

A record of the Brigantian limestone succession in the partly infilled Dale Quarry, Wirksworth

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Abstract. The now partly infilled Dale Quarry exposes a section from the upper part of the Asbian Bee Low Limestones to the Brigantian Monsal Dale and Eyam Limestones. With other quarries in the Wirksworth area, it provides a three dimensional view of the transition from the Derbyshire carbonate platform southwards down the platform margin slope that passes into basinal facies of the Widmerpool Gulf. This paper provides a permanent record of the sedimentary facies and large-scale slump structures in the Brigantian Monsal Dale Limestones in Dale Quarry. The platform margin slope is dominated by bioturbated argillaceous wackestone that was deposited below wave base and derived from carbonate mud and comminuted bioclasts reworked from shallow carbonate platform environments. It also displays a range of soft sediment deformation structures, including both the compressional and extensional parts of slump sheets and an eroded syn-sedimentary thrust. An additional aim of this paper is to make a case for re-exposing these features in the event of any re-development or landscaping of the Dale Quarry site.

Dale Quarry (SK283452) is one of a number of disused quarries in the Wirksworth area that provide excellent exposures of the late Dinantian succession. These can be used to re-construct the three-dimensional facies geometry and evolution of the southern margin of the Derbyshire carbonate platform during the Asbian and Brigantian (Fig. 1). The Wirksworth area also demonstrates the transition from the Derbyshire carbonate platform to the Widmerpool Gulf to the south. The succession in Dale Quarry can be traced into cyclic shallowing-upwards limestones deposited in shallow water on top of the Derbyshire carbonate platform exposed in Middle Peak Quarry 500 m to the north (Walkden, 1982; Vanstone, 1996). The succession in that quarry contains palaeokarstic surfaces that are not represented in Dale Quarry, suggesting the succession in Dale Quarry represents a setting deeper down the palaeoslope. Seismic lines shot across the southern margin of the Derbyshire carbonate platform along strike to the east show that this part of the platform was progradational, building out southwards into the Widmerpool Gulf (Fraser *et al.*, 1990).

The succession in Dale Quarry includes the upper part of the Asbian Bee Low Limestones (still exposed), a complete section through the Brigantian Monsal Dale Limestones (now mainly obscured) and the lower few metres of the Eyam Limestones (Shirley, 1959; Frost & Smart, 1979; Walkden, 1982; Oakman, 1986). Unfortunately Dale Quarry has been infilled and much of the sedimentary succession together with the large-scale slump structures has been buried. This paper records the succession of Dale Quarry before infilling, concentrating on the facies types and slump structures in the Monsal Dale Limestones.

The Bee Low Limestones, still exposed in the lower eastern part of Dale Quarry, comprise about 25 m of thickly bedded, bioclast, peloid, grainstone/packstone, with bedding planes marked

by palaeokarstic surfaces overlain by thin volcanic derived soils. The Bee Low Limestones are capped by a karstic surface that has removed a few metres of the uppermost Asbian (Walkden, 1982). The Monsal Dale and Eyam Limestones were formerly exposed in the main southern and southwestern quarry face and in the limestone pillar left behind by quarrying in the central part of Dale Quarry (Fig. 1). This pillar was not quarried because it contains shafts and chambers associated with Burton's Lead Vein that left it in an unstable state (Frost & Smart, 1979). The southern and southwestern faces of the

