The Orustdalen Formation of Brøggerhalvøya, Svalbard: A fan delta complex of Dinantian/Namurian age

By Ian J. Fairchild[1]

Abstract

The Orustdalen Formation of Brøggerhalvøya is well exposed on two coastal sections and is 200—250 m thick. It consists dominantly of siliceous conglomerates and sandstones with subordinate shales and impure coal. One horizon low in the sequence yielded spores of uppermost Dinantian/lowermost Namurian age. Three sedimentary facies have been recognised. The fluvial channel facies (interbedded conglomerates and cross-stratified sandstones) are interpreted as braided stream deposits with flow directions to south and west. A shale facies, sometimes with drifted plant remains, is interpreted as overbank in origin. Highly quartzose, medium-to-coarse-grained, cross-stratified sandstones make up the reworked facies where palaeocurrents are bimodal or indicate movement to the NE. The Formation is thought to represent sediments shed from an early Carboniferous fault scarp eroding a siliceous Lower Palaeozoic source terrain. The proximity of a nearby coastline led to the construction of fan deltas where fluvial deposits were reworked by waves and/or tides. Early diagenetic events include the local development of pyrite, kaolinite and calcite cements. Reddening probably occurred during Middle Carboniferous times beneath an exposed land surface. Following burial, pressure solution and quartz cementation eliminated porosity at depths greater than 1000 m.

Introduction

The association of conglomerates with coal is unusual (Heward 1978), but is found in a number of Upper Devonian and Lower Carboniferous sequences in Svalbard (Dineley 1958; Birkenmajer 1964; Worsley and Edwards 1976; Gjelberg 1978; Gjelberg and Steel 1979). A discussion of the Brøggerhalvøya Lower Carboniferous, conglomerates and sandstones with subordinate shales and coals, is thus of interest in contributing to an understanding of this facies association. These strata are restricted to an anticlinical inlier on the south-west coast of the peninsula (Fig. 1), resting unconformably on the Precambrian Kongsvegen Group (Harland et al. 1979) and underlying limestones and red terrigenous clastics correlated with the Moscovian (Middle Carboniferous)

[1] Department of Geological Sciences, Birmingham University, P.O. Box 363, Birmingham B15 2TT, England.

Scheteligfjellet Member (Cutbill and Challinor 1965). The sequence was briefly described by Holtedahl (1913) and Orvin (1934). It was later correlated on lithological grounds with similar sequences further south in the Tertiary fold belt of west Spitsbergen, named the Orustdalen Formation, and suggested to be of Namurian age (Cutbill and Challinor 1965). A description and interpretation of a single coastal section (referred to as the Kulmodden Formation) was given by Barbaroux (1968). The contact with overlying Middle Carboniferous in one section was described by Holliday (1968). The present paper figures the sequence on the coastal sections , provides palaeontological evidence as to its age and offers interpretations of the depositional environments and diagenetic history.

In central and north-east Brøggerhalvøya, Lower Carboniferous sediments are absent, the Upper Palaeozoic sequence commencing with the Middle Carboniferous (?Bashkirian) Brøggertinden Formation. The contrast with SW Brøggerhalvøya may be partly explained by Tertiary strike-slip faulting which has brought SW Brøggerhalvøya northwards relative to the central part of the peninsula (Challinor 1967) along the line of the Kvadehuken fault. It may also be partly due to Carboniferous faulting as is explained later (Fig. 7).

The two coastal sections of the Orustdalen Formation on either side of the anticlinical axis were measured (Figs. 1, 2). Inland outcrops are very poor. Stereographic projections of poles to bedding define a cylindrical fold plunging at about 3° to 040°. Three bedding readings of dips of 20—30° to the NE do not fit this simple pattern. Negligible fold plunge was assumed when processing palaeocurrent data.

Lithostratigraphy, palynology and chronostratigraphic problems

The contact with the underlying mica schists is clearly unconformable, although faulted in the NW section (Challinor 1967). The upper contact is taken immediately below the appearance of fine-grained carbonate as limestones and in the matrix of conglomerates. This contact is discussed further below.

The two sections are comparable in thickness, the NW one being 224 m thick (but faulted at top and bottom) and the SE one being 203 m. Both sections contain gaps which probably conceal small faults. A total thickness of around 250 m is thus probable, much thicker than earlier estimates (Orvin 1934; Barbaroux 1968). In the following discussion a shorthand notation is used: NW for the NW section and SE for the SE section followed by a figure for the height about the section base (e.g. NW: 181 m).

Fig. 1 (right) summarizes the lithological features of the sections. Precise correlation is clearly not possible, but the overall similarity of the sections in terms of thickness and lithology suggests that the height above section base provides a rough means of correlation.

