Mapping the Extent and Distribution of Oil Formation in the Upper Bakken Formation, Williston Basin

Geochemistry and Petrography

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USGS science for a changing world

Why not vitrinite reflectance?

Suppressed vs. True Vitrinite

Variations in Petroleum Kinetics

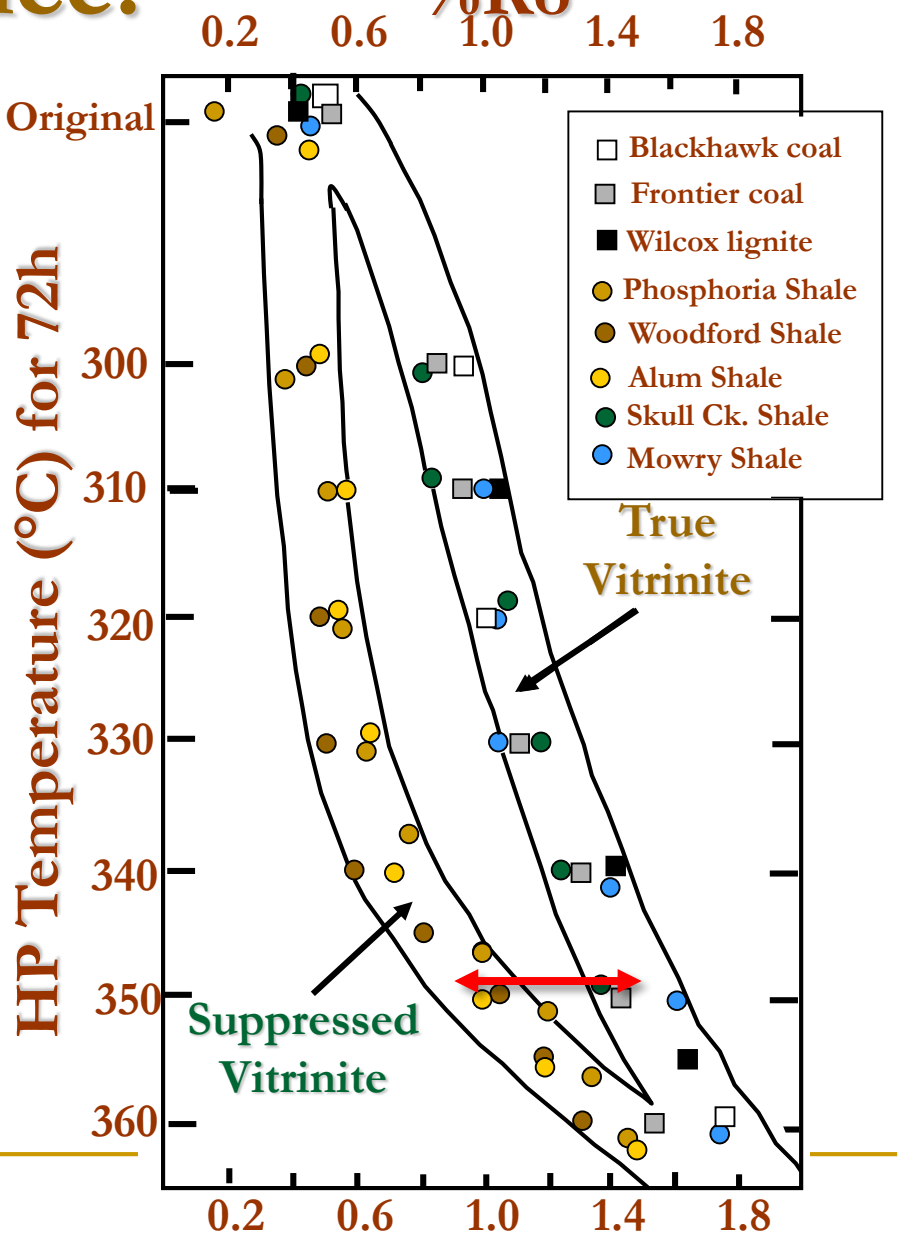
Vitrinite Reflectance: Suppressed vs. True Trends

True vitrinite from land plants (not hydrogen-rich vitrinite)

- Wilcox lignite
- Blackhawk coal (w/resinite)
- Frontier coal

Suppressed vitrinite from a different precursor (pyrobitumen, graptolites, chitinozoans, etc.)

- Phosphoria (Permian)
- Woodford (Dev-Miss)
- Alum (Cambrian)



Lewan (1993)

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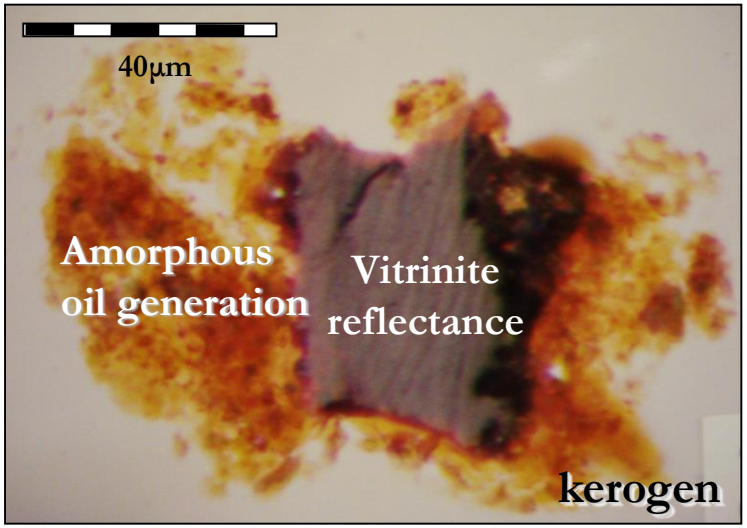
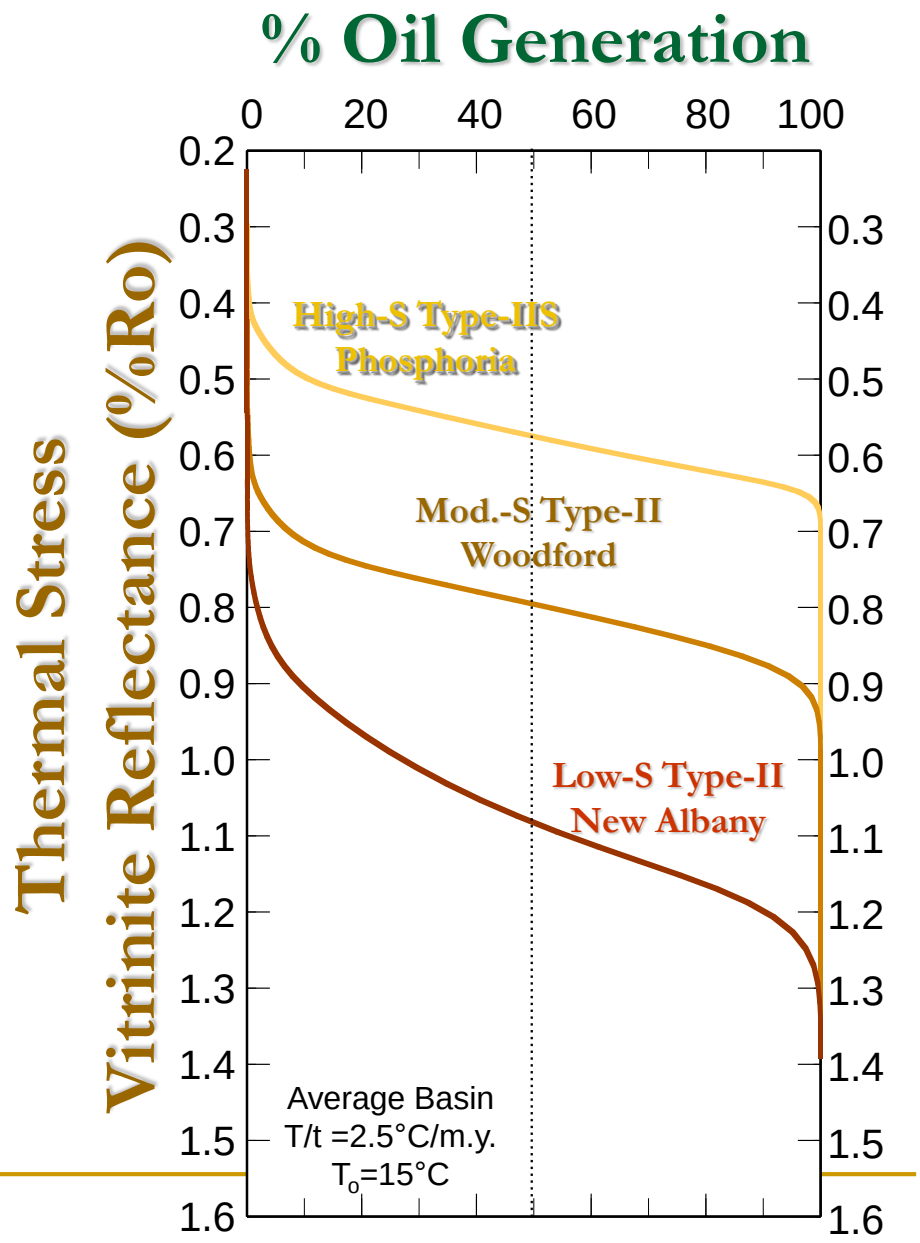
Oil Generation occurs at different Thermal Stress Levels; therefore, at different Vitrinite Reflectance Values





