Integrating Geochemical and Petrographic Analyses to Better Understand Proximal to Distal Variations in Source Rocks, Using an Example from the Bashkirian in the United Kingdom*

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Abstract

Mudstone lithofacies are now known to be highly variable, impacting on all aspects of their source, seal and reservoir potential in different locations within the basin. Previously, much of this variability has been interpreted by examining chemical proxies and their subtle variability in redox sensitivities (particularly the presence of anoxia). However, some of the interpretations from geochemistry appear to be at odds with conclusions reached from the petrographic and detailed logging studies. The aim of this article is to investigate these discrepancies and refine stratigraphic models to provide a clear insight into how a source rock varies laterally within a basin. This is achieved by integrating detailed (sub-mm to 10s m scale) petrographic analyses of lithofacies (grain size, mineralogy, fabric), total organic carbon and inorganic geochemical data acquired from a well-constrained proximal to distal succession of Bashkirian-aged mudstones (beds enclosing the Bilinguites gracilis horizon) in the UK Pennsylvanian basin.

Seven lithofacies have been identified in this study (using the combined approach of petrographic and geochemical analysis), which are either bioturbated or organized into thin graded beds. In proximal locations, facies are mainly silt-bearing, clay-rich mudstones with up to 2% TOC and contain <4.5 ppm U and <1.8 ppm Mo. In more distal locations the facies are broadly similar, but contain more clay and TOC (up to 8.9%), with higher concentrations of the redox sensitive elements, up to 25.1 ppm U and up to 205 ppm Mo. When integrated, as in this example, the datasets appear to provide a relatively consistent story, indicating that there are systematic differences in the grain size down the sediment transport path (reflected in compositional variability in the chemical data, and grain size in the petrology) and that typically more organic matter was preserved downdip in conditions that may have been prone to developing anoxia (high trace element concentrations). Somewhat counterintuitively, slower sediment accumulation rates updip (perhaps accommodation limited) may be the primary cause of the lateral differences. Sediment accumulation rates downdip were more continuous and faster, enabling a higher proportion of organic matter to be preserved by relatively continuous burial. This study demonstrates the need to integrate geochemical and petrographic methods when seeking to understand controls on source rock facies variability in basins.

Reference Cited

Macquaker, Joe H.S., and A.E. Adams, 2003, Maximizing information from fine-grained sedimentary rocks: An inclusive nomenclature for mudstones: Journal of Sedimentary Research, v. 73/5, p. 735-744.

Integrating geochemical and petrographic analyses to better understand proximal to distal variations in source rocks, using an example from the Bashkirian in the UK.

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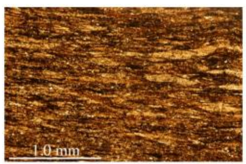

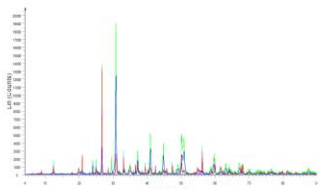

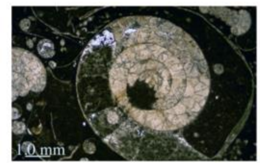

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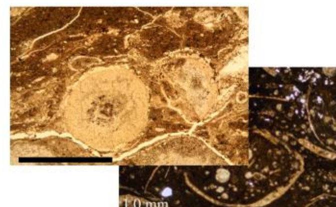
Presenter's notes: My PhD research is focusing in on the variability that we can see in Carboniferous mudstones, in both sedimentology and geochemistry, and the implications that can have when looking for shale gas targets.

Background

- USA: Shale gas is being exploited from a vast number of plays
- UK: Prospective intervals in age equivalent successions

Aims

- Understand the fundamental controls on sedimentation
- Investigate temporal and spatial distribution of organic matter
- Multidisciplinary approach to identify mudstone lithofacies and interpret sediment delivery processes

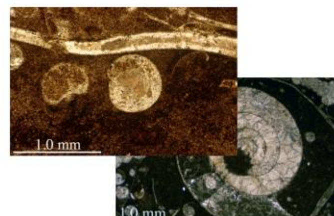


Presenter’s notes: Mudstones can be very important with regard to shale gas and therefore understanding their characteristics and variability is crucial to exploration. This project is multidisciplinary – involving both sedimentology and geochemistry and in this talk I will explain how both of these are important to understanding mudstones and identifying different lithofacies.

Important Questions

1. How do you predict the distribution and concentration of organic matter in the basin?

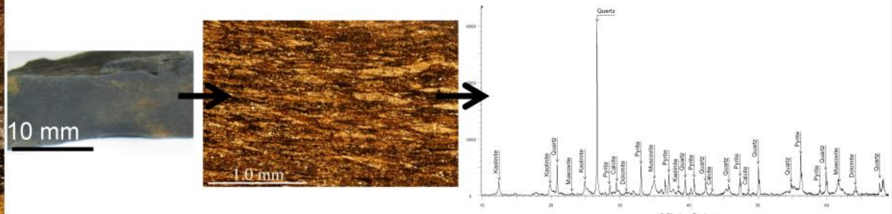
2. How do you understand which fine grained successions are good shale gas prospects?



