandstones and siltstones (Gee & Kumpulainen 1980, p. 19) of low to moderate metamorphic grade that form an upward transition into a main phyllonite mass.

Between Näldsjön and Alsensjön similar relationships are exposed between the Lower and Middle Allochthon, particularly around the flanks of Gammalängesberget and Rödeberget (Figs. 1-3). Here the Offerdal Nappe is dominated by mylonites and phyllonites, although on Rödeberget a few small and restricted outcrops of conglomerate may represent the Offerdal Conglomerate (see also p. 15); beds below the main thrust plane are mylonitised for a thickness of 1-3 m, with 5-20 m of mylonites above grading up into the phyllonites. In the underlying synform the Ordovician-Silurian sequence is generally similar to that in the Offerdal-Änge area up to and including beds assigned to the Ekeberg Greywacke Formation. Below Rödeberget, however, there is a further sequence of sediments above the Ekeberg Greywacke Formation and below the sole thrust and mylonites of the Offerdal Nappe; these are the sediments that we name here as the Röde Formation, and which despite their limited development provide critical evidence towards the

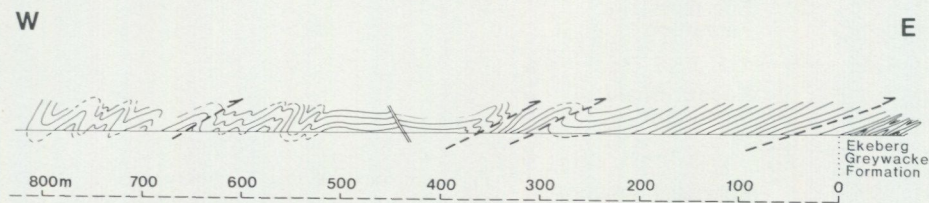


Fig. 4. Schematic section through the Röde Formation in the type section below Rödeberget, showing the general style of folding and minor thrusting; note that the figures given below the diagram refer to linear distances in metres along the road section westwards from the basal Röde contact, and *not* to stratigraphical thicknesses.

interpretation of tectonic and palaeogeographical evolution in this segment of the Caledonides. In order to understand the implications of this evolutionary picture it is important to view the Röde Formation in its broader regional setting.

THE RÖDE FORMATION DEFINITION AND DISTRIBUTION

The type section for the Röde Formation is an almost continuously exposed section on the north side of the road running along the north side of Alsensjön (Figs. 1, 2) and below Gammalängesberget and Rödeberget, between approximately 8.5 km and 7.7 km south-east of Alsen church (Grid References 2868 1423 to 2912 1313). Scattered outcrops of the formation in a restricted area north-east of Gammalängesberget confirm that it forms the centre of the synform below the Middle Allochthon in the region (Fig. 2). Elsewhere, the unit, in association with the underlying Ekeberg Greywacke Formation, is known only from sparse, discontinuous outcrops along and near the road through Landverk (3370 0560), 1 to 3 km NNW of Alsen church (Fig. 1). Because of the limited information available from these other outcrops, the description and interpretation of the formation are based here only on the type section, that we refer to as the Rödeberget section.

The base of the Röde Formation, resting on thinly bedded dark siltstones, shales and interbedded fine turbiditic sandstones of the upper Ekeberg Greywacke Formation, is exposed over a lateral distance of about 25 m, some 100 m west of the small road turning to Rödegård (2868 1400; Fig. 5C). The basal contact itself is within a disturbed zone some 0.5 m thick. A prominent, low angle, undulating thrust, subparallel to the bedding, is the most obvious feature in the contact zone (Fig. 5C), but does not form the basal surface since there are also beds of Röde lithology within minor tectonic slices below this level. We interpret all these structures at the Ekeberg/Röde contact as being minor shear surfaces similar to the style and magnitude of small scale thrusts seen throughout the Lower Allochthon of this area, but markedly different in style from structures present in the overlying Middle Allochthon (see below).

The magnitude of the displacement of the thrust in the basal Röde contact zone cannot be determined from relationships in the Rödeberget section alone. However, similar structures within the Lower Allochthon of the Änge-Offerdal area generally show a movement of 50 m, or rarely up to a maximum of 100 m. In the flat lying eastern fold limbs the thrusts are mostly subparallel to the bedding and thus cut out very little of the original sequence. Since the structures at the Ekeberg/Röde contact at Rödeberget are within an eastern limb and conform with the general regional style, it is unlikely that any significant thickness of beds is cut out here. The lithological contrast across the

boundary is further heightened by differences in tectonic style related to different competencies of the two formations, reflected in the tight and steep isoclinal folding of the more argillaceous Ekeberg strata as opposed to a more open fold style imposed on the coarser Röde sediments. In the light of these relationships we therefore consider that the Ekeberg/Röde contact was probably one of original stratigraphical contiguity.

