Spectral Gamma-Ray Response of Oklahoma Shales in Outcrop

Draft - Subject to Revision

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Caney Shale along Tulip Creek, OK

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[3]Devon Energy, Oklahoma City
[4]Chesapeake Operating, Oklahoma City

Shale Science

Water
Life
Energy

Today's Outline

- Objectives
- Key Findings
- Background/Procedures
- Data and Data Comparisons
  - Summary table
  - K-U-Th triangles
  - K-U-Th in vertical profiles
- Next Steps

Acknowledgements

- Marvin Abbott - USGS OWSC
- Brian Cardott, Neil Suneson - OGS
- Darwin Boardman, Jim Puckette - OSU

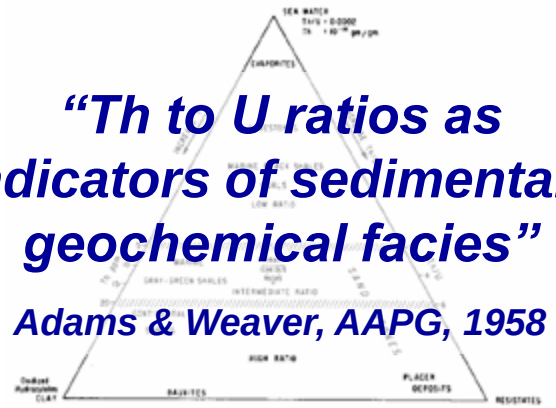
Today's Objectives

- Show examples of spectral gamma-ray response (SGR) for Oklahoma's shales in outcrop: magnitude/relative contributions of K, U, and Th
- Provide context for shales through comparison to some end-member data sets
- Infer stratigraphic implications and bearing on prospectivity of gas shales in Oklahoma

Key Findings - I

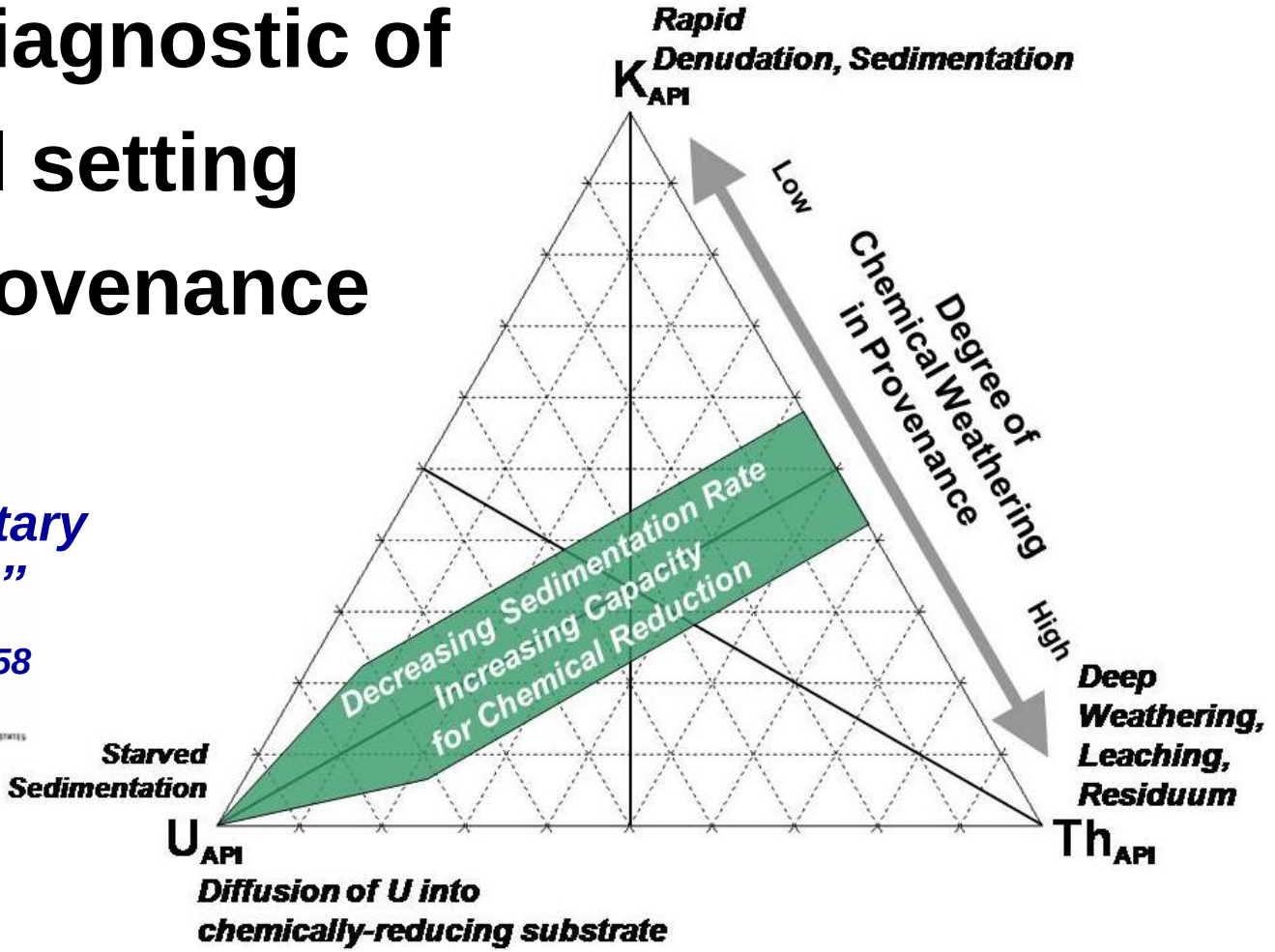
Relative proportions of K, U, & Th as measured with spectral gamma-ray (SGR) at outcrop are diagnostic of

- **depositional setting**
- **sediment provenance**



"Th to U ratios as indicators of sedimentary geochemical facies"

Adams & Weaver, AAPG, 1958



Key Findings - II

- **U-dominant signal**
  - deposition under chemically reducing conditions (conducive to pyrite formation)
  - sedimentation rate **<10 cm / ky**
- **K dominance**
  - sediment from provenance is relatively unweathered
- **Th dominance**
  - deeply-weathered sediment from provenance, a “residuum”

>10 cm / ky
Sedimentation Rate

Oxidizing or **Reducing**
Conditions

Key Findings - III

- Amounts/proportions of K-U-Th are diagnostic of stratigraphy (locally and regionally)
- Some “hot” shale kicks on vertical profiles are K-Th dominated rather than U-dominated
- Woodford displays the most consistency in K-U-Th from outcrop to outcrop, Caney Shale the least

Gamma Ray (GR) - I

- **Spectrometer tuned to measure gamma rays associated with decay of K, U, & Th Series Isotopes**

- **Minerals**
  - **K →Clay minerals, micas, feldspars**
  - **Th →Clay minerals (+ monazite, zircon)**
  - **U →Organics**

Hand-Held Spectrometer
Exploranium GR-320

Gamma Ray (GR) - II

- **API Units → American Petroleum Institute (artificially radioactive formation constructed at University of Houston)**
  - **4% K, 24 ppm Th, and 21 ppm U (200 API units)**
- **Standard Equation (API Units)**

  API = 16 * K% + 8 * U ppm + 4 * Th ppm (Ellis, 1987)

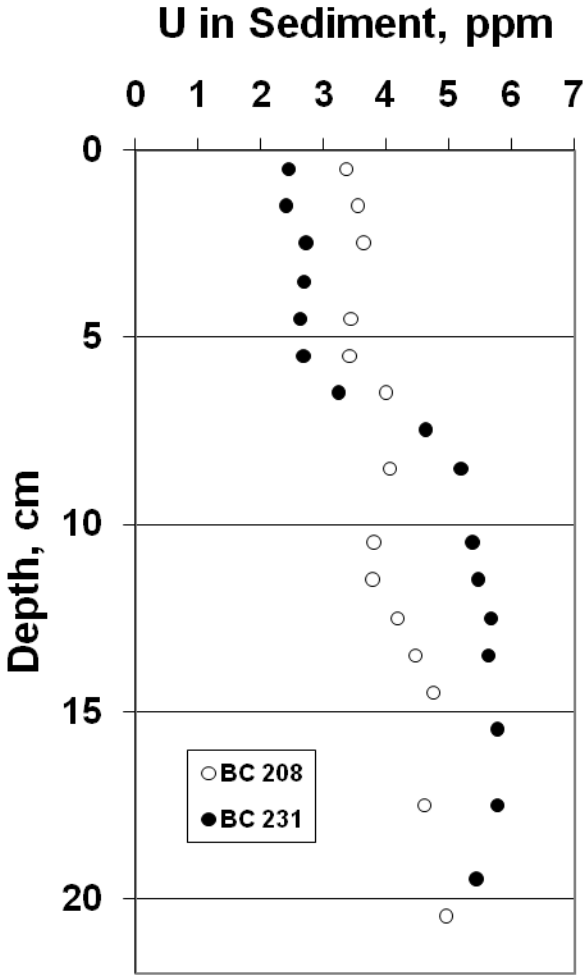
Background Assumptions

- U in sedimentary rocks is a sensitive indicator of redox conditions
  - > occurrence of thin, U-rich marker beds with wide geographic distribution are suggestive of U “fixation” at the sea floor
- Th is insensitive to redox conditions; Th is conserved under earth-surface weathering conditions
- K is relatively more abundant in unaltered igneous / metamorphic rocks (the sedimentary protolith) than in siliciclastic sedimentary rocks of comparable mineralogy (e.g., slate vs shale)

Primary Source of Uranium in Black Shales

Considerations/Assumptions

- **U(VI) is soluble under oxidizing (sea water) conditions (3 ppb)**
- **U(IV) is insoluble in reducing (anoxic mud) environment**
- **U precipitation in mud provides concentration gradient from sea water to mud**
- **Amount of U in substrate becomes time dependent (under conditions of slow sedimentation)**



Klinkhammer and Palmer (1991)

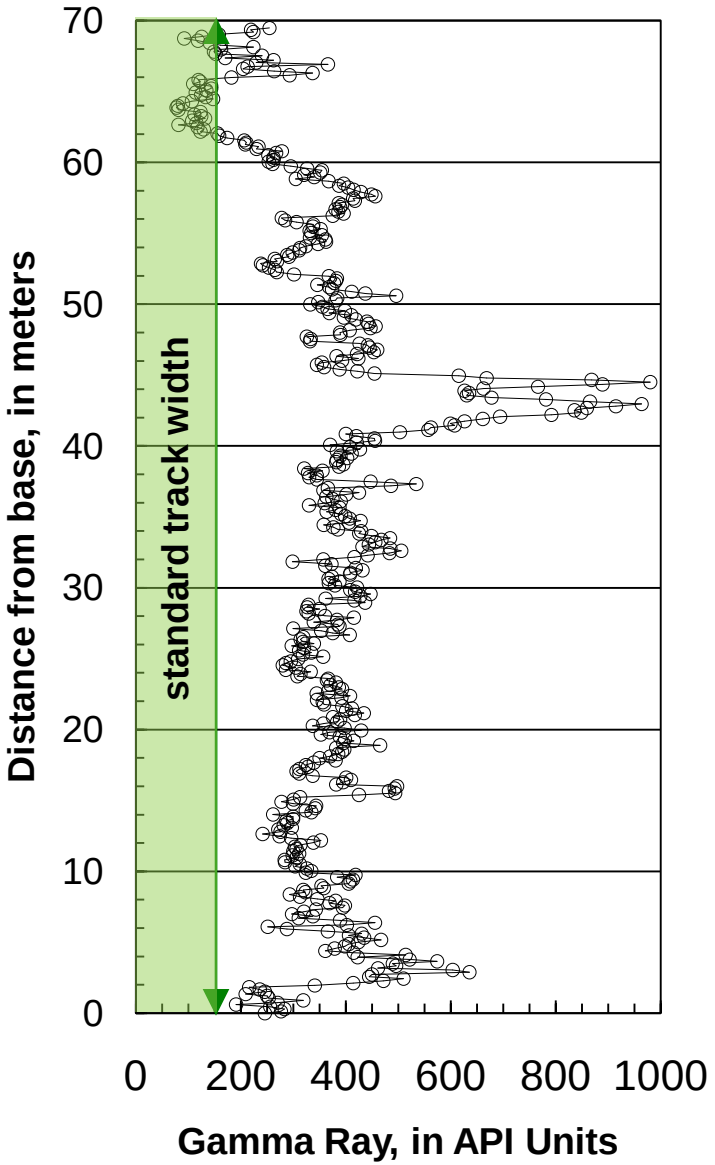
Procedure

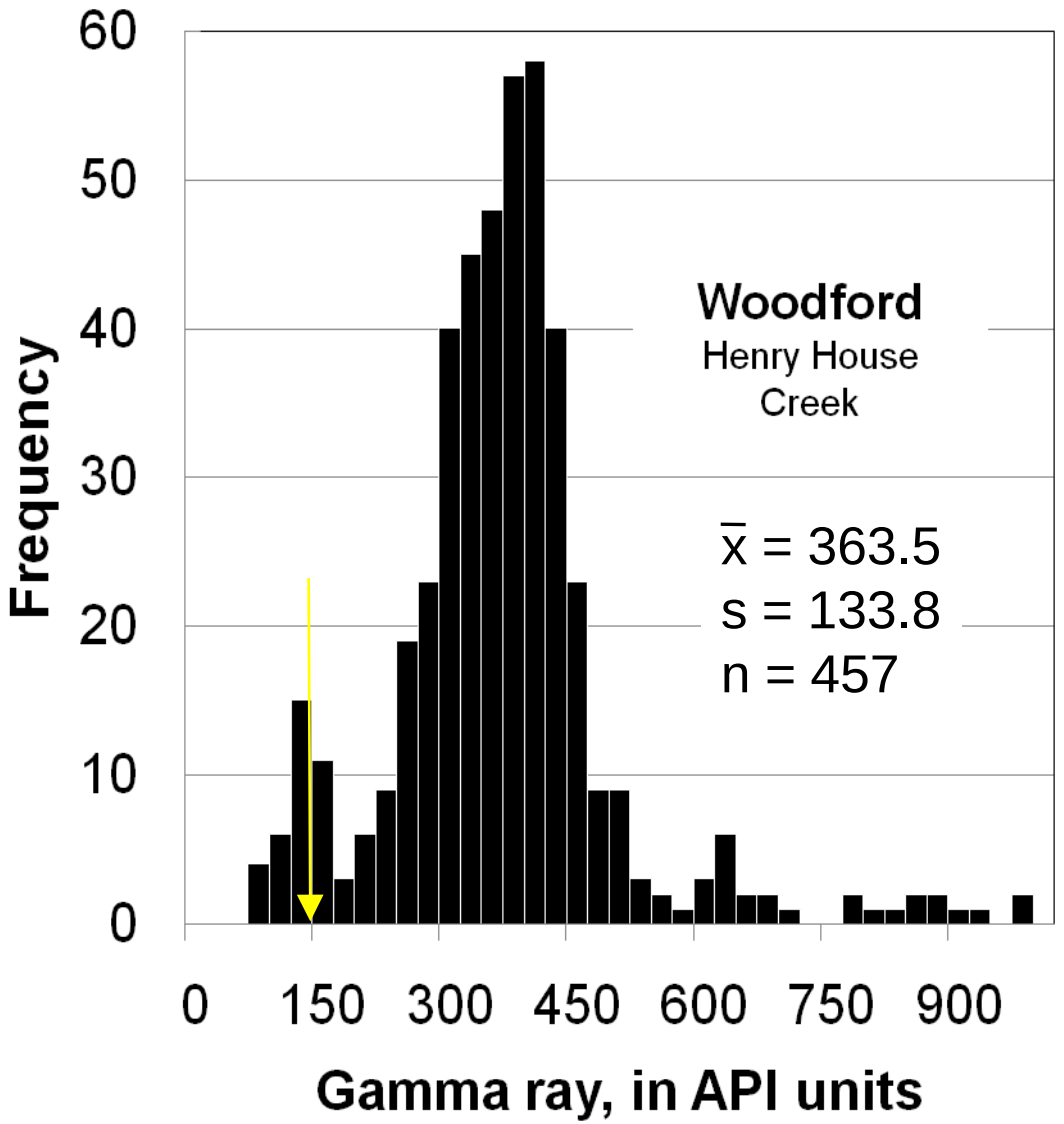
- Measure and describe lithofacies
- Collect SGR data (15 cm between measurements →moving up section*)
- Convert SGR data to API units
- Evaluate Data Trends
  - Data populations plotted on ternary diagrams (normalized K, U, and Th relative to total API)
  - Vertical profiles of K, U, and Th relative to stratigraphic surfaces

