P. Gutteridge

GEOLOGICAL JOURNAL, VOL. 26, 245–269 (1991)

Aspects of Dinantian sedimentation in the Edale Basin, North Derbyshire

PETER GUTTERIDGE*

School of Earth Sciences, Thames Polytechnic, Walburgh House, Bigland Street, London E1 2NG, U.K.

The Dinantian Edale Basin is located to the north of the Derbyshire carbonate platform and underlies the Upper Carboniferous of the central Pennines. The Edale Basin was thought to be part of a large basin which extended from the Derbyshire carbonate platform to the Askrigg Block. The presence of aggregate grains and ooids in the Alport Borehole suggests that a carbonate platform, possibly located on the Holme structural high, was present underneath the central Pennines. This platform is called the Holme Platform.

The Arundian to early Asbian section of the Alport Borehole represents deposition of resedimented shallow-water carbonates with occasional bioturbated periplatform carbonates and basinal shales on the middle part of a carbonate ramp. Volcaniclastic sediments may have been derived from a volcanic centre within the Edale Basin.

A change in sedimentation during the mid-Asbian to the deposition of basinal shales and distal carbonate turbidites is attributed to starvation of the basin. This may have been caused by a combination of the development of accretionary rimmed carbonate shelves and the repeated emergence of shelf carbonates deposited on surrounding carbonate platforms. The late Asbian/early Brigantian section of the Edale Borehole is interpreted as a distal equivalent of the 'Beach Beds' which outcrop at the north margin of the Derbyshire carbonate platform. The 'Beach Beds' represent bioclastic turbidites derived from the Derbyshire carbonate platform.

Throughout the Brigantian, sedimentation in the Edale Basin was dominated by the deposition of distal carbonate turbidites and basinal shales. Variation of dip through the Alport Borehole indicates the common occurrence of slumps throughout the sequence and the presence of either an angular unconformity or a fault within the early Brigantian section.

KEY WORDS Alport Borehole Carbonate turbidites Dinantian Edale Basin Edale Borehole Holme Carbonate Platform

1. INTRODUCTION

The Edale Basin lies to the north of the Derbyshire carbonate platform and is concealed beneath the Upper Carboniferous of the central Pennines. This basin was thought to be part of a large Dinantian basin which extended northwards to the Askrigg Block (e.g. George 1958; Ramsbottom 1969). The Alport and Edale Boreholes were drilled on the culminations of the Alport and Edale Anticlines some 12 km and 3 km respectively north of the Derbyshire carbonate platform (Figure 1). The Dinantian stratigraphy of these boreholes has been described by Hudson and Cotton (1945a,b) and evidence from them has also been used in support of various palaeogeographical and structural models of Dinantian sedimentation (e.g. Miller and Grayson 1982; Grayson and Oldham 1987). The objectives of this paper are to discuss the Dinantian sedimentary evolution of the Edale Basin and the implications for the late Dinantian palaeogeography of the central Pennines.

This study is based on examination of hand specimens and thin sections from the Dinantian sections of the Alport and Edale Boreholes held in the biostratigraphy and borehole collections of the British Geological Survey at Keyworth (Table 1). It was necessary to refer to Hudson and Cotton (1945a,b) for details of large-scale sedimentary features and variations in the Alport and Edale Boreholes because

* Present address: Cambridge Carbonates, 22 George Street, Cambridge CB4 1AJ, U.K.

0072–1050/91/030245–25$12.50

Received 8 July 1989
Revised 20 May 1991

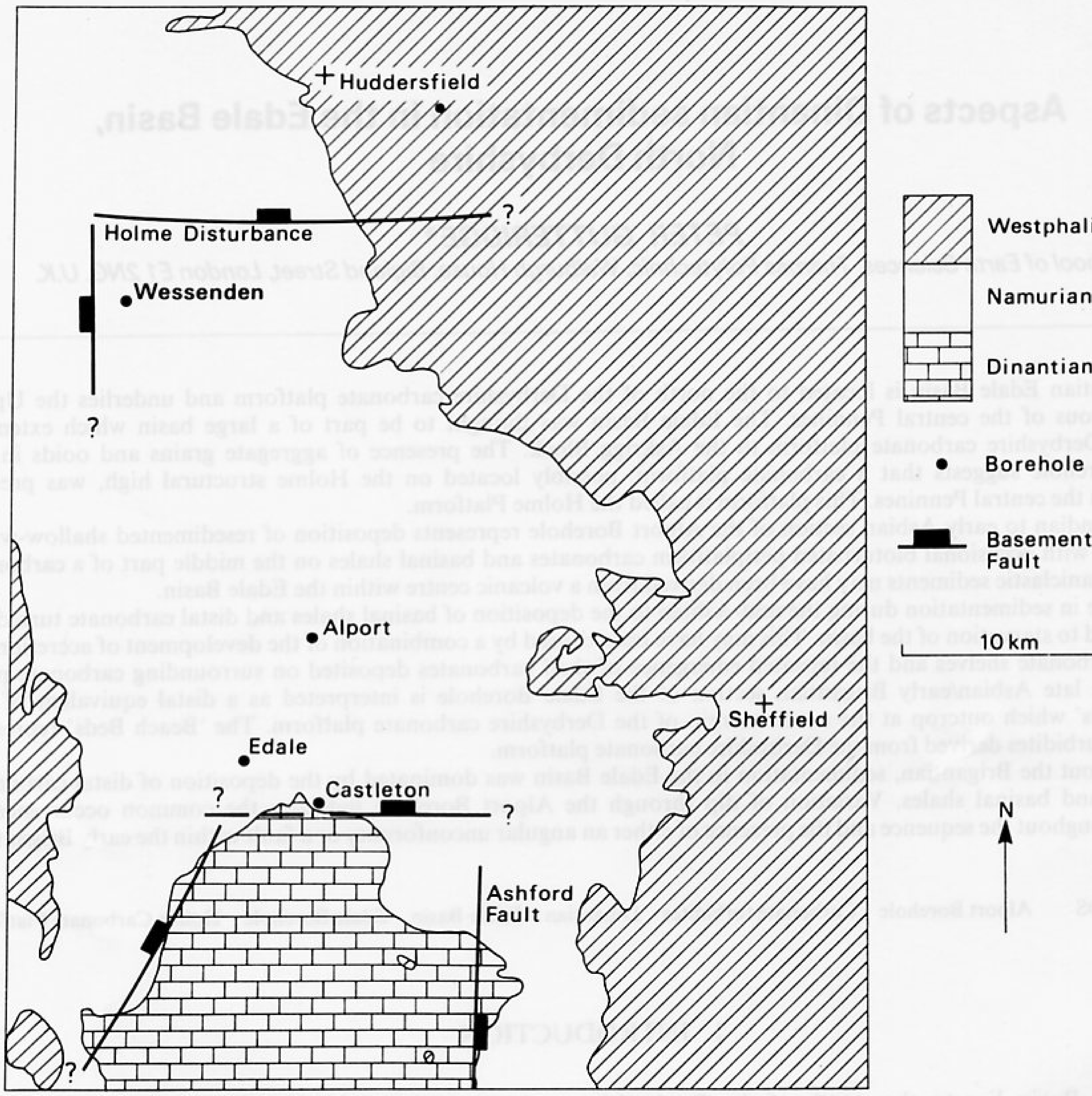

Figure 1. Location of boreholes and structural setting of the Edale Basin, (basement structure from Gutteridge 1987 and Lee 1988).

whole cores have since been broken up for macrofossil sampling. This data, together with that from hand specimens and thin sections was used in compiling Figures 7 to 12. The Edale Borehole was drilled by the cable tool method which results in poor depth control and quality of samples. No wireline logs were run in either well. The details of datum elevations and final depths of the boreholes are given in Table 1. The depths referred to are all measured depths below the drill floor or rotary table.

2. STRUCTURAL SETTING OF THE EDALE BASIN

The structural setting (Figure 1) of the Edale Basin has been interpreted by Lee (1988) using 3D, 2D, and residual gravity modelling. He identified an E–W trending basement fault underlying the northern margin of the Derbyshire carbonate platform. The exact position of this fault is not well constrained by gravity data owing to the conflicting effects of an associated change from carbonate platform to basin facies. Lee also identified a residual gravity high underlying the Holme area which is bounded to the north by an E–W trending, N-declining gravity gradient. This gradient is associated with the E–W trending

Table 1. Details of drilling methods, datum elevations, and total depths. Catalogue numbers of hand specimens and thin-sections refer to British Geological Survey collections housed at Keyworth.

	Alport	Edale
Drilling method	Rotary	Cable tool
Drilling commenced Completed	1939 1941	1937 1938
Drill Floor elevation (OD)	283.5 m (930 ft)	259.1 m (850 ft)
Total Depth Below Drill Floor OD	 778.8 m (2555 ft) −495.3 m (−1625 ft)	 230.7 m (757 ft) 28.4 m (93 ft)
Depth top Dinantian		
Below Drill Floor OD	335 m (1099 ft) −51.5 m (−169 ft)	99.1 m (325 ft) 160 m (525 ft)
Age of sediments at TD	Arundian	late Asbian/early Brigantian
BGS Cat No. of Thin-sections examined	PF 146–291	PF 882–932
BGS Cat No. of Hand specimens examined	Bc 3679A–3819 Bc 1928–1412 Zf 4703–4778 Zf 4817–4867 Zh 509 Zh 626–632 Zh 645 Zh 2572–2906	Bc 10000–9948

Holme Disturbance and also marks the boundary between zones of contrasting structural style in Upper Carboniferous sediments (Wray *et al.* 1930; Bromehead *et al.* 1933). The northern margin of the Holme High is inferred to be controlled by a major E–W trending basement fault with northward downthrow.

The structure of the Edale Basin is interpreted as a half-graben with the main bounding fault associated with the northern margin of the Derbyshire carbonate platform. The hangingwall slope rises northwards towards a footwall crest underlying the Holme area. This interpretation is supported by seismic data (e.g. mapping by Fraser and Gawthorpe 1990). The Alport Borehole was drilled on the southern flank of this residual gravity high and the Edale Borehole occupies a location close to the footwall on which the Derbyshire carbonate platform is located. The half-graben was probably passively infilled by sediment during much of the Dinantian, although reactivation of intrabasinal structures would be expected during the episodes of synsedimentary tectonism identified by Gawthorpe *et al.* (1989).

3. DINANTIAN STRATIGRAPHY OF THE ALPORT AND EDALE BOREHOLES

The inferred ages and correlation of the Dinantian sections of the Alport and Edale Boreholes is shown by Figure 2. Lists of stratigraphically significant fossils can be found in Hudson and Cotton (1945a,b); Davis (1945a,b); Stevenson and Gaunt (1971) and Strank (1981).

Strank (1981, 1987) examined the biostratigraphy of the Alport Borehole and her conclusions were as follows:

449·6–335 m (1475–1099′): not examined
449·6–515·1 m (1475–1690′): late Asbian

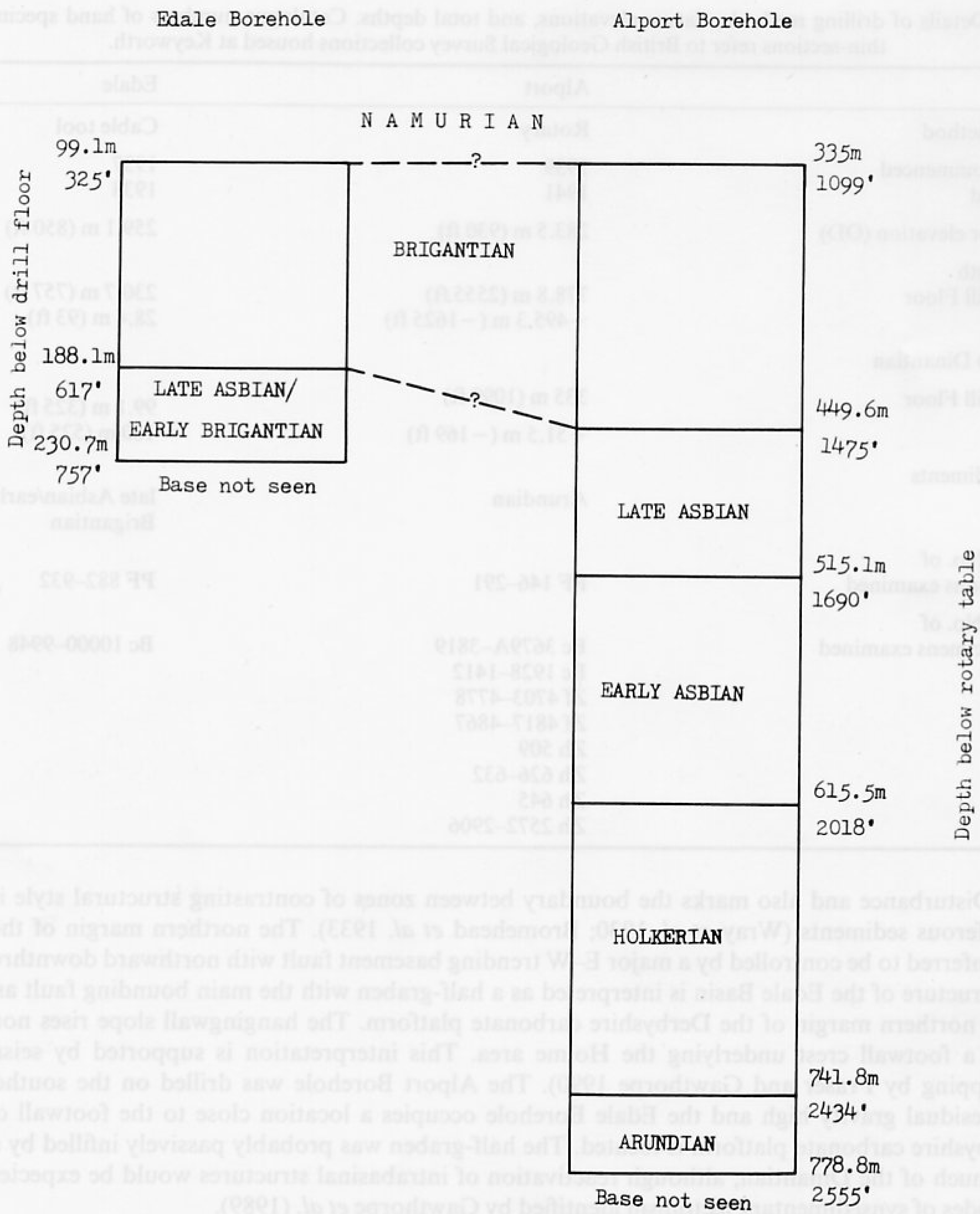

Figure 2. Age and inferred correlations of successions within the Alport and Edale Boreholes.