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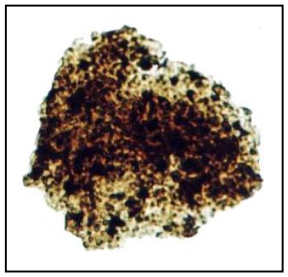
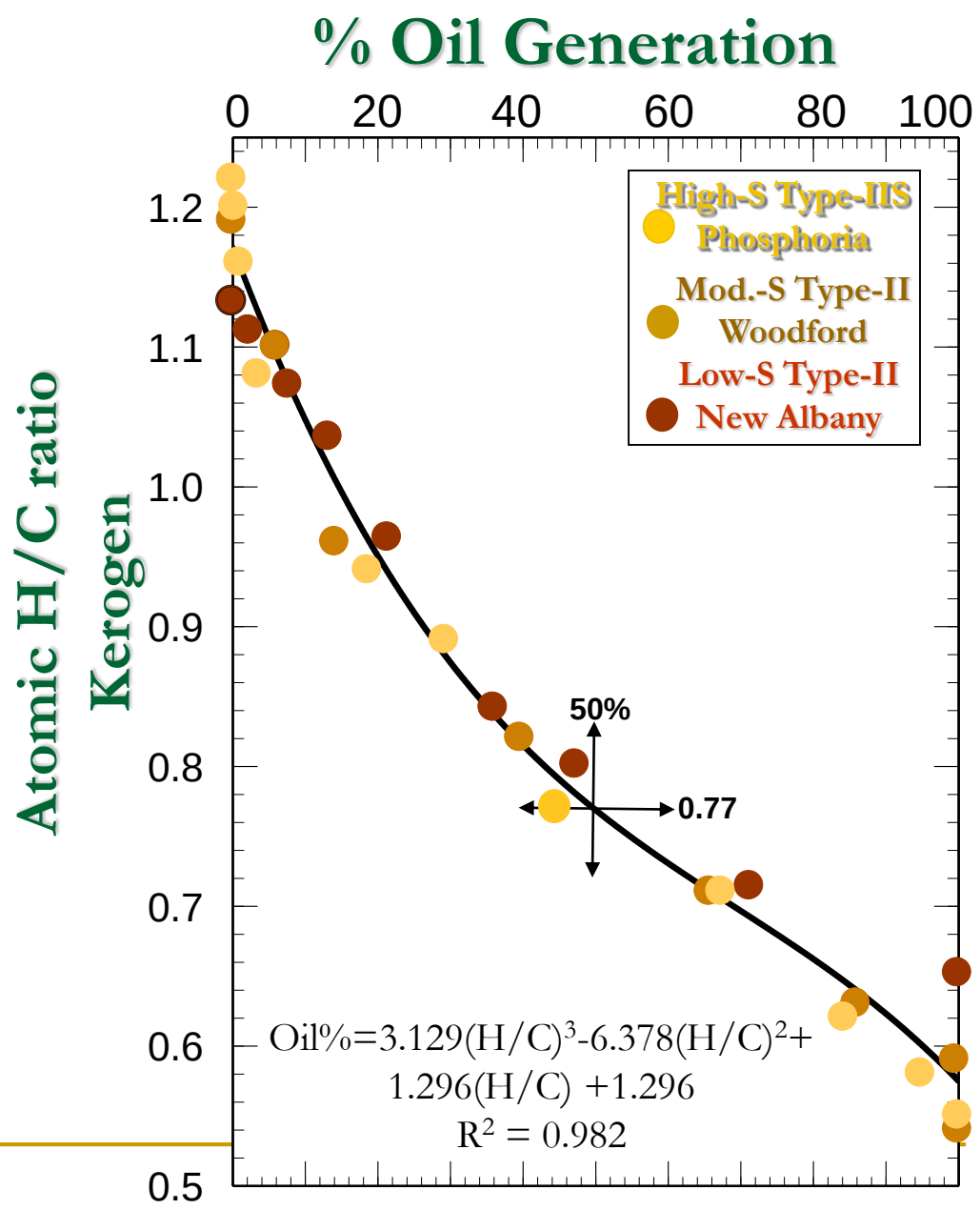
Atomic H/C ratio of Type-II & -IIS kerogen is an indicator of Oil Generation irrespective of sulfur content and kinetics



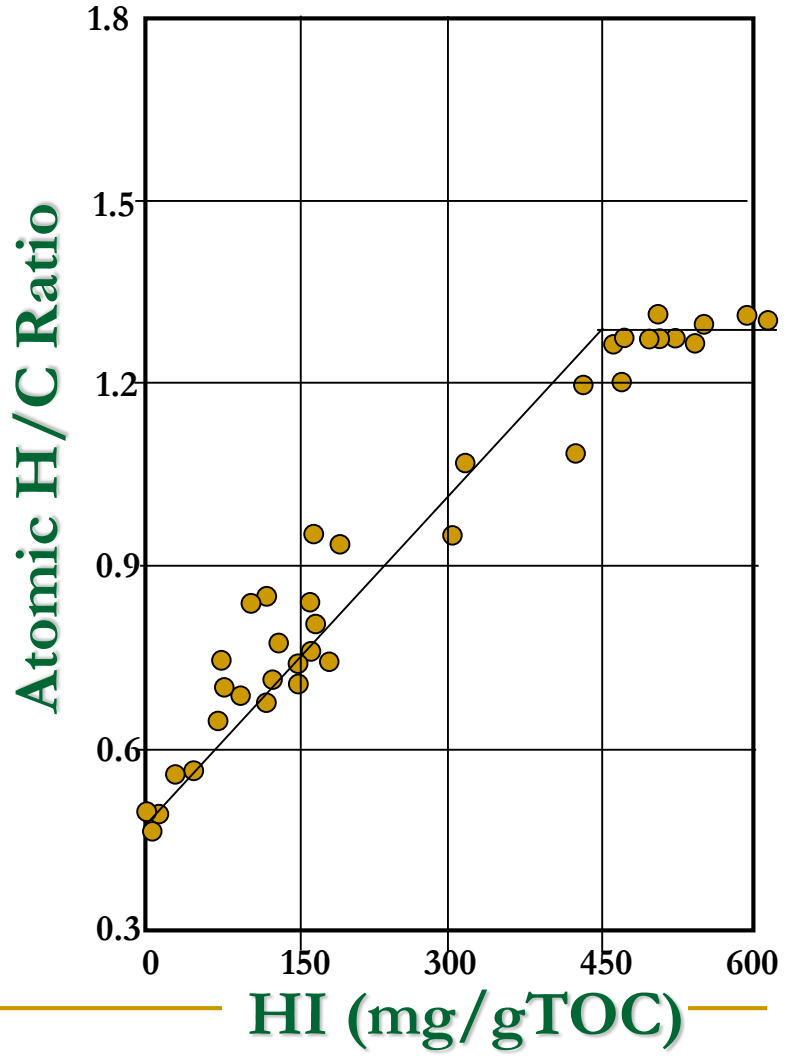


Atomic H/C ratio of kerogen is an excellent measure of oil generation.

Kerogen isolation is time consuming and involves HF, HCl and heavy-liquid separation.

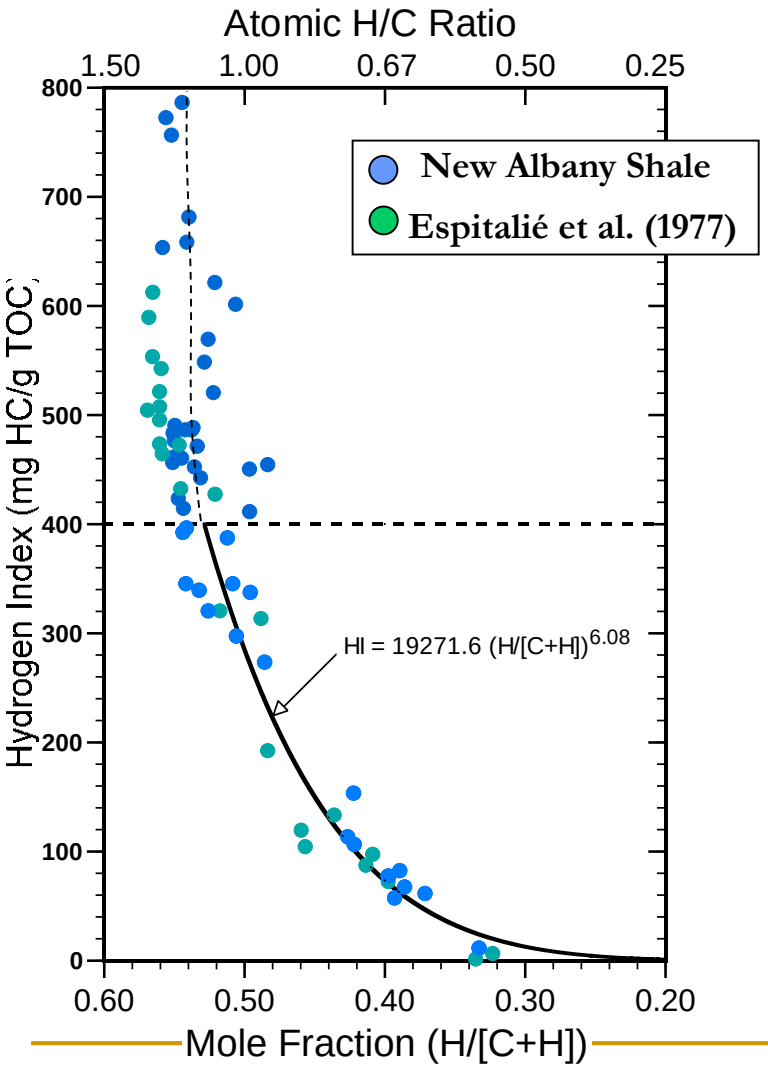
A proxy for atomic H/C ratio of kerogen is Rock-Eval Hydrogen Index (HI) on the whole rock.

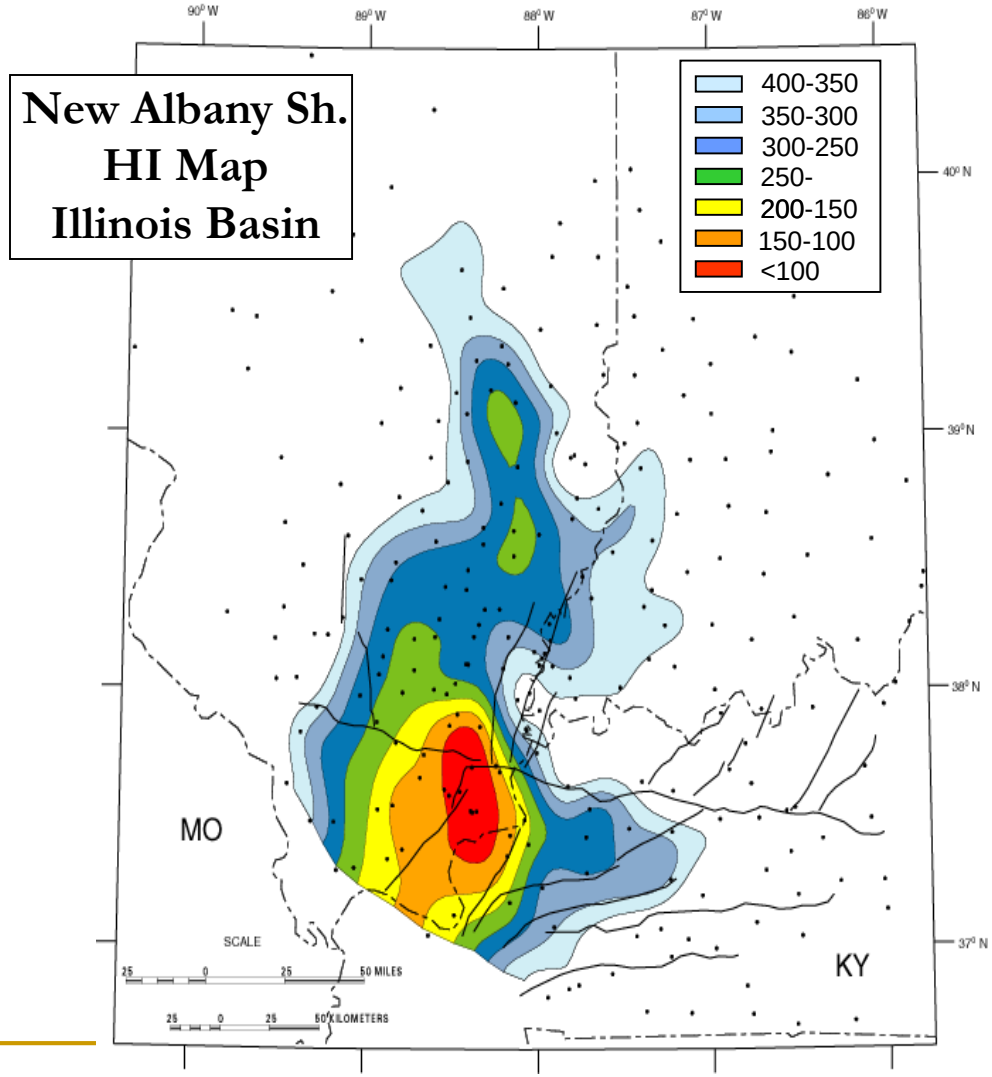
<u>CAVEAT</u>: HI values have a limit above which they no longer correlate with changes in the atomic H/C ratio



