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Localities Explained Series

Sedimentary evolution of the Southern Pennine Basin, Carboniferous (Namurian), U.K.

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Many of the Carboniferous outcrops located in the Derbyshire region of the Peak District National Park, England, have provided sites for both significant and pioneering research relating to the clastic sedimentology of marine palaeoenvironments, particularly so during the 1960s and 1970s when early models describing the sedimentary architecture of fluvio-deltaic, submarine-slope and deep-marine submarine-fan sedimentation were first developed. The area was subject to hydrocarbon exploration from the 1920s to 1950s, which although unsuccessful in economic terms left a legacy of sub-surface data. Despite a long-history of sedimentological research, the deposits exposed at several classic localities in the Pennine Basin continue to broaden and challenge our current understanding of sedimentary processes to this day.

Introduction

This paper introduces a range of classic field localities of the Carboniferous Pennine Basin of Derbyshire (Fig. 1) that allow geologists to study a variety of depositional processes and environments within a shallowing-upward basin infill succession of an intra-continental rift basin, typical of many that developed in the Central Province of the UK during the Namurian of the Carboniferous. The succession of sedimentary strata exposed at these localities records an evolving history of deposition within a range of related depositional environments, including an older carbonate reef and shallow-water carbonate lagoon-platform system (Winnats Pass and Windy Knoll), a deep-water, distal, basin-floor submarine fan system (Mam Tor), a more proximal but still deep-water basin-floor and base-of-slope fan system with major channel deposits (Alport Castles), and a delta-front to delta-plain system with fluvio-deltaic deposits (e.g. Bamford Edge).

Basin Formation

The Southern Pennine Basin was one of many small intra-continental rift basins, collectively termed the Central Province, which evolved across what is now northern England during the Carboniferous. These basins formed in response to Devonian to Lower Carboniferous back-arc rifting associated with closure of the Rheic Ocean further to the south. Rifting established a so-called block-and-basin topography upon which carbonate sedimentary systems evolved in shallow-water areas atop the elevated footwall highs of fault blocks, whilst deep-water basinal mudstones accumulated in hangingwall depressions in the intervening basinal areas. Further water-depth increases arising from regional thermal subsidence at the onset of the Upper Carboniferous led to a shut-down in carbonate production and the development of a so-called “drowning unconformity”, whilst basinal mudstone deposition persisted in the basins for which water depths likely exceeded 500 m.

Provenance studies, including analysis of detrital mineral composition, indicate that the supply of clastic detritus to the Central Province was largely sourced from a metamorphic terrane that occupied a position in the Scottish Caledonides (Laurentia-Baltica), several hundred kilometres to the north. During the Kinderscoutian, more northerly sub-basins such as the Craven Basin of north Yorkshire had largely been infilled and sandy clastic supply spilled southward into the previously starved Southern Pennine Basin. This led to the onset of development of a major turbidite-fronted delta system of Lower Kinderscoutian age, whereby fluvial systems passed over deltaic plains, feeding sediment to a near-coast shelf edge and ultimately down a slope system into deeper-water parts of the basin where sandy submarine-fan systems progressively developed. In the Derbyshire region, this Kinderscoutian sedimentary system progressively evolved and filled the Pennine Basin to produce a shallowing-upward succession in excess of 600 metres thick (Fig. 2). The succession comprises five formal lithostratigraphic units, which in ascending stratigraphic order are: the Edale Shales (basin floor mud-prone deposits), Mam Tor Sandstones and Shale Grit (distal and relatively more proximal deep-water gravity current deposits that accumulated in a series of basin-floor submarine-fan lobes and base-of-slope fans and channels, respectively), the Grindslow Shales (sub-delta-slope mudstones with minor mouth-bar and sandy channel deposits), and the Lower Kinderscout Grit (fluvio-deltaic deposits of braided rivers that accumulated in a delta-plain setting).

(1) The Carbonate Reef: Winnats Pass (SK 129828)

Logistics: limited parking available at Speedwell Cavern car park (note charge). Directly adjacent to the car park is a small quarry (3 m-high cliff), uphill and on the right, which exposes the Beach Beds; continuation up through the impressive Winnats Pass provides a cross-section through Lower Carboniferous carbonate reef system.

Approximately 1.5 kilometres west of Castleton, is the striking feature of Winnats Pass, which is famous for the mining of Blue John, a type of blue-purple-yellow banded fluorite used principally in ornamental jewellery, that is found only in this part of Derbyshire (and at a locality in China!); Blue John is deposited as veins of crystals precipitated from hot fluids (hydrothermal mineralisation) onto the walls of fractures within the Lower Carboniferous limestone present here. Its unique banding and colour is thought to result from staining by hydrocarbon fluids.

The modern geomorphology around Castleton closely mimics the basin physiography present in the Carboniferous period, over 210 million years ago, when the Lower Kinderscout delta system was deposited (Fig. 3). The slopes and high ground to the south and west of Castleton consist of a Lower Carboniferous (Dinantian) carbonate system, which developed on a tectonically elevated horst-block (the so-called Derbyshire Massif); this topographically-elevated palaeogeographic feature formed the southern distal basin margin to the deep-water Southern Pennine Basin. The lower ground in the valley floor around Castleton consists of mudstone of the Edale Shale deposited in deep-water basinal areas adjacent to the carbonate system. The onlap contact of mudstone of the Edale Shale onto the early Carboniferous (Visean) carbonate system is well exposed in a stream-bed directly north of Winnats Pass, between Odin Mine and the abandoned road that once ran beneath the landslip of Mam Tor.

