Architecture and Connectivity of Coal-Bearing Reservoirs: New Insights From Outcrop Analogues*

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Abstract

Predictive model for coal-bearing fluvio-deltaic successions in the subsurface are required to drive the effective and cost efficient hydrocarbon development of both unconventional coal-bed methane and conventional reservoir projects. The Eastern Kentucky and West Virginia road network provide world-class exposures of Upper Carboniferous coal bearing successions where the interplay between sand and shale intervals and intervening coals can be studied in detail. In this paper we present a summary of ongoing research recently carried out on the Pennsylvanian Hyden and Pikeville Formations where architecture and laterial facies variability can be observed and followed for several kilometers thanks to exceptional outcrop quality and dense borehole data from coal mining operations. Coals, usually genetically associated with transgressive system tract, lies often on top of channel-fill sandstone and under shale dominated intervals the latter recording the transition from a flooded coastal plain to shallow to deep marine environment. However coals are found as well draping irregular topographic surfaces where wide and relatively deep (10–20 m) incisions can be recognized. In this situation coals are typically overlain by channel fill sandstone forming the stratigraphical unit above. In this case, the coals are interpreted as forming during a low stand phase and thus possibly the true indicators of development of incised valleys. Five to ten meters-high inclined beds made of mixed heterolithic successions of sandstones and shales are associated with both fluvial-dominated mouth bars and point-bars develop in large meandering river systems often developed within estuarine environment. This study highlights the typical 3D features of these deposits allowing the definition of sedimentological and stratigraphical criteria to distinguish these tow systems in the subsurface. The Carboniferous succession of Eastern Kentucky is compared with the coeval succession in the North Sea (The

Netherlands) to highlight the importance of outcrop based analogues studies to help understanding the overall distribution of subsurface geology by providing practical criteria for a) carrying out a well-to-well correlation and b) reconstruct the overall 3D reservoir architecture.

Selected References

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FACULTÉ DES SCIENCES
Earth and Environmental Sciences

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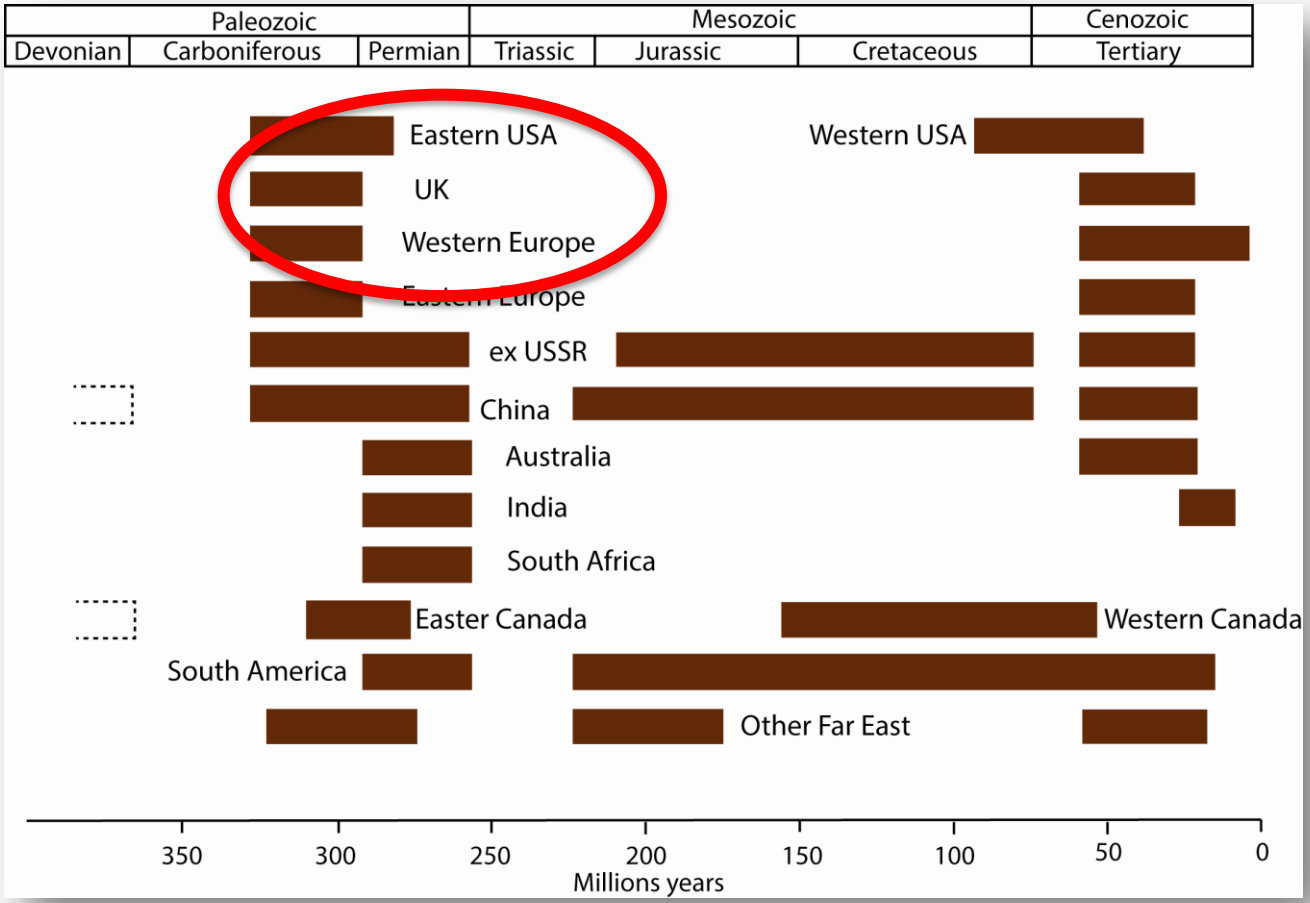
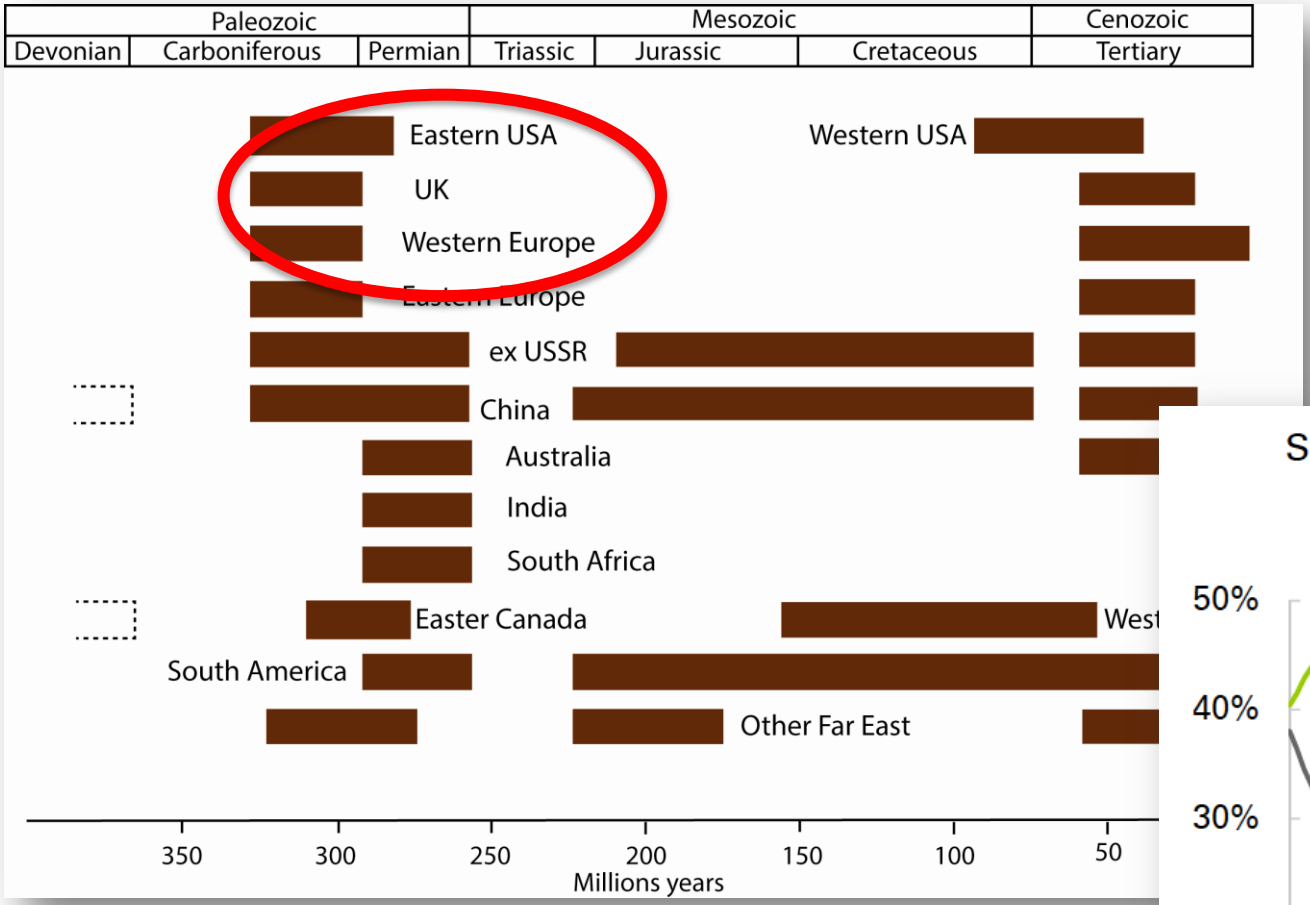
AAPG Annual Convention & Exhibition 2015

SUSTAINED IMPORTANCE OF COAL-BEARING SUCCESSIONS



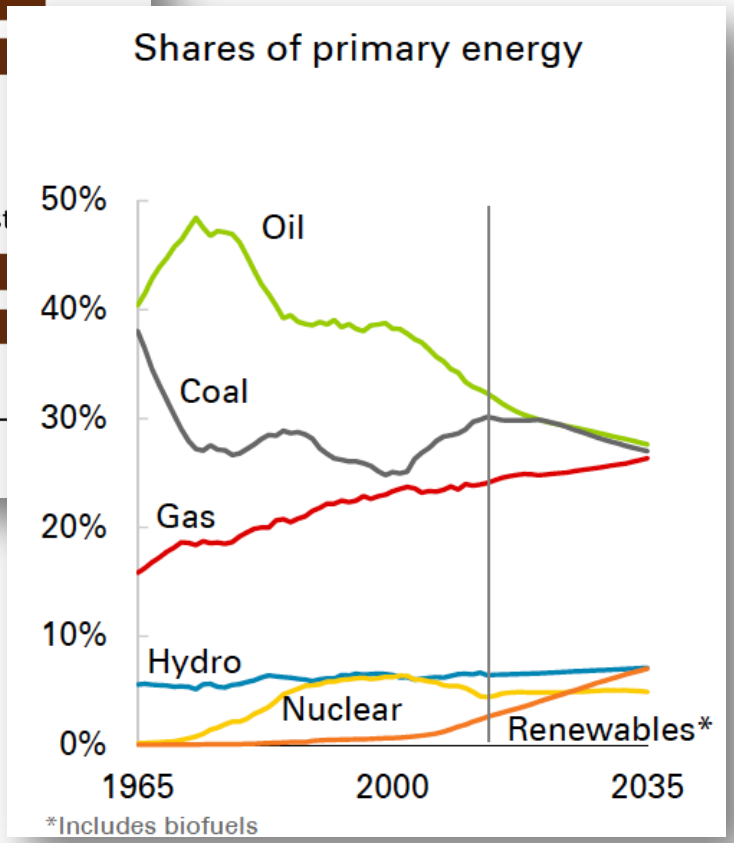
Geological age distribution of principal World's black coal and lignite deposits (modified form Walker, 2000 and Thomas,2002)

SUSTAINED IMPORTANCE OF COAL-BEARING SUCCESSIONS



Geological age distribution of principal World's black coal and lignite deposits (modified form Walker, 2000 and Thomas,2002)

BP Energy outlook 2035



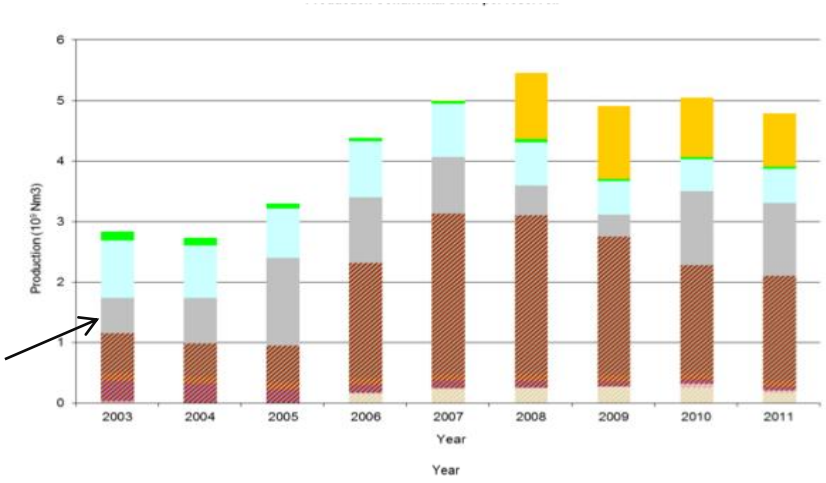
COAL WILL REMAIN AN IMPORTANT GEO-ENERGY RESOURCE IN THE NEAR FUTURE

Producing from Carboniferous the Dutch/UK SNS: Where are we now ?

- Effective production of deep Carboniferous gas reservoirs is largely driven by understanding reservoir properties distribution and sand connectivity in a relatively low net:gross environment.

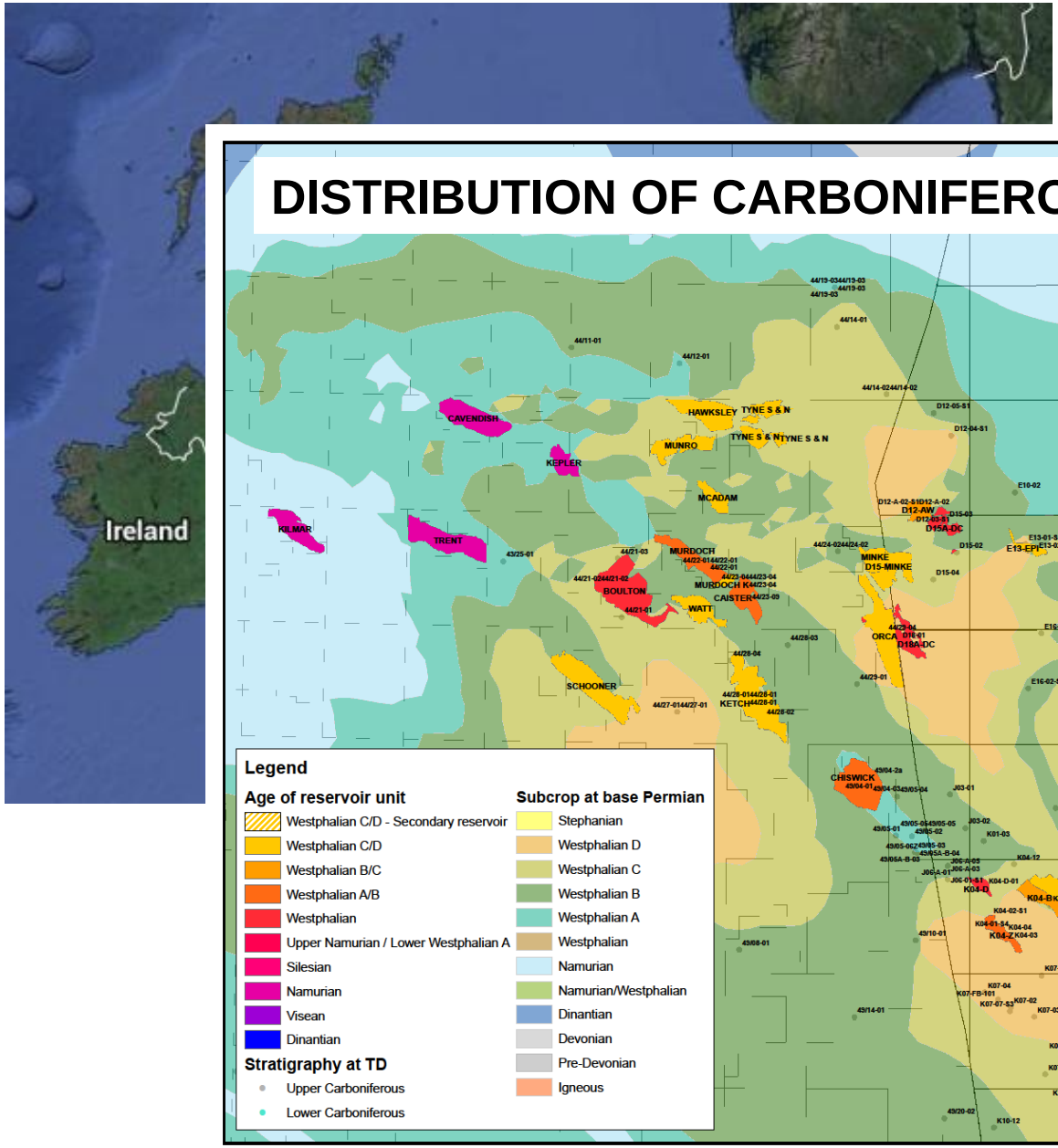
- Develop a predictive model assisting the location and characterization of reservoir quality and connected net-volumes is challenging:
  - complex facies heterogeneity
  - internal reservoir architecture
  - diagenetic history.