516–615·1 m (1693–2018′): early Asbian
615·1–741·9 m (2018–2434′): Holkerian
741·9–778·8 m (2434–2555′): Arundian, base not penetrated.

Hudson and Cotton (1945a) recorded a goniatite/bivalve fauna of P_1P_2 age in the interval 449·6–335 m (1475–1099′) and Stevenson and Gaunt (1971) recorded *C. leion* at a depth of 335 m (1099′). The interval 449·6–335 m (1475–1099′) is thus inferred to be Brigantian.

The upper part of the Dinantian sequence in the Edale Borehole (dated as P_1 and P_2 by Hudson and Cotton 1945b) down to the top of the limestones containing a coral/brachiopod fauna at 188·1 m (617′)

is Brigantian in age. Below 188·1 m (617′) Hudson and Cotton (1945b) inferred a D_1D_2 age because: productids of the *Dibunophyllum* Zone were present at 188·1 m (617′), faunal elements of both the D_1 and D_2 zones were present in the interval 188·1–210·0 m (617–689′) and also because of the abundant occurrence of *Girvanella* between 201·2–210·0 m (660–689′) which they took to be the *Girvanella* band at the D_1/D_2 boundary. The interval 188·1–210·0 m (617–689′) was correlated by Stevenson and Gaunt (1971) with part of the B_2 (late Asbian) section of the Alport Borehole. This suggests that the base of the Brigantian in the Edale Borehole must either be at or below the base of the lower P_1 Zone at 188·1 m (617′) and it is possible that the Edale Borehole reached the latest Asbian. However, the inferred position of the Asbian/Brigantian boundary at 188·1 m (617′) coincides with an upward change from the coral/brachiopod fauna to the goniatite/bivalve fauna and may reflect a facies change. An additional problem in interpreting the biostratigraphy of these boreholes is that the limestones are redeposited and may have undergone several phases of reworking.

4. SEDIMENTOLOGY

The sediments sampled by the Alport and Edale Boreholes have been divided into four facies on the basis of their lithology, microfacies, and fossil content.

4a. Spiculitic wackestone facies

Description. This facies is a wackestone which contains local packstone patches (Figure 3a). Calcified monaxon and triaxon sponge spicules, calcispheres, saccaminopsid foraminifera, and calcified thin-shelled bivalves are also present. These bioclasts are disarticulated, fragmented but unabraded. In many cases, the bioclasts display an arcuate or random alignment (Figure 3b); however, a strong subparallel alignment of bioclasts is sometimes present.

Interpretation. The wackestone texture and the angularity of the bioclasts indicates deposition in a low energy environment, probably below wave base. The restricted fauna indicates conditions of unusual salinity or low oxygenation. A random or arcuate alignment of bioclasts and the local packstone patches are interpreted to be due to intensive bioturbation, whereas, the preservation of a strong parallel alignment of bioclasts is due to a lack of bioturbation. Bioturbation is probably also responsible for disarticulation of the bioclasts without abrading them. It is likely that levels of oxygenation varied, allowing intensive bioturbation to take place during oxygenated conditions whereas the burrowers were excluded when conditions were anoxic.

This facies may represent fine-grained carbonates of shallow water origin which were winnowed from surrounding shallow-water carbonate platforms and deposited from suspension in adjacent basins (e.g. Boardman and Neumann 1984). The spiculitic wackestone facies was recognized by Hudson and Cotton (1945a,b) as a distinct sediment type for which they used the term porcellanous limestone.

4b. Shale facies

Description. This facies consists of laminated, subfissile to fissile, dark to very dark grey siliciclastic silt and clay (Figure 3c). Laminations are defined by the presence of layers a few millimetres thick composed of siliciclastic silt and bioclastic calcisiltite. Occasional coarse-grained layers of disarticulated and fragmented crinoid ossicles and disarticulated fragmented and abraded bioclasts are also present. Contacts between shale and limestone beds show a variety of sharp, erosional, loaded, and transitional contacts. The shale is mainly non-calcareous, but carbonate nodules of probable diagenetic origin are present. These nodules sometimes have a pyritic core which grades outward into a carbonate-rich rim. Disseminated pyrite is common throughout the shale facies and fossils are frequently pyritized.

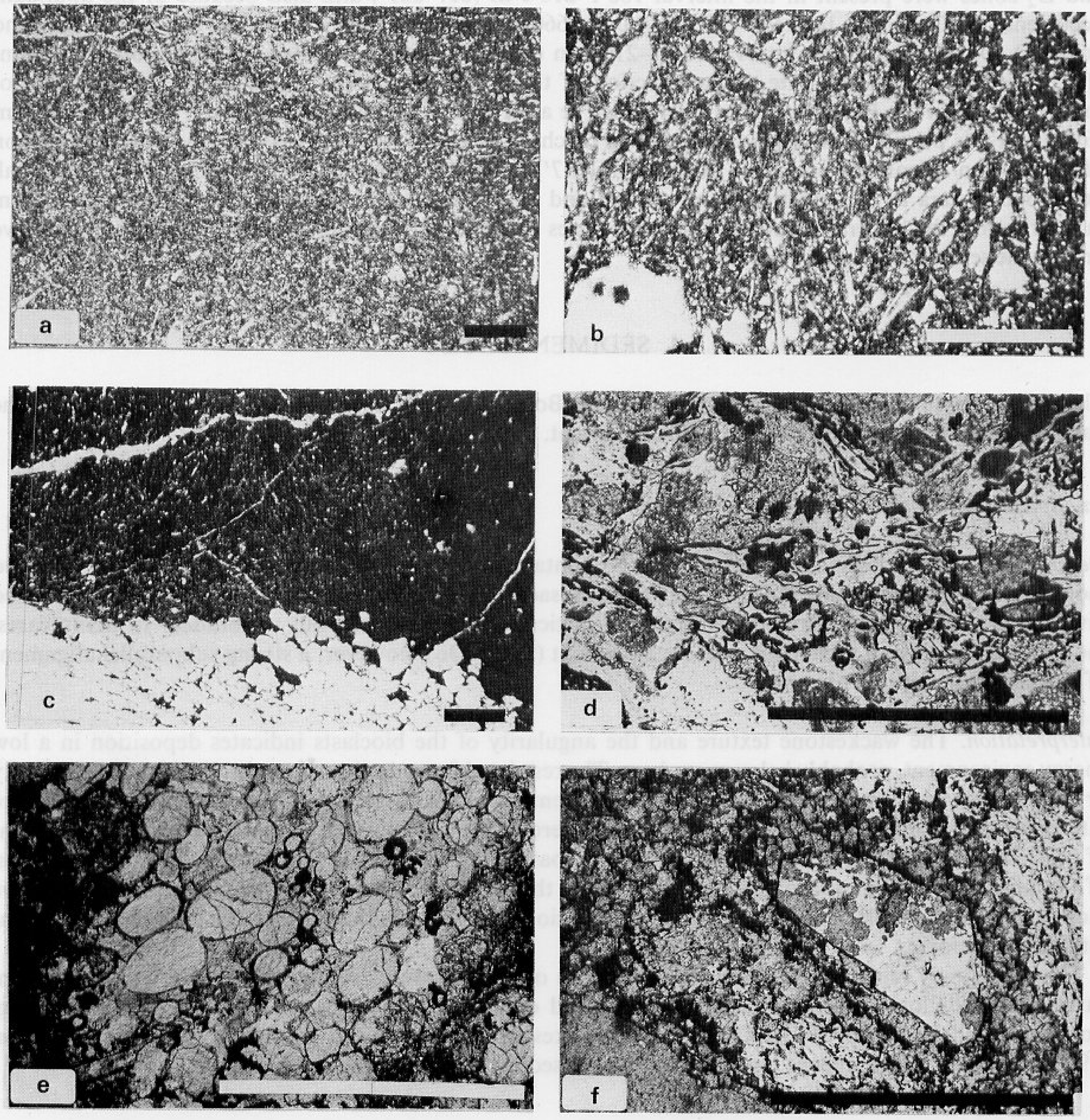

Figure 3. In each case scale bar = 2 mm. Specimen numbers refer to slides curated with the British Geological Survey, Keyworth. (a) Spiculitic wackestone facies. Bioturbated wackestone with calcitized spicules and finely comminuted molluscan clasts. Holkerian Alport Borehole. 736·4 m (2416′) PF 286. (b) Spiculitic wackestone facies. Bioturbated wackestone with calcitized spicules, mollusc fragments, and echinoderm plate. Holkerian, Alport Borehole. 741·0 m (2431′) PF 289. (c) Shale facies. Siliciclastic mudstone with fragmented bioclasts and showing neomorphic recrystallization of carbonate. Brigantian, Alport Borehole. 421·8 m (1384′) PF 187. (d) Volcaniclastic facies, Concavoconvex glassy hyaloclastite particles dispersed in a bioclastic grainstone, Brigantian, Edale Borehole 165·8 8–167·6 m (544–550′) PF 907. (e) Vesicular glassy hyaloclastite particle, vesicles relatively undeformed. Brigantian, Alport Borehole 431·3 m (1415′) PF 190. (f) Reworked basalt clast with groundmass feldspars showing weak preferential alignment and an altered feldspar phenocryst. Brigantian, Edale Borehole 164·3–165·8 m (539–544′) PF 905.

The fauna and flora within the shale facies include goniatites, dunbarellid and posidoniid bivalves, brachiopods, crinoids, and carbonized plant and wood fragments (lists of taxa are given in Hudson and Cotton 1945a,b and Stevenson and Gaunt 1971). Most of the goniatites are preserved on their sides, although some came to rest on their venter. Most of the dunbarellids and posidoniids are disarticulated, but some valves are held together by the ligament. Brachiopods are rare but appear to have been preserved with their spines intact in their presumed life position. *Chondrites* and ?*Zoophycus* burrows have also been found. Some areas of neomorphic recrystallization of carbonate and veins of displacive fibrous 'calcite beef' are present (Figure 3c).

Interpretation. The sharp, loaded, and erosional contacts between shale and limestone beds seen in hand specimens are interpreted as basal contacts of rapidly deposited, resedimented limestones. Transitional contacts between fine-grained limestones and shale beds are interpreted as the graded tops of resedimented limestones. The presence of shale (type 2) intraclasts within the limestones shows that the shale facies represents a detrital sediment rather than a pressure dissolution residue. The fine-grain size indicates deposition in a low energy environment below the influence of wave reworking. The layers and lenses of disarticulated and fragmented bioclastic material were deposited either as distal carbonate turbidites or represent episodes of winnowing.

The general preservation of lamination indicates an absence of burrowing organisms, possibly due to anoxic conditions. The occasional presence of *Chondrites* suggests dysaerobic conditions (e.g. Bromley and Ekdale 1984). The degree of oxygenation of the environment, thus, appears to have been low. The presence of *in situ* brachiopods, however, indicates that bottom conditions were at least periodically oxygenated. The nature of the sediment substrate is uncertain, the scarcity of benthic fauna could indicate either anoxic bottom conditions or a soupy substrate (e.g. Holdsworth 1966). The presence of woody plant material indicates that an emergent area may have been present in the vicinity.

4c. *Volcaniclastic facies*

Description. Volcaniclastic sediments occur either as bedded tuffs several mm to cm in thickness or as particles dispersed within the bioclast grainstone/packstone facies. Two types of volcaniclastic particles are present:

1. Isotropic clear or yellow/brown glassy particles up to 2 mm in size which have a concavo-convex shape. They range from highly angular to well rounded (Figure 3d). Some of these clasts have a more irregular shape and contain vesicles which are subspherical or elongate ellipsoids (Figure 3e).
2. Rounded coarse sand- to fine granule-sized clasts of altered basalt which contain plagioclase and pyroxene phenocrysts (Figure 3f) and groundmass plagioclase, pyroxene and opaque minerals. A preferential alignment of phenocrysts is sometimes present. These clasts are often altered to chlorite and calcite.

The bedded tuffs show normal grading and have loaded and erosional bases. Intervals displaying convolute lamination passing up into rippled cross-lamination are sometimes present. There is often a strong preferential alignment of the long axes of tuff particles parallel to bedding. Tuff particles within one bed often show a wide variation in angularity.

Interpretation. The glassy nature of the tuffs, their concavoconvex shape, and the presence of vesicles in some clasts resemble hyaloclastite particles which are produced when magma comes into contact with water during submarine or phreatomagmatic eruptions (Heiken 1972; Fischer and Schminke 1984; Suthern 1984). The angularity of many particles suggests that they have undergone little reworking and may be of local derivation. The wide range of angularity, however, suggests that individual beds contain particles which have had varied histories of reworking. Tuff clasts which contain elongate vesicles probably originated as magma which was chilled during degassing. The elongate shape of the vesicles was produced by deformation during flow. The size grading, loading, and erosional contacts at the base of bedded tuffs indicates rapid deposition from a waning flow. The presence of ripple cross-bedding suggests subaqueous deposition. The basalt clasts are interpreted to have been derived by erosion of either lavas or shallow intrusive bodies.

It is difficult to determine the composition of the original magma from these altered tuff particles. However, their association with clasts of basalts and the general character of Dinantian volcanism in northern England (e.g. Walters and Ineson 1981) suggests that the most likely composition is basic.

