PS Reconstruction of Channel and Barform Architecture in a Pennsylvanian Fluvio-Deltaic Succession: Brimham Grit, Northern England*

Roman Soltan[1], Nigel P. Mountney[1], William D. McCaffrey[1], and Douglas A. Paton[1]

Search and Discovery Article #50884 (2013)**
Posted October 31, 2013

*Adapted from poster presentation given at AAPG 2013 Annual Convention and Exhibition, Pittsburgh, Pennsylvania, May 19-22, 2013

[1]Fluvial Research Group, School of Earth and Environment, University of Leeds, Leeds, United Kingdom (romansoltan@btinternet.com)

Abstract

Pebbly fluvio-deltaic sandstones of the Brimham Grit (Kinderscoutian, northern England) form a complex array of Millstone Grit tor outcrops, which enable 3-D lithofacies architecture to be determined in detail whereby relationships between adjacent sand-bodies representing a range of channel, barform, dune and sheet-like elements can be used to reconstruct the flow behavior of a braided channel network.

Although the depositional paleoenvironment was supplied with sediment delivered from a range of provenances, the dominant supply was from eroded remnants of Scottish and Norwegian Caledonian Mountains located ~450 and ~950 km towards the north and northeast, respectively. Previous studies suggest that the system evolved from a shelf-edge- to slope-ramp delta, which ultimately delivered sediment to a series of submarine fans developing in the deep-water depocenter of the Craven Basin.

A detailed depositional model depicting the fluvial processes responsible for generating the preserved stratigraphic architecture has been developed through high-resolution architectural analysis utilizing 1D sedimentary logs, 2-D architectural panels, pseudo-3-D fence diagrams and paleocurrent rose diagrams. Sedimentary lithofacies include trough- and planar cross-bedded sets, compound co-sets of cross-strata, planar-bedded sandstones and gravel beds, collectively organized to define a variety of architectural elements including single-story, multilateral- and multi-story channel elements, downstream- and laterally-accreting macroforms. Architectural elements are typified internally by distinctive lithofacies arrangements with highly variable paleocurrent distributions that are indicative of barforms that systematically changed from lateral to downstream accretion, with accumulation occurring in a poorly-confined network of fluvial channels allied with major sandy barforms, indicative of a frequently avulsing braided fluvial system in an upper-delta plain setting. The presence of plant fossils (e.g. calamites stem remnants) implies local swamp-like conditions adjacent to active channel belts and a degree of channel-bank stability.

Data from this study are contributing to a broader research program investigating the linkage of fluvio-deltaic successions from shelf-edge deltas to slope and submarine-fan successions, with a focus on the influence of basin morphology on sediment delivery mechanisms in the Craven, South Pennine and North Staffordshire Basins of the UK.

Reconstruction of channel and barform architecture in a Pennsylvanian fluvio-deltaic succession: Brimham Grit, northern England

Roman Soltan, Nigel P. Mountney, William D. McCaffrey and Douglas A. Paton — Fluvial Research Group, School of Earth and Environment, University of Leeds, Leeds, LS2 9JT, UK

FRG — UNIVERSITY OF LEEDS

Abstract

Pebbly fluvio-deltaic sandstones of the Brimham Grit (Kinderscoutian, northern England) form a complex array of Millstone Grit tor outcrops, which enable 3D lithofacies architecture to be determined in detail whereby relationships between adjacent sand-bodies representing a range of channel, barform, dune and sheet-like elements can be used to reconstruct the flow behavior of a braided channel network.

Although the depositional paleoenvironment was supplied with sediment delivered from a range of provenances, the dominant supply was from eroded remnants of Scottish and Norwegian Caledonian Mountains located ~450 and ~950 km towards the north and northeast, respectively. Previous studies suggest that the system evolved from a shelf-edge- to slope-ramp delta, which ultimately delivered sediment to a series of submarine fans developing in the deep-water depocenter of the Craven Basin.

A detailed depositional model depicting the fluvial processes responsible for generating the preserved stratigraphic architecture has been developed through high-resolution architectural analysis utilizing 1D sedimentary logs, 2D architectural panels, pseudo-3D fence diagrams and palaeocurrent rose diagrams. Sedimentary lithofacies include trough- and planar cross-bedded sets, compound co-sets of cross-strata, planar-bedded sandstones and gravel beds, collectively organised to define a variety of architectural elements including single-storey, multilateral- and multi-storey channel elements, downstream- and laterally-accreting macroforms.

Architectural elements are typified internally by distinctive lithofacies arrangements with highly variable palaeocurrent distributions that are indicative of barforms that systematically changed from lateral to downstream accretion, with accumulation occurring in a poorly-confined network of fluvial channels allied with major sandy barforms, indicative of a frequently avulsing braided fluvial system in an upper-delta plain setting. The presence of plant fossils (e.g. *calamites* stem remnants) implies local swamp-like conditions adjacent to active channel belts and a degree of channel-bank stability.

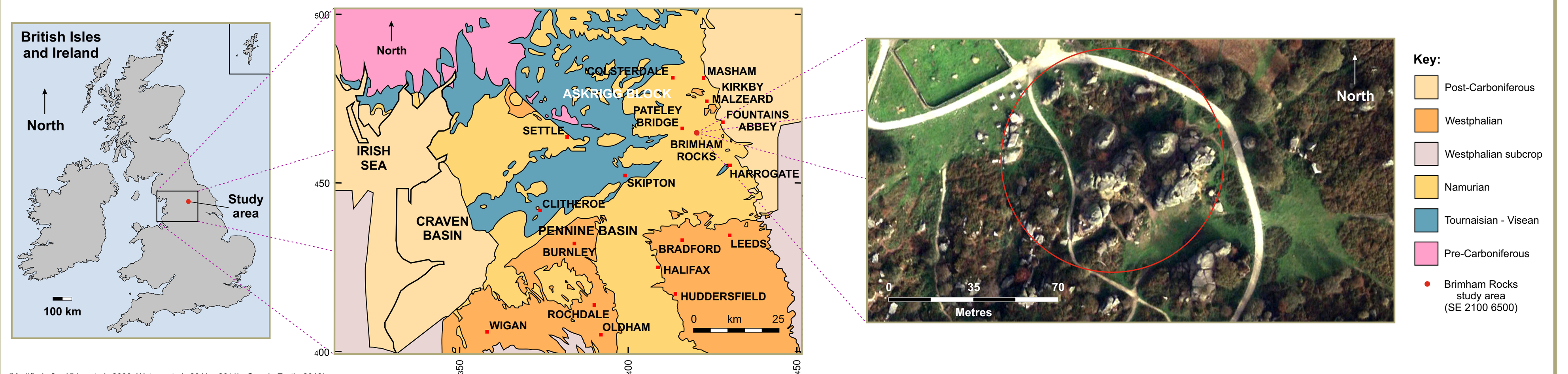
Data from this study are contributing to a broader research programme investigating the linkage of fluvio-deltaic successions from shelf-edge deltas to slope and submarine-fan successions, with a focus on the influence of basin morphology on sediment delivery mechanisms in the Craven, South Pennine and North Staffordshire Basins of the UK.

Location - Brimham Rocks

- Situated to the north of the village of Summerbridge, North Yorkshire, UK
- Encompasses an elevated position of 295 m O.D.
- Underlying geology forms part of the Kinderscout Group (Carboniferous Millstone Grit series)[1]
- Bashkirian Stage (Namurian Regional Stage) - pebbly quartzo-feldspathic (subarkose) sandstone
- Millstone Grit series encompasses conglomerates, grits, sandstones, shales with rare thin impure limestones and beds of chert
- Inferring a relatively diverse sequence of depositional palaeo-environments
- Unique style of outcrop within the Pennine region
- No contemporary publications that attempt to interpret the:
  - Exceptional style of the three-dimensional exposures
  - Underlying geology of the area.

Brimham Rocks location map and geological map depicting dispersal of Carboniferous strata within the Central Pennine Basin of northern England

- Main map inset shows Brimham Rocks centred on grid reference SE2100 6500
- Encompassing ~0.2 km² of National Trust moorland - Site of Special Scientific Interest (SSSI)
- Expanded map view highlights geology associated with the study and adjacent areas
- Google Earth aerial image depicts the typical nature of the "tor-like" outcrops (Red circle)
- Located centrally within the main outcrops associated with the Brimham Grit
- Image provides an indication of the sites fragmented nature
- Note the three-dimensional form of the outcrop pattern, which lends itself to high-resolution analysis of the sedimentary architecture