Espitalié et al. (1977)

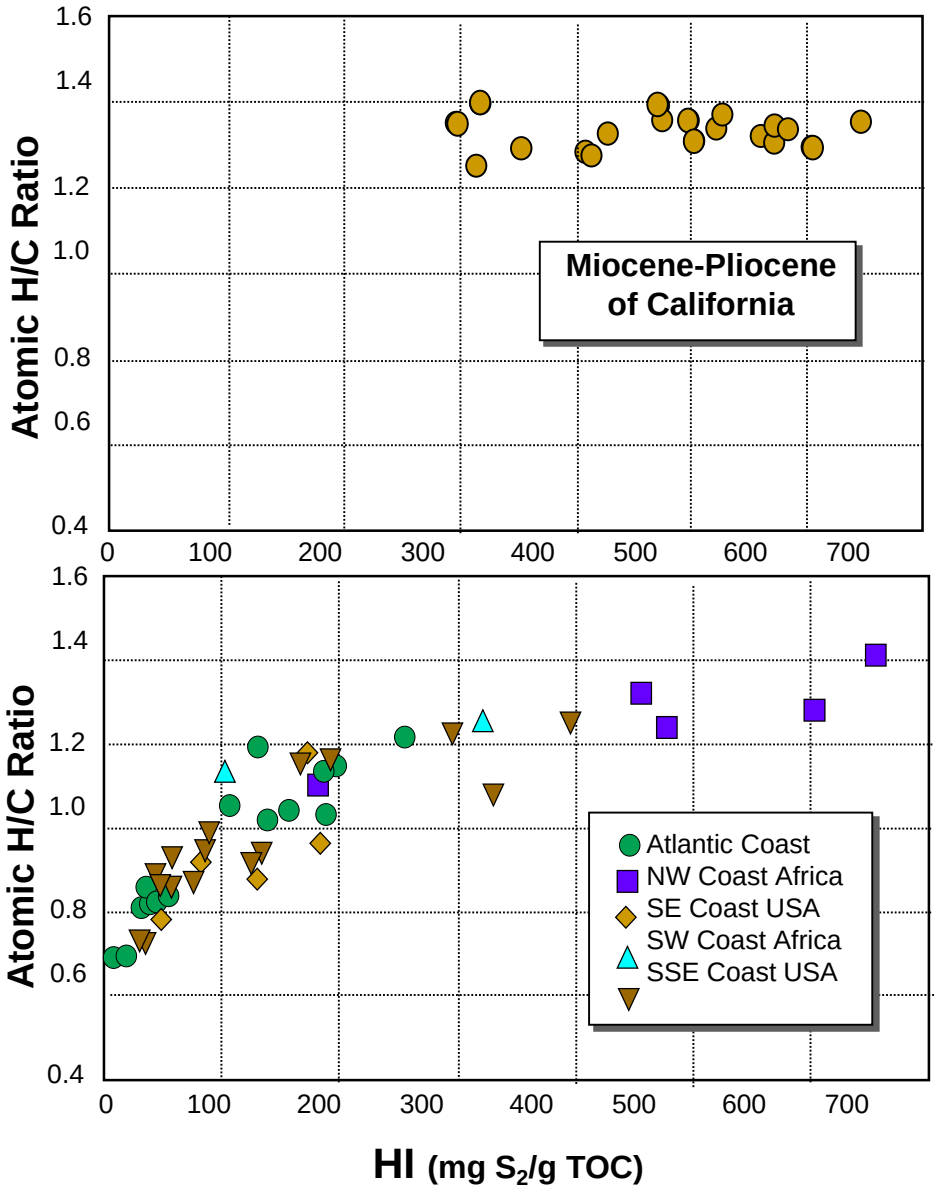
Calibration of atomic H/C to HI is critical.





Lewan et al. (2002)

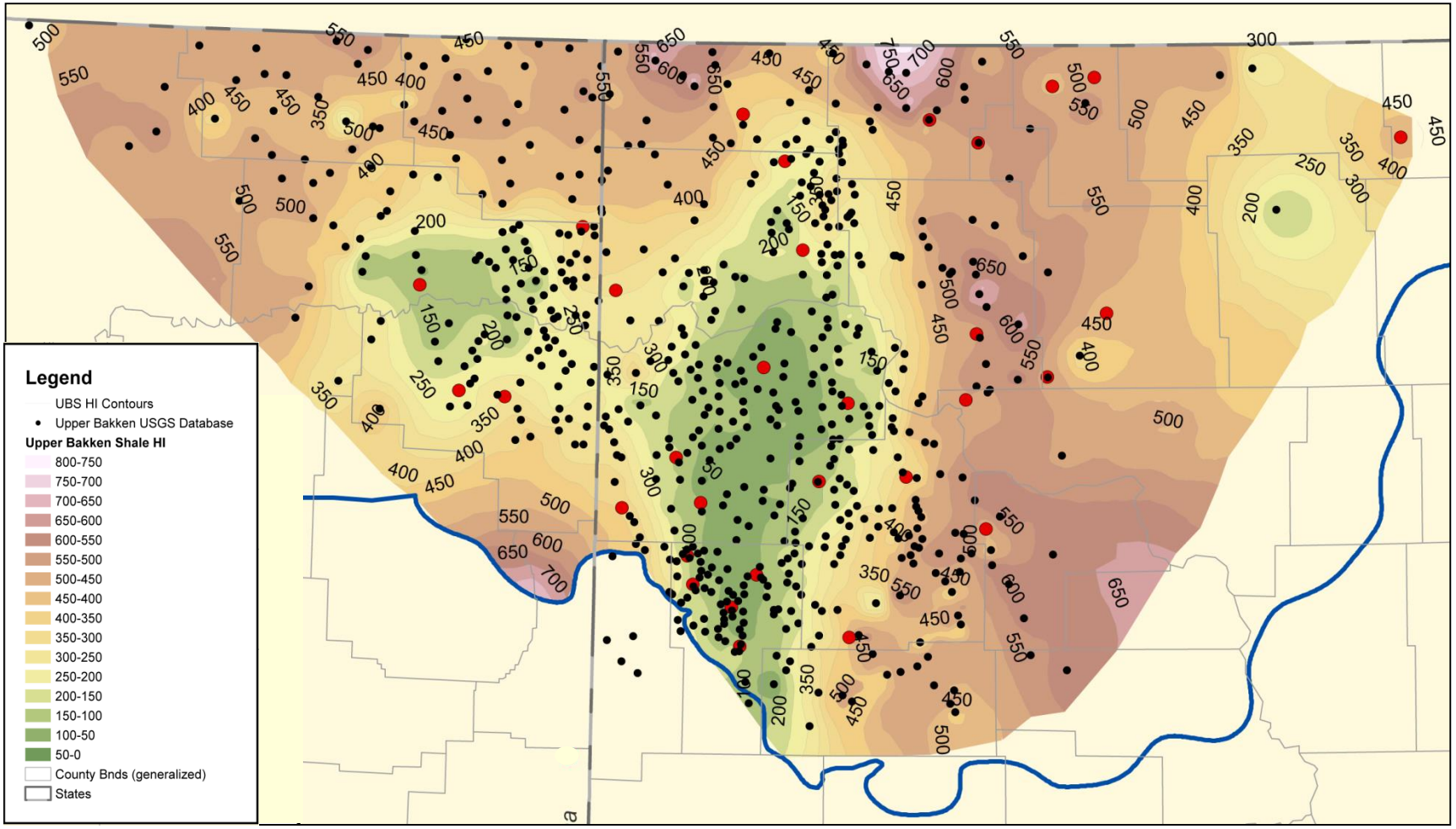
Calibration of Atomic H/C ratio of kerogen to HI of Rock is Essential in Using HI as a Proxy



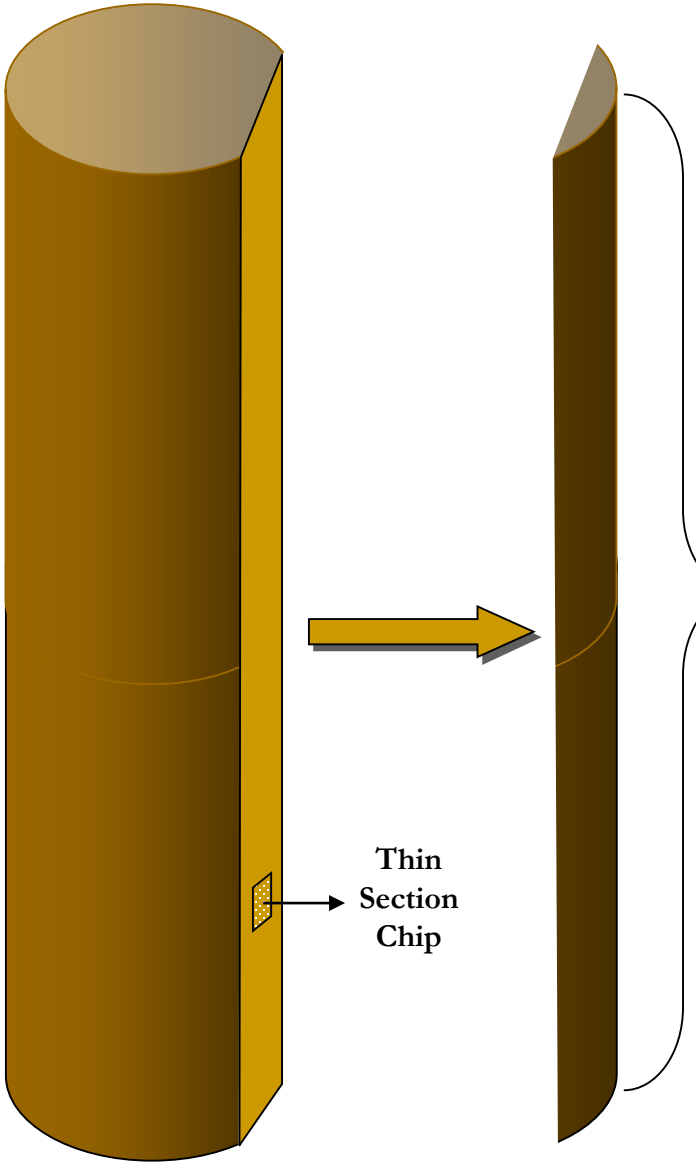
Baskin (1997)