4d. Bioclastic grainstone/packstone facies

Description. This facies comprises predominantly medium- to dark-grey, argillaceous packstone and grainstone consisting of fine- to very fine-grained comminuted bioclasts with beds containing coarse bioclasts and intraclasts (Figure 4). The bioclasts commonly show a preferential alignment subparallel to bedding, whereas an arcuate or random alignment is rare. Some beds show normal size grading together with an upward change from a packstone/grainstone to a wackestone/carbonate mudstone texture. This varies from thickly-bedded limestones interbedded with occasional shale partings to thinly-bedded limestones within thick sequences of the shale facies. Contacts between limestone and shale beds (e.g. in hand specimen Bc1723 618·1m 2028′) are often eroded and loaded. In some cases the limestones grade transitionally into shale. There are occasional *Chondrites* burrows (e.g. Bc1827 701·5 m 2301′) in this facies.

Bioclasts include brachiopod valves and spines, calcified mollusc shells, and fenestrate and stick-type bryozoans (Figures 4a,b). Disarticulated and abraded skeletal algae are common including *Koninckopora*, *Stacheoides*, *Stacheia*, palaeoberesellids, and calcified dasycladacean algae. Foraminifera are common and include archaediscids, endothyrids, saccaminopsids, earlandiids, tetrataxids, and less common agglutinating types. Lists of foraminifera are given in Davis (1945a,b) and Strank (1981). Sponge spicules and trilobite fragments are also present.

The majority of bioclasts in this facies are disarticulated, fragmented and show varying degrees of rounding (Figure 4a). The intensity of micritization of allochems varies from fresh unmicritized grains to complete replacement by micrite (Figure 4b). Faecal pellets are also present. Bioclasts occasionally show borings up to 50 μm in diameter which may have been the work of sponges. Some bioclasts are wholly or partially coated by micrite which may be of oncolitic or intraclastic origin. Non-skeletal grains are common and include ooids, aggregate grains, and intraclasts. Ooids are formed by a peloid or bioclast nucleus surrounded by cortex which contains both radial and tangential fabrics. Aggregate grains consist of peloids, micritized bioclasts, and oolitically coated grains bound by micritic cement (Figure 4c). Thin section PF 284 and hand specimen Bc1875 (736·1 m 2415′) contain stromatolitic lamination which encloses bioclast wackestone sediment similar to the spiculitic wackestone facies. This is either part of an oncolite or a reworked stromatolite. Six types of intraclasts have been recognized in this facies (Figure 5) and their stratigraphical occurrence is shown by Figures 7, 8, 9, and 10.

Type 1: Spiculitic wackestone (Figure 5a).

These intraclasts contain abundant monaxon spicules and calcispheres with subordinate thin-shelled bivalves and fenestrate bryozoans. These bioclasts are disarticulated and fragmented but are unabraded. The bioclasts commonly display a random or arcuate alignment, a parallel alignment is rare. These intraclasts occur throughout the Alport Borehole and in the Brigantian section of the Edale Borehole.

Type 1 intraclasts are identical to the spiculitic wackestone facies. These intraclasts were reworked from a low energy subtidal environment deposited below wave base. Although bottom conditions were sufficiently oxygenated to allow bioturbation of the sediment, conditions may have been periodically anoxic.

Type 2: Clastic Mudstone (Figure 5b).

These intraclasts are composed of siliciclastic silt and clay and are sometimes partly dolomitized. Bioclasts are rare and include thin-shelled bivalves, disarticulated crinoid ossicles, and foraminifera. One intraclast (538·0 m 1765′ PF 236) contains a burrow. These intraclasts range from fine-cobble to medium-sand in size and are either platy in shape of have been deformed during compaction

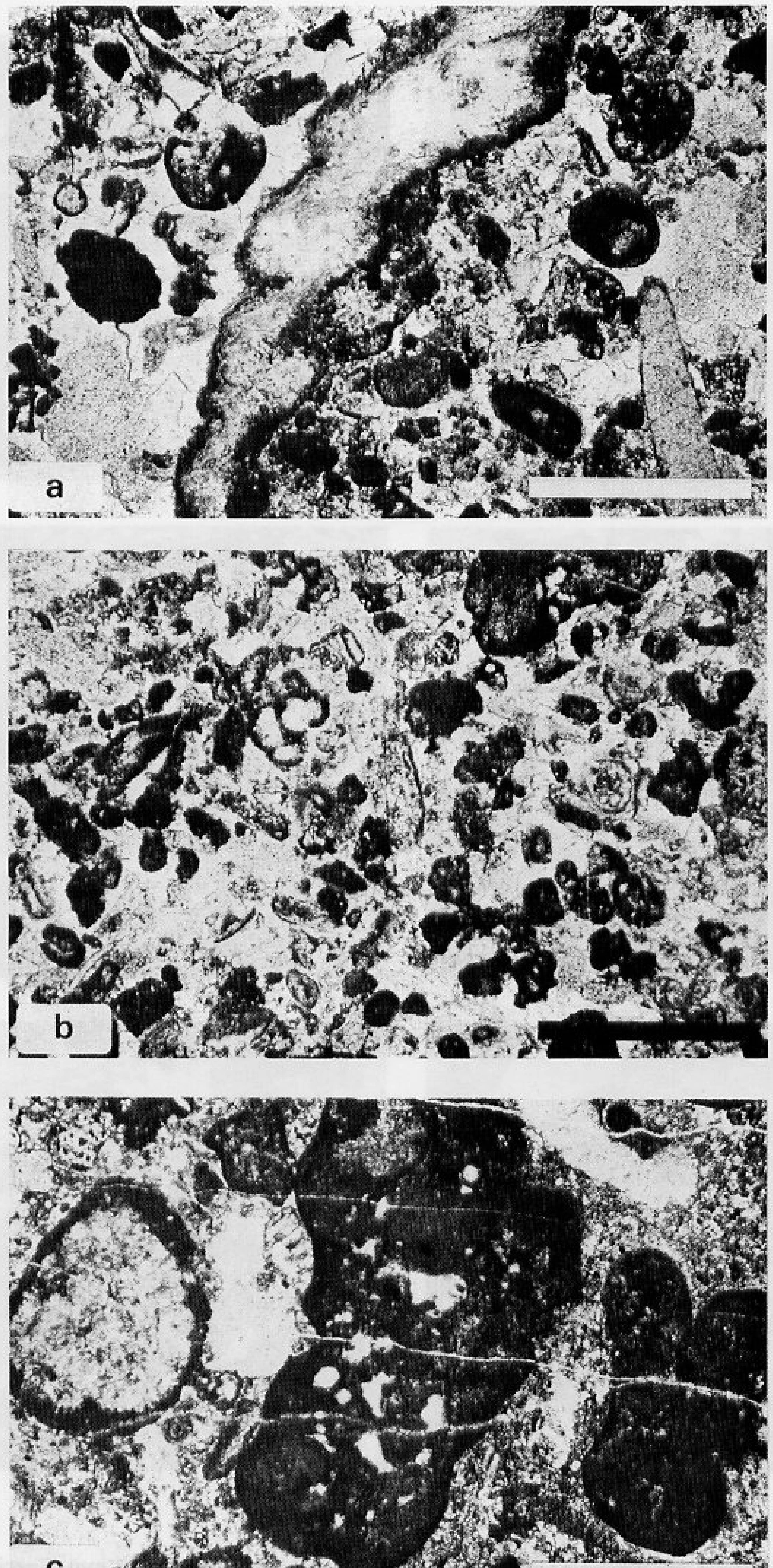

Figure 4. Bioclastic grainstone/packstone facies. In each case scale bar = 2 mm. Specimen numbers refer to slides curated with the British Geological Survey, Keyworth. (a) Poorly-sorted bioclast peloid ooid grainstone. Allochems include heavily micritized and abraded brachiopod shell fragment, micritized ooids and bioclasts. Late Asbian, Alport Borehole 490·7 m (1610′) PF 220. (b) Sorted bioclast peloid grainstone. Allochems show a wide variation in degree of micritization. Late Asbian, Alport Borehole 490·7 m (1610′) PF 220. (c) Aggregate grains containing micritized ooids, bioclasts, and peloids. Early Asbian, Alport Borehole 538·0 m (1765′) PF 236.

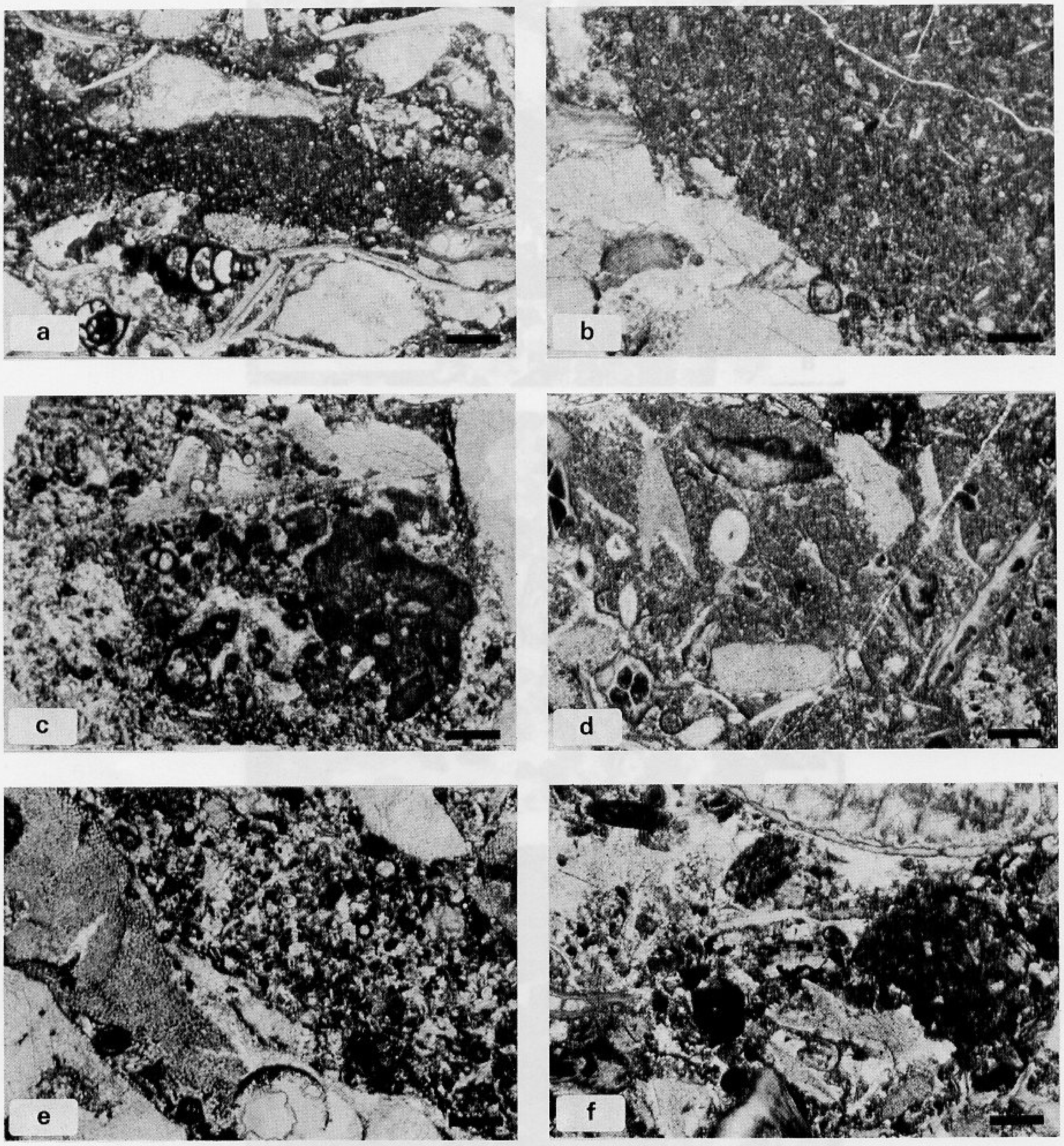

Figure 5. Intraclasts in the bioclastic grainstone/packstone facies. In each case scale bar = 2 mm. Specimen numbers refer to slides curated with the British Geological Survey, Keyworth. (a) Shale intraclast (Type 1) showing signs of compaction between other allochems. Holkerian, Alport Borehole 637·3 m (2091′) PF 266. (b) Spiculitic wackestone intraclast (Type 2) Early Asbian, Alport Borehole 564·5–564·8 m (1852–1853′) PF 251. (c) Peloid aggregate grainstone intraclast (Type 3). This contains micritized ooids and bioclasts including algae and foraminifera. A large aggregate grain is present containing micritized bioclasts and ooids. Holkerian, Alport Borehole 722·1 m (2369′) PF 277. (d) Part of Type 4 intraclast. The presence of large fragments of fenestrate bryozoans and the texture of the carbonate mud suggests that this was derived from a carbonate mud mound. Holkerian, Alport Borehole 721·8 m (2368′) PF 276. (e) Fine-grained sorted grainstone intraclast (Type 5). Holkerian, Alport Borehole 666·3 m (2186′) PF 267. (f) Bioclast peloid wackestone/packstone intraclast (Type 6). Early Asbian, Alport Borehole 564·5–564·8 m (1852–1853′) PF 248.

of the surrounding sediment. These intraclasts are identical to the shale facies. They occur in the Holkerian to Brigantian section of the Alport Borehole but have not been found in the Edale Borehole. The platy shape of these intraclasts suggests that they were derived from a fissile sediment and their deformed or smeared-out shape indicates that they were soft during reworking and the early stages of compaction. These intraclasts originated as rip-up clasts of deep-water shales eroded during transportation of resedimented carbonates.

Type 3: Bioclast–peloid–ooid packstone/grainstone (Figure 5c).