Winnats Pass itself provides a cross-section through the carbonate system passing from the back reef at the top of the pass (which is well exposed at the small disused quarry of Windy Knoll), into a reef-core complex in the central part of the pass, to outer fringing fore-reef facies that represent a lower-reef talus or apron facies at the bottom of the pass, close to Speedwell Cavern (Fig. 4). The reef-core complex consists mainly of crinoidal calcarenties with corals and brachiopods (coarse-grained fragments of shelly debris), whereas lower energy back reef settings represent the site of accumulation of finer-grained limestones with ooliths, calcareous algae and an overall higher micritic mud content. Both these facies accumulated on sub-horizontal surfaces by aggradation as long as relative sea-level rises permitted. The fringing fore-reef facies is characterised by coarse-grained, bioclastic limestone with an abundance of fossil fragments of varied type that were washed off the main reef to accumulate as deposits on the fore-reef slope, which was inclined at an angle of up to 27° (Fig . 4B). Depositional dips are recorded by geopetal structures: small cavities (e.g. within the central parts of shells) which were partly infilled with minerals and acted as palaeo-spirit-levels recording the palaeohorizontal at the time of deposition.

At the mouth of Winnats Pass (just 20 m west of Speedwell Cavern car park) is a small outcrop of coarse bioclastic limestone beds (Fig. 4C). Locally these are termed the “Beach Beds” and they comprise shelly debris composed chiefly of crinoids and a variety of shelly fauna indicative of a faunal community that lived in a shallow-water lagoonal setting in the back-reef. The Beach Beds form a fringing apron around the lower flanks of the fore-reef facies and are deposited in inclined packages that dip at a shallower angle than beds in the fore-reef. Three possible models are proposed for the formation of Winnats Pass and the Beach Beds: 1) an incised valley related to a large-magnitude relative sea-level fall whereby a lowstand shoreline was established in a position around the base of Winnats Pass; 2) a post-Carboniferous erosional feature; 3) a former submarine canyon which lay between reef bodies that fringed the rimmed shelf, down which storms washed limestone detritus including the debris of shelly fauna from the reef crest and back-reef. The latter is the most popular model, and thus the Beach Beds are perhaps inappropriately named.

(2) The basin-floor submarine-fan succession: Mam Tor (SK 130835)

Logistics: limited parking available just past Blue John Cavern car park. Pass through the east gate at the turning circle at the end of the made road and follow a path off to the left (northwest) towards the main face of the landslip (~200 m total).

Two kilometres northwest of Castleton is the peak of Mam Tor (Fig. 5). Locally known as the “Shivering Mountain”, this well-known landslip feature owes its inherent instability to an interbedded succession of sandstones and relatively less permeable mudstones, which crop-out on an over-steepened slope that was influenced by freeze-thaw processes during the period of transition from the end of the last glacial episode to the present interglacial. The main landslip is over 4000 years old, around 1000 metres in length and continues to move up to 1 metre per year today. Repeated repairs to the now closed A625 main road have resulted in a “stratigraphy” of multiple layers of tarmac, deformation of which records the progressive movement of the landslip in recent decades, with evidence for gradual back-rotation of the old road preserved.

Namurian Edale Shale deposits (black mudstone beds) crop out in the hummocky ground to the bottom left of the main Mam Tor land scar and these comprise fissile, laminated, organic-rich and pyritic mudrocks with rare, orange-coloured ironstone horizons and concretions. These mudrocks represent hemi-pelagic and pelagic deep-water mudstone accumulation in a low-energy basin-floor setting prior to the onset of supply of coarser-grained sediment from the north into the Southern Pennine Basin. Limited oxygen supply in these deep-water settings resulted in enhanced preservation of organic matter in these mudstones, which elsewhere form prolific source-rocks for hydrocarbons in North Sea. Goniatites can be found, along with bivalves, within better-cemented fossiliferous horizons and these rapidly-evolving organisms serve as the basis for a biostratigraphic framework that aids in dating and correlation between basins of the Central Province in the Pennines and beyond.

Outcropping in the main cliff face are interbedded deep-water mudstones and gravity-current sandstones of the Mam Tor Sandstones. These deposits overlie the Edale Shale and mark the arrival of sediment supplied from the Lower Kinderscoutian delta system into the deep-water part of the Southern Pennine Basin (Fig. 2). Sediment was transported and deposited by sedimentary gravity currents: sediment-water mixtures that travel due to gravity acting on the density contrast between the mixture and ambient basinal fluid. Gravity currents travelled down the basin slope to the basin floor where they punctuated periods of background mudstone deposition and accumulated fan-lobe systems. Vertically through the 120 m-thick succession, sandstone beds show an overall increase in bed thickness and grain size, likely recording overall progradation of the submarine-fan system. On closer inspection smaller-scale cycles defined by upward increases in sand bed thickness can be seen on a scale of 5 to 10 m, and these may have been driven by smaller changes in sea-level (eustasy) or local sediment supply (e.g. episodic avulsion of sediment feeder channels), either of which could have influenced the frequency of generation and size of sediment-laden flows reaching the basin floor.

Gravity-current deposits are composed of assemblages of sedimentary structures that provide insight into processes of sediment transport and deposition. Sole structures present on the underside of sandstone beds are formed either by objects carried within the flow interacting with the muddy sea-bed (e.g. grooves and prods that form tool marks) or by the action of fluid turbulence upon the muddy sea-bed (e.g. flutes) (Fig. 6). These features are useful indicators of either the orientation (e.g. grooves) or direction (e.g. flutes or prods) of gravity-current transport (palaeoflow). Sedimentary structures that indicate palaeoflow demonstrate that gravity currents entered the Southern Pennine Basin from the north, travelled approximately southwards before being deflected by the higher-relief carbonate system at the distal southern margin of the basin (e.g. localities such as Mam Tor) (Fig. 1). Bulbous and irregular depressions called load structures can also be found on the underside of sandstones beds. Loads form most readily when sand beds are deposited above mud layers resulting in a density inversion with the denser sand sinking into an underlying muddy substrate. In response mud is often displaced upwards into tapering structures called flames. An abundance of non-marine plant material (e.g. *Calamites*) within sandstone beds records the incorporation of organic material of non-marine origin (likely derived from the delta plain) into gravity currents, prior to their transport down into deep-water parts the basin; thus, the occurrence of plant debris is not necessarily itself indicative of a non-marine depositional environment.