Above the contact zone there are thinly bedded siltstones and sandstones (c. 1 m) of the Röde Formation before the base of the first thick quartzite in the sequence. Above this, tectonic complication (Fig. 4) makes it impossible to measure a true stratigraphical thickness, but we estimate that as much as 75–80 m of Röde beds may be present up to the base of the Offerdal Nappe. The main structural elements in the Rödeberget section are shown schematically in Figs. 3 and 4. In the western part of the section (west of 525 m from the contact zone) the steep, inverted limbs of the open folds have a general dip of 75° – 80° NW and strike N 60° E, with the more flat-lying (and right way up) limbs dipping at 15° – 40° N to NW. In the centre of the section (about 430 m west of base) the beds strike N 35° W and dip at 5° to 15° NE, apparently reflecting the plunge of the syncline. Further east the dip increases again in the eastern limb of the fold, reaching 30° – 35° NW at 150 m west of the contact. The minor thrust planes throughout the section have an average dip of about 35° NW in the western limb, 30° NW in the hinge and about 20° NW in the eastern limb. In contrast, the major thrust plane at the base of the Middle Allochthon above the Röde Formation dips at 10° NW at the most, and above this level the rocks of the Offerdal Nappe are frequently imbricated, with the schistosity climbing rapidly from subparallel to the thrust plane to about vertical; these structures are thus markedly different in style from those in the Röde Formation and from those throughout the Lower Palaeozoic sequence of the Lower Allochthon.

LITHOLOGY AND PETROGRAPHY

The Röde Formation comprises mainly medium- to thick-bedded, olive to green and red-spotted micaceous quartzites interbedded in various proportions with green and reddish purple shales and silty shales.

In the quartzites the reddened patches and spots are elongated along the lamination and mostly represent concentrations of opaque iron oxides. Fine to very fine grained sandstones are the dominant lithologies, with subordinate coarse siltstones and medium grained sandstones. In composition these rocks are quartzose wackes and arenites. Quartz grains are variably rounded and sorted although a dominance of subangular or subrounded grains is most common. Simple quartz is usually by far the main grain type but polycrystalline grains are present in appreciable amounts in some beds; some grains show

straining and contacts are often sutured. Feldspars are generally badly altered, or at least partially corroded and clouded, and are thus difficult to identify but appear to comprise fairly low amounts (<5%); plagioclase is more common than potash feldspar except in a few samples. Lithic fragments are uncommon, limited to occasional rounded siltstone inclusions in the sandstones. White mica (mostly 1–5%) is widely distributed through beds, but is most noticeable as clusters of aligned laths associated with opaque iron oxides along reddened partings in the quartzites (mica up to 14%, haematite up to 24%). There is widespread sericitisation and chloritisation of both matrix and grains. Carbonate appears to overgrow silica and clay matrices as a secondary cement.

The shales comprise thin tabular sets in which the clay-rich laminae and beds are reddish, while the coarser, siltier lithologies are green or yellowish-green. The red colouration appears to result from finely disseminated haematite in the sediment. The argillaceous matrix supports small, angular or poorly rounded grains of quartz and plagioclase feldspar, with minute flakes of white mica which are particularly well developed and well aligned along shear planes. Carbonate cement is prominent in the sericitised and chloritised matrix.

SEDIMENTARY STRUCTURES AND DEPOSITIONAL ENVIRONMENTS

Above the basal contact zone in the Rödeberget section the lowest metre of siltstones and thin (<3 cm) sandstones in the Röde sequence lack characteristic sedimentary structures; the first massive quartzite is 21.5 cm thick. In higher beds, depositional structures are best preserved in the flatter-lying strata towards the core of the syncline, where quartzites include a variety of bed forms and lamination types. In the fine grained argillaceous lithologies most structures have been obliterated by tectonic deformation. Some shales display well developed flat laminae, 1–2 mm thick, but these result from a realignment of detrital grains and flaky minerals that produces a marked fissility; in thin section the bedding commonly shows tight corrugation oblique to and independent of the tabular layers.

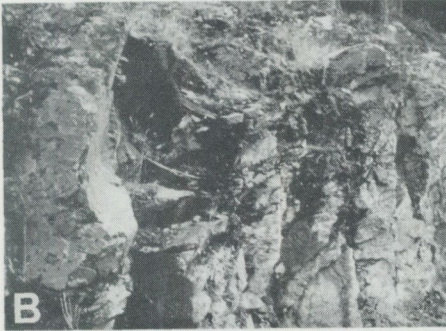
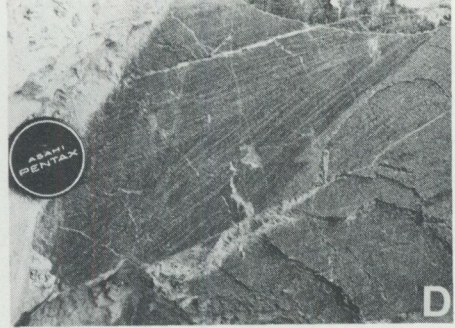
The quartzites occur singly in beds up to 25 cm thick among the shales and silty shales (Fig. 5F), or in units of grouped sets up to 2 m or more thick (Figs. 5D, E). The latter dominate particularly in the central part of the syncline. Some units appear massive, but in others the common sedimentary structures are flat bedding, cross-stratification and cross-lamination. The laminae are often pronounced and are generally from 2 to 10 mm thick, becoming picked out in many beds by the reddened partings. Where grading by upward-fining is discernible, the mica-rich reddened bands correspond to the upper, finer parts of layers. This indicates that the textural lamination represents an original