These intraclasts are recognized by their grain-supported texture, the presence of peloids, ooids, aggregate grains, *Koninckopora*, and calcispheres. Other allochems include fragmented skeletal green algae, *Girvanella*, and foraminifera. The bioclasts are disarticulated, fragmented, well rounded and are intensively micritized. Ooids are formed by a peloid or bioclast nucleus surrounded by a cortex which contains both radial and tangential fabrics. Aggregate grains are made up of micritized bioclasts and peloids. One intraclast found in the Alport Borehole (PF 277 722 m 2369′) contains an isopachous fibrous fringe cement similar to marine and beach rock cements (e.g. see review in Bricker 1971). These intraclasts occur throughout the Alport and Edale Boreholes.

The grain-supported texture of the sediment, high degree of disarticulation, fragmentation, and rounding of allochems suggests that original deposition took place in a moderate to high energy environment. A shallow-water provenance is indicated by the occurrence of ooids, aggregate grains, and the high degree of micritization (Fabricius 1977). The occurrence of both radial and tangential fabrics in the cortex of ooids suggests a variable frequency of agitation (Bathurst 1975). The abundance of both skeletal algae and micritized grains indicate deposition in the photic zone. These intraclasts imply the presence of a shallow water area, probably a carbonate shelf or the shallow part of a carbonate ramp in the vicinity of the Edale Basin.

Type 4: Peloidal bioclast wackestone (?Carbonate mud mound) (Figure 5d).

This intraclast type is a bioclast wackestone containing large fragmented fenestellid bryozoans, short articulated crinoid stems, crinoid arm plates, large calcified sponge spicules, and micritized brachiopod and ostracod valves. The micrite matrix shows a variation from an homogeneous micrite to a peloidal micrite. One intraclast was found in the Holkerian of the Alport Borehole at 721·8 m (2368′ PF 276).

The peloidal texture of the micrite matrix is similar to textures of the carbonate mud within carbonate mud mounds described by Gutteridge (1983), Lees and Miller (1985), and Miller (1986). Fenestrate bryozoans were also common constituents of carbonate mud mounds (Pray 1958; Troell 1962; Lees 1964; Gutteridge 1983; Lees and Miller 1985). Derivation from a carbonate mud mound is probable.

Type 5: Sorted bioclast grainstone/packstone (Figure 5e).

These intraclasts have a grain-supported texture and contain bioclasts ranging in size from very fine to coarse sand. The bioclasts include disarticulated, fragmented, and well-rounded calcitized molluscs, fenestrate bryozoans, brachiopod shell and spine fragments, and *Koninckopora*. These bioclasts show variable degrees of micritization. These intraclasts occur throughout the Alport Borehole and in the Brigantian of the Edale Borehole.

The diversity of bioclasts suggests derivation from an environment of normal marine salinity. The presence of skeletal algae and the high degree of micritization suggests deposition in the photic zone. The very high degree of abrasion and grain-supported texture indicates original deposition in a high energy environment. The good sorting could originate either by intensive reworking or selective deposition. These intraclasts are similar to the bioclastic grainstone/packstone facies and were derived either from a high energy shallow water bioclastic sediment, or by erosion and redeposition of resedimented bioclastic limestones.

Type 6: Bioclast peloid wackestone/packstone (Figure 5f).

These intraclasts are characterized by the presence of disarticulated angular fragmented bioclasts in a micrite matrix. They contain calcitized molluscs preserved as micrite envelopes, calcispheres, ostracods, brachiopod shell fragments, occasional sponge spicules, thin-shelled bivalves, foraminifera, and skeletal algae. Some allochems have been bored. Bioclasts often show a random of arcuate preferential alignment. These intraclasts occur throughout the Alport and Edale Boreholes.

The lack of abrasion of bioclasts and the presence of a micrite matrix indicates a low energy environment with minimal reworking. The random and arcuate alignment of bioclasts suggests that the sediment has been bioturbated. These intraclasts were probably derived from a low energy subtidal sediment which was deposited below wave-base.

Interpretation. The occurrence of reworked shallow water allochems and intraclasts in limestones interbedded with basinal shales suggests that they represent shallow water sediment redeposited in a deeper-water environment. The eroded and loaded contacts between limestones and shales, the internal grading of limestones suggests scouring prior to deposition from a waning current, possibly as turbidites. The common occurrence of preferential parallel alignment of bioclasts suggests either systematic deposition, probably as a result of bedload processes, or a high degree of winnowing. The occasional occurrence of random or arcuate alignment of bioclasts is attributed to bioturbation. The high degree of disarticulation and fragmentation of bioclasts indicates the sediment as a whole has undergone a prolonged history of reworking. However, the wide variation in roundness shown by allochems within a single specimen indicates that different components of the sediment have undergone differing degrees of reworking.

The diversity of allochems within this facies suggests deposition in, or derivation from a fully marine, shallow-water environment. The predominance of micritized ooids with radial cortices suggests that in their original depositional environment periods of reworking were infrequent with intervening episodes of slow sedimentation when micritization took place. Fabricius (1977) suggested that the formation of aggregate grains requires a degree of turbulence to allow cementation of the constituent grains with infrequent reworking so that the constituent grains are not disturbed. Additionally, Fabricius (1977) notes the common occurrence of aggregate grains in sediment bound by subtidal algal mats. The presence of type 3 intraclasts indicates early consolidation of this sediment. This facies was derived from a relatively shallow-marine environment with low to moderate energy levels, relatively low rates of biogenic sediment production (inferred from common non-skeletal grains and high degree of micritization). Type 6 intraclasts are inferred to have been derived from a subwave base environment or in sheltered parts of a shallow-marine environment. Types 1, 2, and 5 intraclasts were derived from reworking of the spiculite wackestone, shale, and resedimented limestones deposited in deeper water during transportation of the resedimented limestones.

5. SEDIMENTARY EVOLUTION: EVIDENCE FROM THE ALPORT BOREHOLE

5a. Dips within the Alport Borehole

Figure 6 shows the variation of dip through the Alport Borehole. Dip direction and borehole drift are not known. This shows:

1. Dip increases uniformly downwards from horizontal at 298·7 m (980′) to 6° at 429·8 m (1410′) just above the base of the Brigantian. Here dip increases abruptly to 10° increasing downwards to 12° at the bottom of the borehole.

   This abrupt increase in dip can be interpreted as an angular unconformity or a fault. The magnitude of an unconformity or throw of a fault is less than the resolution of the biostratigraphical dating and there is no evidence of repeated or missing section from lithological data. The absence of fracturing (Hudson and Cotton 1945a), together with the pattern of dip variation either side of the abrupt change in dip which shows no evidence of fault drag which may be associated with a fault suggest that an unconformity may be present.

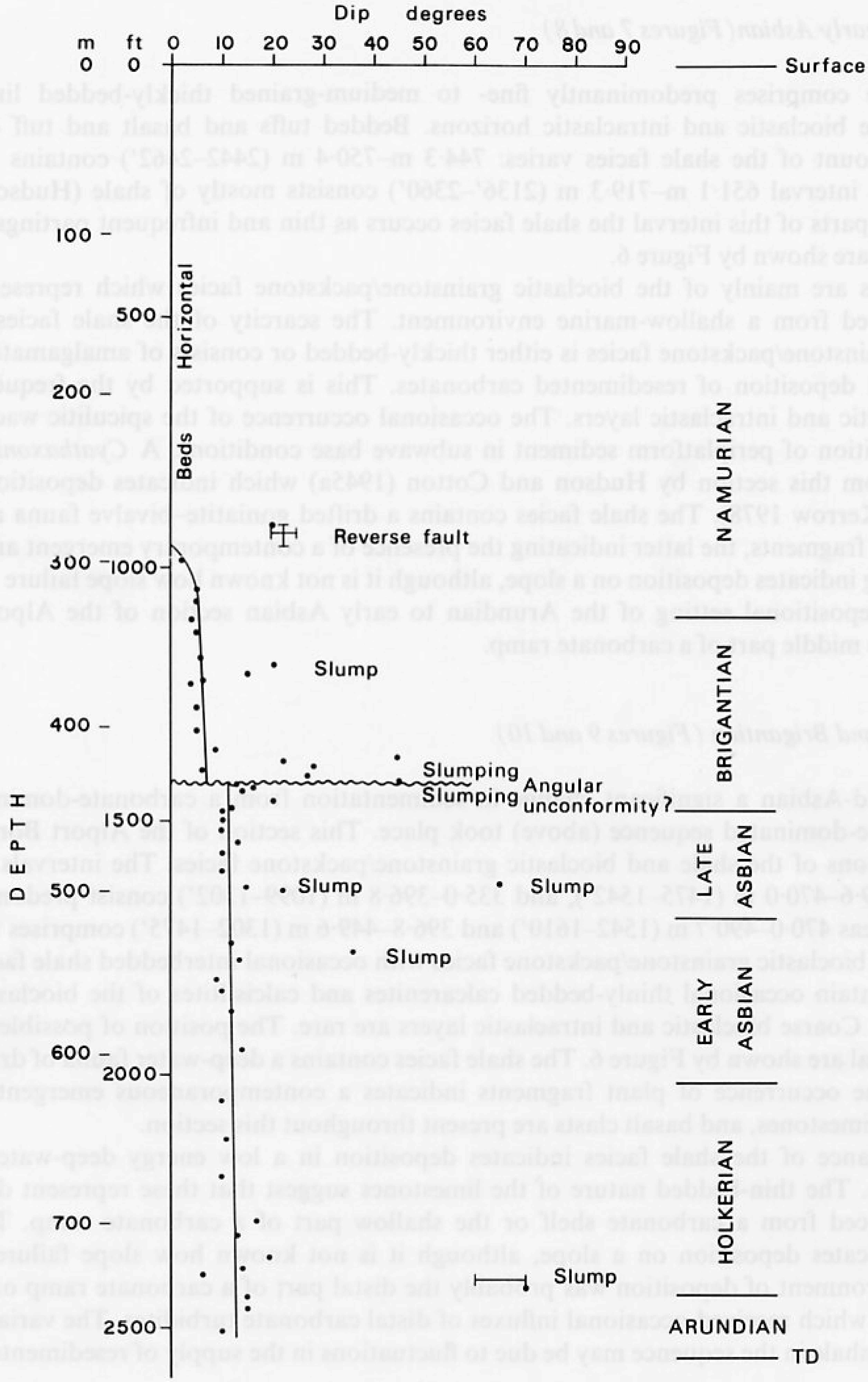

Figure 6. Dips within the Alport Borehole. Data from Hudson and Cotton (1943, 1945a).

2. There are several intervals of high dip (typically 20°–50°, up to a maximum of 70°–80°. Some of these intervals correspond with the occurrence of slumping described by Hudson and Cotton (1945a) and are interpreted as slumped units.

A similar study of dip variation was not possible for the Edale Borehole owing to the drilling method used.

5b. Arundian to early Asbian (Figures 7 and 8)

This sequence comprises predominantly fine- to medium-grained thickly-bedded limestones with infrequent coarse bioclastic and intraclastic horizons. Bedded tuffs and basalt and tuff clasts are also present. The amount of the shale facies varies: 744·3 m–750·4 m (2442–2462′) contains frequent shale partings and the interval 651·1 m–719·3 m (2136′–2360′) consists mostly of shale (Hudson and Cotton 1945a). In other parts of this interval the shale facies occurs as thin and infrequent partings. The position of slumped units are shown by Figure 6.

The limestones are mainly of the bioclastic grainstone/packstone facies which represent redeposited carbonates derived from a shallow-marine environment. The scarcity of the shale facies suggests that the bioclastic grainstone/packstone facies is either thickly-bedded or consists of amalgamated beds, which implies proximal deposition of resedimented carbonates. This is supported by the frequent occurrence of coarse bioclastic and intraclastic layers. The occasional occurrence of the spiculitic wackestone facies represents deposition of periplatform sediment in subwave base conditions. A *Cyathaxonia* phase fauna was recorded from this section by Hudson and Cotton (1945a) which indicates deposition in relatively deep water (McKerrow 1978). The shale facies contains a drifted goniatite–bivalve fauna and occasional carbonized plant fragments, the latter indicating the presence of a contemporary emergent area. The occurrence of slumping indicates deposition on a slope, although it is not known how slope failure was induced.

The general depositional setting of the Arundian to early Asbian section of the Alport Borehole is interpreted as the middle part of a carbonate ramp.

5c. Late Asbian and Brigantian (Figures 9 and 10)

During the mid-Asbian a significant change in sedimentation from a carbonate-dominated sequence (below) to a shale-dominated sequence (above) took place. This section of the Alport Borehole contains variable proportions of the shale and bioclastic grainstone/packstone facies. The intervals 490·7–516·6 m (1610–1695′), 449·6–470·0 m (1475–1542′), and 335·0–396·8 m (1099–1302′) consist predominantly of the shale facies whereas 470·0–490·7 m (1542–1610′) and 396·8–449·6 m (1302–1475′) comprises thickly-bedded limestones of the bioclastic grainstone/packstone facies with occasional interbedded shale facies. The shale-rich intervals contain occasional thinly-bedded calcarenites and calcisiltites of the bioclastic grainstone/packstone facies. Coarse bioclastic and intraclastic layers are rare. The position of possible slumped units within this interval are shown by Figure 6. The shale facies contains a deep-water fauna of drifted goniatites and bivalves. The occurrence of plant fragments indicates a contemporaneous emergent area. Bedded tuffs, tuffaceous limestones, and basalt clasts are present throughout this section.

The predominance of the shale facies indicates deposition in a low energy deep-water environment below wave base. The thin-bedded nature of the limestones suggest that these represent distal turbidites which were sourced from a carbonate shelf or the shallow part of a carbonate ramp. The occurrence of slumping indicates deposition on a slope, although it is not known how slope failure was induced. The overall environment of deposition was probably the distal part of a carbonate ramp or a siliciclastic-dominated slope which received occasional influxes of distal carbonate turbidites. The variable proportion of limestone and shale in the sequence may be due to fluctuations in the supply of resedimented carbonates.