This classic outcrop is known to many geologists as an example of distal “Bouma-like” turbidite beds, a type of gravity current deposit in which there is an idealised vertical suite of sedimentary structures that occur in a predictable ascending order: massive (structureless) sandstone (Ta); parallel-laminated sandstone (Tb); cross-laminated sandstones (Tc); parallel-laminated siltstone (Td); and hemi-pelagic mudstone (Te). Locally, these deposits were first described by Allen (1960) who linked them to an origin further upslope within the basin. Turbidites are considered to be deposited from a turbulent waning flow that became progressively more dilute in sediment concentration distally as the flow ran across the basin floor (Fig. 7). However, recent research has begun to recognise different styles of gravity-current development. Flows may also undergo significant segregation of low settling velocity material (e.g. elongate clasts and finer-grained clay) towards the rear of the flow, making the rear-ward part behave more like a laminar debris flow compared to the turbulent flow head (Fig. 7). Such behaviour is called hybrid flow and produces distinct deposits (hybrid beds), which contain a linked-debrite component (mudclast- and clay-rich sandstone) and turbiditic component (relatively clay-poor sandstone), both deposited during a single flow event (Fig. 8). The Mam Tor Sandstones at Mam Tor are dominated by hybrid event beds, whereas classical distal turbidites are relatively subordinate.

(3) The proximal basin floor to base of slope submarine fan succession: Alport Castles (SK 141915)

Logistics: limited parking available on south side of A57 by Alport Bridge. Take the footpath north to Alport Farm; follow the path across the stream, and head uphill before contouring left to 'The Tower' (~2 km total). Care should be taken on uneven ground to avoid deep crevasses present below the outcrop.

Alport Castles is another rotational landslide and is one of the largest in the UK. It is located northwest of Ladybower Reservoir and north of the Snake Pass (A57) road on the eastern flank of the Alport River valley. The back scarp (400 m long and 55 m high) provides excellent exposure of the Shale Grit Formation and lowermost Grindslow Shale (Fig. 2).

In a style similar to that at Mam Tor, the succession here comprises interbedded mudstone and gravity-current-deposited sandstone beds. However there are a number of contrasts between these outcrops. Geometrically, sand bodies at Alport Castles are either sheet-like or channelized and lenticular with erosive bases that can be stepped with up to 1 metre of basal-relief (Fig. 9B). Lenticular sand bodies are often infilled with thick, massive (i.e. structureless) sandstone beds that can be stacked into packages that are themselves up to 10 metres thick. Amalgamation of sand beds resulted from flows that were highly erosive or occurred in relatively rapid succession; thus, in such cases the intervening mudstone on the sea floor was thin and easily eroded, allowing sand to be deposited directly onto underlying sand beds. Amalgamation can be recognised where there are sudden grain size changes or where thin mudstone beds are truncated laterally within sandstone packages (Fig. 9C).

Clusters of angular mudstone clasts supported in a coarse clean sandy matrix can often be found along the base of incision surfaces, typical at the base of lenticular sand bodies, and these are termed mud-clast breccias (Fig. 9D-E). These deposits represent localized sea-floor erosion and bypassing of finer-grained material further downstream to distal fan settings. Lenticular sand bodies record the cutting and infilling of distributary channels on the proximal basin-floor fan by gravity currents. Such breccias are common in the prominent lower channel sand body (Fig. 9A, base denoted by red arrows) in which sandstone beds show an overall decrease in thickness upwards, replaced by mudstone beds of increasing thickness. This trend may reflect earlier high-energy incision by gravity currents that gave way to weaker and less frequent gravity currents during channel infilling.

Hybrid beds, like those found at Mam Tor, are rare in the Shale Grit Formation. Instead, gravity-current sandstone deposits more closely resemble those of conventional turbidites with examples of high-density turbidites (dominated by structureless sandstones) and low-density “Bouma-like” turbidites, many characterized by large amplitude, sinuous-crested, current-ripple laminated sandstones indicative of deposition under a unidirectional waning current (Fig. 9C). Flutes, grooves, load and flame structures are very common and collectively indicate a dominant palaeocurrent towards the south (Fig. 1). Thus, channel sandstone packages here are typically considered to be contemporaneous to basin-floor fan sandstones with a similar composition located 5 km further southward into the basin at Mam Tor (Fig. 11).

(4) The delta plain succession: Bamford Edge (SK 210847)

Logistics: limited parking available along the minor road that runs below the edge. Park by a gate and stile at SK215839; follow the track across the moor towards the edge. Note that this locality is on Open Access Land but no other approach to the one described here should be used. IMPORTANT: no hammering and no sample collection at this locality.

Bamford Edge exposes the Kinderscout Grit that lies stratigraphically above the Shale Grit and the Grindslow Shales (Fig. 2). This succession is characterised by coarse-grained “gritstone” facies, with large-scale sets of cross-bedding. The deposits of the Kinderscout Grit represent one of several deltaic systems that prograded from north to south across the area. The edge of the delta fed the slope systems of the Shale Grit and the Grindslow Shales, and they in turn fed the Mam Tor Sandstones, the unit that accumulated as a submarine fan on the floor of the Southern Pennine Basin. Large-scale cross-bedded sets in the Kinderscout Grit at Bamford Edge are each up to 4 m in thickness (Fig. 10) and record the migration of large barforms present in braided channels in a delta-plain setting. The dip-direction of inclined foresets present in the cross-bedded deposits record an overall southerly migration direction, implying the presence of rivers that flowed to a delta edge that lay to the south. The deposits at Bamford Edge record a relatively late stage of filling of the Southern Pennine Basin; their proximity to the southern basin margin near Castleton implies that the basin had largely been filled by the time that the delta had prograded southwards to this position. Similar deltaic facies to this occur in the Kinderscout Grit further north and it is these that were likely contemporaneous with the slope system at Alport Castles and the basin-floor fan at Mam Tor (Fig. 11); thus, the fluvio-deltaic systems represented by the Kinderscout Grit served to feed sediment southwards into the basin.