bedding fabric and that in the coarser Røde lithologies there is a concordant relationship between tectonic and depositional structuring.

Extraformational conglomerates are absent, but a few thin horizons of intraformational mud flake bands occur in the basal parts of massive or flat bedded quartzites. There are occasional levels where small flame structures and loading at the contact of quartzites on underlying shales indicate soft sediment deformation. In massive quartzites, the bases are mostly sharp, and where they overlie other quartzites appear to be erosional; however, the upper boundaries are more often transitional, with some showing a rapid grading up into finer, more argillaceous lithologies although there is no lamination visible through the bulk of the bed. Many of the flat bedded and cross-stratified quartzites are grouped, with cosets of lithologically similar sets mostly from 2–10 cm thick. In the higher part of the sequence, quartzite cosets include rather more of the thicker sets, and individual sets may reach up to 15–20 cm. Some sets show an overall grading, with an increase of silt and finer lamination in the upper part.

In the grouped cross-stratified units, the lower boundaries of sets are variously slightly erosional or abrupt, with a plane or weakly curved basal surface, or some appear to be gradational. The geometry of lower curved surfaces can only be generalised as forming relatively broad, shallow troughs (since no three-dimensional aspect can be seen, cf. Allen 1963, Fig. 2). Lamination generally appears flat and tabular or only slightly discordant to the basal surface (Figs. 5D, E). Towards the outer edges of troughs there is some steepening in the dip of laminae (Fig. 5D), but cross-lamination is generally at

Fig. 5. Structural and sedimentological features in the Røde Formation, Rødeberget section; distances quoted for each feature illustrated refer to distances west of the basal contact as shown in Fig. 4. (A) 285 m – relatively open style of folding in thick (50 cm) band of quartzites above low angle thrust on which hammer is resting (length of hammer 28 cm). (B) 330 m – open syncline in thick-bedded quartzites showing general fold style in relatively competent beds in the section (total height at left margin of photograph c. 2 m). (C) 5 to 25 m – prominent low-angle undulating thrust at contact zone of Ekeberg Greywacke Formation and Røde Formation (total height at left margin of photograph c. 3.5 m). (D) 620 m – cross-laminated quartzite cosets; note the generally low angle of discordance between the cross-lamination of sets and their lower, erosional bounding surfaces; the photograph shows the increased dip of the internal laminae and greater curvature of the basal surface towards the edge of a trough, where there is marked angular divergence against the adjacent set (diameter of lens cap 54 mm). (E) 620 m – cross-laminated quartzite cosets; the lower part of the photograph shows the gently curved, lower erosional bounding surface of one set; note the low angle of cross-lamination in relation to this surface, and also the low angular divergence between laminae in adjacent sets higher in the deposit (diameter of lens cap 54 mm). (F) 610 m – flat bedded quartzites interbedded with siltstone-shale units; note the abrupt, flat contacts between the 'coarse' and 'fine' units (length of match box 6 cm). (G) 325 m – rippled surface of cross-laminated quartzite (length of hammer head 17 cm).



a very low angle (Fig. 5E). Thus it is often not possible to determine whether sets belong to flat bedded or to planar or trough cross-laminated units. The angular discordance between the lamination of adjacent sets is commonly low ($<10^\circ$), although in some faces much steeper divergence (up to 25°) is evident (e.g. Fig. 5D).

For those examples in which the relationships are clear, the cross-lamination in planar cosets appears to be the *lambda* and *mu* types of Allen (1963), resulting from the migration of trains of small scale asymmetrical ripples with essentially straight crests. This is consistent with a well preserved rippled surface seen in outcrop (Fig. 5G), showing straight to slightly sinuous crested, small, shallow ripples (wavelength 2.5 cm, amplitude 1–2 cm). Among the cross-laminated quartzites, ripples in the upper parts of some sets are generally shallow, often less than 1 cm in amplitude, and with wavelengths of 2–10 cm. Those trough sets that can be identified with certainty are mostly small scale features of *nu* type, which again arise from migration of trains of asymmetrical ripples, but of linguoid shape. A bedding surface with small, shallow, cusped ripples of this type (wavelength 2.5–5 cm, amplitude <1 cm) is exposed in the section 620 m west of the base. For cross-stratified quartzites with thicker (10–20 cm) individual sets, the equivalent large-scale laminar structures are *omikron* and *pi* types, which reflect essentially comparable processes of bed load migration as large ripples or dunes. Since the lamination in such sets is seen to be discordant to the bounding surfaces in one direction only, and appears parallel or nearly so in the face at right angles, it may be that many of the apparently flat-bedded tabular sandstones in other parts of the Rödeberget section (see above) are also of these types.

