Effects, Influences and Controls of Sedimentology, Stratigraphy, Tectonics, Paleogeography and Diagenesis on Hydrocarbon and Mineral Accumulations in the Cambrian-Ordovician Knox Group in Kentucky*

Patrick J. Gooding[1]

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Abstract

The Cambrian-Ordovician Knox Group in Kentucky exceeds 3500 feet in thickness and signifies one of the largest buildups of carbonates identified in the United States. Evidence supports the interpretation that these sediments were deposited on a broad, gently sloping, continental shelf in a warm, shallow, low-energy marine environment during a period of relative structural tranquility and represent accumulations in a uniform sequence of subtidal, intertidal, and supratidal conditions. Vertical distribution of lithologic types indicates a shallowing-upward sequence with abundant depositional cycles. This pronounced sequence indicates that the rate of deposition generally kept pace with subsidence of the craton. The porosity characteristics of these carbonates are secondary due to chemical and physical changes, such as dolomitization, hydrothermal activity, solution channels or fractures. Disturbed and destroyed bedding due to chemical alteration and bioturbation are common in addition to fractures which are extensive and complex.

Many geomorphic processes were active during subaerial exposure of these carbonate sediments. The paleogeography is characterized by numerous residual hills; sinkholes; interrupted, elongate and steep sided valleys of limited extent with a lack of a well developed drainage pattern, all indicating karstification. A well developed brecciated zone containing angular re-worked Knox fragments and bentonite is also present at the base of the Middle Ordovician, with relief on the paleosurface varying about 500 feet, further supporting karst.

Significant amounts of petroleum and natural gas have been produced from Cambrian-Ordovician sediments throughout the United States. In Kentucky, hydrocarbon entrapment occurs at or near the unconformable surface and is closely associated with residual highs, fractures and faults. Hydrocarbons generated from Devonian black shales and driven by pressures exerted by fluids and gases migrate from deep in the Appalachian and Illinois basins both vertically and horizontally, through faults, fractures, joints, weakened bedding planes, vugs, breccias, unconformable surfaces and along the flanks of the Cincinnati Arch to accumulate in Knox reservoirs. Brecciated and fracture zones related with the unconformity also serve as a host for mineralization, and these deposits contain varying amounts of quartz, galena, sphalerite, barite, calcite, and fluorite resulting from various episodes of hydrothermal action.

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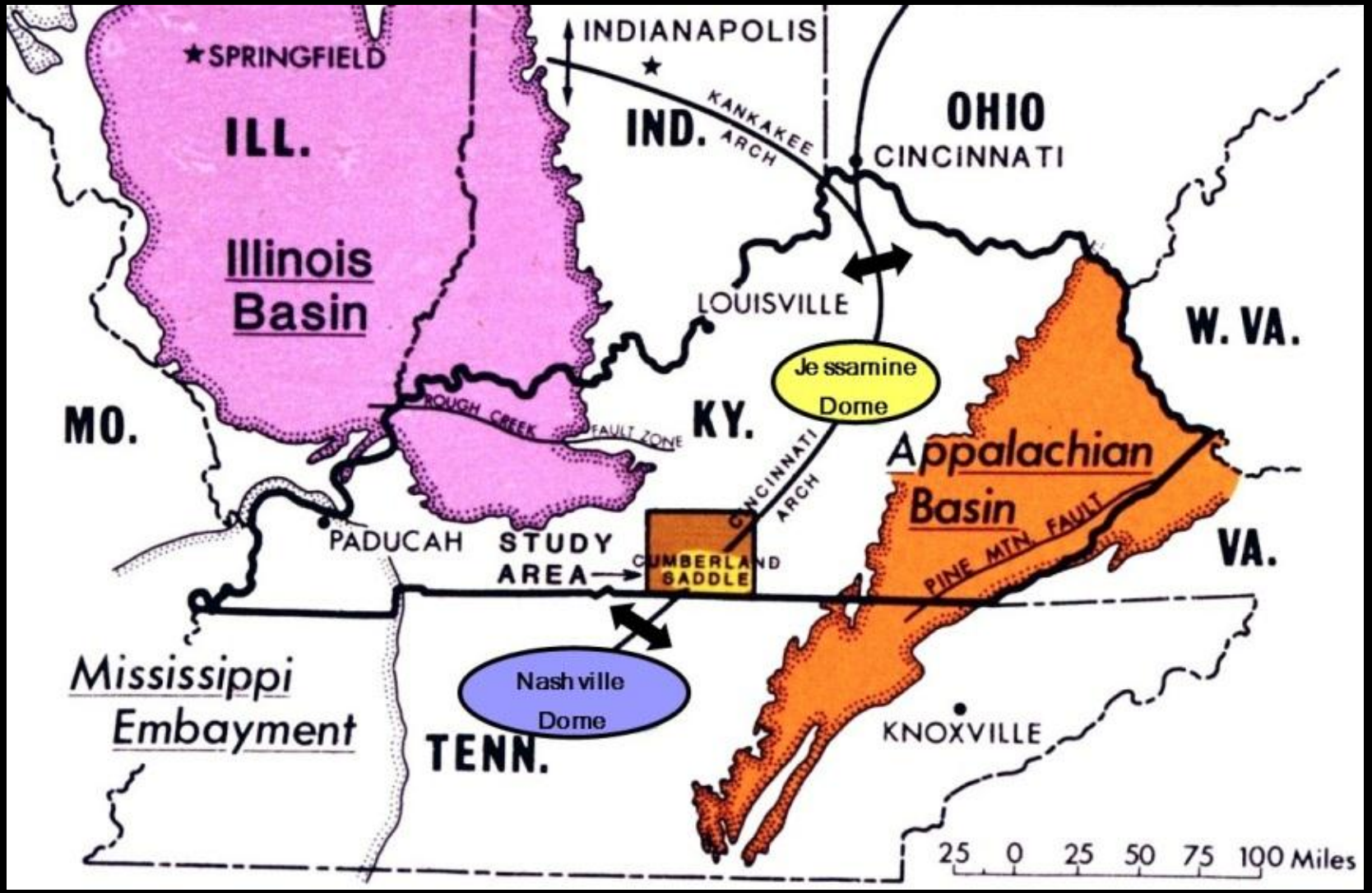
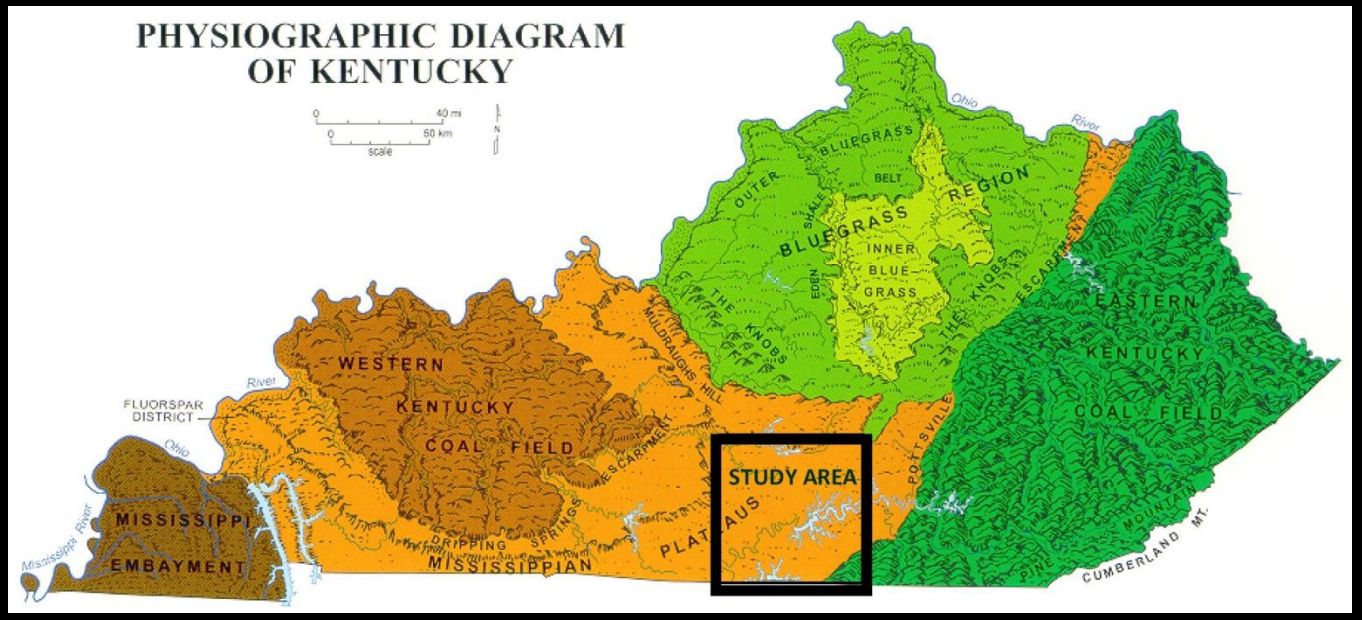
Kentucky Geological Survey

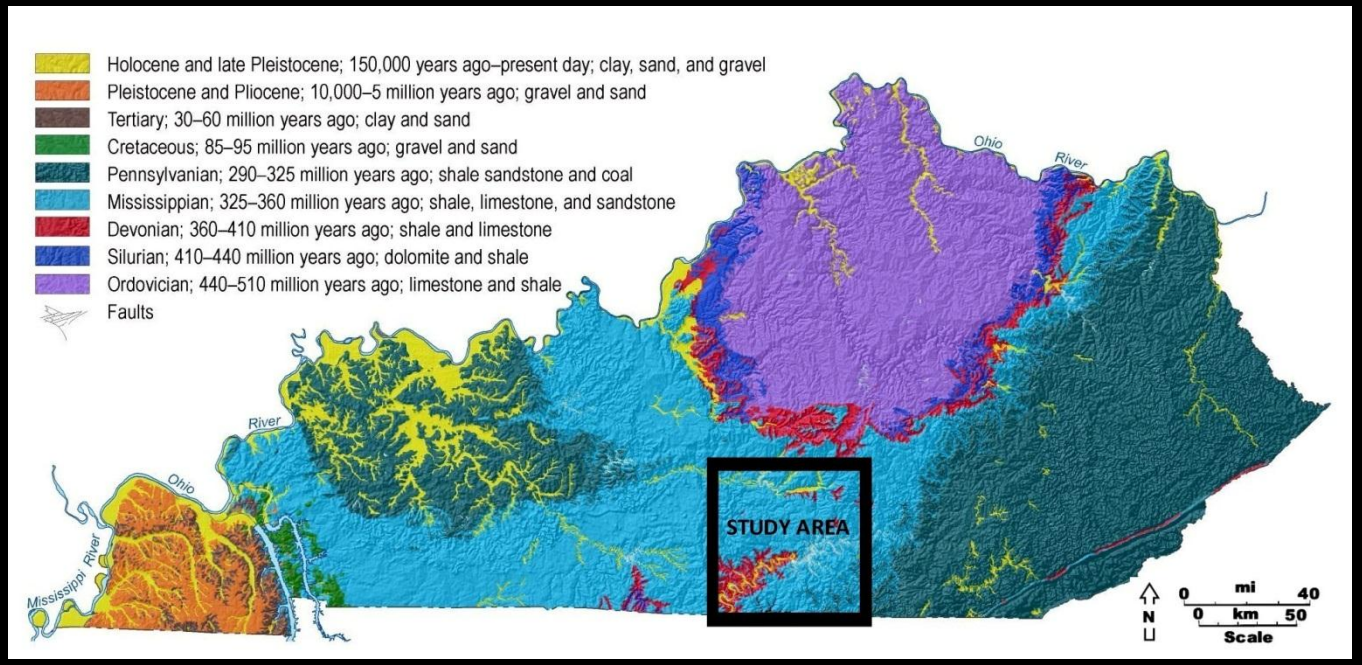
AAPG 2013
Annual Convention & Exhibition
Pittsburgh, PA