Depositional model

Study of these outcrops allows construction of a 3D depositional model that places the described localities and their depositional environments in the context of the Southern Pennine Basin (Fig. 11). Figure 11A depicts a simplistic model, based on Walker's (1960) pioneering model, in which depositional environments are portrayed as coeval (active at the same time). However, the model can be refined using sequence stratigraphic concepts that account for the influence of changes in relative sea level upon the timing and location of deposition within the basin. During episodes of relative sea-level fall, delta-plain areas in shallow-shelf settings tend to be bypassed and sediment is instead delivered into deeper-water parts of basins via submarine feeder channels cut by erosional flows and located across slope systems. Sediment bypassed through these slope channels was delivered deeper into the basin to form submarine-fan systems (e.g. Mam Tor) (Fig 11A, time 1). Later, when relative sea-level stabilized or began to rise again, submarine channels that were previously erosional became sites of active deposition and began to infill, thereby trapping increasing volumes of sand further upstream in slope-channel complexes (e.g. Alport Castles channel sandstones) and leaving the distal submarine-fan systems deeper in the basin relatively sediment starved (Fig 11B, time 2).

Summary

The outcrops in the Southern Pennine Basin allow study of a range of sedimentary depositional processes and environments. Limitations in the ability to correlate between relatively small, isolated outcrops leaves the succession open to alternative interpretations and various basin depositional models have been proposed: one is relatively simplistic; another is more complex and invokes controls such as relative sea-level change as a mechanism to account for the location and timing of deposition within the basin. These localities occur within a relatively small area of the Derbyshire

Peak District, are easily accessible and are served by a variety of excellent local tea-shops!

Suggestions for further reading

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FIGURE CAPTIONS

Figure 1. Location map of key outcrops within the Southern Pennine Basin. Inset: simplified geological map with palaeocurrent data collected from the Mam Tor Sandstones and Shale Grit Formation demonstrating deflection of

sedimentary gravity currents at the basin margin. Mapped colours correspond to those on Figure 2.

Figure 2. Stratigraphy of the Carboniferous succession in the Southern Pennine Basin.

Figure 3. Modern physiography around Winnats Pass and Mam Tor reflects that present during the Kinderscoutian. A carbonate reef system forms the high ground (centre and left), whereas onlapping silliciclastic successions infill what was the deeper-water part of the basin in the valley floor (Edale Shales) and on higher ground at Mam Tor (Mam Tor Sandstones; right).

Figure 4. (A) Outcrops of limestone near the bottom of Winnats Pass; (B) fore-reef coarse bioclastic crinoidal limestone; (C) shallower-dipping Beach Beds close to the car park of Speedwell Cavern.

Figure 5. Basin floor interbedded mudstone and gravity-current sandstone beds of the Mam Tor Sandstones outcropping at the Mam Tor landslip. Outcrop approximately ~500m wide.

Figure 6. (A) Flute mark; (B) prod mark; (C) multiple groove marks; (D) model for the development of scour marks by the action of fluid scour on the substrate and origin of tool marks generated by the differing interaction between tools carried within the flow and the substrate; the mechanism of preservation of these sole structures as casts on the undersides of sandstone beds is indicated.

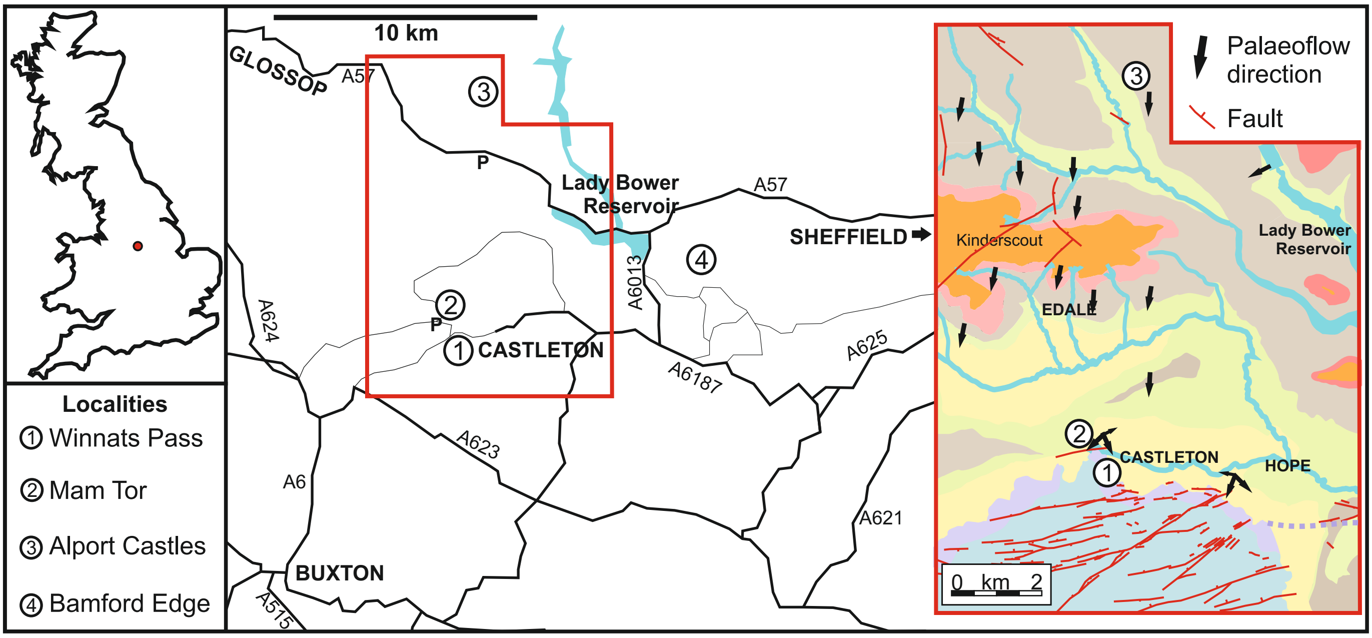
Figure 7. Contrasting gravity currents and their resultant deposits. Turbidity currents typically reduce in sediment concentration as they travel distally and produce a “Bouma-like” deposit. Hybrid flows undergo strong segregation of clay and low-settling-velocity material towards the rear of the flow to produce distinct deposits known as hybrid event beds.