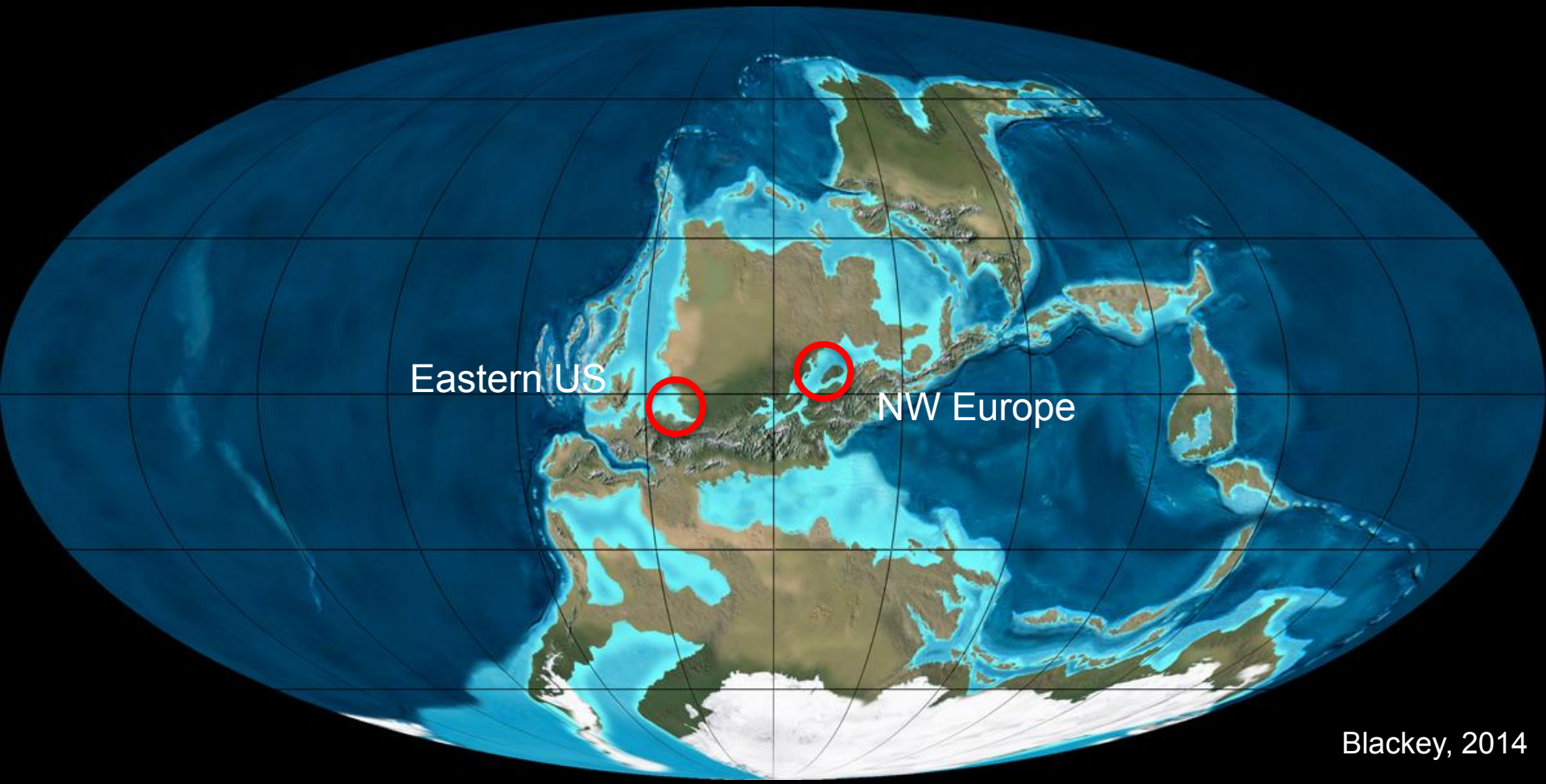
Carboniferous Reservoirs



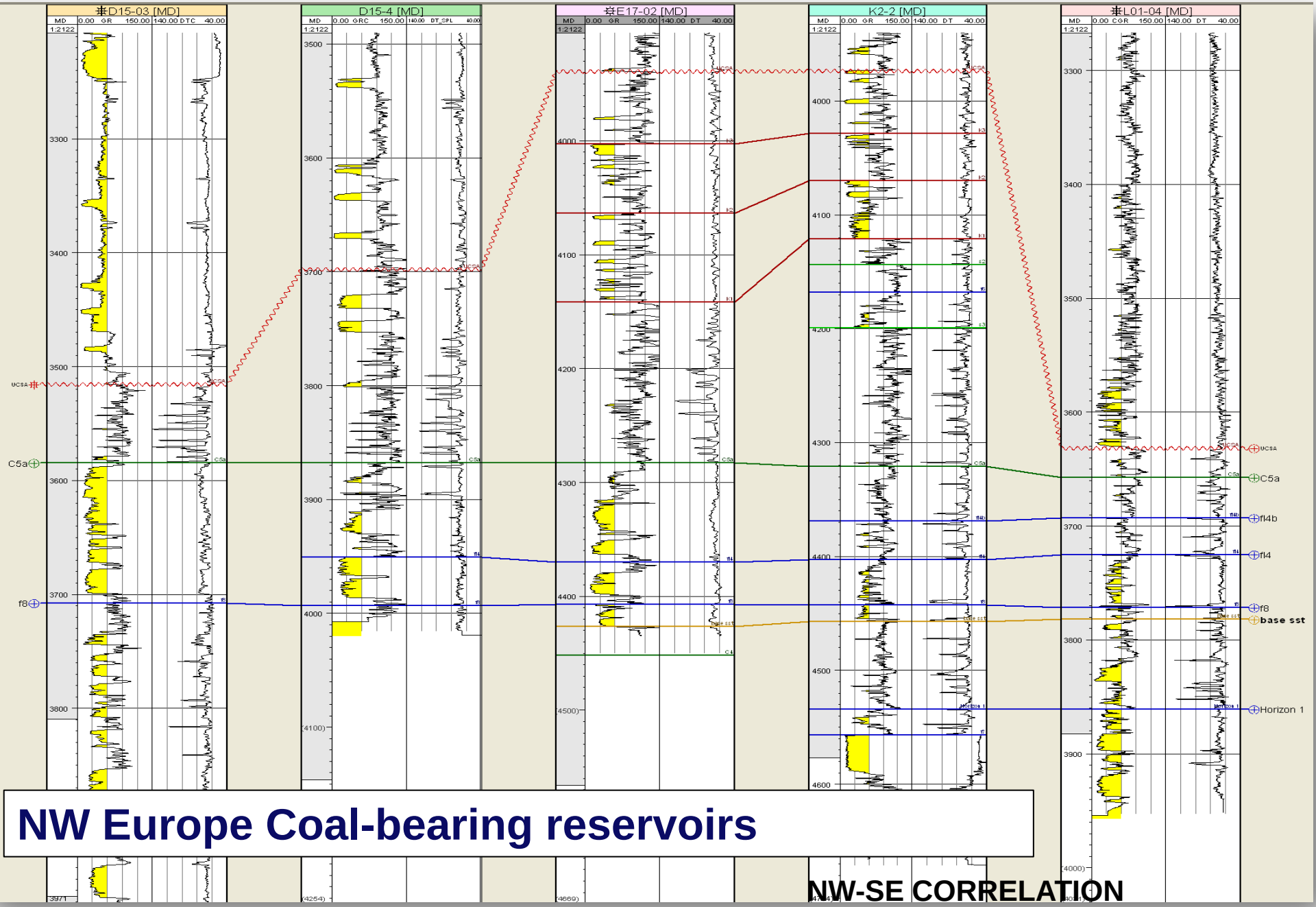

North Sea
Denmark
United Kingdom
Isle of Man
Ireland
Netherlands
Belgium
Germany
Luxembourg

DISTRIBUTION OF CARBONIFEROUS FIELDS IN THE SNS



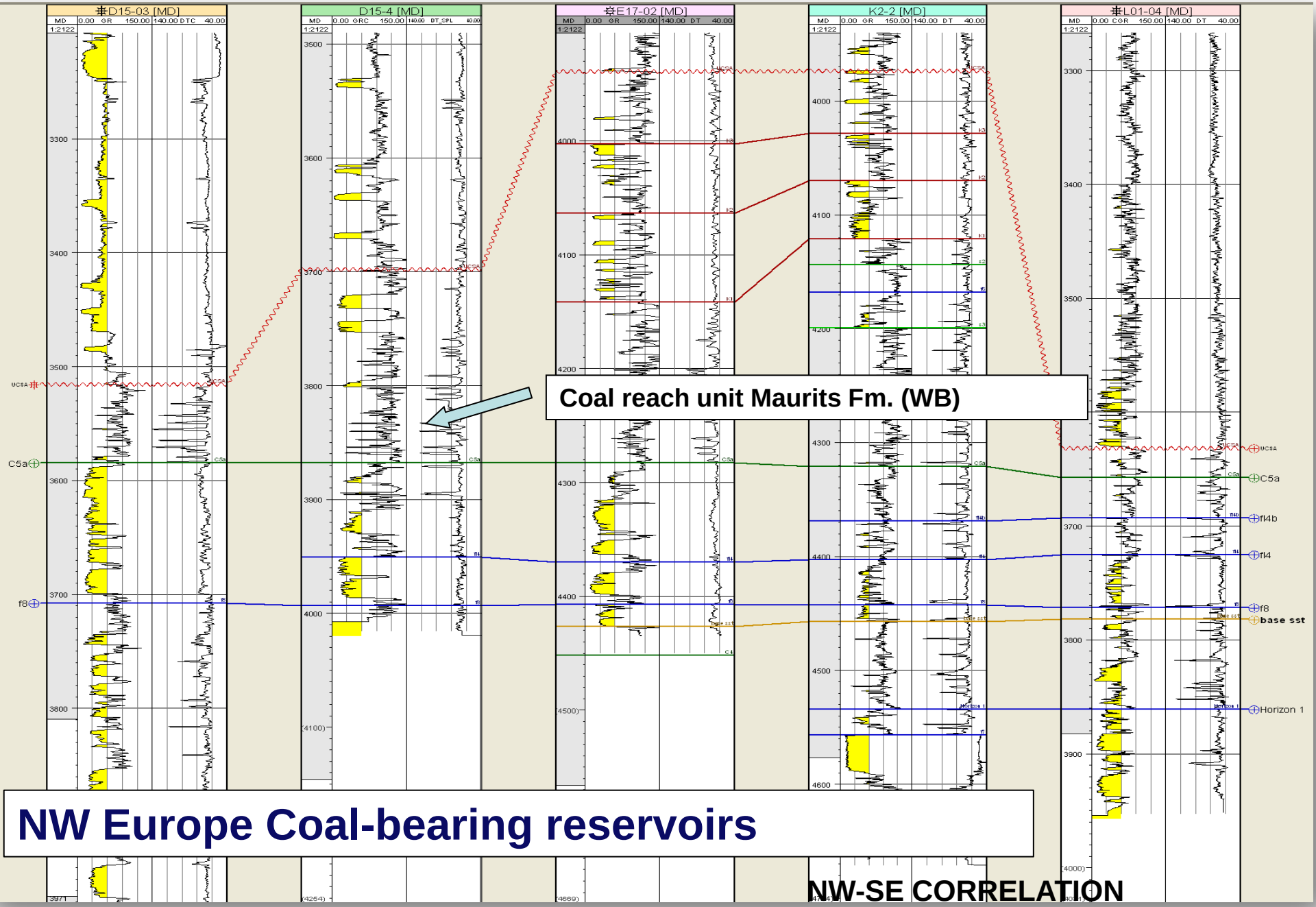


Upper Carboniferous (Westphalian B / Mid Pennsylvanian)