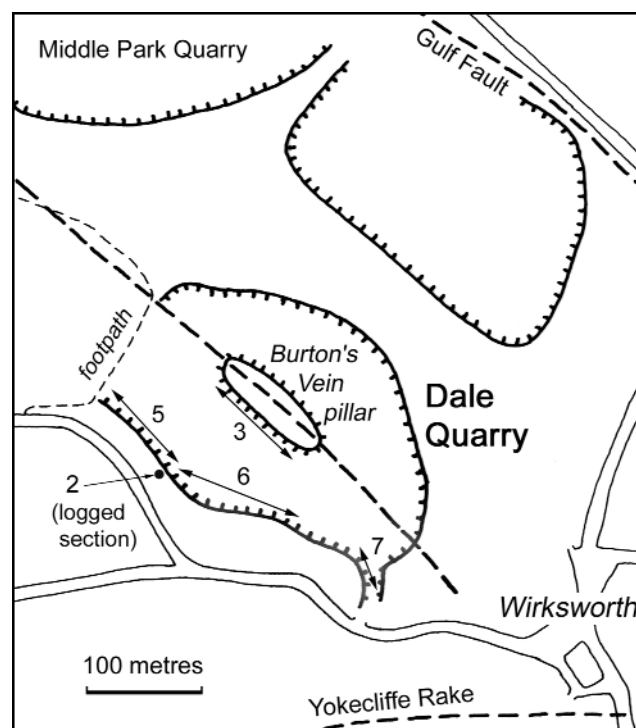


Figure 1. The location of Dale Quarry and other quarries close to Wirksworth. Positions of the logged and measured sections are identified by their figure numbers in this paper.