6. SEDIMENTARY EVOLUTION: EVIDENCE FROM THE EDALE BOREHOLE

6a. Late Asbian/early Brigantian (Figure 11)

This section comprises mainly bioclastic grainstone/packstone facies and thinly-bedded shale facies. The spiculite wackestone facies was not recorded from the Edale Borehole. There are occasional horizons of reworked volcaniclastic particles and bedded tuffs. The bioclastic grainstone/packstone facies was derived

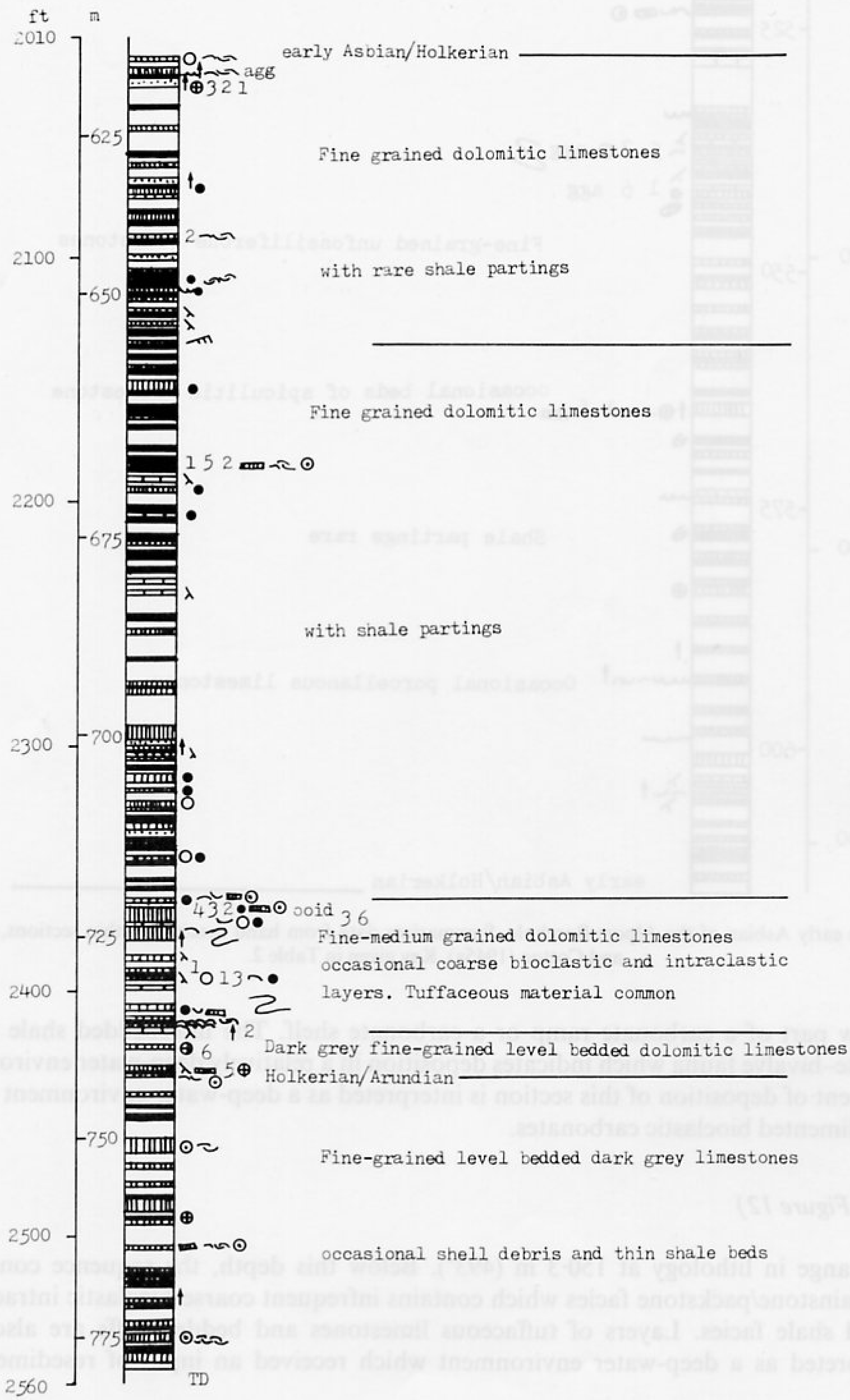

Figure 7. Log of the Arundian and Holkerian section of the Alport Borehole. Summarizes data from hand specimens, thin sections, and from Hudson and Cotton (1945a). Key given in Table 2.

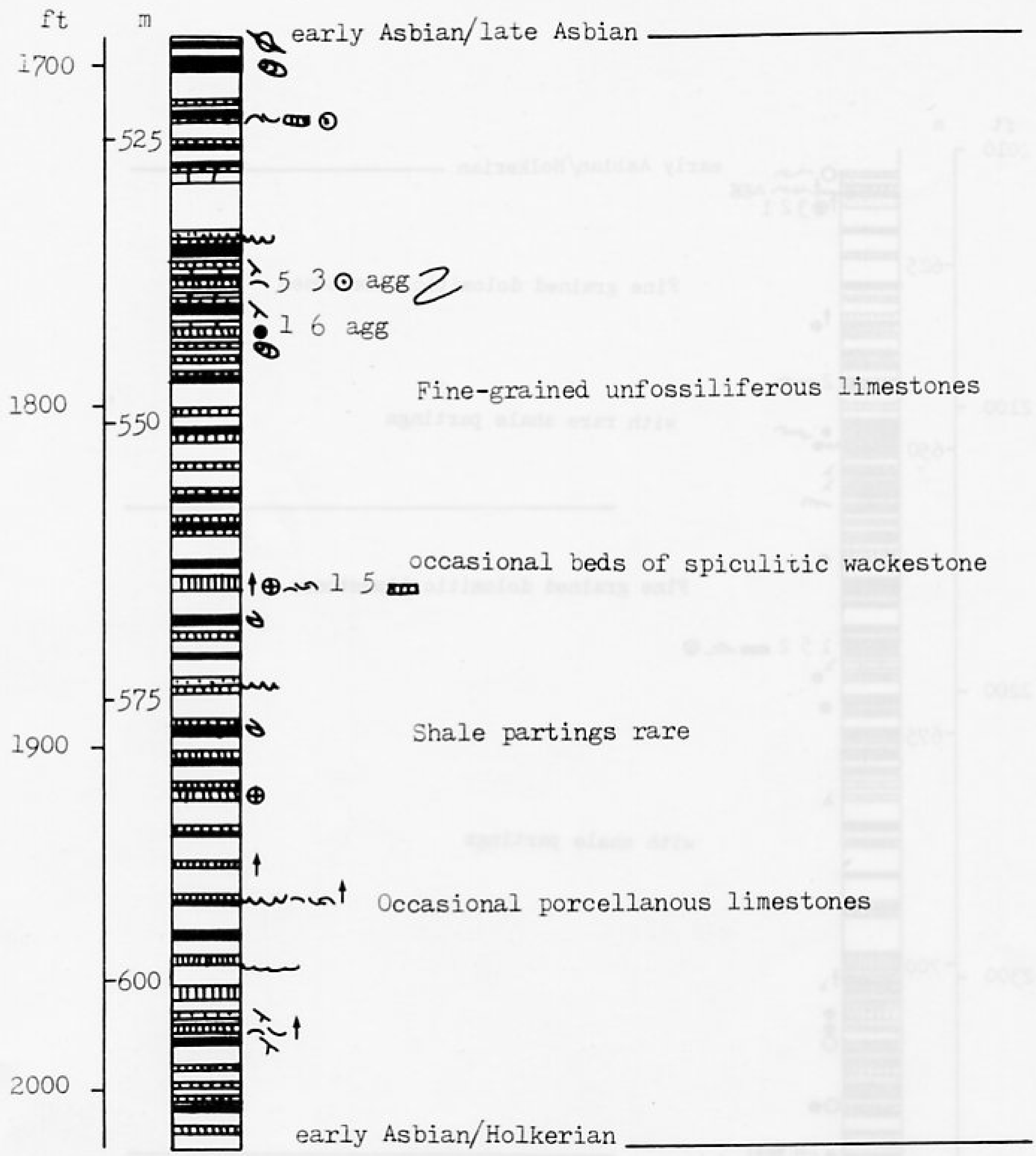

Figure 8. Log of the early Asbian of the Alport Borehole. Summarizes data from hand specimens, thin sections, and from Hudson and Cotton (1945a). Key given in Table 2.

from the shallow part of a carbonate ramp or a carbonate shelf. The interbedded shale facies contains a drifted goniatite–bivalve fauna which indicates deposition in a relatively deep-water environment.

The environment of deposition of this section is interpreted as a deep-water environment which received an input of resedimented bioclastic carbonates.

6b. Brigantian (Figure 12)

There is a change in lithology at 150·3 m (493′). Below this depth, the sequence consists mainly of the bioclastic grainstone/packstone facies which contains infrequent coarse bioclastic intraclastic horizons and interbedded shale facies. Layers of tuffaceous limestones and bedded tuffs are also present. This section is interpreted as a deep-water environment which received an input of resedimented bioclastic carbonates.

Above 150·3 m (493′) the sequence comprises mainly the shale facies with some thinly-bedded (few cm to mm) beds of graded bioclastic calcarenites and calcisiltites of the bioclastic grainstone/packstone facies. The shales contain a drifted goniatite–bivalve fauna together with some fragmented plant material.

The shale facies was deposited by settling from suspension of distal siliciclastic sediment in a deep

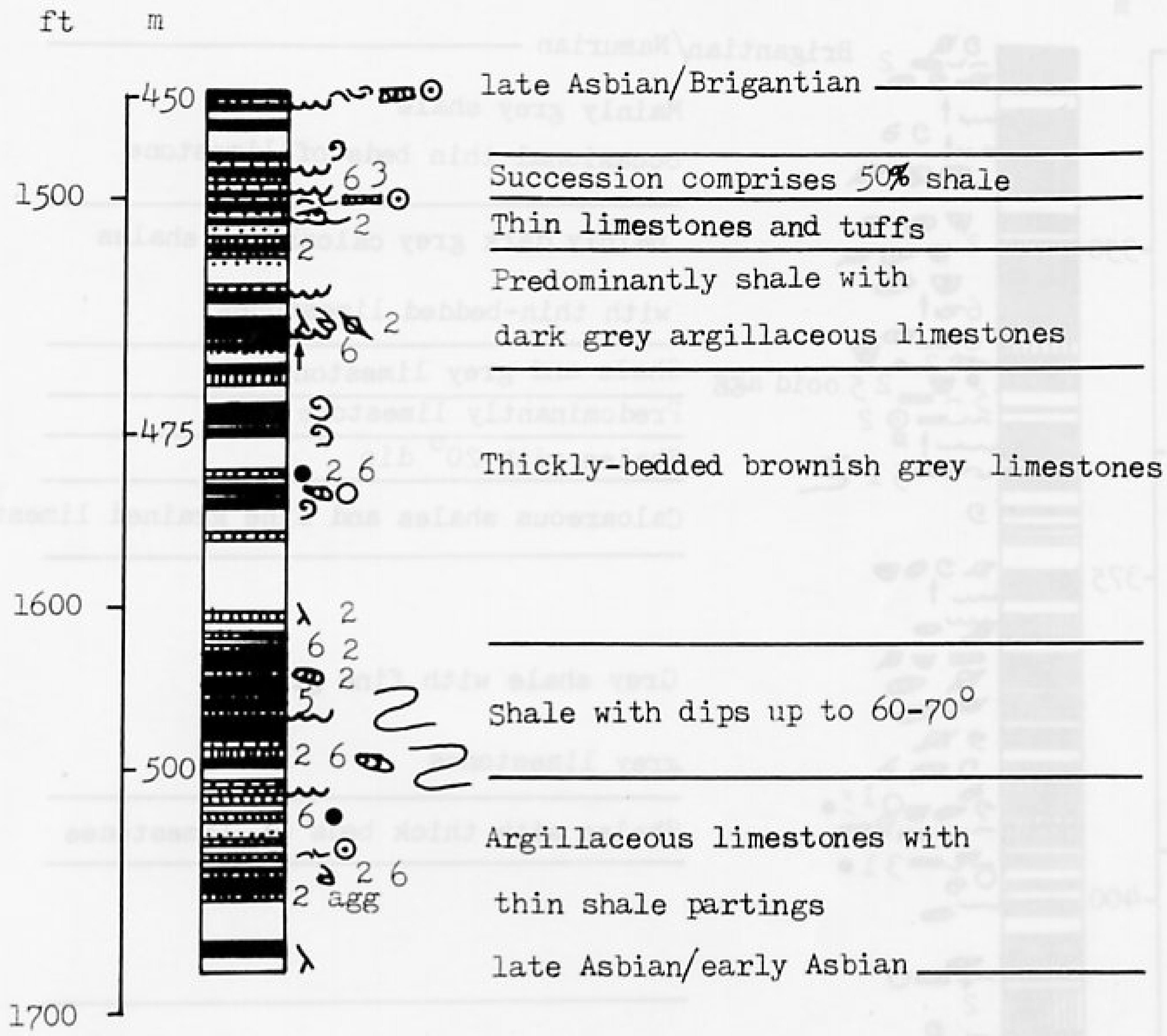

Figure 9. Log of the late Asbian of the Alport Borehole. Summarizes data from hand specimens, thin sections, and from Hudson and Cotton (1945a). Key given in Table 2.

marine environment. The thinly-bedded nature and the fine grain size of the bioclastic grainstone/packstone facies suggests that these represent distal bioclastic turbidites. The carbonate turbidites were sourced from a shallow water carbonate environment. The environment of deposition of the late Brigantian section is interpreted as a carbonate-starved basinal or slope environment.

7. REGIONAL SYNTHESIS

7a. Sedimentary evolution of the northern margin of the Derbyshire carbonate platform

The nearest Dinantian outcrop to the Edale Basin is the Derbyshire carbonate platform whose northern margin is exposed immediately to the south of the study area (Figure 13). The sedimentary evolution of the platform margin during the late Dinantian provides the context in which to interpret the sedimentary development of the Edale Basin.