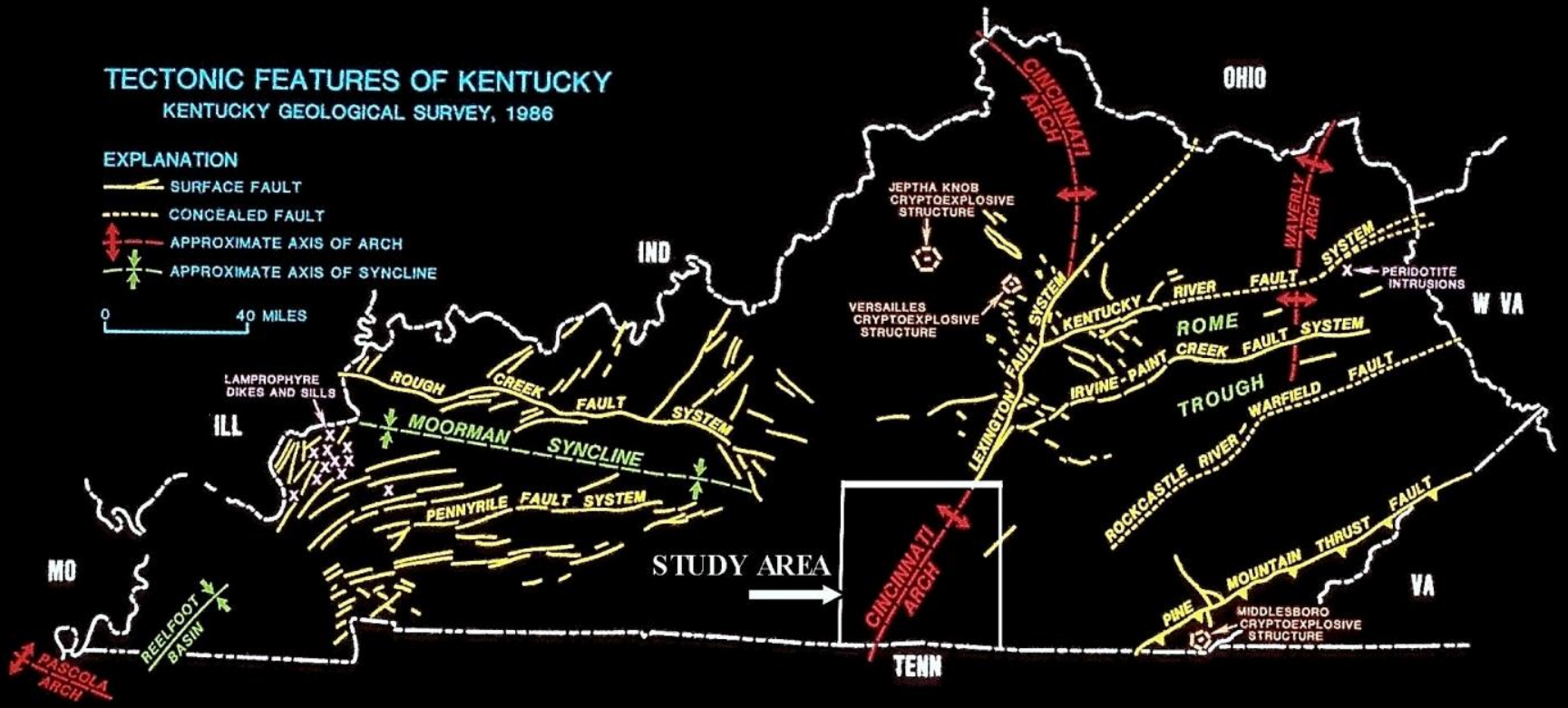
Location of Study Area

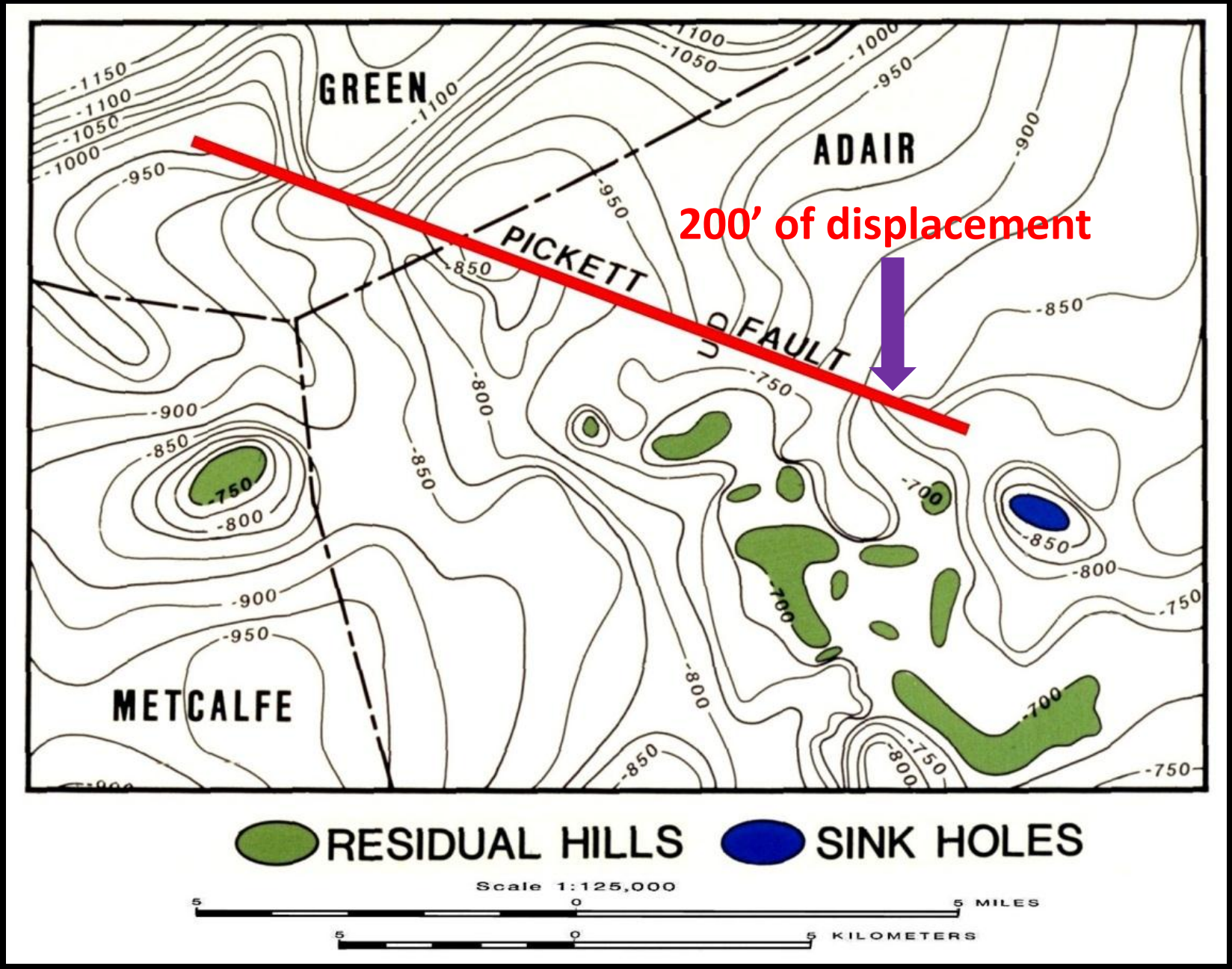


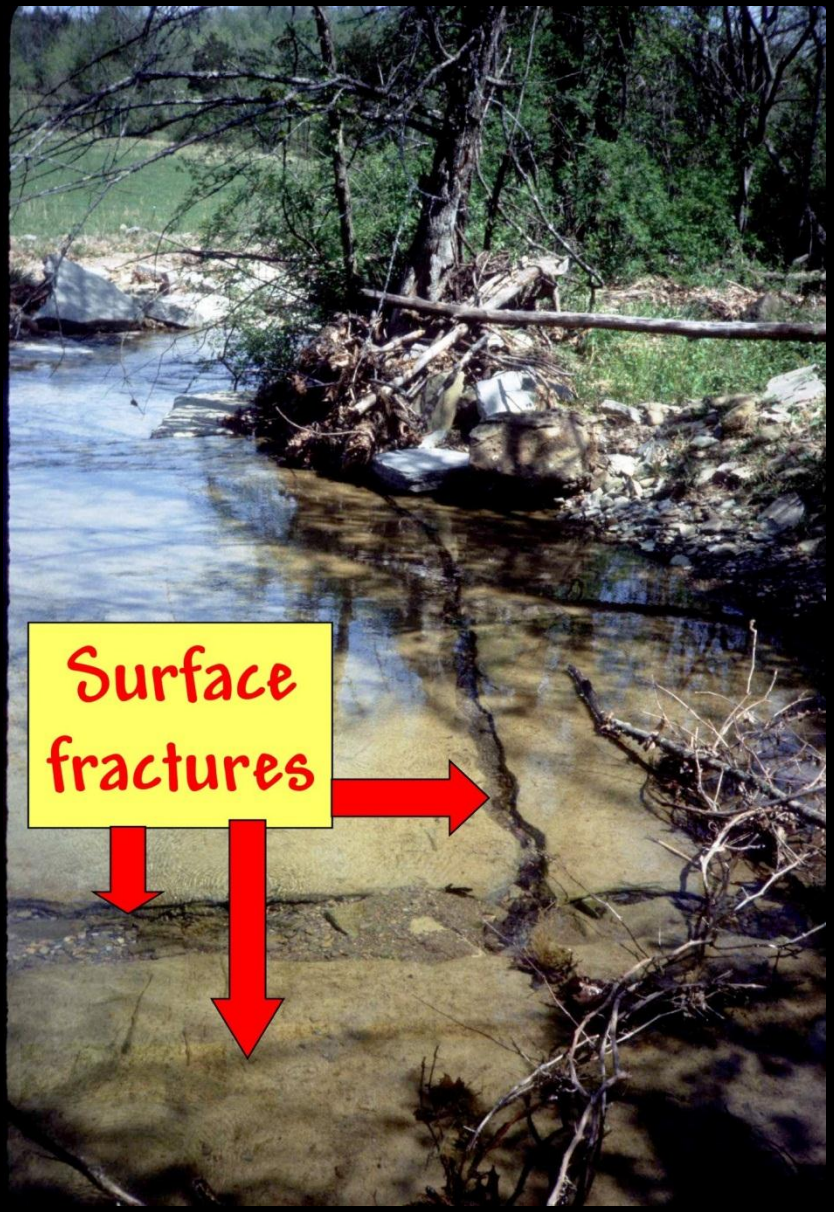
Major Regional Tectonic Features in Kentucky and Adjacent States

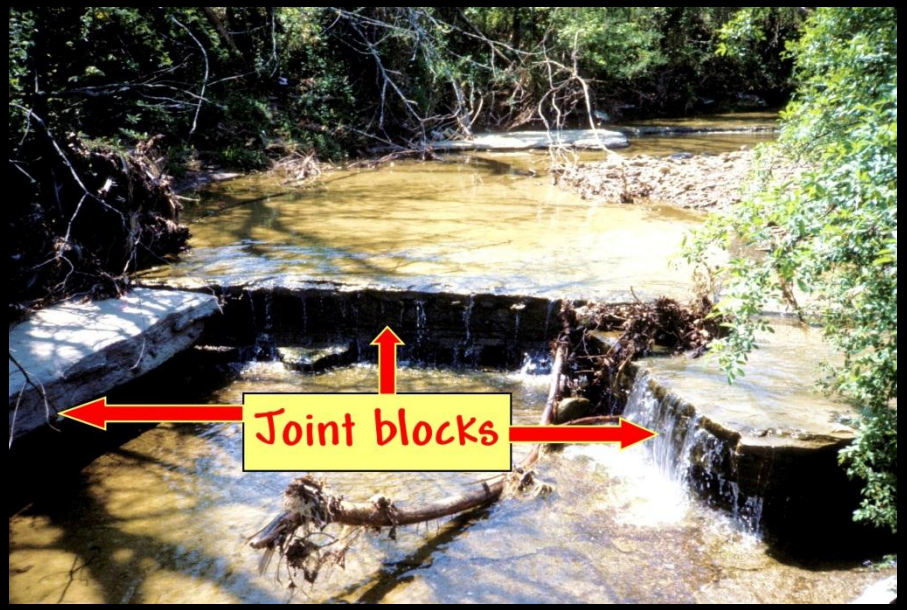

PHYSIOGRAPHIC DIAGRAM
OF KENTUCKY
0 40 mi
0 50 km
scale
N
Ohio River
OUTER BLUEGRASS BELT
INNER BLUEGRASS REGION
EDEN SHALE
THE KNOBS
KNOBS ESCARPMENT
EASTERN KENTUCKY COAL FIELD
POTTSVILLE ESCARPMENT
PINE MOUNTAIN
CUMBERLAND MT.
WESTERN KENTUCKY COAL FIELD
MULDRAUGHS HILL ESCARPMENT
FLUORSPAR DISTRICT
Ohio River
Mississippi River
MISSISSIPPI EMBAYMENT
DRIPPING SPRINGS
MISSISSIPPIAN
PLATEAUS
STUDY AREA


Holocene and late Pleistocene; 150,000 years ago–present day; clay, sand, and gravel
Pleistocene and Pliocene; 10,000–5 million years ago; gravel and sand
Tertiary; 30–60 million years ago; clay and sand
Cretaceous; 85–95 million years ago; gravel and sand
Pennsylvanian; 290–325 million years ago; shale sandstone and coal
Mississippian; 325–360 million years ago; shale, limestone, and sandstone
Devonian; 360–410 million years ago; shale and limestone
Silurian; 410–440 million years ago; dolomite and shale
Ordovician; 440–510 million years ago; limestone and shale
Faults
Ohio River
Ohio River
Mississippi River
STUDY AREA
N
0 mi 40
0 km 50
Scale

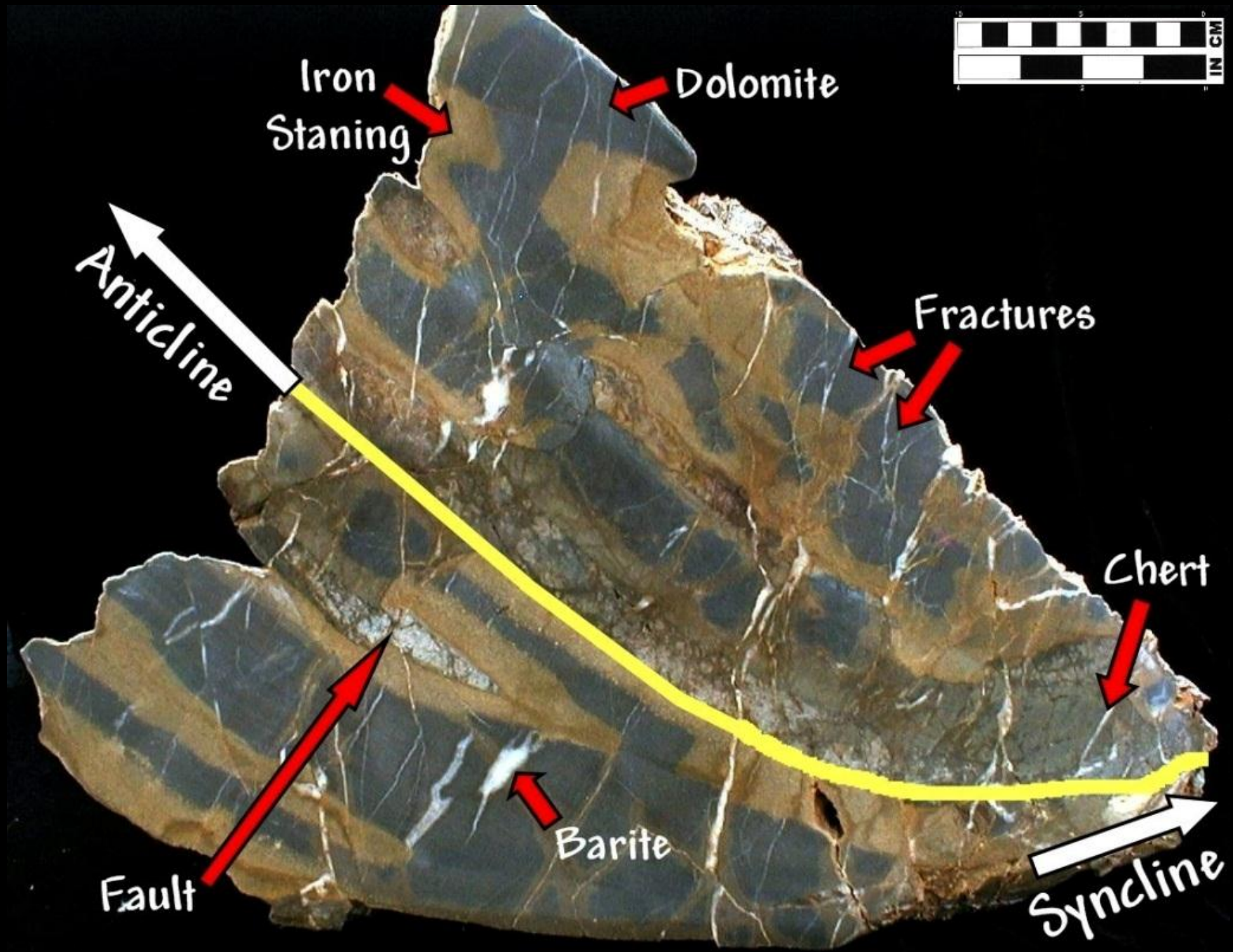

TECTONIC FEATURES OF KENTUCKY
KENTUCKY GEOLOGICAL SURVEY, 1986
EXPLANATION
SURFACE FAULT
CONCEALED FAULT
APPROXIMATE AXIS OF ARCH
APPROXIMATE AXIS OF SYNCLINE
0
40 MILES
OHIO
IND
ILL
MO
W VA
VA
TENN
CINCINNATI ARCH
JEPTHA KNOB CRYPTOEXPLOSIVE STRUCTURE
VERSAILLES CRYPTOEXPLOSIVE STRUCTURE
WAVERLY ARCH
PERIDOTITE INTRUSIONS
KENTUCKY RIVER FAULT SYSTEM
ROME TROUGH
IRVINE-PAINT CREEK FAULT SYSTEM
WARFIELD FAULT
ROCKCASTLE RIVER FAULT
PINE MOUNTAIN THRUST FAULT
MIDDLESBORO CRYPTOEXPLOSIVE STRUCTURE
LEXINGTON FAULT SYSTEM
LAMPROPHYRE DIKES AND SILLS
ROUGH CREEK FAULT SYSTEM
MOORMAN SYNCLINE
PENNYRILE FAULT SYSTEM
REELFOOT BASIN
PASCOLA ARCH
STUDY AREA
CINCINNATI ARCH

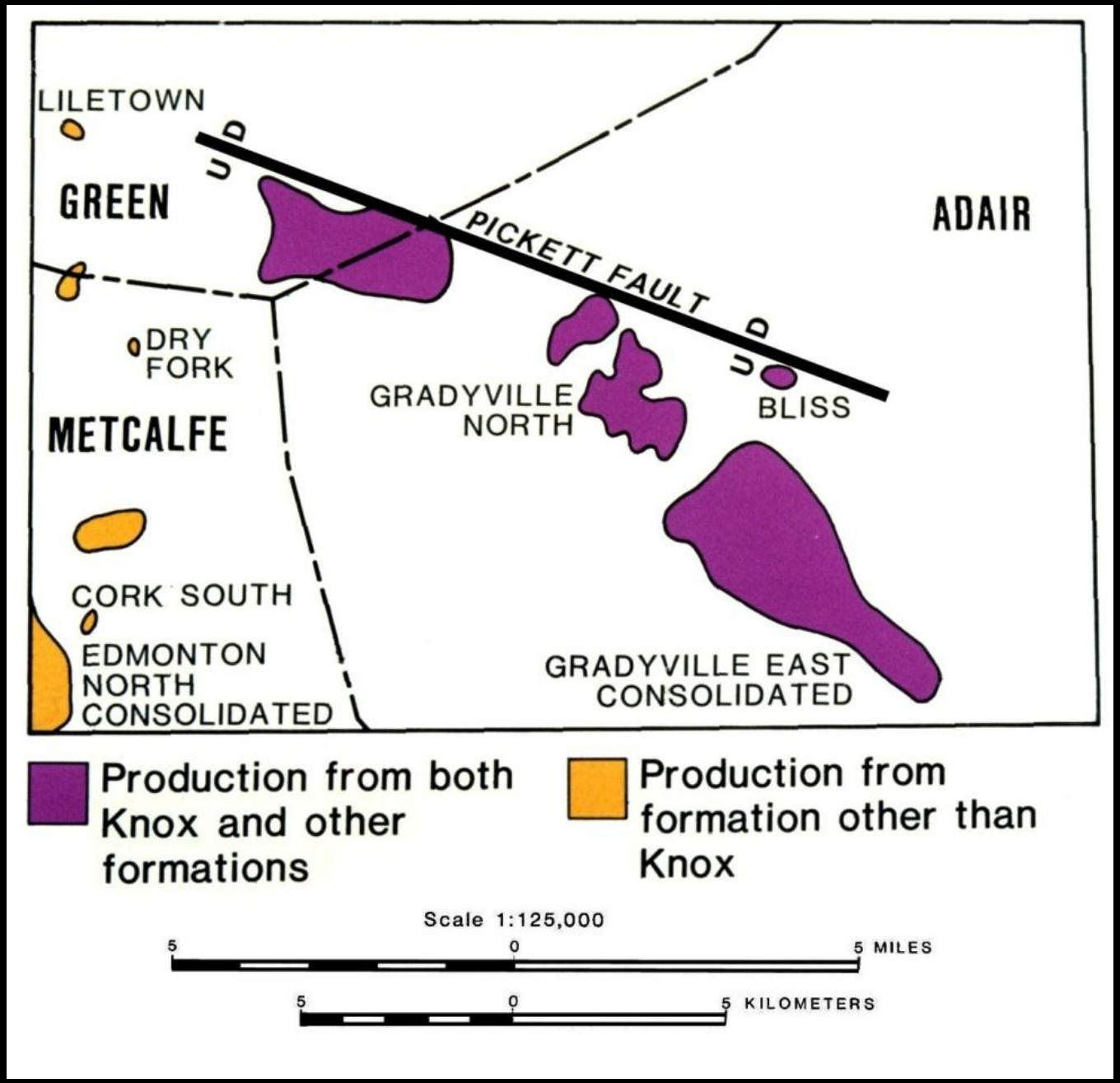

GREEN
ADAIR
PICKETT
FAULT
200’ of displacement
METCALFE
-1150
-1100
-1050
-1000
-950
-900
-850
-800
-750
-700
RESIDUAL HILLS
SINK HOLES
Scale 1:125,000
5 0 5 MILES
5 0 5 KILOMETERS