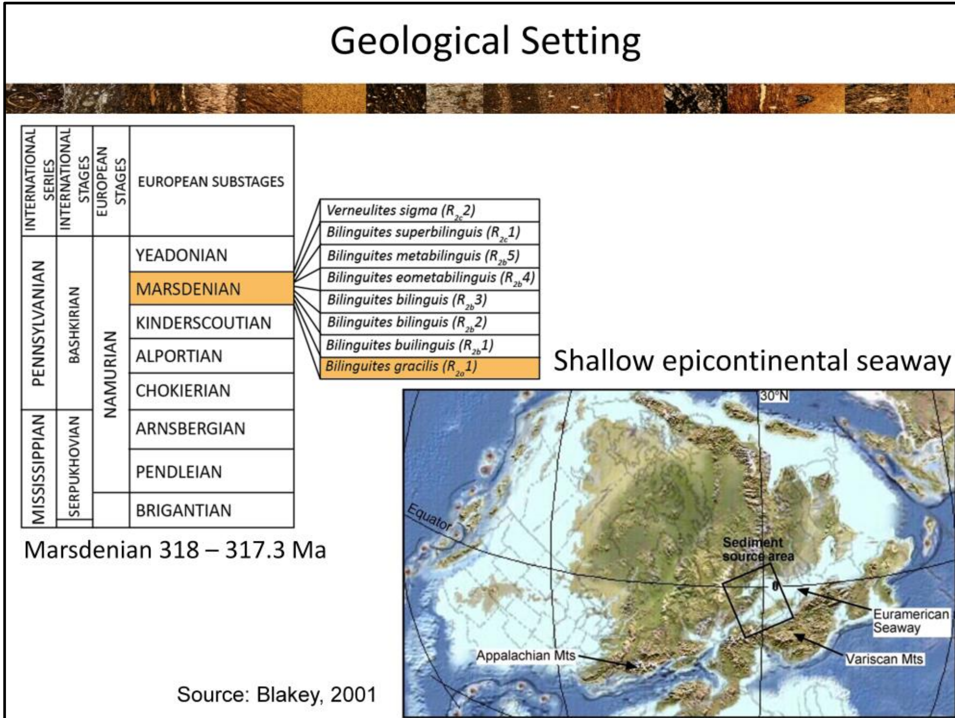
Presenter's notes: These key questions are examined in this research and answers can be derived by examining variations on a local and regional scale.

Multidisciplinary Approach

- Thin section analysis (optical and SEM)
  - Define lithofacies
  - Interpret processes operating at site of deposition



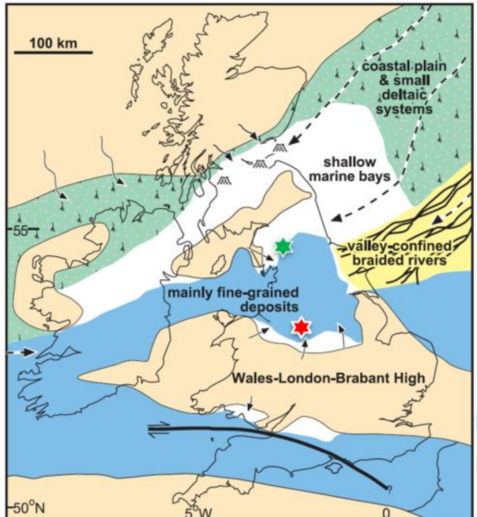
- Whole rock geochemical methods (XRF, XRD, C/S, DTA)
  - Highlight compositional variability between lithofacies and location
  - Examine enrichment in redox-sensitive elements as proxies for anoxia
  - Calculate organic matter abundances to show the distribution and concentration between lithofacies and across the basin



Presenter's notes: Over time the appearance of the planet and the land masses have changed due to the ever moving tectonic plates and variations in sea level. In the Carboniferous the UK looked very different to today – as it was just south of the equator and much of the UK was below sea level. The seaway that spanned much of the UK was more restricted from the open shelf and closer to the sediment source than the big open US basins.

Bashkirian Palaeogeography

Distal to Proximal Transect



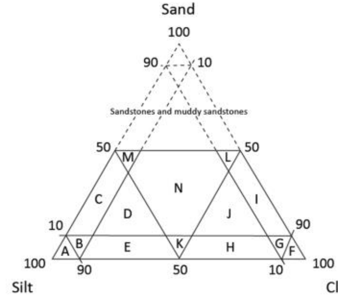
Brough (Proximal)

Oakamoor (Distal)

Presenter's notes: Zooming in, here is a palaeogeographic map for the Namurian. The studied sections cover an interval that represents a major marine transgression producing a broad marine shelf. During the transgression, the main sediment source is pushed back to the northeast. Oakamoor, in the south, is the most distant from this source, but some sediment was also supplied from the south to this location. Pule Hill is closer to this major source. In the north, Brough is located away from the major fluvial and deltaic systems, in an area of shallow-water marine bays.