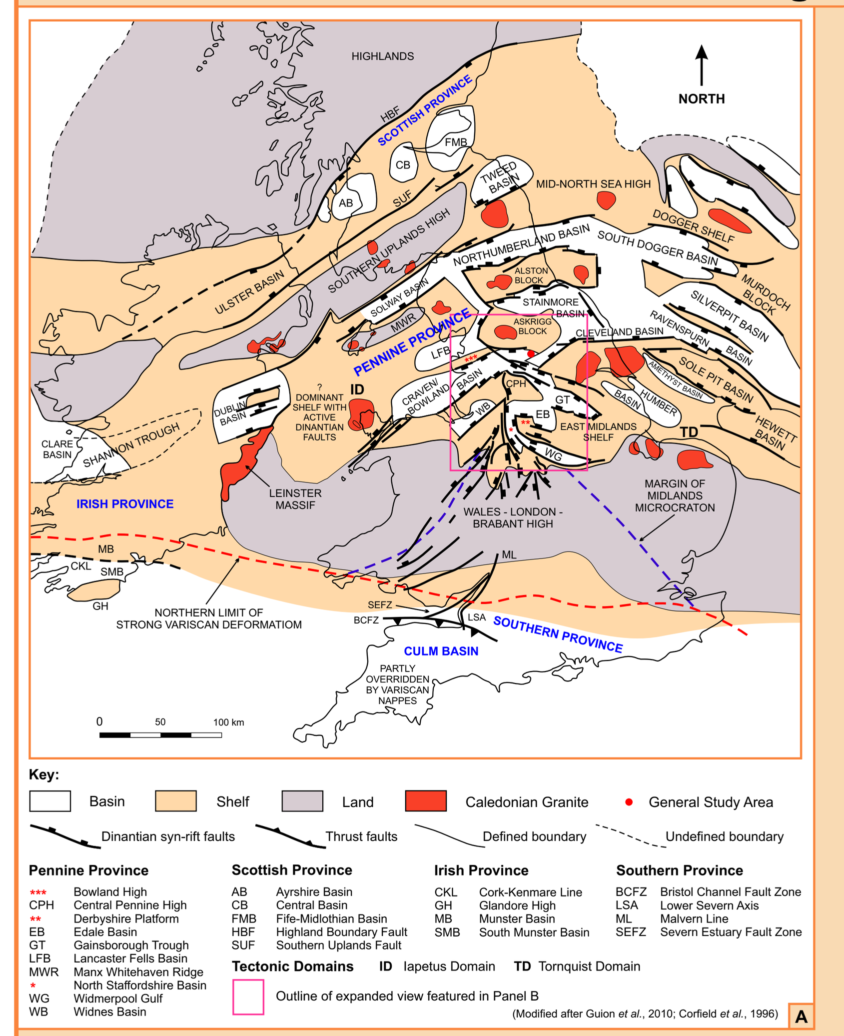


(Modified after Kirby *et al.*, 2000; Waters *et al.*, 2011a, 2011b; Google Earth, 2013)

Typical Kinderscoutian (Bashkirian 322.8- to 314.6Ma)[7] outcrops observed at Brimham Rocks (SE2068 6498)

- Sedimentary architectures represent a remnant of an upper-delta plain system
- Palaeoenvironment: laterally unconfined braided fluvial system, influenced by episodic marine transgressions
- Lower Brimham Grit succession - situated above the R. nodosum goniatite zone (R1b2) (Ramsbottom, 1977)
- Unique three-dimensional nature of the gritstone tors facilitate high-resolution architectural analysis
- Study methods involve detailed reconstruction of the sedimentology and bed-set architecture in orientations parallel and perpendicular to the inferred palaeoflow
- Data collated have facilitated high-resolution palaeoenvironmental reconstruction and model development
- Relating small-scale observations of facies to larger-scale architectural elements.

Carboniferous Palaeotectonic Setting - northern England



A. Dinantian (359.2-330Ma) palaeogeographic map depicting key provinces and tectonic structures

- Dinantian extensional episode associated with the Variscan Orogeny - tectonic activity and back-arc extension[9]
- Accommodation space generated through initial Dinantian faulting, superseded by Namurian subsidence[10]
- Caledonian structures influenced location and alignment of fault-bounding half grabens[9;11;12]
- Caledonian (Devonian) granite intrusions encouraged the Alston and Askrigg blocks to resist subsidence[9;11;12]
- Cyclical sedimentation generated through interaction between subsidence and eustatic fluctuations in sea level[13]
- Superseding Limestone-Mudstone-Sandstone-Seatearth-Coal units form cyclothems with varying complexity and scale[13]
- Subdivided into Dinantian (or 'Mountain') Limestone, Namurian Millstone Grit and Westphalian Coal Measures[13]
- Subdivision based on biostratigraphy with relatively rare goniatites, non-marine bivalves and palynomorphs (spores)[13]
- Millstone Grit - First or Top Grit (Rough Rock); Second Grit (Flagstone); Third Grit (Well-jointed); Fourth Grit (Kinderscout Grit)[2;14]

B. Expanded view - Central Pennine Province depicting inferred major basement fault block-basin locations

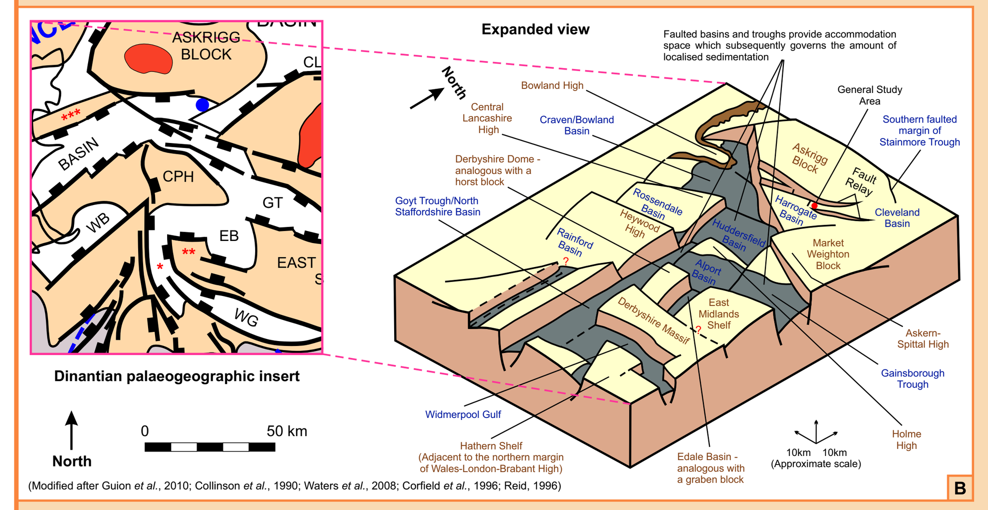
- Various blocks and basins governed localised sedimentation[15]
- Basin morphology "small linked basins" constrained sediment accumulation[10] within Central Province of northern England
- Topographic lows - deep sediment accommodation space acted as locations for clastic deposition
- Topographic highs - formed platforms that were dominated by carbonate deposition
- The Craven Basin (Bowland Basin) is a component of the rift basins series[16]
- Intracratonic Craven sedimentary basin[17; 18] - represents key northeast-southwest-trending half graben[19]
- Bathymetry generated by carbonate platforms and deep-water basins developing between fault blocks[15]
- Bathymetry associated with the Pennine Basin is now occupied by the present-day Pennines[20]
- Development of a complex bathymetry is attributed to the Hercynian (or Variscan) Orogeny[9; 15]
- Thermal relaxation and crustal extension - generated rift-grabens/half-grabens/troughs[21], devided by tilt-block highs/platforms[22]

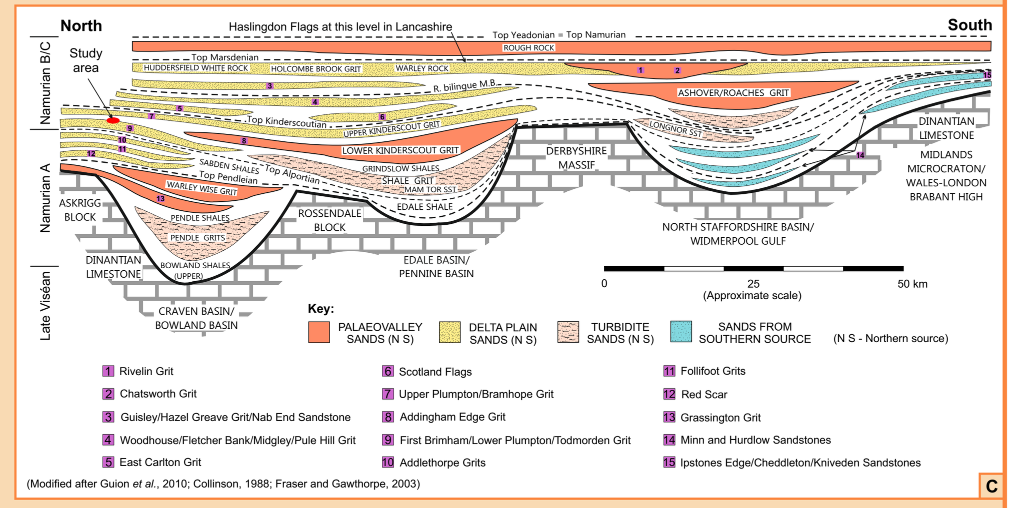
C. Early Namurian (Carboniferous c. 325-320Ma) palaeobathymetry - Central Pennine Province

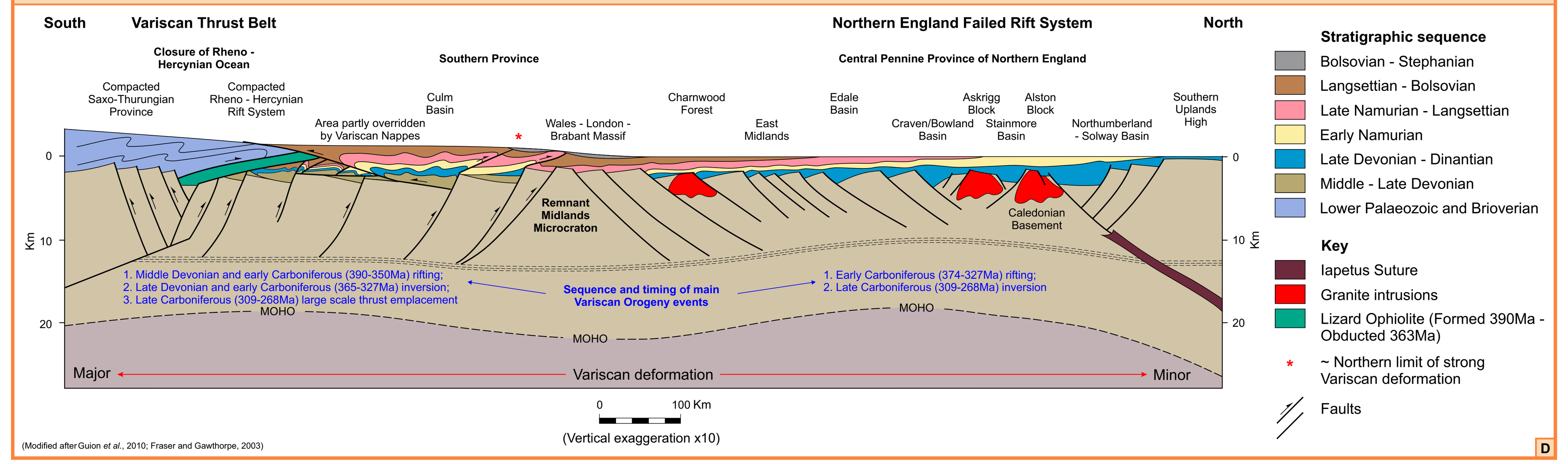
- Cross-section showing palaeobathymetry and implied associations of subsequent Namurian sandstone and shale distribution
- Basin architecture was governed mainly by tectonic developments associated with fault propagation, growth and death[23]
- "Burial or breaching of crossover basement ridges" aided basin connectivity altering hydrologically closed rifts to open rifts[cf. 23]
- Basins to the north of the Derbyshire Massif were supplied with sediments from northerly provenance
- Staffordshire Basin was supplied with sediments from a southerly provenance
- Early sedimentation implies that the Derbyshire Massif acted as a barrier to sediment flow
- Sediments diverted (e.g. Roaches Grit) into Staffordshire Basin, via Widmerpool Gulf