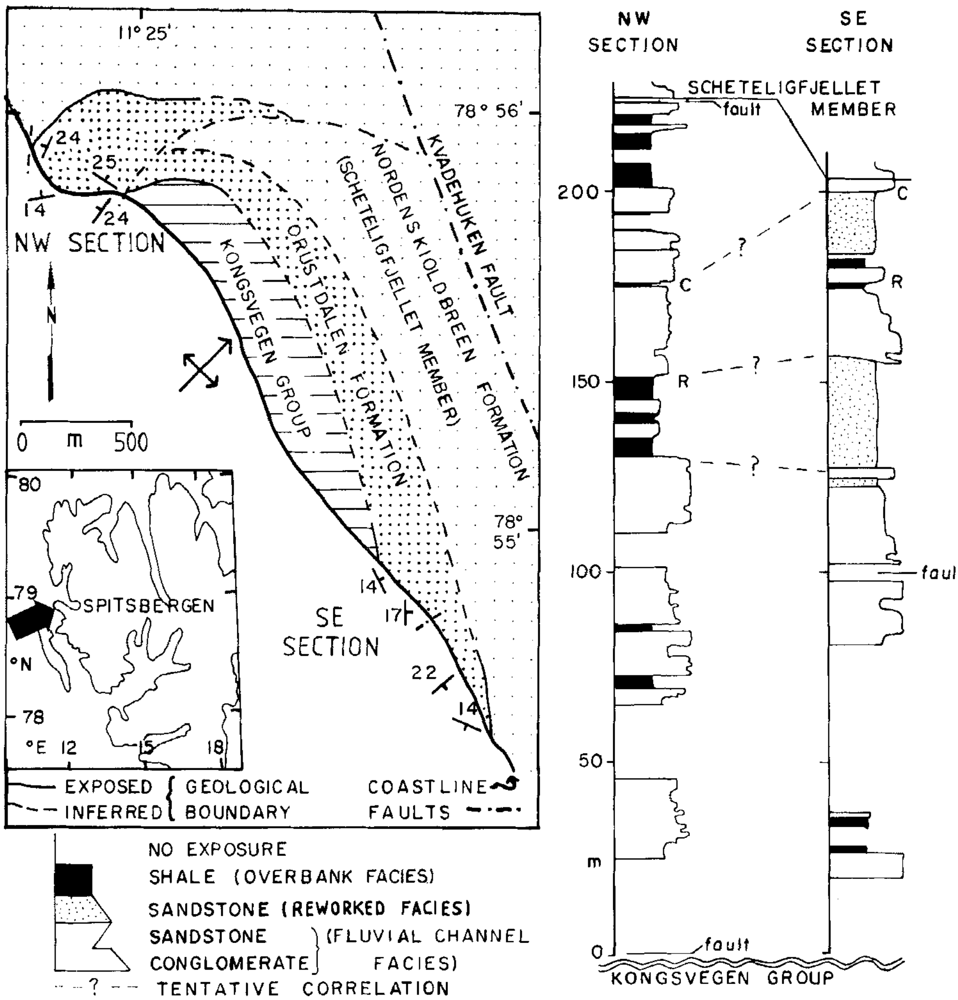


Fig. 1. *Summary of Orustdalen Formation geology. Small inset shows location of map of SW Brøggerhalvøya. On the sections, R = lower limit of patchy reddening of beds; C = lower limit of occurrence of red and yellow chert clasts.*

Dr. N.F. Hughes has carried out palynological investigation of six samples (stratigraphically located on Fig. 2) of which only two yielded any spores. He reported that the most productive sample, from NW:33 m (sample number F6810; Sedgwick Museum preparation X475/2), is moderately rich in palynomorphs, although the number of species is lower than usual in Europe. *Lycopora pusilla* (Ibr.) and small *Densosporites* are common. The age appears to be Latest Dinantian to Earliest Namurian, approximately NM to NC zones (Clayton et al. 1977).

The position and nature of the upper contact of the Orustdalen Formation is discussed further below. This partly is because of a divergence of views of previous workers and partly because the question of continuity or discontinuity

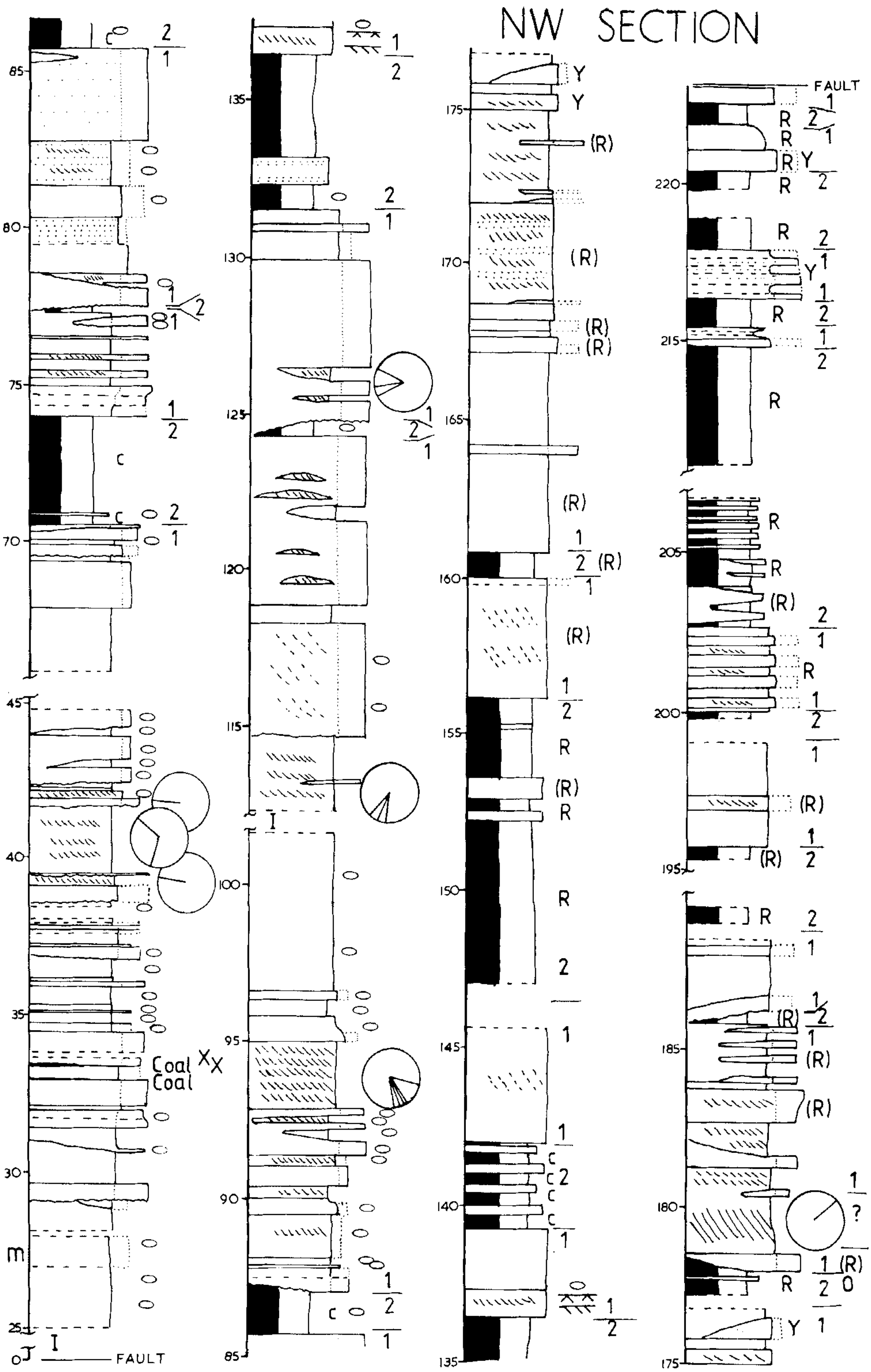
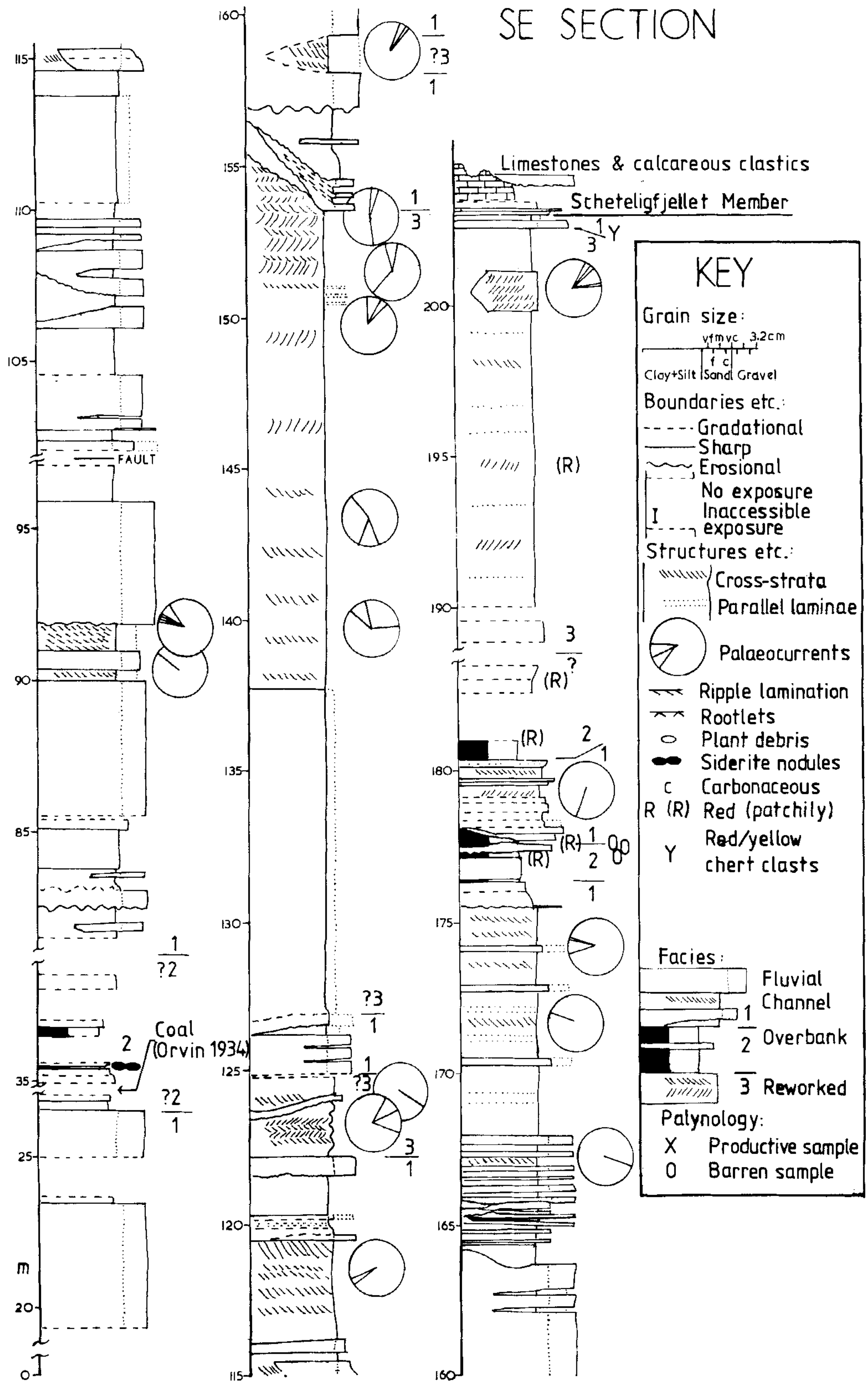