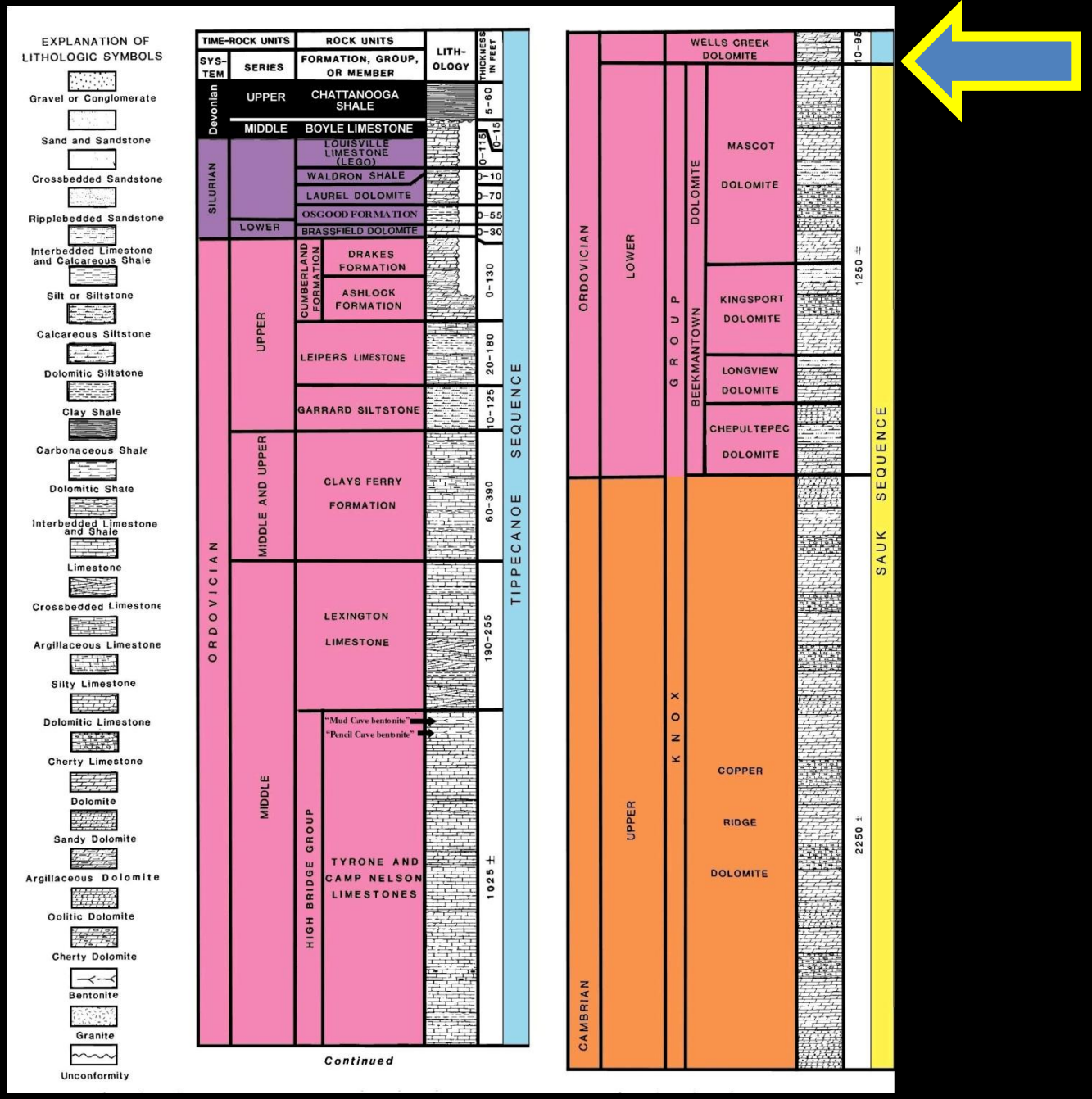


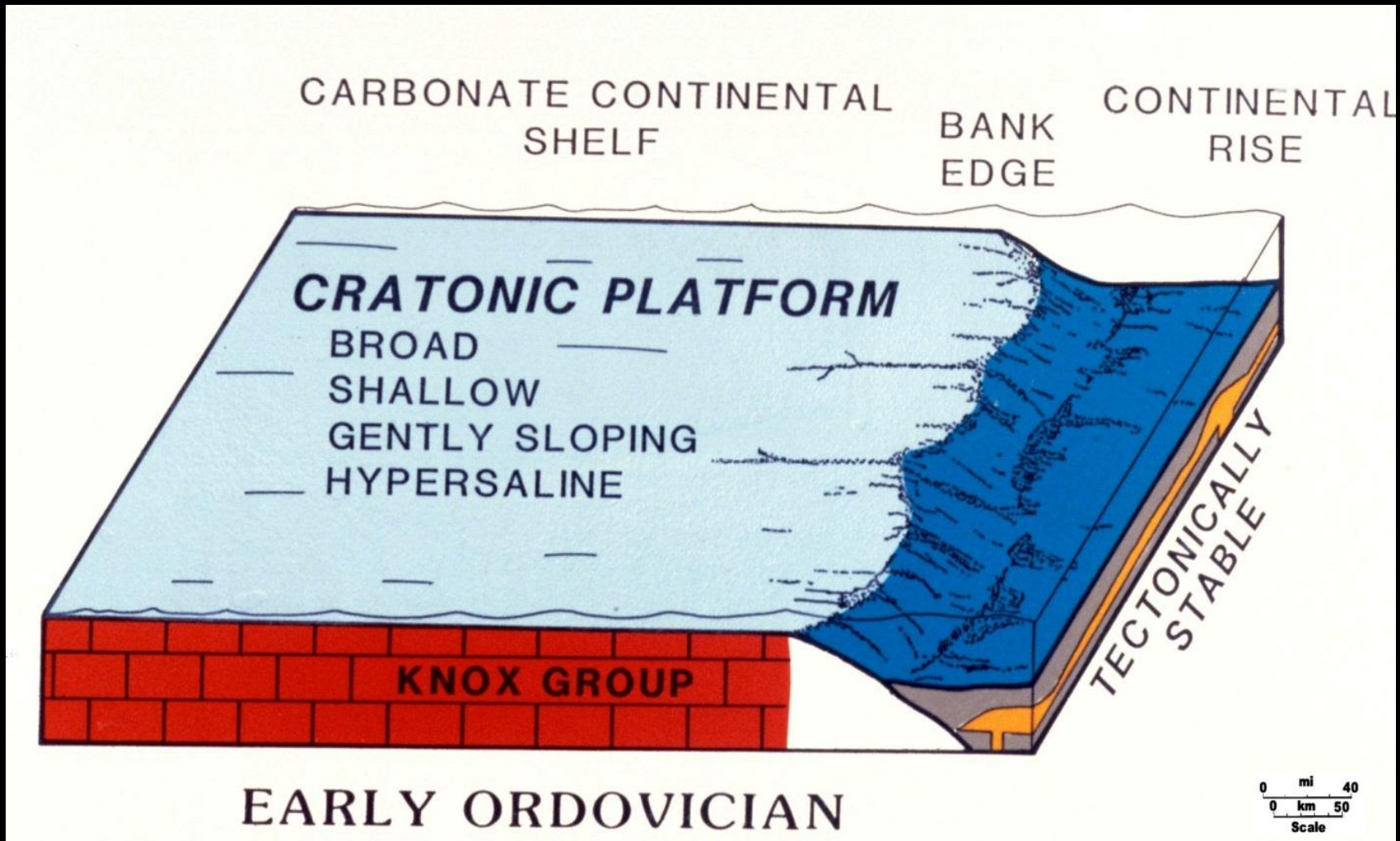


Surface Expression of the Pickett Fault


Iron
Staning
Dolomite
IN CM
Anticline
Fractures
Chert
Barite
Fault
Syncline


LILETOWN
GREEN
ADAIR
PICKETT FAULT
DRY FORK
METCALFE
GRADYVILLE NORTH
BLISS
CORK SOUTH
EDMONTON NORTH CONSOLIDATED
GRADYVILLE EAST CONSOLIDATED
Production from both Knox and other formations
Production from formation other than Knox
Scale 1:125,000
5 0 5 MILES
5 0 5 KILOMETERS


EXPLANATION OF LITHOLOGIC SYMBOLS
Gravel or Conglomerate
Sand and Sandstone
Crossbedded Sandstone
Ripplebedded Sandstone
Interbedded Limestone and Calcareous Shale
Silt or Siltstone
Calcareous Siltstone
Dolomitic Siltstone
Clay Shale
Carbonaceous Shale
Dolomitic Shale
Interbedded Limestone and Shale
Limestone
Crossbedded Limestone
Argillaceous Limestone
Silty Limestone
Dolomitic Limestone
Cherty Limestone
Dolomite
Sandy Dolomite
Argillaceous Dolomite
Oolitic Dolomite
Cherty Dolomite
Bentonite
Granite
Unconformity
TIME-ROCK UNITS
SYSTEM
SERIES
ROCK UNITS
FORMATION, GROUP, OR MEMBER
LITHOLOGY
THICKNESS IN FEET
Devonian
UPPER
CHATTANOOGA SHALE
5-60
MIDDLE
BOYLE LIMESTONE
0-15
SILURIAN
LOUISVILLE LIMESTONE (LEGO)
0-115
WALDRON SHALE
0-10
LAUREL DOLOMITE
0-70
OSGOOD FORMATION
0-55
LOWER
BRASSFIELD DOLOMITE
0-30
ORDOVICIAN
UPPER
CUMBERLAND FORMATION
DRAKES FORMATION
ASHLOCK FORMATION
0-130
LEIPERS LIMESTONE
20-180
GARRARD SILTSTONE
10-125
MIDDLE AND UPPER
CLAYS FERRY FORMATION
60-390
MIDDLE
LEXINGTON LIMESTONE
190-255
HIGH BRIDGE GROUP
"Mud Cave bentonite"
"Pencil Cave bentonite"
TYRONE AND CAMP NELSON LIMESTONES
1025 ±
TIPPECANOE SEQUENCE
Continued
ORDOVICIAN
LOWER
WELLS CREEK DOLOMITE
10-95
GROUP
BEEKMANTOWN DOLOMITE
MASCOT DOLOMITE
KINGSPORT DOLOMITE
LONGVIEW DOLOMITE
CHEPULTEPEC DOLOMITE
1250 ±
KNOX
UPPER
COPPER RIDGE DOLOMITE
2250 ±
CAMBRIAN
SAUK SEQUENCE



EARLY ORDOVICIAN

Deposition of the Knox Group

- Warm Climate
- Sporadic Rainfall
- Dry Trade Winds
- Net Loss of Water by Evaporation
- Hypersaline Conditions

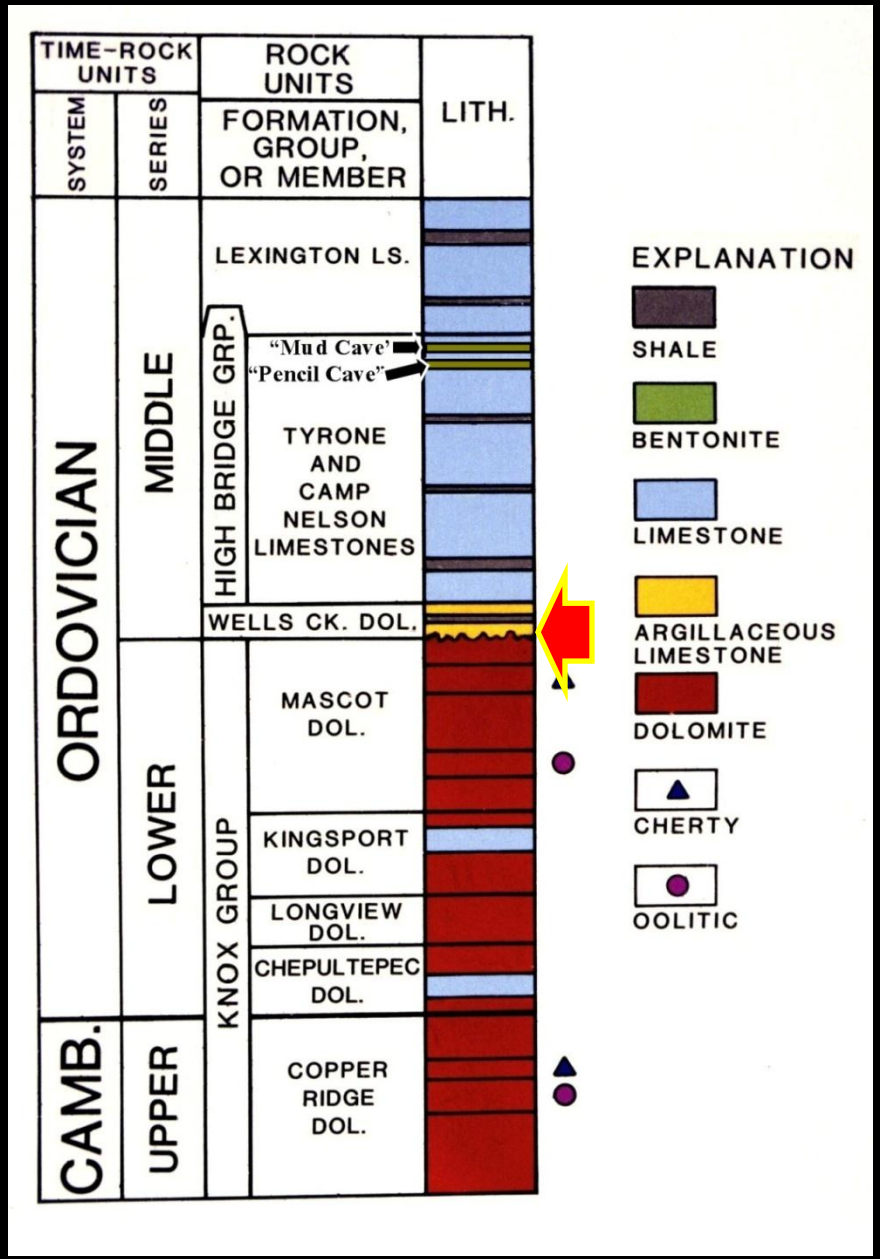
Deposition of the Knox Group

- Relative Structural Serenity
- Tectonically stable

Thick sequence of shallow-water carbonates, in excess of 3500', suggests that the rate of deposition generally kept pace with subsidence of the craton.

Deposition of the Knox Group

- Carbonates accumulated in an uniform sequence of subtidal, intertidal, and supratidal.
- Vertical distribution of lithology indicates a shallowing-upward depositional sequence.
- Numerous depositional cycles noted.

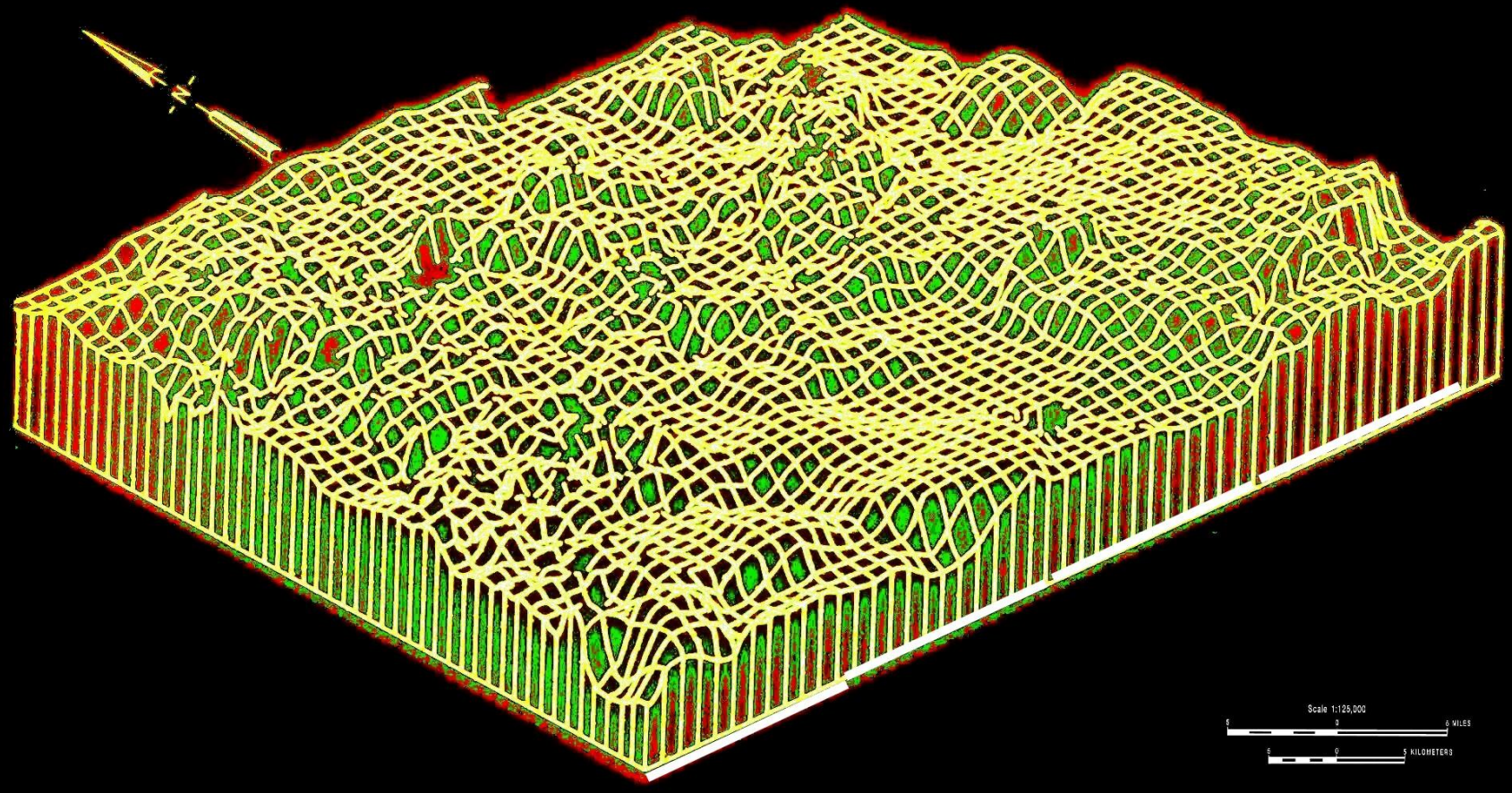


Close of the Early Ordovician

- Sea retreated
- Widespread unconformity
- Knox surface subjected to erosion and weathering.

Many geomorphic processes were in operation during an extensive period of subaerial exposure, resulting in development of …..