Among the grouped and solitary 'coarse members', the various combinations of upward-fining planar and trough cross-stratified sandstones, with some massive or flat-bedded sandstones and ripple cross-laminated fine sandstones and siltstones, are all features typical of fluvial sedimentation, with structures produced by lateral accretion in channels and the downstream migration of ripples (e.g. Allen 1964, 1965; Miall 1978; Walker & Cant 1979). The reddening of the sediments and the absence of marine fossils support this origin of the Röde Formation. Sedimentary structures characteristic of lower flow regimes, and the absence of extraformational conglomerates and coarse-grained sediments throughout the sequence indicate deposition in a distal, meandering stream environment. Sandstone units represent bed-load sediment deposited in shallow channels or on point bars, while the 'fine member' units of siltstones and shales represent levee or flood plain deposits (e.g. Collinson 1978). Supporting evidence for the environmental interpretation of the more argillaceous sediments is lacking at Rödeberget, but it is likely that any features such as desiccation structures, plant rootlets or bioturbation have been destroyed by tectonics and the regional metamorphism.

AGE AND CORRELATION

As yet the Röde Formation has yielded no fossils (including palynomorphs) to provide direct palaeontological evidence as to its age, so that dating of the beds must rely on an assessment of their stratigraphical relationships to units in the area that do contain diagnostic faunal criteria. The question of these relationships has been discussed by a number of authors in the past, with various conclusions, though there has been no appreciation of the significance of the Röde sediments. Högbom (1909, p. 321 and pl. 2, Fig. 8) mentioned the greenish quartzites and shales in the Rödeberget area, and interpreted them as lying within the 'mylonitic thrust zone between the underlying folded Silurian and the overthrust masses'. In his regional mapping he later (Högbom 1920, p. 52) left the interpretation of these beds open, regarding them as equivalent either to uppermost Ordovician – lowest Silurian quartzites that occur further to the east (Kyrkås Quartzite Formation), or to the Ede Quartzite Formation of approximately the same age. Thorslund (1948) provided important data on Silurian stratigraphy in the Alsen-Offerdal area, but linked together in ascending order the Offerdal Conglomerate, the Ekeberg Greywacke Formation and the Bångåsen Shale Formation within a separate tectonic unit that he named the Ekeberg Nappe. In this interpretation Thorslund (1948, p. 28) correlated the Offerdal Conglomerate with the basal Silurian Ede Quartzite, and the Ekeberg Greywacke with the Berge Limestone. Subsequently, Thorslund (1960a, pp. 34, 41; 1960b, pp. 103, 109) included the Ekeberg Nappe sequence in the so called Föllinge Nappe, but maintained his correlation of the Offerdal Conglomerate (which he now referred to the Olden Nappe) with the Ede Quartzite Formation. In these later papers Thorslund (1960a, p. 41; 1960b, p. 110) clearly commented that the youngest Silurian beds then known in Jämtland belonged to the Ekeberg Greywacke as seen in the Ekeberg synform, with no mention being made of the beds in the Rödeberget area.

Asklund (1960a, p. 35) briefly mentioned the Röde sandstones and quartzites at Rödeberget, and considered the underlying argillaceous sediments (i.e. upper Ekeberg Greywacke as described here – see Figs. 2, 3, 4) to be of late Ordovician age. Above the sandstones he recognised 'a strongly deformed conglomerate' that he equated with the Offerdal Conglomerate, and he included the complete argillite-sandstone-conglomerate sequence within a single tectonostratigraphical unit, referred to the Olden Nappe. Asklund's 'deformed conglomerate' is fairly certainly represented mostly by what we refer here to the mylonites and phyllonites of the Offerdal Nappe, but on the flanks of Rödeberget we have observed a few isolated outcrops of polymict conglomerate that probably represent the true Offerdal Conglomerate as seen to the north of the Offerdal area. Since 1960 there has been no further mention of the Röde sediments in any accounts dealing with Jämtland stratigraphy and

structure, apart from a brief comment by Gee (*in* Gee & Kumpulainen 1980, p. 40) as to the uncertainty of their age.