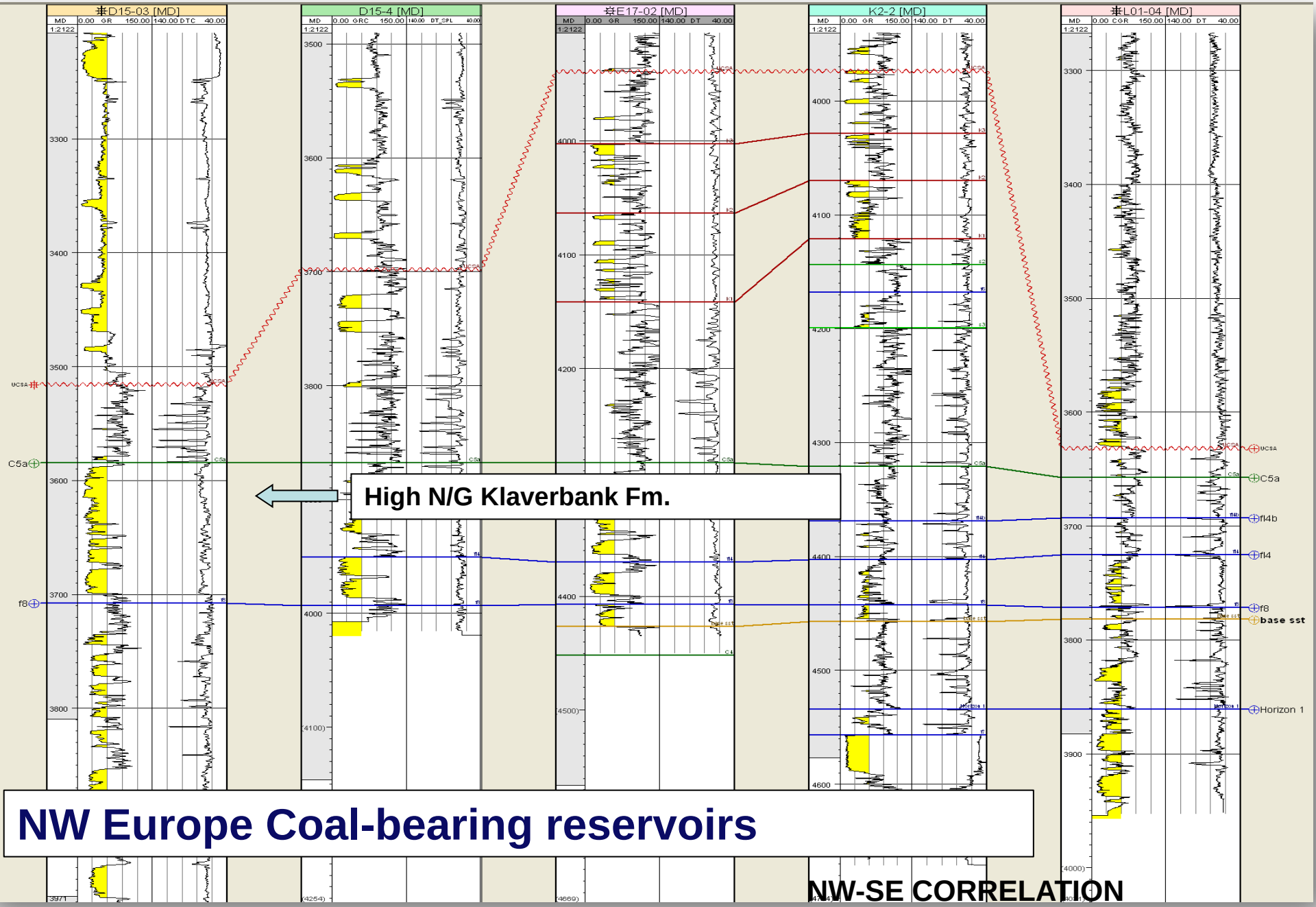


NW Europe Coal-bearing reservoirs

NW-SE CORRELATION

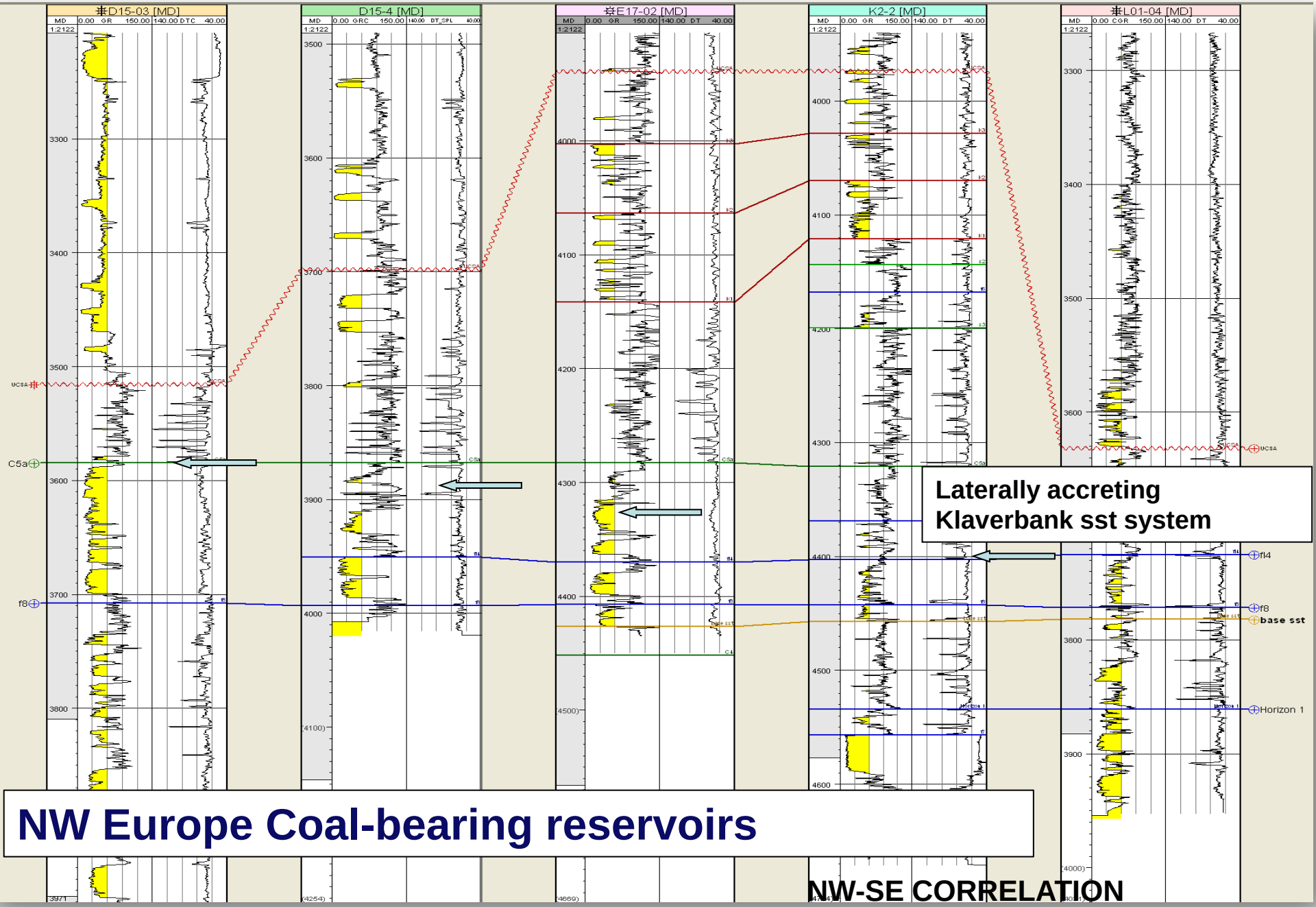


NW Europe Coal-bearing reservoirs

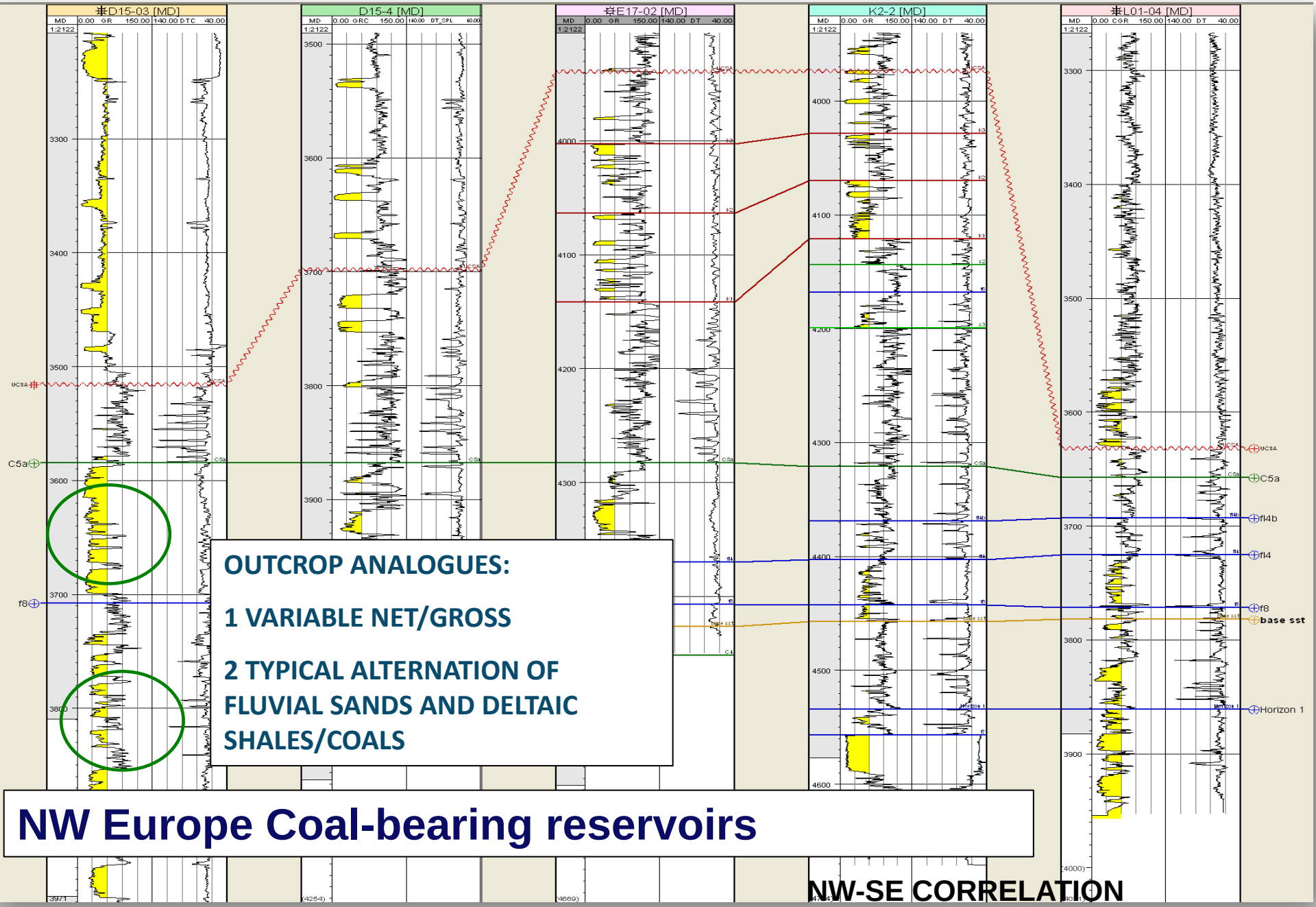


NW Europe Coal-bearing reservoirs

NW-SE CORRELATION

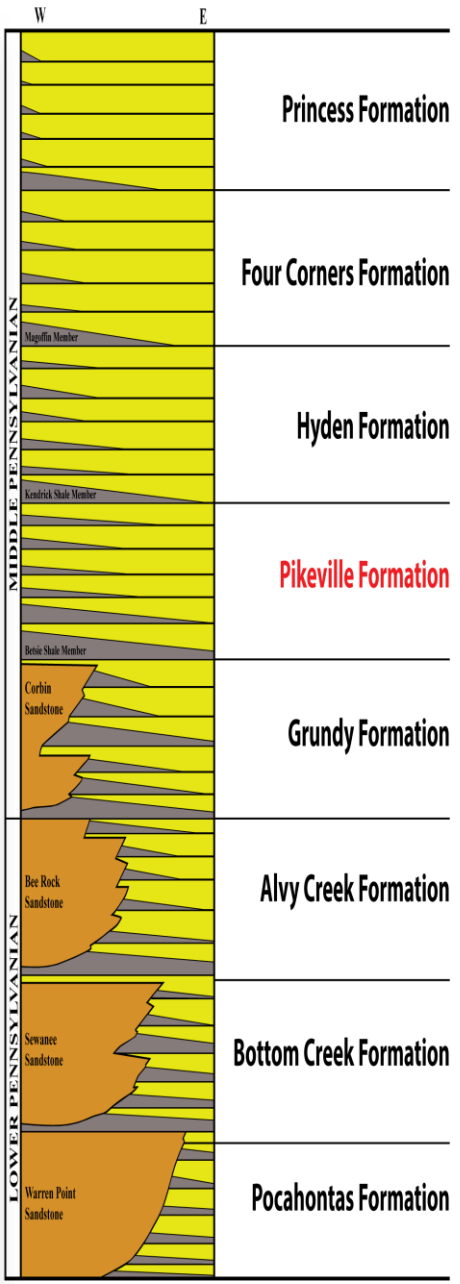


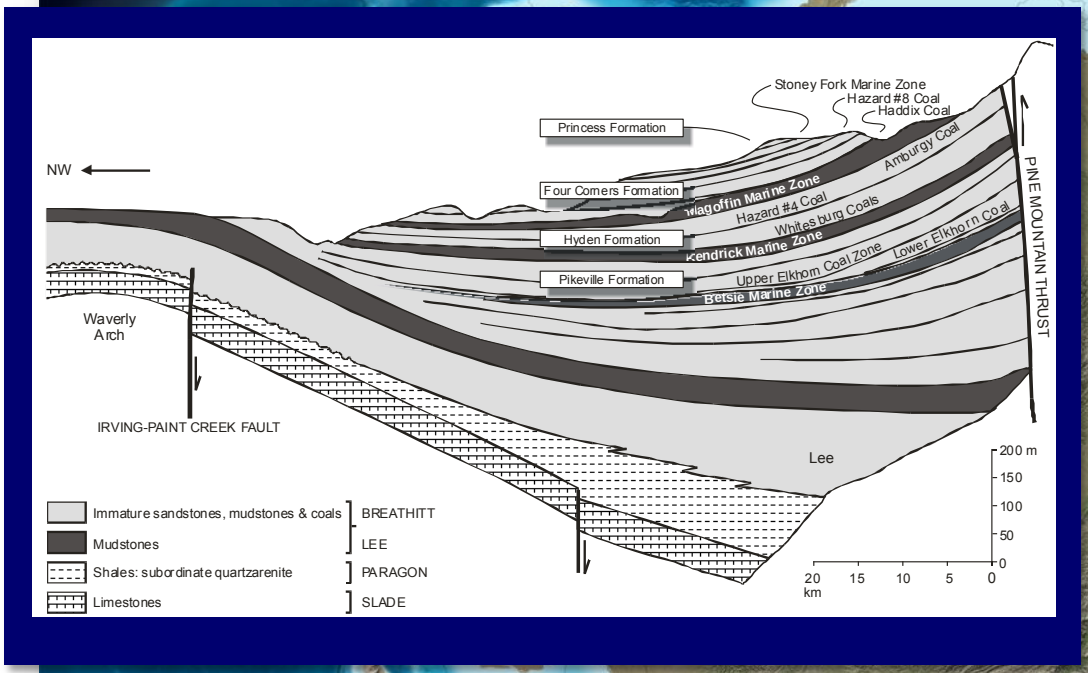
NW Europe Coal-bearing reservoirs



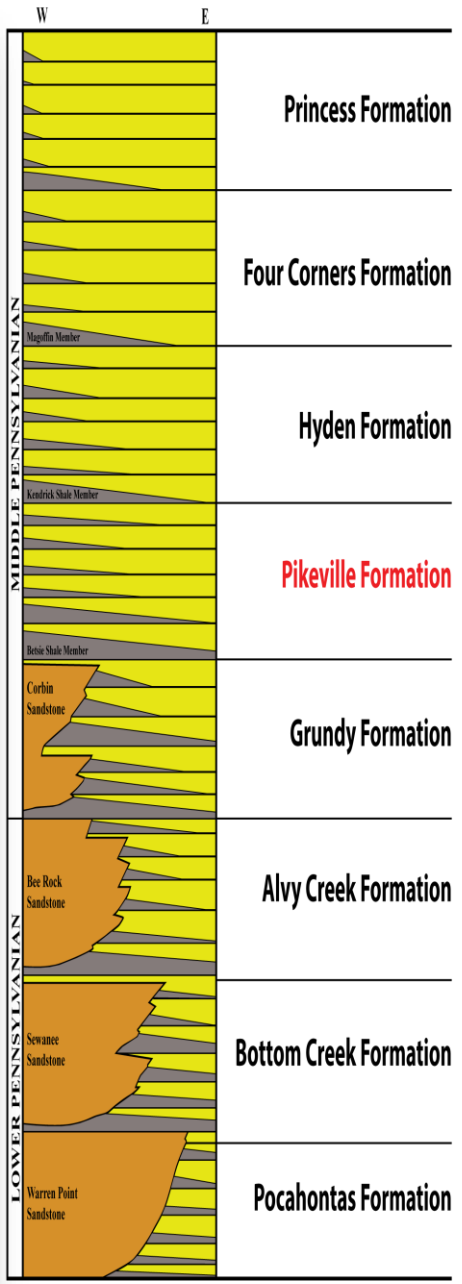
NW Europe Coal-bearing reservoirs


Eastern
Kentucky
Westphalian B / Middle Pennsylvenian


W
E
MIDDLE PENNSYLVANIAN
LOWER PENNSYLVANIAN
Princess Formation
Four Corners Formation
Magoffin Member
Hyden Formation
Kendrick Shale Member
Pikeville Formation
Betsie Shale Member
Corbin Sandstone
Grundy Formation
Bee Rock Sandstone
Alvy Creek Formation
Sewanee Sandstone
Bottom Creek Formation
Warren Point Sandstone
Pocahontas Formation
Breathitt Group sequences


Stoney Fork Marine Zone
Hazard #8 Coal
Haddix Coal
Princess Formation
Amburgy Coal
NW
Four Corners Formation
Magoffin Marine Zone
Hazard #4 Coal
Whitesburg Coals
Hyden Formation
Kendrick Marine Zone
Lower Elkhorn Coal
Upper Elkhorn Coal Zone
Pikeville Formation
Betsie Marine Zone
PINE MOUNTAIN THRUST
Waverly Arch
IRVING-PAINT CREEK FAULT
Lee
200 m
150
100
50
0
20 15 10 5 0
km
Immature sandstones, mudstones & coals
Mudstones
Shales: subordinate quartzarenite
Limestones
BREATHITT
LEE
PARAGON
SLADE