Figure 8. Example of a hybrid event bed deposit from Mam Tor in which there is a lower weakly structured clay poor sandstone (1) directly overlain by a mudclast- and clay-rich sandstone (2) within the same sand bed.

Figure 9. (A) Sheet and lenticular channel-like sand bodies of the Shale Grit Formation, Alport Castles; (B & C) mud-clast-rich, coarse-grained, clean sandstone above an erosional scour surface records gravity-current bypass and winnowing; (D) stepped margins on the base of incisional channel sandstone bodies; (E) current-ripple laminated turbidites; (F) erosionally-generated sandstone-bed amalgamation and truncation of intervening mudstone deposits.

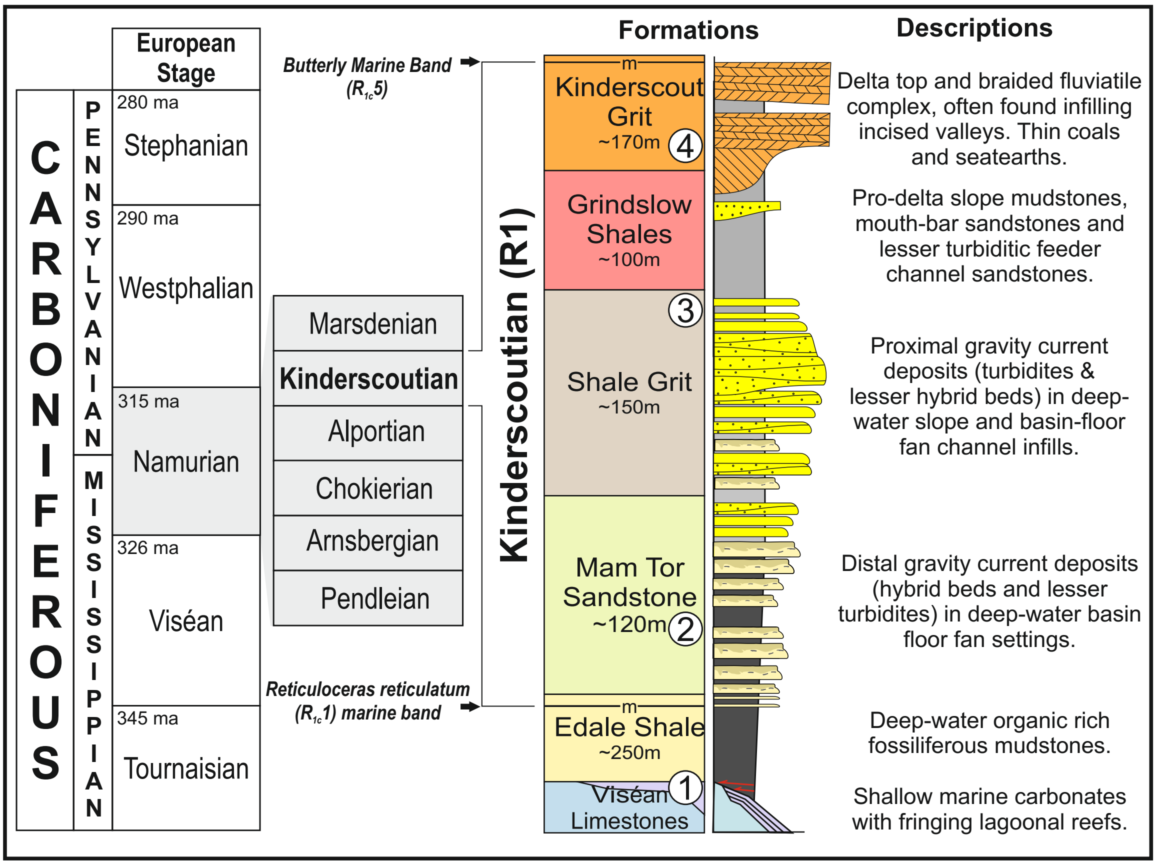
Figure 10. Large-scale planar-tabular cross-bedded sets of very-coarse-grained sandstone and granulestone at Bamford Edge. Such deposits record the migration of large barforms within a braided fluvial channel network on an extensive delta plain.

Figure 11. (A) Block diagram illustrating the main depositional environments and the relative location of the described localities; (B) model to account for how sand can be deposited at different positions during different states of relative sea level.



Localities
1 Winnats Pass
2 Mam Tor
3 Alport Castles
4 Bamford Edge
10 km
GLOSSOP
A57
Lady Bower Reservoir
SHEFFIELD
CASTLETON
BUXTON
A624
A6
A6013
A6187
A625
A623
A621
A515
Palaeoflow direction
Fault
Kinderscout
EDALE
CASTLETON
HOPE
Lady Bower Reservoir
0 km 2

Figure 1.



European Stage
CARBONIFEROUS
PENNSYLVANIAN
MISSISSIPPIAN
280 ma
Stephanian
290 ma
Westphalian
315 ma
Namurian
326 ma
Viséan
345 ma
Tournaisian
Butterly Marine Band
(R1c5)
Marsdenian
Kinderscoutian
Alportian
Chokierian
Arnsbergian
Pendleian
Reticuloceras reticulatum
(R1c1) marine band
Kinderscoutian (R1)
Formations
Kinderscout Grit
~170m
4
Grindslow Shales
~100m
3
Shale Grit
~150m
Mam Tor Sandstone
~120m
2
Edale Shale
~250m
1
Viséan Limestones
Descriptions
Delta top and braided fluviatile complex, often found infilling incised valleys. Thin coals and seatearths.
Pro-delta slope mudstones, mouth-bar sandstones and lesser turbiditic feeder channel sandstones.
Proximal gravity current deposits (turbidites & lesser hybrid beds) in deep-water slope and basin-floor fan channel infills.
Distal gravity current deposits (hybrid beds and lesser turbidites) in deep-water basin floor fan settings.
Deep-water organic rich fossiliferous mudstones.
Shallow marine carbonates with fringing lagoonal reefs.