Fig. 2. *Stratal sections of the NW and SE coastal sections of the Orustdalen Formation. Pebbly sandstones (< 30% pebbles) have the gravel mode dashed whereas conglomerates (> 30% pebbles) have the sand mode dashed and the gravel mode solid.*


SE SECTION
Limestones & calcareous clastics
Scheteligfjellet Member
KEY
Grain size:
vf m vc 3.2cm
f c
Clay+Silt Sand Gravel
Boundaries etc.:
Gradational
Sharp
Erosional
No exposure
Inaccessible exposure
Structures etc.:
Cross-strata
Parallel laminae
Palaeocurrents
Ripple lamination
Rootlets
Plant debris
Siderite nodules
C Carbonaceous
R (R) Red (patchily)
Y Red/yellow chert clasts
Facies:
Fluvial
Channel
1
2 Overbank
3 Reworked
Palynology:
X Productive sample
O Barren sample
FAULT
Coal (Orvin 1934)
m

of sedimentation from Lower to Middle Carboniferous times is important particularly as a climatic change appears to have taken place at around this time in Svalbard (Gjelberg and Steel 1979). It must first be emphasised that there is no angular unconformity within the Carboniferous sequence. The clearest change in lithology is a sharp boundary upwards to reddened conglomerates with micritic carbonate matrix, associated with marine limestones. This boundary is here taken to be the upper boundary of the Orustdalen Formation in agreement with Cutbill and Challinor (1965), Challinor (1967), and Holliday (1968) who have referred the overlying beds to the Moscovian Schetcligfjellet Member of the Nordenskiøldbreen Formation. This is based on a similarity of macrofauna (Holtedahl 1913) and facies, but apparently no fusulinid dating has been done to rule out a possible Bashkirian age. These overlying beds contain a similar pebble suite to the Orustdalen Formation, but also contain quartz arenite pebbles resembling Orustdalen Formation lithologies. These may be the same as the banded grey quartzite pebbles noted by Holliday (1968) to be present only in the Scheteligfjellet Member. The lithostratigraphic boundary between the Orustdalen Formation and the Scheteligfjellet Member is also thought to be the most probable position of the Lower-Middle Carboniferous boundary.

Other workers (Holtedahl 1913 and Barbaroux 1968) have placed the Lower-Middle Carboniferous boundary lower in the section apparently on the basis of absence of plants and presence of patchy reddening in the upper part of the Orustdalen Formation as defined here .However such lithostratigraphic indicators are unsatisfactory since they may be postdepositional in origin. A thick zone of red weathering of Hecla Hoek rocks under Middle Carboniferous strata occurs in Brøggerhalvøya (Challinor 1967). Evidence is presented later that Orustdalen Formation sediments were incompletely cemented until deeply buried and were subject to reddening after sedimentation and before complete cementation. Thus reddening of the permeable upper part of the Orustdalen Formation in Middle Carboniferous times would have been almost inevitable, and it is also clear that if any plants fossils were present in strata that were reddened, then these fossils would have been oxidized and hence destroyed. Barbaroux (1968) attached great significance to what he called a hardground at SE: 175 m. This horizon shows a band of very compact silica-cemented sandstones overlain by a discontinuous pebble band, then a quartz arenite with patches of the compact lithology, which differs from the rest of the rock only in the lack of kaolinitized feldspar. The term "hardground" (cf. Bathurst 1975), is inappropriate since cementation (see next section) was secondary.