Gamma-Ray Response

U N I T	API	K	U	Th	Norm U	*n*
Woodford - Henry House Creek, OK	**363.5**	**1.7**	**38.5**	**7.2**	**84.2**	*457*
Woodford - 77D, Arbuckles, OK	**367.8**	**2.0**	**38.3**	**7.5**	**82.6**	*350*
Woodford - Lake Classen, OK	**362.3**	**2.2**	**36.5**	**8.8**	**79.2**	*366*
Excello Shale - Tulsa, OK	**271.1**	**2.1**	**24.2**	**10.7**	**70.6**	*7*
Barnett Shale - North Texas	**302.0**	**3.1**	**23.9**	**15.1**	**61.8**	*130*
Caney Shale - JL Shale Pit, SE OK	**273.8**	**3.1**	**20.1**	**15.8**	**57.7**	*53*
Chattanooga - Tahlequah, OK	**265.5**	**3.8**	**19.1**	**12.8**	**57.1**	*45*
Caney Shale - Delaware Creek, SE OK	178.6	**1.9**	11.3	**14.2**	49.0	*121*
U. Fayetteville - Marshall, AR	135.2	**1.5**	9.3	**9.0**	54.0	*227*
L. Fayetteville - Snowball, AR	185.8	**3.4**	8.9	**15.0**	37.2	*58*
Caney Shale - Pine Top, SE OK	149.0	**2.1**	8.9	**10.8**	47.3	*309*
Caney - Tulip Creek, Arbuckles, OK	134.5	**1.9**	7.9	**10.1**	46.6	*146*
L. Fayetteville - Fayetteville, AR	171.4	**3.8**	6.7	**14.1**	31.4	*36*
Ark. Novac. - Potato Hills Area, OK	95.6	**1.8**	4.5	**7.8**	34.5	*24*
Fayetteville "Type" - Fayetteville, AR	115.2	**2.1**	3.0	**14.3**	20.8	*92*
Sylvan Shale - Arbuckles, OK	115.7	**3.1**	2.5	**11.6**	17.3	*13*