Karst Topography



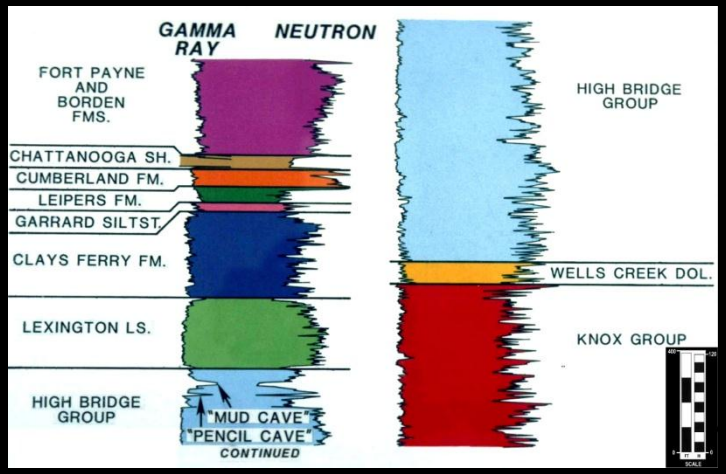
Transect plot of the eroded surface at the top of the Knox Group

Knox Paleosurface Characterized by:

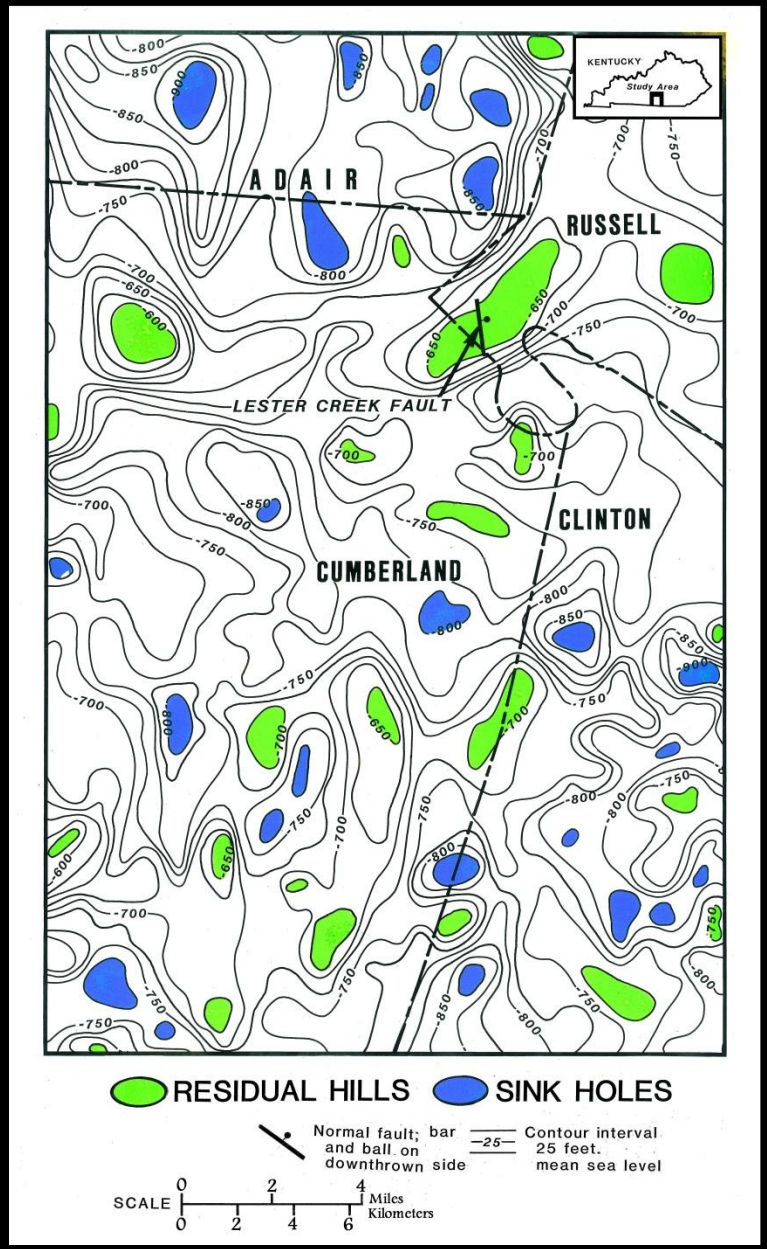
- Sinkholes.
- Residual hills.
- Interrupted, elongated & steep-sided valleys.
- No well developed drainage patterns developed.

400 Cores

700 Well Samples



In addition, more than 3000 geophysical logs, geologic and drillers logs.



Evidence Used To Identify Unconformity

1. Break in stratigraphic record.
2. Abrupt change in lithology.
3. Occurrence of a brecciated zone.
    - Weathered, etched & angular fragments.
    - Reworked material.
    - Volcanic ash.
    - Oil residues.

4. Weathered chert.
5. Porous zones.
6. Breccias.
7. Karst topography.
    - Residual hills.
    - Sinkholes.
    - Lacks well developed drainage pattern.
8. Relief on the Knox paleosurface varies as much as 500 feet.

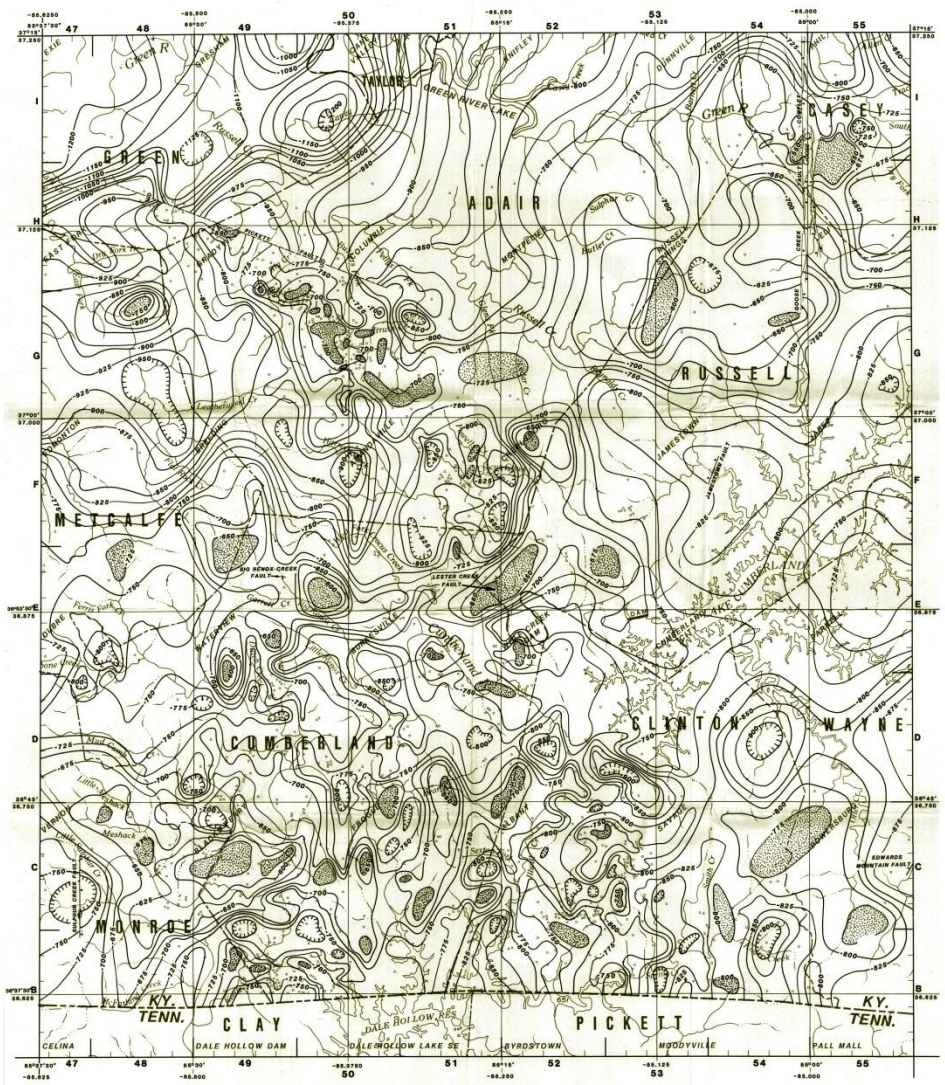
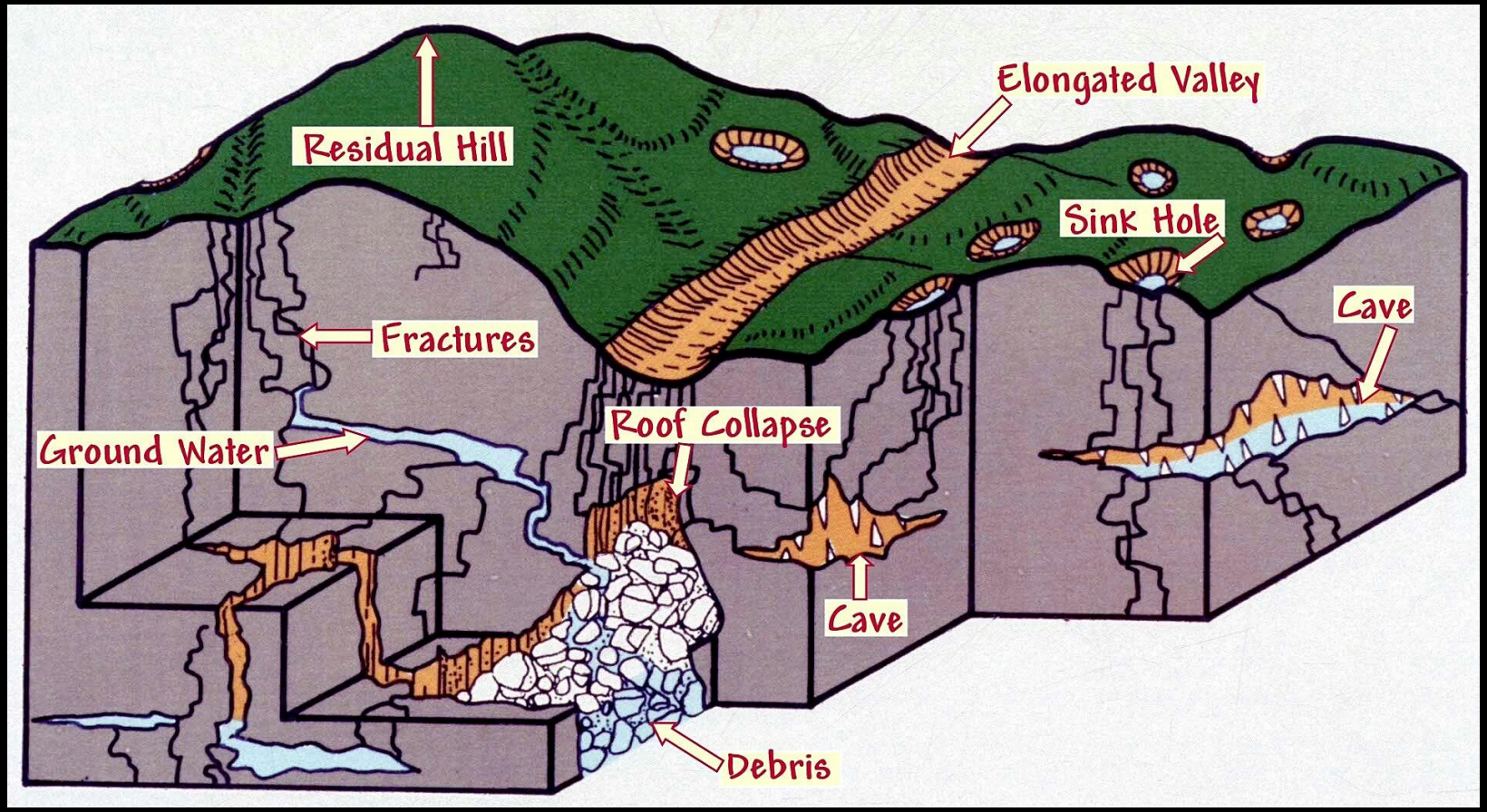
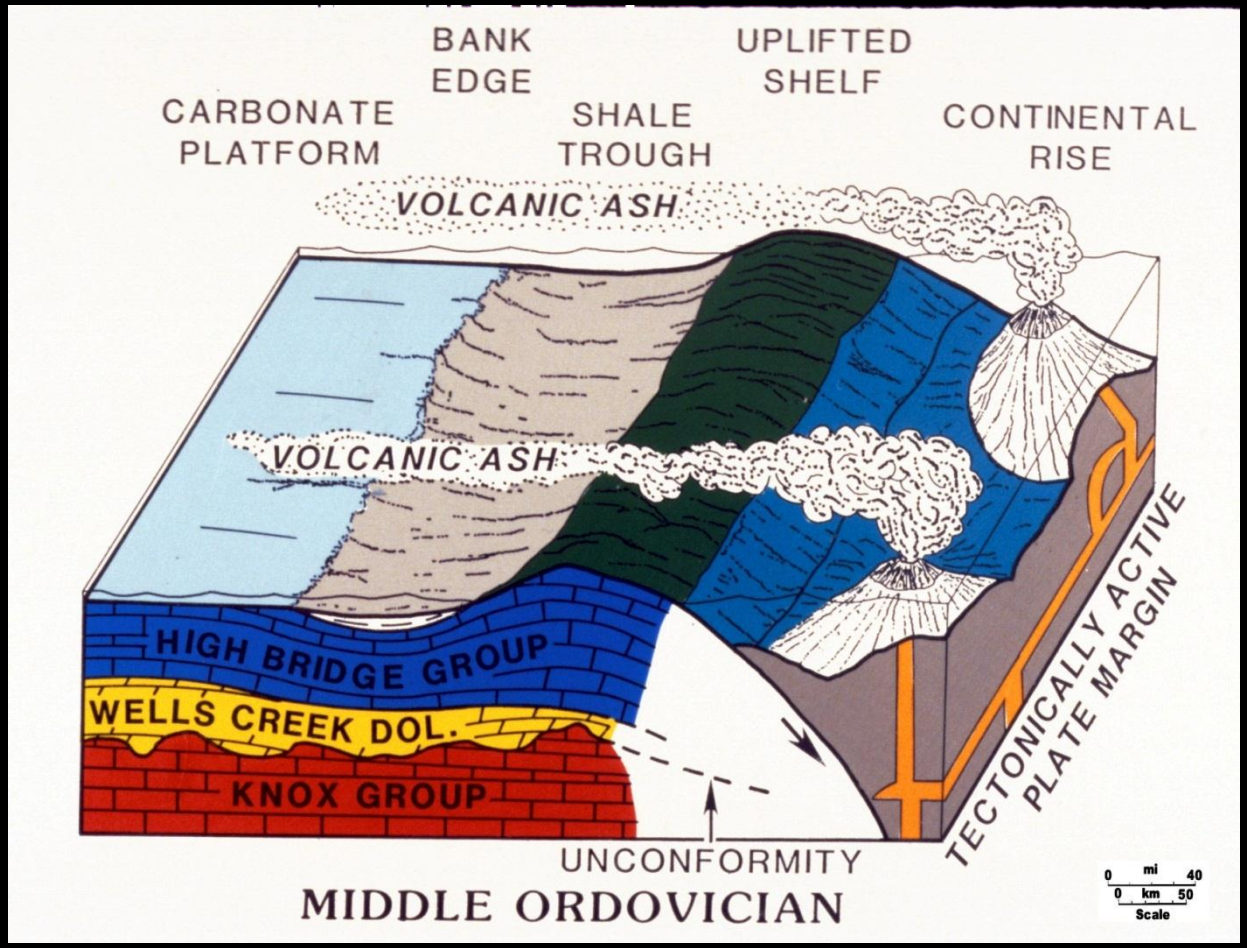
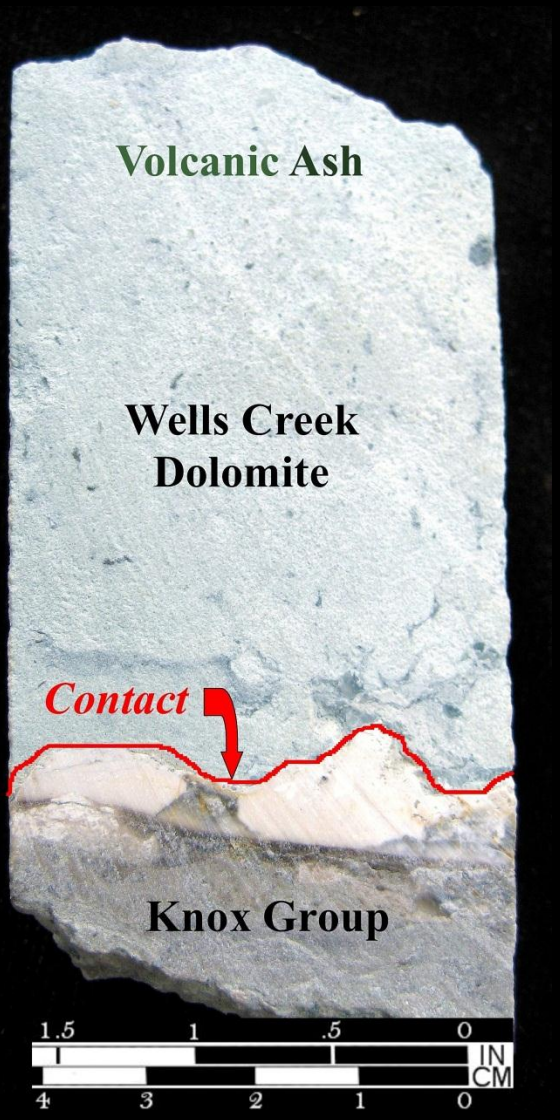
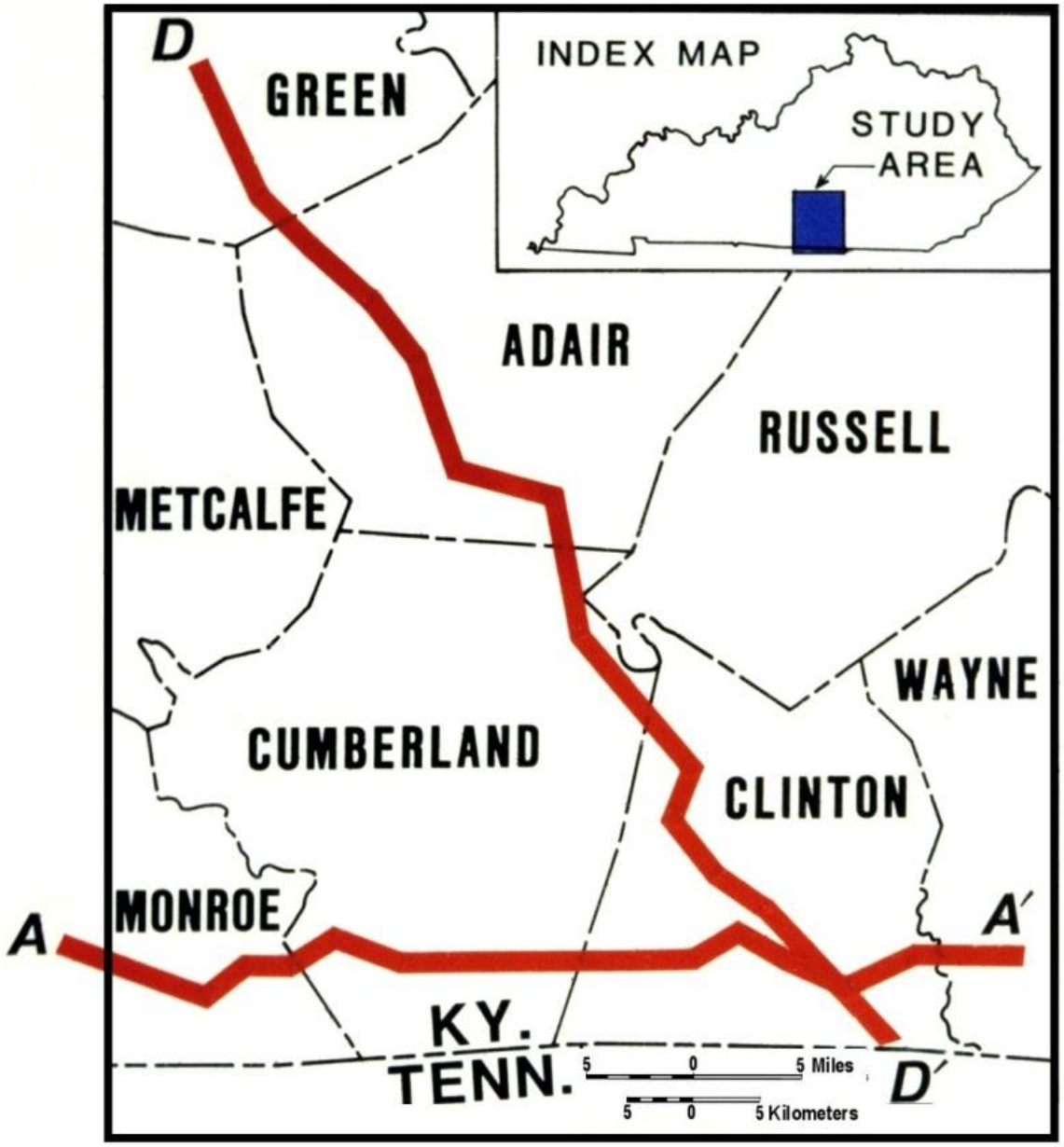