During the Asbian the Derbyshire carbonate platform was surrounded by a high-angle margin with depositional dips of up to 30° towards the basin (the 'Apron Reef' of previous workers, e.g. Broadhurst and Simpson 1967, 1973; Stevenson and Gaunt 1971). Examination of the shelf/shelf margin transition by the author supports the work of Parkinson (1965) which implies that the shelf margin grew predominantly by accretion during the Asbian. The timing of initiation of the high-angle margin is not known owing to a lack of exposure.

During the late Asbian and early Brigantian a complex of coarse bioclastic grainstone shoals developed in association with the platform margin (Eden *et al.* 1964; Stevenson and Gaunt 1971). These shoals comprise stacked large-scale bedforms up to 20 m in thickness which prograded basinward and spilled over the platform margin (Gawthorpe and Gutteridge 1990).

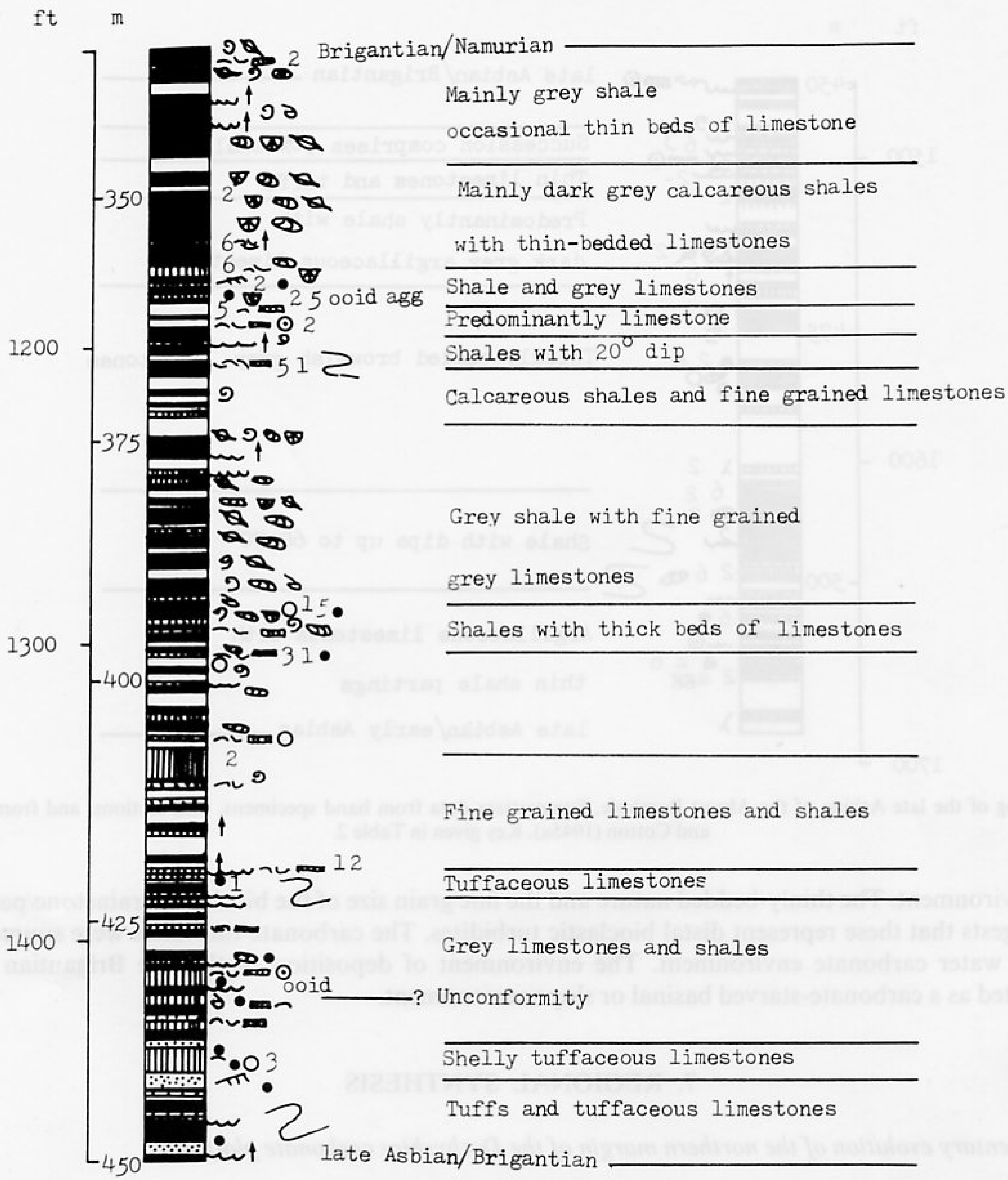

Figure 10. Log of the Brigantian of the Alport Borehole. Summarizes data from hand specimens, thin sections, and from Hudson and Cotton (1945a). Key given in Table 2.

The 'Beach Beds' is a distinctive unit of coarse bioclastic grainstone which contains disarticulated and highly rounded allochems. Sedimentary structures suggest that they represent resedimented bioclastic limestones which were deposited as turbidites (Sadler 1964). The 'Beach Beds' onlap the high-angle Asbian shelf margin and the Castleton Borehole demonstrates that they interfinger with and are overlain by basinal sediments of Brigantian age (Stevenson and Gaunt 1971). The stratigraphical position of the 'Beach Beds' is thus partly equivalent to the shelf margin grainstone shoals. The 'Beach Beds' are interpreted as resedimented bioclastic limestones which were supplied from the bioclastic grainstone shoals which spilled over the platform margin.

The Derbyshire carbonate platform was later onlapped by basinal sediments consisting of shales and distal carbonate turbidites (Hudson and Cotton 1945a fig. 7; Stevenson and Gaunt 1971; Ford 1987).

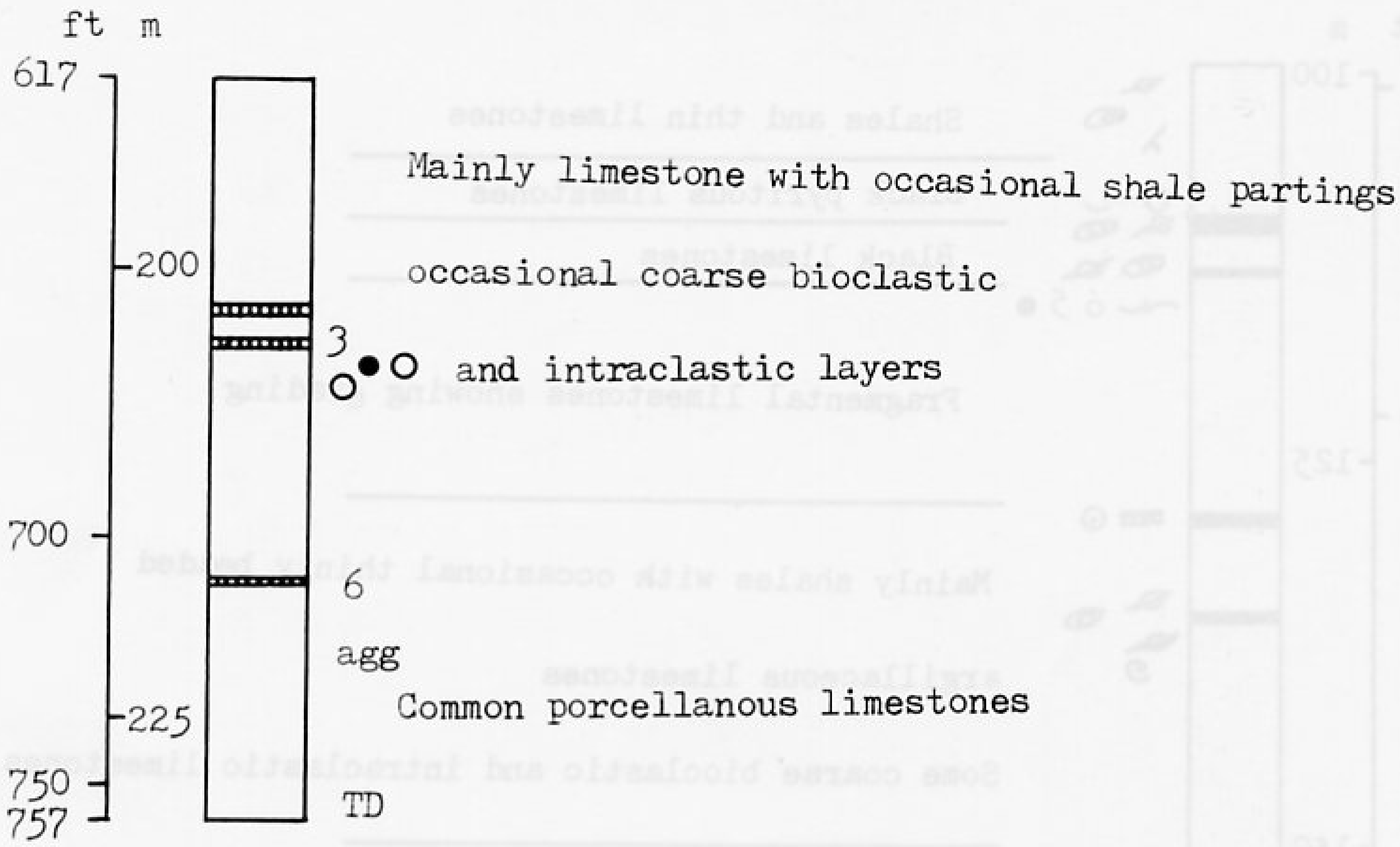

Figure 11. Log of the late Asbian/early Brigantian section of the Edale Borehole. Summarizes data from hand specimens, thin sections, and from Hudson and Cotton (1945b). Key given in Table 2.

Later, during the late Brigantian/early Namurian, part of the shelf margin collapsed forming the Treak Cliff boulder bed (Simpson and Broadhurst 1969; Ford 1987).

7b. Provenance of the bioclastic grainstone/packstone facies

Sediments deposited along the northern margin of the Derbyshire carbonate platform consist mainly of a bioclast/peloid assemblage (e.g. Schofield and Adams 1985; Walkden personal communication 1989; Gawthorpe and Gutteridge 1990) which differs from the bioclast/aggregate grain/ooid/peloid assemblage found within the Alport Borehole. Oolitic sediments are occasionally developed at the Derbyshire carbonate platform margin. These comprise a superficial coating around unmicritized coarse bioclast nuclei which contrasts with the micritized ooids with thick coatings developed around micritized sand-sized allochems found in the Alport Borehole. Petrographical variations in recent sediments deposited at carbonate platform margins has been shown to be related to the windward/leeward setting and the degree of protection of the platform margin (e.g. Mullins and Neumann 1979; Hine *et al.* 1981; Hine and Mullins 1983). the petrographical differences between resedimented limestones found in the Alport Borehole and those found on the Derbyshire carbonate platform may indicate derivation from a separate carbonate platform.

Fraser and Gawthorpe (1990), on the basis of seismic mapping, identified a carbonate platform developed over the footwall crest to the north of the Edale Basin (Figures 13 and 14). Their interpretation is supported by the sequence encountered in the Wessenden Borehole. This platform will be referred to as the Holme Platform. The reworked allochems of shallow water origin found in the Alport Borehole are inferred to have formed on the Holme Platform.

The provenance of sediments within the Edale Borehole is more problematic. The lower carbonate-rich section is of late Asbian/early Brigantian age which is in the same age interval as the 'Beach Beds'. Since this section represents thinly-bedded resedimented carbonates interbedded with basinal shales, it could represent a distal part of the 'Beach Beds' submarine fan. In support of this, the Castleton Borehole shows that 'Beach Beds' sedimentation ceased during the early Brigantian and there is a change to shale-dominated basinal sedimentation at a similar level in the Edale Borehole. Against this correlation is the rare occurrence of aggregate grains and type 3 intraclasts within the Edale Borehole suggesting some sediment input from the north. Ooids, however, have not been found within the Edale Borehole. The