As noted above (p. 10), our mapping indicates that the Röde Formation is in stratigraphical continuity with the underlying sediments of the Lower Allochthon, and moreover, that in contrast to the interpretations of Thorslund (1948, 1960a, 1960b) and Asklund (1960a), these beds are then cut with sharp structural discontinuity by the tectonostratigraphically overlying Offerdal Nappe of the Middle Allochthon. The mineralogical composition of the Röde Formation sediments is consistent with the subgreenschist to low greenschist regional metamorphic grade throughout the Lower Allochthon, and thus provides additional evidence for separation from the Middle Allochthon in which mylonites close to the base of the Offerdal Nappe contain higher grade garnetiferous mica schists (Andréasson & Gorbatshev 1981, Fig. 3E and p. 342). Strömberg's (1975) interpretation of a late Precambrian age for the Offerdal Conglomerate further negates previous correlations with the Ede Quartzite.

In assessing faunal data from the Palaeozoic sequence in the Lower Allochthon, it is necessary to draw on evidence from outside the immediate vicinity of Rödeberget, and particularly from the Jämtängen, Kriken, Ede and Ekeberg synforms in the Offerdal-Änge area (Figs. 1, 2). Above undoubted Ordovician sequences, the Ede Quartzite Formation yields rich shelly faunas considered to be of early Llandovery age (e.g. Boucot & Johnson 1964); the beds represent near-shore marine sands deposited in a transgressive sequence over the underlying late Ordovician Kogsta Shale Formation. The Ede Quartzite grades conformably upwards into more offshore (and lower energy) carbonate facies of the Berge Limestone Formation, which contains Lower to Middle Llandovery brachiopod and coral faunas. Further transgression is then continued into the thin limestones, dark mudstones and black shales of the Bångåsen Shale Formation, which contains prolific graptolite faunas at many localities; the shale sequence extends at least as high as the *Monoclimacis crenulata* Biozone at the top of the Llandovery Series (Thorslund 1948; Larsson *in* Gee & Kumpulainen 1980, p. 39).

On the basis of the firm graptolite evidence from the Bångåsen Shale, it is reasonable to assume that the conformably succeeding Ekeberg Greywacke Formation is thus of latest Llandovery to Wenlock age, and probably not younger than early Wenlock. Such an assumption is strengthened by the nature of the lower Ekeberg sediments, which mostly comprise graded turbidites that were probably deposited rapidly and reflect a direct continuation of the same transgressive cycle seen in the underlying units. Until recently, the only fossil known from the Ekeberg Greywacke also supported this view of a Wenlock age. The coral described by Thorslund (1948) as *Favosites gothlandicus* forma *forbesi*, from a clast in an intraformational mud-flake conglomerate at the

Ekeberg type section (4335 1114), while not tying down the age of the beds precisely, has generally been taken as indicative of the Wenlock (e.g. Thorslund 1960a, p. 34; 1960b, p. 103; Gee 1975a, p. 21). However, this whole assumption was then cast in doubt by a preliminary reidentification (by E. Klaamann) of the Ekeberg coral as *Favosites* cf. *subgothlandicus* (see Karis *in* Gee & Kumpulainen 1980, p. 40; note that the name quoted as *F.* cf. *subatlanticus* was a misquotation – there is no coral of that name). As noted by Karis (*in* Gee & Kumpulainen 1980), this coral is not known elsewhere from beds older than the basal Ludlow (*Neodiversograptus nilssoni* Biozone), and since the Ekeberg specimen was derived as a clast it would imply that part of the sequence, together with the overlying Röde Formation, was at least of early Ludlow age or younger (see also Gee 1978, p. 66; Gee & Zachrisson 1979, p. 23; Dyrelis *et al.* 1980, p. 253).

The implications of this evidence are of prime importance both for this paper and for the interpretation of the tectonic history of this part of the Caledonides; either the Ekeberg Greywacke would have had to be deposited over a long period of time from about the latest Llandovery to at least the early Ludlow or later, or one would need to invoke a break of some magnitude above the Bångåsen Shale Formation. There is no evidence from field relationships of either of these possibilities. The additional implication would be that nappe emplacement across the Lower Palaeozoic sequence in Jämtland did not take place until at least post-early Ludlow time, and again this would be at variance with the probable Wenlock age climactic tectonism in the central Caledonides as adduced from structural relationships in adjacent areas of Norway and Sweden (e.g. Gee 1975b, p. 505; Roberts 1978, p. 31).