The question of the degree of continuity of sedimentation can now be discussed. There is no evidence for a significant break in sedimentation within the Orustdalen Formation, which near its base is latest Dinantian/earliest Namurian in age. A humid climate for the lower part of the sequence is suggested by abundant plant fossils. Interstitial kaolinite and kaolinitized feldspars, which indicate formation from acid waters (typical of humid climates), are found even within the patchily reddened upper part of the sequence. This succession is succeeded sharply by a limestone-red bed sequence of Middle Carboniferous age containing calcretes, indicating a distinctly drier climate than previously. This information is consistent with a hypothesis of fairly continous sedimentation with only a minor break at the top of the Orustdalen Formation. Under this hypothesis the Lower-Middle Carboniferous boundary could lie within or at the top of the Orustdalen Formation. This would fit other areas of Svalbard where sedimentation was apparently contiuous across the Lower-Middle Carboniferous boundary (Gjelberg and Steel 1979). However the evidence is also consistent with a hypothesis of a more prolonged time-gap at the top of the Orustdalen Formation. This hypothesis is favoured by the following argument.

In Brøggerhalvøya NE of the Kvadehuken fault, the presumed Bashkirian Brøggertinden Formation, consisting of over 300 m of red terrigenous clastics with calcretes (and some marine limestone in one section) occur beneath definite Moscovian limestone (Cutbill and Challinor 1956). Available palaeocurrents (25 readings, personal observation) are consistently towards the northern quadrants. SW Brøggerhalvøya, where such a sequence is lacking (assuming the Moscovian age of the Scheteligfjellet Member there to be correct) thus seems to have been part of the source area for the Brøggertinden clastics. Therefore a stratigraphic break in SW Brøggerhalvøya very roughly coinciding with the Bashkirian stage, seems more likely than a regime of continous sedimentation. This argument is however negated if the Tertiary dextral strike-slip movement on the Kvadehuken fault (Challinor 1967) which separates NE and SW Brøggerhalvøya was several tens of kilometres rather than a lesser amount. Such a large movement would allow the SW Brøggerhalvøya area to have lain south of the source area for the Brøggertinden Formation.

Petrography and diagenetic history

The highly siliceous nature of the clasts is a notable feature. Pebble-grade material is sub-rounded and consists of sub-equal metamorphic quartzite (white or grey in hand specimen) and chert (generally black in hand specimen, but also red or yellow near the top of the sequence). Many chert fragments contain abundant poorly preserved Radiolaria. Mica schist like that of the underlying Kongsvegen Group is rare. Sand and granule grade detritus is dominantly monocrystalline quartz with subordinate quartzite and chert, and minor, completely kaolinitized feldspar. Heavy minerals, visible in very fine sands and silts, are dominantly zircon, with some green tourmaline. Original grain outlines are often obscured by quartz overgrowth, but can usually be seen by cathodoluminescence (Fig. 3b), where sand-sized detritus is seen to be subangular.

The main diagenetic features are cementation by quartz, kaolinite, pyrite and calcite, pressure solution, and haematite formation (=reddening). In addition, at one horizon, shales contain siderite nodules. Such nodules are typical of early diagenesis in freshwater, coal-bearing sequences (Curtis and Spears 1967).

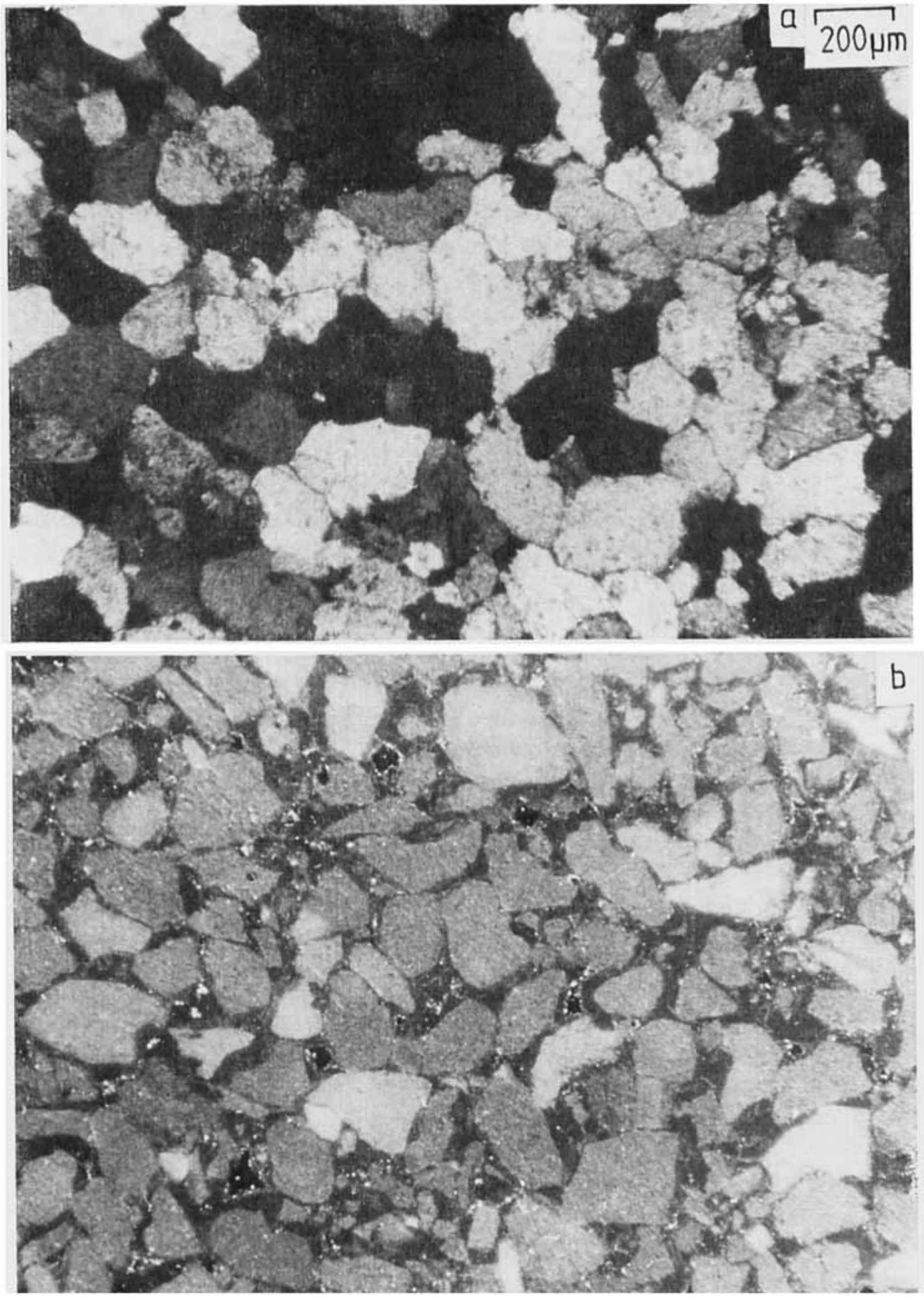


Fig. 3. *Photomicrographs of a quartz arenite (SE :176 m) ;* a) *crossed polars,* b) *luminescence. In* b) *dark areas are non-luminescing diagenetic overgrowths.*