Upper Bakken HI Map

w/additional data from 31 wells (●) for calibration



Composite samples taken over the length of available core*



Composite Core Samples

More representative
More cost-effective

Upper Bakken Mean Composited Thickness
7.6 ± 4.2 ft
Mean Upper Bakken Thickness ≈ 11 ft

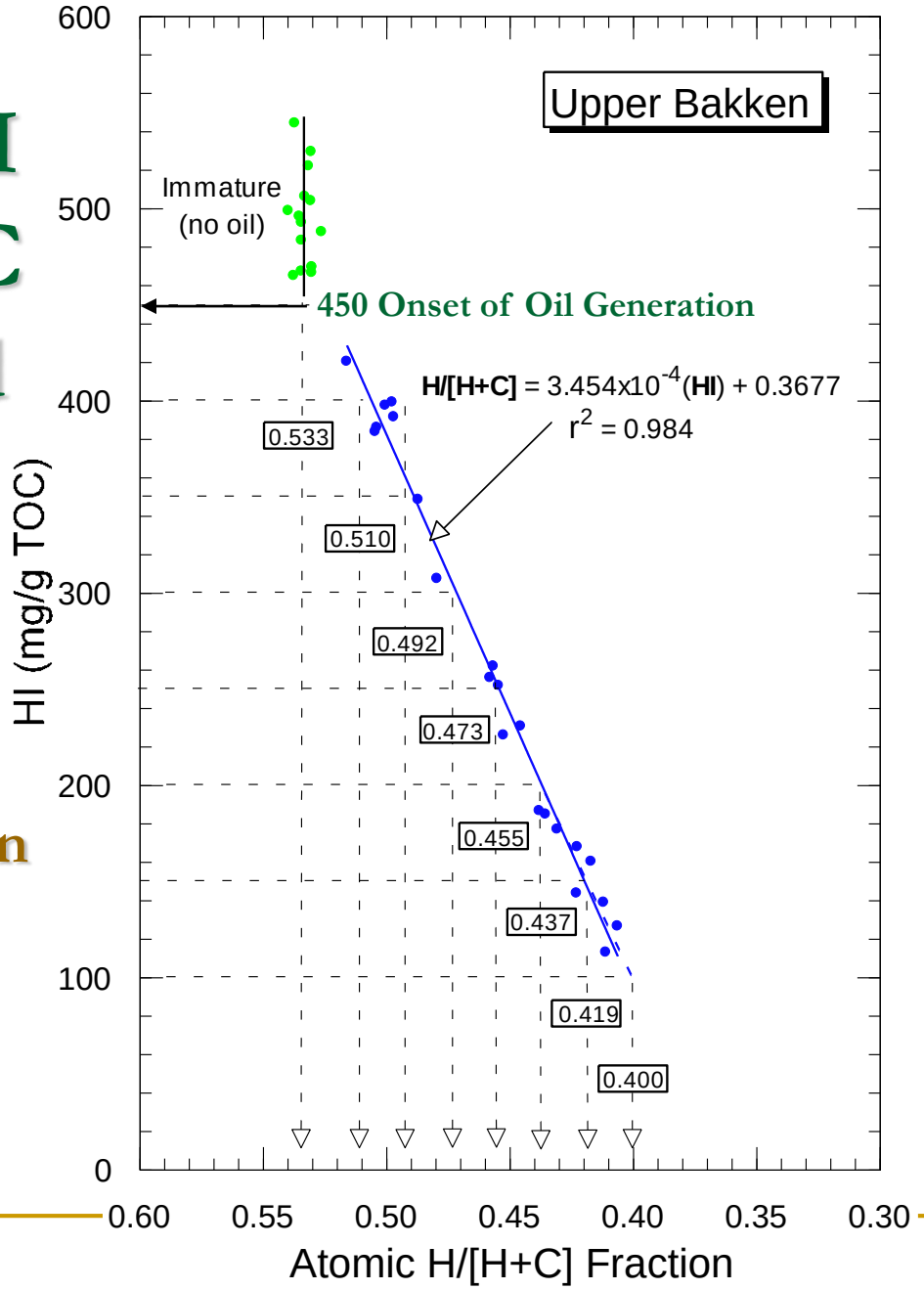
*NDGS: Julie LeFever & Staff (Kent Hollands, Karew Schumacher & Matt Weiler)
USGS: John Rhoades & Staff (Josh Hicks & Terry Huber)

Calibration of HI with Atomic H/C Ratio of Isolated Kerogens

$\delta^{13}C_{Kerogen} = -29.8 \pm 0.4‰$

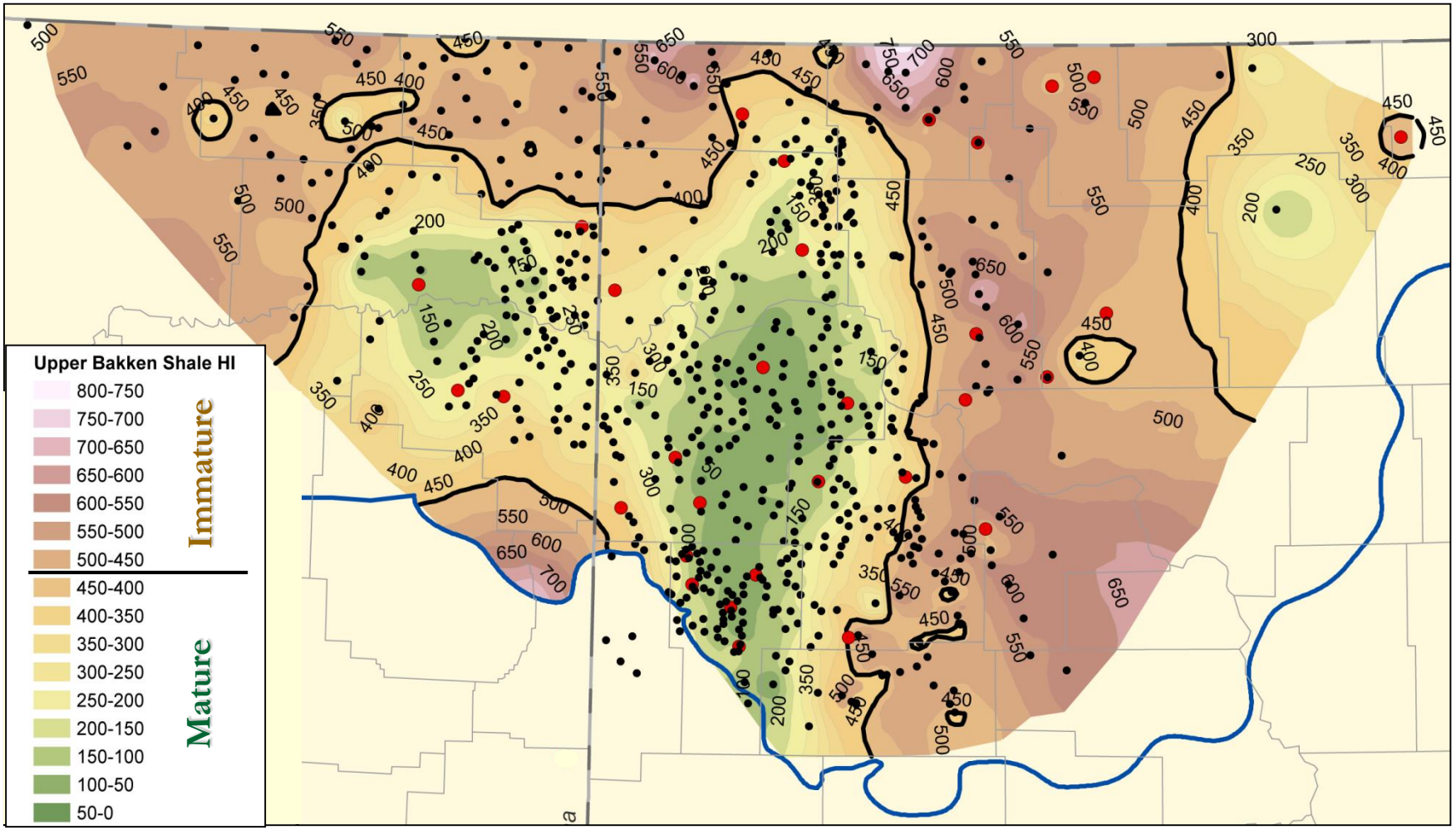
No Change in the Kerogen at HI values >450

Onset of Oil Generation at HI values <450

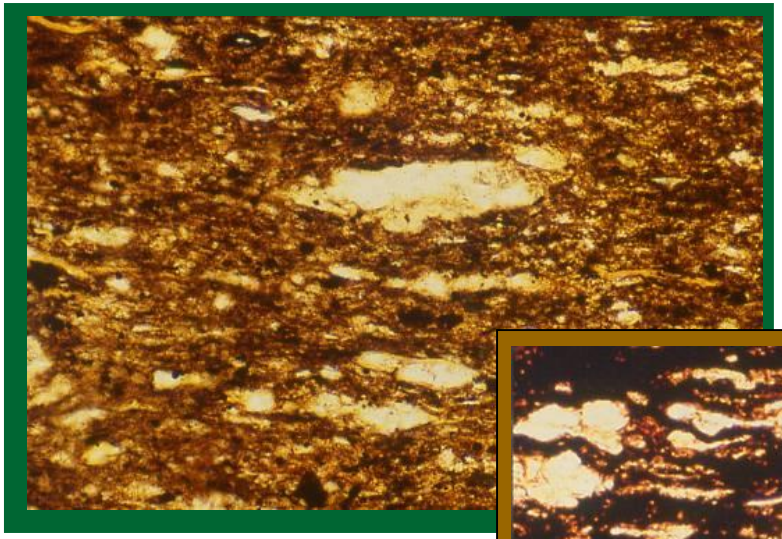


Upper Bakken Pod of Active Source Rock

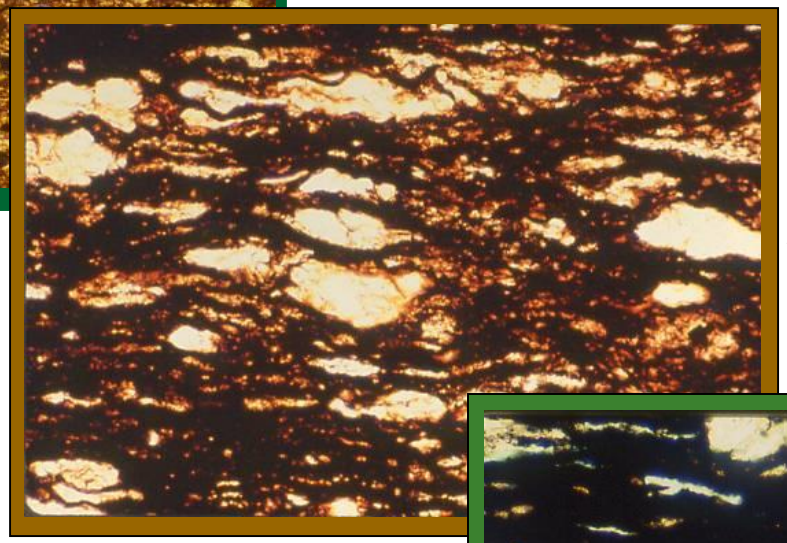
450 HI Onset of Oil Generation (——)