Woodford Shale

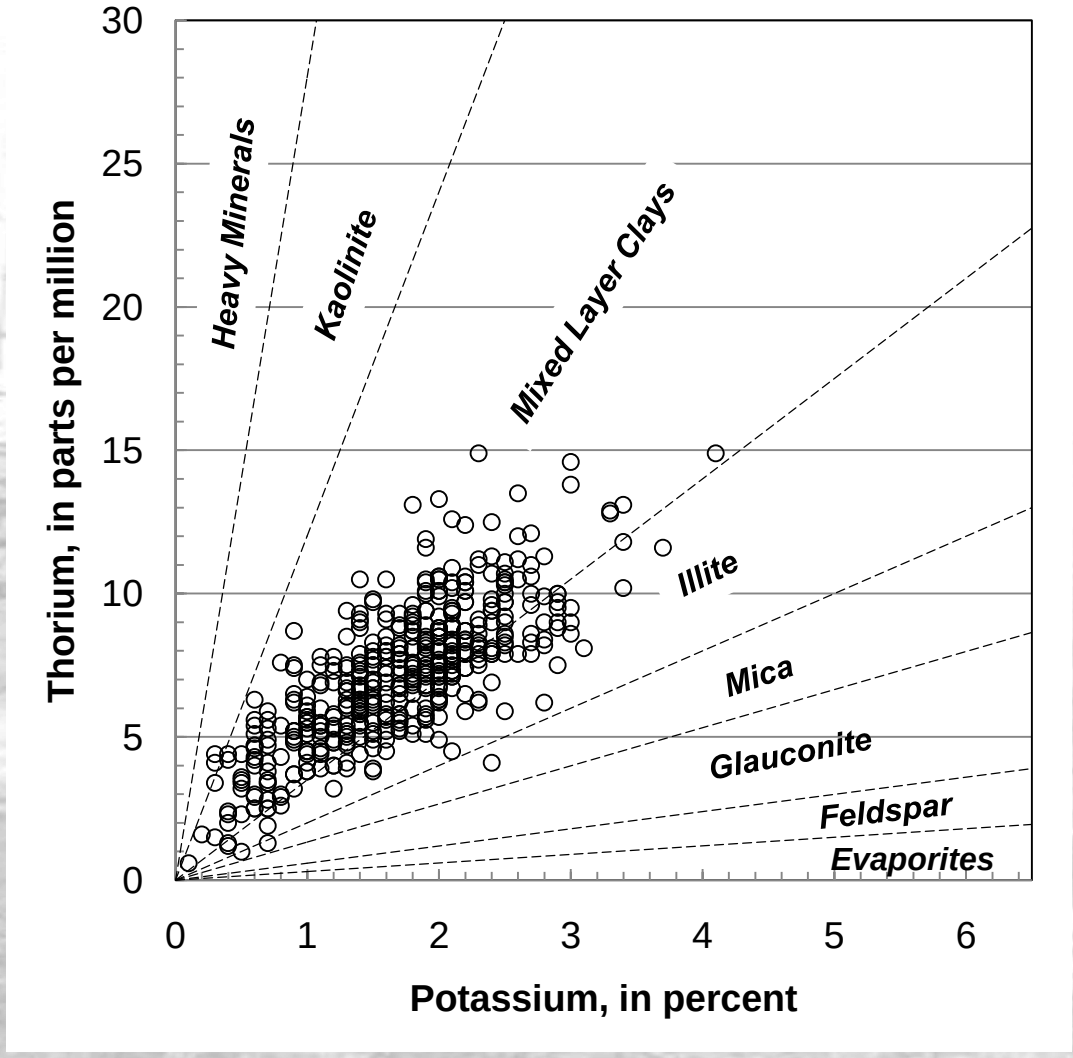




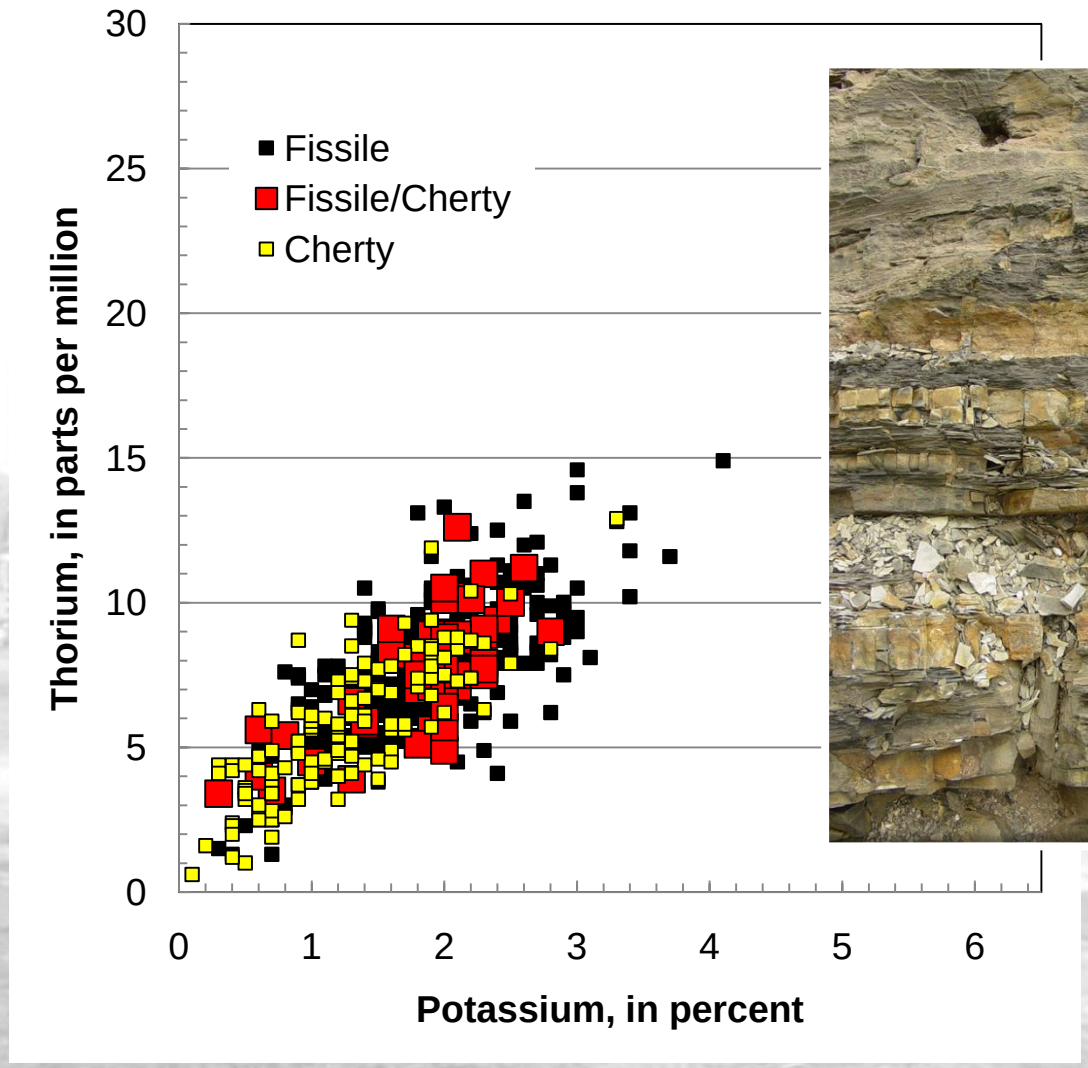
Woodford Shale

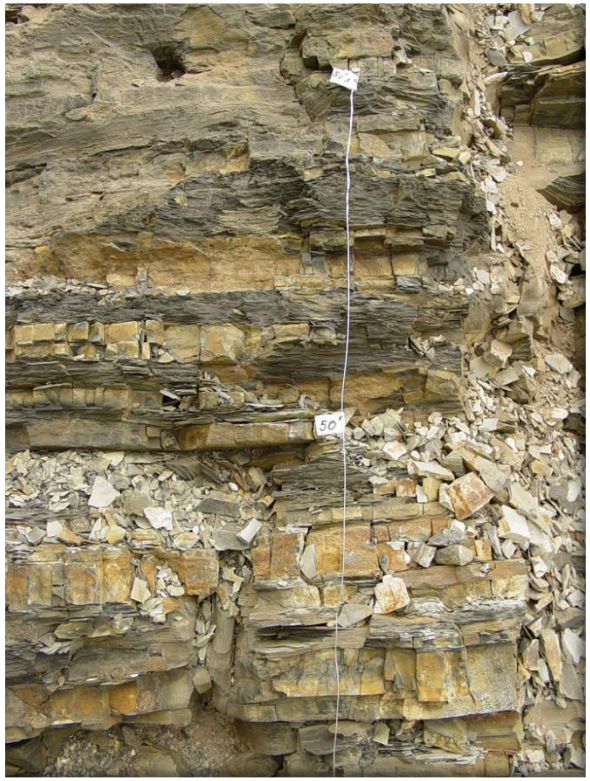
Woodford Shale

Henry House Creek

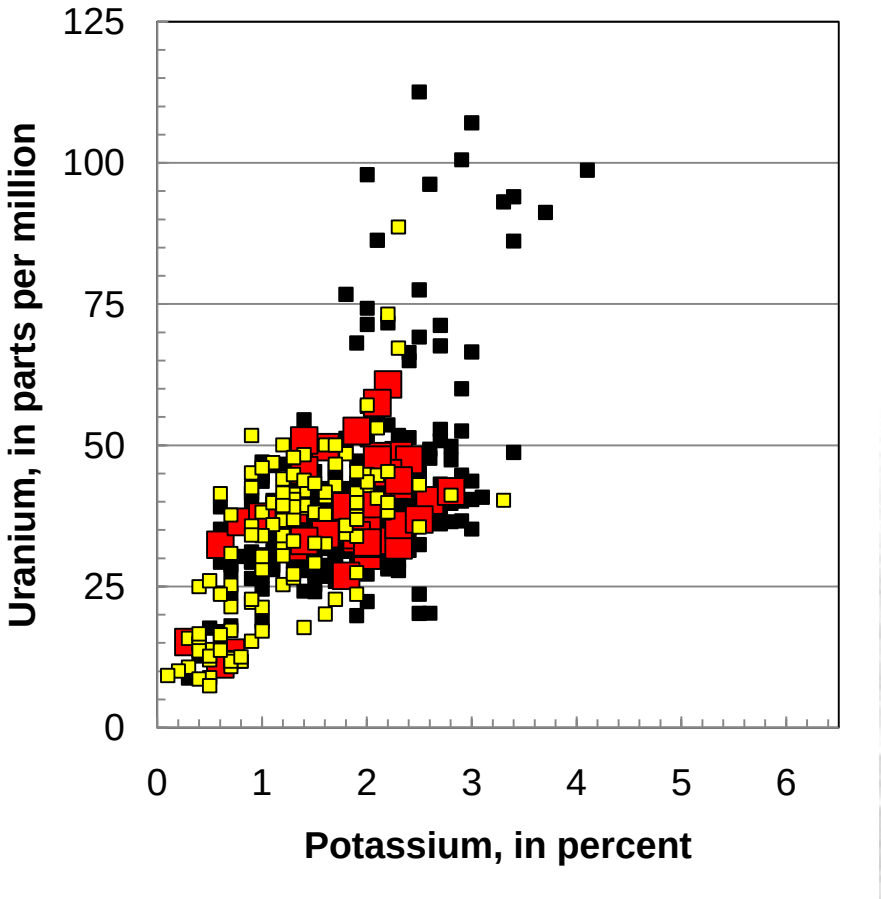


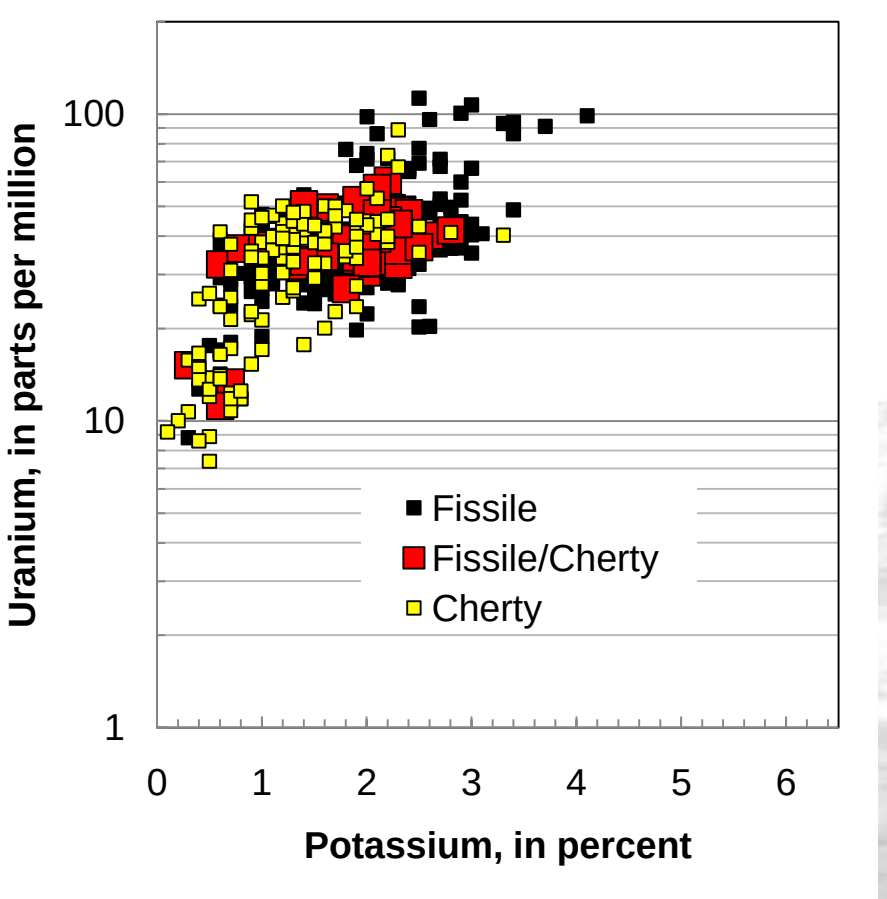
Woodford Shale



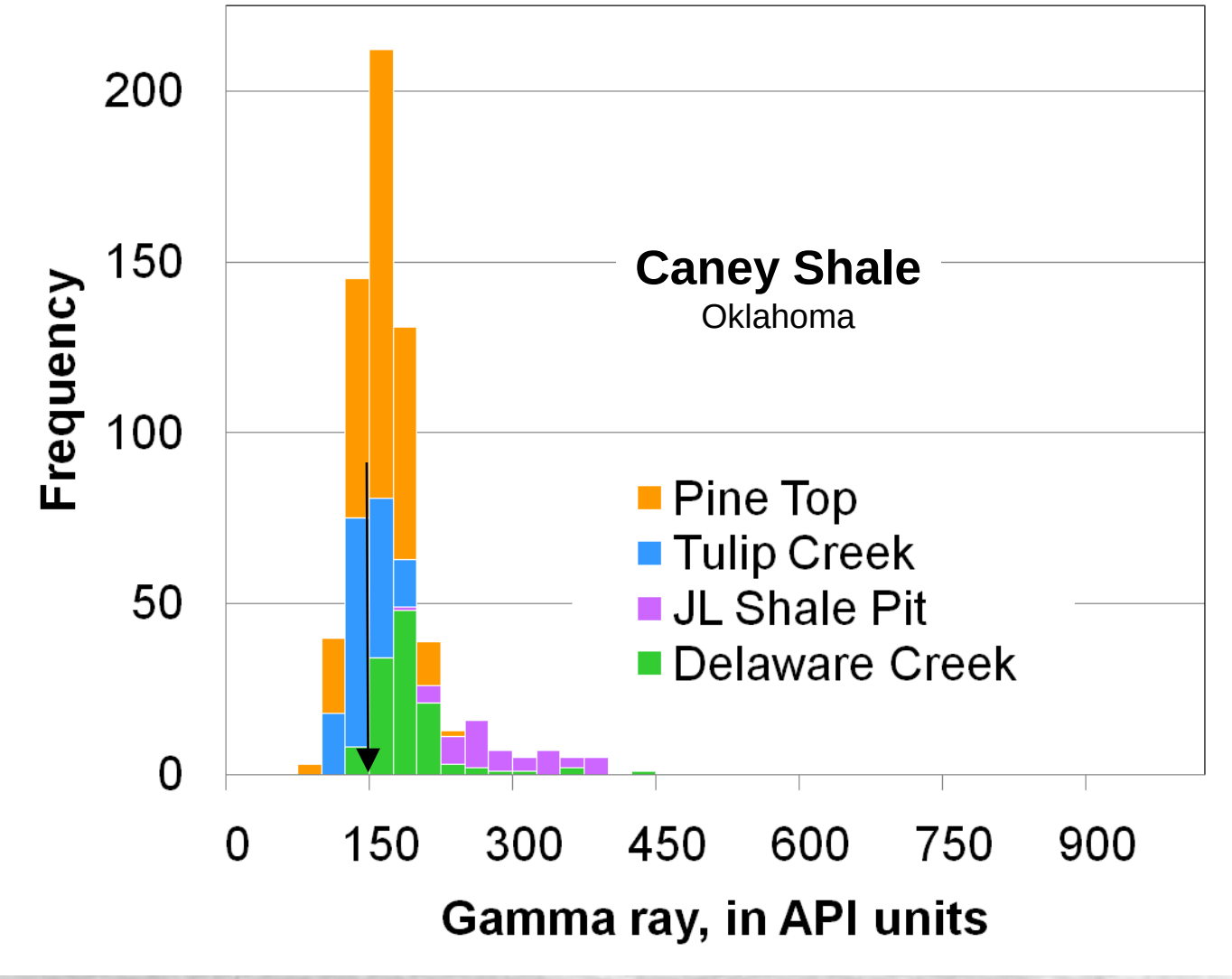


Woodford Shale

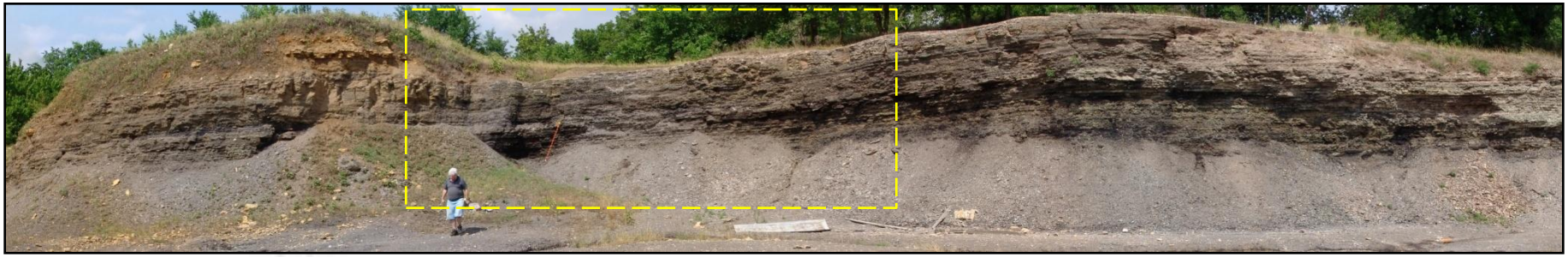




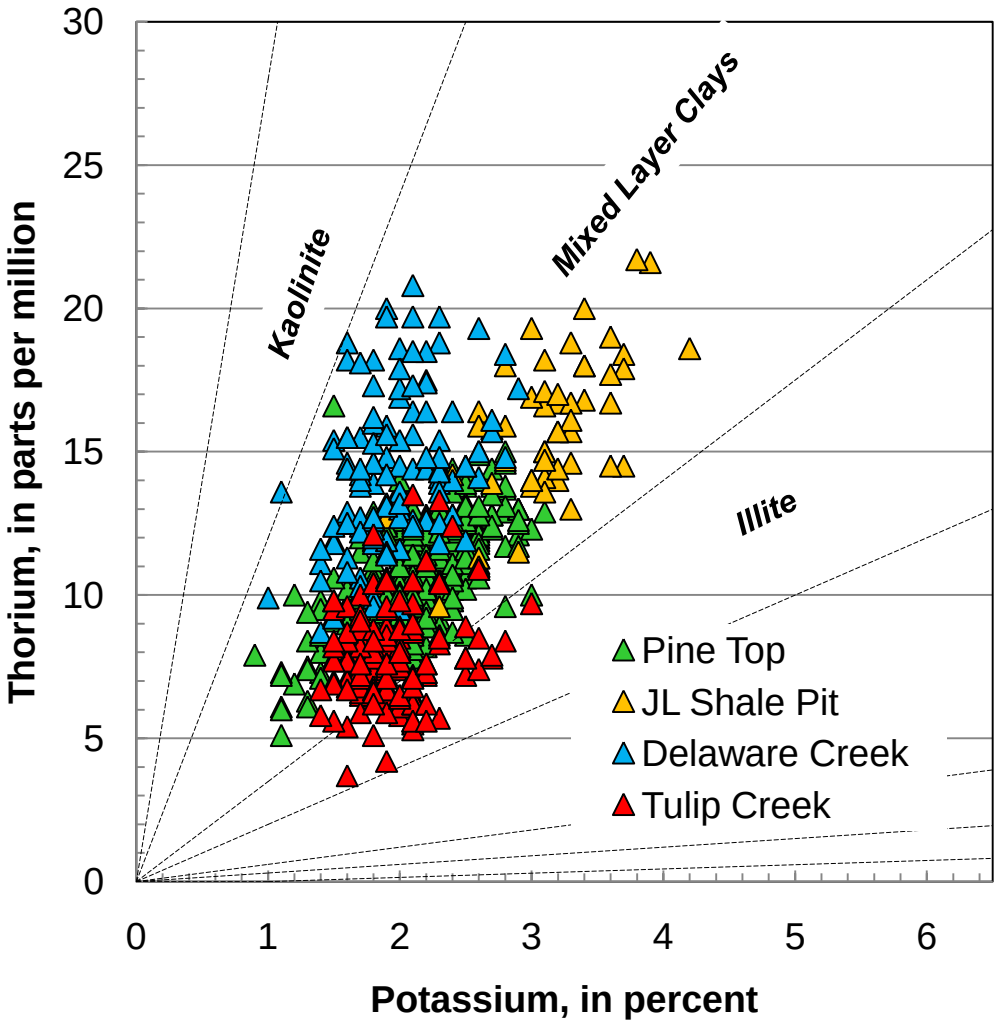
Caney Shale


Caney Shale
Oklahoma
Pine Top
Tulip Creek
JL Shale Pit
Delaware Creek
Frequency
200
150
100
50
0
0
150
300
450
600
750
900
Gamma ray, in API units

Caney Shale

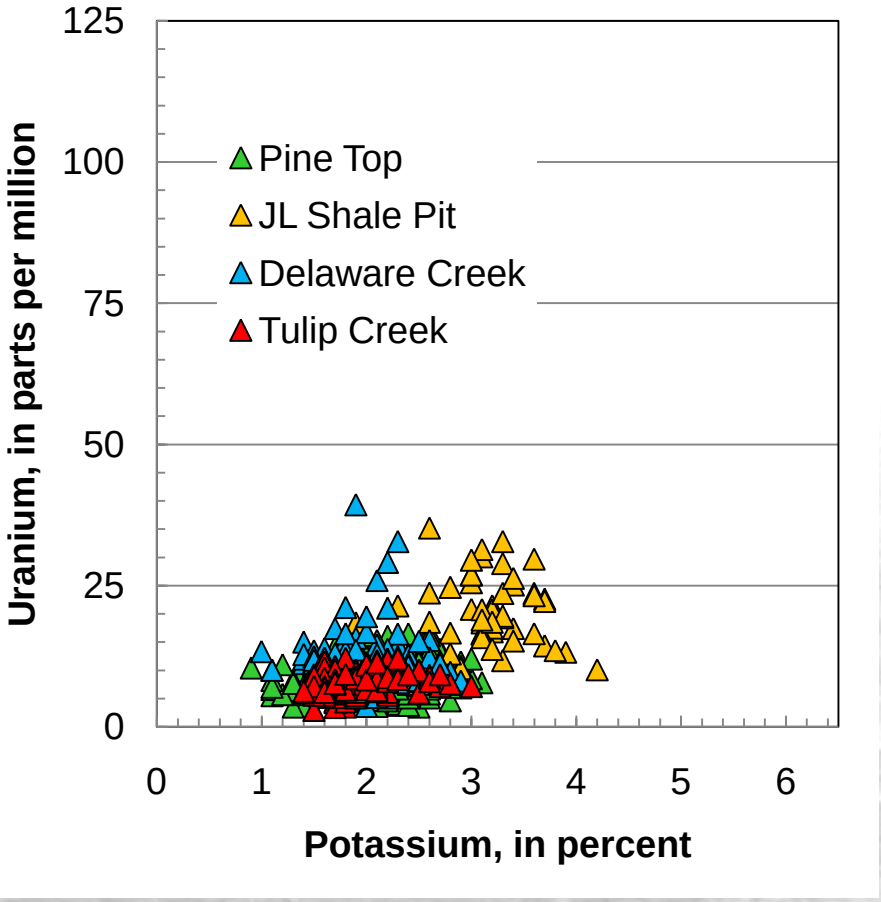


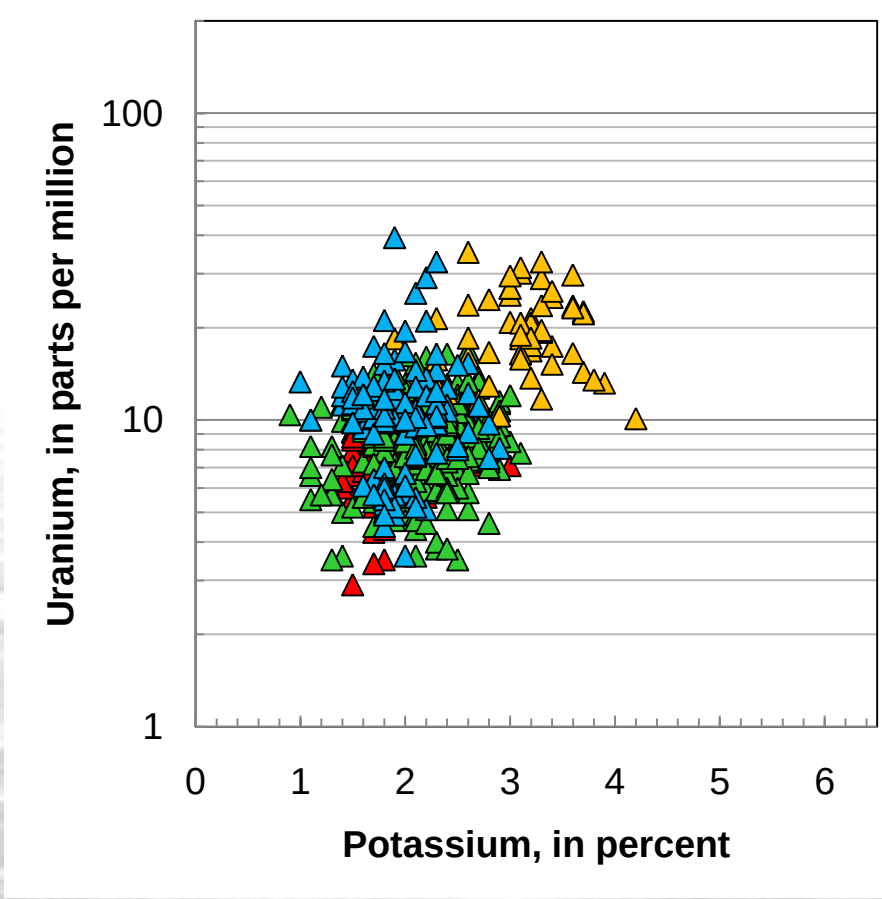
Caney Shale


Thorium, in parts per million
Potassium, in percent
0
5
10
15
20
25
30
0
1
2
3
4
5
6
Kaolinite
Mixed Layer Clays
Illite
Pine Top
JL Shale Pit
Delaware Creek
Tulip Creek