Figure 2.

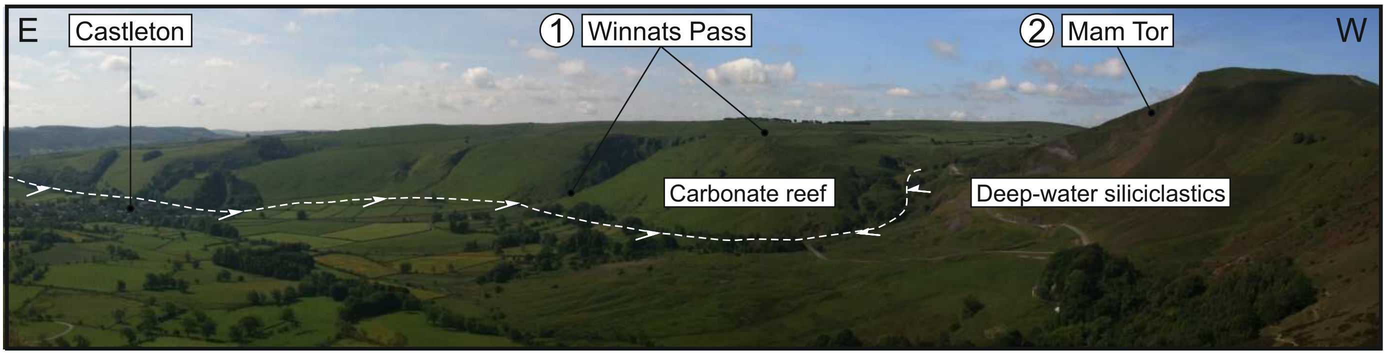

E
Castleton
1
Winnats Pass
2
Mam Tor
W
Carbonate reef
Deep-water siliciclastics

Figure 3.

Figure 4.

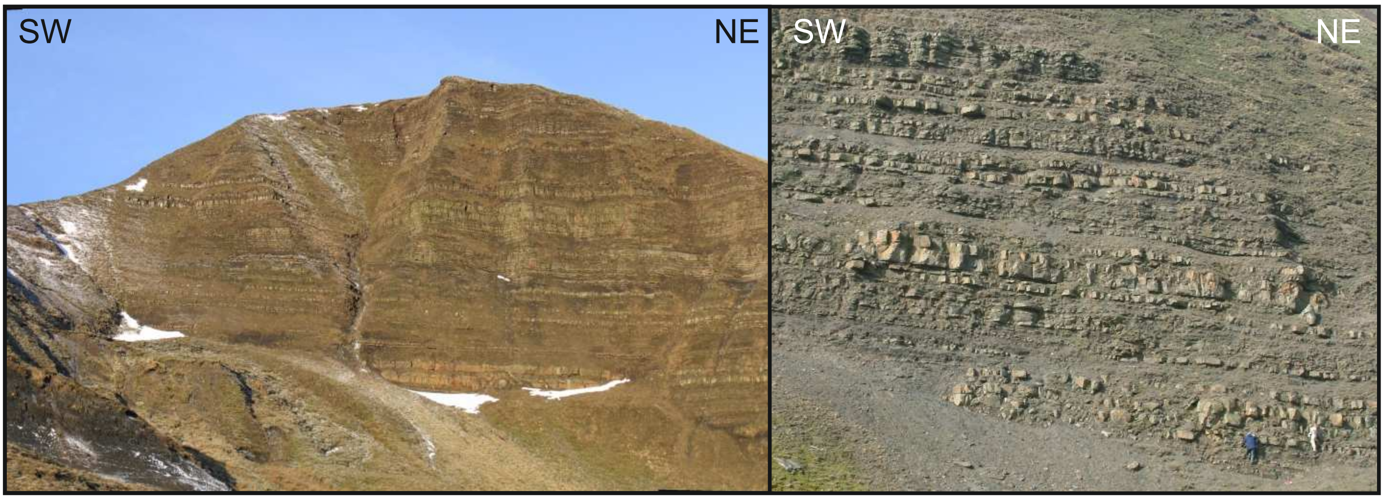


Figure 5.