D. Cross-section depicting structural framework associated with the Variscan Orogeny – Post Collision

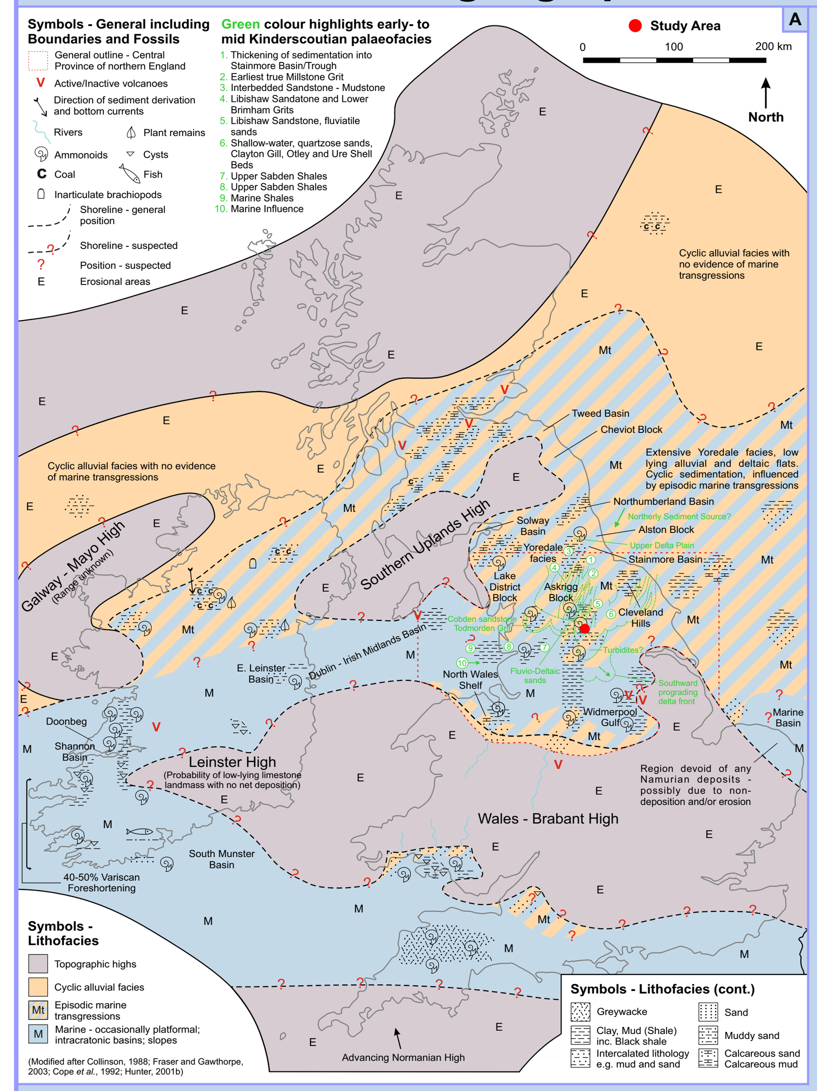
- Variscan orogeny - Mid- to Late Palaeozoic collisional event, spanning late Devonian (c. 370Ma) to early Permian (c. 299Ma)[24]
- Displacement and subsequent closure of the Rheic Ocean enabled the formation of Pangaea supercontinent[25]
- Fusion occurred along the Rheic-Rhenohercynian Suture Zone aligned northeast-southwest, impacting northwest Europe[24]
- Facilitated by Gondwana's northern migration and collision into Laurussia, along an obduction-collision (destructive) zone[25]
- Midlands Microcraton partitions southern and northern regions of initial rifting and subsequent inversion
- Southern Uplands High and Midlands Microcraton constrain northern and southern boundary of Central Pennine Province
- Extensional stresses were prominent during initial stages of the Namurian or possibly during latter stages of the Dinantian[10; 26]
- Basin development, via post-extensional thermal sag, superseded extensional stresses during the Namurian[12; 18; 19; 26; 27; 28; 29]

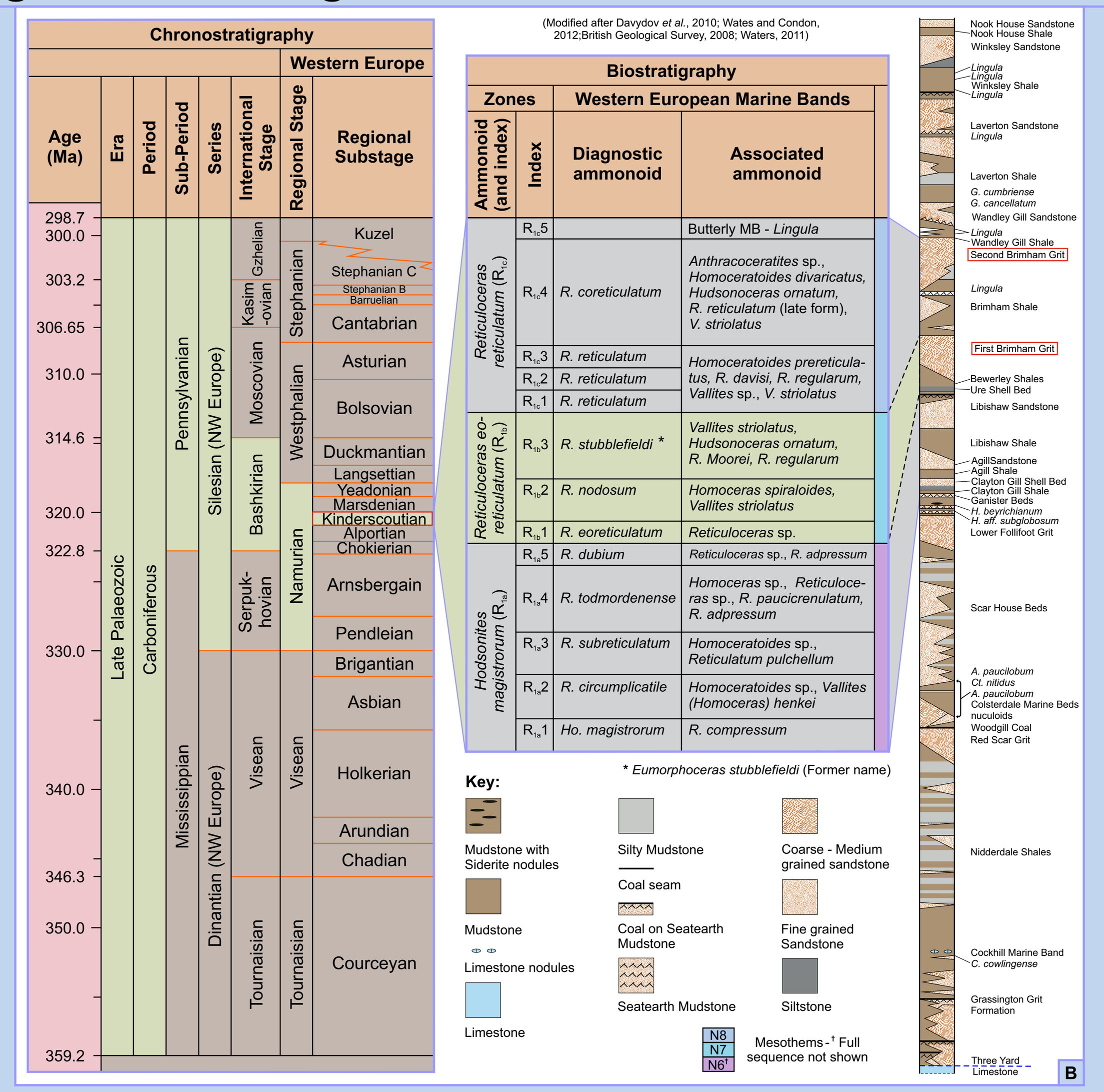






Carboniferous Palaeogeographic Setting - northern England





A. Early Namurian (c. 325-320Ma) palaeogeography - United Kingdom, Ireland and North Sea

- Carboniferous rocks formed by terrestrial - deltaic - paralic - marine environments - underlie ~75% of N. England
- Sedimentary deposits within Craven Basin - Carboniferous age or younger
- Fluvio-deltaic environment - dominant depositional regime - during Namurian
- Turbidite-fronted deltas supplied initial basin-fill sediments - from north-north easterly provenance
- Subsequent sheet deltas - accommodated by regional subsidence during the Namurian
- By late Namurian the Wales-Brabant High also contributed to sediment input
- Lowstand was related with clastic coarse-grained sand influx, provenance from Caledonian Mountains
- Highstand was related with deposition of goniatite marine bands
- Eustasy controlling-factor, although sedimentation and tectonic activity both had considerable influence
- Climate, sea or lake level fluctuations - also liable for key variations - basin-scale sedimentary configurations
- Wales-London Brabant and Southern Uplands Highs, partitioned Britain and Ireland into depositional regions
- Subdivided into the Pennine, Scottish, Irish and Southern Provinces and Culm Basin