These anomalies have now been resolved by a further examination of the Ekeberg coral, and by discoveries of fossils in the upper part of the Ekeberg Greywacke Formation. Following his initial study of the favositid collected by Thorslund (see above, p. 17), E. Klaamann has had the opportunity to study the specimen (Fig. 6) in greater detail. Dr. Klaamann informs us (personal communication 1981) that the specimen is strictly indeterminate at the species level because of its poor preservation, and that more material would be required to identify it firmly other than as *Favosites* sp. However, from his re-examination, he is also now of the opinion that it is probably not related to *F. subgothlandicus*, but may be closest to *F. subforbesi* Sokolov, 1952. The latter species is known only from a narrow stratigraphical interval in the early Wenlock of the Baltic area, including the Jaani beds of Estonia and the Upper Visby and Högklint Beds of Gotland (e.g. Sokolov 1952, p. 36; Klaamann 1964, p. 71; 1970, p. 116; 1977, p. 35; 1979, p. 81). Despite the remaining uncertainty as to its precise specific identification, this reassessment of the Ekeberg coral therefore removes the implication of a Ludlow age, but on balance can again be regarded as consistent with the Wenlock age suggested by

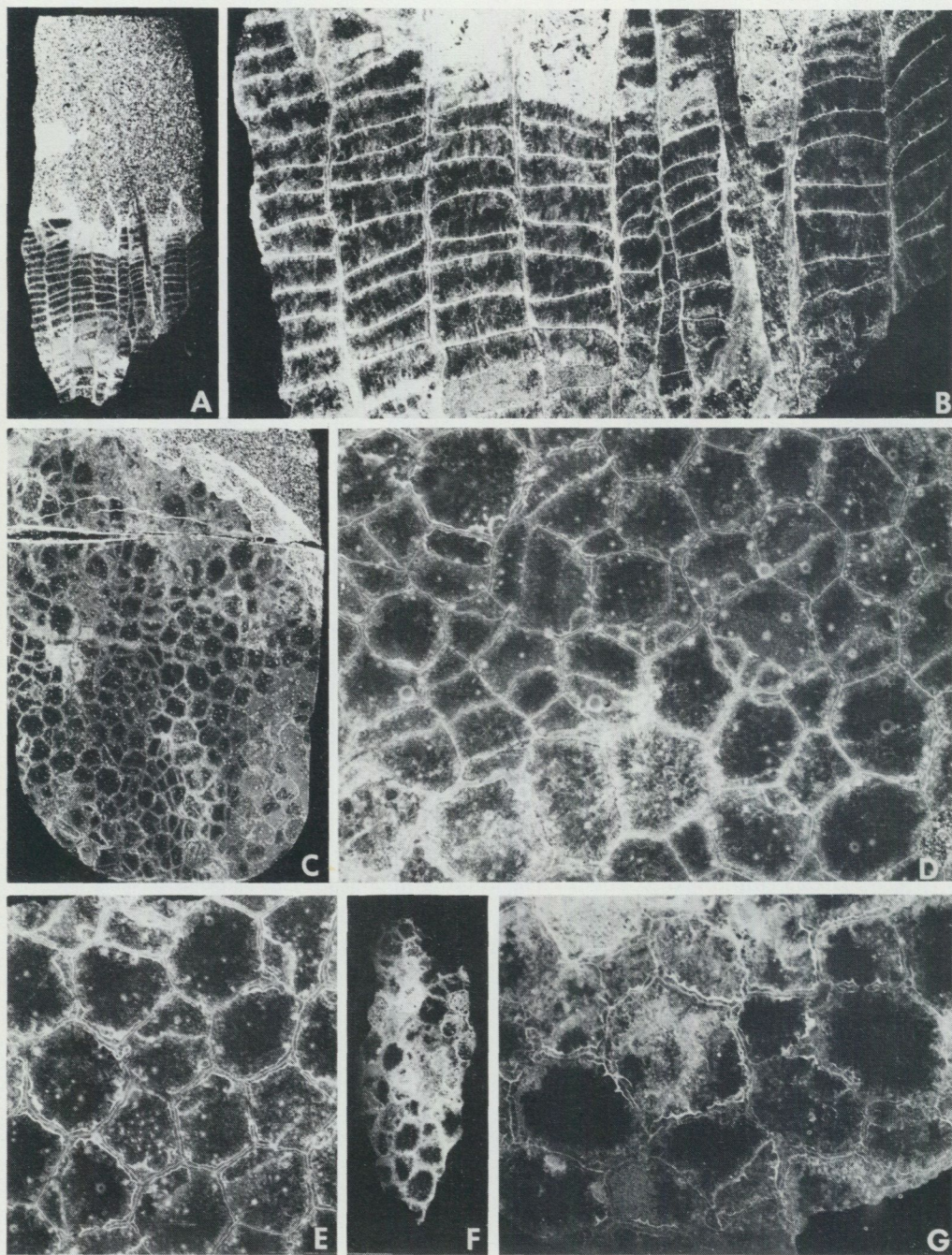


Fig. 6. *Favosites* sp., from clast in Ekeberg Greywacke Formation, north side of main road at Ekeberg, 2.75 km NNE of Offerdal Church (4335 1114); figured Thorslund 1948, p. 21, Fig. 14 and Pl. 1, figs. 1, 2; all sections are cut from the same specimen (SGU Type 1316a). (A), (B) – SGU Type 1316c, longitudinal section; (C), (D), (E) – SGU Type 1316b, transverse section; (F), (G) – SGU Type 1316d, transverse section. Figs. A, C, F x 2; Figs. B, D, E, G x 8.

the superposition of the Ekeberg Greywacke on the Upper Llandovery beds of the Bångåsen Shale Formation.