Eastern Kentucky
Westphalian B / Middle Pennsylvenian


W
E
MIDDLE PENNSYLVANIAN
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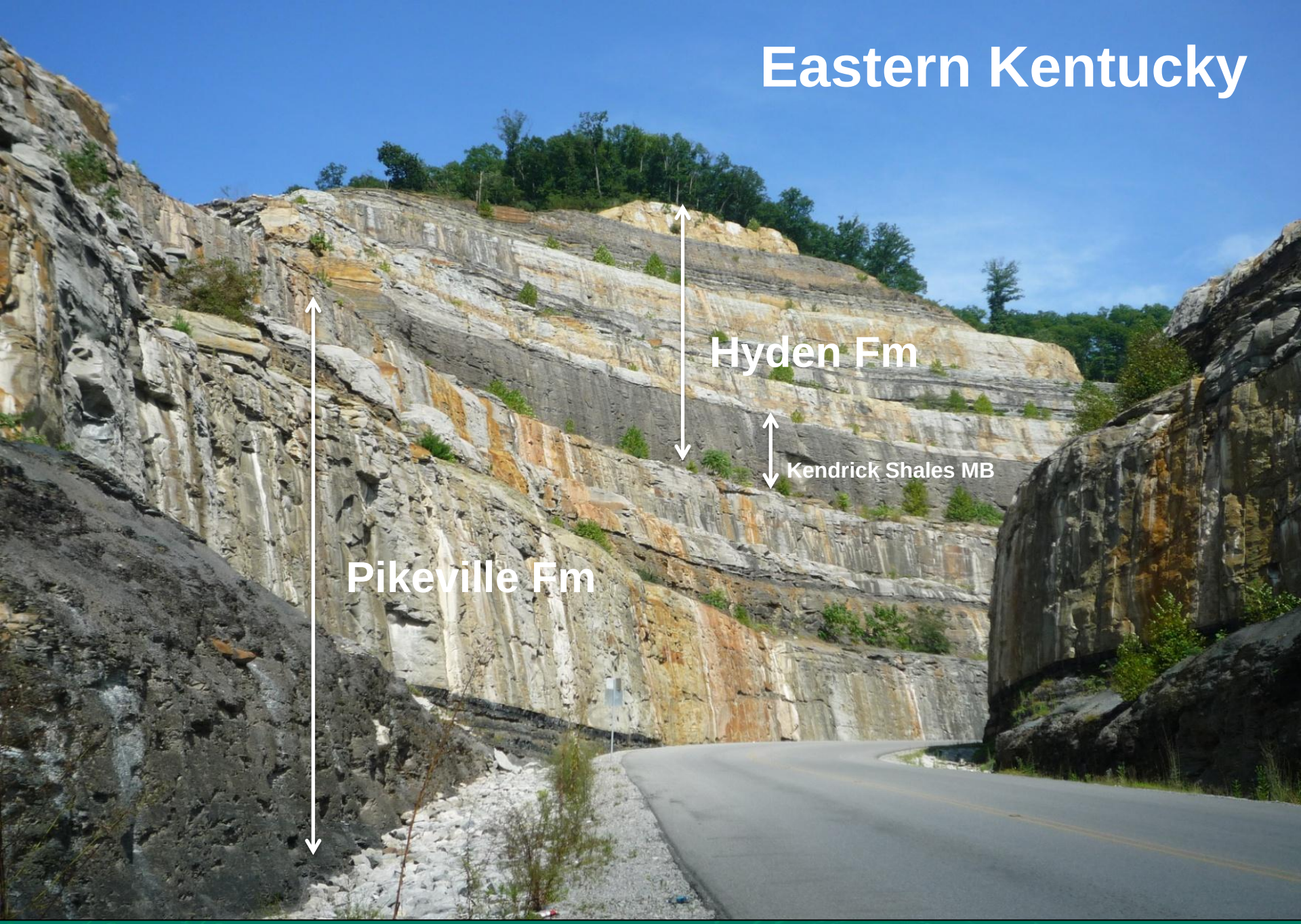
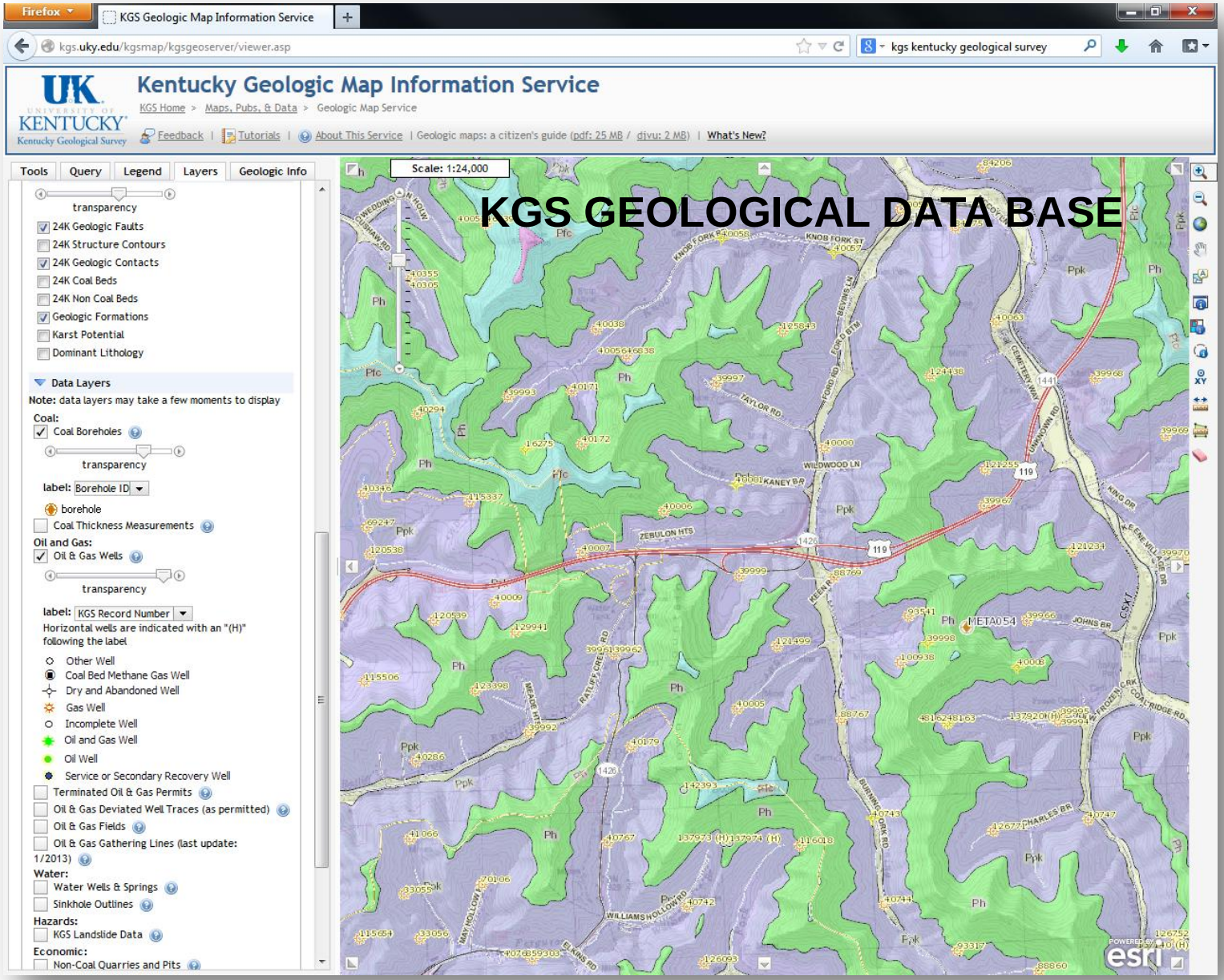
Breathitt Group sequences

Eastern Kentucky

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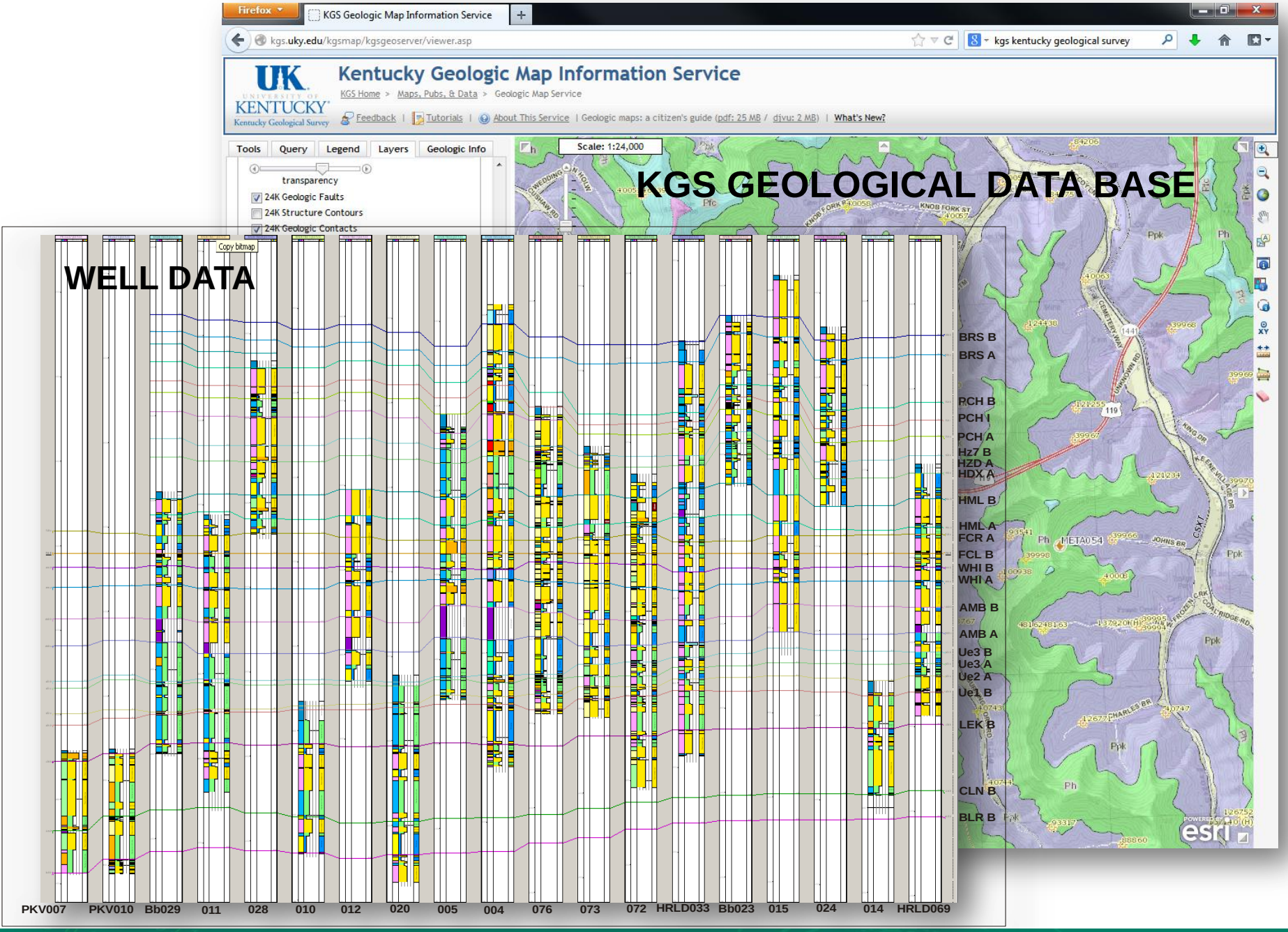
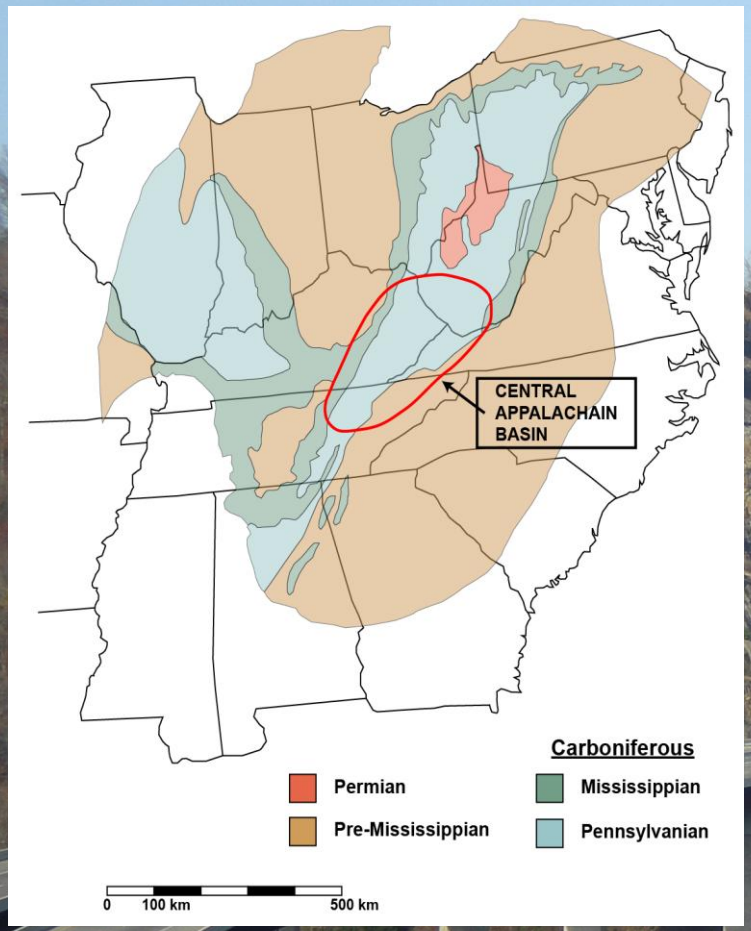
kgs kentucky geological survey
Kentucky Geologic Map Information Service
KGS Home > Maps, Pubs, & Data > Geologic Map Service
Feedback | Tutorials | About This Service | Geologic maps: a citizen's guide (pdf: 25 MB / djvu: 2 MB) | What's New?
Tools
Query
Legend
Layers
Geologic Info
transparency
24K Geologic Faults
24K Structure Contours
24K Geologic Contacts
24K Coal Beds
24K Non Coal Beds
Geologic Formations
Karst Potential
Dominant Lithology
Data Layers
Note: data layers may take a few moments to display
Coal:
Coal Boreholes
transparency
label: Borehole ID
borehole
Coal Thickness Measurements
Oil and Gas:
Oil & Gas Wells
transparency
label: KGS Record Number
Horizontal wells are indicated with an "(H)" following the label
Other Well
Coal Bed Methane Gas Well
Dry and Abandoned Well
Gas Well
Incomplete Well
Oil and Gas Well
Oil Well
Service or Secondary Recovery Well
Terminated Oil & Gas Permits
Oil & Gas Deviated Well Traces (as permitted)
Oil & Gas Fields
Oil & Gas Gathering Lines (last update: 1/2013)
Water:
Water Wells & Springs
Sinkhole Outlines
Hazards:
KGS Landslide Data
Economic:
Non-Coal Quarries and Pits
Scale: 1:24,000
KGS GEOLOGICAL DATA BASE
esri


Kentucky Geologic Map Information Service
KGS GEOLOGICAL DATA BASE
WELL DATA
Tools
Query
Legend
Layers
Geologic Info
transparency
24K Geologic Faults
24K Structure Contours
24K Geologic Contacts
Scale: 1:24,000
BRS B
BRS A
PCH B
PCH I
PCH A
Hz7 B
HZD A
HDX A
HML B
HML A
FCR A
FCL B
WHI B
WHI A
AMB B
AMB A
Ue3 B
Ue3 A
Ue2 A
Ue1 B
LEK B
CLN B
BLR B
PKV007
PKV010
Bb029
011
028
010
012
020
005
004
076
073
072
HRLD033
Bb023
015
024
014
HRLD069


Eastern Kentucky
Kendrick Shale Mbr
Hyden Fm
Kendrick Shale Mbr
Pikeville Fm



Kendrick Shale Mbr

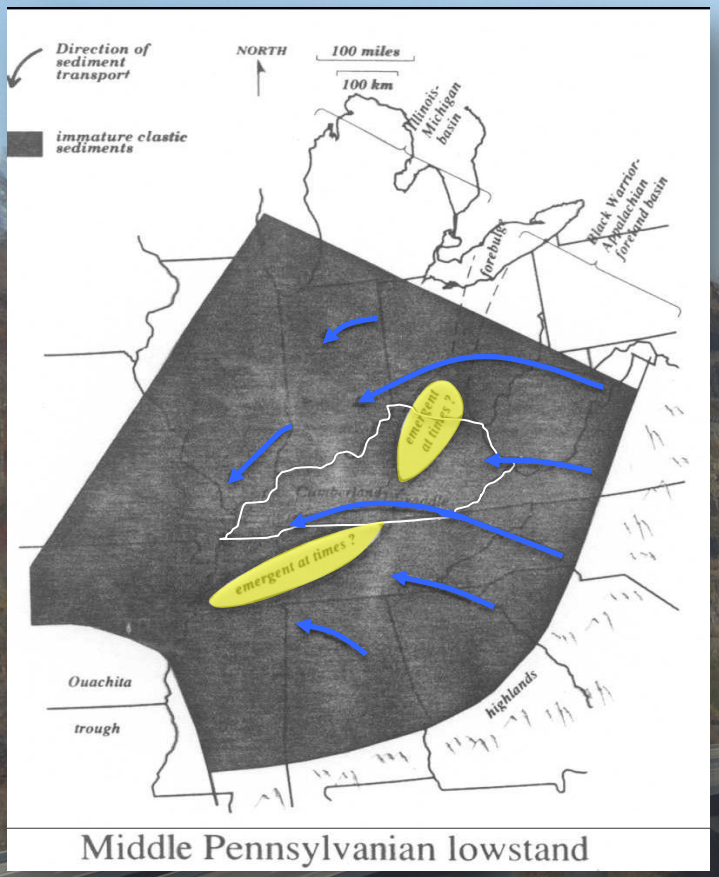
Hyden Fm

Kendrick Shale Mbr

Pikeville Fm

1) Can we describe and quantify the stratigraphic and sedimentologic changes along the plaeoflow direction (east to west) ?
2) Paleo-drainage dominated by westwards paleoflow? Any influence from local highs?
3) What's the impact on reservoir continuity and modelling ?

Eastern Kentucky



Middle Pennsylvanian lowstand

Chesnut, 1993

Kendrick Shale Mbr

Hyden Fm

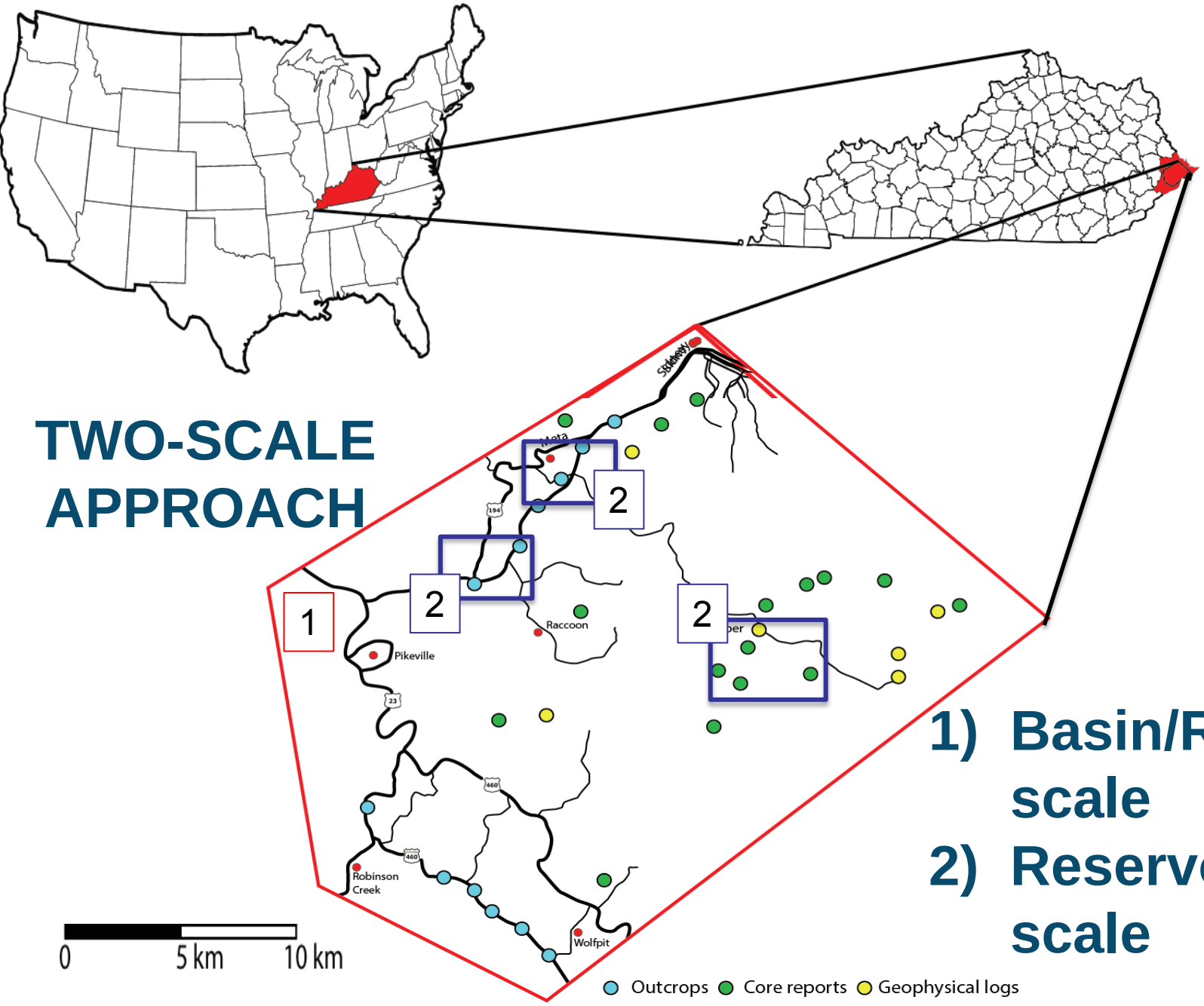
Kendrick Shale Mbr

Pikeville Fm

1) Can we describe and quantify the stratigraphic and sedimentologic changes along the plaeoflow direction (east to west) ?
2) Paleo-drainage dominated by westwards paleoflow? Any influence from local highs?
3) What's the impact on reservoir continuity and modelling ?