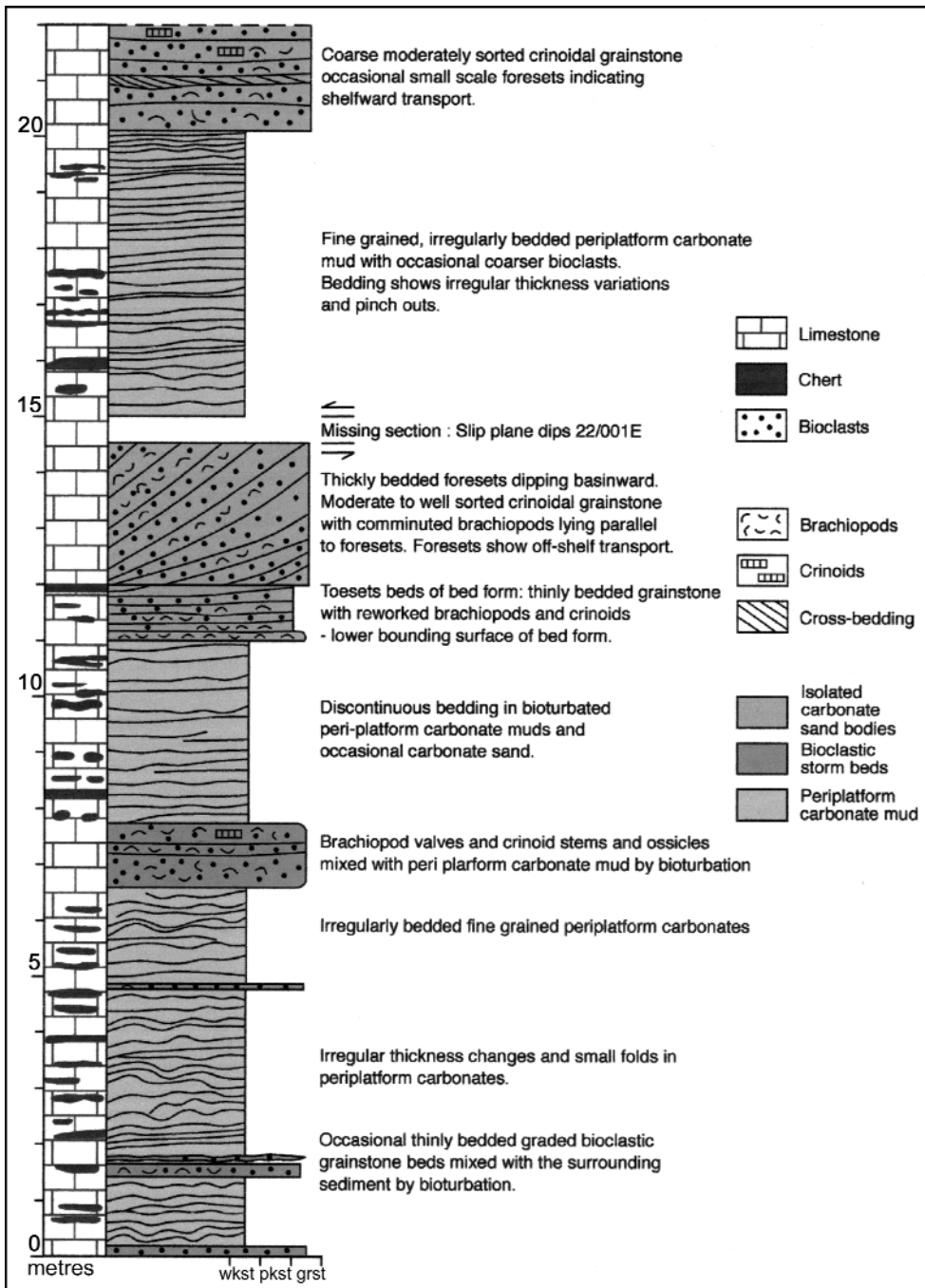


Figure 2. Sedimentological log of the southwest face of Dale Quarry; the position of the log is also shown on Figures 1, 5 and 6. All but the top 2-3 m of the logged section is now obscured.

quarry were measured and logged before it was infilled. The surviving faces of Dale Quarry can be viewed from a public footpath that leaves the Wirksworth-Hopton road at SK281541. Access to the lower part of Dale Quarry is possible from a point next to a garage entrance at SK284540. The face on the west side of this lower entrance was also measured, although this has not been infilled; it is becoming overgrown and filling up with other debris.

Sedimentology

A sedimentological log of the southwest face of Dale Quarry shows the occurrence and relative

abundance of the three depositional facies of the Monsal Dale Limestones described below (Fig. 2). The logged section is cut by one of the major slide planes described below. The three depositional facies are as follows.

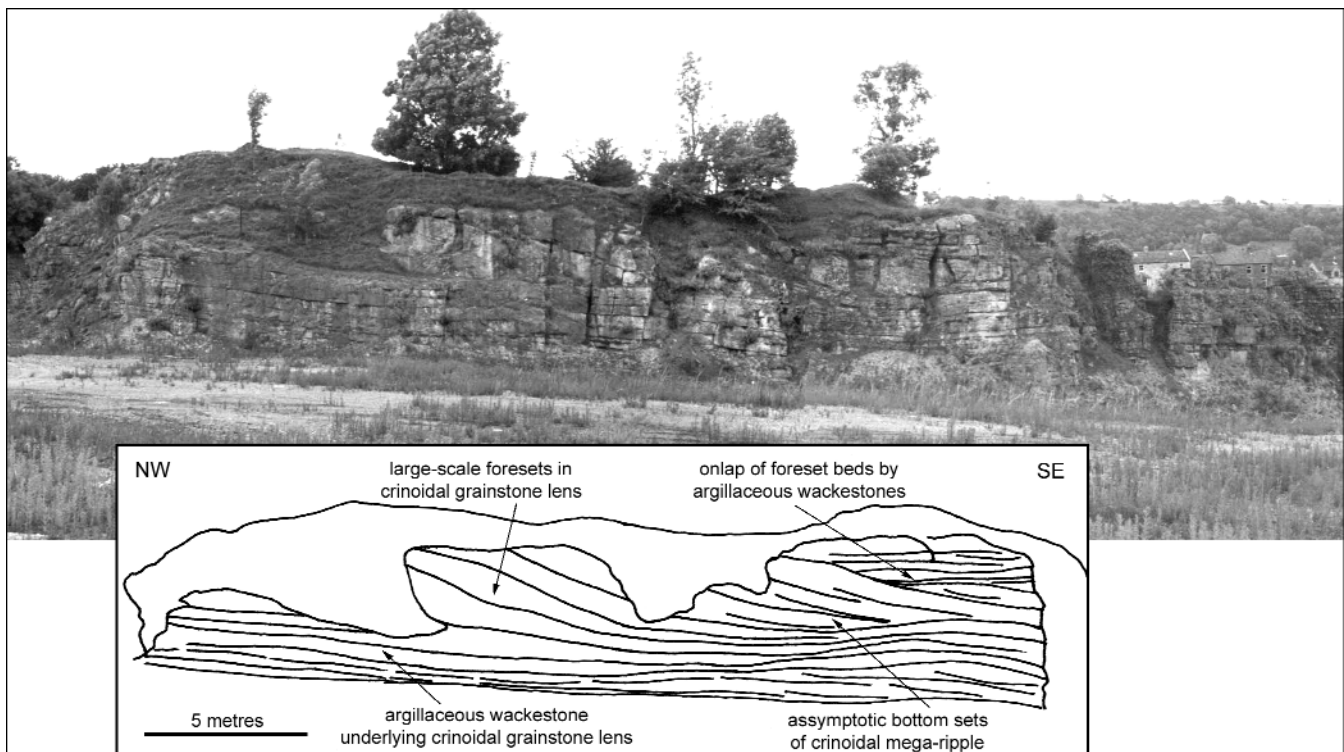
Argillaceous wackestone: indicated as periplatform carbonate mud on Figure 2. This forms much of the Monsal Dale Limestones. It is a wackestone to carbonate mudstone with fragmented and comminuted bioclasts that include brachiopods, crinoids and foraminifera. The sediment is mottled and has a patchy distribution of bioclasts. Bedding planes are represented by argillaceous partings up to 10 mm thick made up of concentrations of