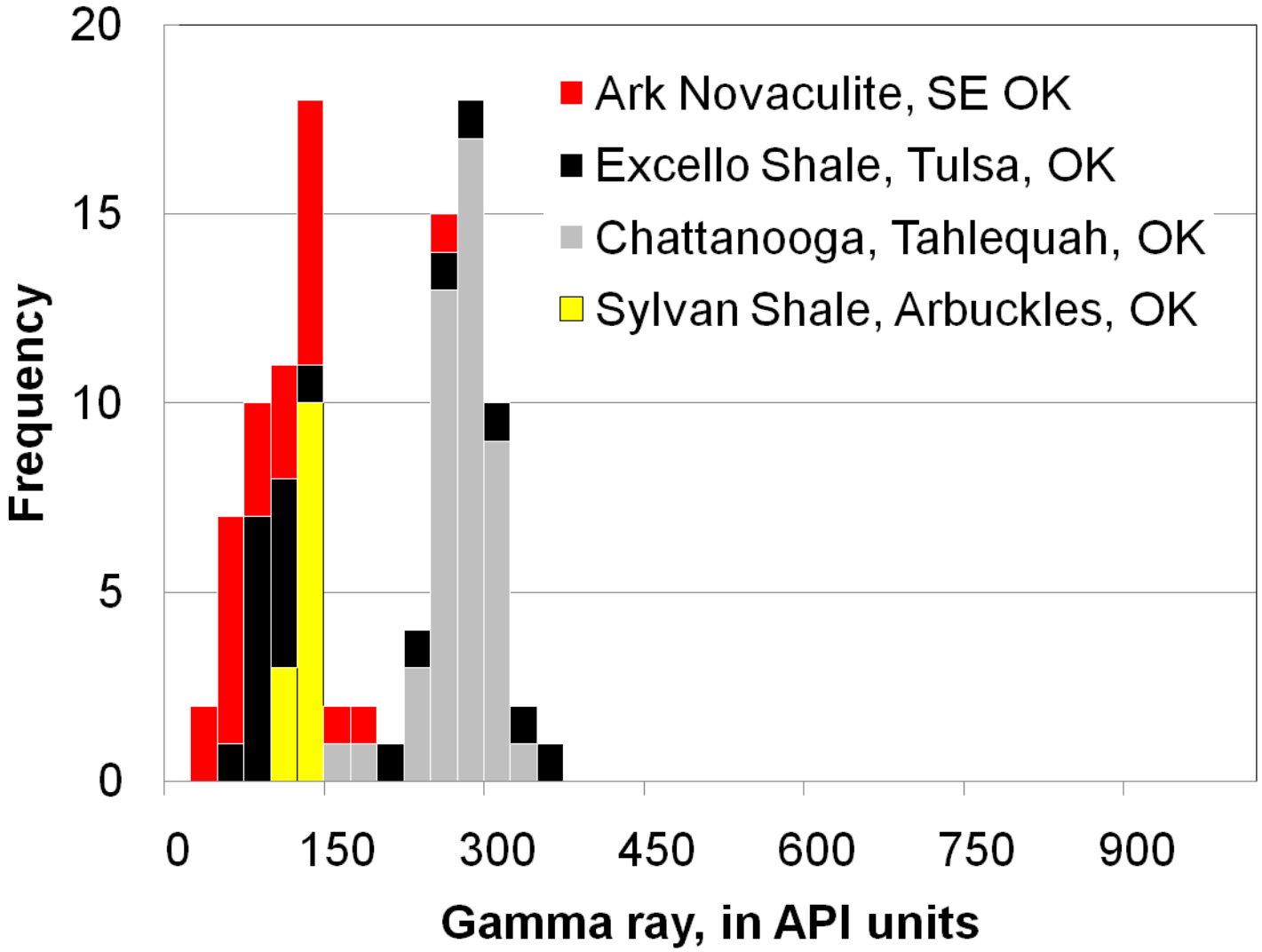

Tulip Creek
Arbuckles, Oklahoma

Caney Shale

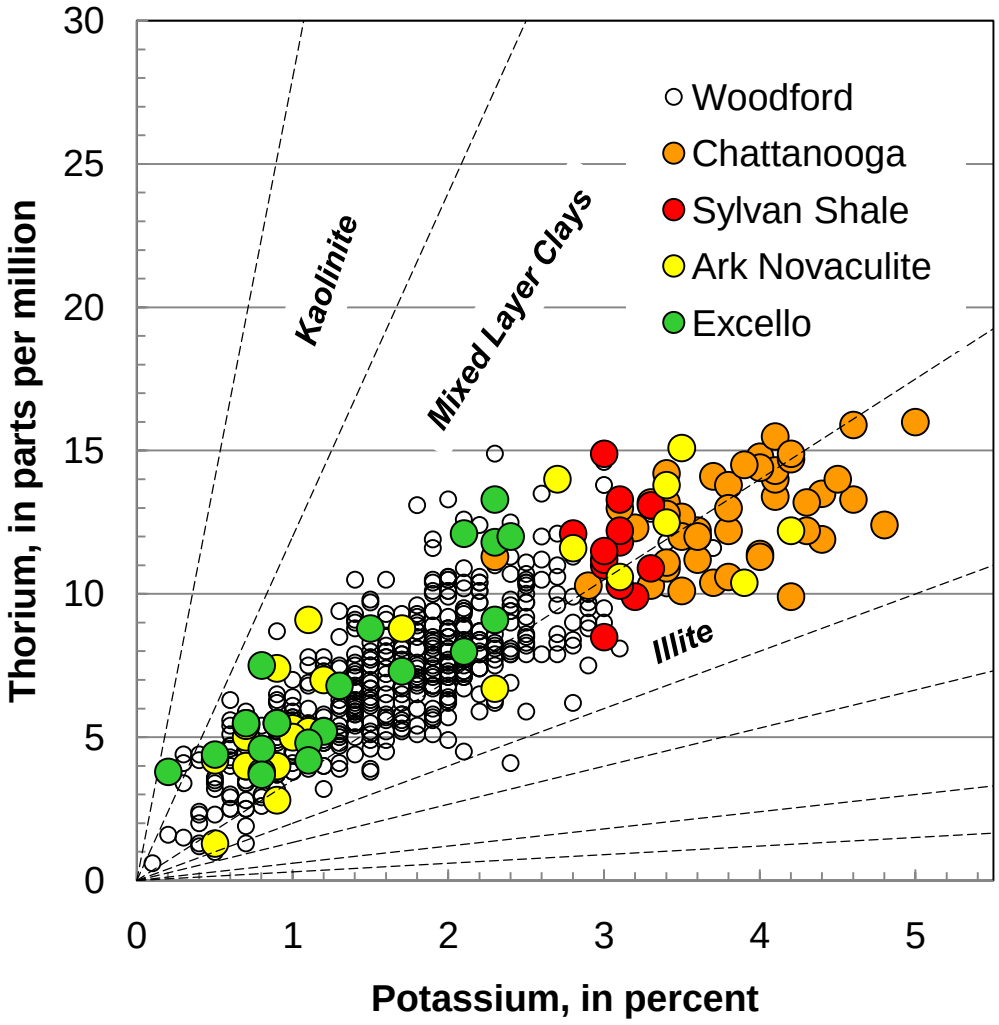

125
100
75
50
25
0
Uranium, in parts per million
Pine Top
JL Shale Pit
Delaware Creek
Tulip Creek
0
1
2
3
4
5
6
Potassium, in percent


100
10
1
Uranium, in parts per million
0
1
2
3
4
5
6
Potassium, in percent

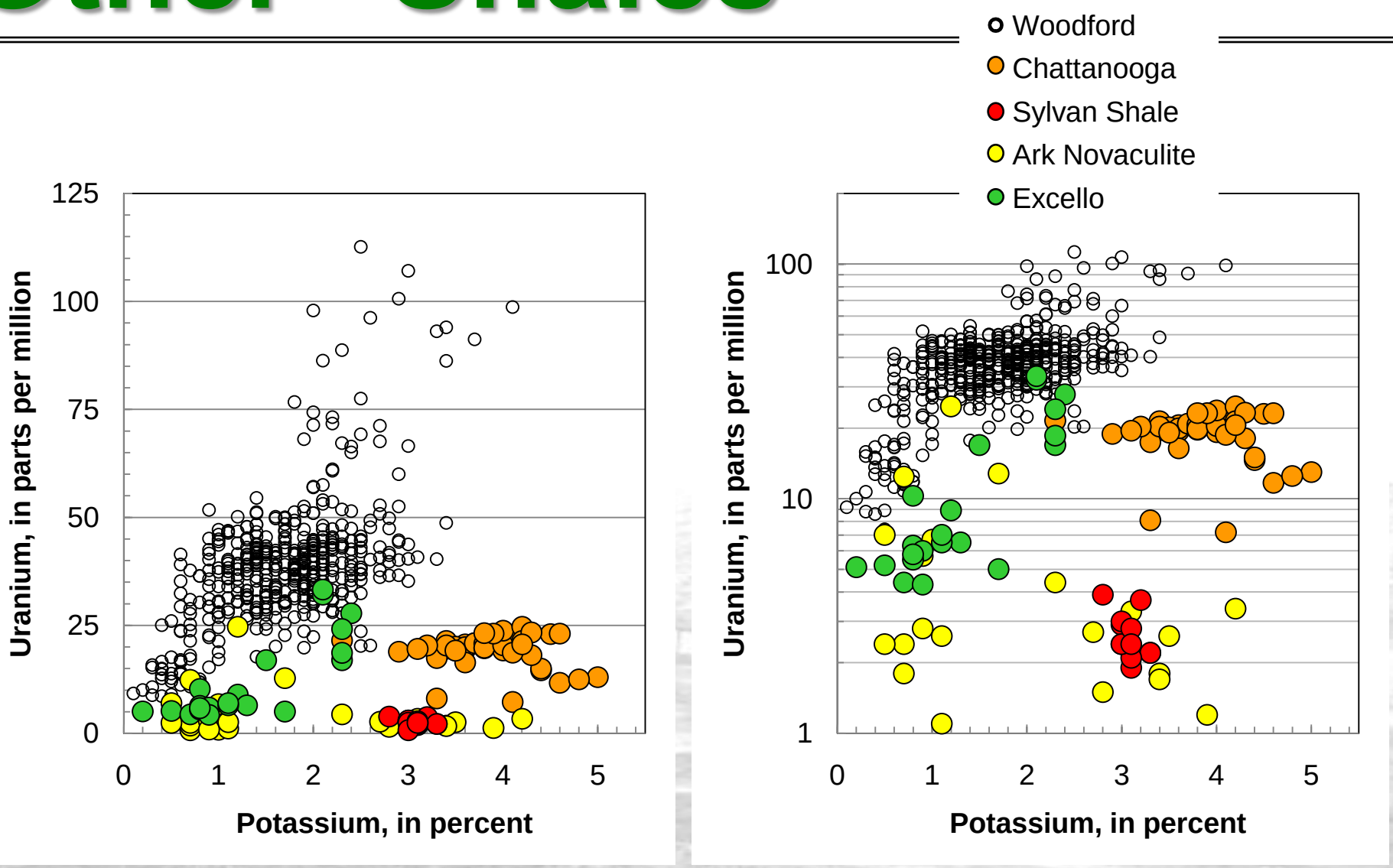
Other “Shales”



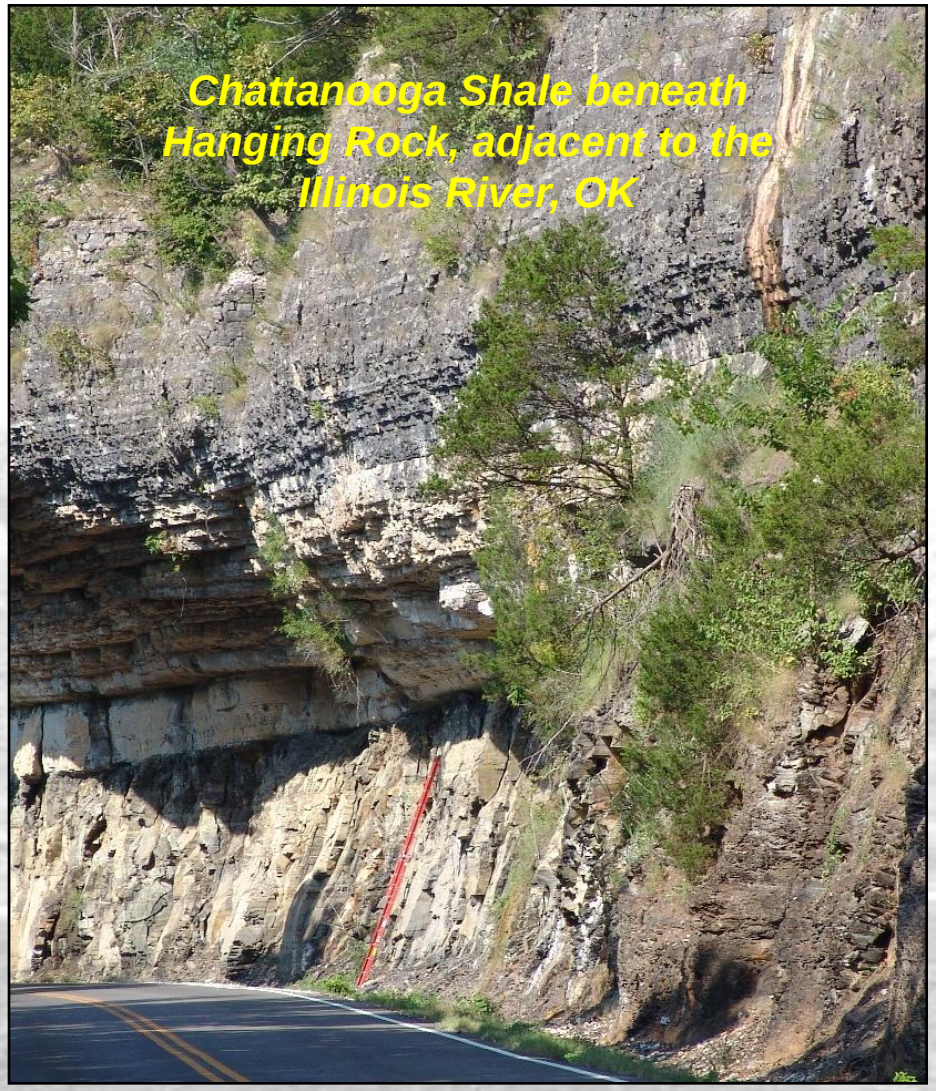
Other “Shales”

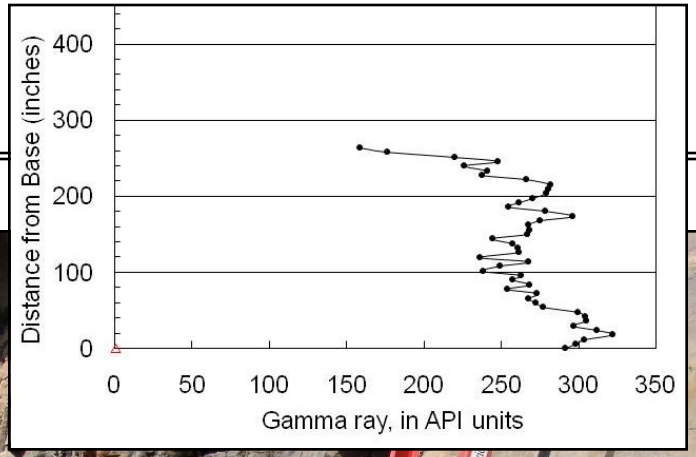


Other “Shales”

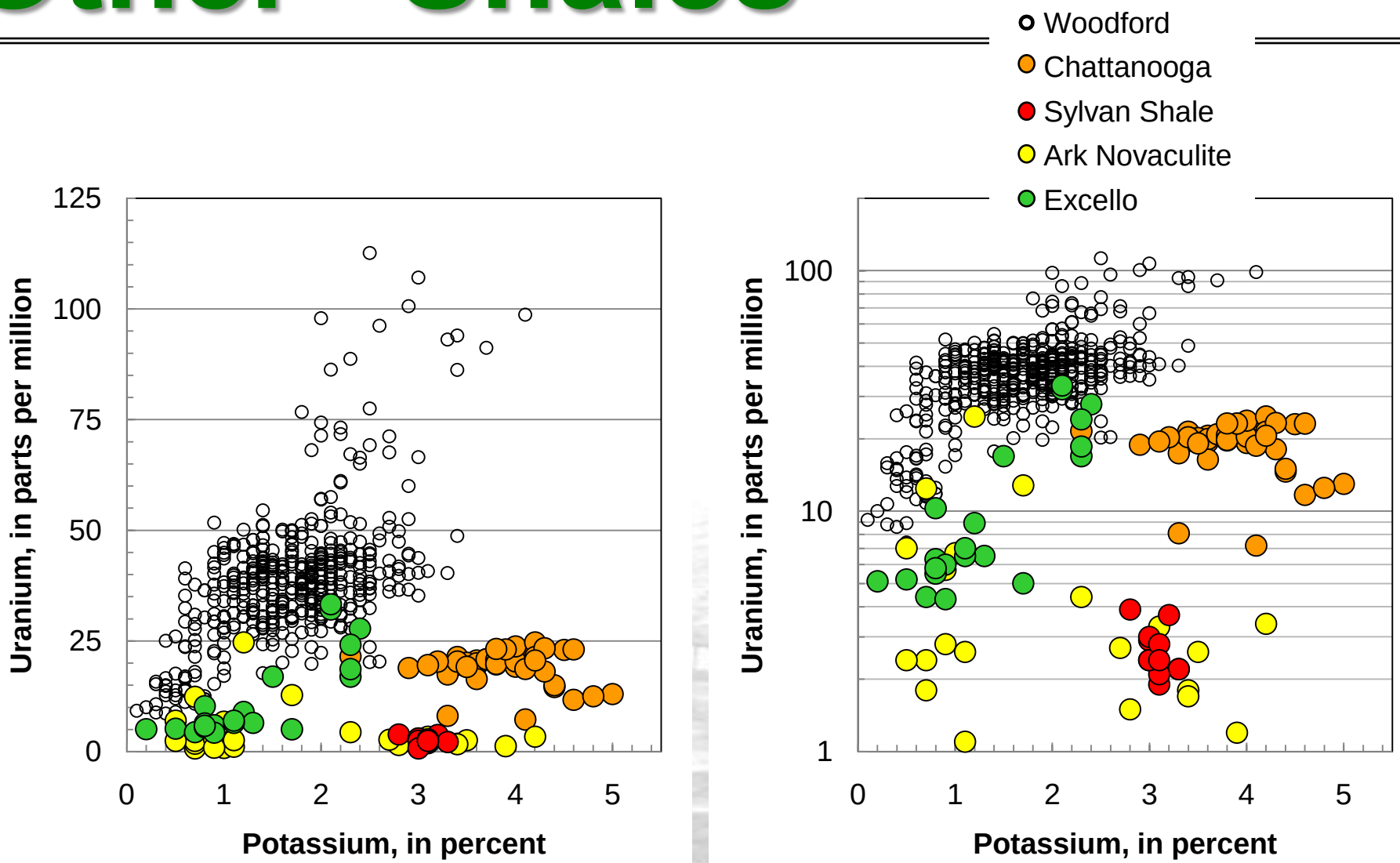


Chattanooga





Other “Shales”