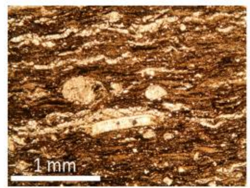
Lithofacies Identification

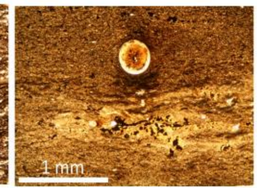
- Composition
- Fabric
- Fossil content
- Grain size
- Organic matter
- Geochemical variability



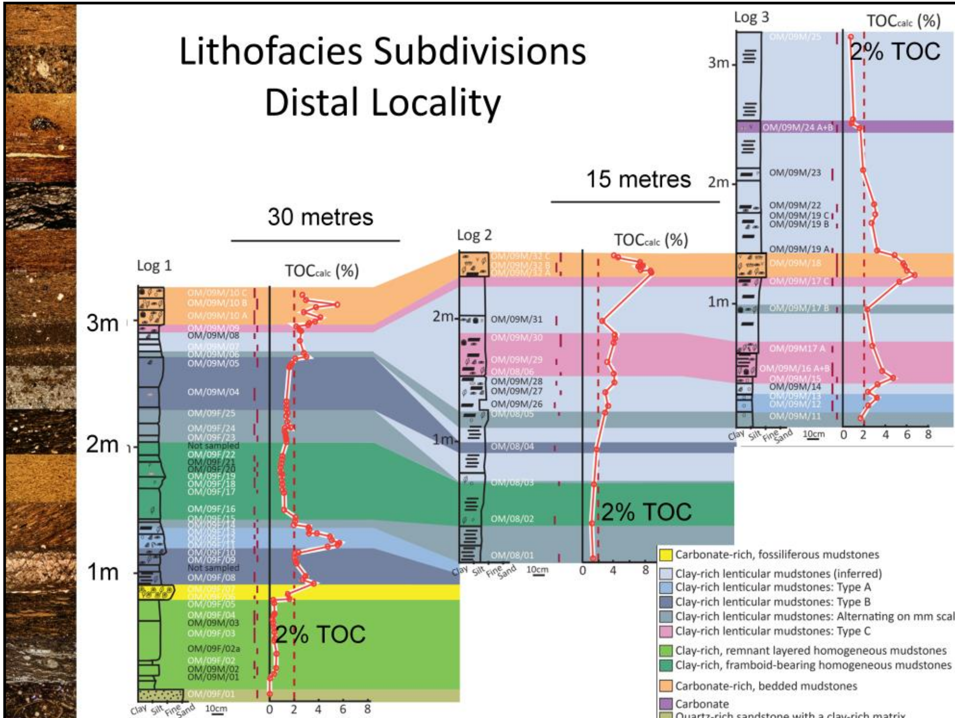
A: Silt-dominated mudstone
B: Silt-rich mudstone
C: Sand-bearing, silt-rich mudstone
D: Sand and clay-bearing, silt-rich mudstone
E: Clay-bearing, silt-rich mudstone
F: Clay-dominated mudstone
G: Clay-rich mudstone
H: Silt-bearing, clay-rich mudstone
I: Sand-bearing, clay-rich mudstone
J: Sand and silt-bearing clay-rich mudstone
K: Silt and clay-bearing mudstone
L: Sand and clay-bearing mudstone
M: Sand and silt-bearing mudstone
N: Sand, silt and clay-bearing mudstone

Adapted from Macquaker and Adams 2003





Presenter's notes: Mainly based on sedimentology but supported by geochemical variations, explain what a lithofacies is and the criteria for identification- fabric, composition and discuss other variables such as fossil content, grain size, organic matter content

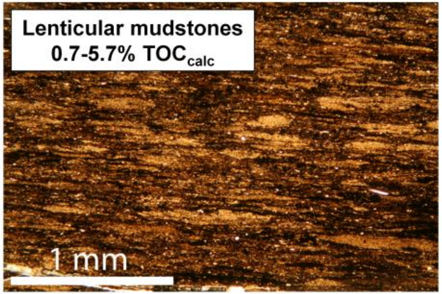


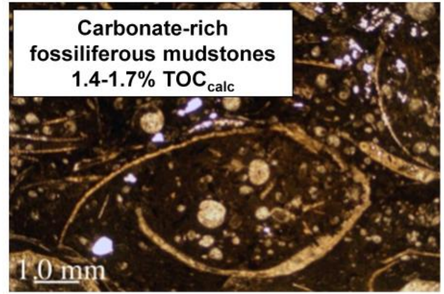
Presenter's notes: This is the distal setting which has 4 main lithofacies – outlined in the next slide. Three logs have been sampled comprehensively in order to study the variation in detail. The logs cover an overall vertical thickness of approximately 5 m and cover a lateral area of 45 m.