numerous pressure dissolution seams. The beds are 0.05-0.25 m thick, show abrupt thickening and thinning, and are often thrown in to small-scale upright folds and monoclinical flexures. Tabular to rounded nodules of chert several 10s to 100s mm long are common in this facies, in layers parallel to bedding.

The occurrence of argillaceous sediment and carbonate mud suggests that the wackestone was deposited in a low energy, poorly winnowed environment below normal wave base. The mottling of the sediment is interpreted as the result of burrowing, indicating deposition in well-oxygenated, open marine conditions. The highly broken up and rounded bioclasts suggests that they have been repeatedly reworked and winnowed, and were probably derived from higher energy conditions in shallow water where they were subjected to continual wave or tidal reworking. This facies is interpreted as a mixture of periplatform carbonate mud and finely comminuted bioclasts that were winnowed from the shallow water environments on the top of the carbonate platform. The sediment was transported off the platform by storm and tidal currents and deposited below wave base on the platform margin slope. The abrupt thickness changes of beds and the common flexures are interpreted to result from down-slope creep of the semi-lithified sediment. This suggests that deposition took place on a slope.

Thinly bedded bioclast packstone/grainstone: indicated as bioclastic storm beds on Figure 2. This occurs as beds up to 0.2 m thick, interbedded with the argillaceous wackestone described above. It consists of coarse abraded bioclasts including brachiopod shells and spines, crinoid ossicles and spines and foraminifera. Bioclasts that have been bored and micritised are common. Beds have erosional, loaded bases and are sometimes graded with transitional tops. Some of the thinner beds have irregular, undulatory and transitional tops and bases and some of these beds occur as horizons of irregular bioclastic lenses enclosed by the argillaceous wackestone.

The abraded, bored and micritised bioclasts suggests that they have a prolonged history of reworking and transportation that may have included long periods resting undisturbed on the seabed between periods of transport. The beds with erosional bases, grading and transitional tops suggest that they represent rapidly deposited influxes of bioclastic sediment. These bioclastic beds were probably generated by storm action over higher energy environments on the shallower part of the carbonate platform. The bioclasts were reworked and redeposited below normal wave base on the platform margin slope. Some of the thinner beds were mixed with the surrounding sediment by intensive burrowing.



Figures 3 and 4. Composite panoramic photograph showing an isolated crinoidal grainstone carbonate sand body; length of section is about 50 m. This is the exposed top of the now buried limestone pillar containing Burton's Lead Vein in the central part of Dale Quarry. The sketch shows the sedimentological interpretation of the internal structure and lateral relationships of the crinoidal grainstone carbonate sand body seen in the photograph.