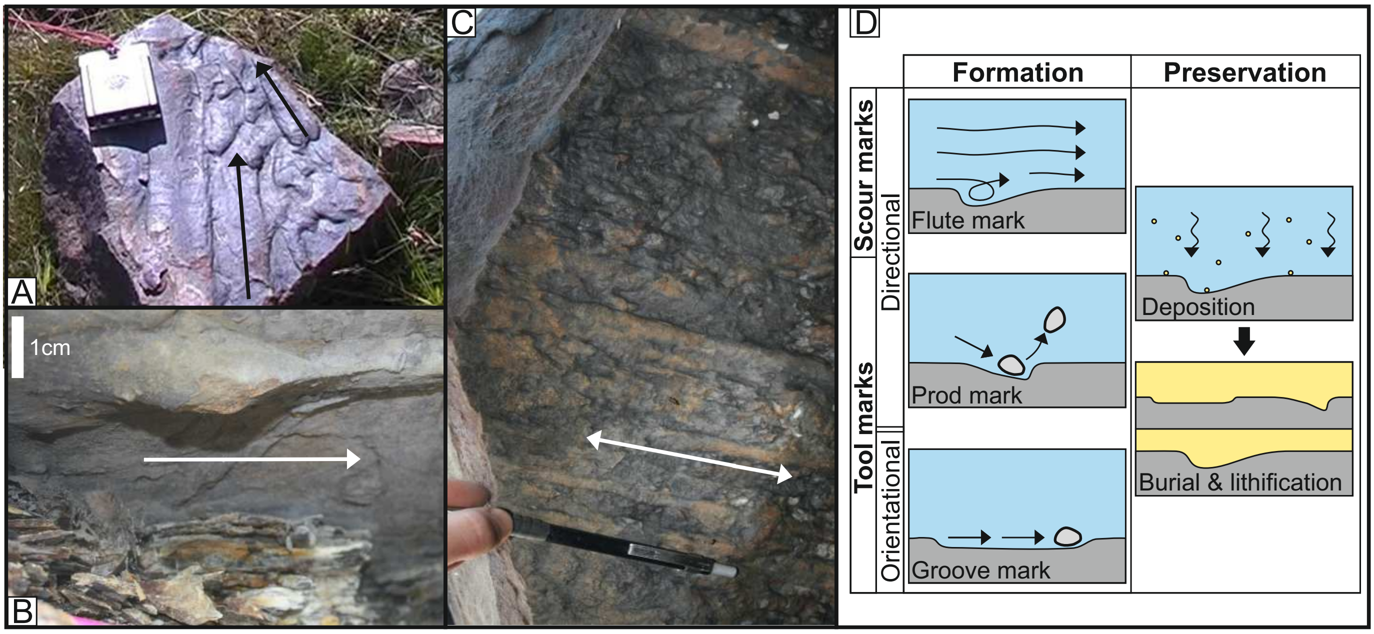

A
B
1cm
C
D
Formation
Preservation
Scour marks
Tool marks
Directional
Orientational
Flute mark
Prod mark
Groove mark
Deposition
Burial & lithification

Figure 6.

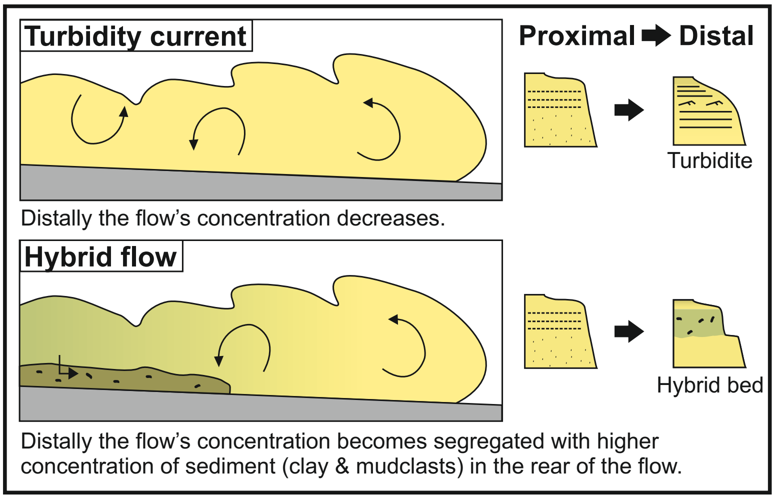

Turbidity current
Proximal
Distal
Turbidite
Distally the flow's concentration decreases.
Hybrid flow
Hybrid bed
Distally the flow's concentration becomes segregated with higher concentration of sediment (clay & mudclasts) in the rear of the flow.

Figure 7.

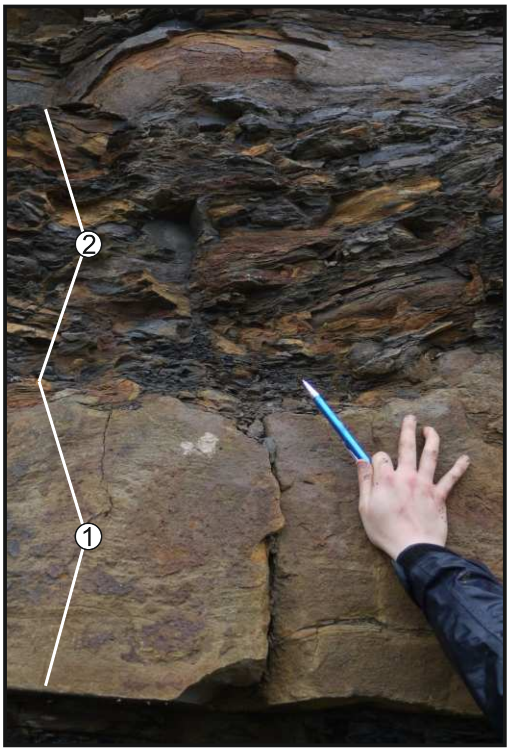


Figure 8.