B. Carboniferous Chrono- and Bio- Stratigraphic sequence related to the Lower Brimham Grit

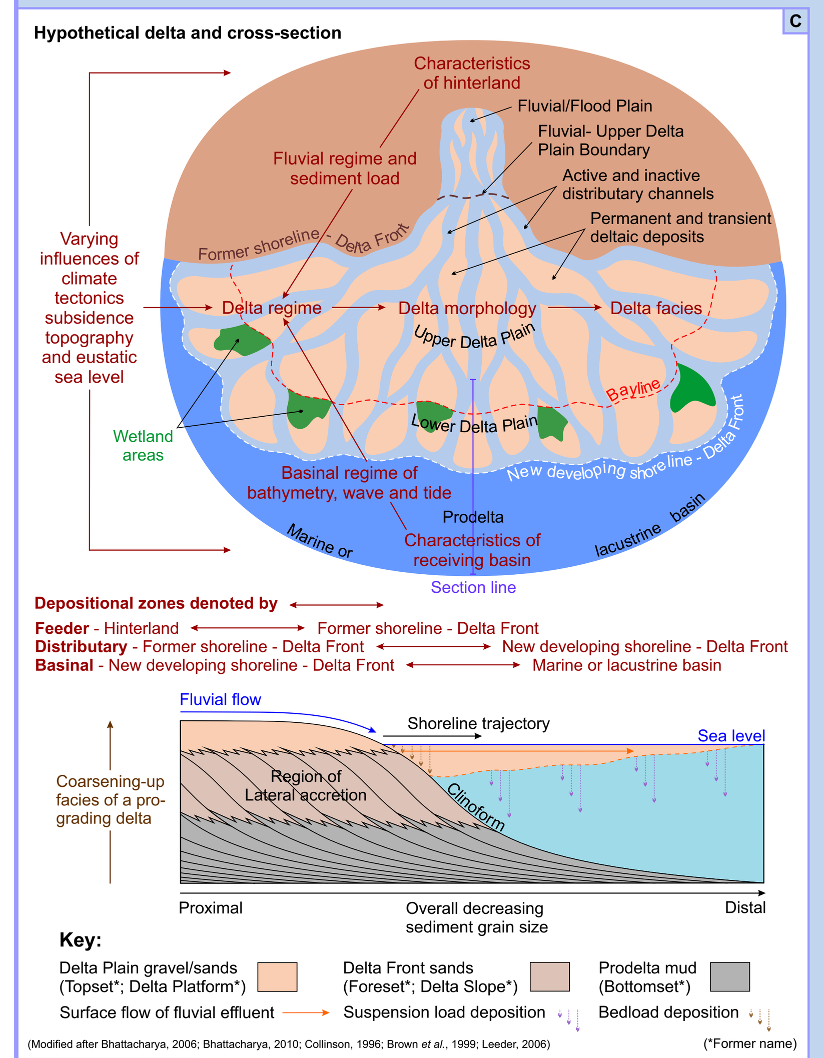
- Lower Brimham Grit is situated between the Beverley and Brimham Shales
- Constrained within N7 mesothem and the Kinderscoutian *Reticuloceras eoreticulatum* (R_{1b}) ammonoid zone
- Stratigraphic column is capped by Westphalian deposits and encompasses Colsterdale, Upper Nidderdale and Kirkby Malzeard regions
- Bashkirian Stage (322.8-314.6Ma) is concomitant with the Gondwanan Late Palaeozoic Ice Age, E. Australia
- 2 glacial (C2 and C3) - 1 interglacial (C2-C3) periods influenced sedimentation around Pennine Basin region
- C2 (323-321.5Ma) - low-amplitude hemipelagic sedimentation limited the progradation of large sandbodies and amplified the rate of marine flooding
- C3 (319.5-316Ma) - virtually basinwide progradation of coarse, pebbly sheet-like fluvio-deltaic sandbodies
- Pennine Basin experiencing maximum degree of sea-level flooding episodes and incision surfaces
- C2-C3 (321.5-319.5Ma) - related to passive eustatic sea-level oscillations and renewal of ammonoid genera[35]
- Pennine Basin was influenced by gradual accumulation of hemipelagic and distal turbidite sediments[35]
- Linked to a relatively lower magnitude of sea-level oscillation and no significant incision episodes[35]
- Latter stages (320.2-319.5Ma) - encompass Kinderscoutian N7 mesothem, *R. eoreticulatum* (R_{1b}) and *R. nodosum* ($R_{1b}2$) marine bands
- Infer the Lower Brimham Grit succession was deposited during a period of relatively stable eustatic sea-level

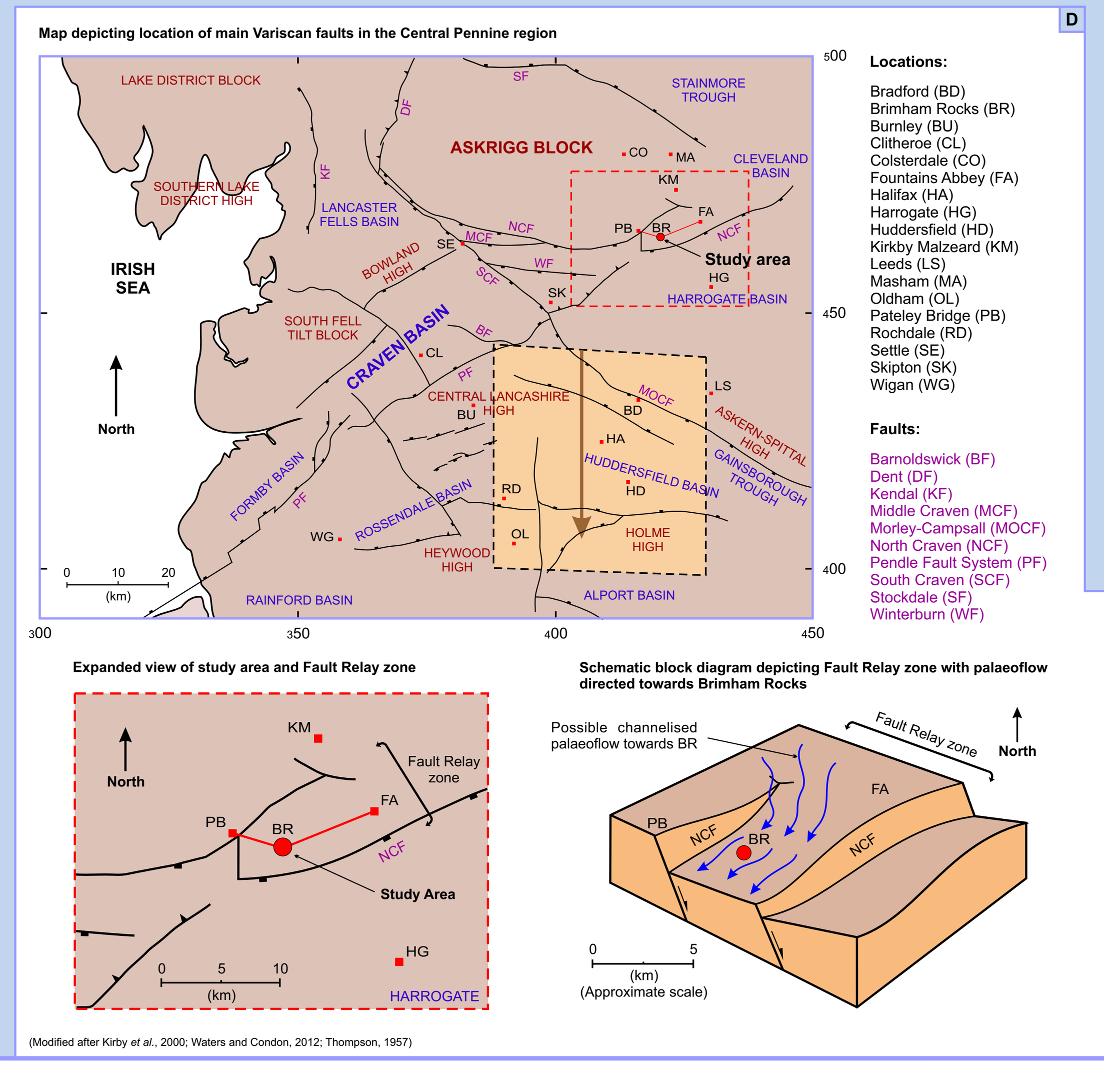
C. Hypothetical delta - cross-section with main zones and factors affecting morphology - facies

- Plan view of a progradational deltaic system highlighting the result of fluvial discharge into open water
- Seaward shoreline extension is generated at the point of the river's terminus on a basin's shoreline
- Generally regressive systems[36;37;38], deltas consist of a subaerial delta plain, subaqueous delta front and prodelta
- Cross-section highlights three main deltaic zones: Delta plain - Delta front - Prodelta systems
- Lateral accretion and coarsening up sequences - indicative of progradational deltaic systems
- Delta morphology and facies are influenced by fluvial sediment grain size and supply rate, density of fluvial and basin water, basin currents and effects of subsidence and eustatic sea-level adjustment on base level[39]
- Although deltaic systems can be classified on basis of whether they are: (i) fluvial-; (ii) wave-; or (iii) tide-dominated[40] - In reality the three end-member classification is too simplistic
- Deltaic systems possess a variety of facies sequences - therefore they are not identifiable from specific
- facies sequence/model[36; 41]
- Grain size component of sediments conveyed to the delta front are also imporant[42]
- Majority of deltaic systems are influenced temporally and spatially by all three end-members[37;38;39;43]
- Late Pendleian - Kinderscoutian transition of the southern boundary - Askrigg Block - from a distinct shelf-(block) edge- to gradually inclined ramp- delta[18; 26]; active during Lower Brimham Grit deposition
- Facilitating shift from deep-water turbidite-fronted- to gradually inclined shallow-water ramp- deltaic system[18; 26]