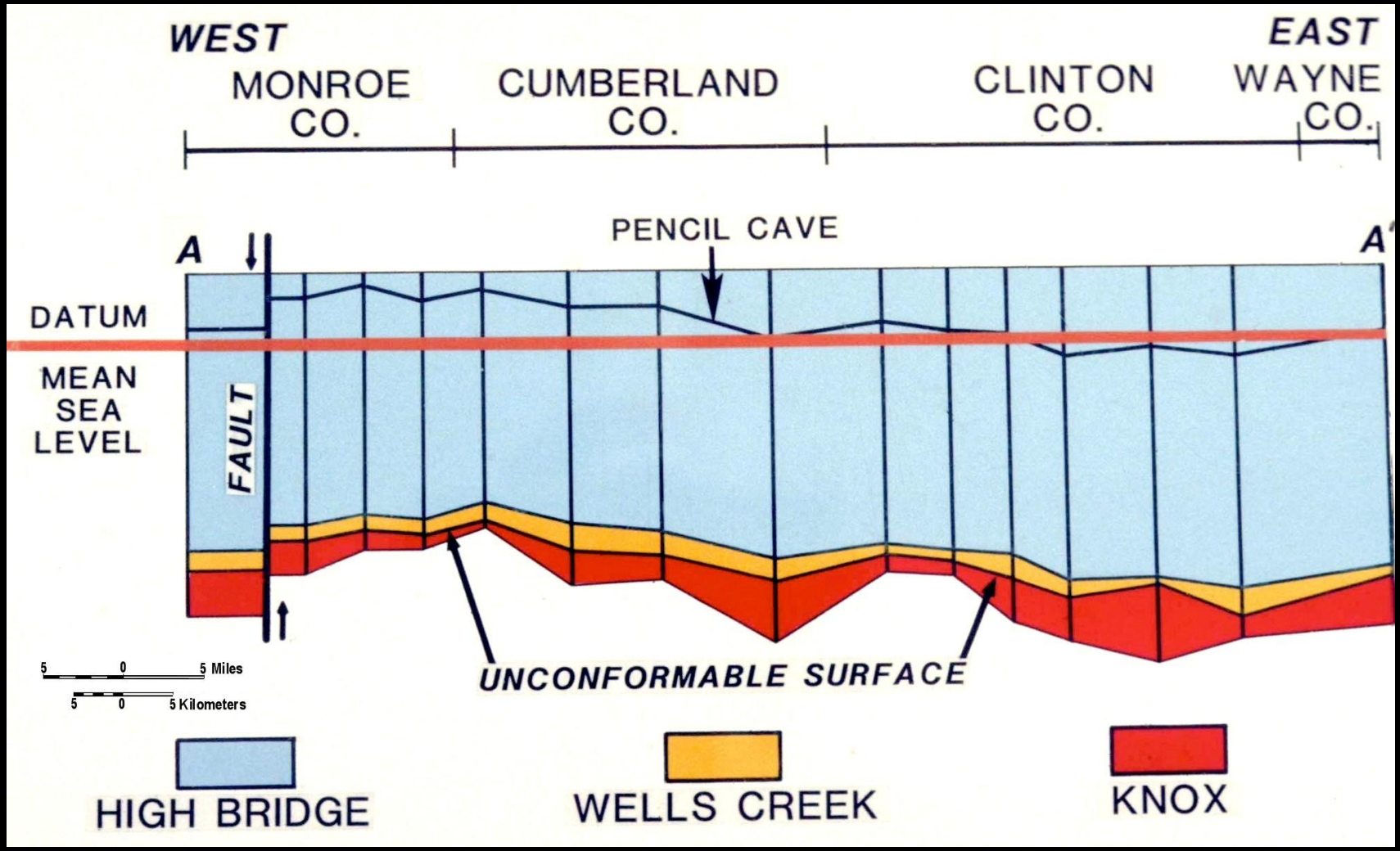
Figure 2. Paleotopographic Map on Top of the Cambrian-Ordovician Knox Group

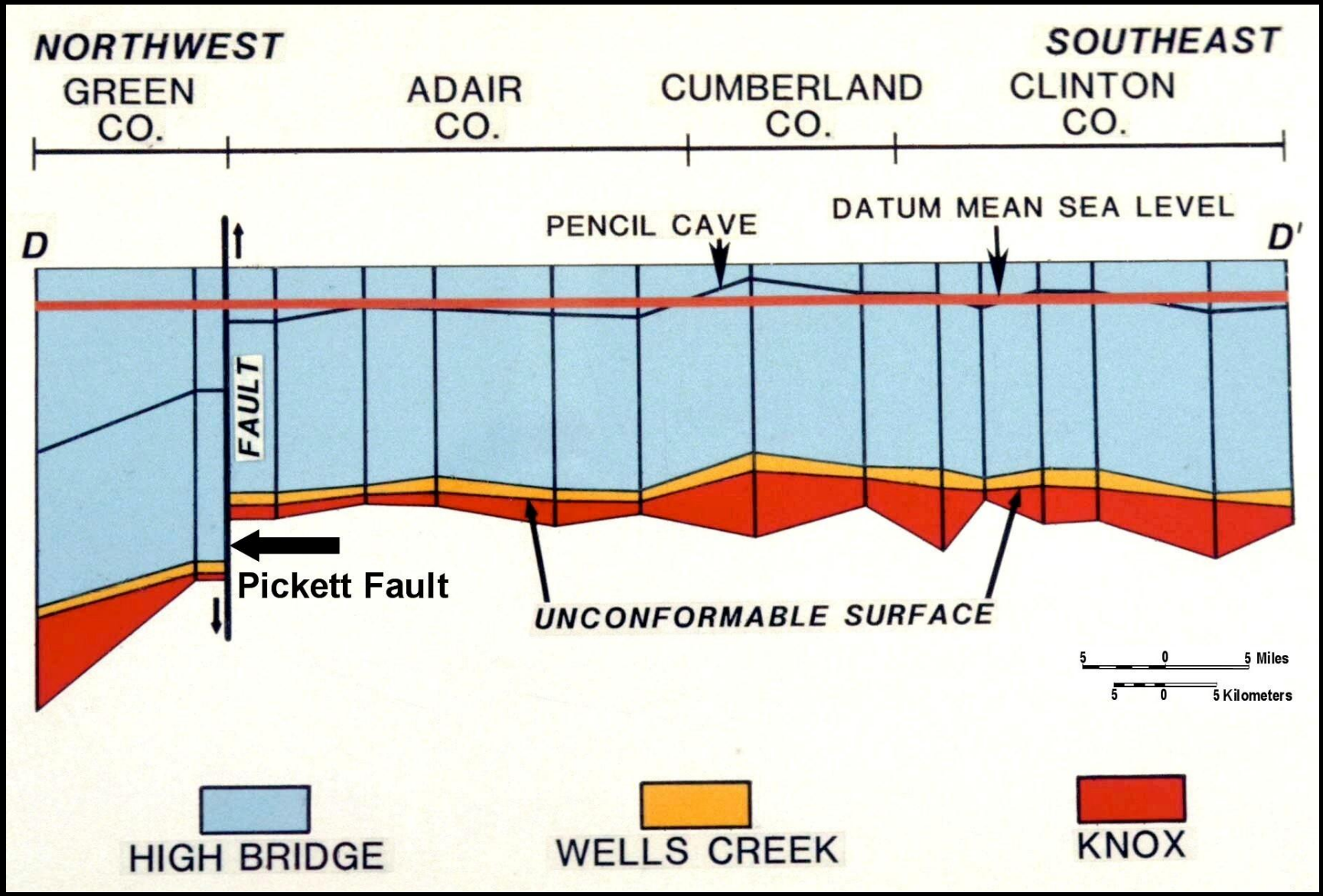

Residual Hill
Elongated Valley
Sink Hole
Cave
Fractures
Ground Water
Roof Collapse
Cave
Debris

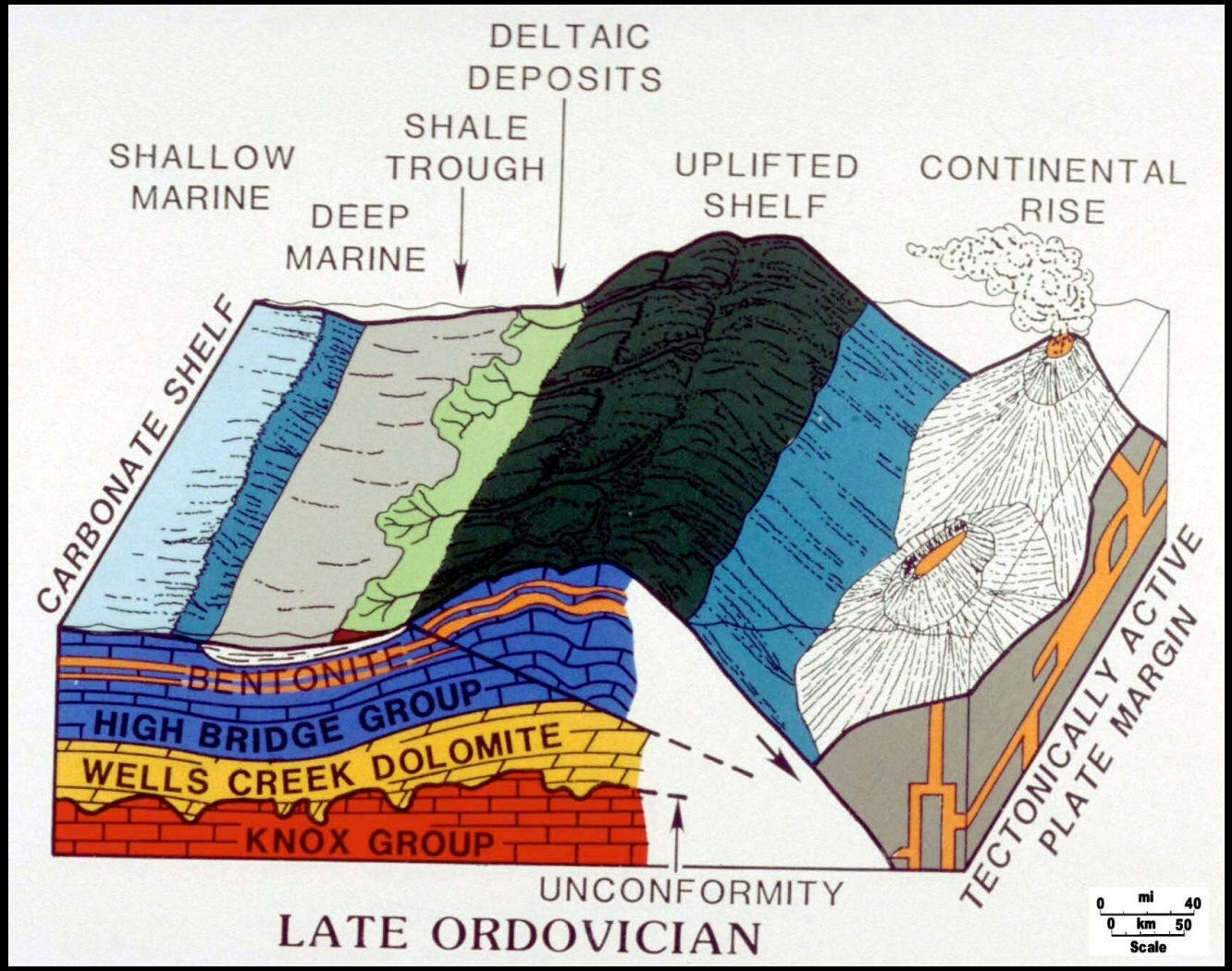

BANK EDGE
UPLIFTED SHELF
CARBONATE PLATFORM
SHALE TROUGH
CONTINENTAL RISE
VOLCANIC ASH
VOLCANIC ASH
HIGH BRIDGE GROUP
WELLS CREEK DOL.
KNOX GROUP
UNCONFORMITY
TECTONICALLY ACTIVE PLATE MARGIN
0 mi 40
0 km 50
Scale
MIDDLE ORDOVICIAN

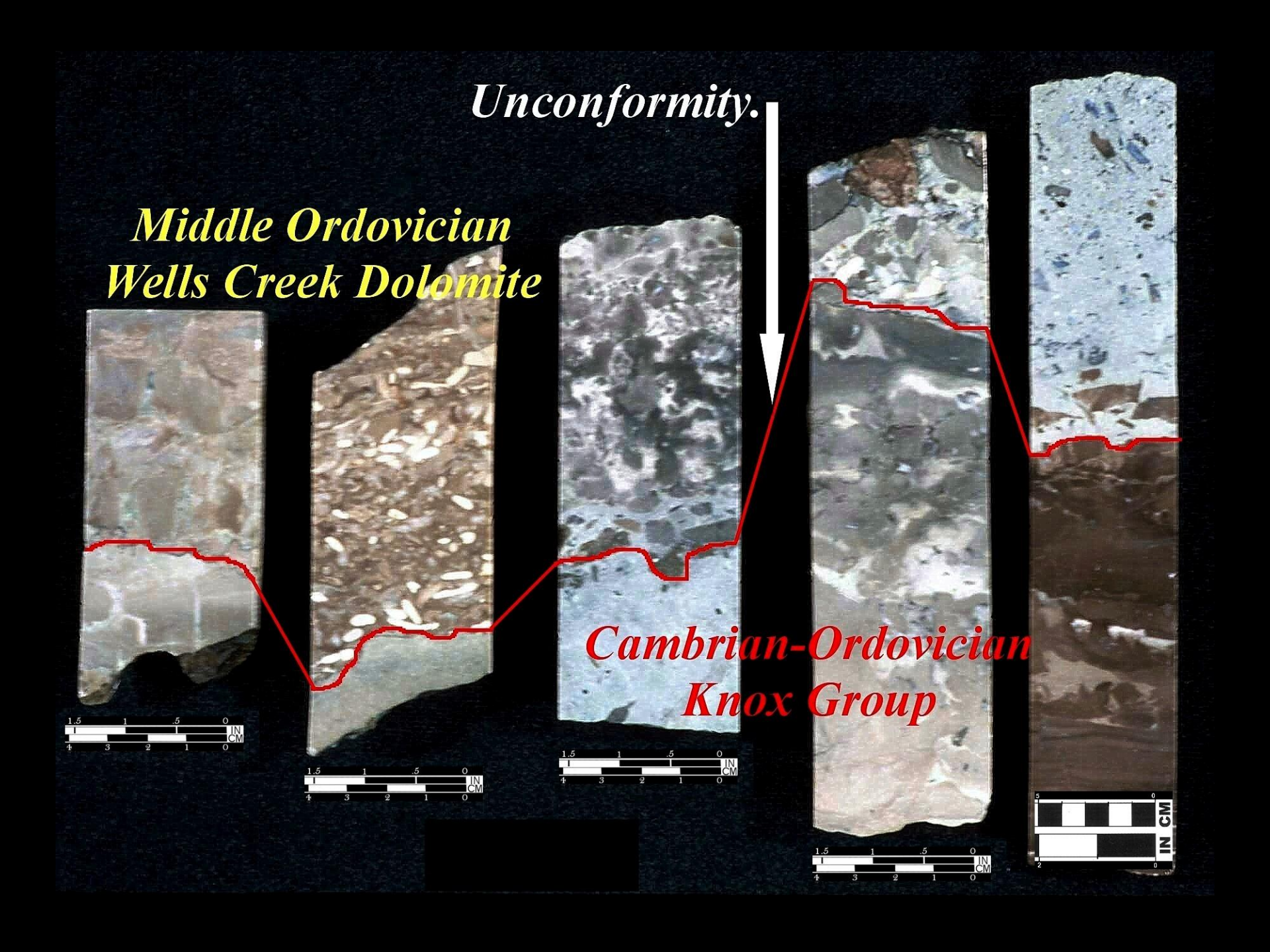

Volcanic Ash
Wells Creek Dolomite
Contact
Knox Group
1.5 1 .5 0
IN
CM
4 3 2 1 0


D
GREEN
INDEX MAP
STUDY
AREA
ADAIR
RUSSELL
METCALFE
WAYNE
CUMBERLAND
CLINTON
A
MONROE
A´
KY.
TENN.
D´
5 0 5 Miles
5 0 5 Kilometers