Study Approach

- Regional and Reservoir-scale approach
  - 30 x 30 km area
  - 0.5 x 0.5 km area (sector models)
- Closely spaced detailed stratigraphic logs (1:20 scale) of outcrop sections and cores.
- Large photo-panel correlations
- Deatiled petrographic study using conventional petrography and QEMSCAN (UNIGE)
  - Provenance, texture, diagenesis (ca. 300 samples)
- Reservoir Property analysis
- Data integration in Geo-cellular models



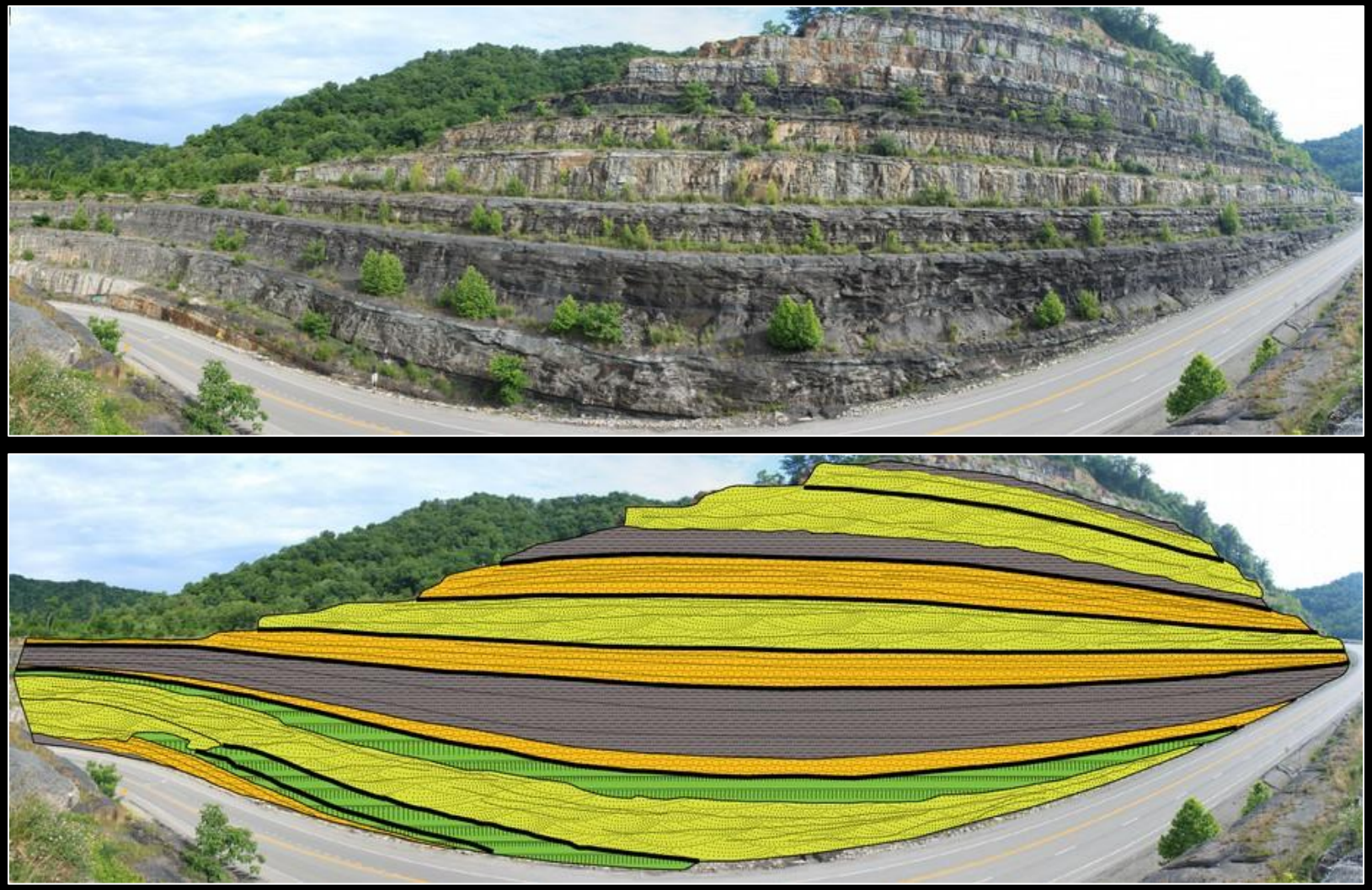
TWO-SCALE APPROACH

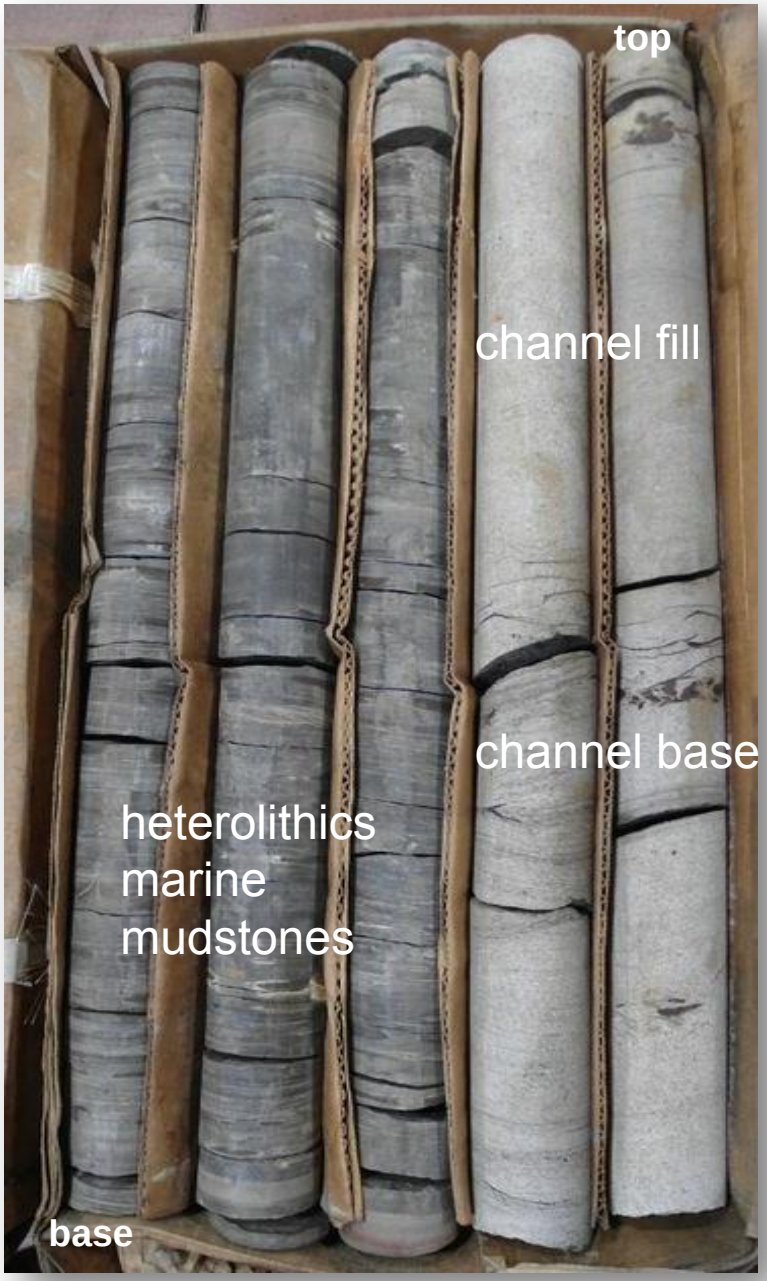
1) Basin/Regional scale
2) Reservoir /Field scale