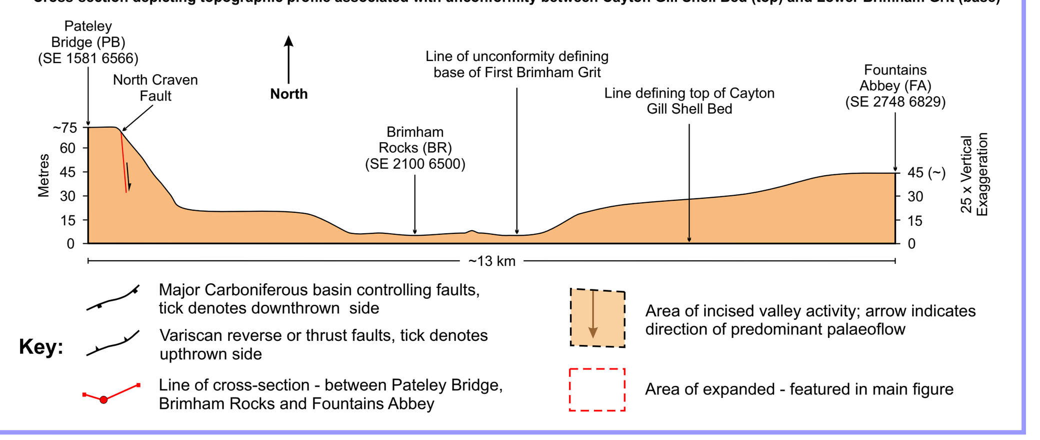
D. Variscan faults and Mid- to Late Kinderscoutian Incised Valley - Central Pennine Province

- Older Dinantian syn-rift megasequence - basinal mudstones/calciturbidites - denote sediment-starved basin[30]
- Younger early post-rift megasequence typified by substantial Namurian pro-delta marine mudstone deposits[30]
- Relic syn-rift bathymetry was filled during mid- to late Namurian by south-southwesterly prograding deltas[30]
- Initial sequence - include extensive Carboniferous marine-band mudstones - linked to maximum sea-level[30]
- Distributary channel/mouth bar deposits and incised valley fills are associated with fluvial activity[30]
- Latter stages of basin fill (mid- to late Namurian) relate to prograding deltas that formed the Lower Brimham Grit deposits
- During Mid- to Late Kinderscoutian, Central Pennine Province was influenced by major incised palaeovalley[35] trending north–south, representing Type 1 discontinuity/unconformity - sea-level minima/sequence boundary[35]
- Deposition of Lower Brimham Grit, possibly influenced by palaeocurrents flowing towards the incised valley
- Brimham Rocks situated between two sections of the North Craven Fault (Fault Relay zone - Expanded view)
- Initial palaeocurrents may have been channelled through fault relay zone towards Brimham Rocks
- Possibly responsible for generating the unconformity that underlies the Lower Brimham Grit
- Block diagram depicts possible scenario for palaeoflow being directed towards Brimham Rocks
- Initial palaeoflow predominantly from the north and northeast
- Isopach cross-section of succession between (Top) Cayton Gill Shell Bed and (Base) Lower Brimham Grit
- Topographic profile possibly influenced palaeocurrents and deposition of Lower Brimham Grit
- Emplacement of Lower Brimham Grit is related to development of an upper-delta plain braided fluvial system
- Barform elements undertook both lateral- and downstream accretion due to bedform/channel migration
- Palaeoflow possibly associated with relatively open incised palaeovalley formed within fault relay zone





Cross-section depicting topographic profile associated with unconformity between Cayton Gill Shell Bed (top) and Lower Brimham Grit (base)



CiPEG — Centre for Integrated Petroleum Engineering and Geoscience

Fluvial Research Group, School of Earth and Environment, University of Leeds, Leeds LS2 9JT UK, http://frg.leeds.ac.uk

Contacts: Roman Soltan, email: ee07r2s@leeds.ac.uk, mobile: +44 (0)7908118017

AREVA · bhpbilliton · ConocoPhillips · nexen · Saudi Aramco · Shell · TULLOW OIL · woodside

Reconstruction of channel and barform architecture in a Pennsylvanian fluvio-deltaic succession: Brimham Grit, northern England

FRG

UNIVERSITY OF LEEDS

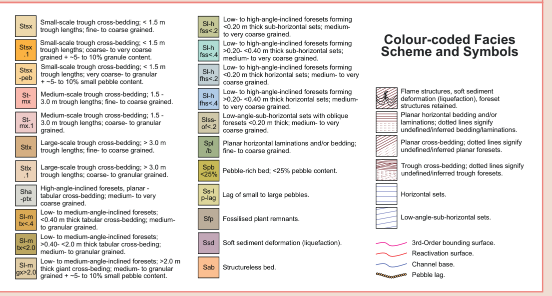
Roman Soltan, Nigel P. Mountney, William D. McCaffrey and Douglas A. Paton – Fluvial Research Group, School of Earth and Environment, University of Leeds, Leeds, LS2 9JT, UK

Sedimentary Facies examples - Brimham Rocks

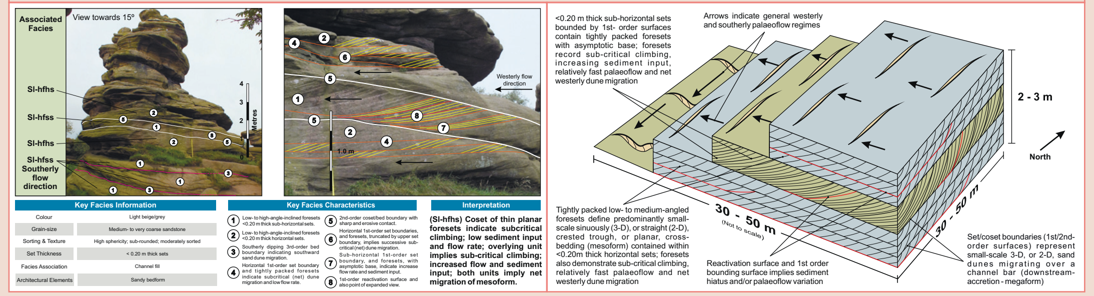
Lithofacies and Facies Scheme

- Facies are classified objectively based on colour, composition, texture, sedimentary structures and bedding[39; 54]
- Temporal and spatial variations give rise to facies associations due to changes in the depositional palaeoenvironment[39]
- Facies are allocated a unique code reflecting lithology type and defining characteristics based on a modified and extended version of Miall's (2010) classification scheme, for example; "Stsx" represents "Small-scale Trough Cross-Bedding; <1.5 metre trough lengths"
- Bounding surfaces - based on Miall's (2010) hierarchy of depositional units in alluvial deposits, facilitate discrimination between autocyclic or allocyclic processes to ascertain how each were likely responsible for lithofacies deposition and preservation of architectural elements[46]
- References to cross-bedding size, trough shape and dune facies observations, for example, are relative to outcrops at Brimham Rocks, not to general literature
- Colour coded schematic facies illustrations depict subject facies and adjacent facies associations
- Illustrations are annotated with main sedimentary features and general palaeoflow direction
- Depicted facies highlight variable foreset, set, coset and bed morphology:
  - variable palaeoflow direction, strength and amount of sediment influx
  - 2-D (i.e. straight-crested) and 3-D (i.e. sinuously-crested) dune migration
  - sub-critical climbing represents aggradation of bedforms at a low angle of climb
  - active and variable braided fluvial system influenced by flood events
- Southerly and westerly palaeocurrents imply northern and southern sediment provenance

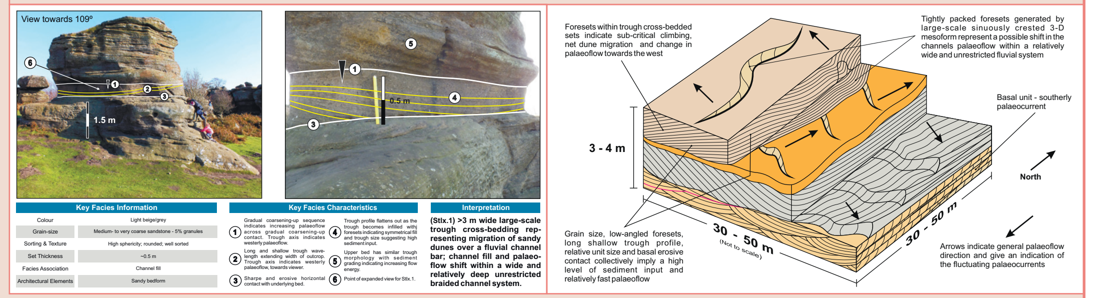
Colour-coded Facies Scheme and Symbols



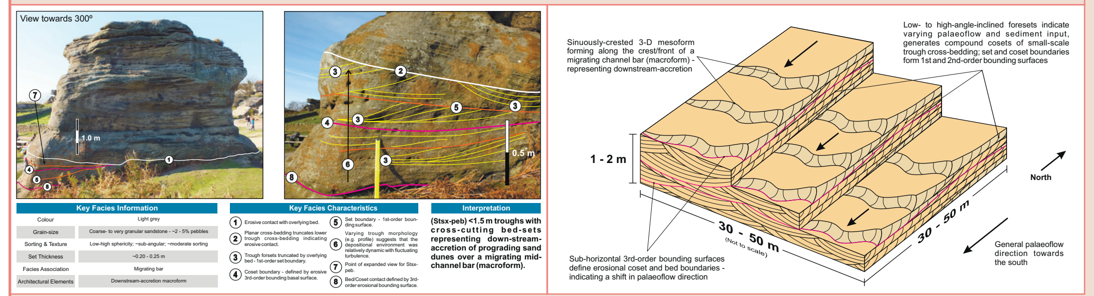
Facies Sl-hfhs <0.20 m - Low- to high-angle-inclined foresets <0.20 m thick horizontal sets



