Sequence Stratigraphy as Expressed by Shale Source Rock and Reservoir Characteristics – Examples from the Devonian Succession, Appalachian Basin*

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Abstract

Most shale gas reservoir properties reflect a history of base-level fluctuations that can be cast in terms of a predictive sequence stratigraphic famework. Our approach to the sequence stratigraphy of the Devonian gas shale succession of the Appalachian Basin is grounded in the transgressive-regressive (T-R) sequence concept. A single T-R sequence comprises transgressive systems tract (TST) deposits overlain by a regressive systems tract (RST) succession, the contact being a maximum flooding surface (MFS); the sequence is bounded on top and bottom by maximum regressive surfaces (MRS) or equivalent ravinement surface. Early results of a multi-faceted investigation of the Devonian shale succession of the Appalachian Basin reveal that such parameters as mineralogy, microfabric, TOC, and source rock quality vary predictably within the T-R sequence stratigraphic framework. A general increase in silica, much of it diagenetic, and reduction of clay upward through the TST reflects the rapid landward migration of the shoreline. Further, spectral gamma-ray analysis reveals generally increasing levels of authigenic uranium through the TST. TST deposits are commonly pyritiferous and organic-rich, both parameters attaining maximum values close to the MFS. Increasing thermal maturity of these deposits is accompanied by increasing porosity, principally nanoporosity. Bacterial reworking of transgressive organic -rich sediment, especially proximal to maximum base level, appears to have resulted in some degree of vitrinite suppression. Accumulation of RST deposits is recorded by increasing clay and detrital quartz and concomitant dilution of the organic flux. The result is higher bound water contents and a pervasive planar clay-grain microfabric disrupted only by occasional discrete detrital quartz lamina or isolated grains. Base-level minimum is defined by minimal TOC and local carbonate horizons. The predictive capabilities inherent to sequence stratigraphy make it especially applicable to exploration programs of seemingly homogenous shale successions.

References

Blauch, M., N. Houston, M. Seyman, and R. Reese, 2009, Technique reuses frac water in shale: American Oil and Gas Reporter, v. 52/9, p. 103-107.

Embry, A., E. Johannessen, D. Owen, B. Beauchamp, and P. Gianolla, 2007, Sequence stratigraphy as a "concrete" discipline: Report of the ISSC task group on sequence stratigraphy, 104 p. Web accessed 12 July 2011.

Slatt, R.M., and N.R. O'Brien, 2011, PoreTypes in the Barnett and Woodford Gas Shales: Contribution to Understanding Gas Storage and Migration Pathways in Fine-Grained Rocks: Search and Discovery Article #80166, Web accessed 13 July 2011, http://www.searchanddiscovery.com/documents/2011/80166slatt/ndx_slatt.pdf

Wedepohl, K.H., 1971, Environmental influences on the chemical composition of shales and clays *in* L.H. Ahrens, F. Press, S.K. Runcorn, and H.C. Urey, (eds.) Physics and Chemistry of the Earth: Pergamon Press, p. 307-333.

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…sedimentologic/stratigraphic attributes related to base level fluctuations and manifested by systems tract variations include a variety of parameters critical to source rock and reservoir properties…