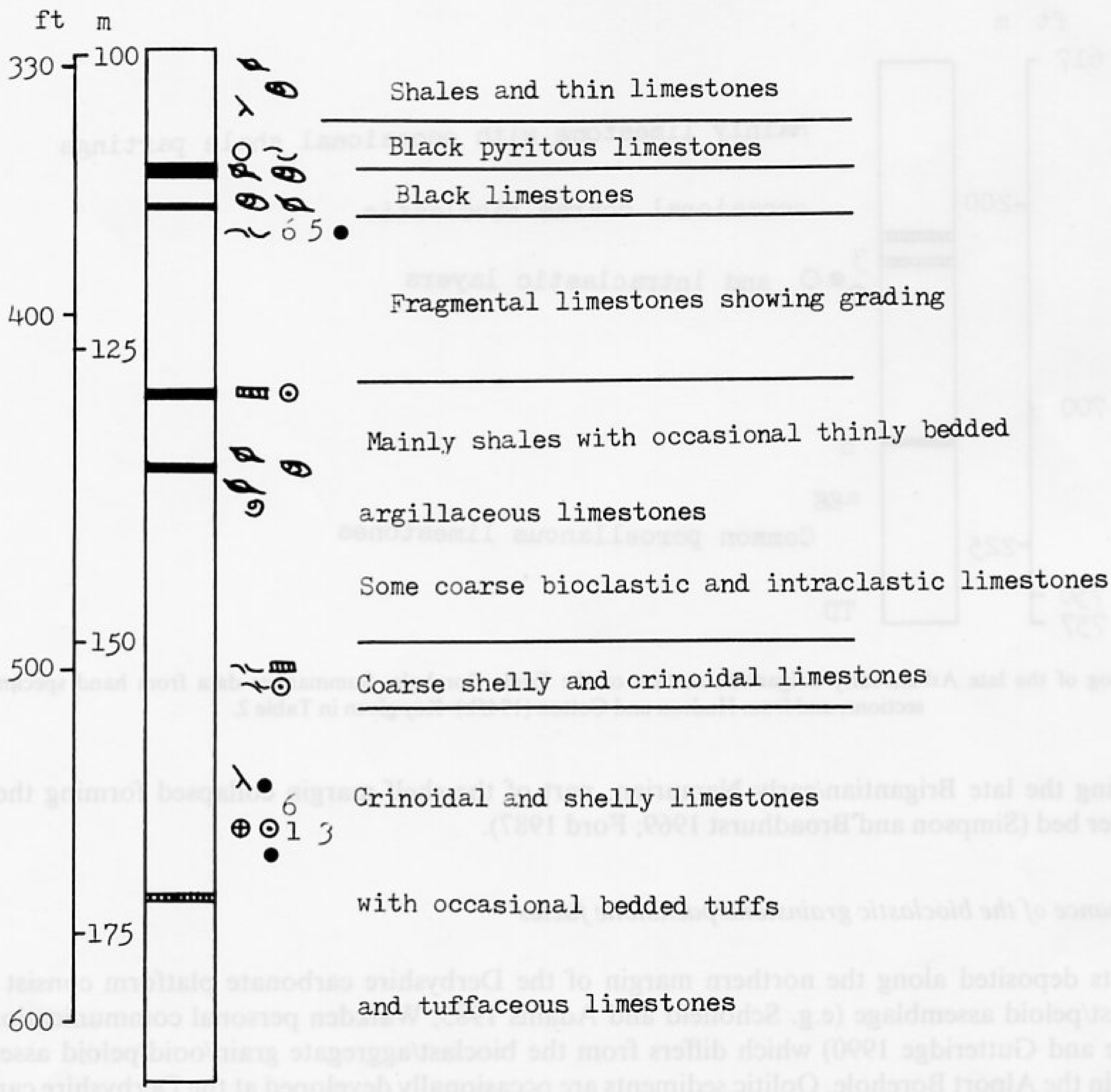

Figure 12. Log of the Brigantian section of the Edale Borehole. Summarizes data from hand specimens, thin sections, and from Hudson and Cotton (1945b). Key given in Table 2.

correlation of the lower part of the Edale Borehole with part of the 'Beach Beds' submarine fan should be taken as a model pending further biostratigraphical or seismic study.

7c. *Dinantian sedimentation in the Edale Basin*

Figures 13 and 14 show an interpretation of the Edale Basin and the palaeogeography of the central Pennine area immediately to the north of the Derbyshire carbonate platform. In the following discussion, the terminology of carbonate platforms, shelves, and ramps defined by Read (1982, 1985) is used.

Sedimentation during the Arundian to early Asbian is represented in the Alport Borehole and is interpreted as a middle carbonate ramp setting. From regional considerations the palaeoslope direction is inferred to have been southwards down the hangingwall dip slope of the half-graben. The variable proportion of shale and limestone in the sequence is thought to be due to episodic progradation and retreat of the carbonate ramp which may have been caused by fluctuations of subsidence rate or sea level.

During the Asbian sedimentation changed from a carbonate ramp to a deep ramp or siliciclastic-dominated slope setting. This sediment starvation of the Edale Basin may be due to one or more of the following processes: suppression of carbonate production within the basin; drowning or emergence of surrounding

Table 2. Key to sedimentary logs (Figures 7 to 12).

No data		Goniatites	
Spiculitic wackestone facies		Posidonid bivalves	
Bioclastic grainstone/packstone facies		Dunbarellid bivalves	
Shale facies		Intraclast types	1 2 3 4 5 6
Bedded tuffs		Intraclast unspecified	
Basalt/Tuff clast		Aggregate grain	agg
Reworked brachiopods		Ooid	ooid
Insitu brachiopods		Graded bedding	
Reworked crinoids		Loaded contact	
Reworked corals		Ripple lamination	
Plant fragments		Bioturbation	
Stromatolitic lamination		Slumping	

carbonate platforms or the development of carbonate shelves with high angle accretionary margins in areas surrounding the Edale Basin.

Gawthorpe (1986, 1987) suggested that a similar change from carbonate-dominated, to distal siliciclastic sedimentation during the Chadian/Arundian in the Bowland Basin was due to suppression of carbonate production by siliciclastic input to the basin. The main type of carbonate sedimentation in the Edale Basin was by redeposition of shallow-water sediments with *in situ* production being suppressed throughout the late Dinantian. The change from carbonate-dominated to siliciclastic-dominated sedimentation during the mid-Asbian must be explained in other terms.

James and Mountjoy (1983) showed that sediment starvation of a basin could be achieved if carbonate production on surrounding platforms was shut down by drowning or emergence. There is no evidence of regional drowning of the Derbyshire carbonate platform during mid-Asbian times which could account for this change in sedimentation.

Sedimentation over much of the Derbyshire carbonate platform during the Asbian and Brigantian was by shallowing-upwards cyclic shelf carbonates capped by emergent surfaces (Bridges 1982; Walkden 1987). The time represented by these emergent surfaces is not certain but it is possible that, cumulatively, they account for a large proportion of the late Dinantian. Carbonate production on the Derbyshire carbonate platform may thus have been shut off for long periods resulting in sediment starvation of surrounding basins. There is also evidence of early lithification of these sediments (Walkden 1987), which could have been responsible for trapping of sediment on the shelf. Cyclic shallowing-upwards sedimentation became

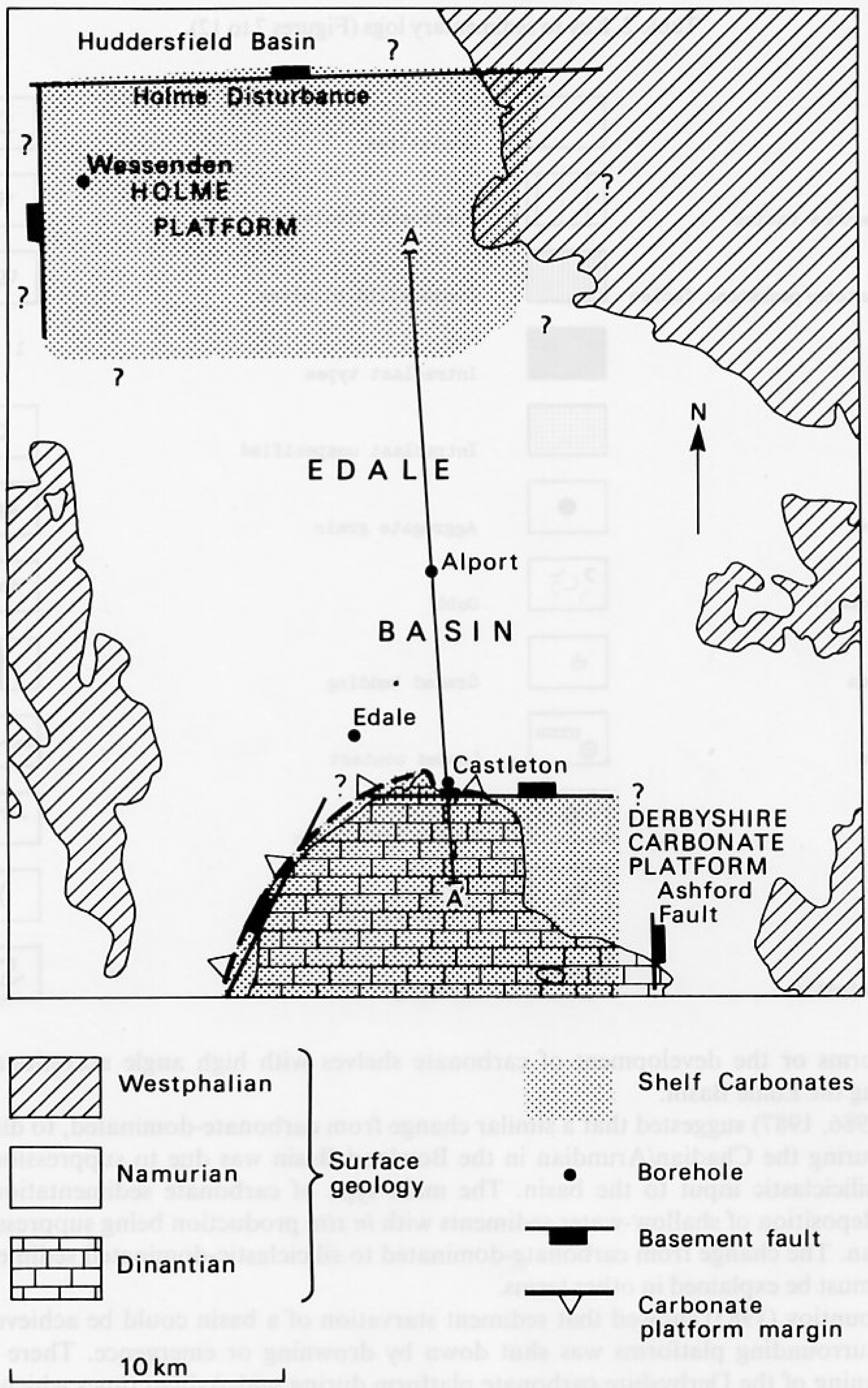

Figure 13. Inferred late Asbian palaeogeography of the Edale Basin and Derbyshire Carbonate Platform.

established on the Derbyshire carbonate platform at the Holkerian/Asbian boundary which predates the major change in carbonate sedimentation in the Edale Basin. The influence of cyclic shelf sedimentation may have been an important influence on basinal sedimentation but cannot fully account for the observed change in the Edale Basin.

The predominantly accretionary growth of the Derbyshire carbonate platform during the Asbian implies

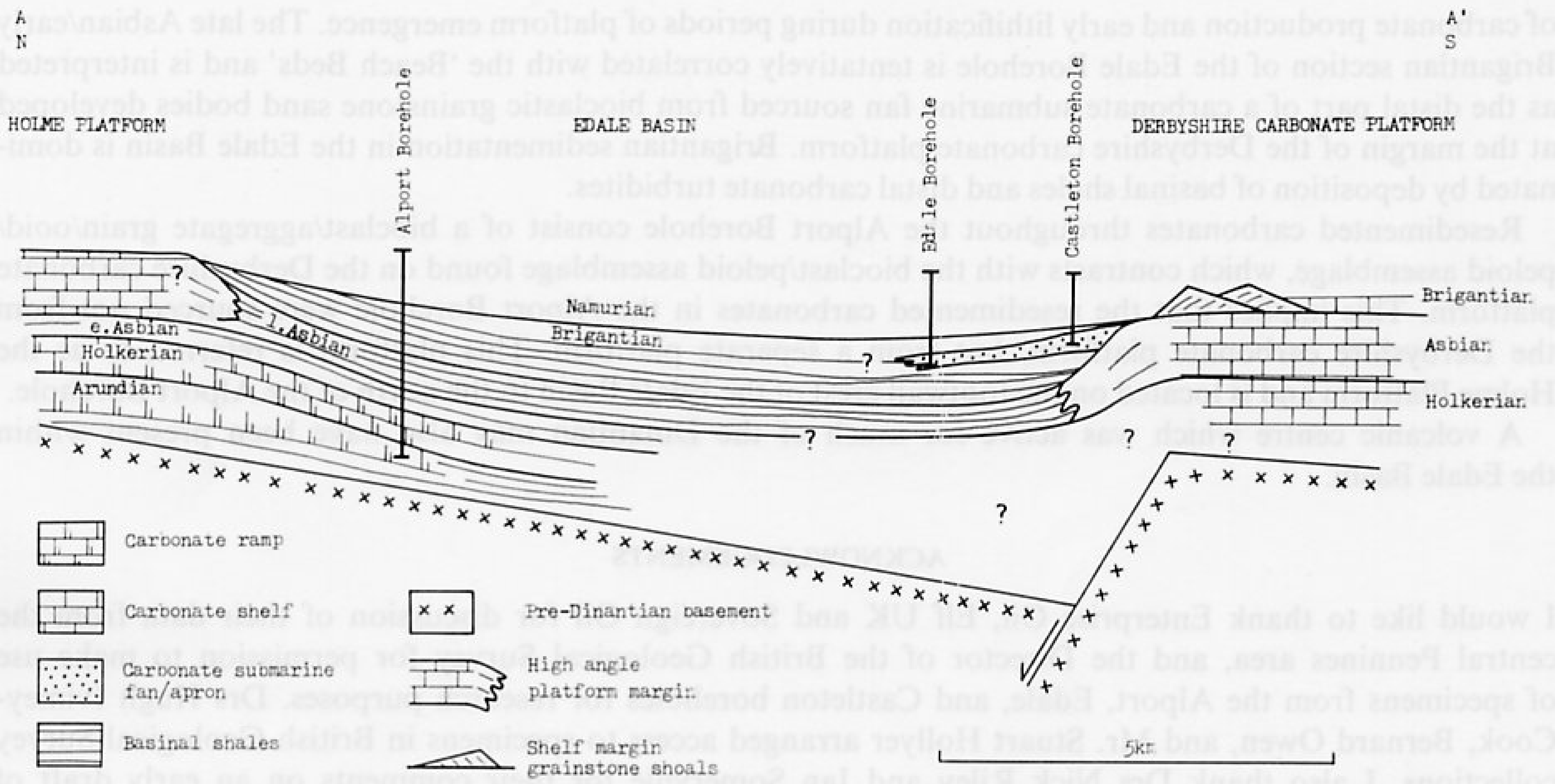

Figure 14. Sedimentary evolution of the Edale Basin. Line of section given on Figure 13.

that there was minimal export of shallow-water sediments to basins surrounding the platform. Consequently, the basinal sequences would be starved of shelf-derived carbonates and would be dominated by distal siliciclastic sediment. The change from carbonate-dominated to shale-dominated sequences in basinal areas may reflect the development of accretionary carbonate shelves surrounding the Edale Basin.

The lower carbonate-rich part of the Edale Basin is interpreted as a distal part of the 'Beach Beds' submarine fan system. This was derived from shelf margin bioclastic grainstone shoals on the Derbyshire carbonate platform. The change to distal siliciclastic sedimentation in this case is interpreted either as a result of shut-off of carbonate supply or switching of turbidite deposition within the basin.