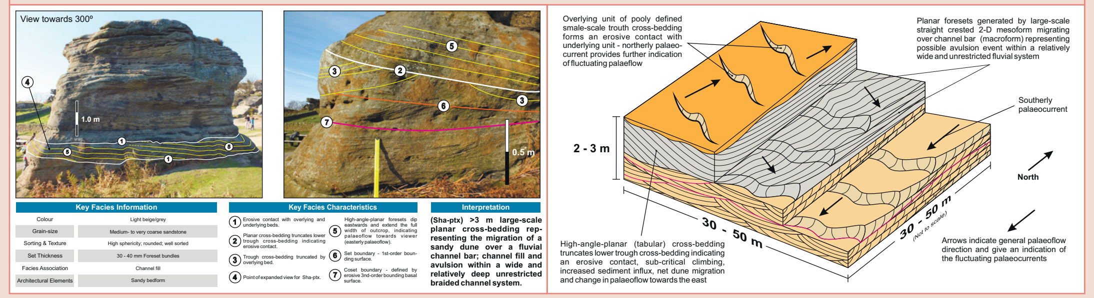
Facies Stlx.1 - Large-scale trough cross-bedding > 3 m trough lengths



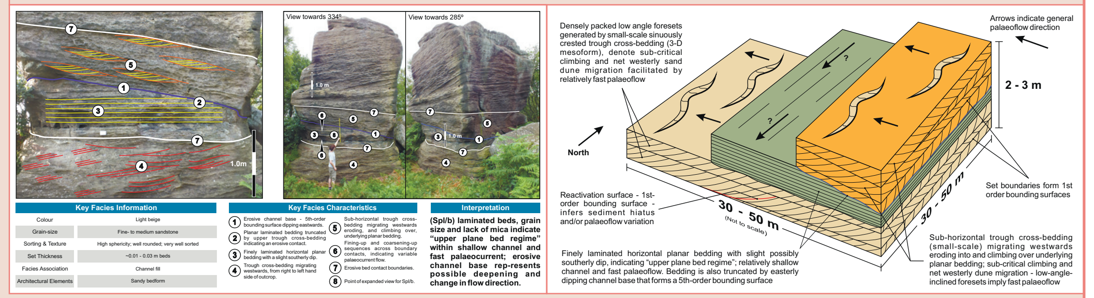
Facies Stsx-peb - Small-scale (< 1.5 m) trough cross-bedding containing ~5 - 10% small pebble inclusions



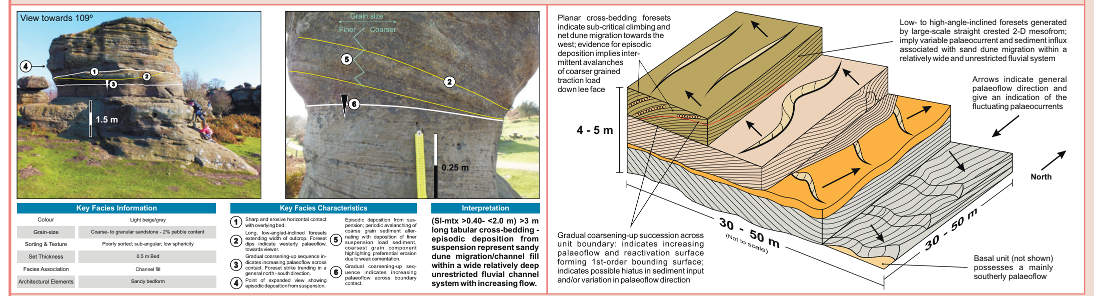
Facies Sha-ptx - High-angle-inclined foresets, large-scale planar tabular cross-bedding



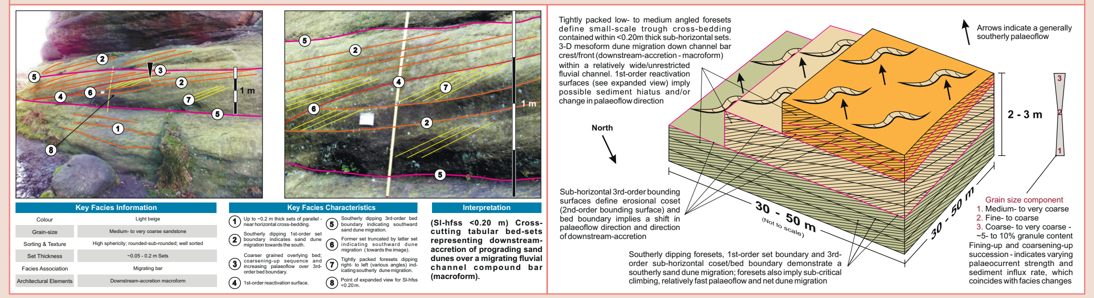
Facies Spl/b - Planar horizontal laminations and/or bedding



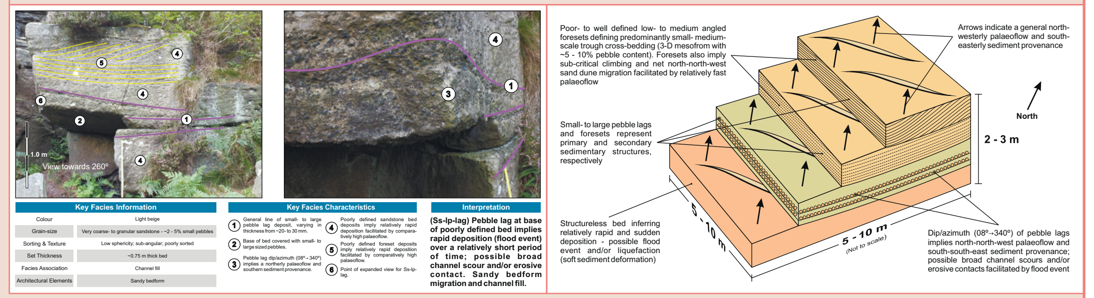
Facies Sl-mtx >0.40- <2.0 m - Low- to medium-angle-inclined foresets; >0.40- <2.0 m thick tabular cross-bedding (with evidence of episodic deposition from suspension)



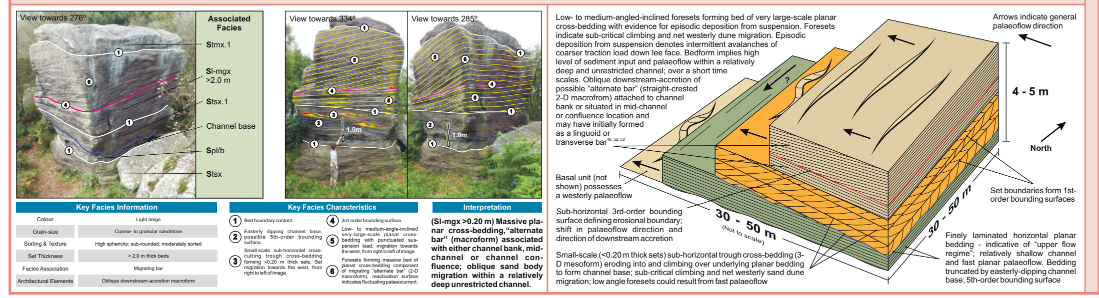
Facies Sl-hfss <0.20 m - Low- to high angled foresets <0.20 m thick sub-horizontal sets



Facies Ss-lp-lag - Small- to large pebble lag

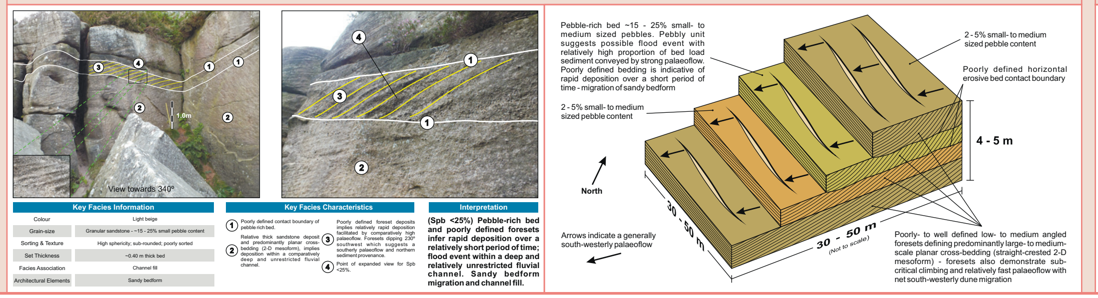


Facies Sl-mgx >2.0 m - Low- to medium-angle-inclined foresets, >2.0 m thick, very-large-scale cross-bedding

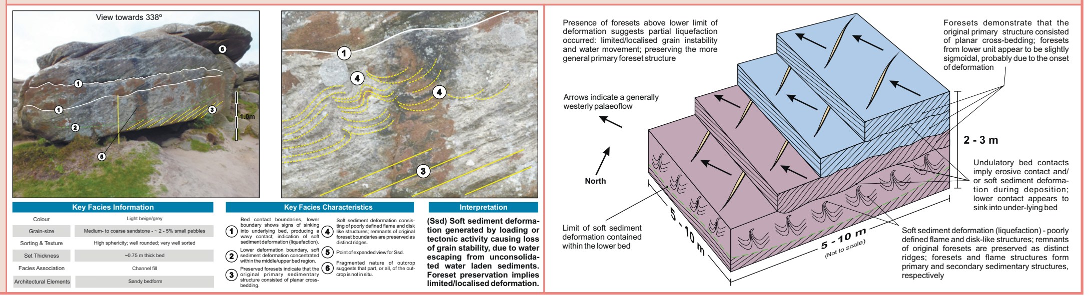


Small-scale (<0.20 m thick sets) sub-horizontal trough cross-bedding (3-D mesoform) eroding into and climbing over underlying planar bedding to form channel base; sub-critical climbing and net westerly sand dune migration; low angle foresets could result from fast palaeoflow