Crinoidal grainstone: indicated as isolated carbonate sand bodies on Figure 2. This occurs as isolated lenses up to 5 m in thickness and 30-50 m long, surrounded by and overlapped by the argillaceous wackestone. It comprises moderate to poorly sorted coarse bioclastic grainstone with abraded crinoids, brachiopod valves and spines and foraminifera. Many bioclasts have been micritised and bored. One of these lenses is exposed at the top of the Burton's Lead Vein pillar (Figs. 5 and 6). The lower part of the exposure is made up of the thinly bedded argillaceous wackestone with layers of tabular chert nodules. The lens of crinoidal grainstone can be seen in the upper part of the face. The left end (northwest) of the face consists of large-scale cross stratification dipping to the southeast. The set is some 4-5 m thick and individual sets are 0.5-1.0 m thick. Some small-scale cross bedding is superimposed on the large foresets. The foresets can be traced to the right (southeast) end of the face where they become asymptotic bottom sets and are overlapped by the thin beds of the argillaceous wackestone.

This structure is interpreted as an isolated mega-ripple up to 5 m in thickness and at least 45 m long of bioclastic sediment that indicates sand transportation to the southeast. The size of these crinoidal grainstone structures suggests that they migrated only during high-energy events such as storms and were built up by repeated storm activity. However, the presence of superimposed small scale cross stratification suggests that those deposited above normal wave base were reworked. The dip direction of the cross-bedded in this and other crinoidal mega-ripples formerly exposed in Dale Quarry indicate a consistent off-shelf transport direction down to the south or southeast.

This predominance of off-shelf sediment transport into the basin may suggest the southern platform margin was in a leeward setting. However, transport directions in shelf margin carbonate sands of equivalent age from the northern margin of the Derbyshire carbonate platform are also predominantly off-shelf and into the Edale Basin to the north (Gawthorpe & Gutteridge, 1990; Gutteridge, 1991). This suggests that the predominant wind direction may not be the only factor in determining transport direction at a platform margin.

Soft sediment deformation structures

Figures 5 and 6 show a measured section of the main south face of Dale Quarry before it was infilled; the level of infill is now some 1-2 m below the top of the face. Two slip planes are indicated. Slip 1 represents an initial slope failure that forms the basal slide plane of a large-scale slump sheet made up of recumbent folds. This is interpreted as the up-dip part of a slip plane with structural rollover of the slumped beds on to the slip plane. The slump sheet was at least 50 m long, though its

original dimensions along depositional strike are not known. The convergence of folds in this slump sheet and the sense of structural rollover suggest that this slump moved down a slope dipping to the south or southeast. An upright fold at the western-most end of this section (Fig. 5) shows an apparent overturning to the northwest. Walkden (1970) regarded this as an anomalous structure because it apparently indicates a palaeoslope dipping to the northwest, as opposed to the general palaeoslope dip south of southeast interpreted from the regional facies analysis. However, this fold was associated with the initial slump that has had its upper limb cut off by a second slide plane (Slip 2).

Slip 2 could previously be followed for at least 100 m along the whole length of the quarry face to the southeast (Figs. 5 and 6). Apart from some structural rollover in the sediment overlying the slump plane, there are no slump folds associated with this second failure surface. However, its sense of movement and amount of displacement can be estimated because it intersects one of the crinoidal grainstone mega-ripples (Figs. 2 and 6). This shows it had a vertical displacement of at least 15-20 m and a lateral displacement of at least 40-50 m to the southeast. This syn-sedimentary deformation probably formed at a depth of several tens of metres in the sediment.

Another complex sequence of syn-depositional slumping is exposed (Fig. 7) at the lower entrance of Dale Quarry (Fig. 1). The lowermost slump plane on the right hand side of Figure 7 (southeast main face of Dale Quarry) is seen in strike view. The geometry of the structural rollover suggests that the sense of movement is into the quarry face. This slump plane can be traced round (to the left of Figure 7) into the lower entrance where it can be seen in dip section. This thrust plane has been folded and cut by a higher sub-horizontal slump plane that forms the 'sole' thrust of a set of imbricate structures, each bounded by smaller-scale oblique slump planes. This was later eroded, and a graded bed of very coarse brachiopod crinoidal grainstone buried and eroded the imbricate stack. A third thrust plane then over rode the eroded slump sheet. The sense of movement of these thrusts is towards the south and southeast. This slumping may have taken place at a shallow level (probably on the order of a few metres) in the sediment. Fractures and articulated brachiopods in this section contain traces of live oil.