WEST
EAST
MONROE CO.
CUMBERLAND CO.
CLINTON CO.
WAYNE CO.
A
A'
PENCIL CAVE
DATUM
MEAN SEA LEVEL
FAULT
5 0 5 Miles
5 0 5 Kilometers
UNCONFORMABLE SURFACE
HIGH BRIDGE
WELLS CREEK
KNOX


NORTHWEST
SOUTHEAST
GREEN CO.
ADAIR CO.
CUMBERLAND CO.
CLINTON CO.
D
D'
PENCIL CAVE
DATUM MEAN SEA LEVEL
FAULT
Pickett Fault
UNCONFORMABLE SURFACE
5 0 5 Miles
5 0 5 Kilometers
HIGH BRIDGE
WELLS CREEK
KNOX


DELTAIC DEPOSITS
SHALE TROUGH
SHALLOW MARINE
DEEP MARINE
UPLIFTED SHELF
CONTINENTAL RISE
CARBONATE SHELF
BENTONITE
HIGH BRIDGE GROUP
WELLS CREEK DOLOMITE
KNOX GROUP
UNCONFORMITY
TECTONICALLY ACTIVE PLATE MARGIN
0 mi 40
0 km 50
Scale
LATE ORDOVICIAN


Unconformity.
Middle Ordovician
Wells Creek Dolomite
Cambrian-Ordovician
Knox Group

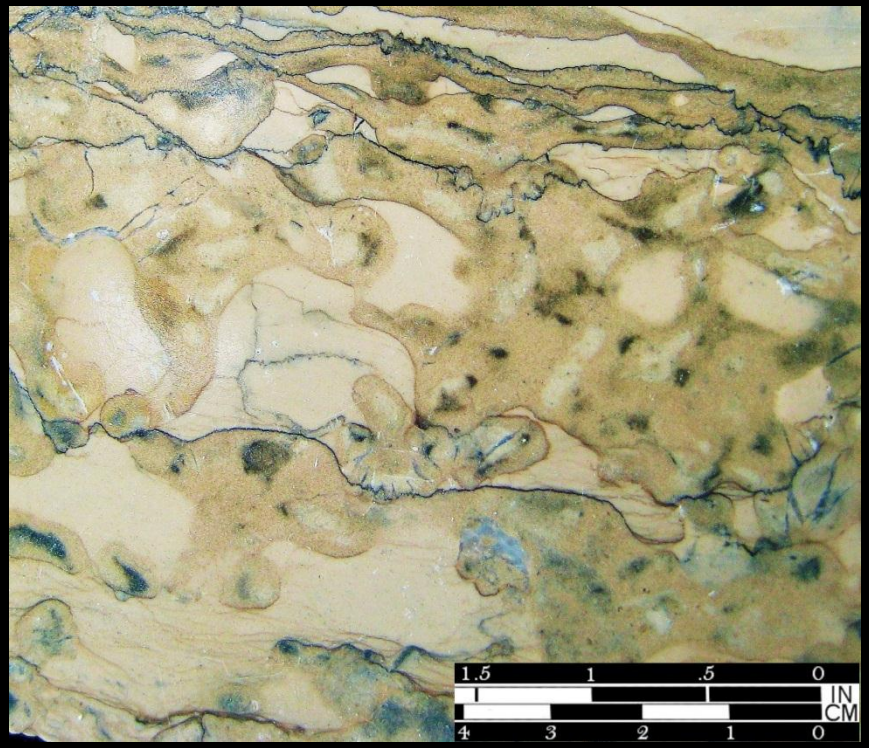
WELLS CREEK DOLOMITE

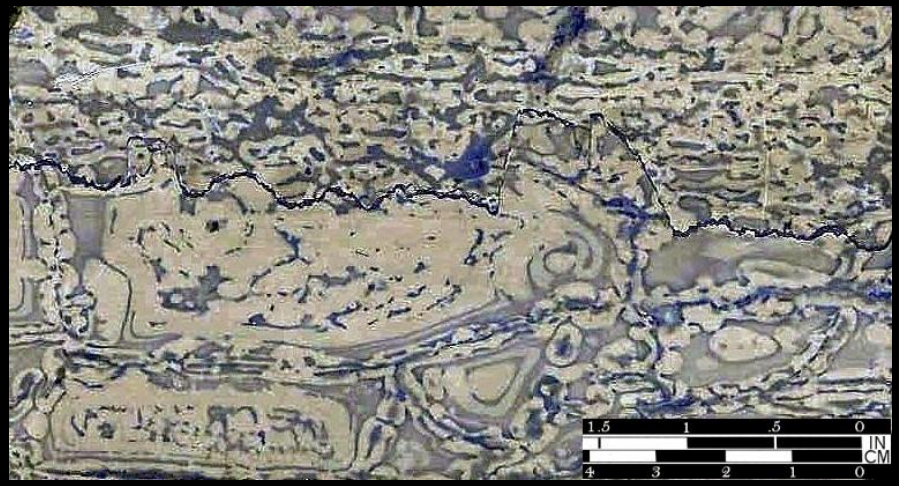
Unconformable surface

KNOX DOLOMITE

Original bedding and fabric of Knox preserved in packstone

Rarely preserved laminations with stylolite and burrowing





Various examples of bioturbation.

Various Minerals Present in the Knox Group.

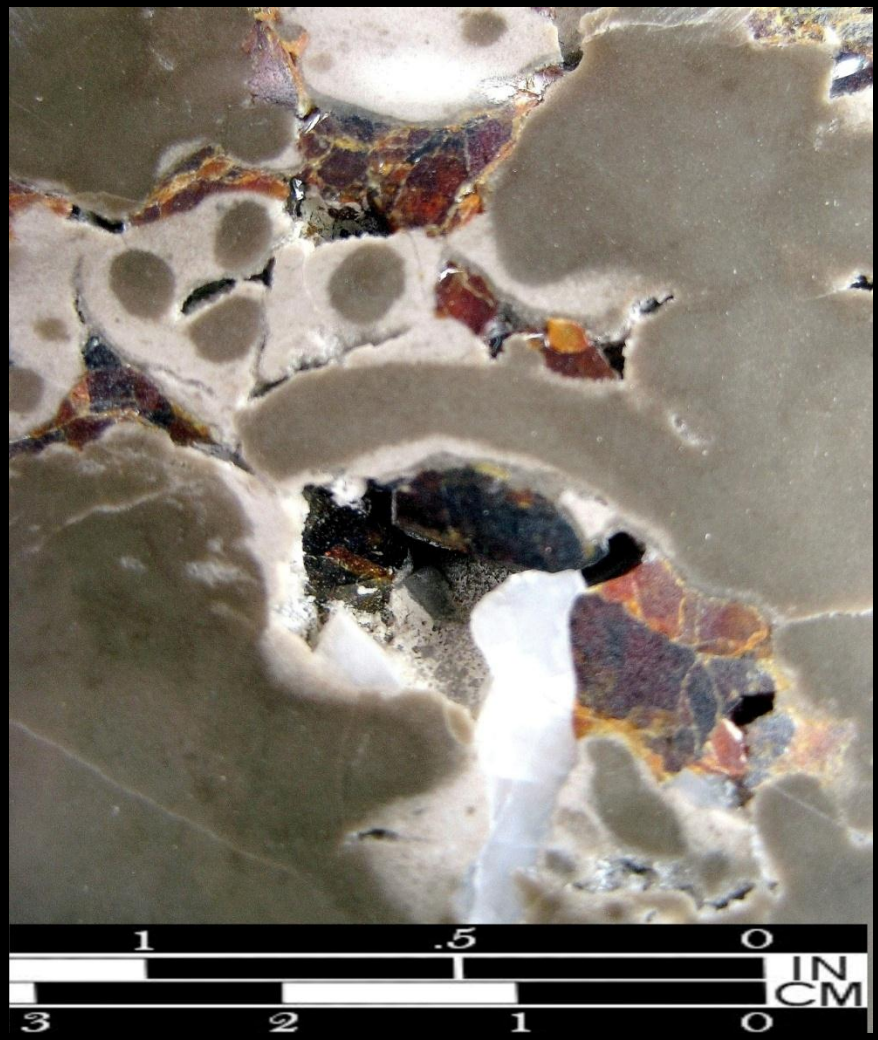
A Result of Hydrothermal Activity


1.5 1 .5 0
IN
CM
4 3 2 1 0


1.5 1 .5 0
IN
CM
4 3 2 1 0


1.5 1 .5 0
IN
CM

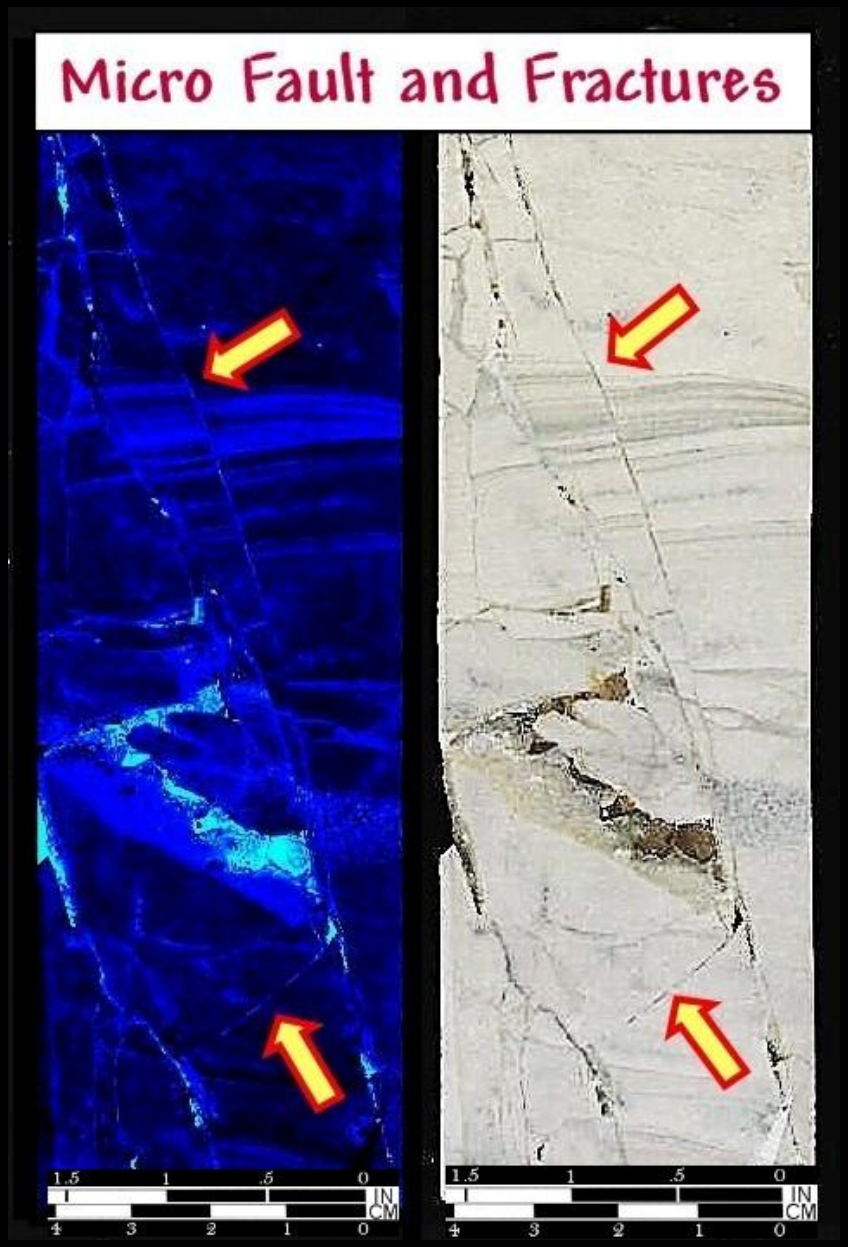
Chemical alterations with silica replacement



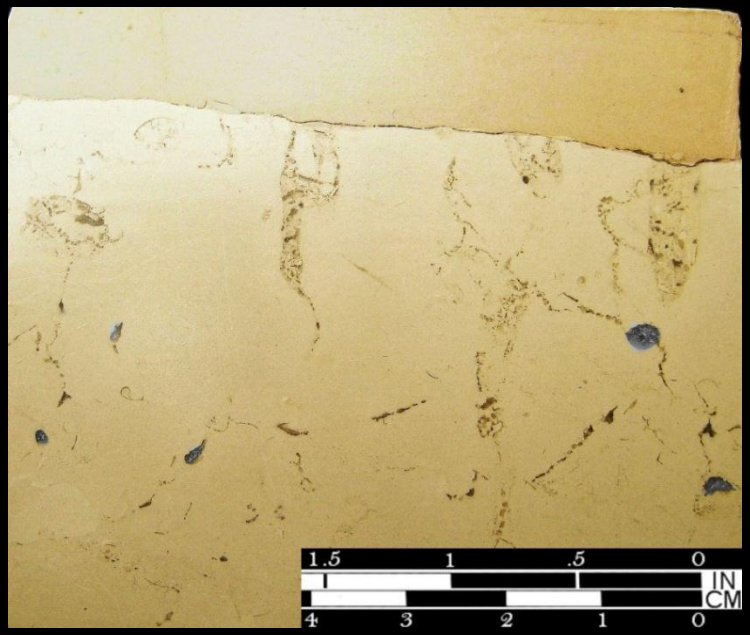
Vugs filled with quartz and sphalerite

Partly mineralized quartz-filled vugs

Micro Fault and Fractures



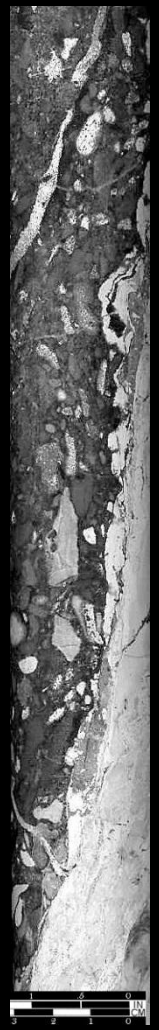
Partly oil-stained polygon-shaped mud cracks.



Quartz-filled birdseye structures

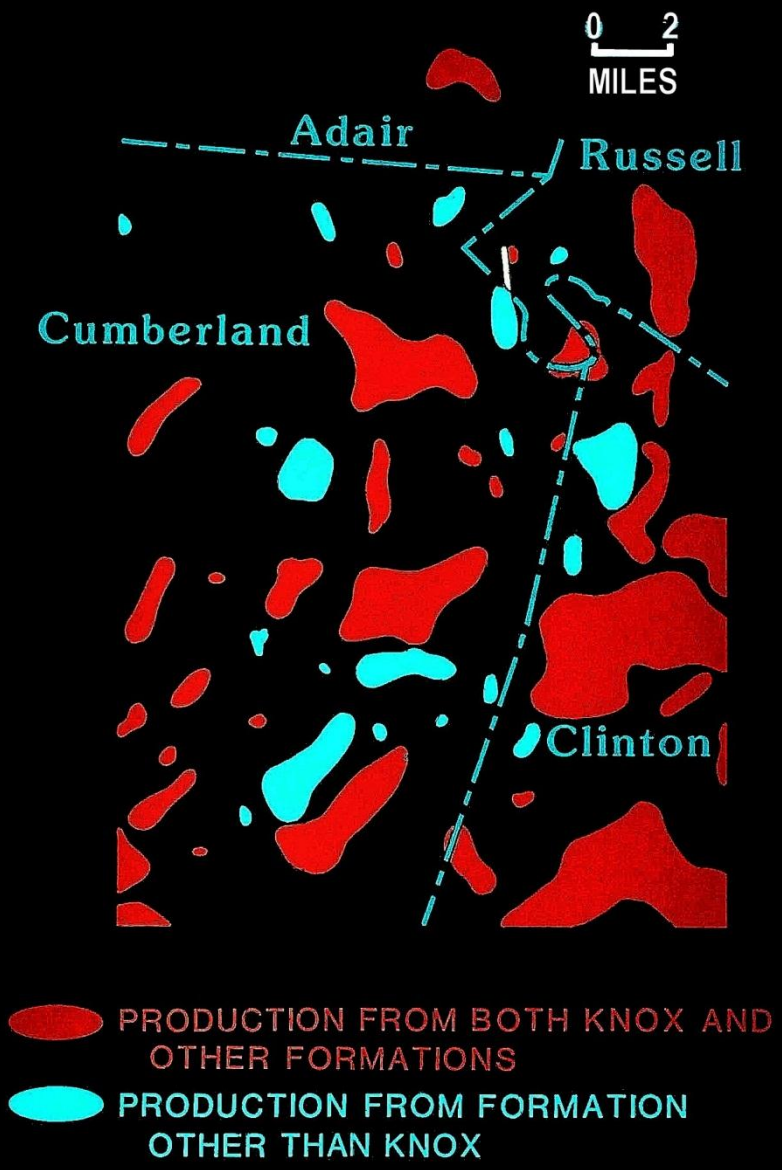
Commonly occurring algae

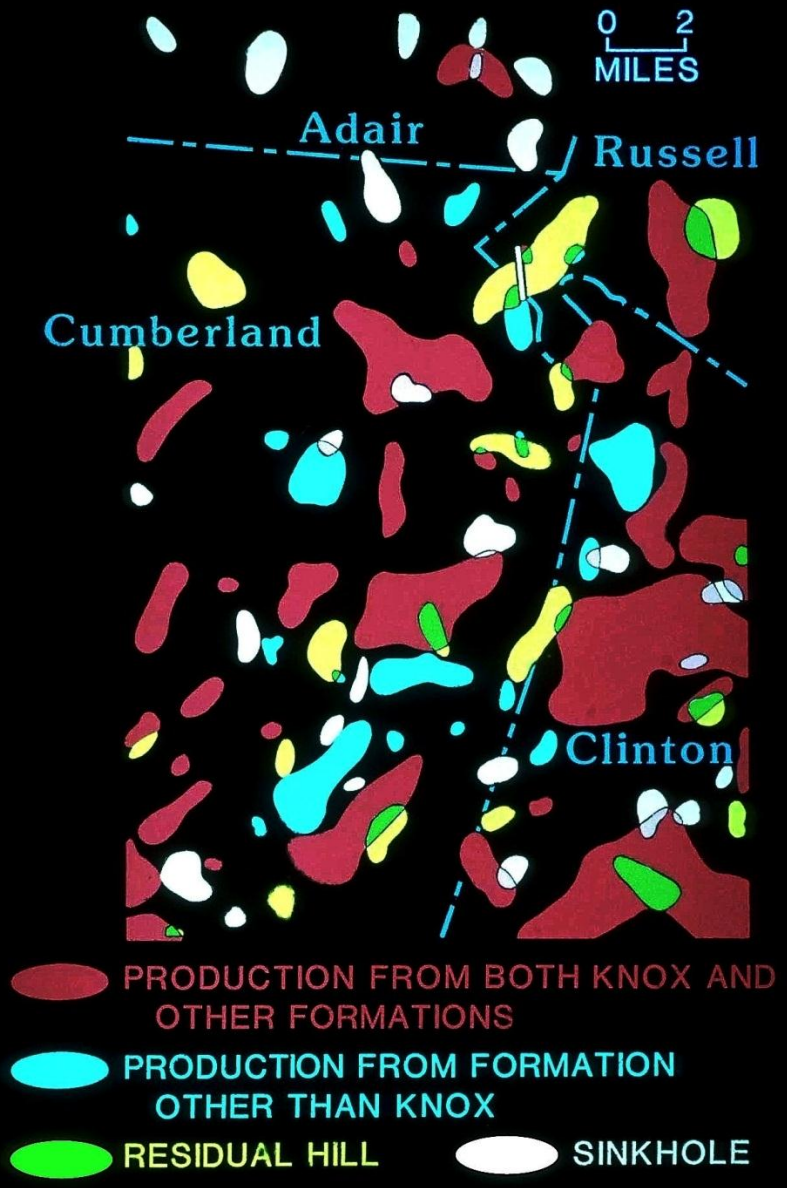
Oil stained Knox Dolomite containing a rarely found fossil