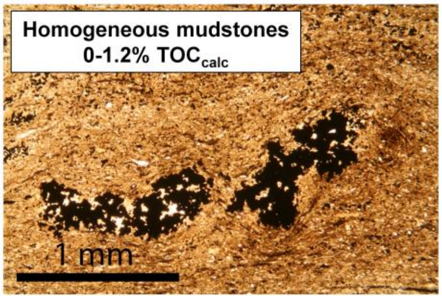
I have marked on the line for 2% TOC as above this it is deemed to be a prospective interval to target for shale gas.

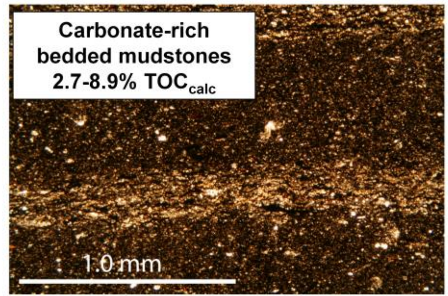
The TOC varied between the lithofacies, as does the geochemistry as we shall see in the data.

Main Lithofacies at Distal Locality



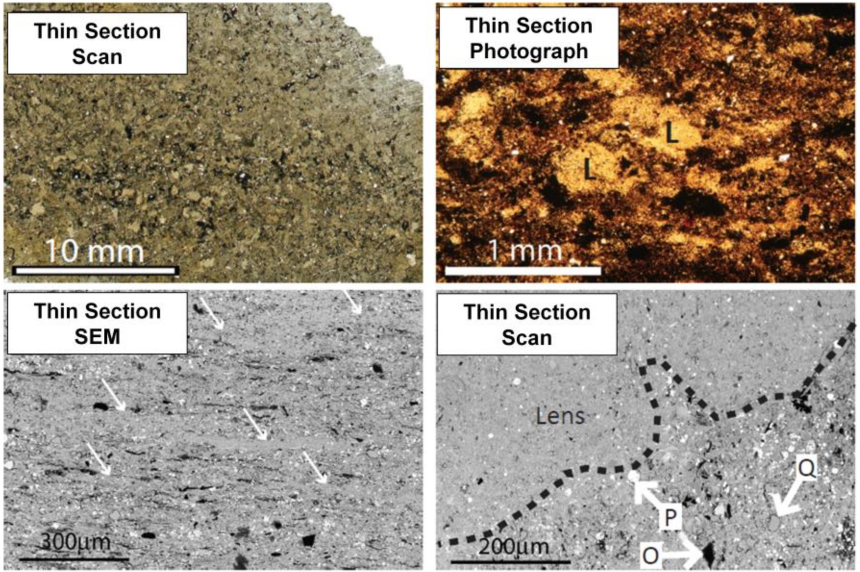






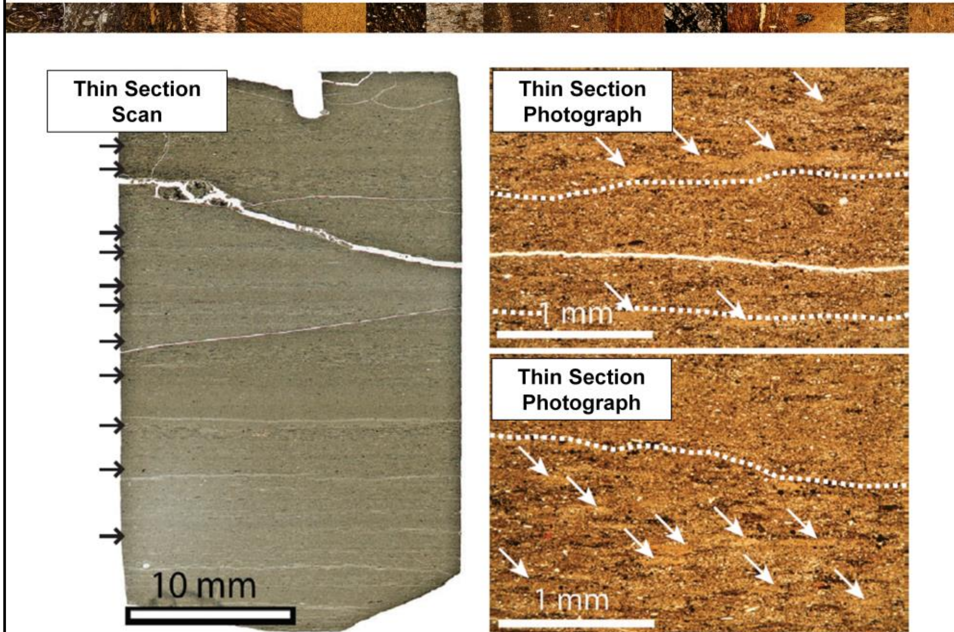
Presenter’s notes: The 4 main lithofacies and corresponding TOC values.