Facies Spb <25% - Pebble rich bed with ~15 - 25% pebble content



Facies Ssd - Soft sediment deformation

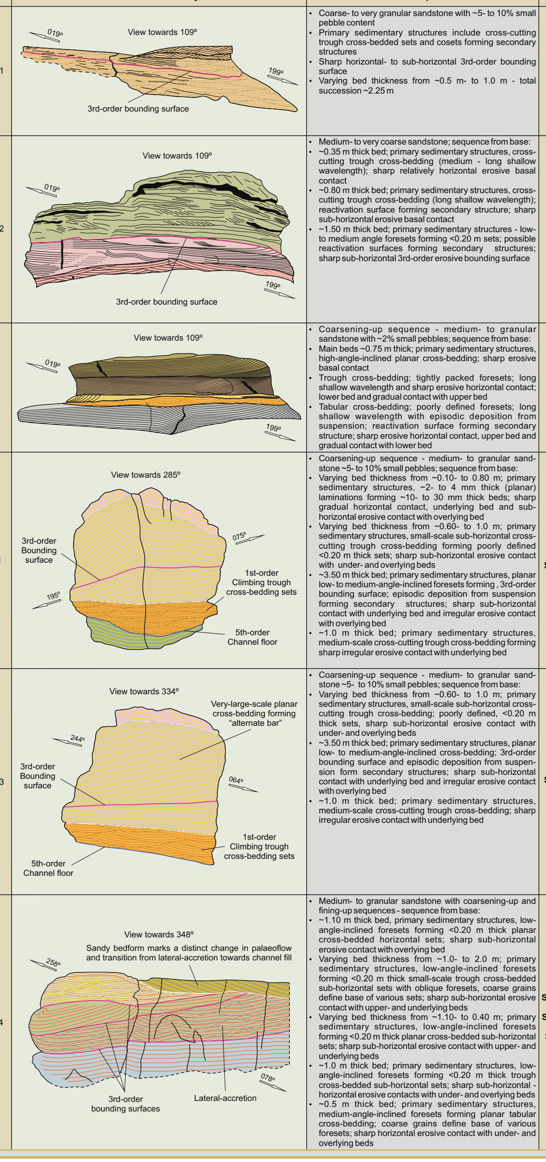


Architectural Elements examples - Brimham Rocks

Architectural elements - summary description and interpretation

- Architectural elements are classified objectively based on Miall's (2010) definition: size of depositional system is ≤ than channel fill and > individual facies
- Architectural element codes are assigned on basis of element's geometry, bounding surfaces, scale, lithology and palaeocurrent characteristics[54]
- References to cross-bedding size, trough shape and dune element observations, for example, are relative to outcrops at Brimham Rocks, not to general literature
- Colour coded element illustrations depict subject elements and adjacent facies associations - annotated with sedimentary features
- Depicted elements show variable foreset, set, coset, bed morphology. Inferring: variable palaeoflow direction, strength and sediment input, 2-D and 3-D straight and sinuously-crested dune migration in a braided fluvial system guided by flood events
- Southerly to westerly palaeoflows imply a northern and southern sediment provenance

Element	Code	Geometry	Description	Facies Association	Interpretation
Downstream-accretion	DA 1			Stsx-peb	
Downstream-accretion (Transitional)	DA 2				
Sandy Bedform	SB				
Channel	CH				
Downstream-accretion (Oblique)	DA 3				
Lateral-accretion	LA 4				



CiPEG
Centre for Integrated Petroleum Engineering and Geoscience

Fluvial Research Group
School of Earth and Environment
University of Leeds
Leeds LS2 9JT UK
http://frg.leeds.ac.uk

Contacts:
Roman Soltan
email: ee07r2s@leeds.ac.uk
mobile: +44 (0)7908118017

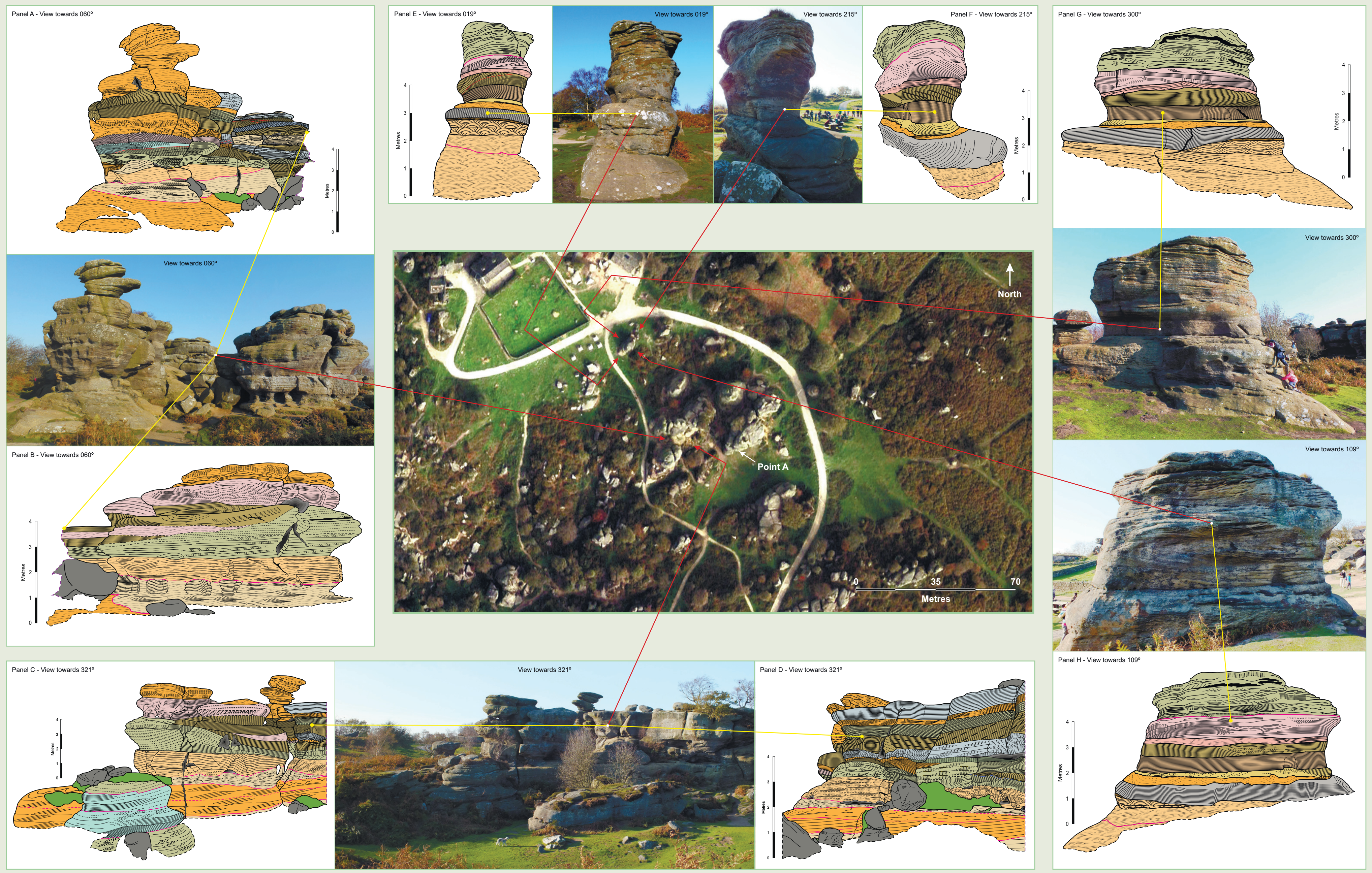
Reconstruction of channel and barform architecture in a Pennsylvanian fluvio-deltaic succession: Brimham Grit, northern England

FRG

UNIVERSITY OF LEEDS

Roman Soltan, Nigel P. Mountney, William D. McCaffrey and Douglas A. Paton – Fluvial Research Group, School of Earth and Environment, University of Leeds, Leeds, LS2 9JT, UK

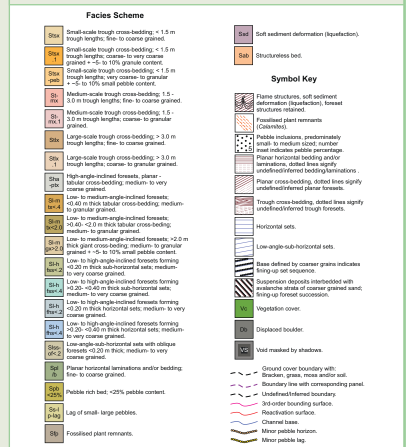
Architectural Panel examples - Brimham Rocks



Images and related Architectural Panels - Brimham Rocks

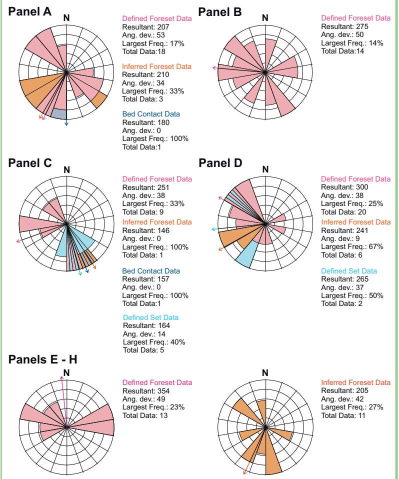
- Images display the study area's fragmented nature and potential for detailed 3-D examination
- Red arrows indicate the position and outlook of the expanded view in relation to the aerial image[55]
- Yellow arrows indicate corresponding position between expanded view and architectural panel
- Panels are colour-coded in line with the sedimentary facies scheme to highlight facies associations