Petrographic Test for Onset of Oil Generation

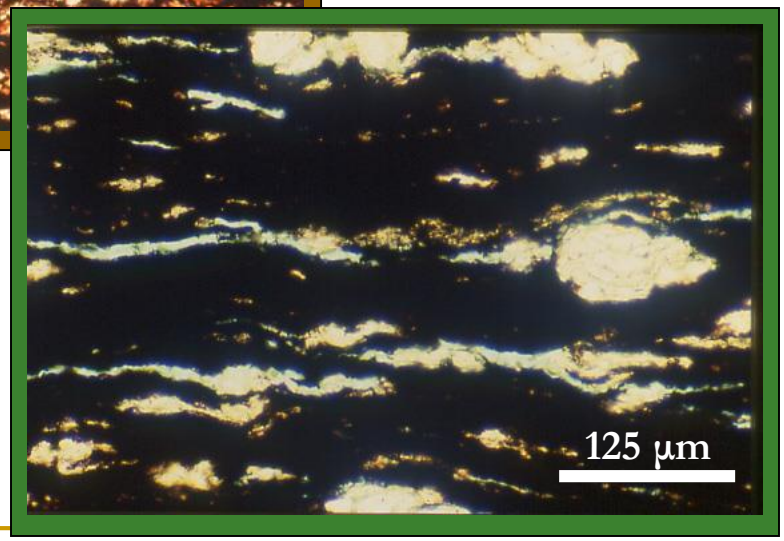


immature unheated
(20μm thick)



kerogen-bitumen
300°C/72h

Onset

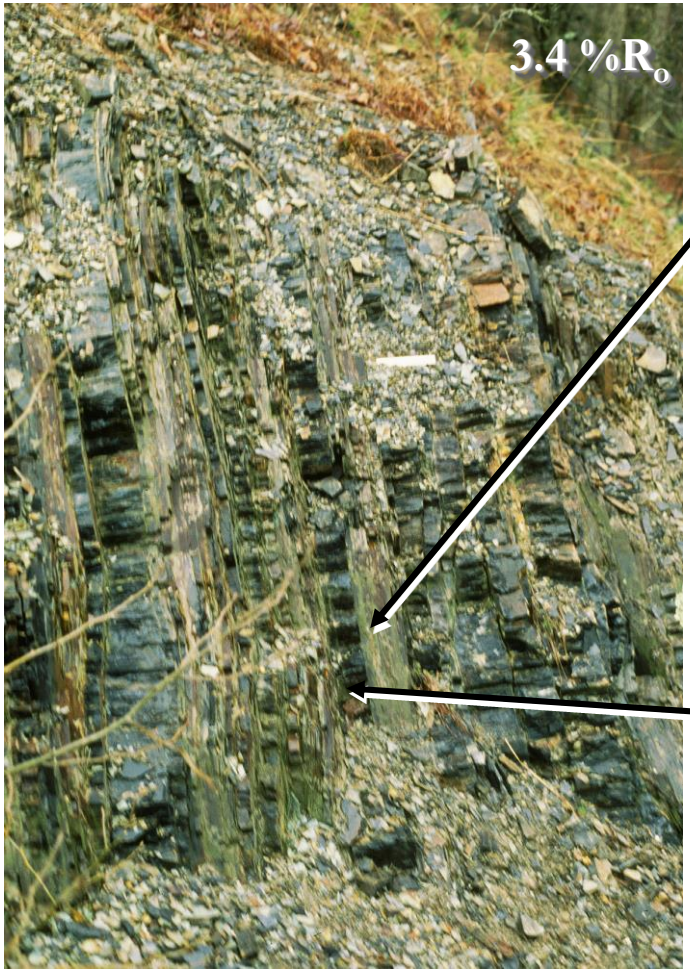


bitumen-oil 352°C/72h

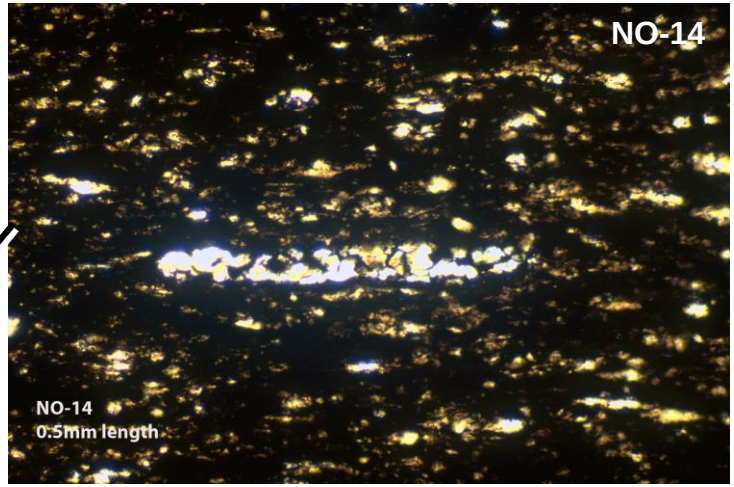
Hydrous Pyrolysis of Woodford Shale Cores

Lewan (1987)

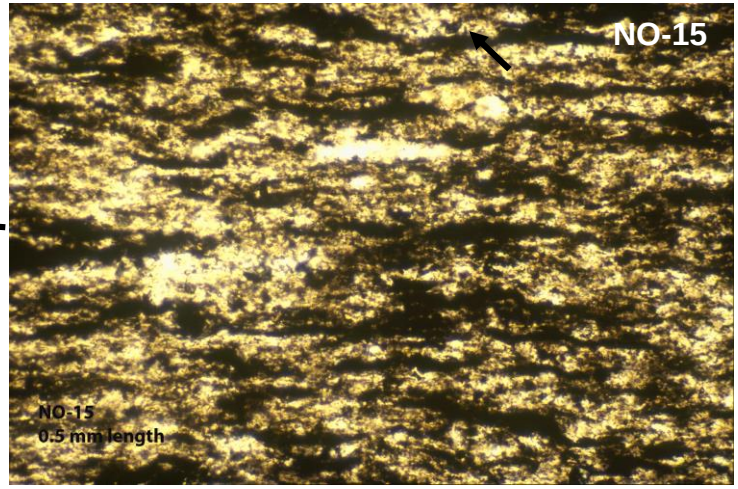
Source Rock Effectiveness & TOC Limits



Caddo Gap, Middle Novaculite
Shale-Chert Sequence



Shale (4.9%TOC) effective source



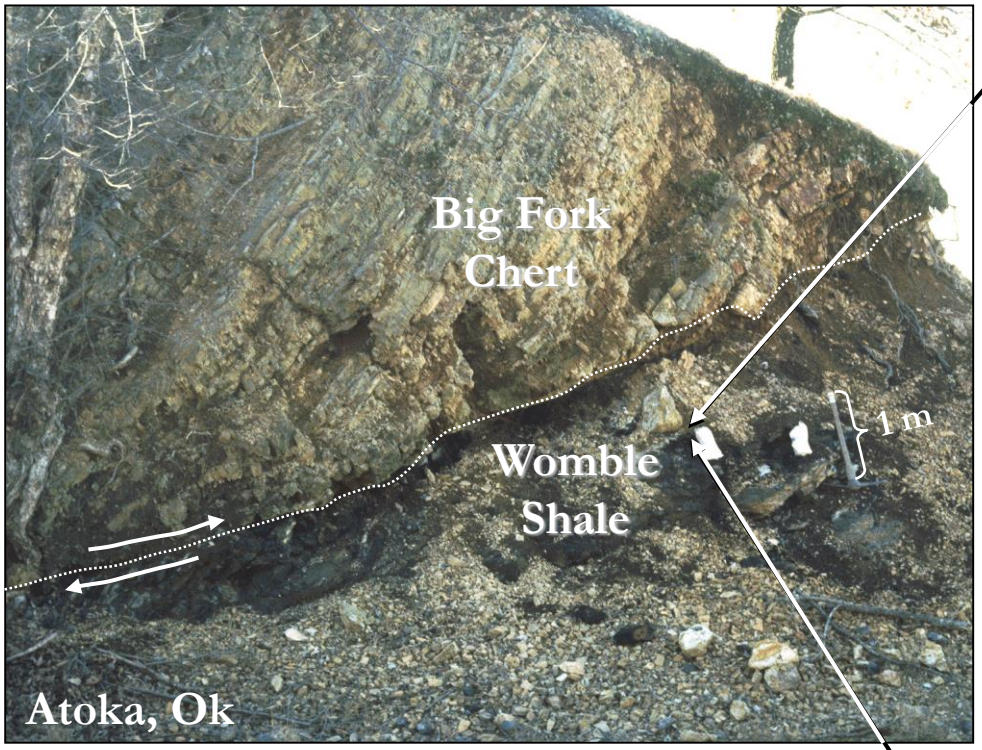
Chert (1.5%TOC) not effective source

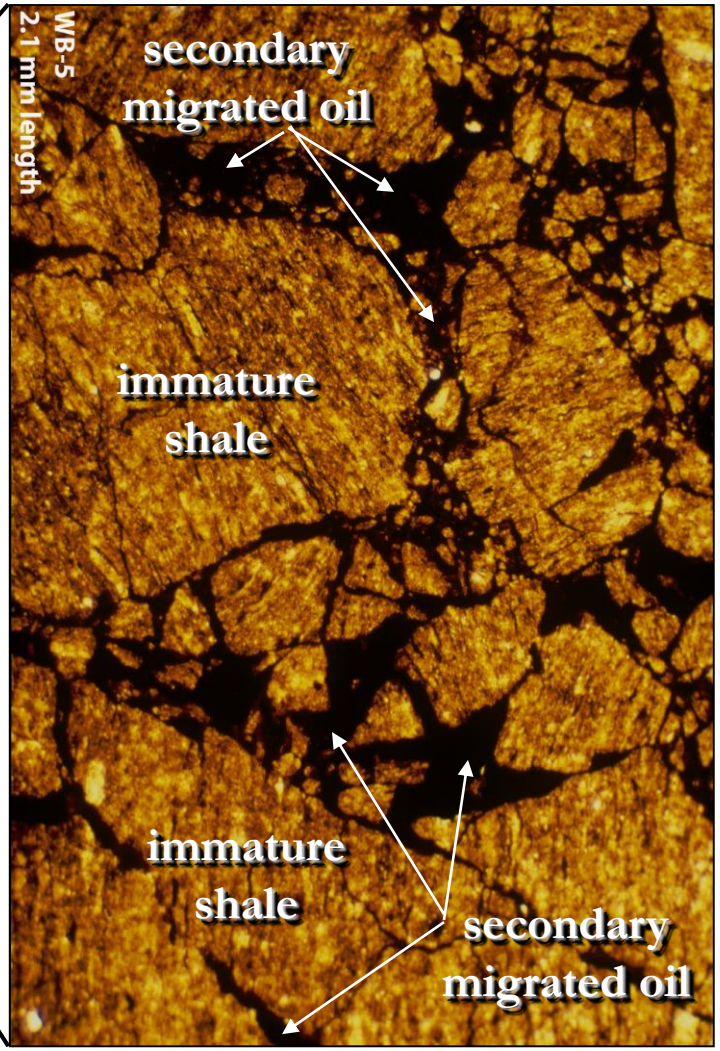
0.5 mm

Source Rock Petrography

Lewan (1987)