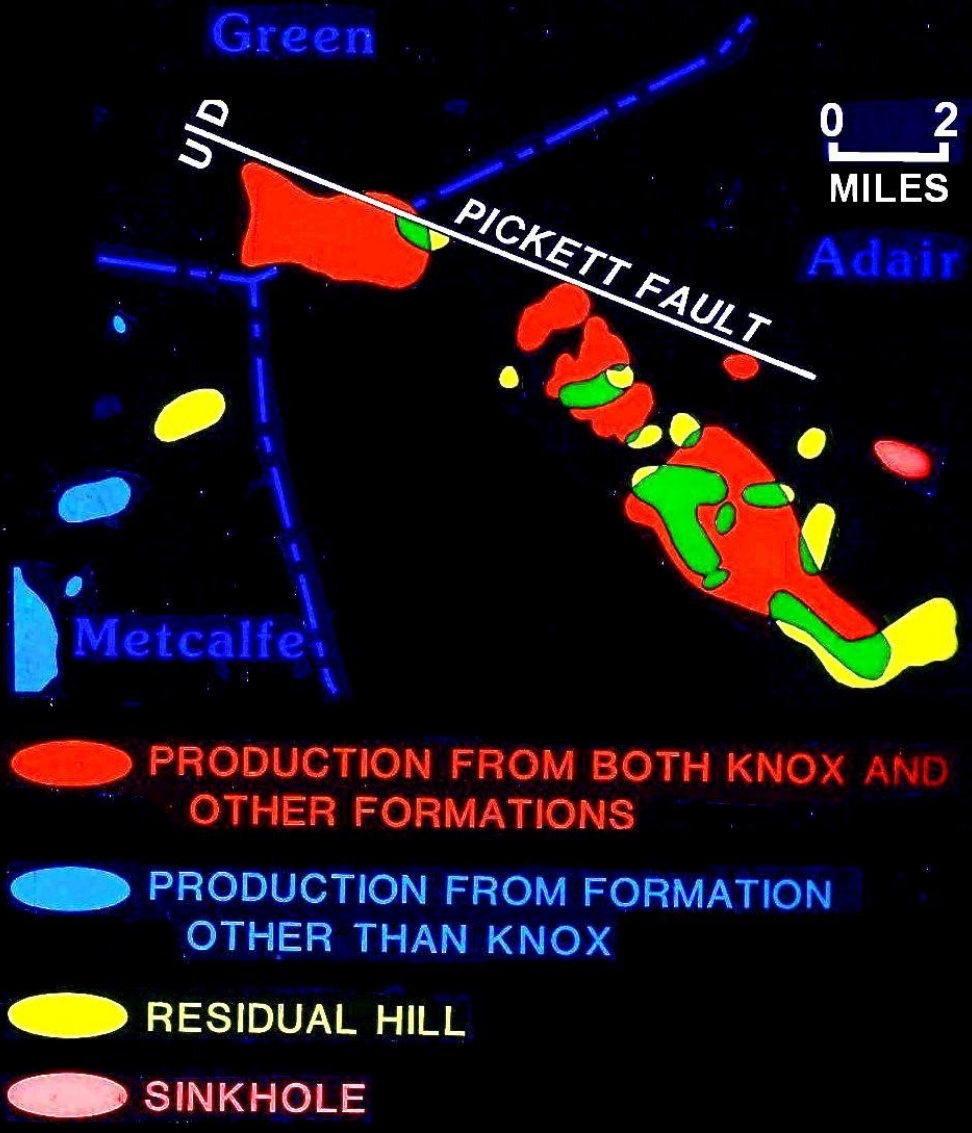


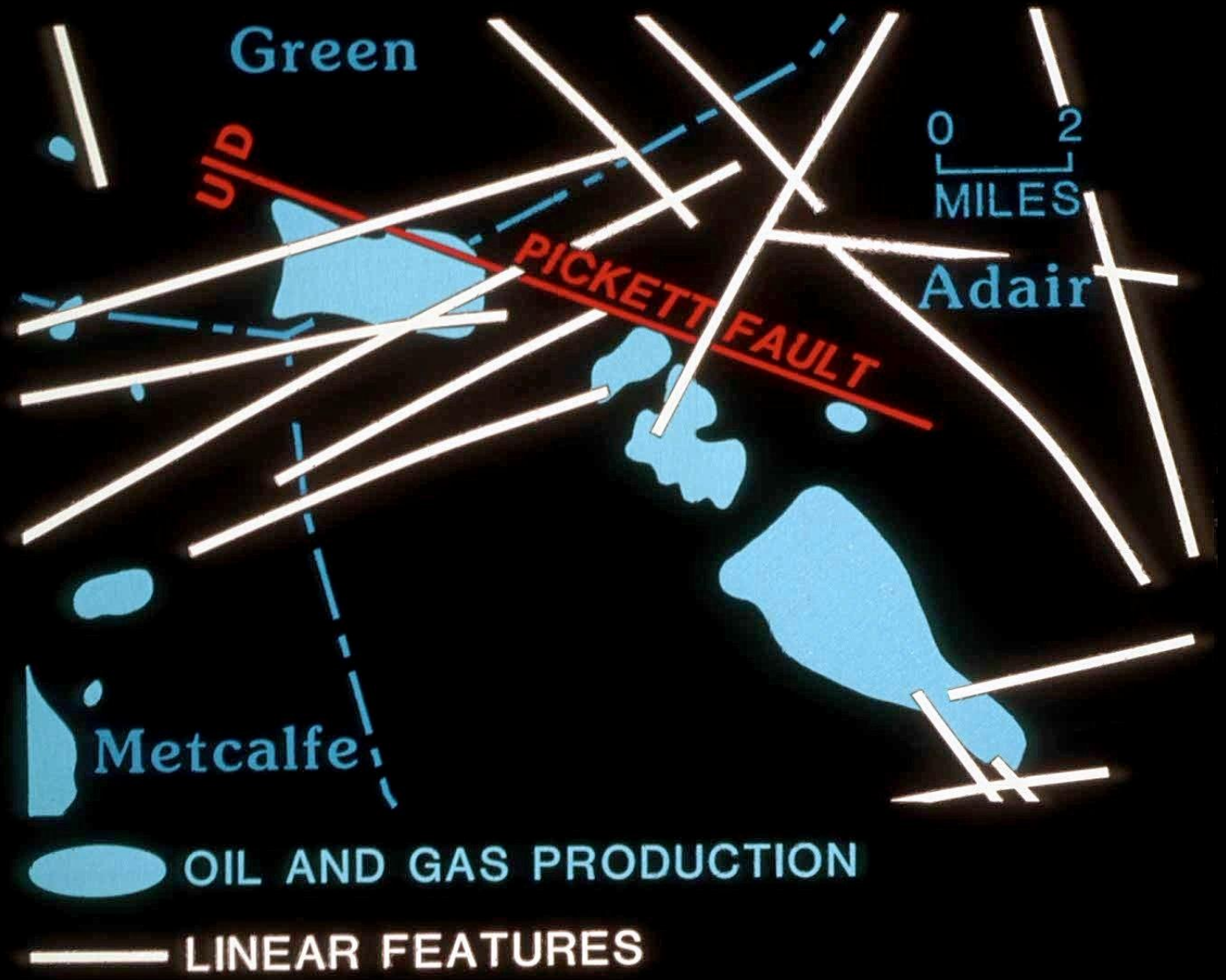
Fractures, breccia, minerals & oil staining

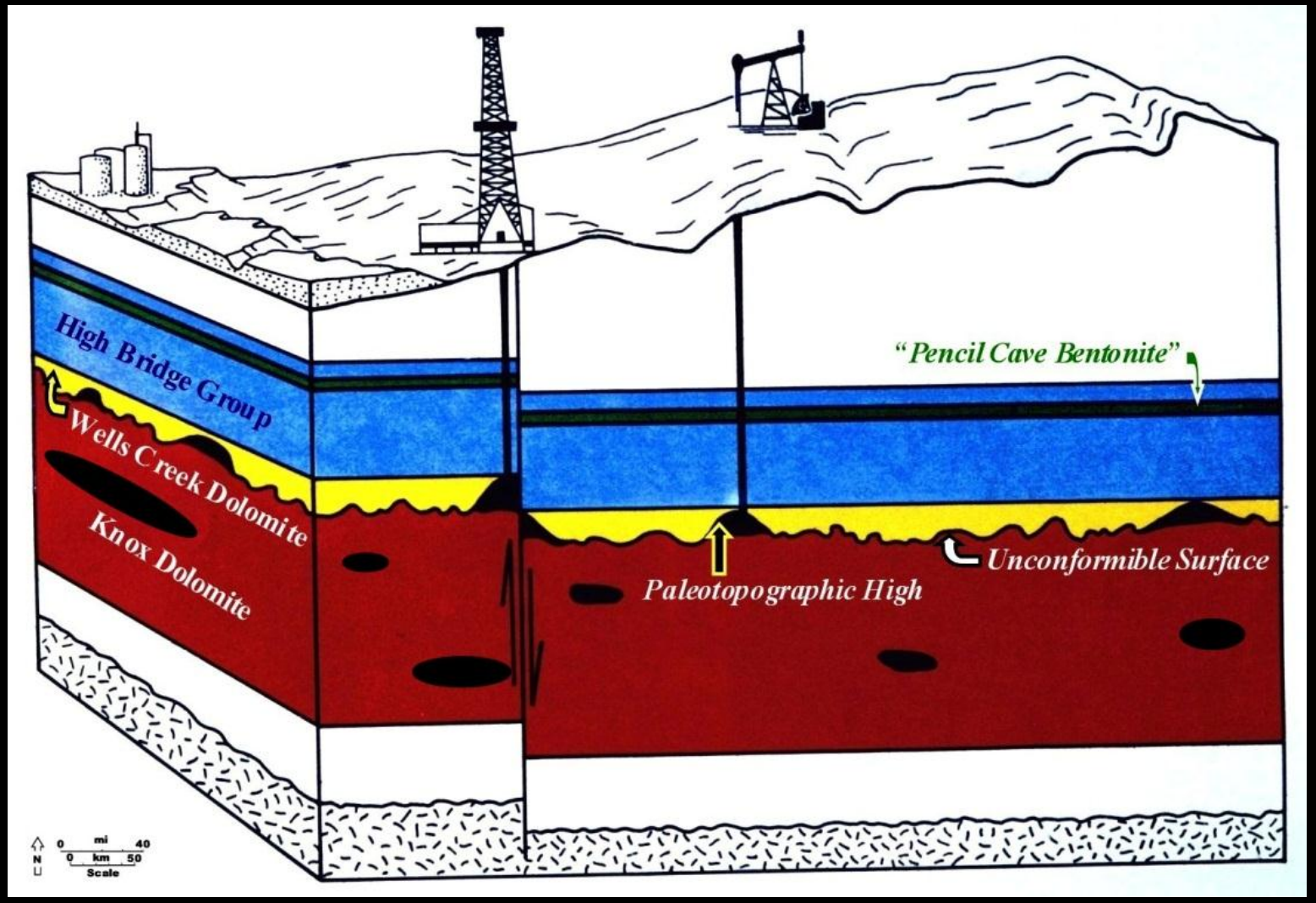
145 years of Exploration


0 2
MILES
Adair
Russell
Cumberland
Clinton
PRODUCTION FROM BOTH KNOX AND OTHER FORMATIONS
PRODUCTION FROM FORMATION OTHER THAN KNOX

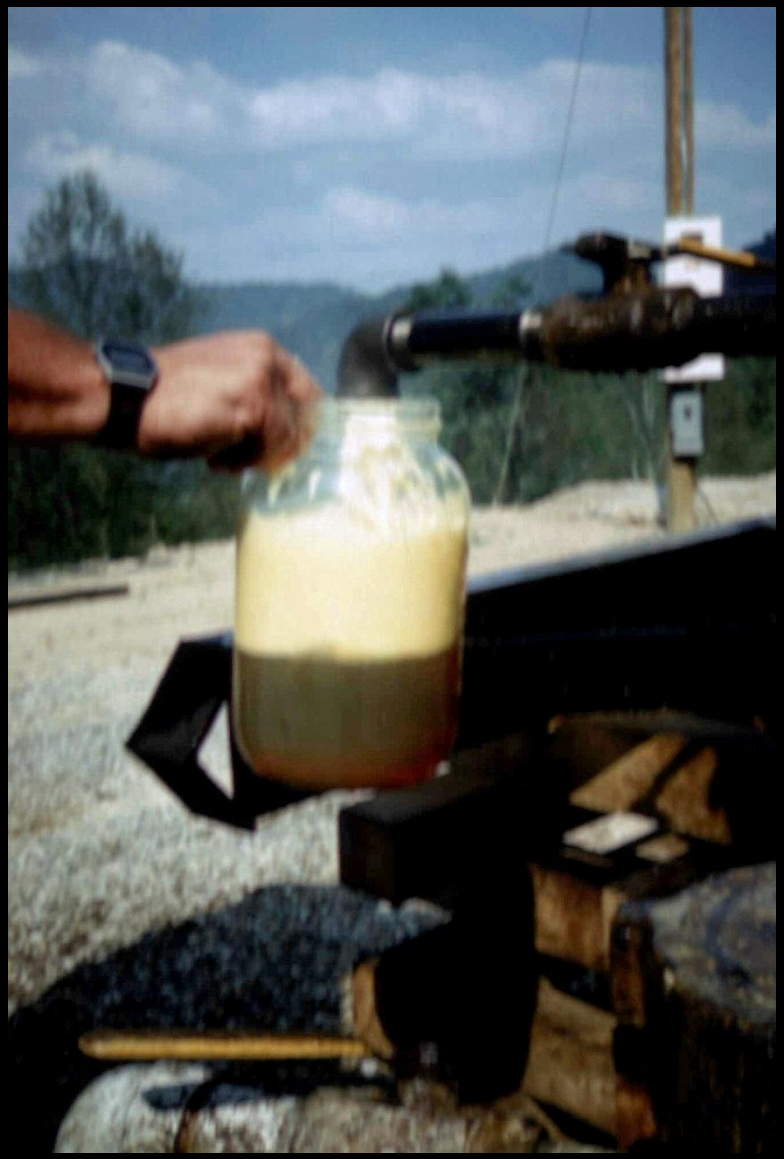

0 2
MILES
Adair
Russell
Cumberland
Clinton
PRODUCTION FROM BOTH KNOX AND OTHER FORMATIONS
PRODUCTION FROM FORMATION OTHER THAN KNOX
RESIDUAL HILL
SINKHOLE


Green
UP
PICKETT FAULT
0 2
MILES
Adair
Metcalfe
PRODUCTION FROM BOTH KNOX AND OTHER FORMATIONS
PRODUCTION FROM FORMATION OTHER THAN KNOX
RESIDUAL HILL
SINKHOLE

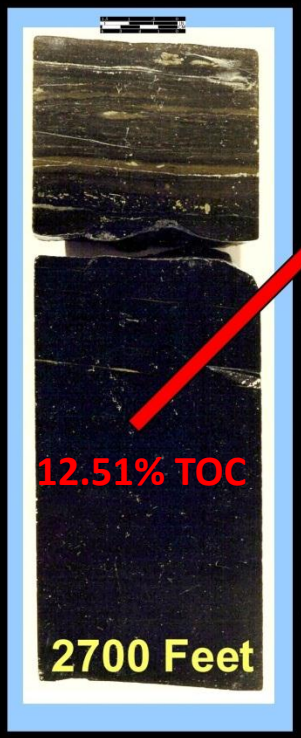

Green
UD
PICKETT FAULT
0 2
MILES
Adair
Metcalfe
OIL AND GAS PRODUCTION
LINEAR FEATURES