Conclusion

Prior to infill, Dale Quarry provided an excellent section of the Brigantian Monsal Dale Limestones in the slope facies of the southern margin of the Derbyshire carbonate platform. Most of the platform margin slope comprises bioclast argillaceous wackestone that was deposited below wave base in low energy conditions. This represents fine-grained carbonate mud and finely divided

Figure 5. Section of the southwest face of Dale Quarry prior to infill showing two slump planes bracketing a slump sheet with recumbent folds. The position of the sedimentological log in Figure 2 is shown, and the location is marked on Figure 1.

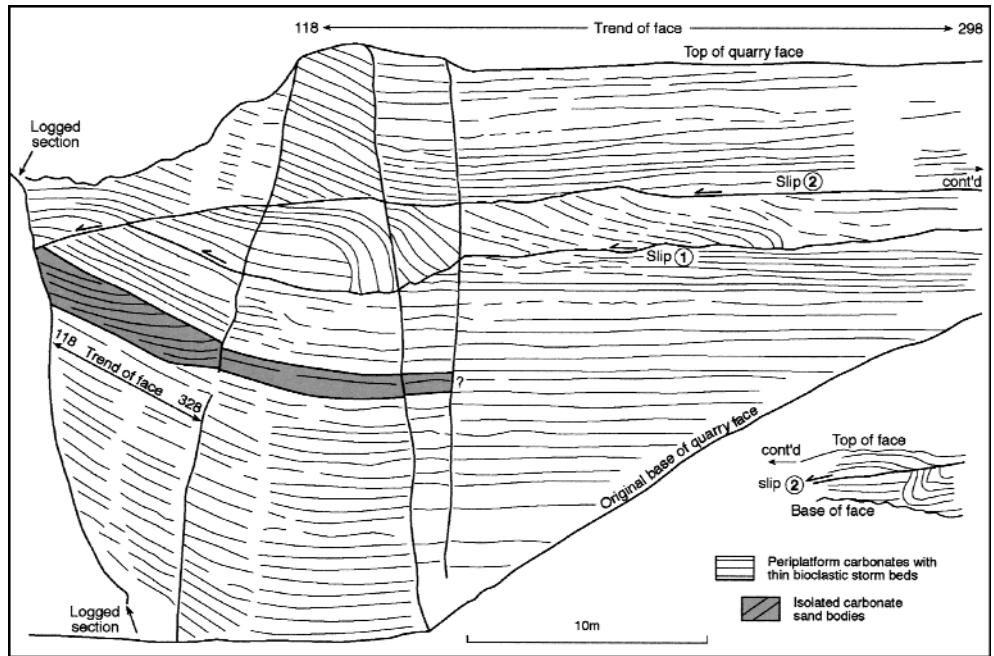


Figure 6. Section of the southwest face of Dale Quarry continued to the southeast of Figure 5. The inset shows the continuation of slip 2 that cuts an isolated crinoid grainstone carbonate sand body. The position of the sedimentological log in Figure 2 is shown, and the location is marked on Figure 1.