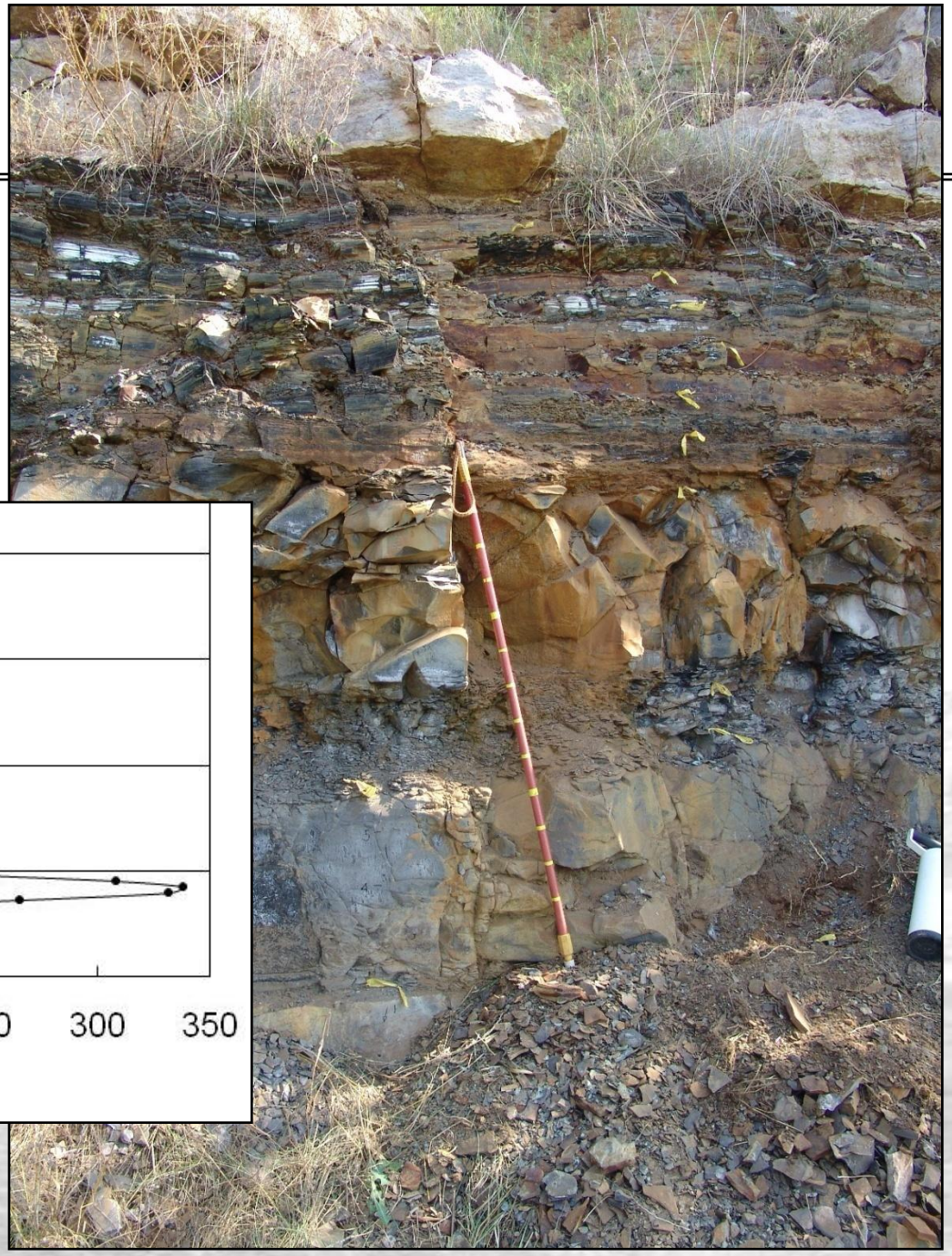
Arkansas Novaculite

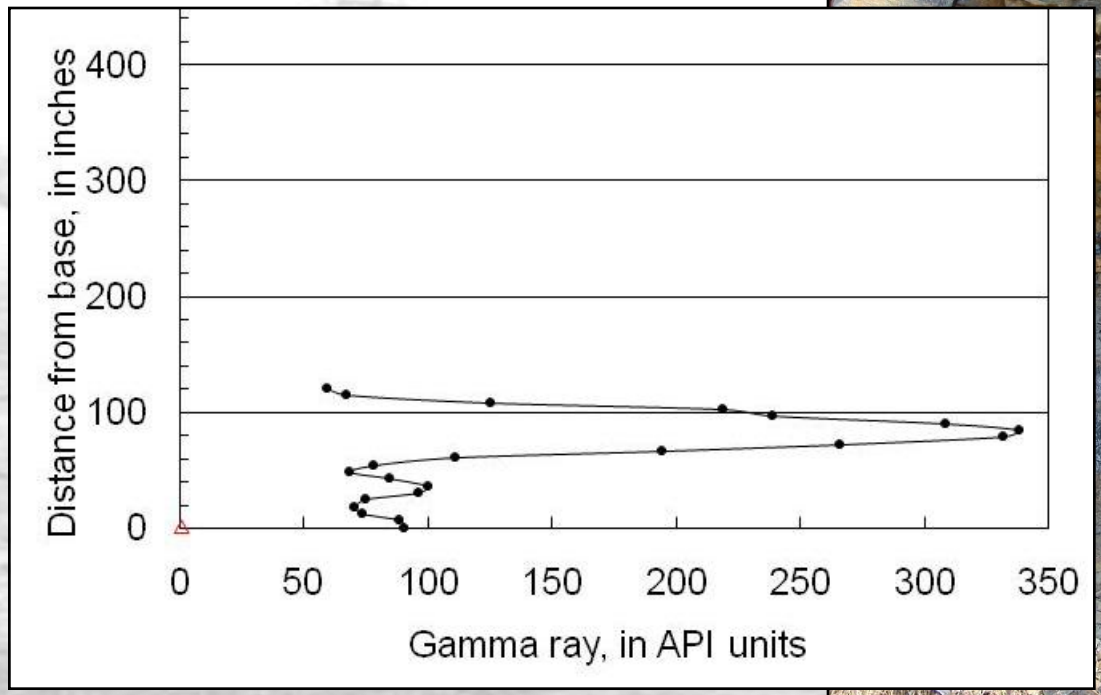
Potato Hills, OK

Excello

Pennsylvanian
Excello Shale

Tulsa, OK



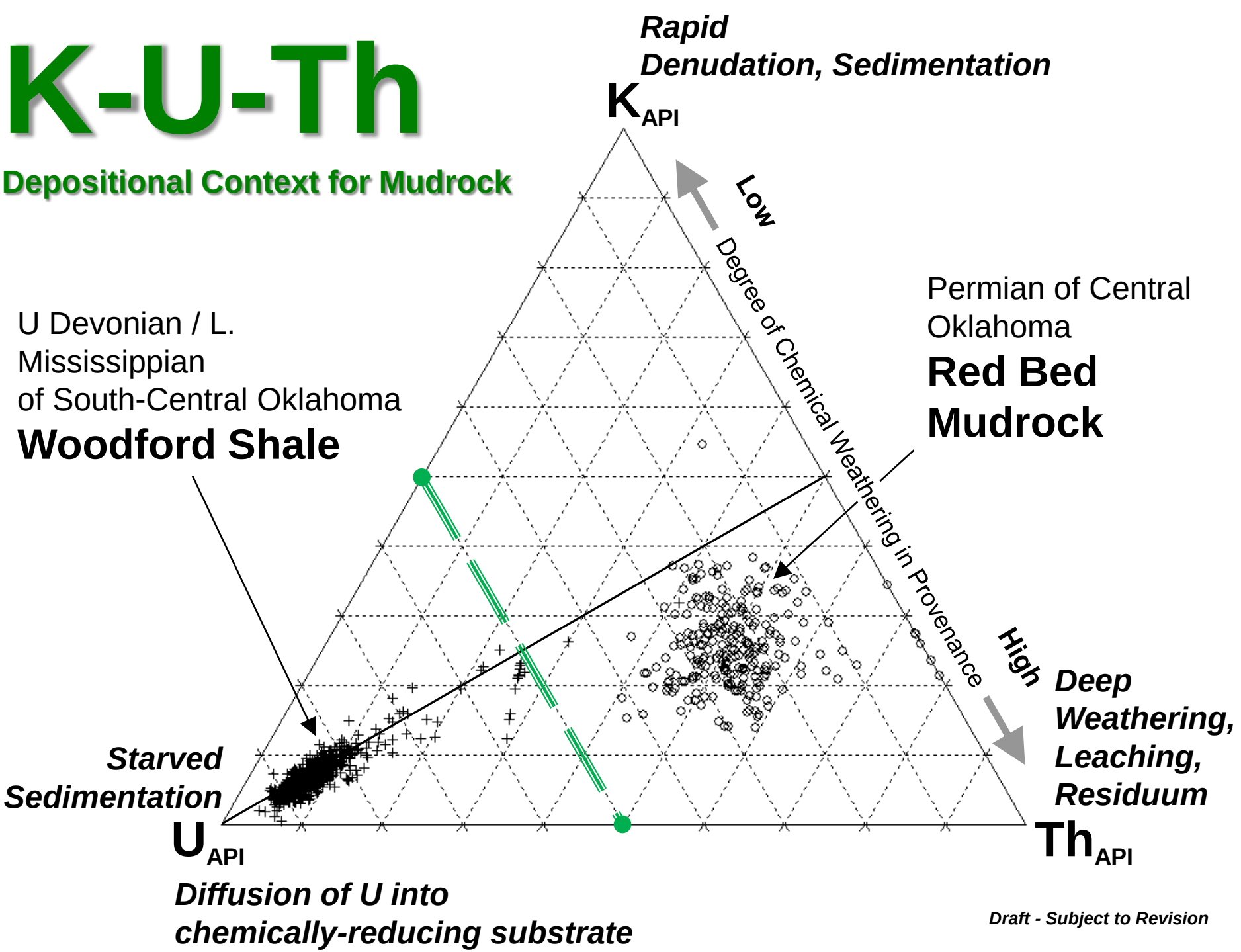


Data Comparisons

- **Woodford Shale - South Central Oklahoma**
- **Permian Red Beds - Central Oklahoma**
- **Black Shale Standard**
- **Line Calculated for Shale from Data of Myers and Wignall (1987)**

K-U-Th

Depositional Context for Mudrock



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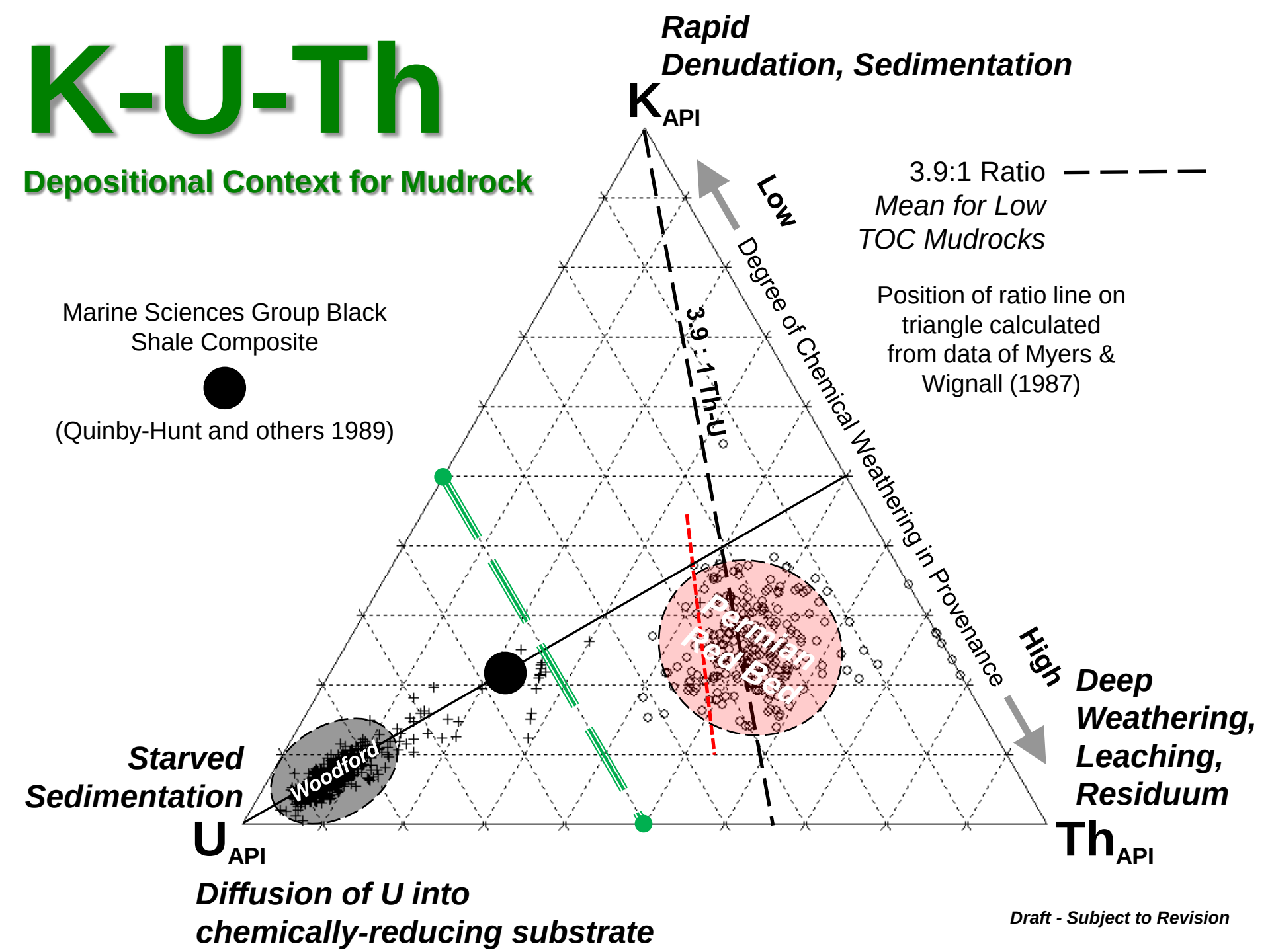
K-U-Th

Depositional Context for Mudrock



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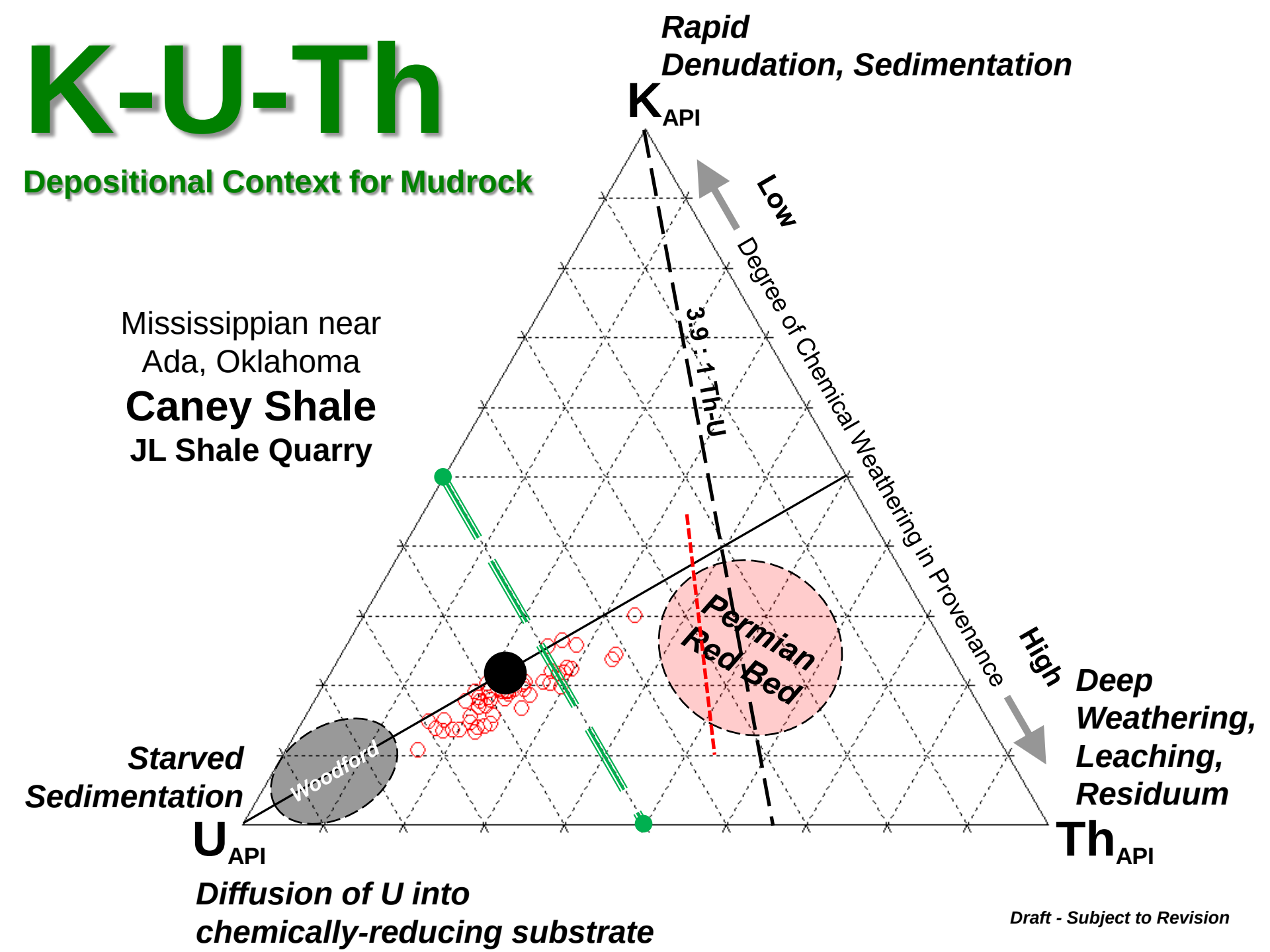
Depositional Context for Mudrock