Colour-coded facies scheme and symbol key



Palaeocurrent Data related to Architectural Panels

- Rose diagrams portray a variety of palaeocurrent (azimuth) data obtained from architectural panels A - H
- The variable palaeocurrent data is indicative of barforms undertaking a combination of both lateral and downstream accretion
- Lower panel sections are predominantly associated with southerly palaeocurrents and channel bar migration
- Upper panel sections are predominantly associated with westerly palaeocurrents and a relatively higher proportion of sand-body deposits
- Palaeocurrents imply that Lower Brimham Grit deposits are associated with a highly variable and fluctuating non-confined fluvial system
- Rose diagrams depict data derived from both direct measurements and inferred from foreset apparent dips and bed contact measurements

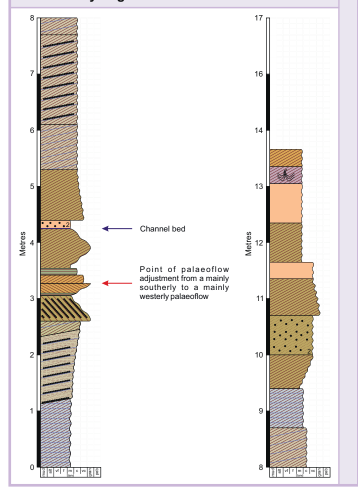


Outcrop Interpretation

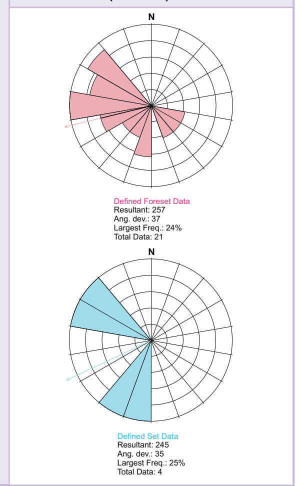
- 2-D image taken from a photogrammetry model[56] created from outcrop section highlighted by Point A (see aerial view image of Architectural Panel section)
- The sedimentary log is colour-coded in line with the sedimentary facies scheme to highlight facies associations
- Basal deposits consists mainly of low-angle-inclined foresets forming <0.20 m thick horizontal and sub-horizontal sets, which represent a southerly migrating channel bar, downstream-accretion with superimposed lateral-accretion
- Subsequent flood event facilitates sand dune deposition, adjustment to westerly palaeflow and channel incision
- Further flood events generate larger sand dunes prior to re-establishment of predominantly low-angle-inclined foresets forming <0.20 m thick horizontal and sub-horizontal sets, which represent a westerly migrating channel bar, downstream-accretion with superimposed lateral-accretion
- Uppermost deposits are dominated by medium-scale sand dunes, indicating amplified palaeoflow and sediment input
- Overall the section represents a large fluvial channel dominated by migrating channel bars, during periods of relatively low palaeoflow and sediment input; in contrast, small- to medium-scale sand dunes dominate during periods of relatively high palaeoflow and sediment input (flood events), facilitating palaeoflow adjustment and channel incision

2-D image taken from photogrammetry model

Sedimentary Log - Point A



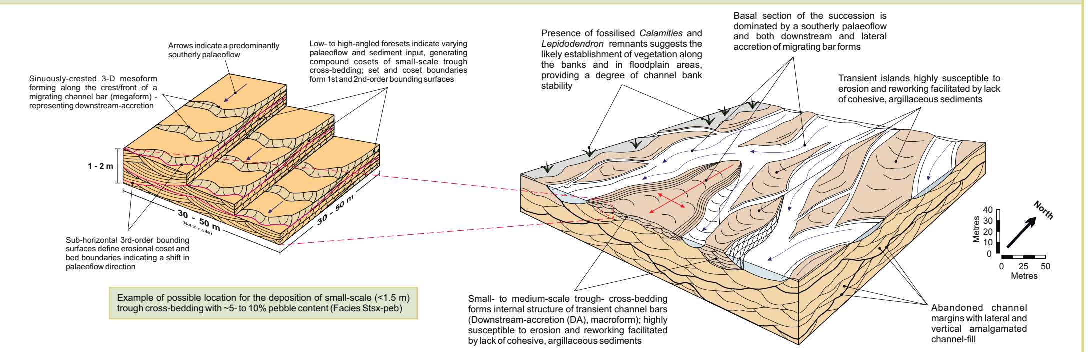
Palaeocurrent (Azimuth) Data - Point A



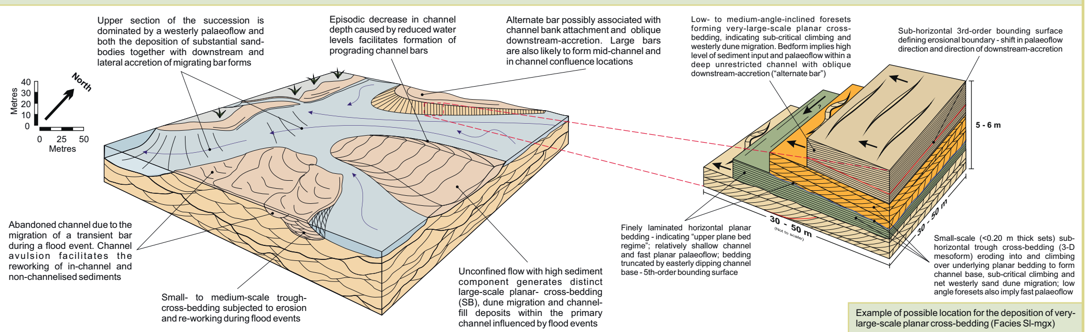
Depositional Model - Brimham Rocks

- Schematic depositional model to account for the distinct variation in the palaeoflow between the basal and upper section of the succession featured in the Outcrop Interpretation section
- The model consists of two interpretations (pre- and post-flood events) which imply that the depositional environment was influenced by two distinct flow regimes
- Each interpretation is annotated with salient points and an expanded image to provide an example of the possible associated facies
- Downstream and lateral-accretion towards the base of the succession are related to the migration of channel barforms associated with southerly palaeoflows and probably relatively low- to medium rates of sediment input
- In contrast, upper sections are related to westerly palaeoflows governing deposition of substantial sand-bodies and either downstream or lateral accretion, linked to the migration of channel barforms
- Uppermost deposits are also probably associated with increased palaeoflow and sediment input
- The sand-bodies probably represent accumulation during and in the immediate aftermath of flood events which may have also facilitated channel avulsion and upward change in the palaeoflow
- The relative size of the sand-bodies implies an increase in sediment influx
- Absence of very-fine-grained sandstone, or mudstone deposits, typically indicative of floodplain sedimentation, implies that the depositional palaeoenvironment was dominated by sandy facies that accumulated in a mobile channel and barform-prone upper delta-plain environment
- Although absence of cohesive and argillaceous sediments would render channel bars, islands and banking liable to lateral and downstream erosion, fossilised plant remnants (e.g. *Calamities* and *Lepidodendron*) suggest that, if not locally, more stable fluvial systems may prevail upstream
- The model suggests that the palaeoenvironment, which varied in its palaeoflow direction, volume and rate of sediment input, was associated with an active braided fluvial system susceptible to avulsion during peak flood events at which time rates of sediment input also increased

Depositional Model: Pre-flood event



Depositional Model: Post-flood event



Conclusion

Throughout the Kinderscoutian, the palaeoenvironment represented by the First Brimham Grit was supplied with sediment delivered from a range of provenances, predominantly eroded remnants of the Caledonian Mountains that lay to the north and northeast. This study has shown that sediments deposited due to predominantly westerly palaeoflows are dominant towards the upper section of the featured succession. Overall, the Brimham Rocks succession is characterised by sand-body architecture indicative of a braided river, though the relationships and palaeoenvironmental significance of the various architectural elements present has not previously been examined in detail. The three-dimensional nature of the outcrops enable the detailed sedimentology and bed-set architecture of this succession to be characterised such that the style of internal facies arrangement present within the various architectural elements, the three-dimensional geometries of these elements, and the relationships of neighbouring elements can all be reconstructed in detail. Fluvial channel elements defined by laterally extensive erosional surfaces contain a hierarchy of sets and cosets of sandstone and conglomerate. Thin (sub-metre), crudely-parallel bedded, gravel- and small-pebble-grade conglomerates represent gravel sheets that migrated as tractional loads in the basal parts of channels. Cosets of both trough and planar-tabular cross-bedded facies represent both laterally-accreting and downstream-accreting macroforms (bars), several examples of which can be shown to have supported superimposed dunes. Palaeocurrent data are highly variable and are indicative of barforms that undertook a combination of both lateral and downstream accretion. Smaller-scale, simple cross-bedded sets represent the migration of isolated dunes within the channels. Less abundant, fine-grained, ripple cross-laminated sandstones, represent microforms developed either on bar tops or in slack-water areas, for example in partially abandoned channel reaches. The overall succession represents the preserved product of an upper-delta plain system that was traversed by a fluctuating and frequently avulsing braided fluvial system, forming a poorly-confined network of fluvial channels that evolved between major sandy barforms. The region was also influenced by episodic marine transgressions generating cyclic alluvial facies. Data from this study are contributing to a broader research programme investigating the linkage of fluvio-deltaic successions from shelf-edge deltas to slope and submarine-fan successions with regard to the role and influence of basin morphology on sediment delivery mechanisms in the Carboniferous, UK. This is important as it will further our understanding and knowledge of the role basin morphology plays in influencing sediment distribution from a deltaic source to basin sink.

References

CiPEG
Centre for Integrated Petroleum Engineering and Geoscience

Fluvial Research Group
School of Earth and Environment
University of Leeds
Leeds LS2 9JT UK
http://frg.leeds.ac.uk

Contacts:
Roman Soltan
email: ee07r2s@leeds.ac.uk
mobile: +44 (0)7908118017