Interstitial kaolinite occurs only occasionally, usually adjacent to quartz grains showing little evidence of overgrowth, suggesting that kaolinite precipitation preceded quartz overgrowth. In general, early kaolinitization of feldspars and associated kaolinite cementation might be expected where pore waters are mildly acid (Engelhardt 1977). Some overgrowth of quartz could be associated, derived from silica released by the decomposition of feldspar. However, the typical feldspar contents of 0—2 % would only provide a small amount of silica which would be difficult to detect.

Pyrite occurs occasionally as stringers parallel to bedding in sandstones, and more often as millimetre-sized clots (Fig. 4a), now mostly oxidised to haematite, enclosing silt and very fine sand sized clasts. Their occurrence is restricted to sandstones which are vertically adjacent to shales. Where clasts straddle the boundary between pyritiferous and pyrite-free areas they generally show a smooth form across the boundary indicating a dominantly cementing origin for the pyrite with only minor replacement. Measurements of minus-cement porosity (the volume occupied by the cement, that is the porosity when cementation started) are in the range of 35—40 %, which Füchtbauer (1974) indicated is typical of uncemented sands.

Calcite occurs patchily as poikilotopic crystals (500—1500 μm) in some sediments at the top of the Formation and in some sands vertically adjacent to the reworked facies (see next section). Quartz grains often show crystal faces against calcite, indicative of quartz overgrowth (Fig. 4b). Measurements of packing density of grains in thin section show that grains are more closely packed in areas lacking calcite cement than in areas having calcite cement in the same thin section. This demonstrates that there was a period of compaction before silica cementation became important. This implies that the crystal faces of quartz against calcite represent partial replacement of the calcite by quartz overgrowths, rather than representing quartz overgrowth followed by calcite cementation. The minus-cement porosity values of 30—33 % for the calcite-cemented areas are thus minimum estimates and indicate a burial depth prior to calcite formation of a few hundred metres at most (Füchtbauer 1974).

Sandstones showing only quartz cementation show more evidence of compaction before cementation, long and concavo-convex contacts being common (Fig. 3b). Some specimens show only pressure solution of clasts with no overgrowth (Fig. 4c—e); these may well have provided a silica source for cementation at other horizons. Measurements of the minus-cement porosity of Fig. 3 gives a value of 22 % indicating a minimum compaction before cementation of 1000 m (Füchtbauer 1974, Fig. 3—43). This shows that quartz cementation did not pre-date the deposition of the Middle Carboniferous deposits, unless an *enormous* amount of pre-Middle Carboniferous erosion occurred.

The reddening of beds higher in the sections is seen in thin section to represent oxidation of iron in clay minerals including that within the matrix of silstones and sandstones, and in the 'dusty' borders to detrital grains showing overgrowth of quartz. The patchy nature of the reddening, even