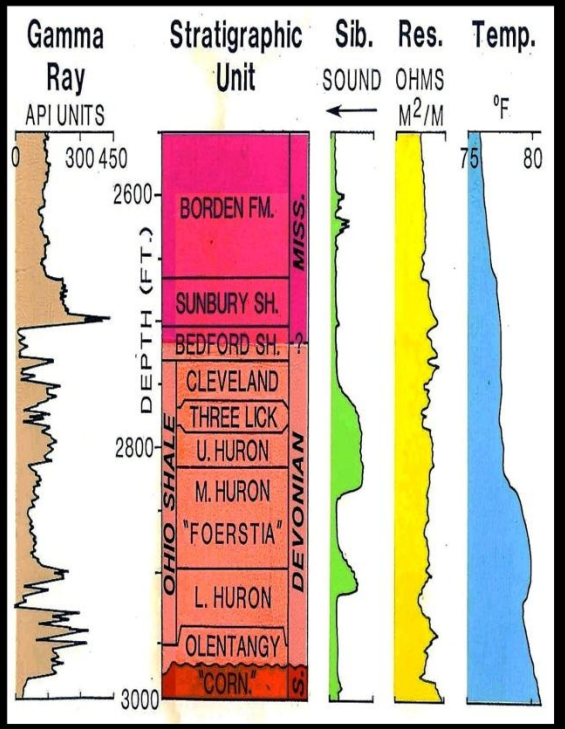
Hydrocarbons occur at or near the unconformity



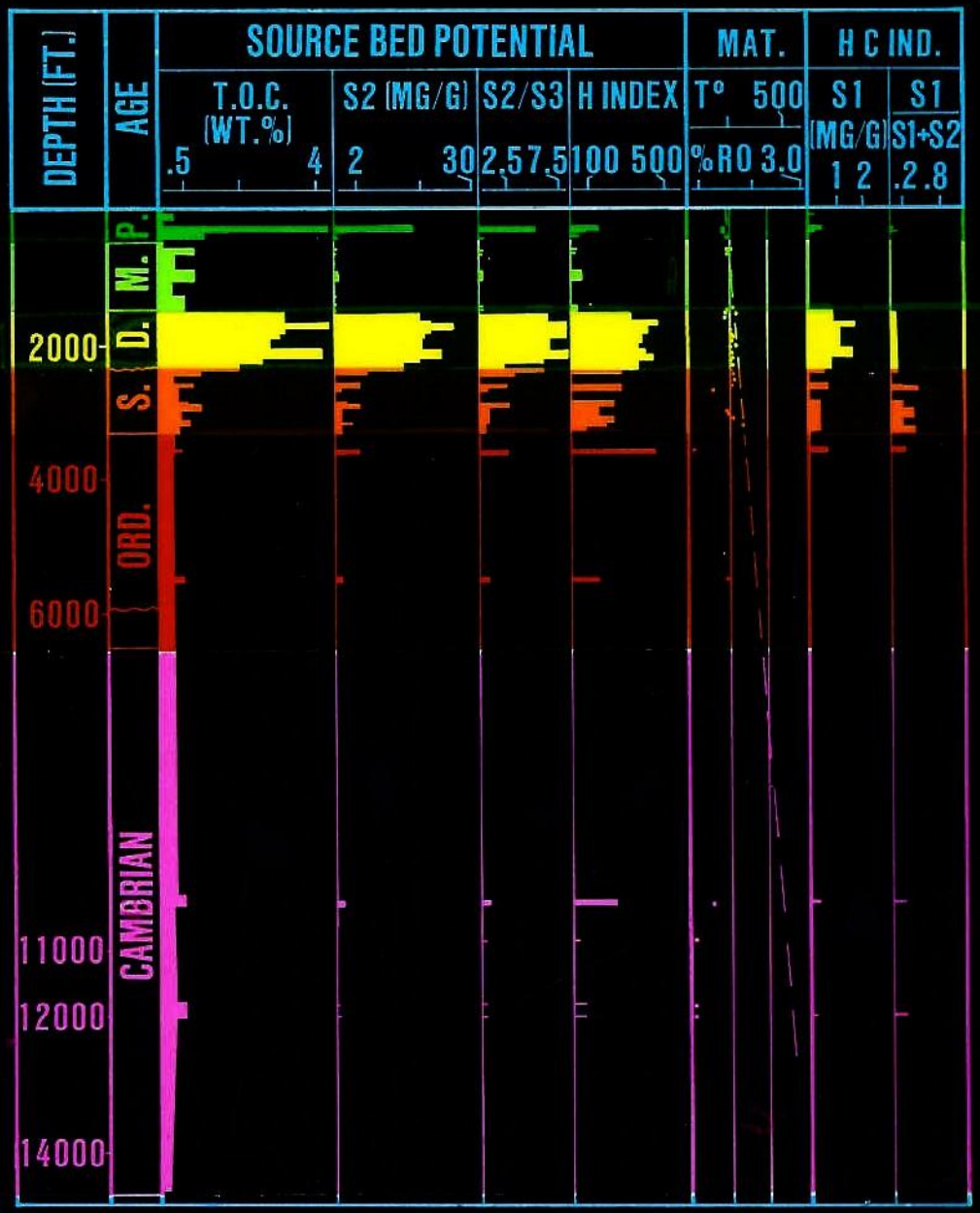
What are the sources of the Hydrocarbons found in the Cambrian-Ordovician in south-central Kentucky?



Sample Number	Depth (ft)	TOC (Wt. %)	S1 (mg/g)	S2 (mg/g)	S3 (mg/g)	Tmax (°C)	Production Index	Hydrogen Index	Oxygen Index
6301-001	2700	12.51	6.61	35.58	0.22	444	0.16	284	2
[illegible]2	2732	4.02	2.85	10.44	0.12	442	0.21	260	3
003	2752	3.06	2.31	6.91	0.14	444	0.25	226	5
004	2774	7.11	3.77	18.43	0.11	443	0.17	259	2
005	2795	6.48	3.27	16.22	0.18	445	0.17	250	3
006	2811	5.91	3.29	16.42	0.22	443	0.17	278	4
007	2900	4.39	2.72	10.96	0.18	442	0.20	250	4
008	2932	5.76	2.72	13.60	<0.10	446	0.17	236	-
009	2948	4.28	2.21	11.77	0.13	443	0.16	275	3
010	2957	7.12	3.32	18.80	<0.10	441	0.15	264	-
011	2972	0.38	0.17	0.28	0.14	437	0.38	73	37

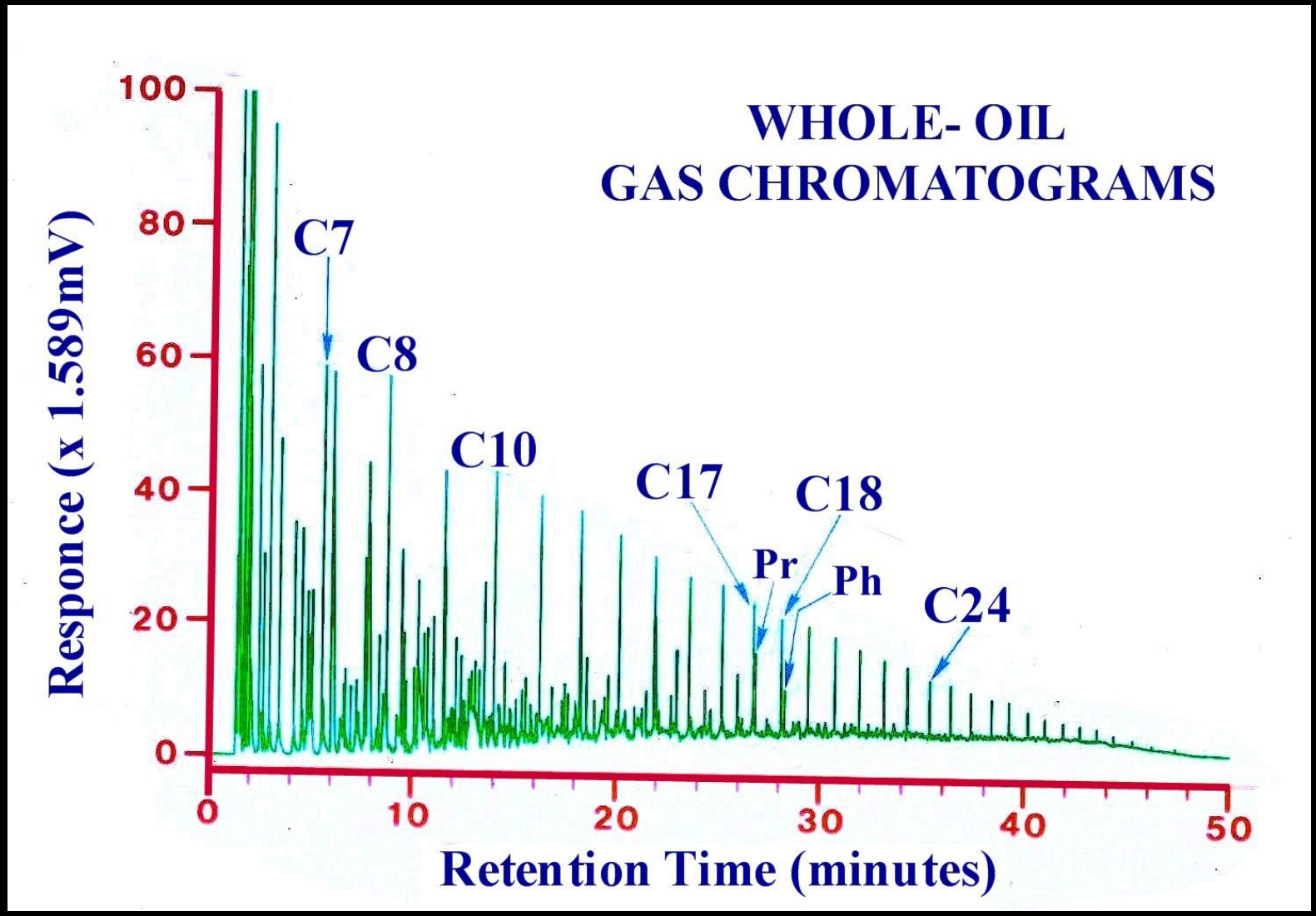


Rock-Eval Pyrolysis and Total Organic Carbon Analysis Results



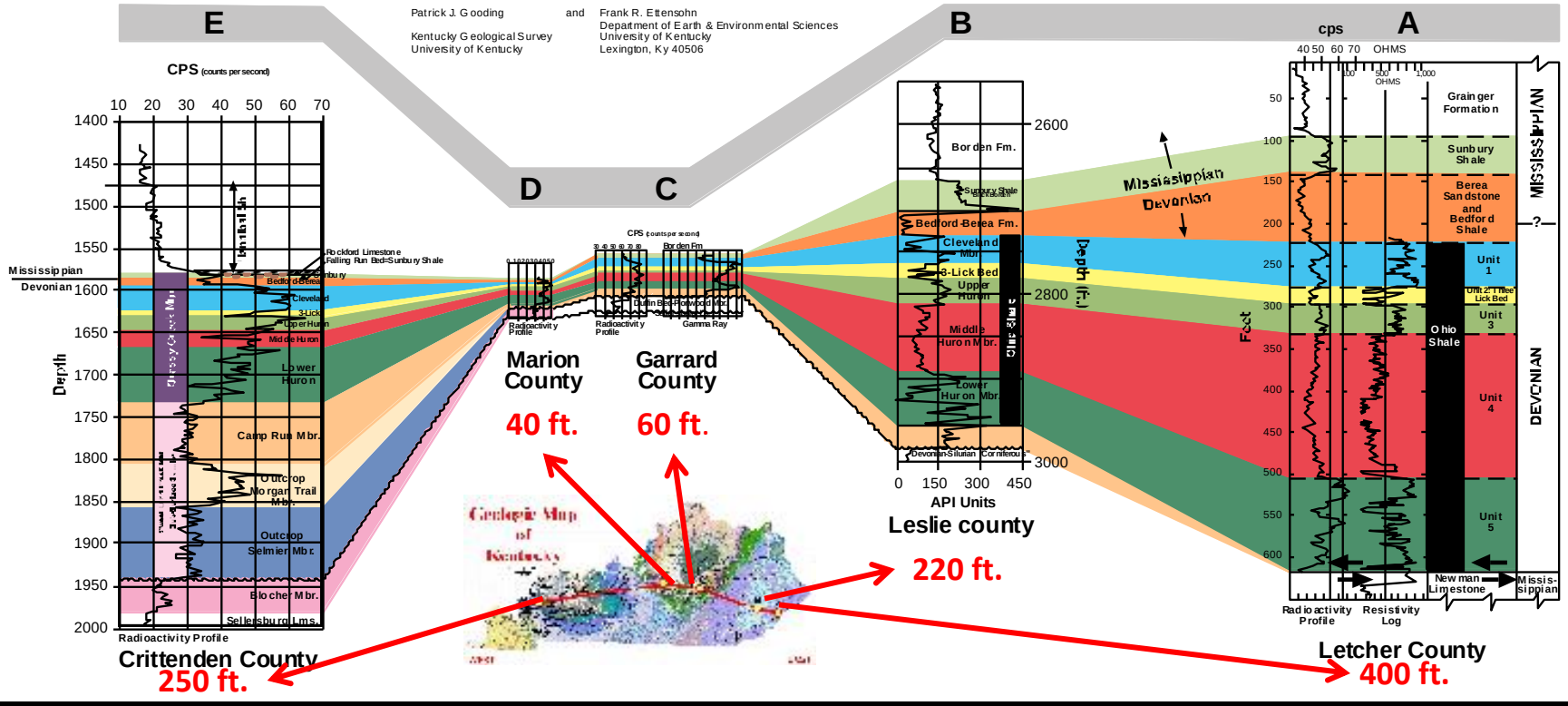
Devonian Shales

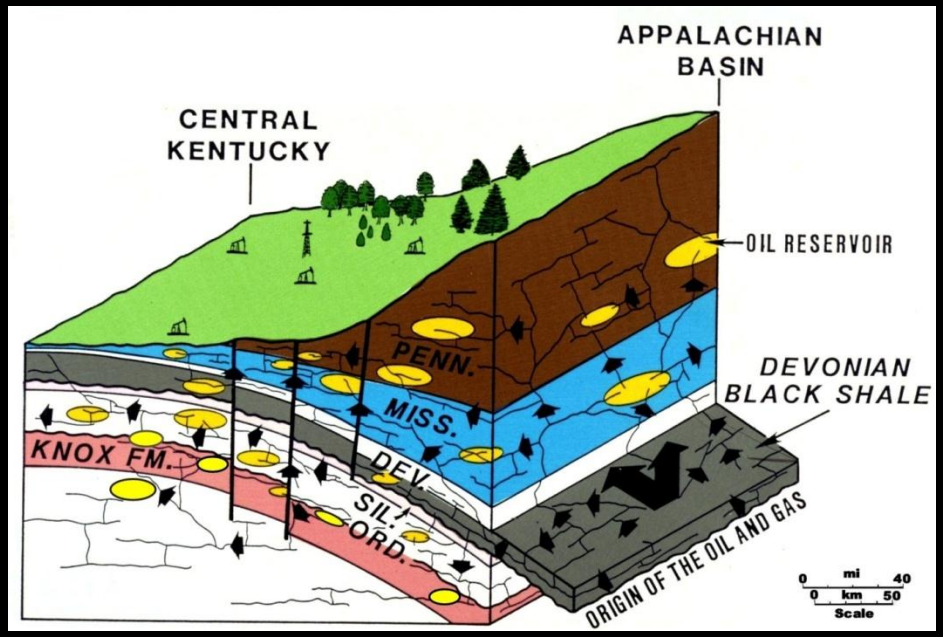
Devonian Shales have TOC Values exceeding 24%

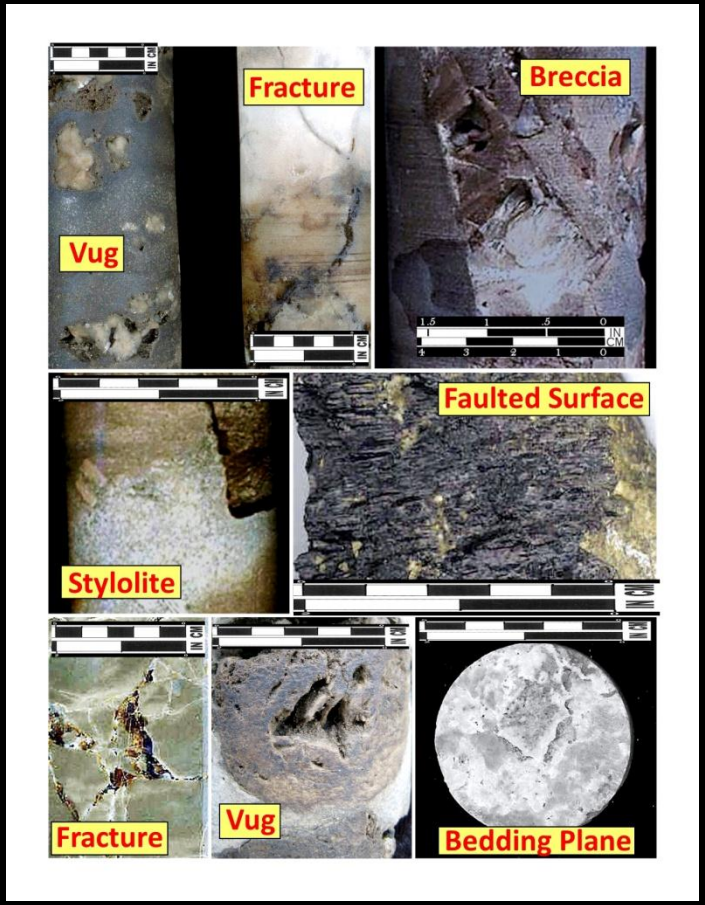

WHOLE- OIL
GAS CHROMATOGRAMS
Responce (x 1.589mV)
100
80
60
40
20
0
C7
C8
C10
C17
C18
Pr
Ph
C24
0
10
20
30
40
50
Retention Time (minutes)

Mississippian-Devonian Black Shales of Kentucky
East-West Transect in Five Cores from the Appalachian Basin to the Illinois Basin

Patrick J. Gooding and Frank R. Ettensohn
Kentucky Geological Survey
University of Kentucky
Department of Earth & Environmental Sciences
University of Kentucky
Lexington, Ky 40506







Hydrocarbons migrate from deep in the Appalachian and Illinois Basins both vertically and horizontally.

THANK YOU