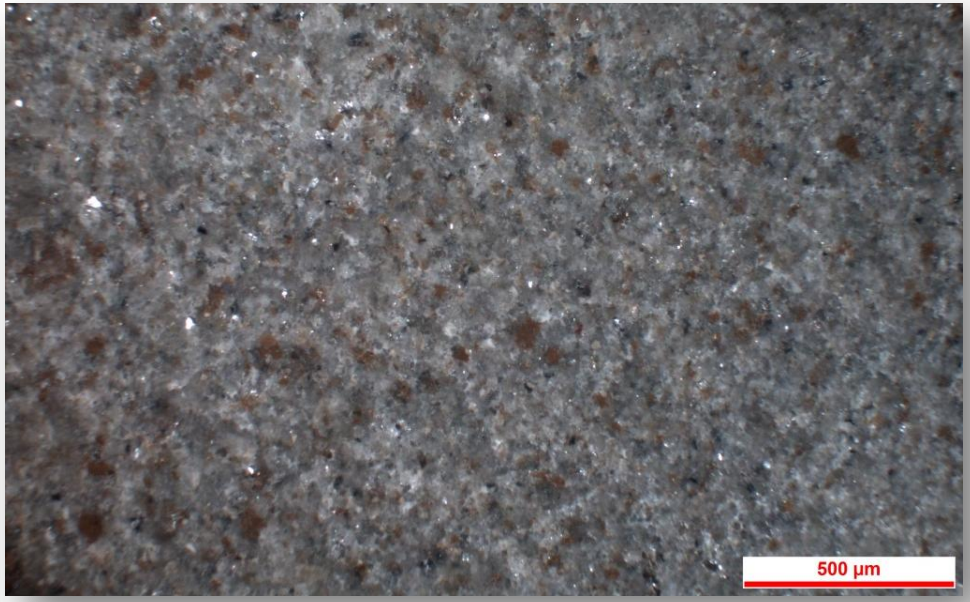
John's Creek outcrop

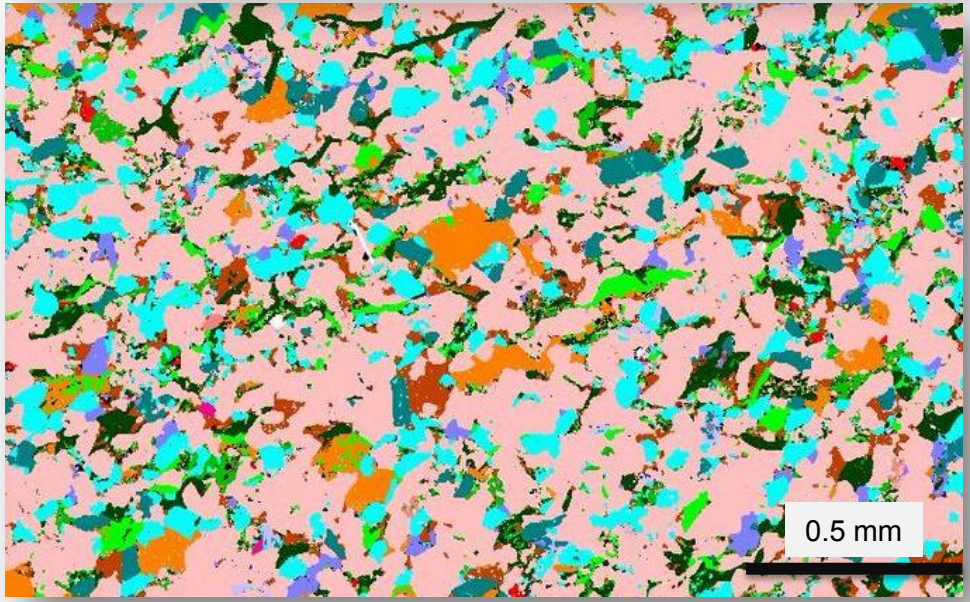
SW

NE



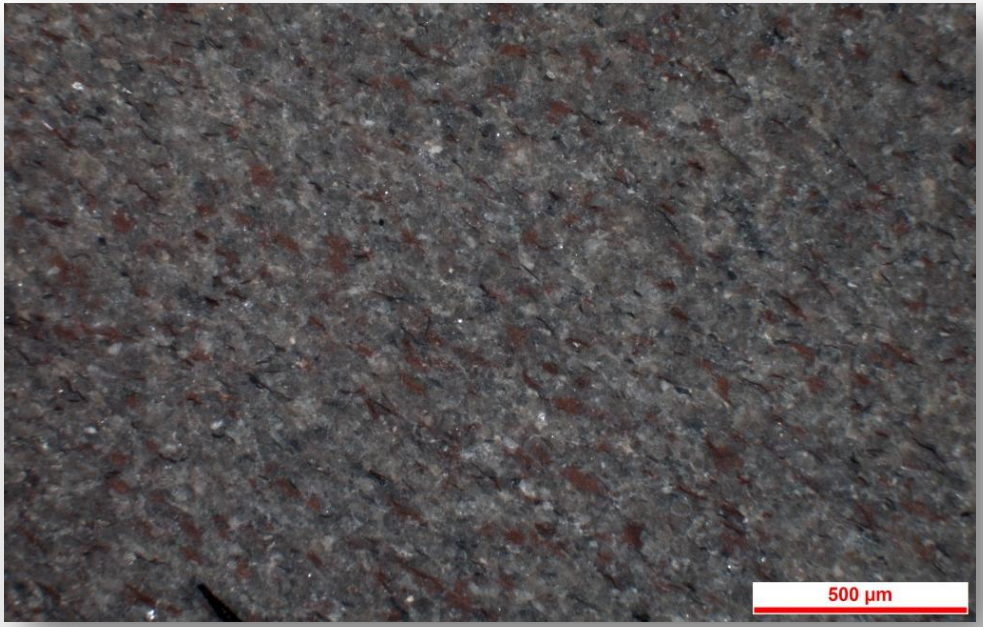

top
channel fill
channel base
heterolithics
marine
mudstones
base

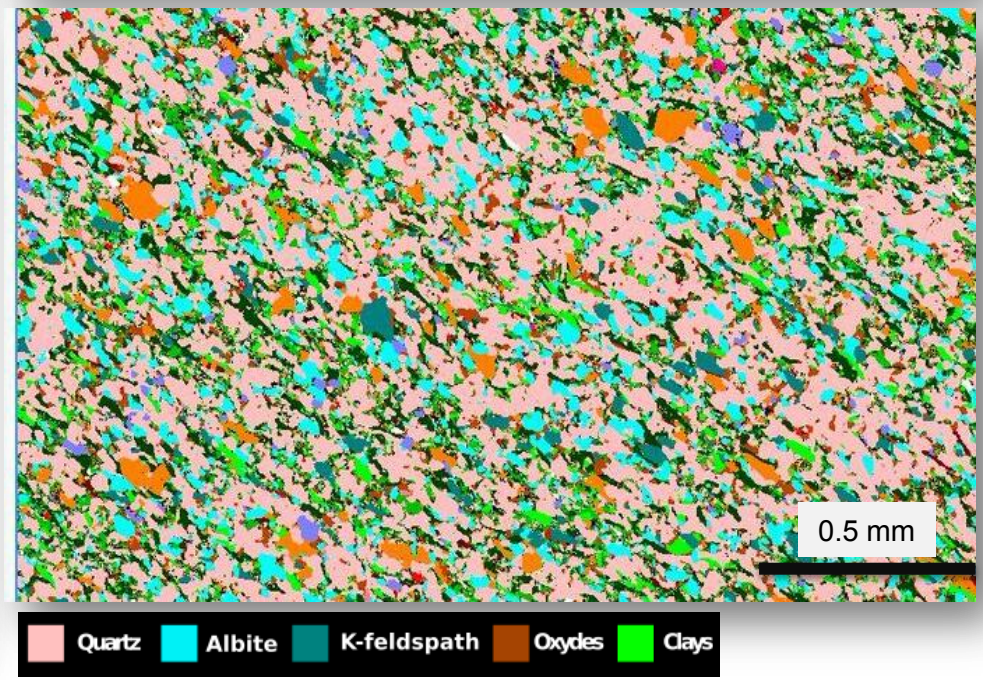

500 µm


0.5 mm

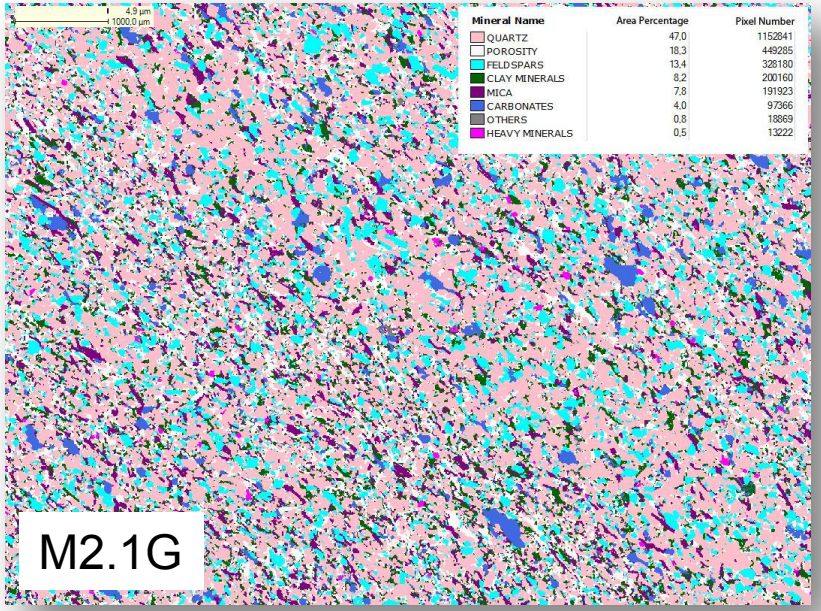

Quartz
Albite
K-feldspath
Oxydes
Clays

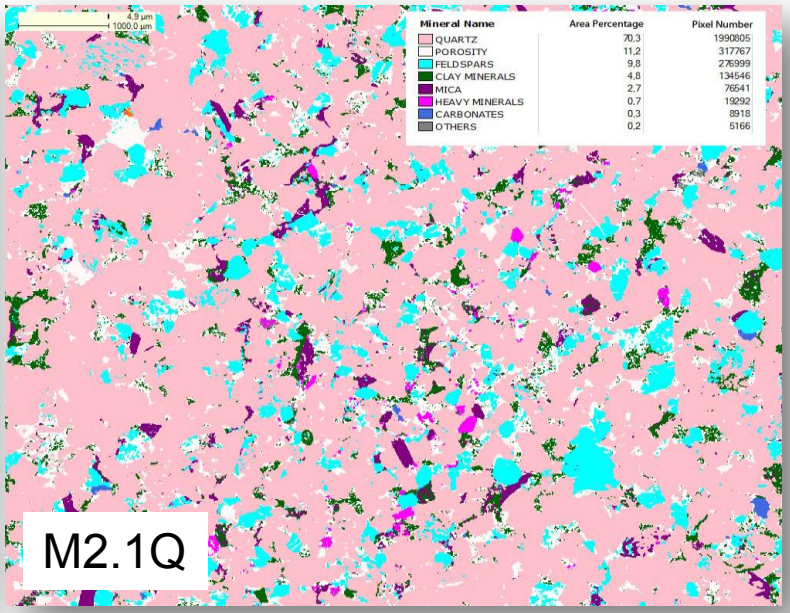

top
heterolithics
prodelta sst to
marine siltstones
base

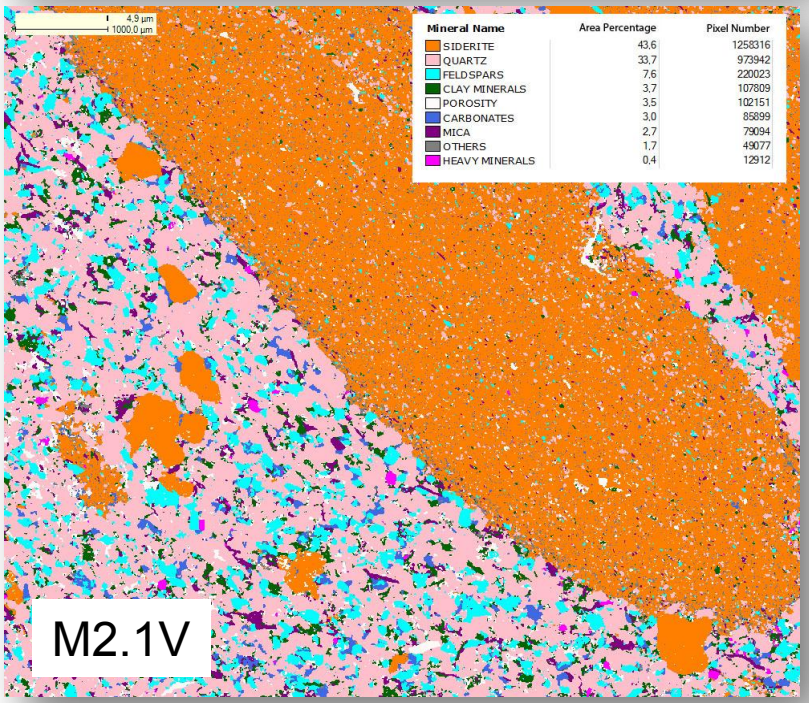

500 µm

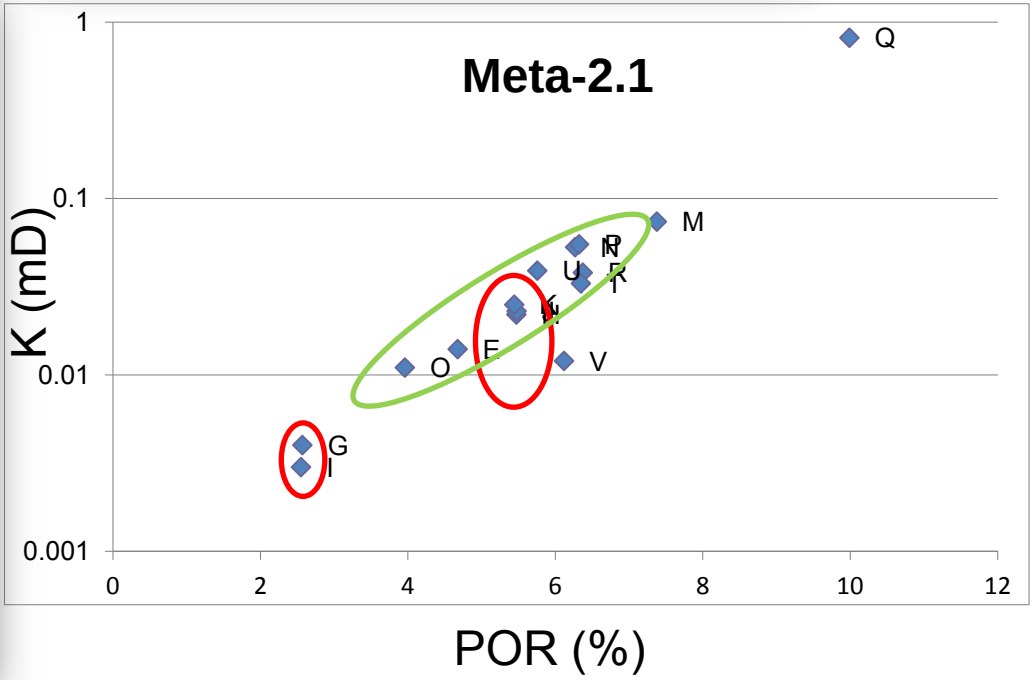

0.5 mm
Quartz
Albite
K-feldspath
Oxydes
Clays

QEMSCAN ANALYSIS







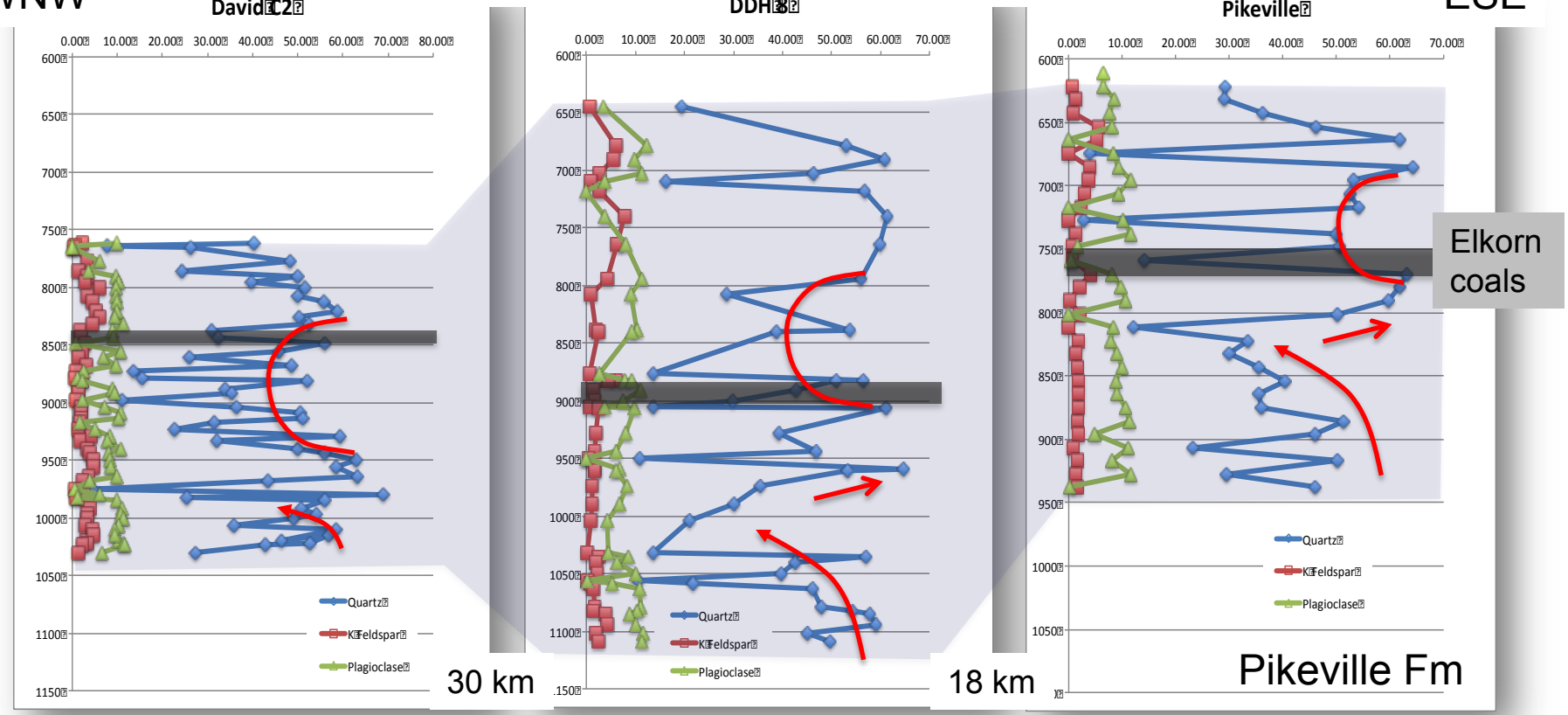


WNW

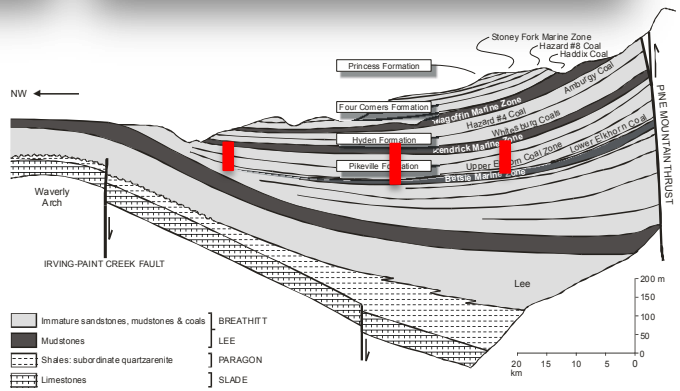
19 miles

11 miles

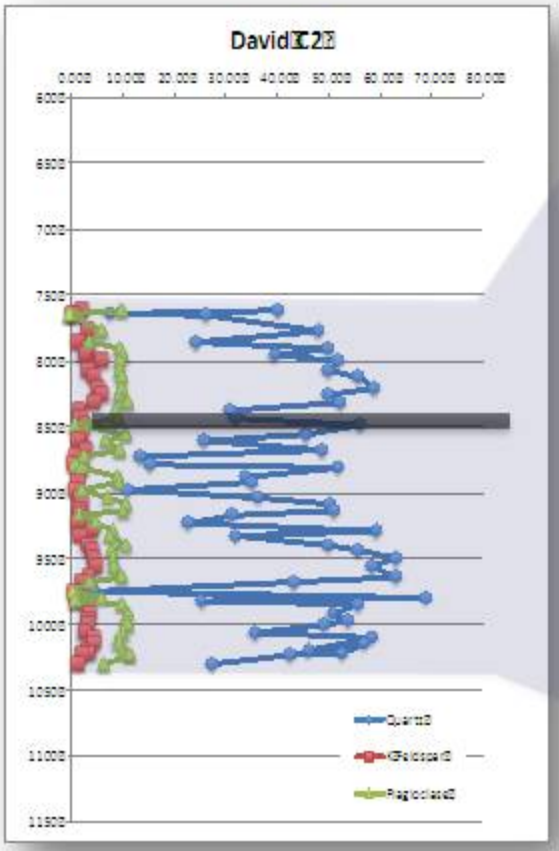
ESE

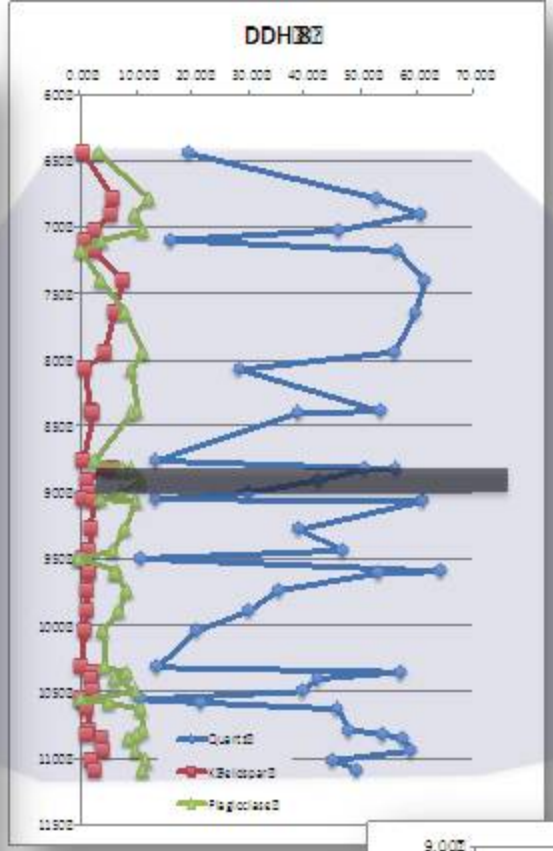


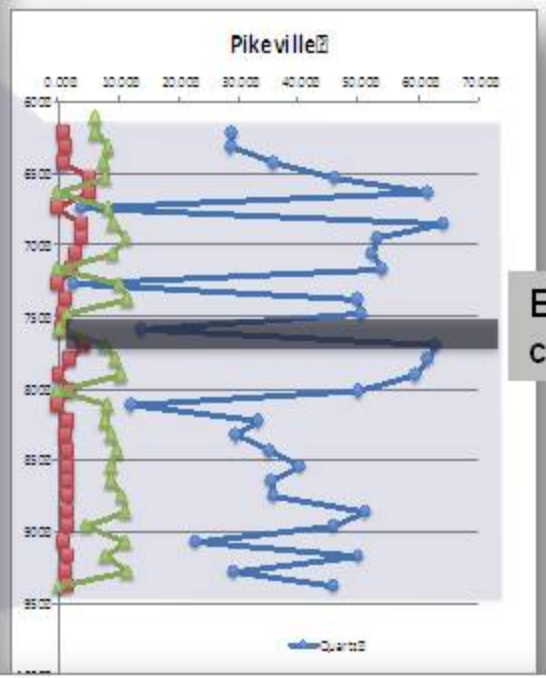
LARGE SCALE APPROCH



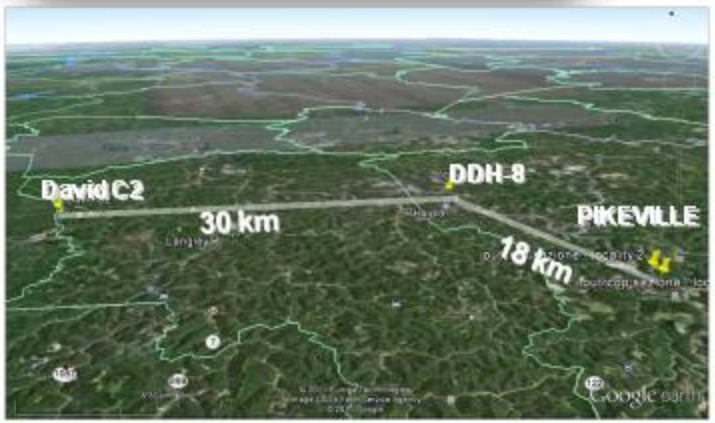
Pikeville Fm: Qz,K-Feld, Plag

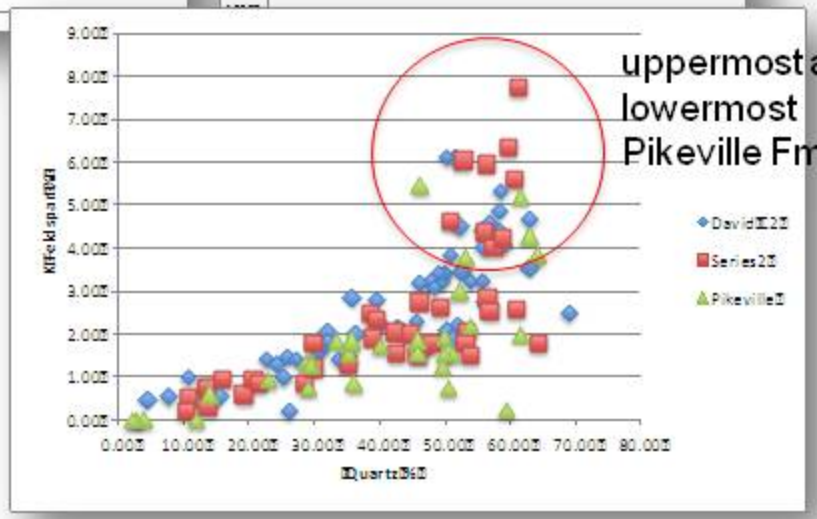






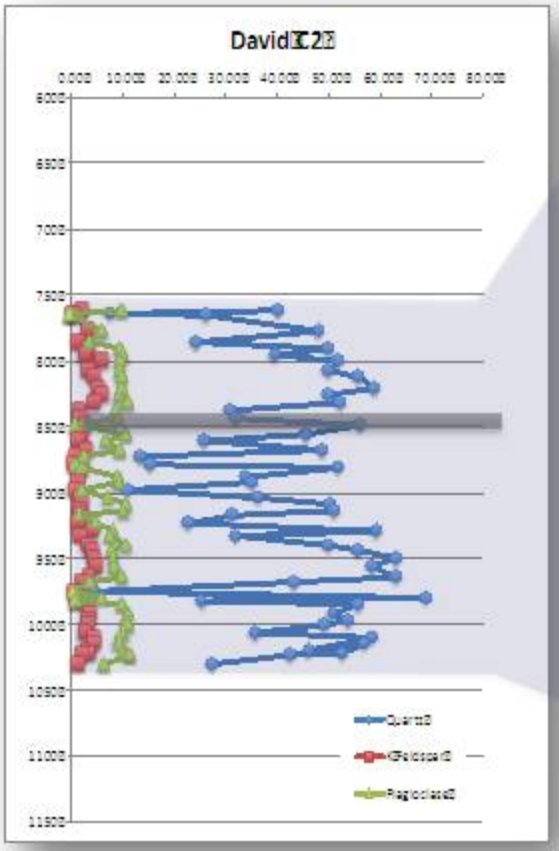
Elkorn coals

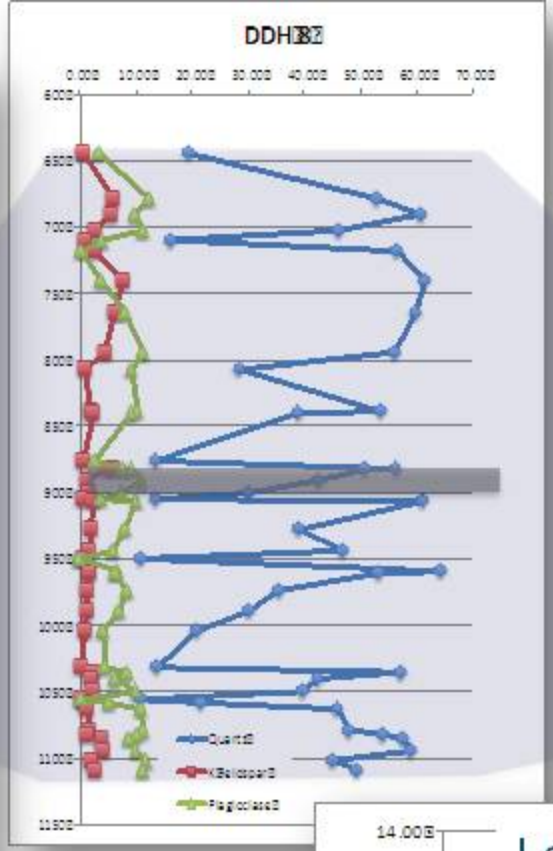