Mississippian near
Ada, Oklahoma

Caney Shale

JL Shale Quarry

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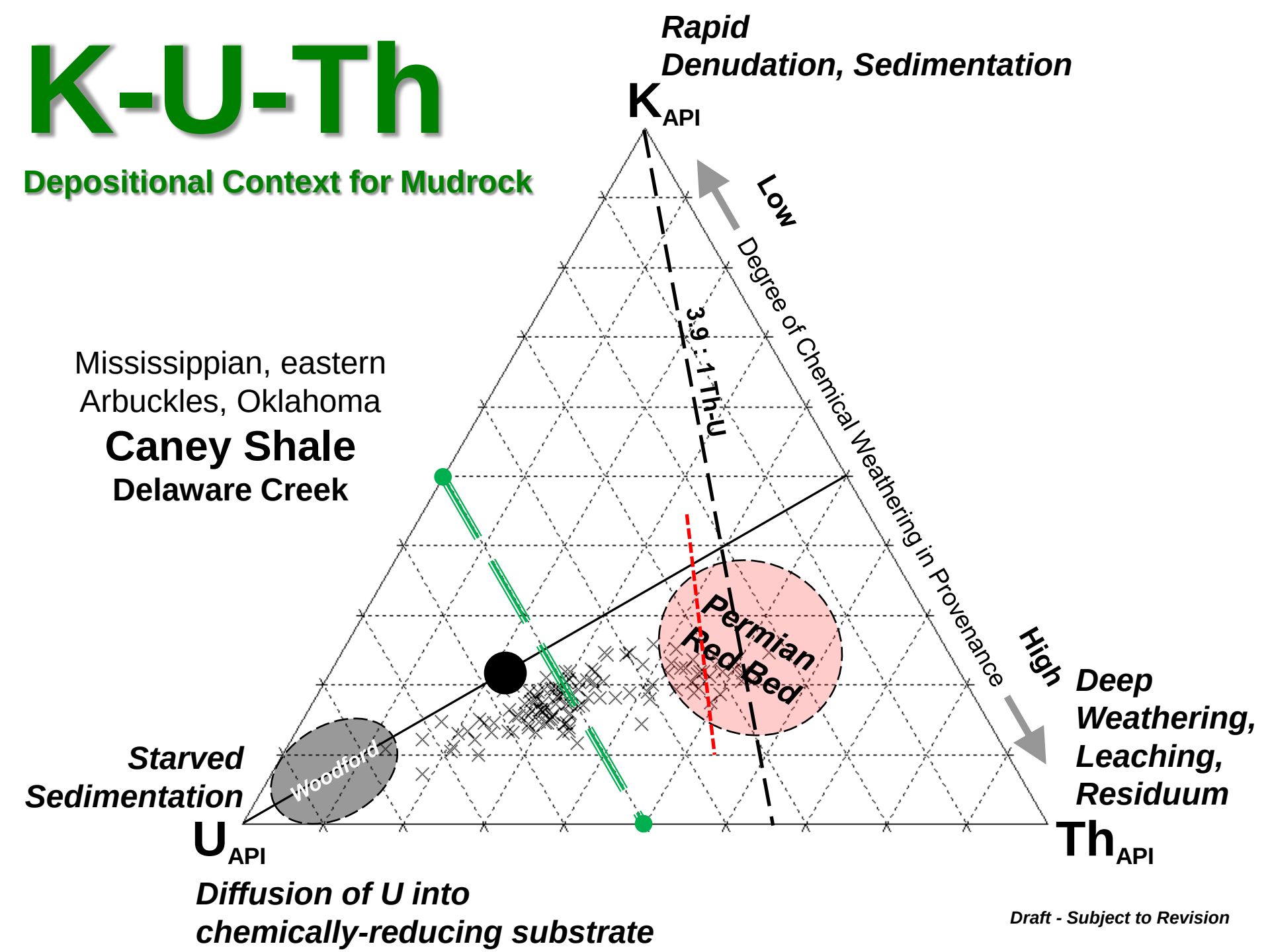
K-U-Th

Depositional Context for Mudrock



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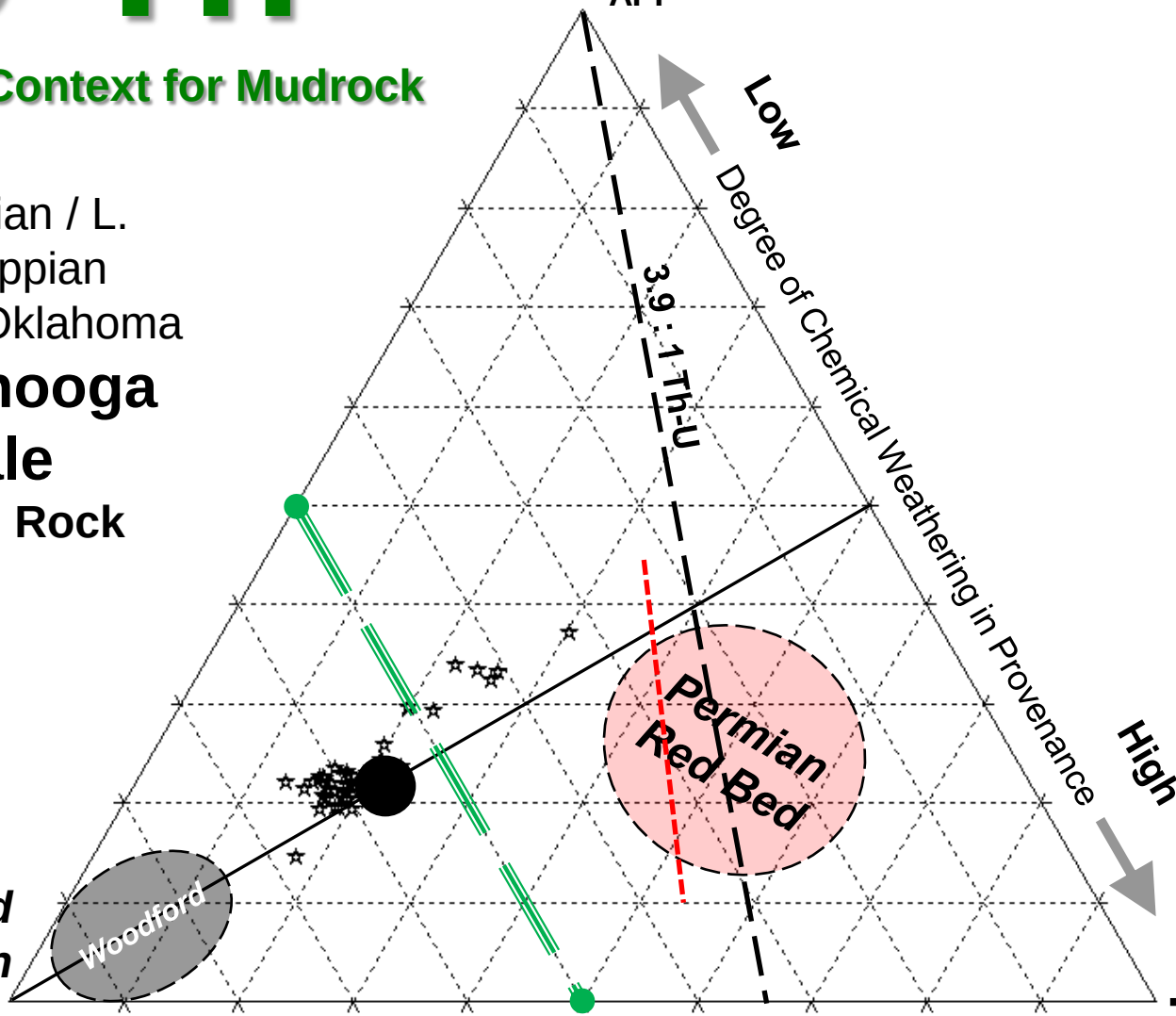
K-U-Th

Depositional Context for Mudrock

U Devonian / L. Mississippian
of eastern Oklahoma
Chattanooga Shale
Hanging Rock



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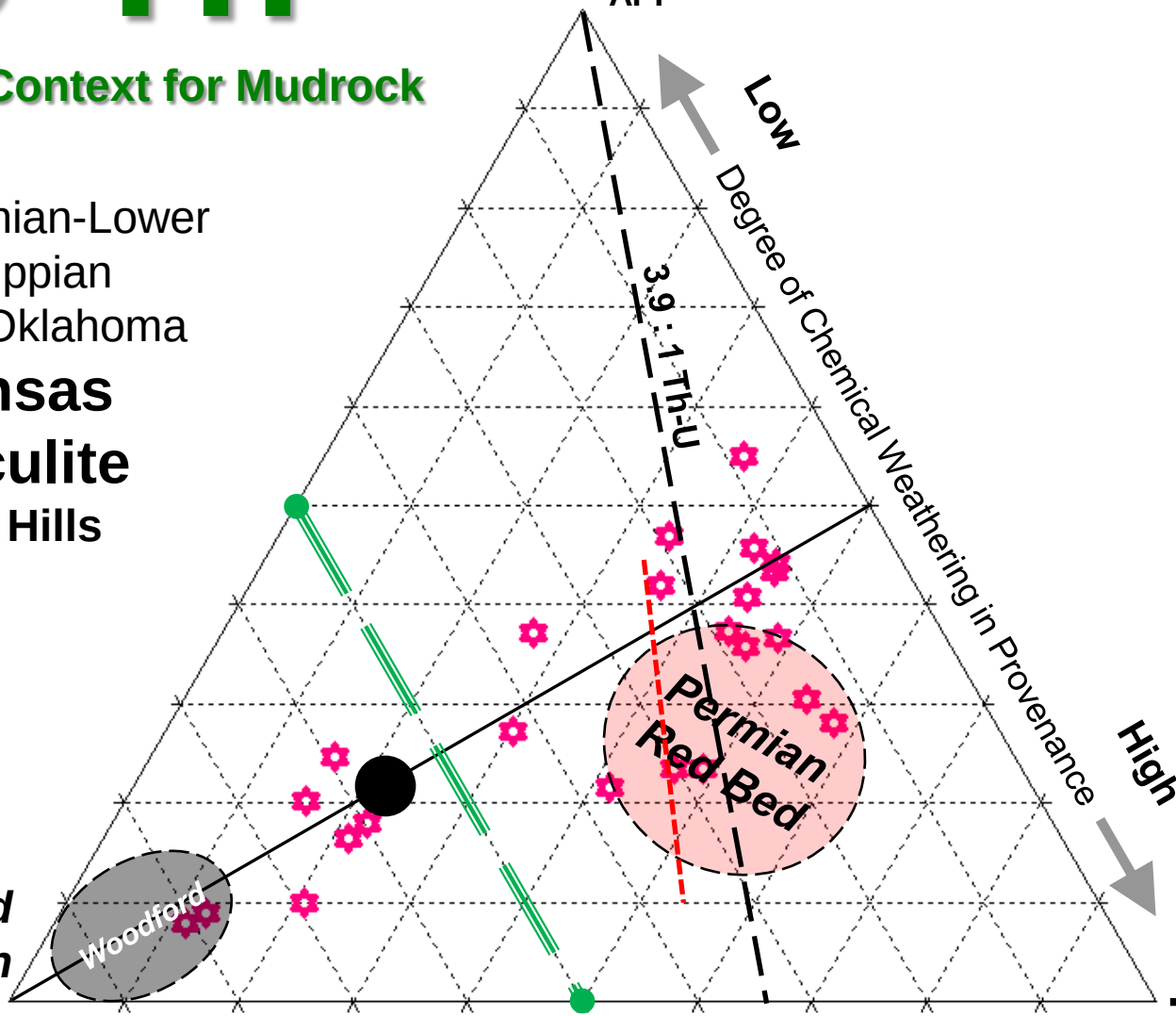
K-U-Th

Depositional Context for Mudrock

Upper Devonian-Lower Mississippian of eastern Oklahoma

Arkansas Novaculite

Potato Hills



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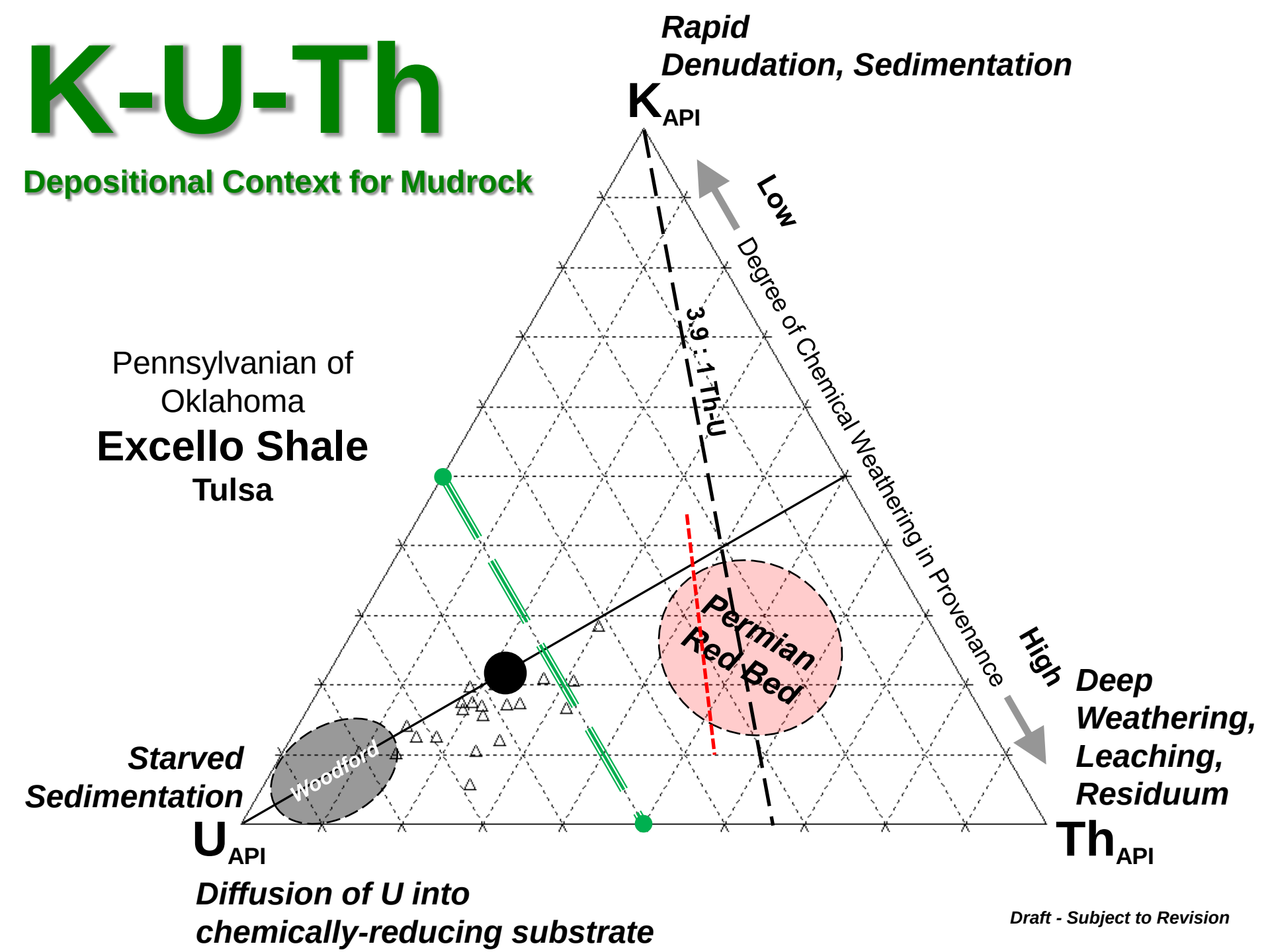
Depositional Context for Mudrock