Lenticular Mudstones

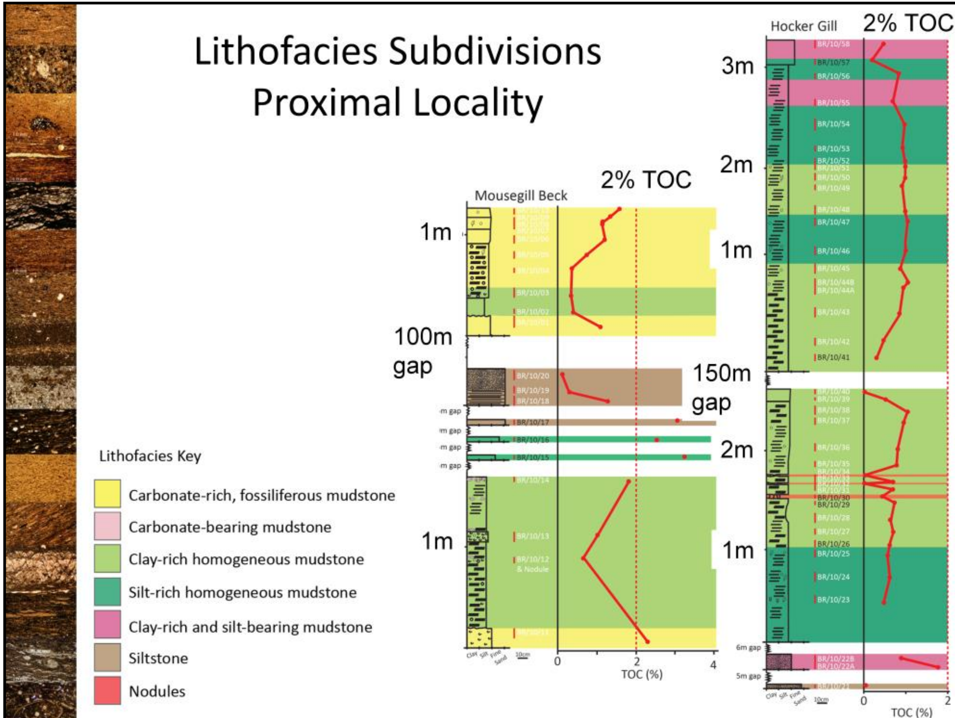


Presenter's notes: The 6 main lithofacies and corresponding TOC values.

Transition Between Lithofacies



Presenter's notes: The 6 main lithofacies and corresponding TOC values.

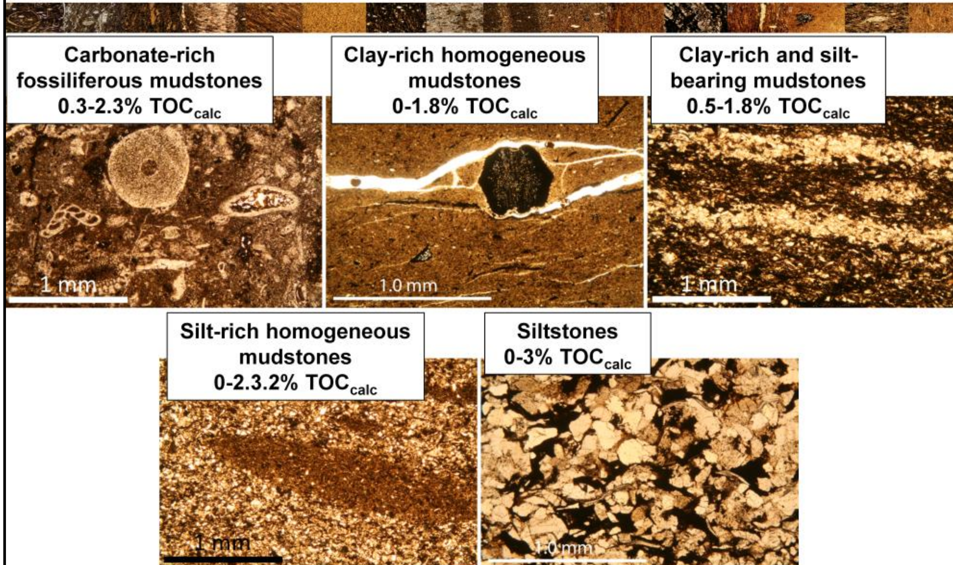


Presenter's notes: This is the proximal setting which has 6 main lithofacies – outlined in the next slide. Three logs have been sampled comprehensively in order to study the variation in detail. The logs are 1 km apart.

I have marked on the line for 2% TOC as above this it is deemed to be a prospective interval to target for shale gas.

The TOC varied between the lithofacies, as does the geochemistry as we shall see in the data.