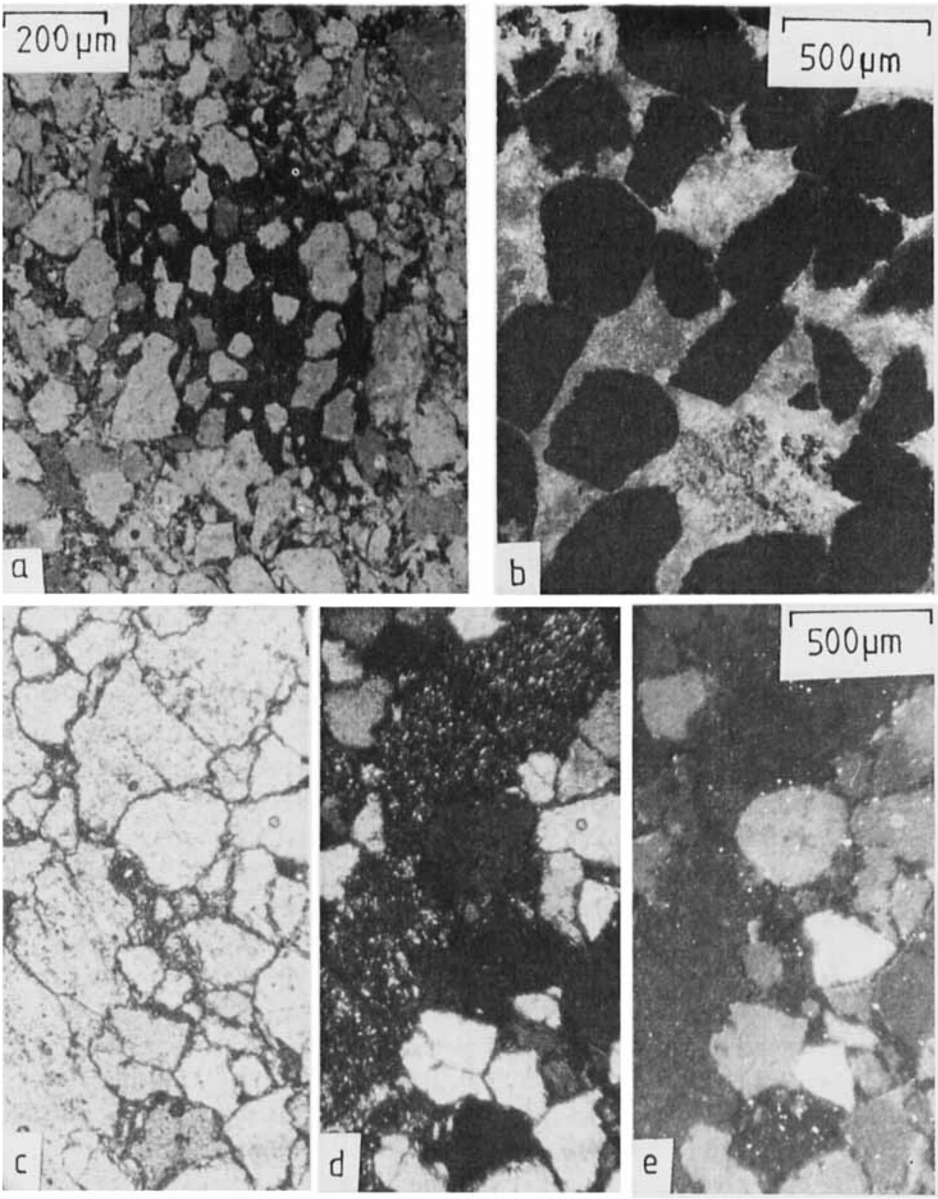


Fig. 4. *Photomicrographs.* a) *Sandstone (SE:185 m) with area showing early cementation by pyrite (black); partially crossed polars. b) Sandstone (SE:120 m) with intergranular calcite cement viewed by cathodoluminescence. Quartz overgrowths are shown by the straight boundaries of some clasts.* c—e) *(SE: 104 m) viewed by transmitted light, under crossed polars and by luminescence, respectively. Clasts are quartz (luminescing) and chert (non-luminescing, microcrystalline). Grain boundaries are concavo-convex or sutured with no sign of quartz overgrowth.*

within a thin section, suggests its post-depositional origin. The occurrence of reddened films on clasts surrounded by quartz overgrowth shows that reddening preceded quartz authigenesis.

In summary, kaolinite, pyrite and siderite formation are very early events. Kaolinite formation probably relates to surface waters or shallow groundwaters with pH lowered by humic acids. The presence of pyrite suggests reducing conditions (probably produced by organic decay reactions in adjacent shales) of shallow burial: sulphur may have been derived from plant matter, or by reduction of sulphate, the latter implying higher salinities of pore water than in the case of siderite nodule formation (Curtis and Spears 1967). Calcite cementation may or may not have pre-dated Middle Carboniferous times, but did pre-date substantial compaction. Calcite formation is restricted to beds where pore waters could have been brackish or saline because of vertically adjacent presumed marine (reworked facies) sediments. Reddening probably occurred during Bashkirian and Moscovian times in response to climatic change (Gjelberg and Steel 1979), lower rainfall giving rise to a low or fluctuating water table and hence oxidising conditions. Following at least 1000 m burial and incipient pressure solution, quartz cementation in some beds and continued pressure solution in others, reduced sandstone and conglomerate porosities to negligible proportions.

Sedimentary facies and depositional environments

Three facies are defined by objective sedimentological criteria, but they are given genetic names here for ease of description. Interpretations are limited by the nature of the exposures, being vertical sections with lateral continuity of only a few metres. Thus lateral changes between facies were not observed and many sandstones which might have showed sedimentary structures in more extensive outcrop, appeared structureless.

FLUVIAL CHANNEL FACIES

Description

This facies occupies the bulk of the sequence and consists of conglomerates and sandstones. Bed tops and bottoms are usually sharp, although gradational (usually fining-upwards) contacts occur occasionally (Fig. 2). Conglomerates usually exhibit 0—5 cm erosion at their bases, exceptionally up to 2 m (Fig. 5a). Beds are impersistent laterally, many wedging out over a few metres laterally, as depicted in Figure 2. Some sandstone and pebbly sandstone lenses in conglomerate clearly represent megaripple bedforms (Fig. 5b), although most probably owe their form to erosion. Within each occurrence of this facies the deposits seem to be randomly interbedded and no overall trends of grain size are apparent.

Conglomerates contain sub-rounded pebbles set in a fairly well-sorted sandy matrix and are distinguished from pebbly sandstones arbitrarily at a