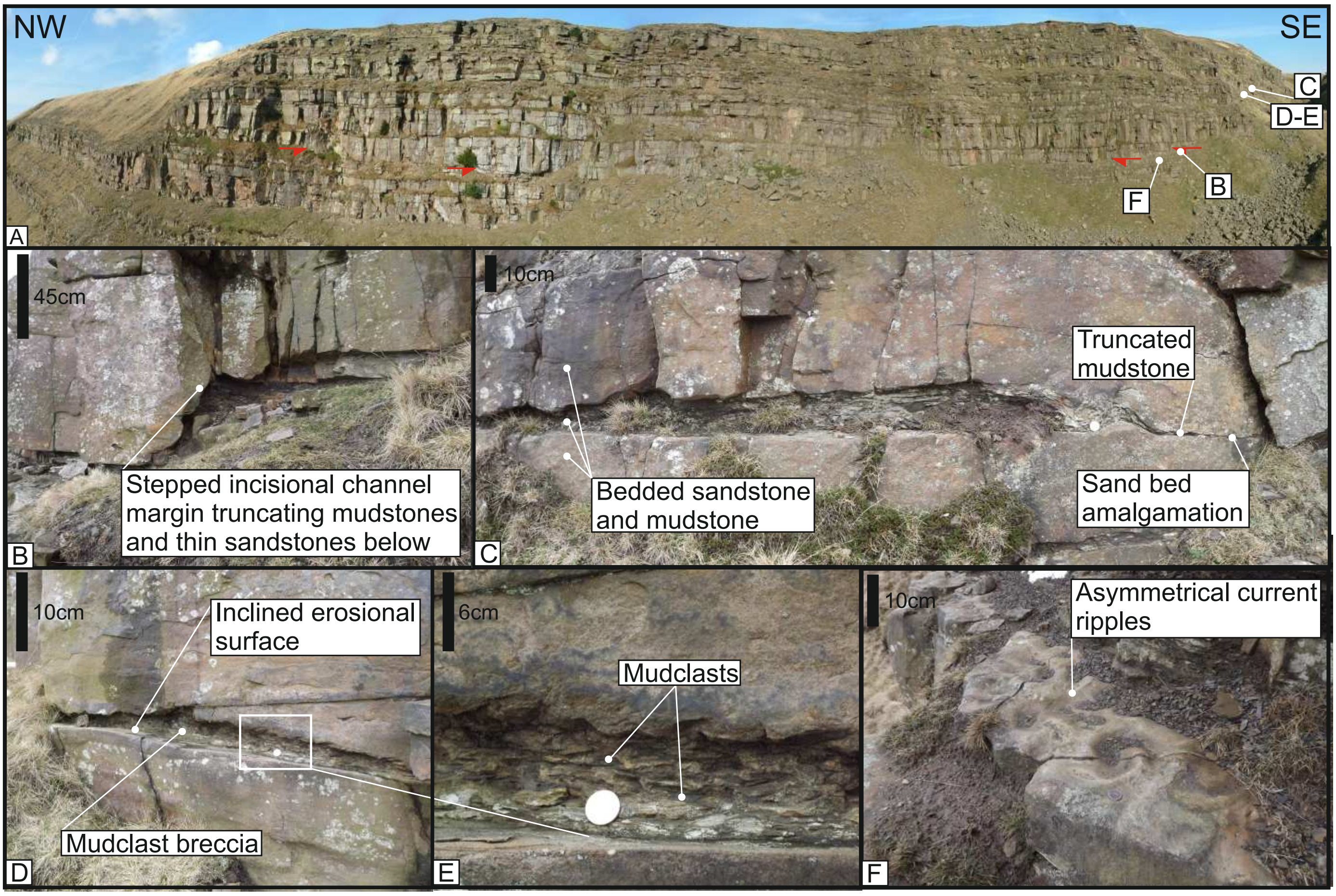

NW
SE
C
D-E
B
F
A
45cm
Stepped incisional channel margin truncating mudstones and thin sandstones below
B
10cm
Truncated mudstone
Bedded sandstone and mudstone
Sand bed amalgamation
C
10cm
Inclined erosional surface
Mudclast breccia
D
6cm
Mudclasts
E
10cm
Asymmetrical current ripples
F

Figure 9.

Figure 10.

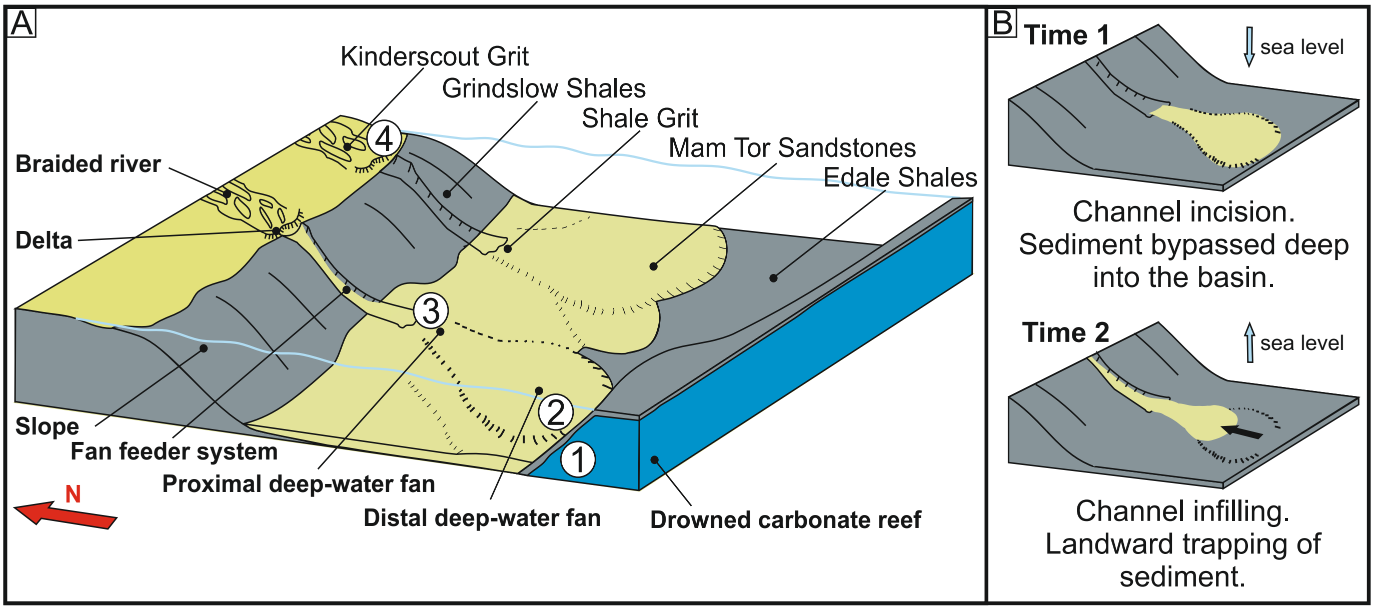

A
Kinderscout Grit
Grindslow Shales
Shale Grit
Mam Tor Sandstones
Edale Shales
Braided river
Delta
4
3
2
1
Slope
Fan feeder system
Proximal deep-water fan
Distal deep-water fan
Drowned carbonate reef
N
B
Time 1
sea level
Channel incision.
Sediment bypassed deep into the basin.
Time 2
sea level
Channel infilling.
Landward trapping of sediment.

Figure 11.