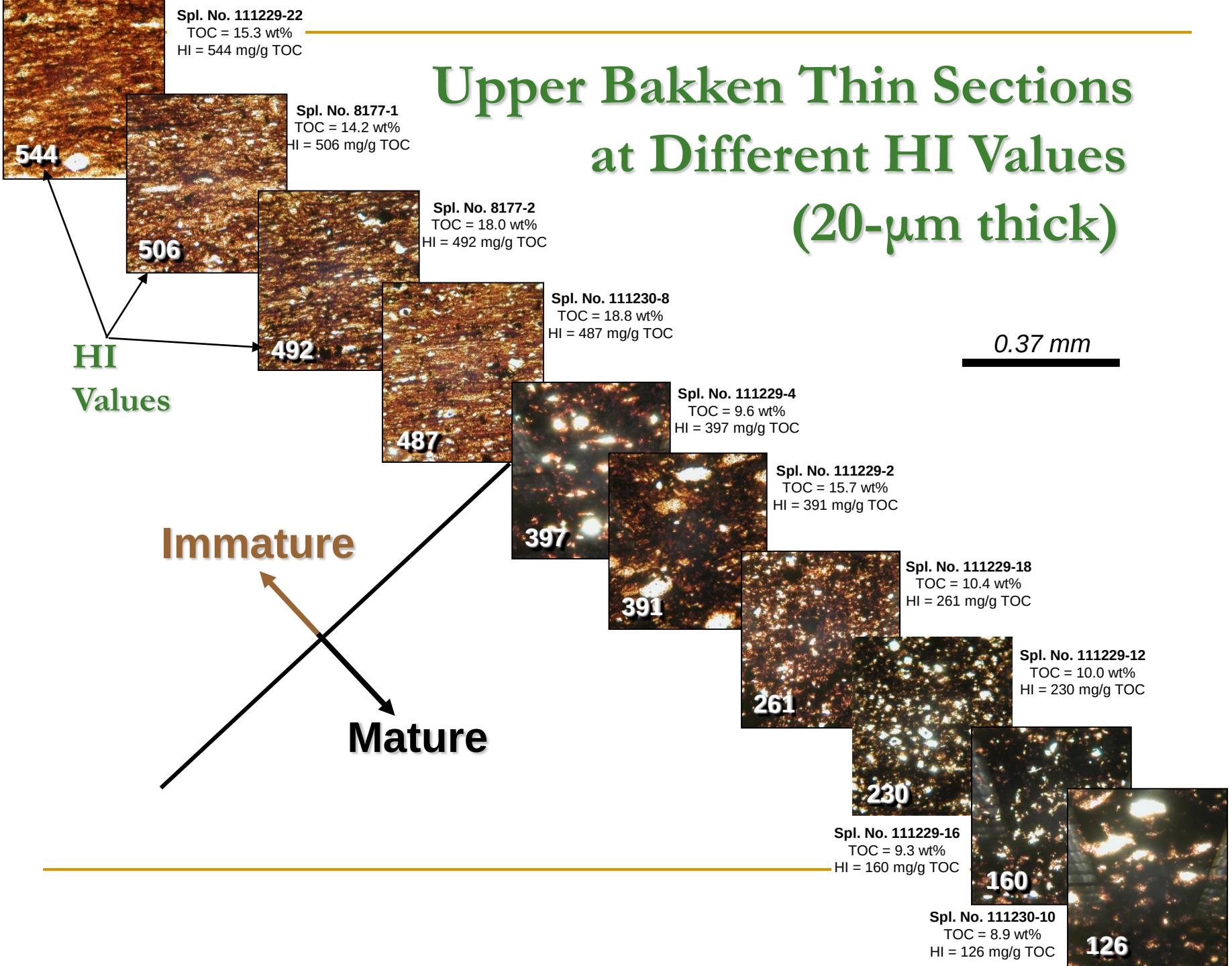
Secondary Petroleum Migration



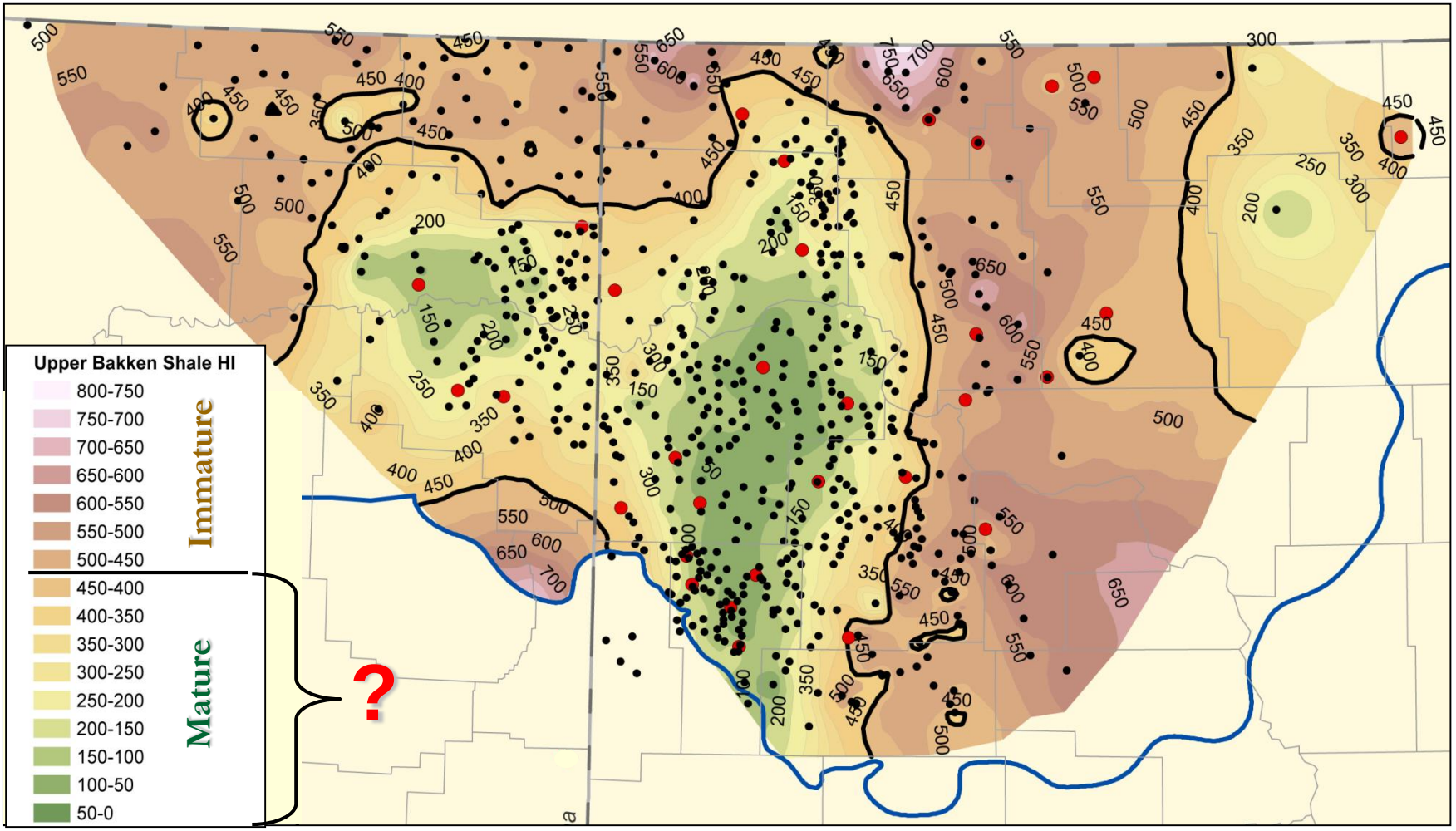


Secondary Migrated Oil vs. *in situ* Generated Oil ?

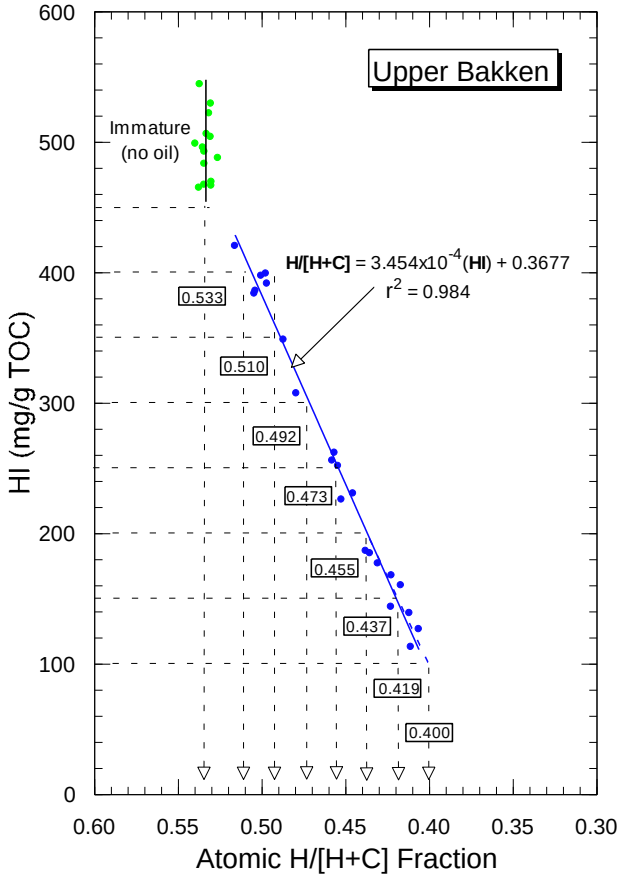
Upper Bakken Thin Sections at Different HI Values (20-µm thick)



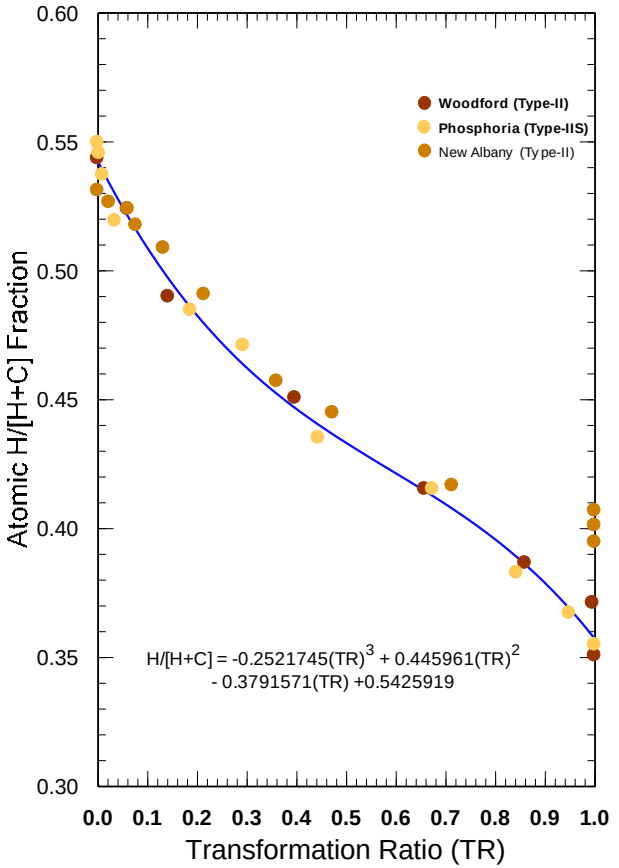
450 HI Onset of Oil Generation (—), but how do the Lower HIs relate to Oil Generation TRs?