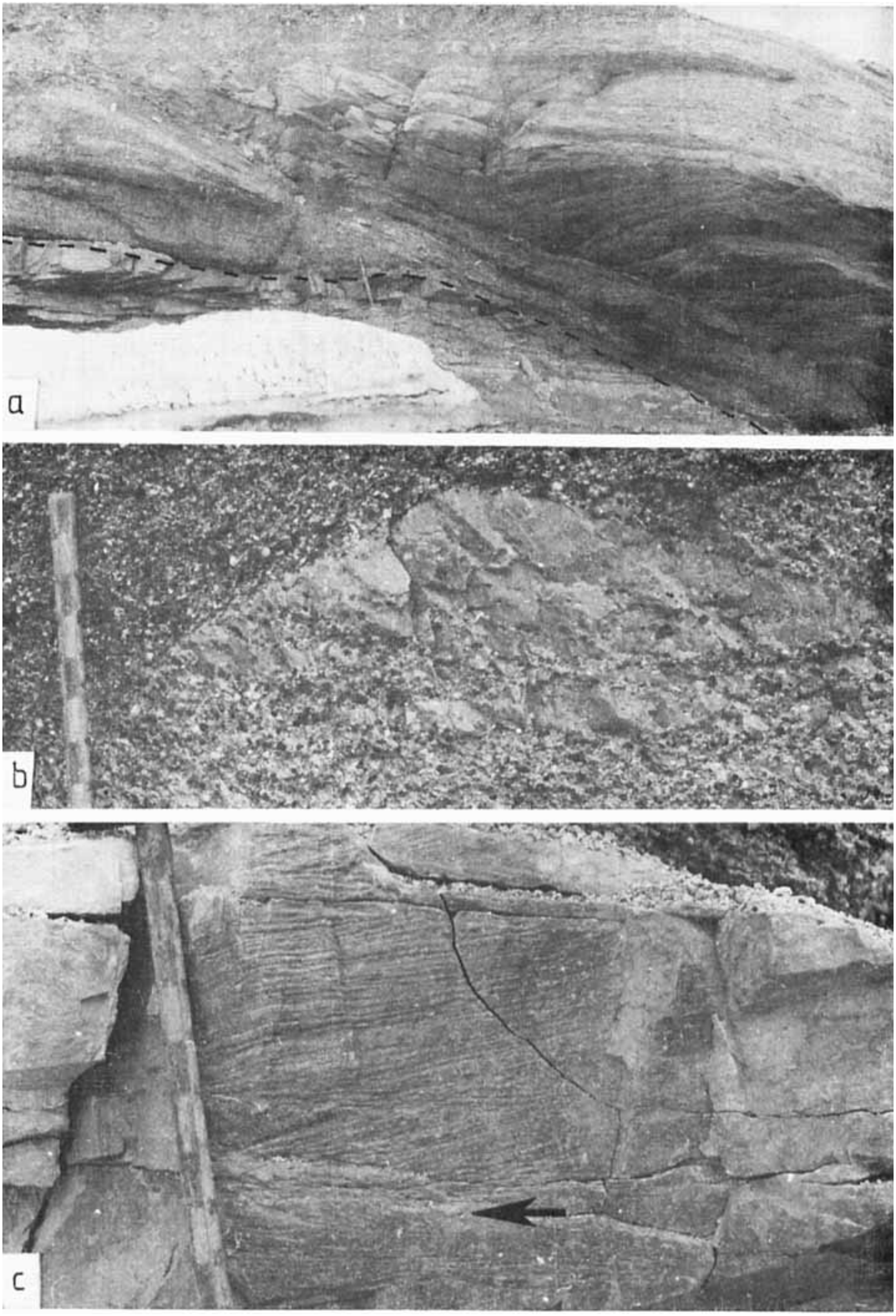


Fig. 5. *Hammer 60 cm long has scale at 5 cm intervals.* a) *SE:153—158 m. Fluvial channel facies downcuts into reworked facies (facies boundary shown by dashed line).* b) *NW:122 m. Lens of sandstone in conglomerate representing a megaripple bedform. Some cross-stratification marked by pebble layers dips to right.* c) *SE:154 m. Reworked facies. Several unimodal sets of cross-strata with one set (arrowed) showing a contrary orientation.*

pebble content of 30 %. It is thought that in general the sand fraction was carried in suspension whilst the pebble fraction was moved by rolling, rather than the sand fraction representing an entirely later infill of a pebble framework. This is because of the well-sorted nature of the sand and the presence of lateral transitions from conglomerate to pebbly sandstone to sandstone. Harms et al. (1975, Fig. 7—3) indicated that a current capable of moving 3 cm pebbles in the bedload can carry up to coarse to very coarse-grained sand in suspension, the corresponding suspension grade for 1 cm pebbles being medium to coarse-grained sand. Such grain size values for sand associated with pebbles of a given size are commonly only exceeded in the Orustdalen Formation with respect to pebble grades of 1.6 cm and less. Such beds can be explained in terms of simultaneous transport of suspended sand and rolling pebbles if coarser pebbles than 1.6 cm were unavailable. Bed thickness is not correlated with grain size (Fig. 6c). Conglomerates are usually structureless or have indistinct parallel bedding marked by variation in the concentration of pebbles. They are very occasionally cross-stratified. Although pebble imbrication is not conspicuous, this is at least partly due to the fact that the pebbles are not markedly elongate.

Sandstones are well-sorted, like the matrix of conglomerates. They are commonly cross-stratified in erosional, fairly tabular sets, median set thickness (Fig. 6a) being 15 cm with a range of 7—55 cm. Palaeocurrents from cross-strata are unimodal in any one bed (Fig. 2), but show a 180° spread overall (Fig. 7).

Both sandstones and conglomerates commonly bear plant fragments. In situ plant growth is indicated at two horizons: by the presence of a 7 cm coal seam with 1 cm underclay at NW:33 m and a rootlet horizon at NW:137 m.

Interpretation

The abundant plant remains and absence of a fauna suggests a continental origin. Traction deposition has been demonstrated by conglomerate texture and the presence of small-scale cross-stratification in sandstones. This, together with the coarseness of the deposits, indicates a fluvial origin. The lack of a clear correlation between bed thickness and maximum clast size and the absence of clasts over 4 cm in size argue against a stream flood origin (Bluck 1967; Steel 1974). The occurrence of randomly and repeatedly interbedded sandstones and conglomerates, rarity of fining-upwards relationships and current-ripple lamination indicate deposition in a braided stream network (Collinson 1978, p. 24). The palaeocurrents, ranging from SSE to NW, indicate derivation of detritus from a source area broadly to the NE. Most conglomerate beds would represent braid bar deposits, but some thin or fining-upwards conglomerates could be channel-floor deposits. Sandstones in general would represent deposition on a megarippled channel floor. The two examples of in-situ plant growth would represent channel levee or bar abandonment.

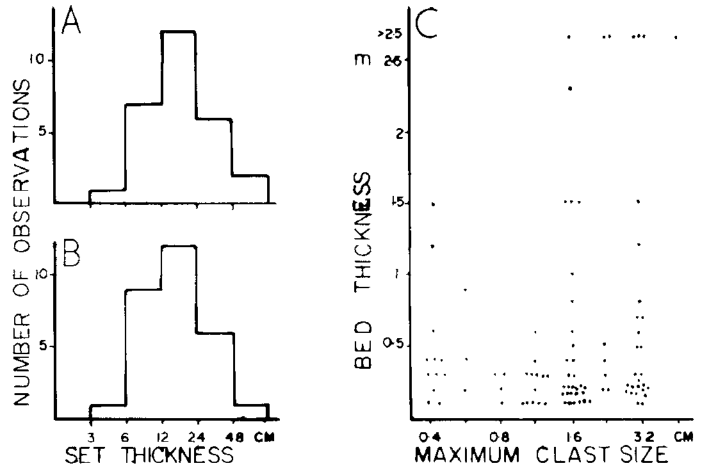


Fig. 6. A, B. *Set thicknesses of cross-strata in the fluvial channel facies and the reworked facies, respectively. A 90 cm tabular set at NW:180 m of uncertain facies is not included here or in Fig. 7A.* C. *Plot of bed thickness versus maximum grain size for conglomerates and pebbly sandstones.*

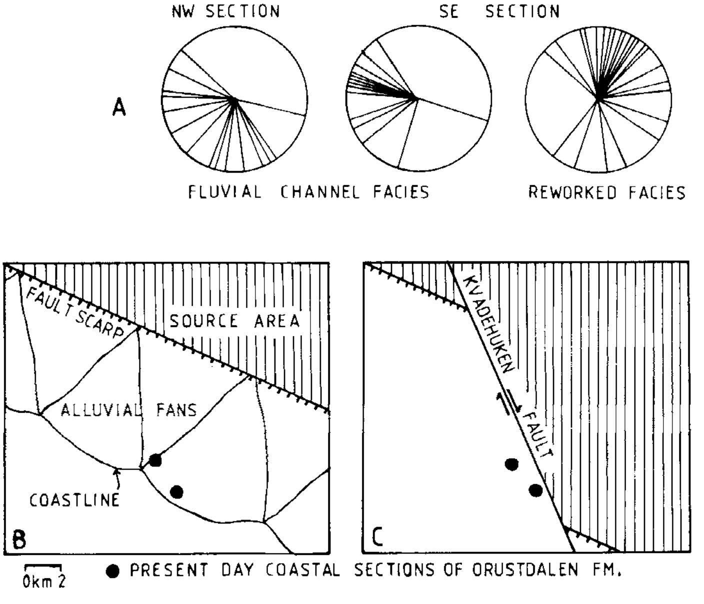


Fig. 7. *Summary palaeocurrents* (A) *and interpretive reconstructions* (B, C). B. *Namurian times. Fan delta sedimentation. The position and orientation of the fault scarp is designed to fit the 'mid-fan' character of the fluvial sediments, the palaeocurrents, and the presence of reworked facies only in the SE section.* C. *Post-movement on the Kvadehuken fault in Tertiary times. The Orustdalen Formation outcrops are brought into juxtaposition with areas lacking Lower Carboniferous sediments. The amount of movement shown is the minimum consistent with the geological reasoning of this paper.*