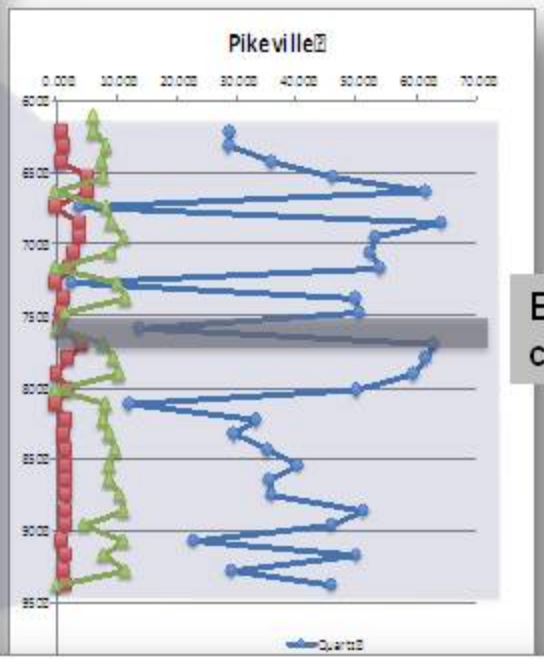


uppermost and lowermost Pikeville Fm

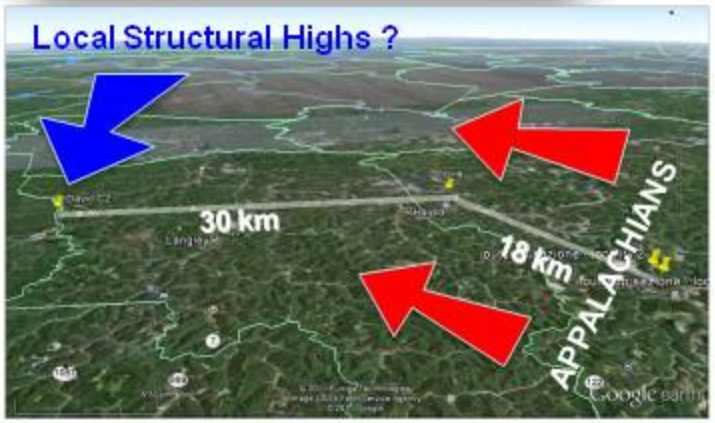
Pikeville Fm: Qz,K-Feld, Plag

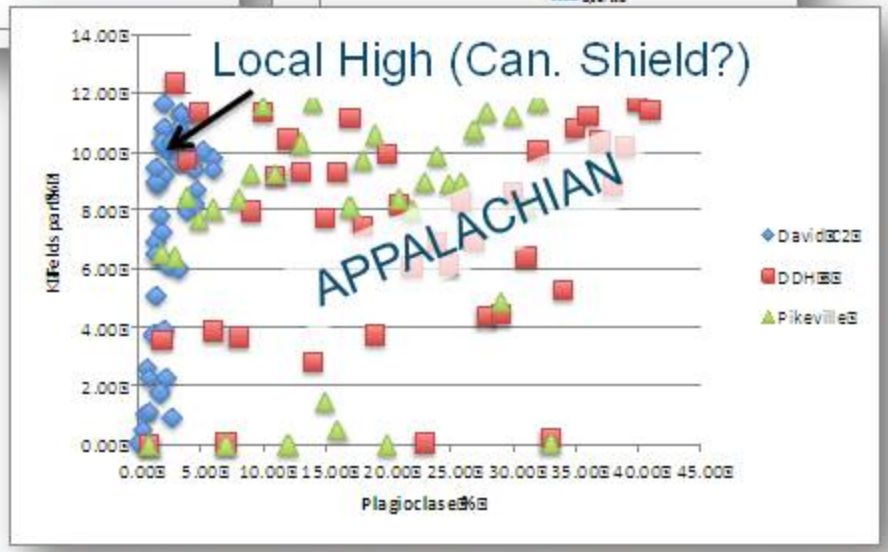


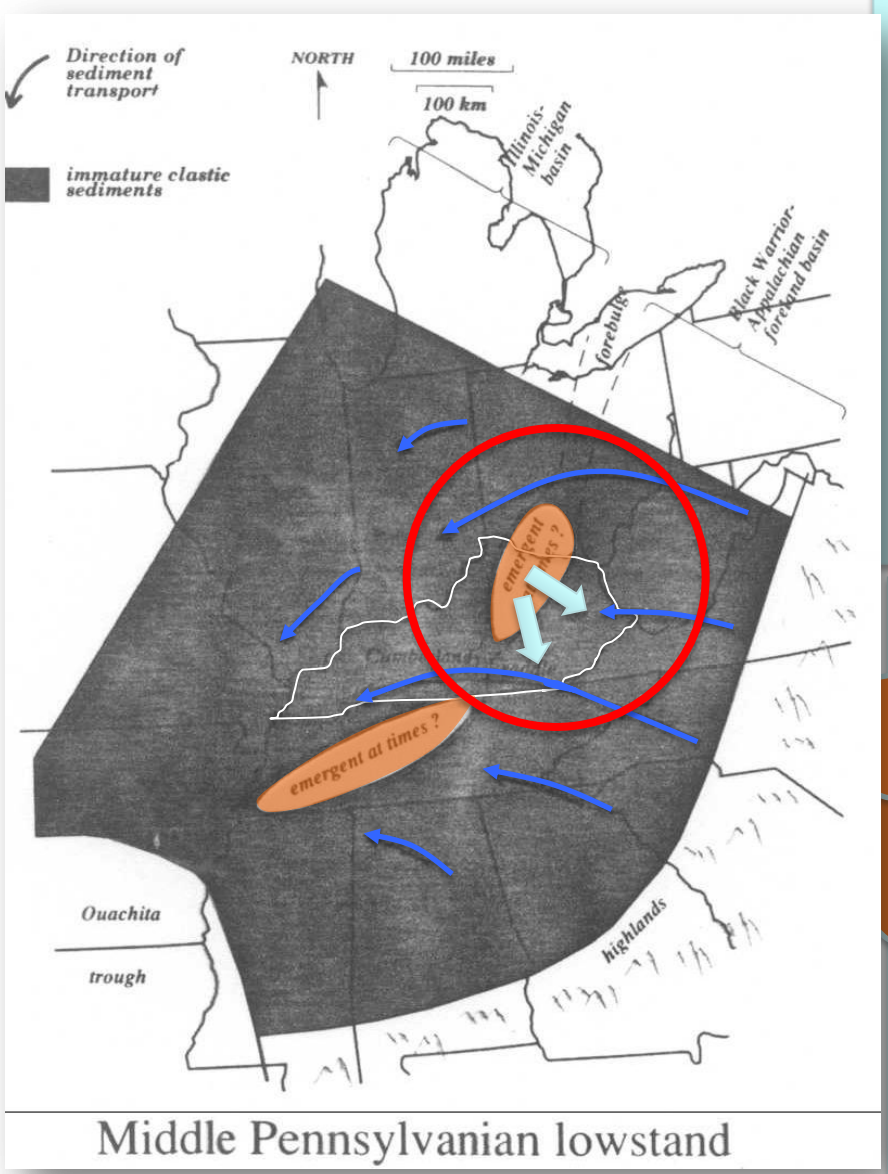


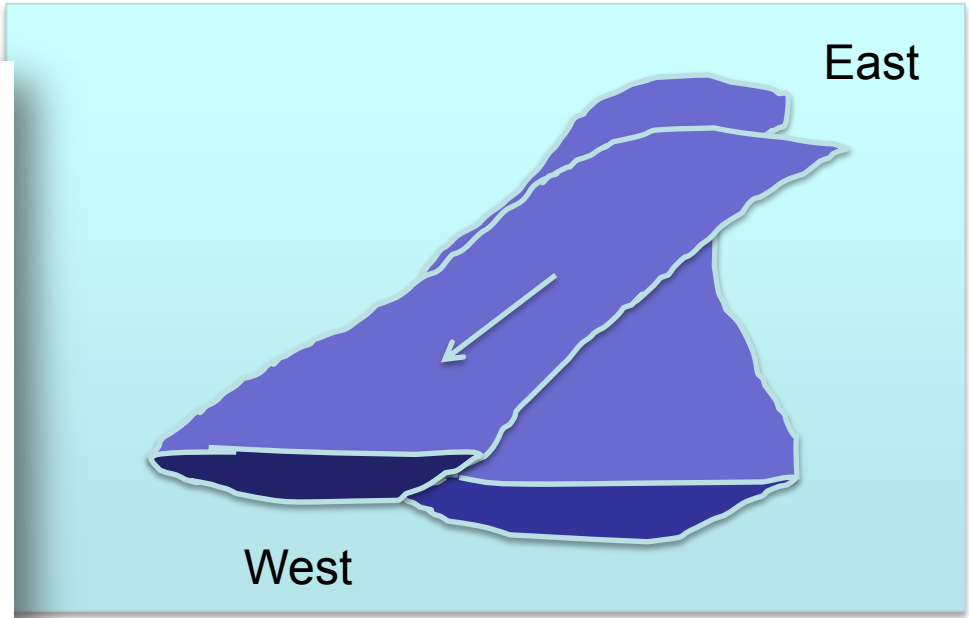


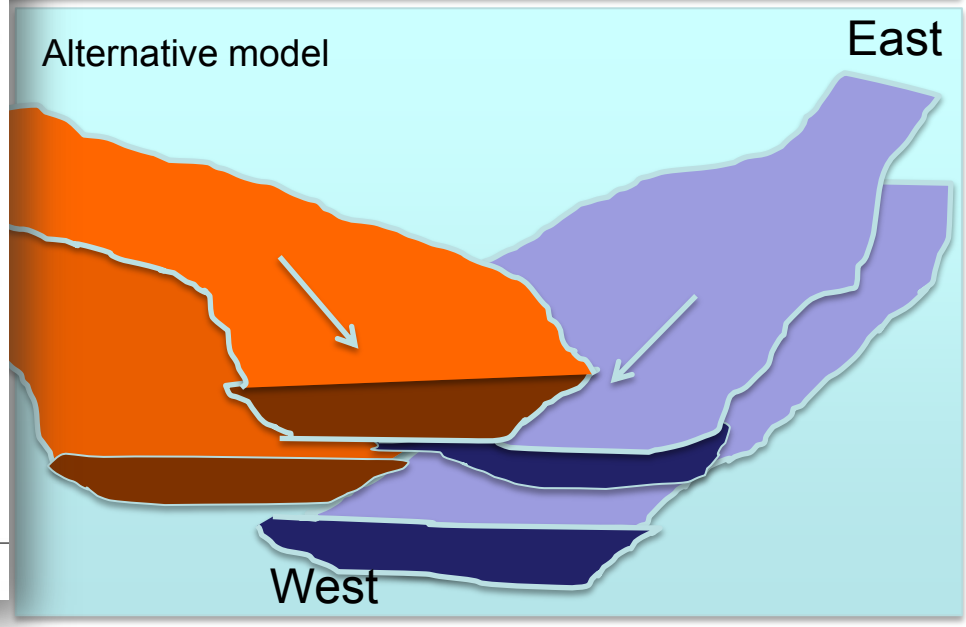
Elkorn coals







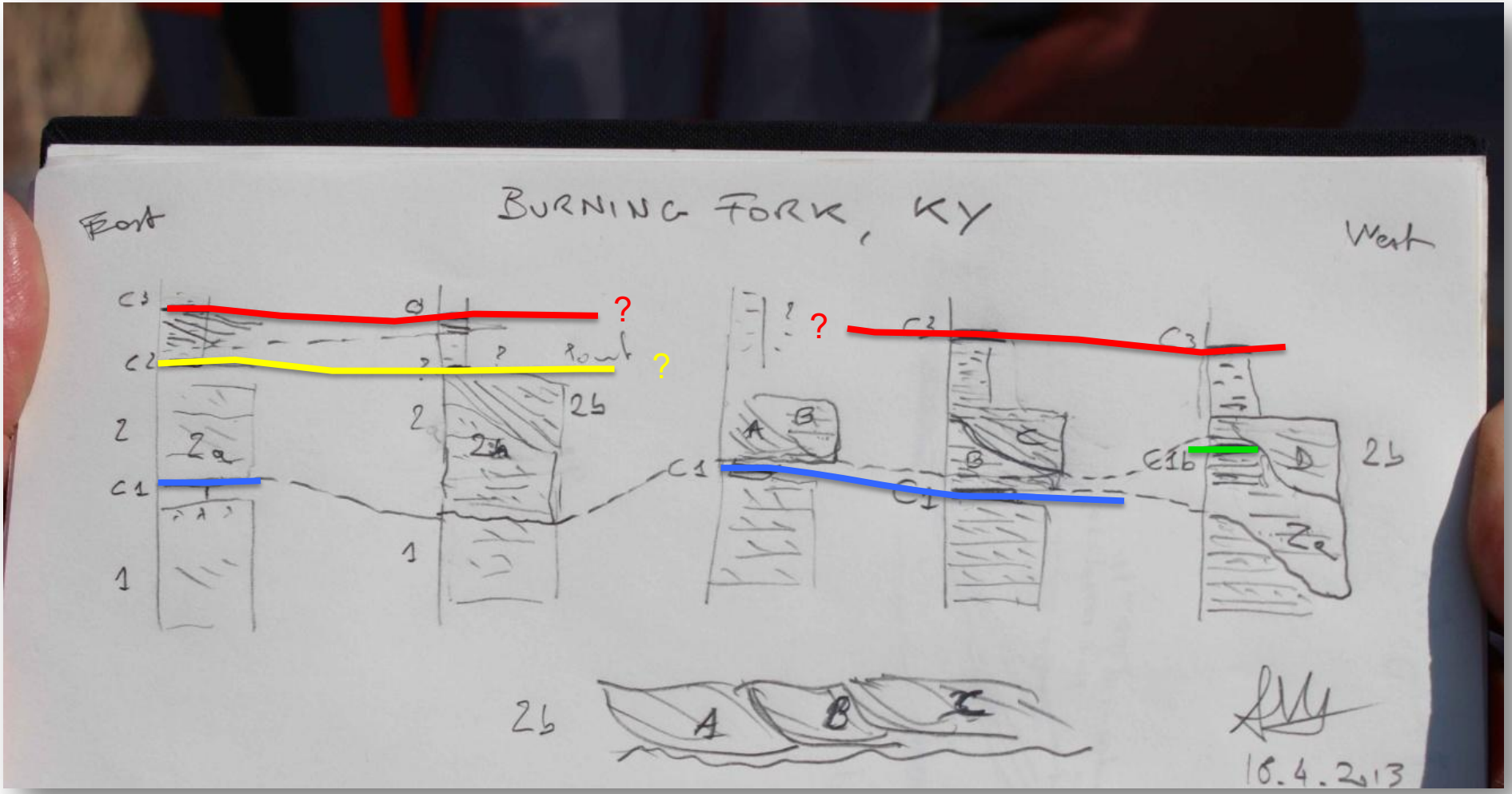




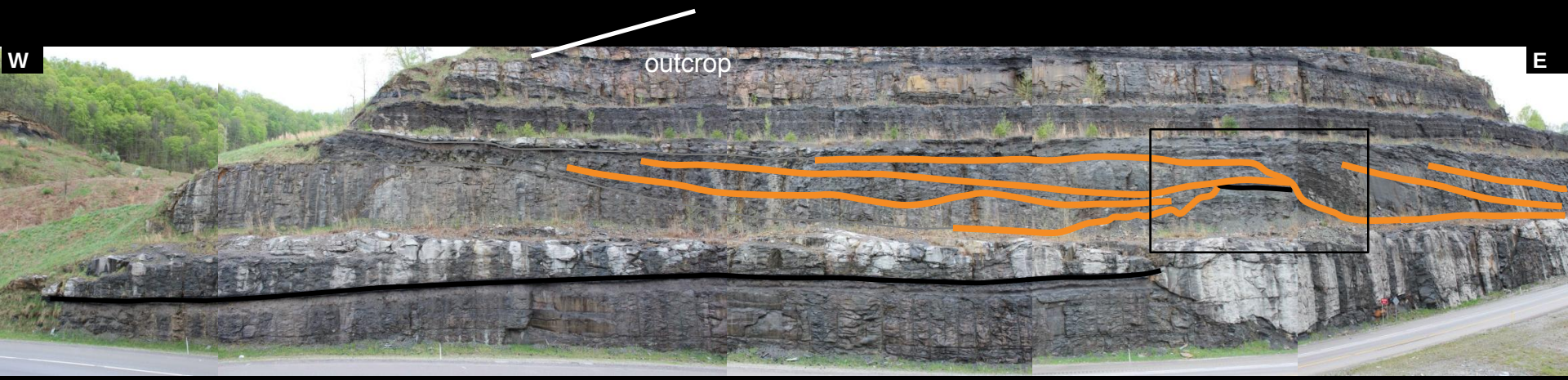
Chesnut, 1993

Sector model approach

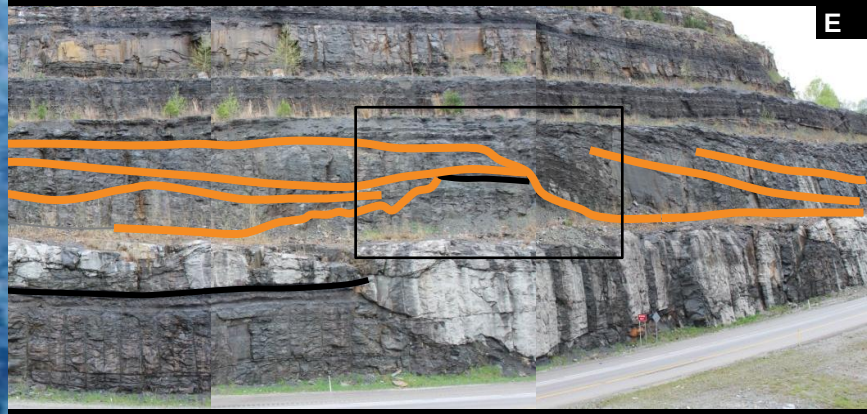
Pikeville Formation - Harold Sst



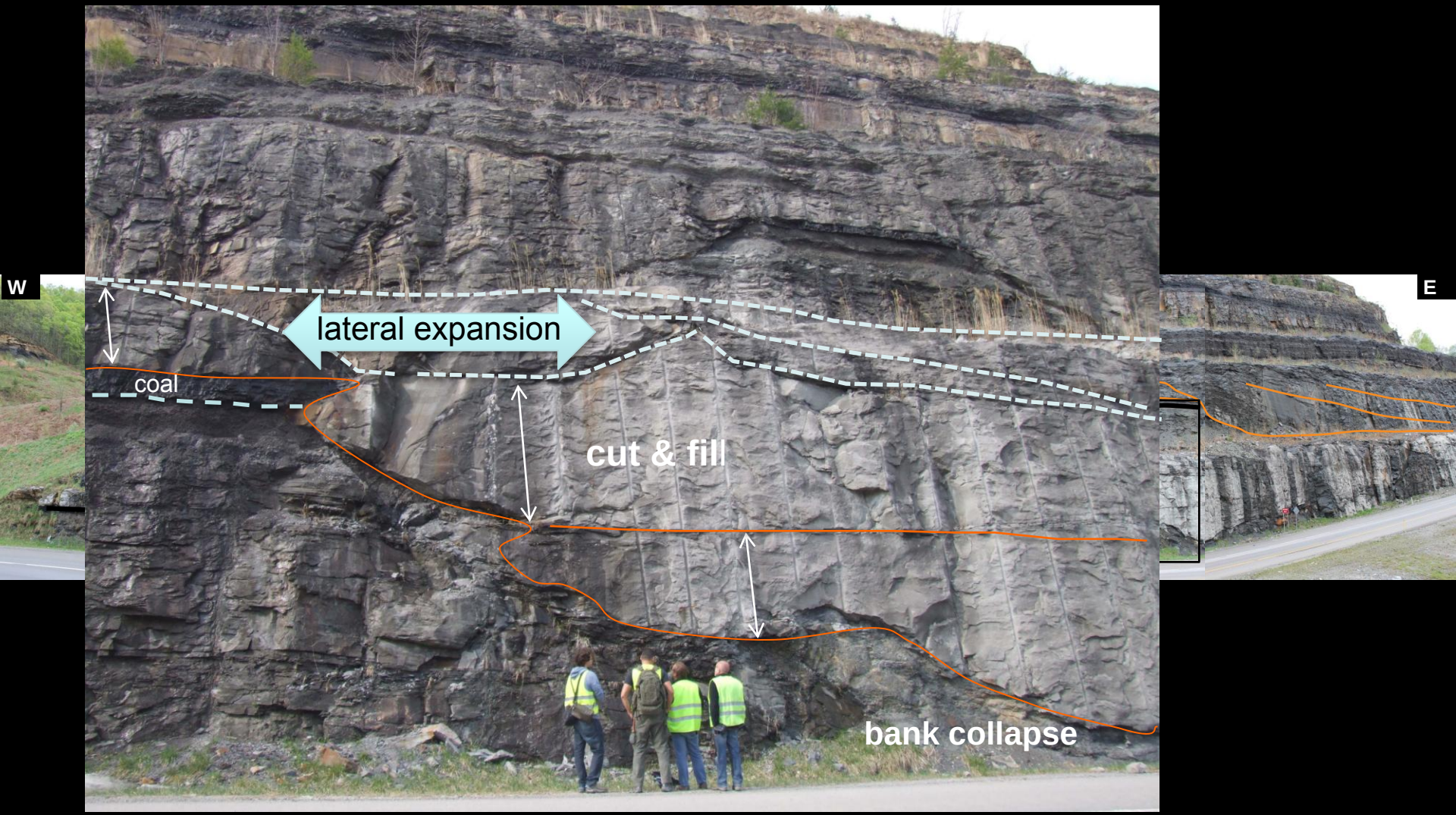
Unraveling internal reservoir architecture

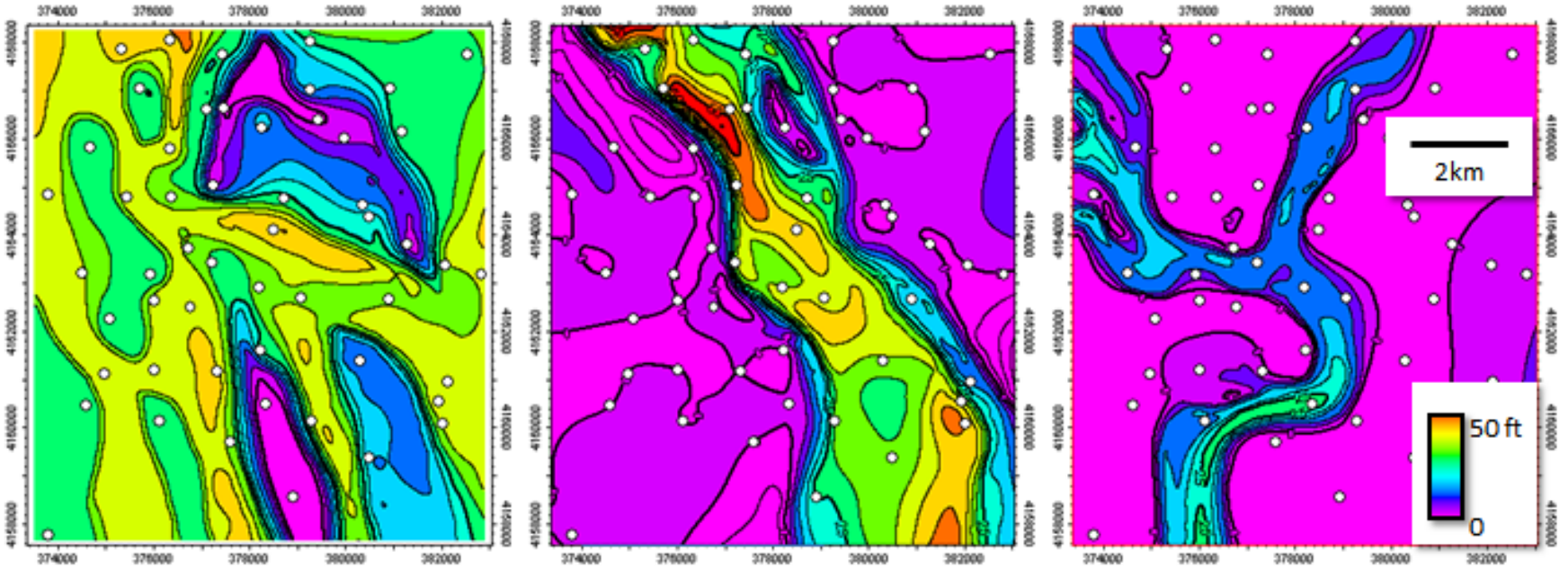

W
outcrop
E

W



E


W
E
lateral expansion
coal
cut & fill
bank collapse



INCISED		AGGRADTIONAL
Complex erosively based networks NOT simple channel-forms.	Networks in which the different "branches" develop more simple channel form geometries.	Aggradational networks.
Bodies 10's km wide	Bodies km's wide	True distributary channel-levee systems.
		Bodies 100's m to 2 km wide

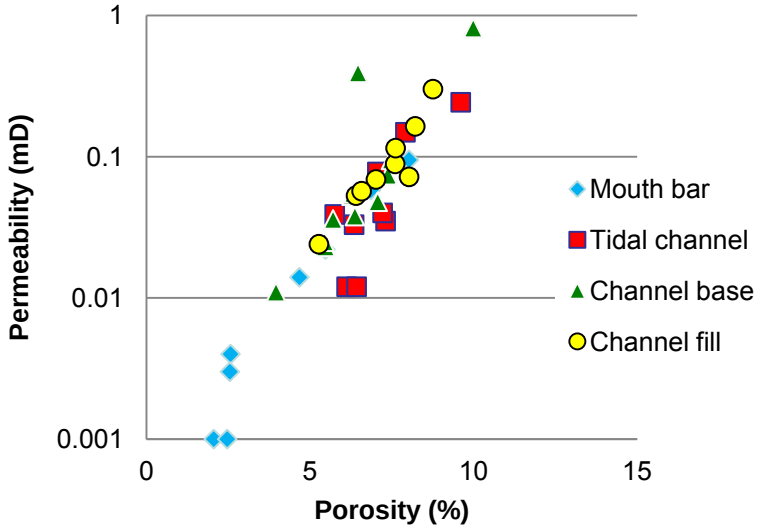
Depositional-dip →