The Brigantian of the Edale Basin represents a distal carbonate ramp or siliciclastic-dominated slope setting. This may represent increasing siliciclastic input to the basin causing shut-down of production on the carbonate platforms. The carbonate platforms were then buried by basinal shales and distal carbonate and siliciclastic turbidites during the Brigantian and early Namurian.

The occurrence of volcaniclastic sediments found by the Alport Borehole suggests that a volcanic centre may have been present within the Edale Basin.

8. CONCLUSIONS

The structural form of the Edale Basin inferred from gravity data is a half-graben. The main bounding fault is associated with the northern margin of the Derbyshire carbonate platform and the hangingwall slope rises northward towards the Holme High.

During the Arundian to early Asbian the deposition within the Edale Basin was on a carbonate ramp, probably dipping southwards towards the Derbyshire carbonate platform. Sedimentation was mainly by resedimented shallow-water carbonates with the occasional deposition of periplatform carbonates, basinal shales, and volcaniclastic sediments.

During the Asbian the sedimentary setting changed from a shallow or mid-carbonate ramp to a distal ramp or siliciclastic-dominated slope on which basinal shales and distal carbonate turbidites were deposited. This is attributed to starvation of the basin of platform-derived carbonate sediments resulting from a combination of the development of accretionary rimmed shelves surrounding the basin and the shut-down of carbonate production and early lithification during periods of platform emergence. The late Asbian/early Brigantian section of the Edale Borehole is tentatively correlated with the 'Beach Beds' and is interpreted as the distal part of a carbonate submarine fan sourced from bioclastic grainstone sand bodies developed at the margin of the Derbyshire carbonate platform. Brigantian sedimentation in the Edale Basin is dominated by deposition of basinal shales and distal carbonate turbidites.

Resedimented carbonates throughout the Alport Borehole consist of a bioclast/aggregate grain/ooid/peloid assemblage, which contrasts with the bioclast/peloid assemblage found on the Derbyshire carbonate platform. This implies that the resedimented carbonates in the Alport Borehole were sourced not from the Derbyshire carbonate platform, but from a separate platform. This platform is referred to as the Holme Platform and is located on the footwall crest of the Edale Basin to the north of the Alport Borehole.

A volcanic centre which was active for much of the Dinantian may also have been present within the Edale Basin.

ACKNOWLEDGEMENTS

I would like to thank Enterprise Oil, Elf UK and Sovereign Oil for discussion of their data from the central Pennines area, and the Director of the British Geological Survey for permission to make use of specimens from the Alport, Edale, and Castleton boreholes for research purposes. Drs Hugh Ivimey-Cook, Bernard Owen, and Mr. Stuart Hollyer arranged access to specimens in British Geological Survey collections. I also thank Drs Nick Riley and Ian Somerville for their comments on an early draft of the manuscript and two anonymous reviewers for their comments on the final manuscript. Stella Gutteridge drew the diagrams.

REFERENCES

Bathurst, R. G. C. 1975. Carbonate sediments and their diagenesis. Developments in Sedimentology, **12**, Elsevier, 658 pp.

Boardman, M. R. and Neumann, A. C. 1984. Sources of periplatform carbonates: Northwest Providence Channel, Bahamas. *Journal of Sedimentary Petrology*, **54**, 1110–1123.

Bricker, O. P. (Ed.) 1971. *Carbonate Cements*. Johns Hopkins Press. 376 pp.

Bridges, P. H. 1982. The origin of cyclothems in the late Dinantian platform carbonates at Crich, Derbyshire. *Proceedings of the Yorkshire Geological Society*, **44**, 159–180.

Broadhurst, F. M. and Simpson, I. M. 1967. Sedimentary infillings of fossils and cavities in limestones at Treak Cliff, Derbyshire. *Geological Magazine*, **104**, 443–448.

——— and ——— 1973. Bathymetry on a Carboniferous reef. *Lethaia*, **6**, 367–381.

Bromehead, C. E. N., Edwards, W. N., Wray, D. A., and Stephens, J. V. 1933. The geology of the country around Holmfirth and Glossop. *Memoir of the British Geological Survey*, Sheet 86.

Bromley, R. G. and Ekdale, A. A. 1984. *Chondrites*: A trace fossil indicator of anoxia in sediments. *Science*, **224**, 872–874.

Davis, A. G. 1945a. Micro-organisms in the Carboniferous of the Alport boring. *Proceedings of the Yorkshire Geological Society*, **25**, 312–318.

——— 1945b. Micro-organisms in the Carboniferous Limestone of the Edale boring. *Quarterly Journal of the Geological Society of London*, **101**, 35.

Eden, R. A., Orme, G. R., Mitchell, M., and Shirley, J. 1964. A study of part of the margin of the Carboniferous limestone 'massif' in the Pin Dale area of Derbyshire. *Bulletin of the Geological Survey of Great Britain*, **21**, 73–118.

Fabricius, F. H. 1977. The origin of marine ooids and grapestone. *Contributions to Sedimentology*, **7**, 113 pp.

Fischer, R. V. and Schminke, H. U. 1984. *Pyroclastic Rocks*. Springer-Verlag, Berlin, 472 pp.

Ford, T. D. 1987. The origin of the Winnats Pass, Castleton, Derbyshire. *Mercian Geologist*, **10**, 241–249.

Fraser, A. J. and Gawthorpe, R. L. 1990. Tectono-stratigraphic development and hydrocarbon habitat of the Carboniferous in northern England. *In*: Hardman, R. F. P. and Brooks, J. (Eds), *Tectonic Events Responsible for Britain's Oil and Gas Reserves. Geological Society Special Publication*, **55**, 49–56.

Gawthorpe, R. L. 1986. Sedimentation during carbonate ramp-to-slope evolution in a tectonically active area: Bowland Basin (Dinantian) northern England. *Sedimentology*, **33**, 185–206.

——— 1987. Tectono-sedimentary evolution of the Bowland Basin, N. England during the Dinantian. *Journal of the Geological Society of London*, **144**, 59–71.

——— and Gutteridge, P. 1990. Geometry and evolution of platform-margin bioclastic shoals, late Dinantian (Mississippian), Derbyshire UK. *In*: Tucker, M. E., Wilson, J. L., Crevello, P. D., Sarg, J. R., and Read, J. F. (Eds), *Carbonate Platforms: Facies, Sequences and Evolution. International Association of Sedimentologists Special Publication*, **9**, 39–53.

———, ———, and Leeder, M. R. 1989. Late Devonian and Dinantian basin evolution in northern England and North Wales. *In*: Arthurton, R. S., Gutteridge, P., and Nolan, S. C. (Eds), *The Role of Devonian and Carboniferous Sedimentation in the British Isles. Occasional Publication of the Yorkshire Geological Society*, **6**, 1–23.

George, T. N. 1958. Lower Carboniferous palaeogeography of the British Isles. *Proceedings of the Yorkshire Geological Society*, **31**, 227–318.

Grayson, R. F. and Oldham, L. 1987. A new structural framework for the northern British Dinantian as a basin for oil, gas and mineral exploration. *In*: Miller, J., Adams, A. E., and Wright, V. P. (Eds), *European Dinantian Environments*, 33–59.

Gutteridge, P. 1983. *Sedimentological study of the Eyam Limestones of the east central part of the Derbyshire Dome*. Unpublished PhD Thesis, University of Manchester.

———, 1987. Dinantian sedimentation and the basement structure of the Derbyshire Dome. *Geological Journal*, **22**, 25–41.

Heiken, G. 1972. Morphology and petrography of volcanic ashes. *Geological Society of America Bulletin*, **83**, 1961–1988.

Hine, A. C. and Mullins, H. T. 1983. Modern carbonate shelf-slope breaks. *In*: Stanley, D. J. and Moore, G. T. (Eds), *The Shelfbreak: Critical interface on Continental Margins. Society of Economic Paleontologists and Mineralogists Special Publication*, **33**, 169–188.

———, Wilber, R. J., and Neumann, A. C. 1981. Carbonate sand bodies along contrasting shallow bank margins facing open seaways in northern Bahamas. *Bulletin of the American Association of Petroleum Geologists*, **65**, 261–290.

Holdsworth, B. K. 1966. A preliminary study of the palaeontology and palaeoenvironment of some Namurian 'bullions'. *Mercian Geologist*, **1**, 315–337.

Hudson, R. G. S. and Cotton, G. 1943. The Namurian of Alport Dale. *Proceedings of the Yorkshire Geological Society*, **25**, 141–173.

——— and ——— 1945a. The Lower Carboniferous in a boring at Alport, Derbyshire. *Proceedings of the Yorkshire Geological Society*, **25**, 254–330.

——— and ——— 1945b. The Carboniferous rocks of the Edale Anticline, Derbyshire. *Quarterly Journal of the Geological Society of London*, **101**, 1–36.

James, N. P. and Mountjoy, E. W. 1983. Shelf-slope break in fossil carbonate platforms: An overview. *In*: Stanley, D. J. and Moore, G. T. (Eds), *The Shelfbreak: Critical interface on Continental Margins. Society of Economic Paleontologists and Mineralogists Special Publication*, **33**, 189–206.

Lee, A. G. 1988. Carboniferous basin configuration of Central England, modelled using gravity data. *In*: Besly, B. M. and Kelling, G. (Eds), *Sedimentation in a synorogenic basin complex: the Carboniferous of northwest Europe*. Blackie and Sons. 69–84.

Lees, A. 1964. The structure and origin of the Waulsortian (Lower Carboniferous) 'reefs' of west-central Eire. *Philosophical Transactions of the Royal Society*, **B247**, 483–531.

——— and Miller, J. 1985. Facies variation in Waulsortian buildups, Part 2; Mid-Dinantian buildups from Europe and North America. *Geological Journal*, **20**, 159–180.

McKerrow, W. S. (Ed.), 1978. *The Ecology of Fossils, An Illustrated Guide*. Duckworth. 384 pp.

Miller, J. 1986. Facies relationships and diagenesis in Waulsortian mud mounds from the Lower Carboniferous of Ireland and N. England. *In*: Schroeder, J. H. and Purser, B. H. (Eds), *Reef Diagenesis*. Springer-Verlag. 311–335.

——— and Grayson, R. F. 1982. The regional context of the Waulsortian facies in northern England. *In*: Bolton, K., Lane, H. R., and LeMone, D. V. (Eds), *Symposium on the Palaeoenvironmental Setting and Distribution of the Waulsortian Facies*. El Paso Geological Society and the University of Texas at El Paso. 17–33.

Mullins, H. T. and Neumann, A. C. 1979. Deep carbonate bank margin structure and sedimentation in the northern Bahamas. *In*: Doyle, L. J. and Pilkey, O. H. (Eds), *Geology of Continental Slopes. Society of Economic Paleontologists and Mineralogists Special Publication*, **27**, 165–192.

Parkinson, D. 1965. Aspects of the Carboniferous stratigraphy of the Castleton–Treak area of North Derbyshire. *Mercian Geologist*, **1**, 161–180.

Pray, L. C. 1958. Fenestrate bryozoan core facies, Mississippian bioherms, southwestern New Mexico. US. *Journal of Sedimentary Petrology*, **28**, 261–273.

Ramsbottom, W. H. C. 1969. Reef distribution in the British Lower Carboniferous. *Nature*, **222**, 765–766.

Read, J. F. 1982. Carbonate platforms of passive (extensional) continental margins: types, characteristics and evolution. *Tectonophysics*, **81**, 195–212.

——— 1985. Carbonate platform facies models. *Bulletin of the American Association of Petroleum Geologists*, **69**, 1–21.

Sadler, H. E. 1964. The origin of the 'Beach Beds' in the Lower Carboniferous of Castleton, Derbyshire. *Geological Magazine*, **101**, 360–372.

Schofield, K. and Adams, A. E. 1985. Stratigraphy and depositional environments of the Woo Dale Limestones Formation (Dinantian), Derbyshire. *Proceedings of the Yorkshire Geological Society*, **45**, 225–233.

Simpson, I. M. and Broadhurst, F. M. 1969. A boulder bed at Treak Cliff, north Derbyshire. *Proceedings of the Yorkshire Geological Society*, **37**, 141–151.

Stevenson, I. P. and Gaunt, G. D. 1971. Geology of the country around Chapel-en-le-Frith. *Memoir of the Geological Survey of Great Britain*, Sheet 99.

Strank, A. R. E. 1981. *Foraminiferal biostratigraphy of the Holkerian, Asbian and Brigantian stages of the British Lower Carboniferous*. Unpublished PhD Thesis, University of Manchester.

——— 1987. The stratigraphy and structure of Dinantian strata in the East Midlands, UK. *In*: Miller, J., Adams, A. E., and Wright, V. P. (Eds), *European Dinantian Environments*. Wiley, 157–175.

Suthern, R. J. 1985. Facies analysis of volcaniclastic sediments: a review. *In*: Brenchley, P. J. and Williams, B. P. J. (Eds), *Sedimentology: Recent Developments and Applied Aspects. Geological Society of London Special Publication*, **18**, 123–146.

Troell, A. R. 1962. Lower Mississippian bioherms of southwestern Montana and northwestern Arkansas. *Journal of Sedimentary Petrology*, **32**, 629–644.

Walkden, G. M. 1987. Sedimentary and diagenetic styles in late Dinantian carbonates of Britain. *In*: Miller, J., Adams, A. E., and Wright, V. P. (Eds), *European Dinantian Environments*. Wiley, 131–155.

Walters, S. G. and Ineson, P. R. 1981. A review of the distribution and correlation of the igneous rocks in Derbyshire. *Mercian Geologist*, **8**, 81–132.

Wray, D. A., Stephens, J. V., Edwards, W. N., and Bromehead, C. E. N. 1930. The Geology of the Country around Huddersfield and Halifax. *Memoir of the Geological Survey of Great Britain*, Sheet 77.