OVERBANK FACIES

Description

This facies is represented by several discrete occurrences, dominantly of shales. These are commonly micaceous and carbonaceous in the lower parts of the sections and gray or reddish in the upper parts. The very impure nature of the 3 m coal, which was formerly worked (Orvin 1934), suggests the accumulation of transported plant debris rather than in situ growth. Siderite nodules occur at SE:35 m. Minor sandstone beds occur at some levels, but do not weather clearly enough to exhibit sedimentary structures.

Interpretation

Suspension deposition was dominant. The occurrence vertically adjacent to fluvial channel deposits suggests an overbank origin of this facies. Major floods are represented by the sandstone beds. A high water table or even a permanent water cover is indicated by the carbonaceous character of many beds, the absence of mudcracking and intraclasts, and the lack of evidence of in-situ plant growth. Bearing in mind the vertical proximity of presumed marine reworked facies the term "overbank" should be understood to include lagoonal or indistributary bay environments.

REWORKED FACIES

Description

The SE section contains several levels of medium and/or coarse-grained highly quartzose sandstones which show an absence of conglomerate interbeds, and different palaeocurrent patterns from the fluvial channel facies. The sandstones are either apparently structureless, or cross-stratified. cross-strata being similar in size (Fig. 6B) and shape to the fluvial channel facies. Palaeocurrent directions at any one horizon either show two opposed modes (Figs. 2, 5c), or a single mode opposed to that of the fluvial channel facies (Figs. 2, 7A). The palaeocurrent data of Barbaroux (1968) appear to have been derived entirely from this facies. Beds of this facies gradationally or sharply overlie fluvial channel facies and the clearest two examples are overlain with pronounced erosion by fluvial channel conglomerates.

Interpretation

The palaeocurrents are critical in the environment interpretation. As the dominant mode is opposite to that of the fluvial channel facies, a fluvial origin for the sandstones is ruled out. Reworking of the sediments by currents near a shoreline is implied. The mineralogical maturity and unfossiliferous nature of the sandstones are consistent with this, as is the gradiation up from fluvial channel facies. Both waves and tides can be important in reworking sediments on modern deltas and other shorelines (Elliott 1978) as can waves with associated longshore currents in large lakes (Fraser and Hester 1977). Abundant sets of cross-stratification generated by low inter-tidal or subtidal dunes or sand waves are a feature of tidal reworking (e.g. Klein 1970). A tidal interpretation would also readily explain the opposed current directions within some beds. However, landward-directed cross-strata are also a feature of bars formed by wave reworking (McGowen 1971). One would expect parallel or low-angle lamination to be found associated with the cross-stratification; this has not been seen but could be hidden within the abundant, apparently structureless beds. Therefore, either tide or wave reworking, or both, were operative.

Environmental synthesis

The highly quartzose nature of the sediments of the Orustdalen Formation is remarkable and seems to have been controlled principally by the nature of the source rocks since rock fragments are almost entirely siliceous. The radiolarian nature of many chert clasts indicates a Palaeozoic rather than Precambrian source. Lower Palaeozoic rocks are absent from the area to the NE of the Brøggerhalvøya Orustdalen Formation outcrops (Harland et al. 1966), but are abundant further south (Harland et al. 1979), although pure cherts are not recorded. Thus the Orustdalen Formation appears to represent erosion of a Lower Palaeozoic sequence NE of Brøggerhalvøya, now otherwise unrepresented in the area.

The facies are distinctive in displaying an interbedding of coarse alluvial deposits with sediments reworked by waves or tides. This association is most common where alluvial fans adjoin a coastline and extend it to form deltas. The term 'fan delta' is often used (e.g. McGowen 1971) although Rust (1979) prefers 'coastal alluvial fan'. The conglomerate/sandstone ratios of the fluvial channel facies equate with a mid-fan position in modern examples (e.g. Boothroyd and Stanley 1975). The scarcity of a fine sediment fraction due to the highly siliceous nature of the source area helps to explain why such coarse sediment was present at the delta front.

Given the absence of glacial sedimentation processes, the presence of gravelly fan deltas normally relates to the proximity of a coastline to a mountainous area uplifted by faulting (Rust 1979; Sneh 1979; Daily et al. 1980). Indeed fault-related sedimentation has been suggested as a scenario for the lower Carboniferous of Svalbard by Birkenmajer (1964) and Gjelberg and Steel (1979). A reconstruction of the local situation is illustrated in Fig. 7B. The presence of an uplifted fault block to the NE of the Orustdalen Formation explains the absence of lower Carboniferous sediments in NE Brøggerhalvøya which is now closely juxtaposed to the Orustdalen Formation outcrops due to Tertiary faulting (Fig. 7C).

Overall the sequence shows a fining-upward trend, as do the other outcrops of the Orustdalen Formation where a distinct shale unit caps the coarser beds (Cutbill and Challinor 1965). This probably represents a decline in, or cessation of, fault-related uplift. In detail, there are a series of downcutting fluvial channel sequences. These could represent either source rejuvenation, or fan channel migration, these possibilities being to some extent inter-related. Interpretation of vertical facies changes in terms of changes in sediment supply (due to changing relief of the source area), relies on identifying the simultaneous occurrence of similar changes in both sections. Some possible examples are indicated by the correlation lines of Fig. 1, but these must be regarded as very tentative. The restricted suite of facies represented, and the lack of fining-upward or coarsening upward sequences on the dekametre (tens of metres) scale attest to a very persistent palaeogeography with only limited variation in shoreline position. Subsidence kept pace with sedimentation to a remarkable degree.

The Brøggerhalvøya conglomerate-coal association, as in the example of Heward (1978), appears to relate to alluvial fan sedimentation. Unlike the latter, no thick coals are preserved representing in-situ plant growth on abandoned alluvial fan lobes. Instead, drifted plants remains are dominant.

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