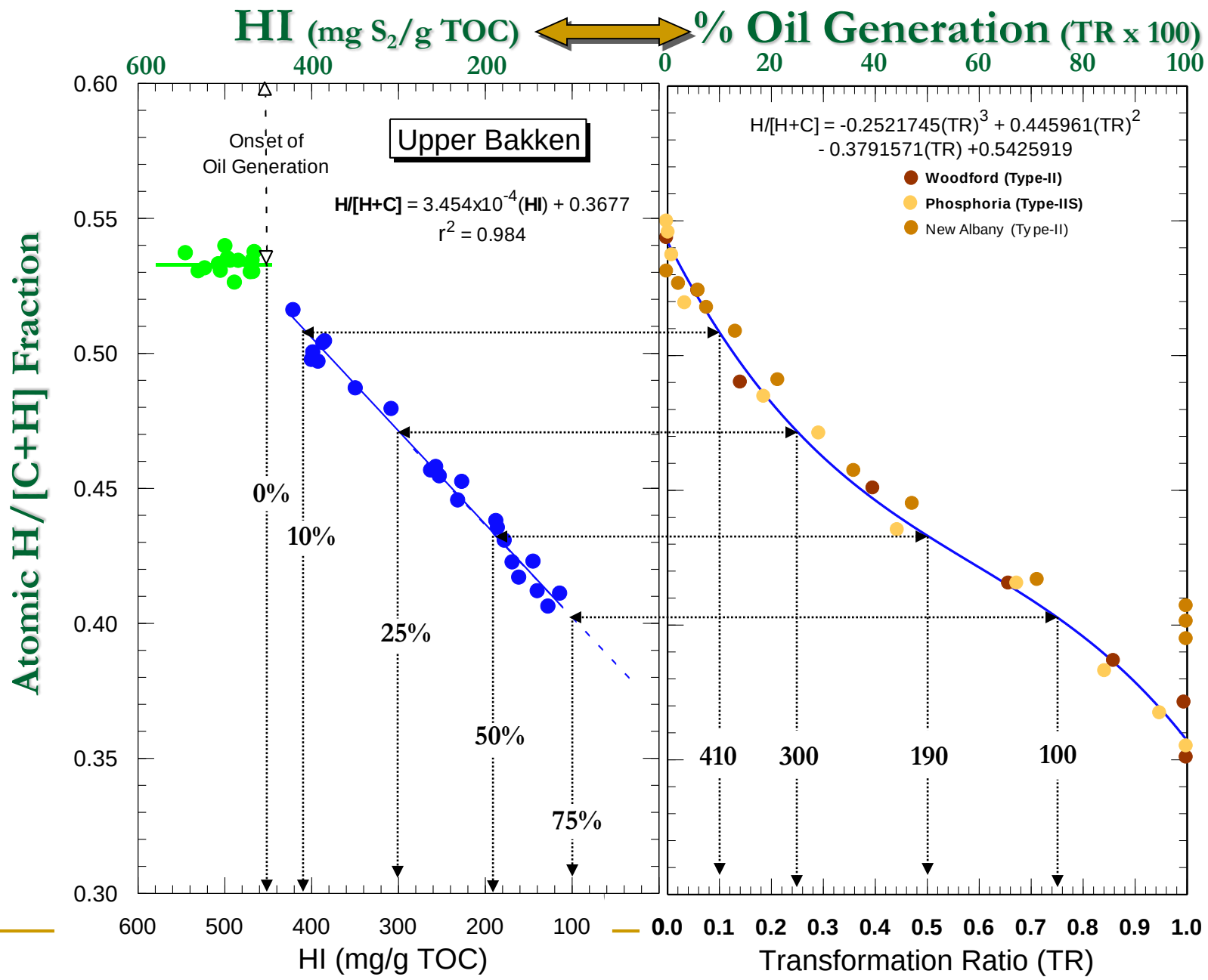


Atomic H/[H+C] is related to HI Values

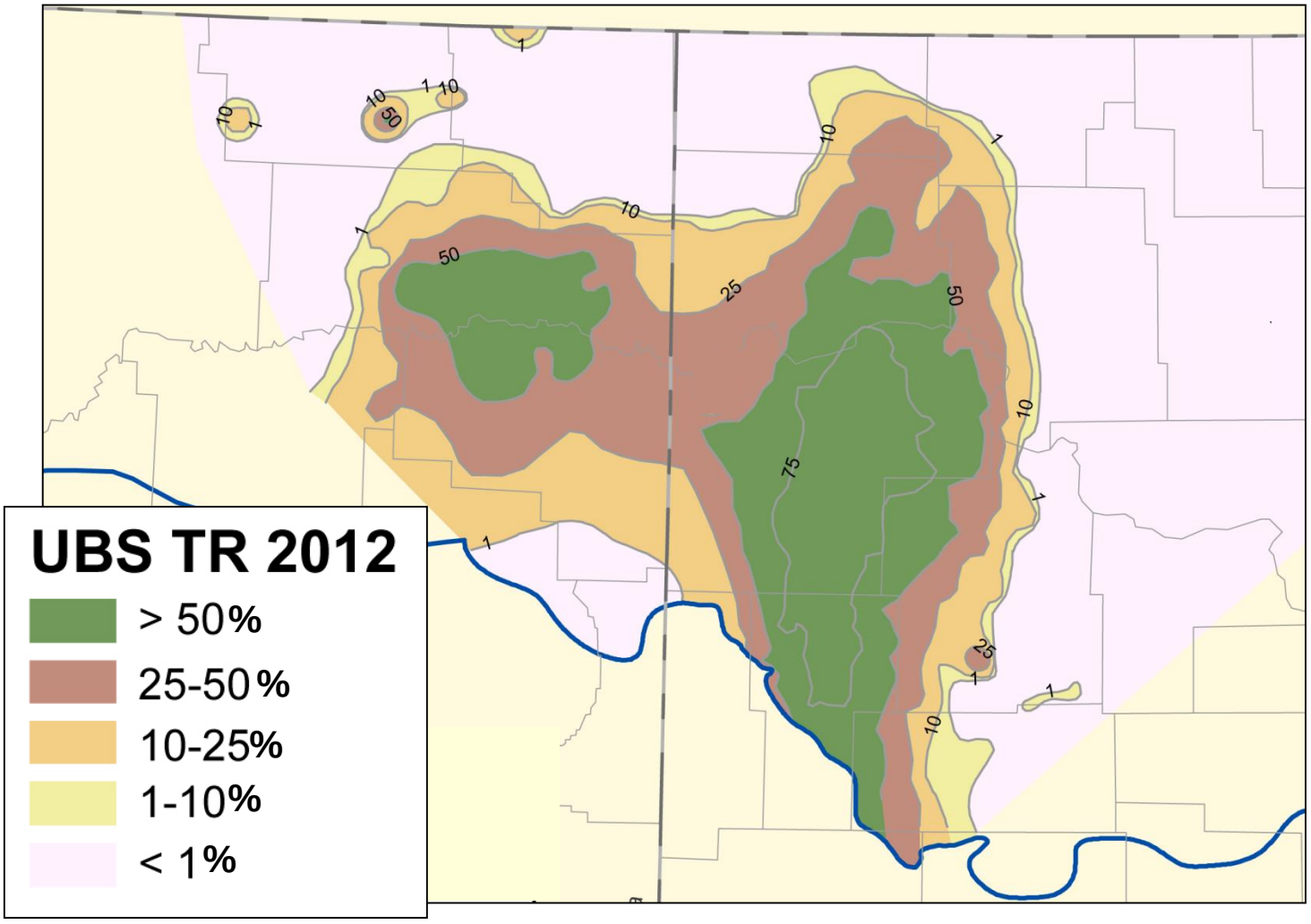


Atomic H/[H+C] is related to Oil Generation TR

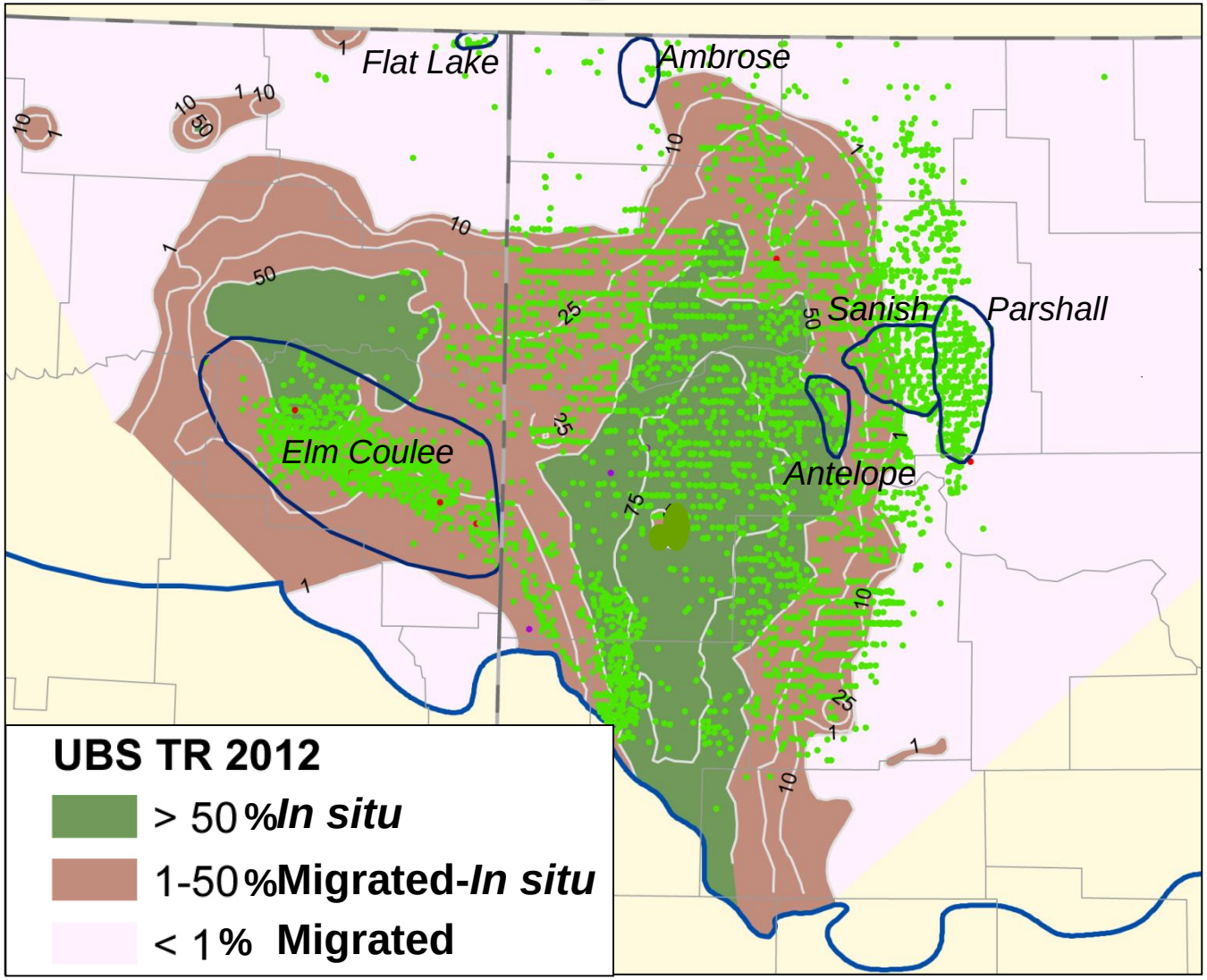



HI (mg S2/g TOC)
% Oil Generation (TR x 100)
600
400
200
0
20
40
60
80
100
Atomic H/[C+H] Fraction
0.60
0.55
0.50
0.45
0.40
0.35
0.30
Onset of
Oil Generation
Upper Bakken
H/[H+C] = 3.454x10-4(HI) + 0.3677
r2 = 0.984
H/[H+C] = -0.2521745(TR)3 + 0.445961(TR)2
- 0.3791571(TR) +0.5425919
Woodford (Type-II)
Phosphoria (Type-IIS)
New Albany (Type-II)
0%
10%
25%
50%
75%
410
300
190