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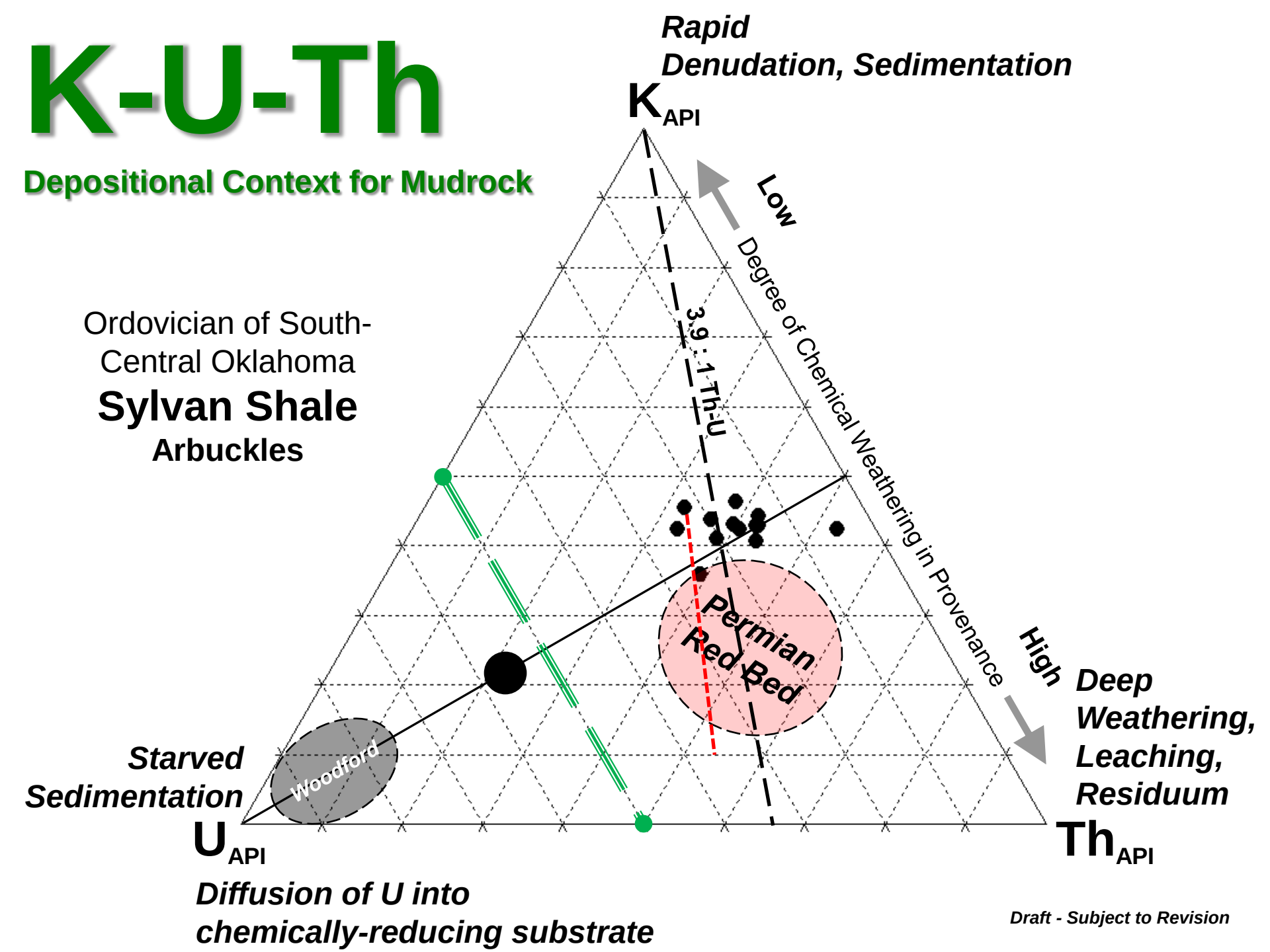
Depositional Context for Mudrock



Ordovician of South-Central Oklahoma

Sylvan Shale

Arbuckles

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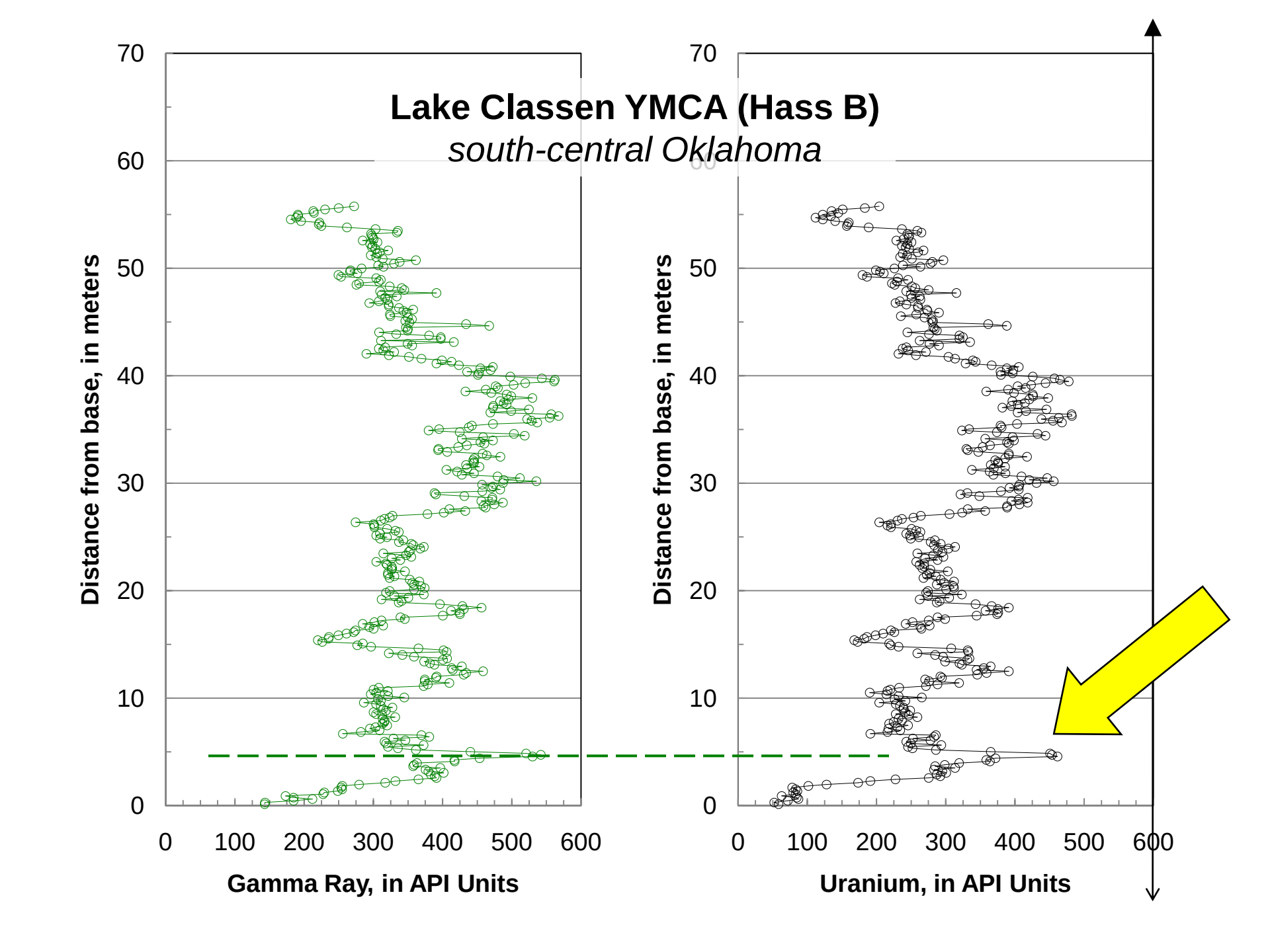
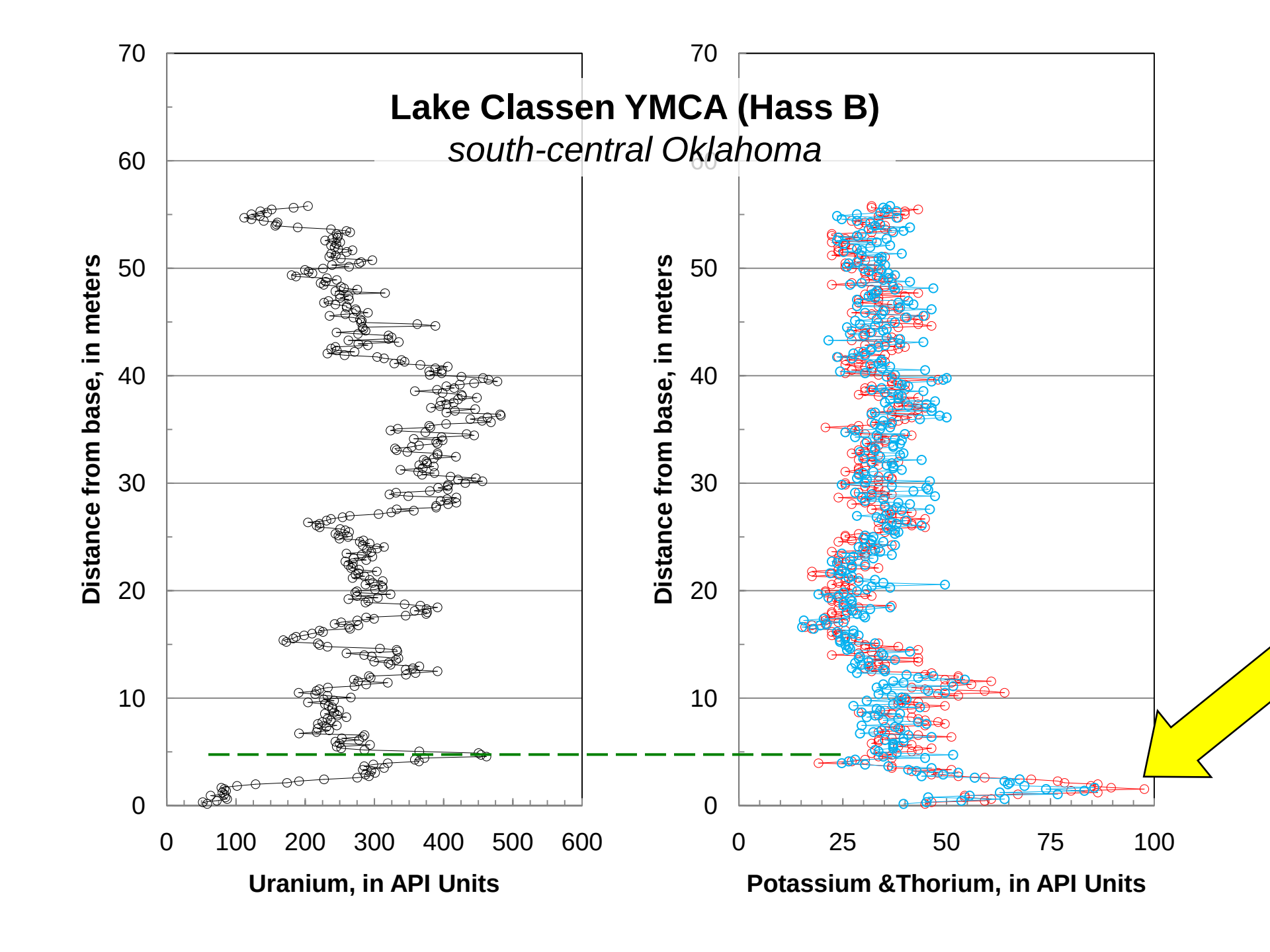
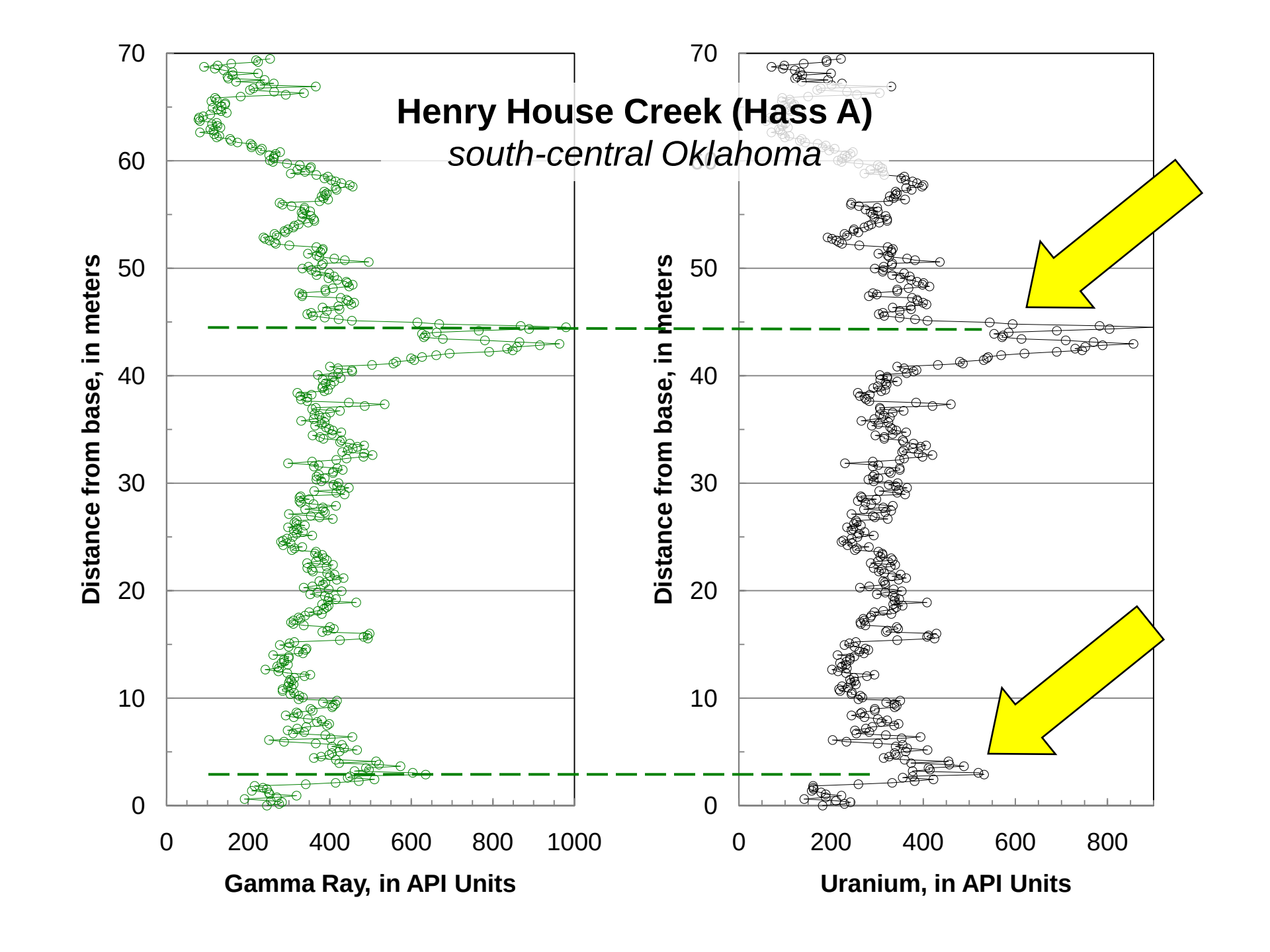
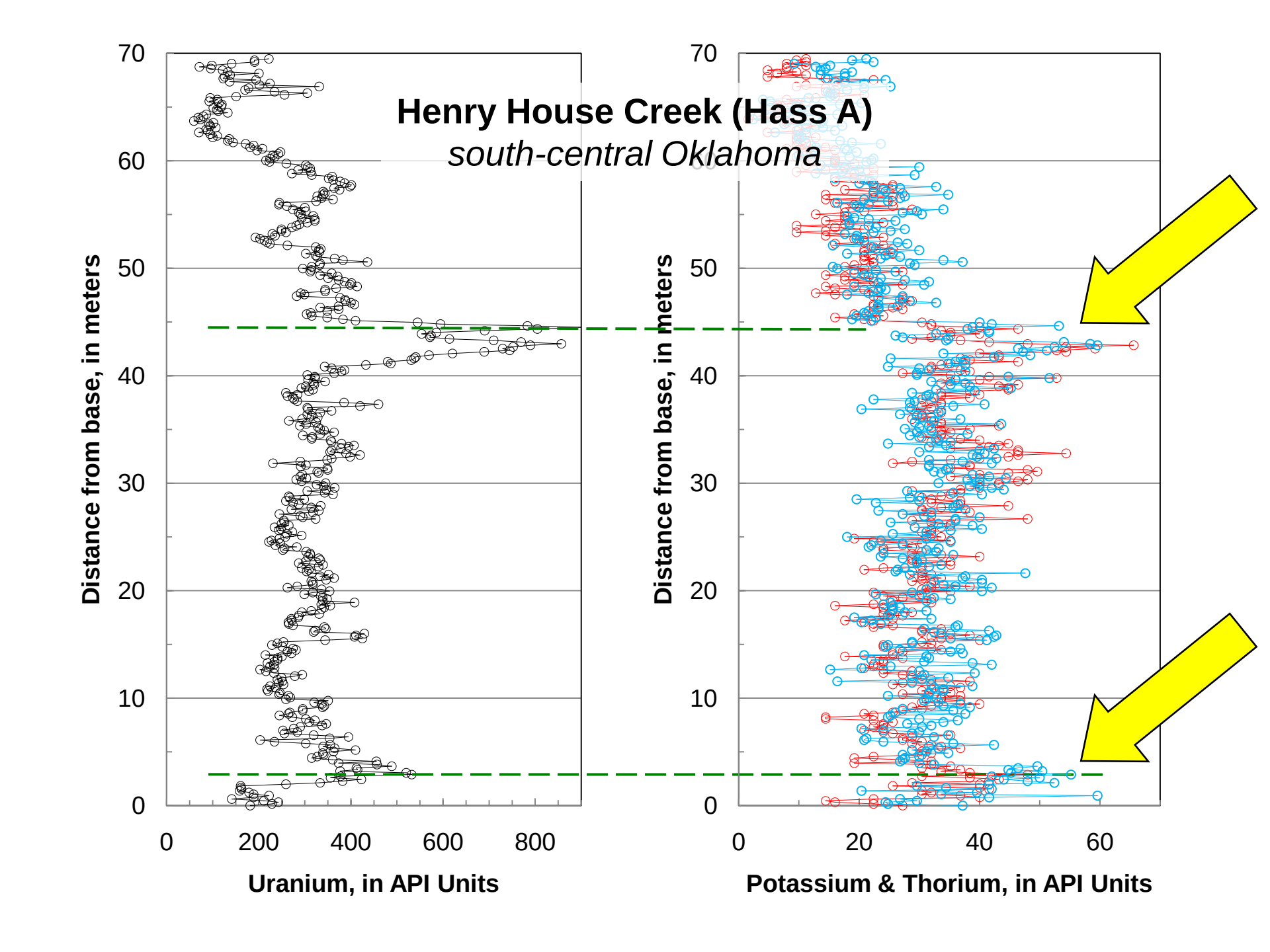
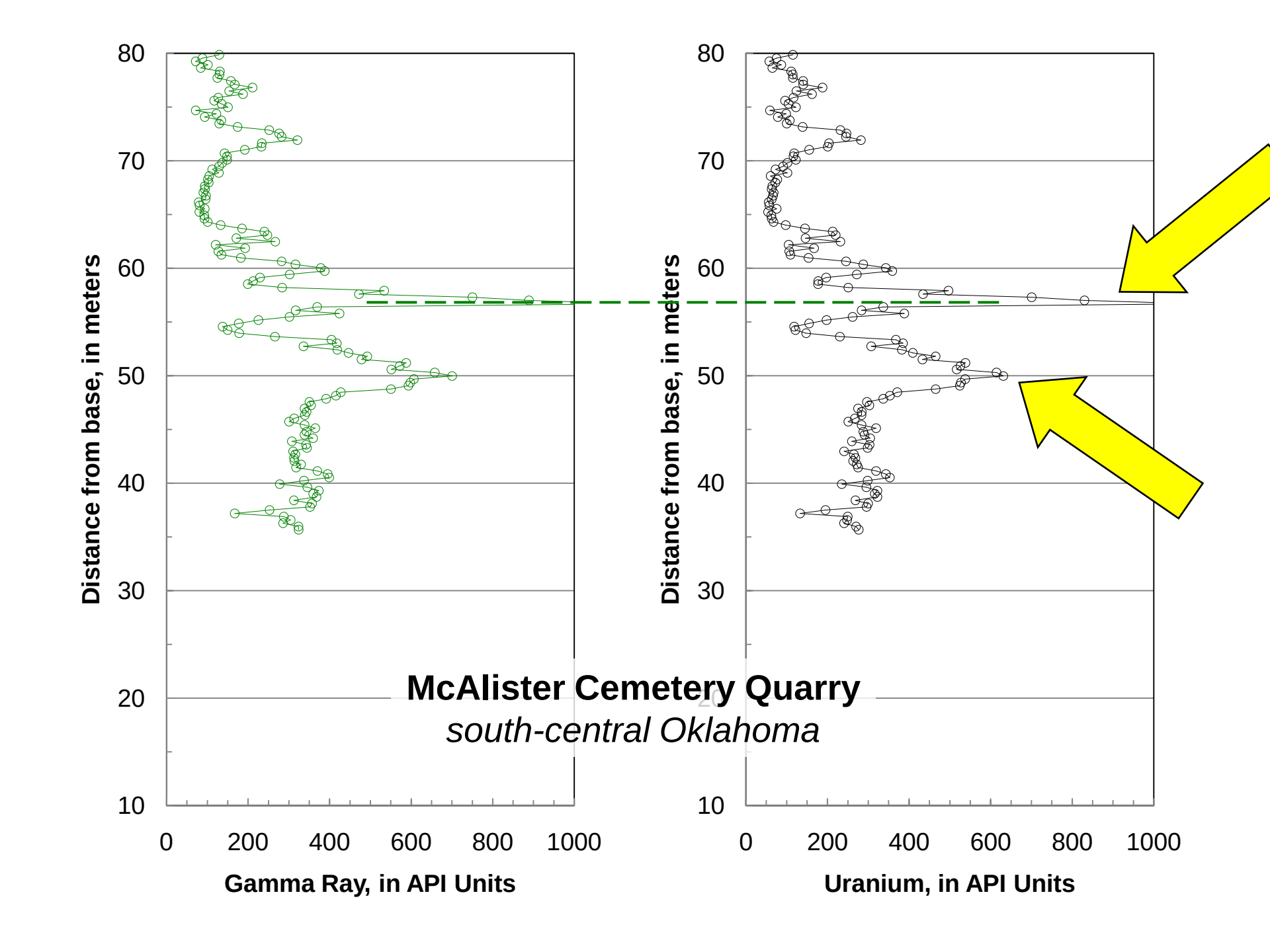
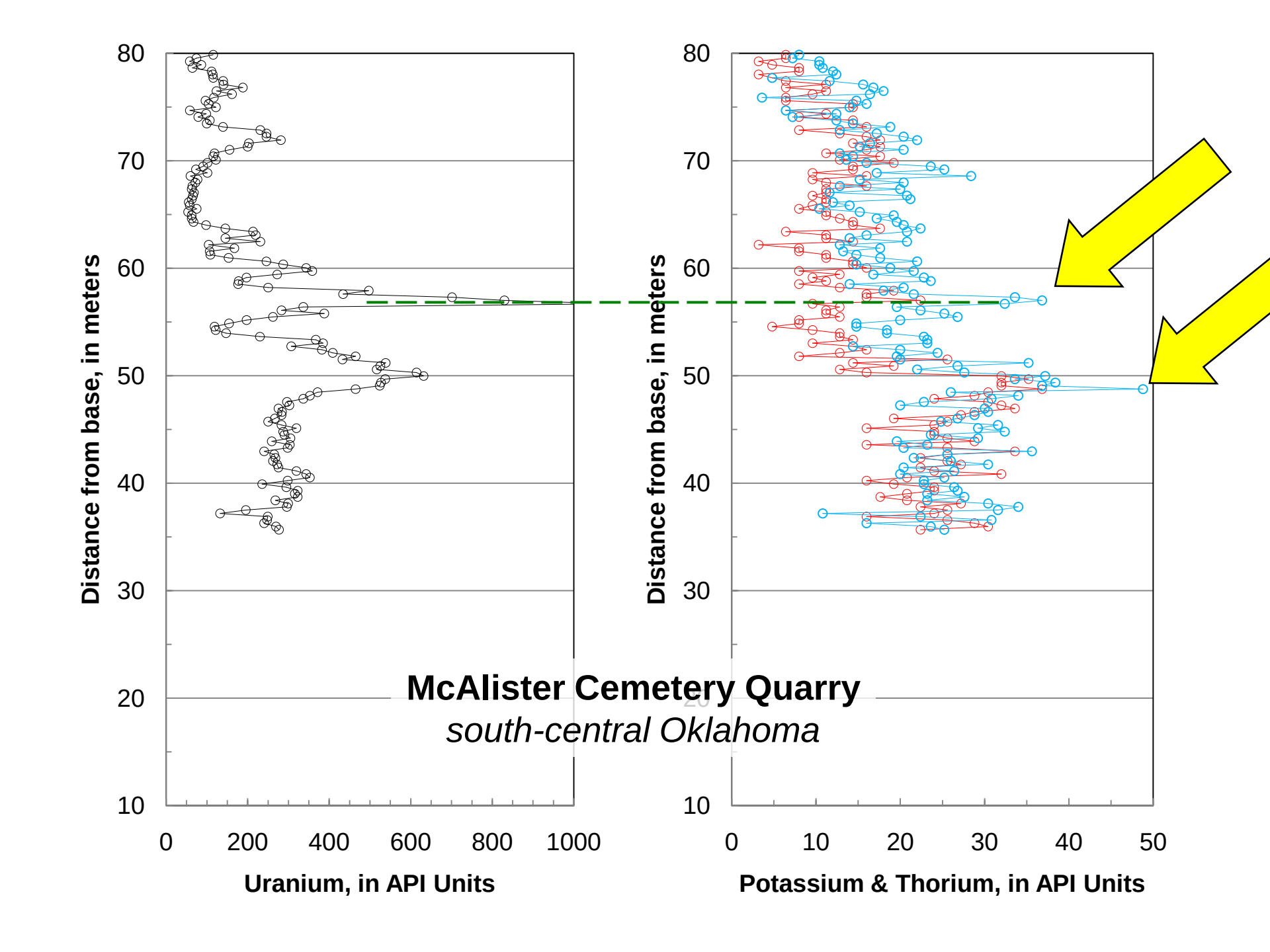