Main Lithofacies at Proximal Locality

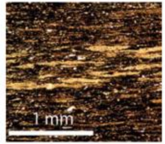


Presenter's notes: The 6 main lithofacies and corresponding TOC values.

Distal - Redox Sensitive Trace Elements

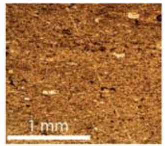
DISTAL

Clay-rich lenticular



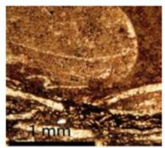
	Proximal	Distal
TOC_{calc} (%)	-	0.7-5.7
Mo (ppm)	-	0.4-205
U (ppm)	-	4.1-25.1
V (ppm)	-	13.5-589.3

Clay-rich homogeneous



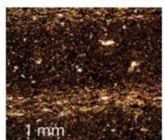
	Proximal	Distal
TOC_{calc} (%)	0-1.8	0-1.2
Mo (ppm)	0.8-1.8	1.9-18.3
U (ppm)	2.4-4.5	5.8-11.9
V (ppm)	87-115	126-232

Carbonate-rich & fossiliferous



	Proximal	Distal
TOC_{calc} (%)	0.3-2.3	1.4-1.7
Mo (ppm)	1.4-2.3	3.6-10.7
U (ppm)	0.4-3.9	8.2-14.8
V (ppm)	14-91	66-252

Carbonate-rich & bedded



	Proximal	Distal
TOC_{calc} (%)	-	2.7-8.9
Mo (ppm)	-	27.8-169.6
U (ppm)	-	6.1-19.7
V (ppm)	-	185-1008

PAAS/Average Shale:

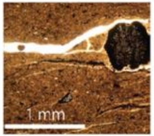
Mo: 1-2 ppm
U: 3 ppm
V: 150 ppm

Presenter’s notes: The 6 main lithofacies and corresponding TOC values.

Proximal - Redox Sensitive Trace Elements

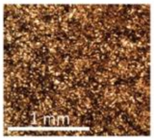
PROXIMAL

Clay-rich homogeneous



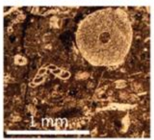
	Proximal	Distal
TOCcalc (%)	0-1.8	0-1.2
Mo (ppm)	0.8-1.8	1.9-18.3
U (ppm)	2.4-4.5	5.8-11.9
V (ppm)	87-115	126-232

Silt-rich homogeneous



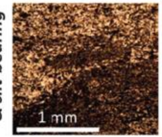
	Proximal	Distal
TOCcalc (%)	0.2-3.2	-
Mo (ppm)	0.9-1.7	-
U (ppm)	2.3-5.0	-
V (ppm)	83-124	-

Carbonate-rich & fossiliferous



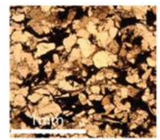
	Proximal	Distal
TOCcalc (%)	0.3-2.3	1.4-1.7
Mo (ppm)	1.4-2.3	3.6-10.7
U (ppm)	0.4-3.9	8.2-14.8
V (ppm)	14-91	66-252

Clay-rich & silt-bearing



	Proximal	Distal
TOCcalc (%)	0.5-1.8	-
Mo (ppm)	1.3-1.5	-
U (ppm)	1.9-4.9	-
V (ppm)	76-113	-

Siltstone



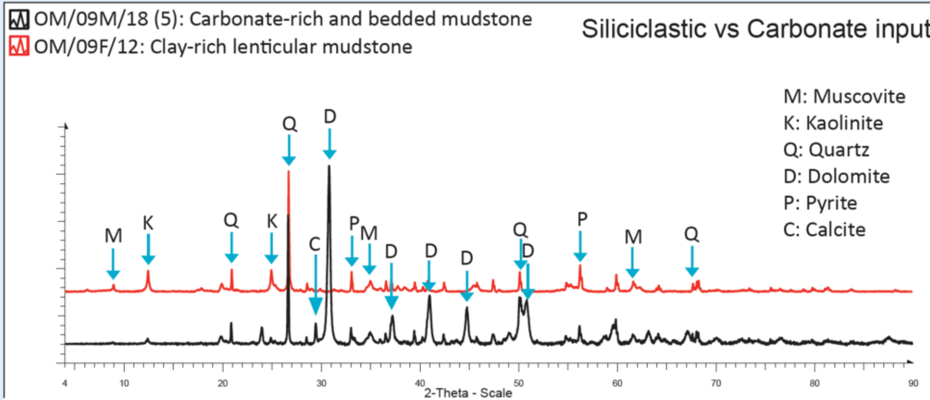
	Proximal	Distal
TOCcalc (%)	0-3.0	-
Mo (ppm)	1.5-1.9	-
U (ppm)	1.3-3.4	-
V (ppm)	60-94	-

PAAS/Average Shale:

Mo: 1-2 ppm
U: 3 ppm
V: 150 ppm

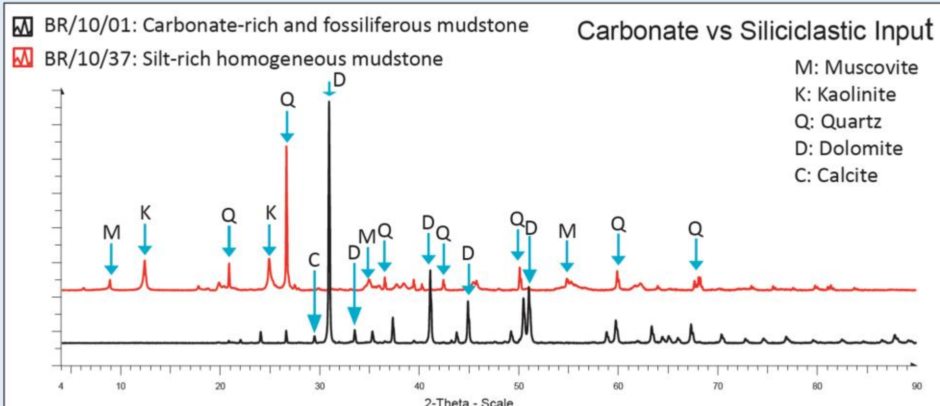
Presenter's notes: The 6 main lithofacies and corresponding TOC values.

Distal setting – variation in XRD profiles



XRD scan displaying the variations between carbonate and siliciclastic inputs at Oakamoor. The main peaks have been identified using the mineral identification database in EVA.

Proximal setting – variation in XRD profiles

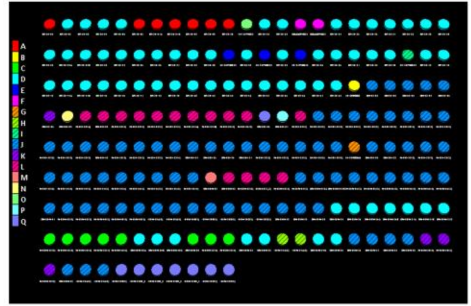


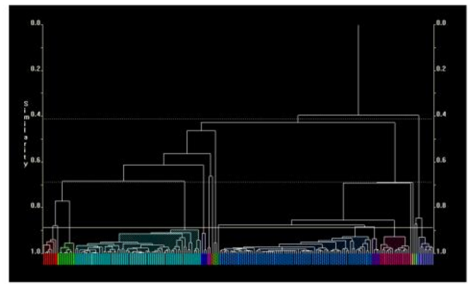
XRD scan displaying the variations between carbonate and siliciclastic inputs at Brough. The main peaks have been identified using the mineral identification database in EVA.

Presenter's notes: No pyrite, rather hematite is seen in these samples. Carbonate-rich profile is cleaner.

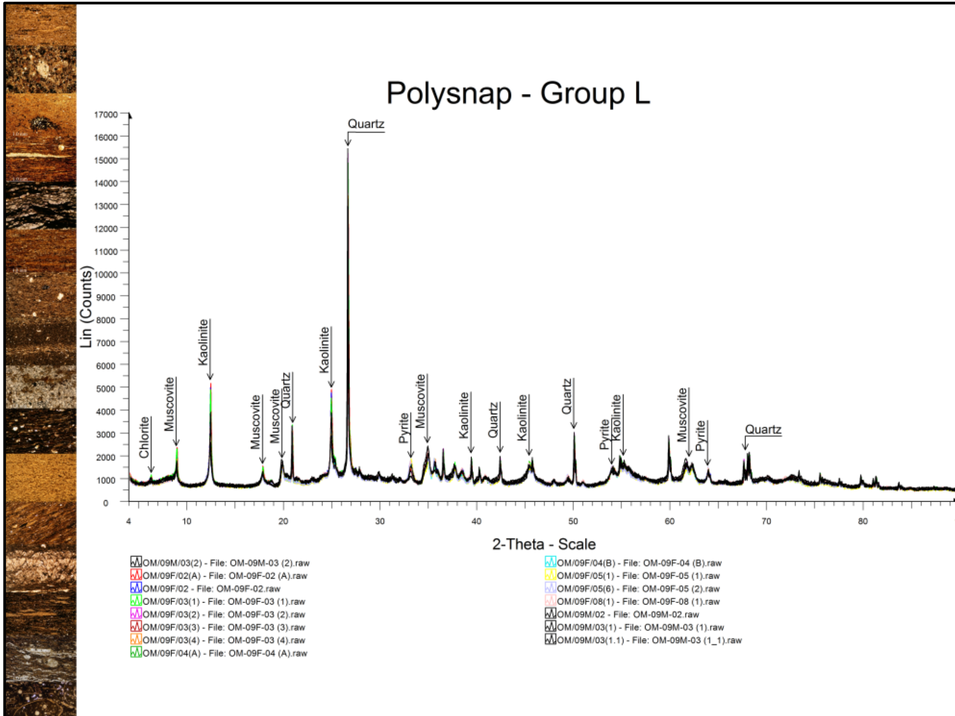
Geochemistry: Polysnap

- Cluster Analysis software
- Patterns from XRD scans
- Background calculations – important for samples with high iron content
- Compositional variations not fabric variations