Conclusive support for this Wenlock date is provided by graptolites that we have collected from shales and mudstones interbedded with thin silty and sandy distal turbidites in the Ekeberg Greywacke Formation on the north side of the road cutting at Jämtängen (Fig. 2; 3934 1489), 250 m east of the road turning down to the football pitch; an accompanying fauna includes indeterminate hyoliths and nautiloids. The graptolites, which are described in the Appendix (p. 21) by R.B. Rickards, indicate a maximum age range from uppermost Llandovery to upper Wenlock, with a lowermost Wenlock age being most probable. In both the Ekeberg and Jämtängen sections, the lower part (20–30 m) of the Ekeberg Greywacke sequence is dominated by massive to thick bedded graded turbidites with intercalated levels of mud-flake conglomerates. These beds are transitional upwards into a more distal turbidite facies, of which about 20 m are exposed in the Jämtängen section, and the graptolites come from the uppermost c. 1 m exposed here, in virtually horizontal beds that we judge to be the youngest present in the road cutting and close to the centre of the synform. Our mapping suggests that no more than 15 m of unexposed, younger Ekeberg beds might be present in the down-plunge centre of the synform immediately to the north. Since the Wenlock graptolites are from beds above the mud-flake conglomerate horizon containing the favositid coral, all question of a Ludlow age for the Ekeberg sequence can thus be discounted. The probable early Wenlock age of the distal turbidite facies within the upper half of the Ekeberg sequence also suggests that there is no major stratigraphical break at the basal contact with the Bångåsen Shale Formation.

Sediments similar to the upper Ekeberg argillites and distal turbidites exposed at Jämtängen and elsewhere in the Alsen-Offerdal-Änge area also crop out below the Röde Formation in its type section (see p. 9). Extensive efforts to obtain fossils from these strongly deformed beds have not been successful, but there is no reason to doubt the lithostratigraphical correlation from Jämtängen as the turbidites are similarly superposed on a full Ede-Berge-Bångåsen-Ekeberg succession as mapped in the eastern limb of the synform from Valne to Röde (Figs. 1, 2). Based on this correlation, the beds immediately below the Röde Formation are of (probable early) Wenlock age. Our interpretation (p. 10) of original stratigraphical contiguity between the Ekeberg and Röde formations thus also implies a Wenlock age for the base of the latter; fairly rapid deposition in the fluvial environments suggests to us that an early to mid Wenlock age is a most likely upper limit for the whole of the Röde Formation.

CONCLUSIONS AND PALAEOGEOGRAPHICAL IMPLICATIONS

The recognition of fluvial sediments of probable Wenlock age in the Lower Allochthon of Jämtland provides important evidence bearing on the evolution of this segment of central Scandinavia. Following on the transgressive Ede-Berge-Bångåsen sequence, the turbidite and conglomeratic facies of the Ekeberg Greywacke Formation indicate a development of tectonically unstable environments leading to rapid infilling of the basin and to the initiation of a regressive regime which led finally to the deposition of the non-marine Röde Formation. Although regression appears to have commenced within Ekeberg times, the continental facies represented by the Röde sediments separate them distinctly from the underlying marine Silurian beds, and on this basis we therefore exclude the Röde Formation from Strömberg's (1974) Änge Group.

In the tectonically complex Rödeberget section it is not possible to reconstruct current directions, but it seems reasonable to suppose that the Röde sediments must have been derived from a westerly to northerly quadrant of a rising Caledonide positive area; the distal environments indicated by the fine-grained sediments and lower flow regime structures suggest that at that time Jämtland was an area of low relief, with a fall line some considerable distance away. Combined with the evidence of cessation of marine deposition over Trøndelag and adjacent regions of Norway by about the end of Llandovery times (e.g. Roberts 1978; Gee 1975b), the Röde Formation gives further support to the interpretation of a climactic phase of orogenic uplift in western Scandinavia as early as Wenlock times. Clastic terrestrial sediments derived from the rising mountain chain and similar to those at Rödeberget would have spread progressively eastwards and south-eastwards across the ancient Baltoscandian Platform (Bassett *in press*), but much of the evidence of this prograding Old Red Sandstone continental veneer has since been removed by later erosion.

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APPENDIX

Our graptolites from the Ekeberg Greywacke Formation at Jämtängen were collected as two separate lots on different occasions, and were submitted to Dr. R.B. Rickards for identification and comment. He subsequently reported separately to us on both collections, and because of the importance of these graptolites in interpreting age relationships in the upper part of the Jämtland Silurian sequence, his descriptions and assessment of the dating indicated by the material are set out below; both collections are from exactly the same locality and level in the Jämtängen section.