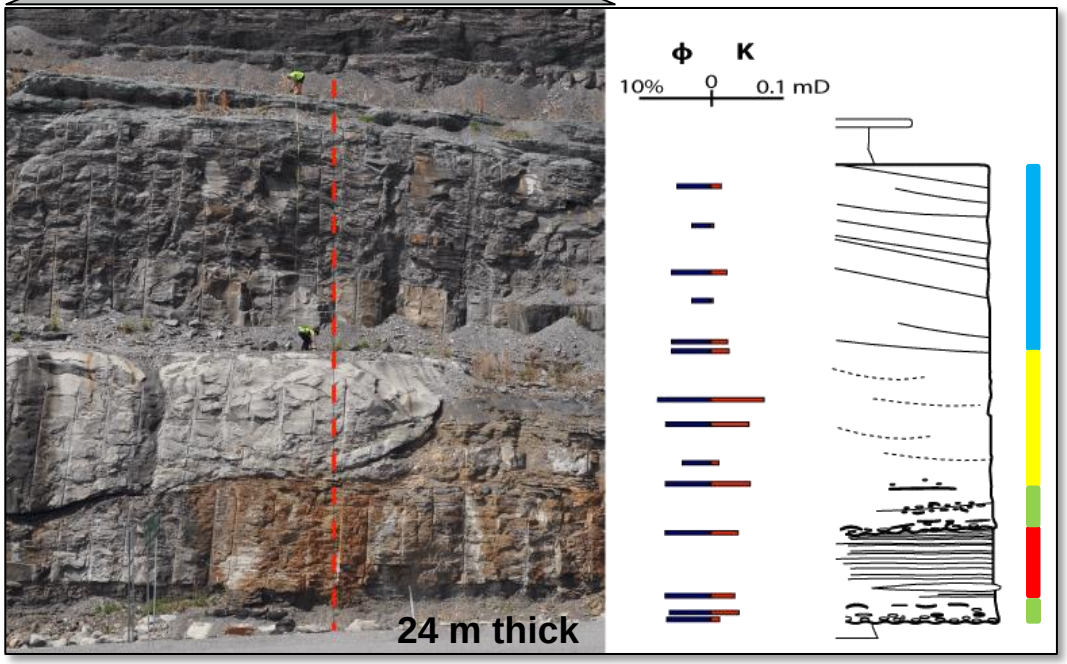
CHANNEL ARCHITECTURE

Williams and Davis in Moscariello et al., 2013

LITHOFACIES CHARACTERIZATION

Reservoir Properties





Fluvial and tidally influenced channel fills have similar Phi-K distribution with higher variability for the latter. Mouth-bar deposits have the highest heterogeneity, while channel-base facies contain high-permeability streaks.

Analyses performed by G. Hunger, A. Le Cotonnec, E. Rusillon

Conclusions

- Composition, architecture and properties of coal-bearing strata bear a complexity which can be unraveled by detailed outcrop studies and integration with subsurface data.
- Two-scale approach is key to predict both large- and small-scale architectural complexity.
  - Integration between sedimentology and petrography to develop conceptual geological model.
  - Detailed architecture of genetic elements in different sequential system tract (incision and aggradational)
- Eastern Kentucky outcrop data are used to build predictive subsurface geological models (UK, Russia).

Conclusions…

TOTAL

Thank You

Kentucky Geological Survey
University Of Kentucky