Presenter's notes: Polysnap is cluster analysis software which has been used in conjunction with the XRD data to split the samples into groups. The aim with the software was to see if it could differentiate groups which would match the groups based on the lithofacies from the thin section analysis. The initial grouping that was suggested was too vague, as it only produced 6 groups. However, with the software it is possible to adjust the groupings by sliding the bar on the dendrogram. This was done in a series of steps to study which samples were being separated out. This dendogram that is shown is the final result from the polysnap analysis after examining the various groupings. Polysnap can be very helpful to interpret a large dataset, however, it cannot replace studying a number of XRD scans as the default setting does not split the samples far enough.

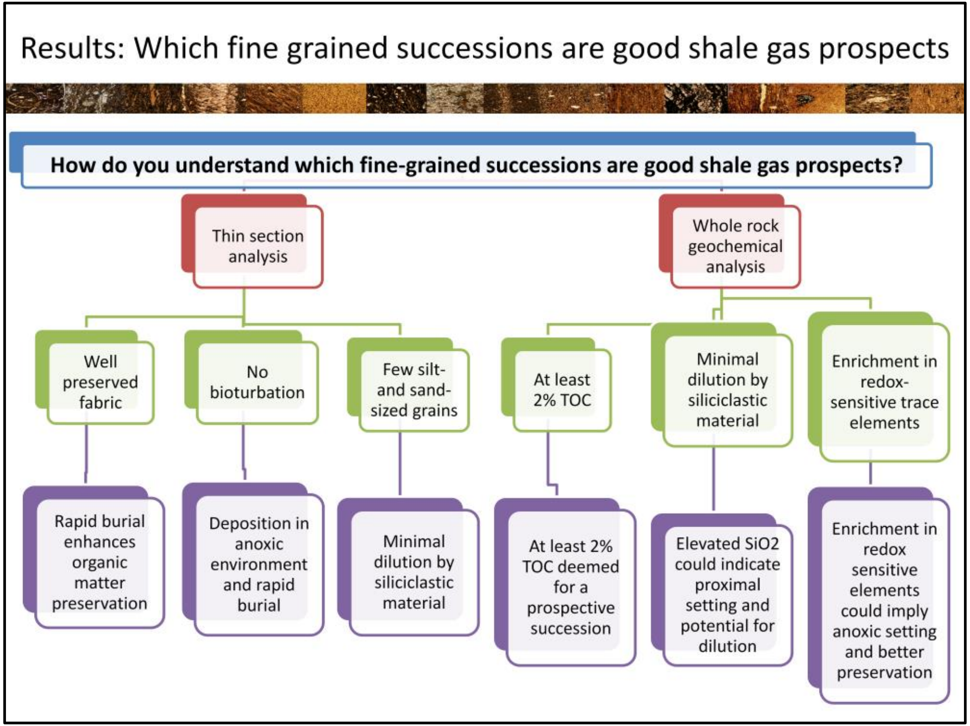


Presenter's notes: An example of one of the groups. This group contains samples from the clay-rich homogeneous lithofacies, but only those from the weathered type, not the framboid-bearing type.

Results: Predicting distribution and concentration of organic matter

How do you predict the distribution and concentration of organic matter in the basin?

- Qu1: Where is the section located in the basin?
  - Proximal – TOC diluted close to source and oxygenated leading to more intense bioturbation
    - Lower preservation potential
  - Distal – TOC not diluted by source and potential anoxic conditions decreasing bioturbation
    - Higher preservation potential
- Qu2: What is the lithofacies?
  - Lithofacies and TOC values correlate – both influenced by depositional and environment processes
    - Lithofacies vary by location so determining lithofacies can assist section location in basin
- Qu3: What is the TOC?
  - Low
    - Oxygenated environment with low preservation potential
  - High
    - Anoxic environment or rapid burial likely resulting in high preservation potential



Presenter's notes: In answering the second question we want to focus in on pelleted mudstones and the more distal location as these are most likely to produce high TOC and a suitable source. Bedded mudstones are more variable in carbon content, however, combined with the pelleted mudstones are likely to produce a prospective succession. Where the homogeneous mudstones dominate the typical TOC values are less than 2% and therefore much less likely to produce a prospective interval.

Major conclusions from this research

- Mudstone fabrics are varied and important for interpreting depositional processes
- Marine band fabrics in this study are not indicative of slow sedimentation
- Mineralogical similarity exists across the basin – variation is more significant in the trace elements
- TOC_{calc} varies between lithofacies and across the basin
- Enrichment in redox-sensitive trace elements can occur with fauna therefore does not necessarily imply anoxic conditions