Graptolites from the Ekeberg Greywacke Formation (by R.B. Rickards)

From the initial collection, four specimens (SGU Types 1304–1307) were recovered on three slabs, with two of the specimens preserved as part and counterpart. One is in low relief (Fig. 7A) with the original periderm present though badly deformed, and with a partial infilling of vein calcite. The remainder are almost flat, slightly pyritised, and with little remaining of the original periderm. All the specimens show faint growth lines in places.

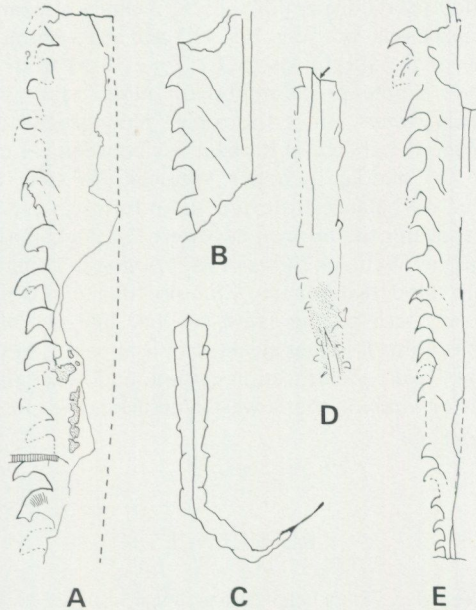


Fig. 7. *Monograptus cf. priodon* (Bronn), from the Ekeberg Greywacke Formation, Jämtängen road section; all Figs. x 5. (A) profile view of SGU Type 1304, probably mesial or distal parts of stipe, specimen in low relief, some periderm preserved (stippled) partially infilled with calcite and with some vein calcite (vertical shading); growth lines shown on second preserved theca. (B) distal thecae of three dimensional specimen, SGU Type 1313a, external mould. (C) dorsal view of twisted specimen, SGU Type 1307b, near proximal end, showing characteristic appearance of hooked monograptid thecae when seen in dorsal aspect. (D) ventral view of poorly preserved proximal end, SGU Type 1305, with possible sricula shown; obscure areas shown by stipple; distally there is some trace of nema (arrowed). (E) almost complete proximal end, SGU Type 1314, in low three dimensions but somewhat crumpled.

At first sight these original specimens were not obviously graptolites, but preparation has uncovered well formed monograptid thecal hooks in one of them (Fig. 7A). Figs. 7C and 7D are of specimens which superficially resemble biserial graptolites but which are, in fact, dorsal (Fig. 7C) and ventral (Fig. 7D) views of monograptids. One of these (Fig. 7D) is probably close to the proximal end with a faint trace of a sicula preserved (shown somewhat idealised in the illustration), and the proximal region is almost certainly quite robust. In all probability all these specimens are referable to the same monograptid species, Fig. 7A being of a mesial or distal region and Figs. 7C and 7D being of specimens quite close to if not actually at the proximal end; faint traces of thecal hooks are visible on both these last specimens.

Working on this premise the mesial or distal part has a dorsal-ventral width of 2.5 mm (Fig. 7A) and a thecal spacing of 10 in 10 mm; and the proximal part has a thecal spacing of approximately 12 in 10 mm (in this region only a lateral width (flattened) could be measured, which is of little use in comparative work).

Both the profile view of Fig. 7A and the dorsal and ventral views of Figs. 7C and 7D are important in that neither give any indication of thecal spines on the hooks, which more or less rules out both the *sedgwickii-halli* evolutionary lineage and the *rickardsii* group of late Llandovery monograptids. Thus it would seem reasonable to assign these robust monograptids to the *Monograptus priodon* lineage, which ranges from the late Llandovery through the Wenlock.

The second collection (SGU Types 1308–1315) includes similar specimens, but some with distinctly better proximal ends (e.g. Fig. 7E) and a few better distal fragments (Fig. 7B). In addition, one of the specimens (SGU Type 1315) from the second collection may be referable to a simple pristiograptid of *dubius* type, possibly *Pristiograptus praedubius* or *P. pseudodubius*. Since the robust monograptid clearly belongs to the *priodon-flemingii* lineage the choice of horizon lies between (a) uppermost Llandovery to low Wenlock, or (b) middle to upper Wenlock. In spite of the preservational problems I am inclined on balance to regard these forms as closer to *M. priodon* and prefer, therefore, to consider the horizon as lowest Wenlock. The form represented by Fig. 7E is closer to the low Wenlock forms of *M. priodon* in being more robust than late Llandovery forms; and the dorsal flexure of the proximal end is not quite characteristic of *M. flemingii*, except perhaps the latest of that lineage, namely *M. f. elegans*. However, the latter has a much longer sicula than is apparent in the Ekeberg material.

Preservation does not make identification certain, and hence the horizon is not quite certain either, but it is my opinion that lowest Wenlock is the most likely stratigraphical level represented.

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