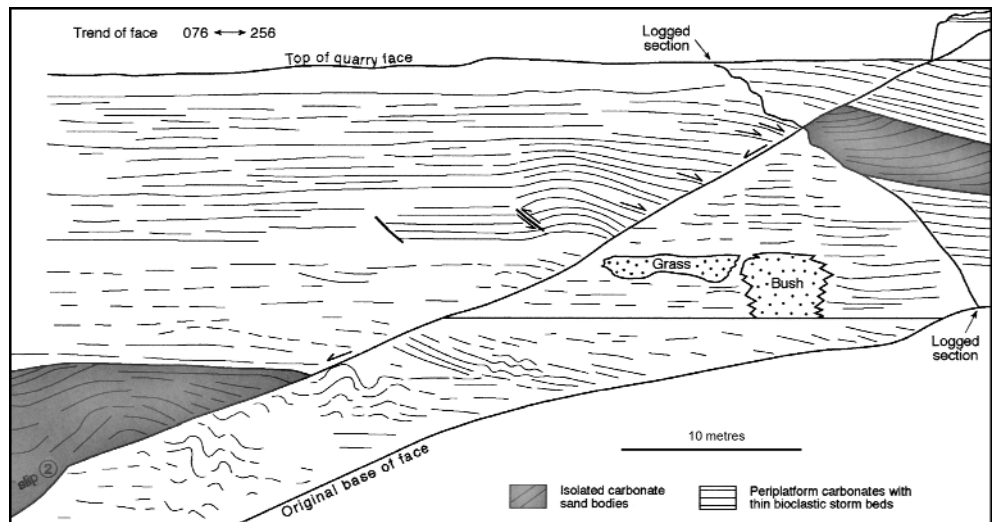
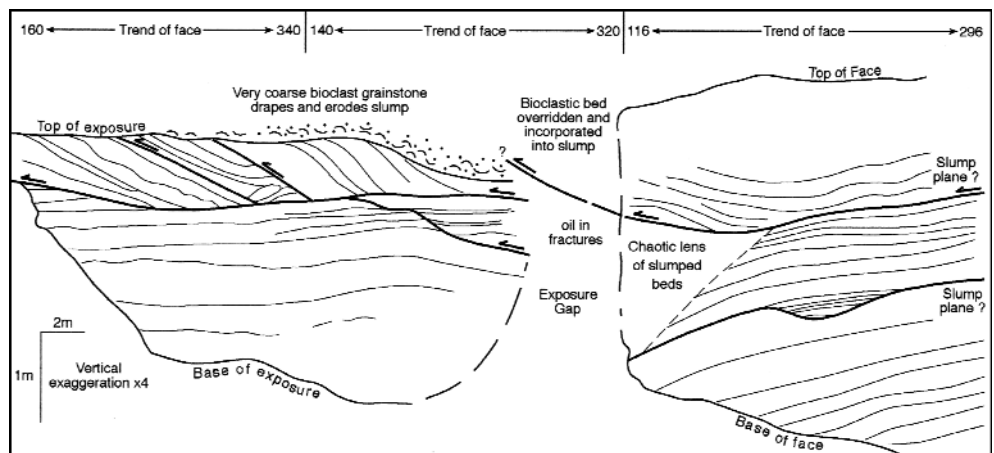


Figure 7. The complex sequence of syn-sedimentary slumping with the development of an imbricate thrust stack eroded by bioclastic bed. The section is exposed at the lower entrance of Dale Quarry; at the location shown on Figure 1.



bioclasts winnowed from shallow carbonate platform settings further up the depositional palaeoslope. The common small-scale, soft-sediment deformation features formed by a progressive down-slope creep of soft of semi-lithified sediment indicating rapid rates of deposition. Coarser bioclastic sediment was deposited on the slope during occasional storm events that caused reworking and deposition of bioclastic sediment derived from shallower water shelf environments. Isolated carbonate sand bodies formed during episodes of reworking and winnowing over the platform slope; this may have taken place during sea level low stands, when wave base over the slope would have been lowered. These bioclastic carbonate sand-bodies show a consistent off-shelf transport direction to the south or southeast. Large-scale syn-sedimentary deformation structures represent both compressional and extensional parts of slump sheets that formed at various levels within the sediment. All these structures indicate a palaeoslope dipping to the south or southeast.

Dale Quarry is in a critical location because the succession can be placed in its correct palaeogeographical and stratigraphical context and can be confidently correlated with platform-top carbonates exposed in Middle Peak Quarry and other disused quarries in the Wirksworth area. Dale Quarry previously provided an opportunity to examine sedimentary structures and large-scale slump structures in three dimensions developed in a carbonate platform margin setting unique in the British Dinantian. These disused quarries in the Wirksworth area represent an important teaching and research resource that need to be conserved. Dale Quarry is a geological SSSI and is described in a forthcoming Geological Conservation Review (Cossey et al, 2003). Any future re-development of the former Dale Quarry site should consider re-exposing these spectacular structures.

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