Lake Classen YMCA (Hass B)
south-central Oklahoma
Distance from base, in meters
0
10
20
30
40
50
60
70
0
100
200
300
400
500
600
Gamma Ray, in API Units
Distance from base, in meters
0
10
20
30
40
50
70
0
100
200
300
400
500
600
Uranium, in API Units


Lake Classen YMCA (Hass B)
south-central Oklahoma
Distance from base, in meters
70
60
50
40
30
20
10
0
0
100
200
300
400
500
600
Uranium, in API Units
Distance from base, in meters
70
50
40
30
20
10
0
0
25
50
75
100
Potassium &Thorium, in API Units


Henry House Creek (Hass A)
south-central Oklahoma
Distance from base, in meters
70
60
50
40
30
20
10
0
0
200
400
600
800
1000
Gamma Ray, in API Units
Distance from base, in meters
70
60
50
40
30
20
10
0
0
200
400
600
800
Uranium, in API Units


Henry House Creek (Hass A)
south-central Oklahoma
Distance from base, in meters
70
60
50
40
30
20
10
0
0
200
400
600
800
Uranium, in API Units
Distance from base, in meters
70
60
50
40
30
20
10
0
0
20
40
60
Potassium & Thorium, in API Units

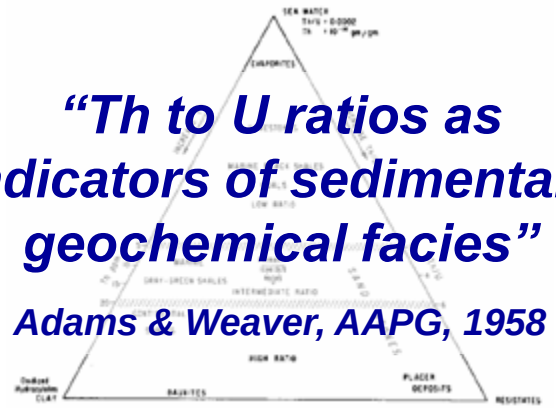

80
70
60
50
40
30
20
10
Distance from base, in meters
0
200
400
600
800
1000
Gamma Ray, in API Units
Uranium, in API Units
McAlister Cemetery Quarry
south-central Oklahoma


Distance from base, in meters
80
70
60
50
40
30
20
10
0
200
400
600
800
1000
Uranium, in API Units
Distance from base, in meters
80
70
60
50
40
30
10
0
10
20
30
40
50
Potassium & Thorium, in API Units
McAlister Cemetery Quarry
south-central Oklahoma

Key Findings - I

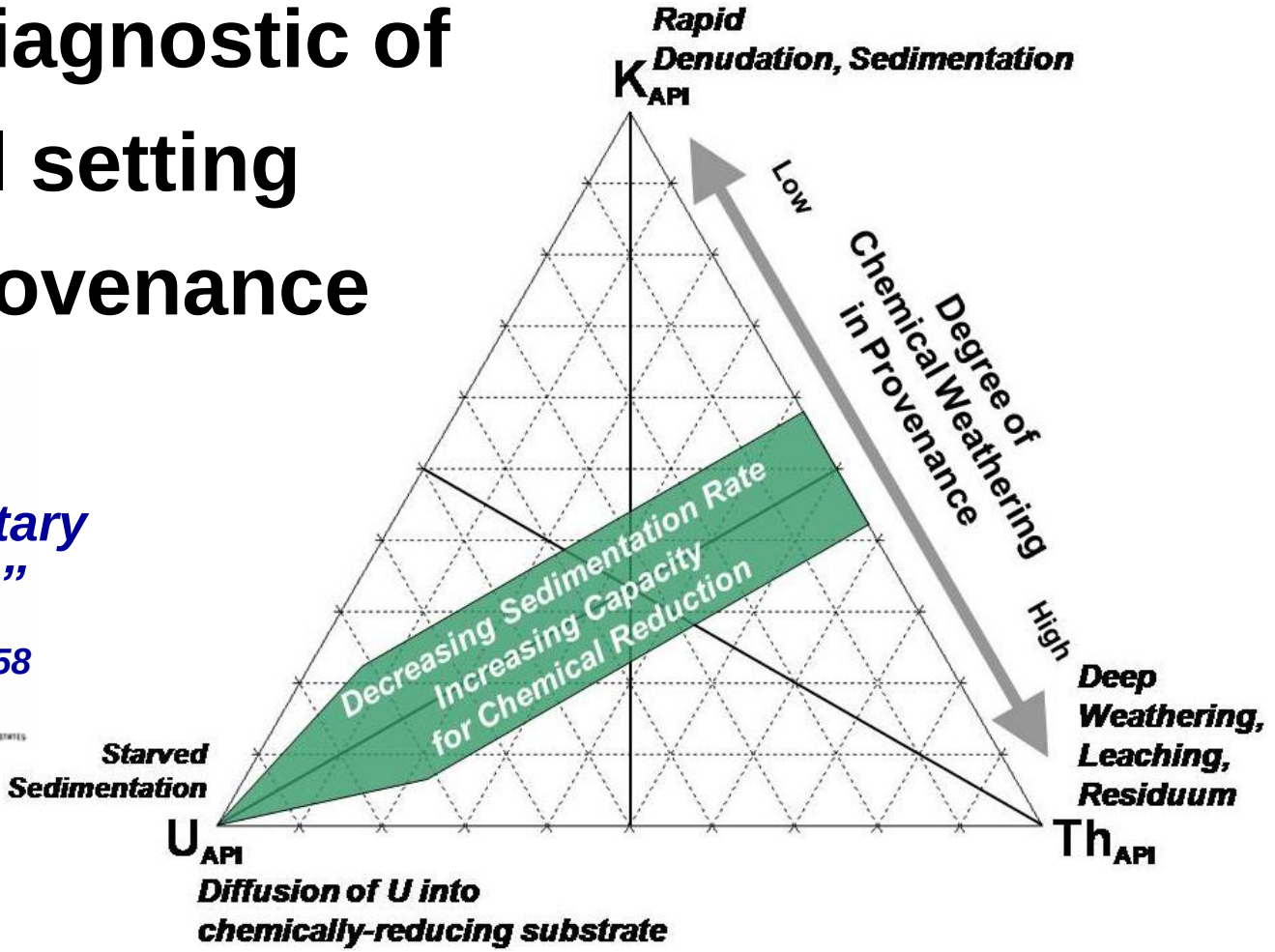
Relative proportions of K, U, & Th as measured with spectral gamma-ray (SGR) at outcrop are diagnostic of

- **depositional setting**
- **sediment provenance**



"Th to U ratios as indicators of sedimentary geochemical facies"

Adams & Weaver, AAPG, 1958



Key Findings - II

- **U-dominant signal**
  - deposition under chemically reducing conditions (conducive to pyrite formation)
  - sedimentation rate **<10 cm / ky**
- **K dominance**
  - sediment from provenance is relatively unweathered
- **Th dominance**
  - deeply-weathered sediment from provenance, a “residuum”

>10 cm / ky
Sedimentation Rate

Oxidizing or **Reducing**
Conditions

Key Findings - III

- Amounts/proportions of K-U-Th are diagnostic of stratigraphy (locally and regionally)
- Some “hot” shale kicks on vertical profiles are K-Th dominated rather than U-dominated
- Woodford displays the most consistency in K-U-Th from outcrop to outcrop, Caney Shale the least

Spectral Gamma-Ray Response of Oklahoma Shales in Outcrop

Draft - Subject to Revision

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Caney Shale along Tulip Creek, OK

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Shale Science

Water
Life
Energy