100
600
500
400
300
200
100
HI (mg/g TOC)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Transformation Ratio (TR)

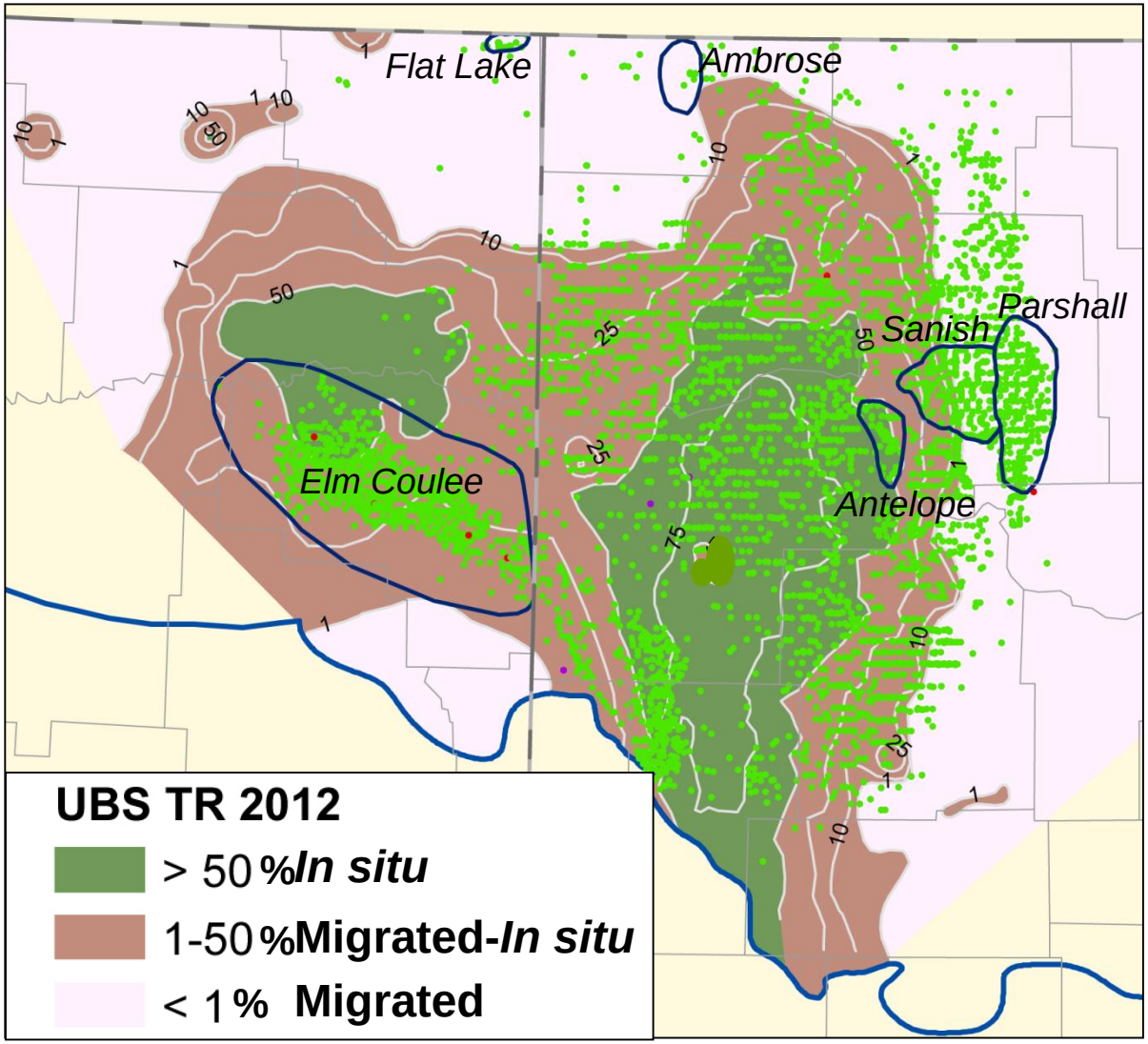
Upper Bakken Oil Transformation Ratio (TR)



Bakken Oil Migrated vs. *In situ*

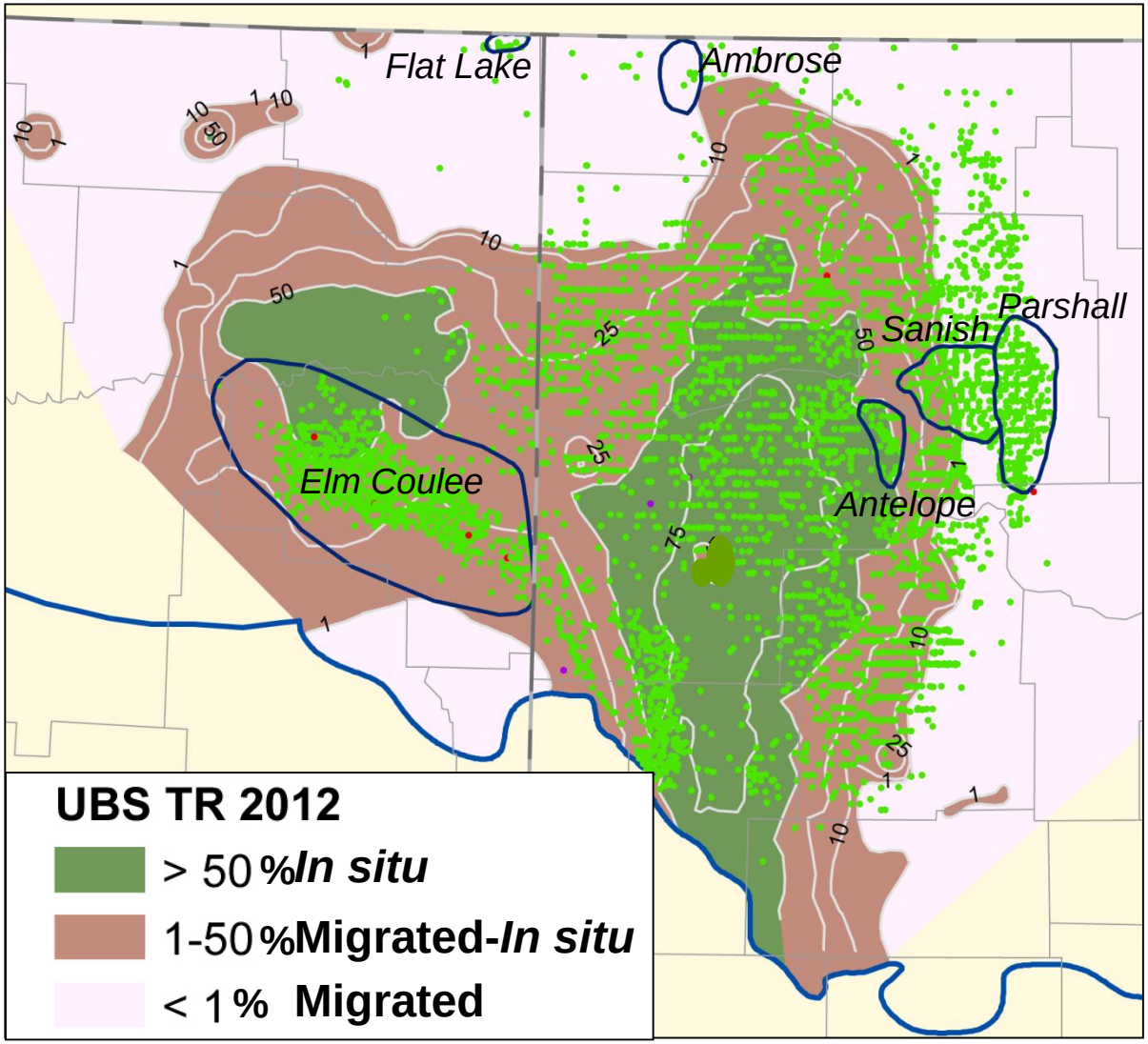


Take Home Points



1. HI of 450 is Onset of oil generation.
2. Calibration with HP gives TR map.
3. Fields (migrated versus *in situ*).
4. Bakken is still generating oil.

Ongoing Research



1. Calibration of 1-D & 3-D models w/TR.
2. Preferred migration pathways in basin.
3. Realistic oil charge for the Bakken