…organic carbon content …

…mineralogy …

…grain size …

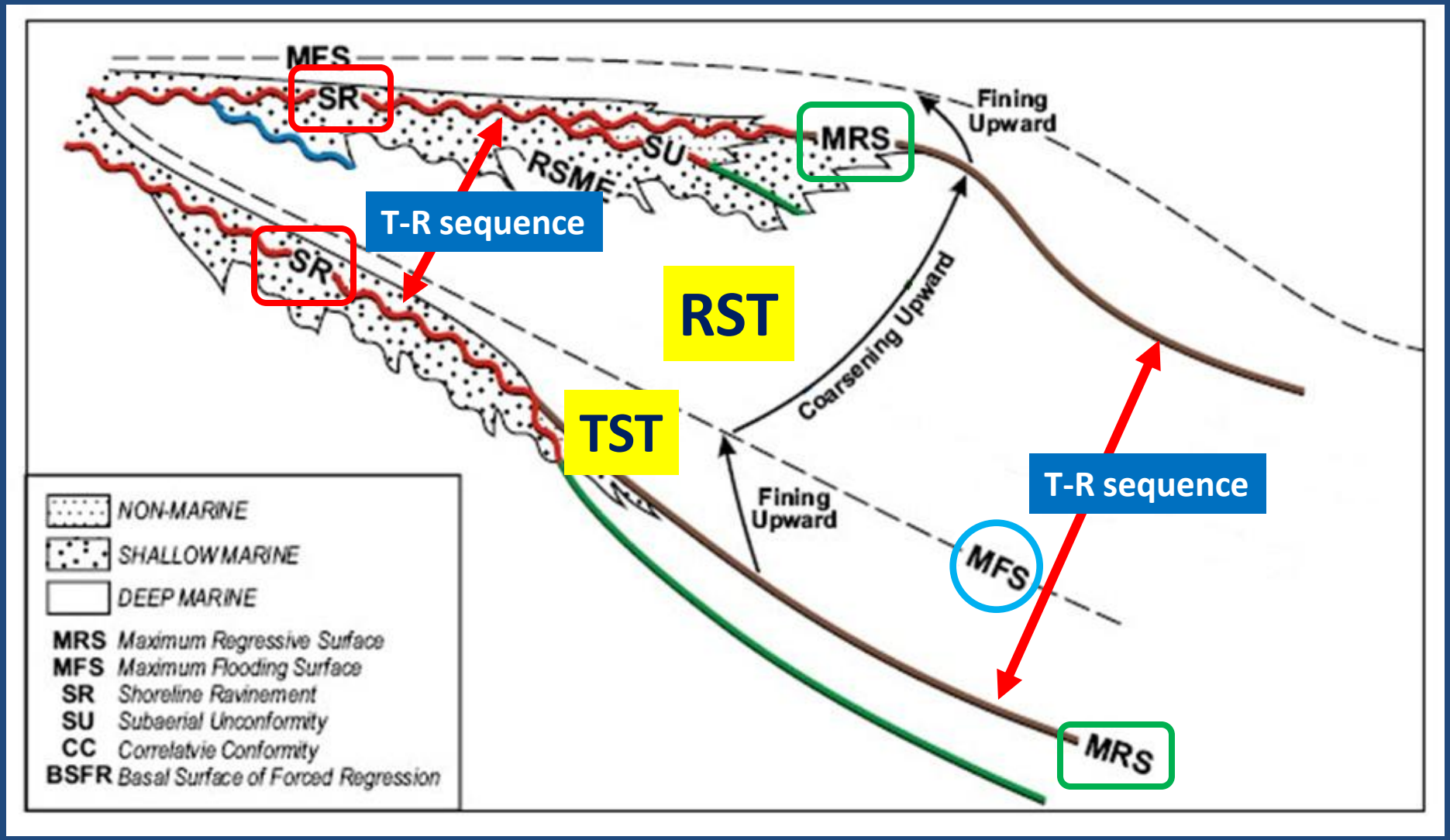
…microfabric…

…bedform geometry…

…diagenetic components…

…porosity, permeability, brittleness…

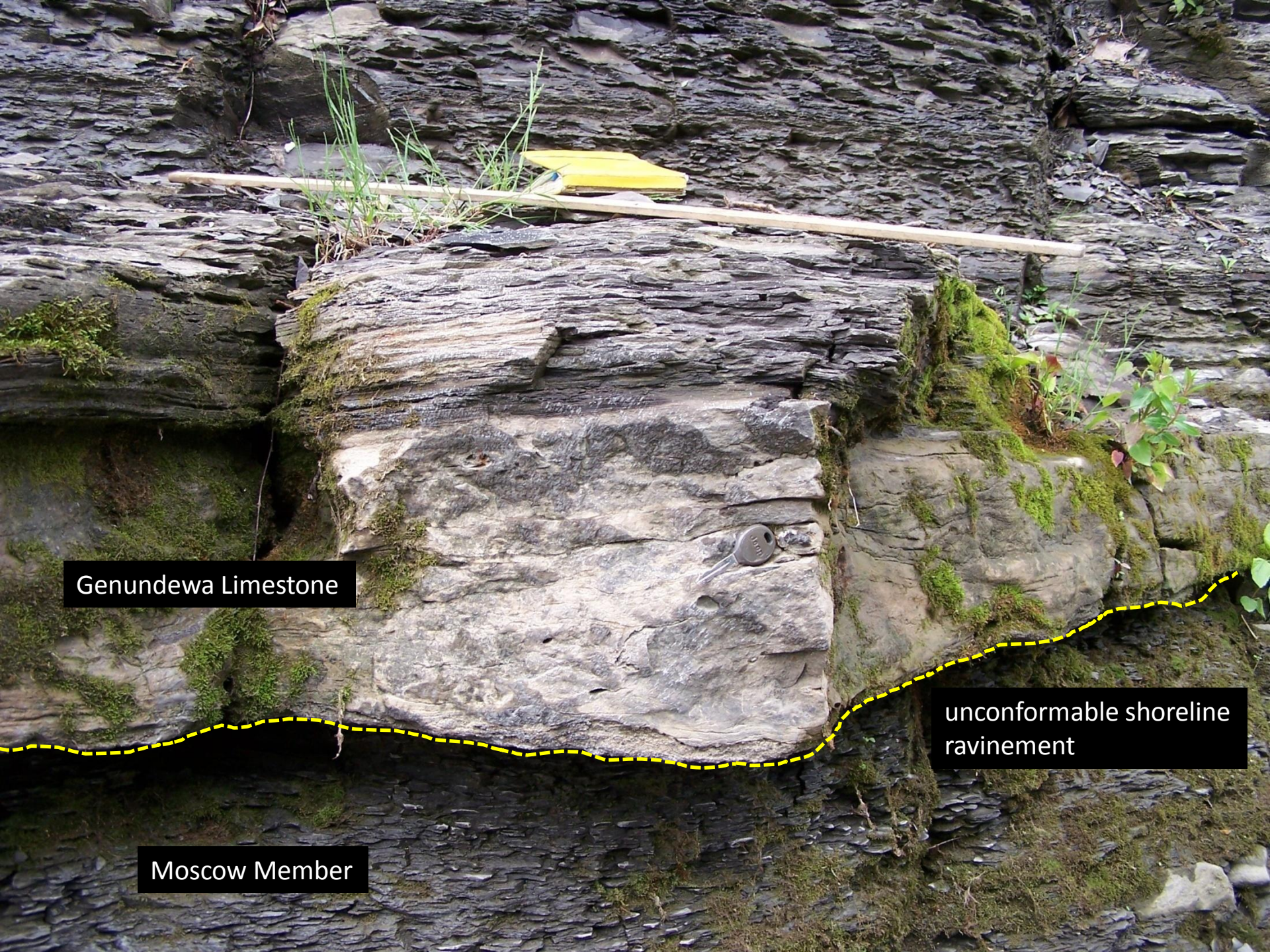
… transgressive-regressive sequence …

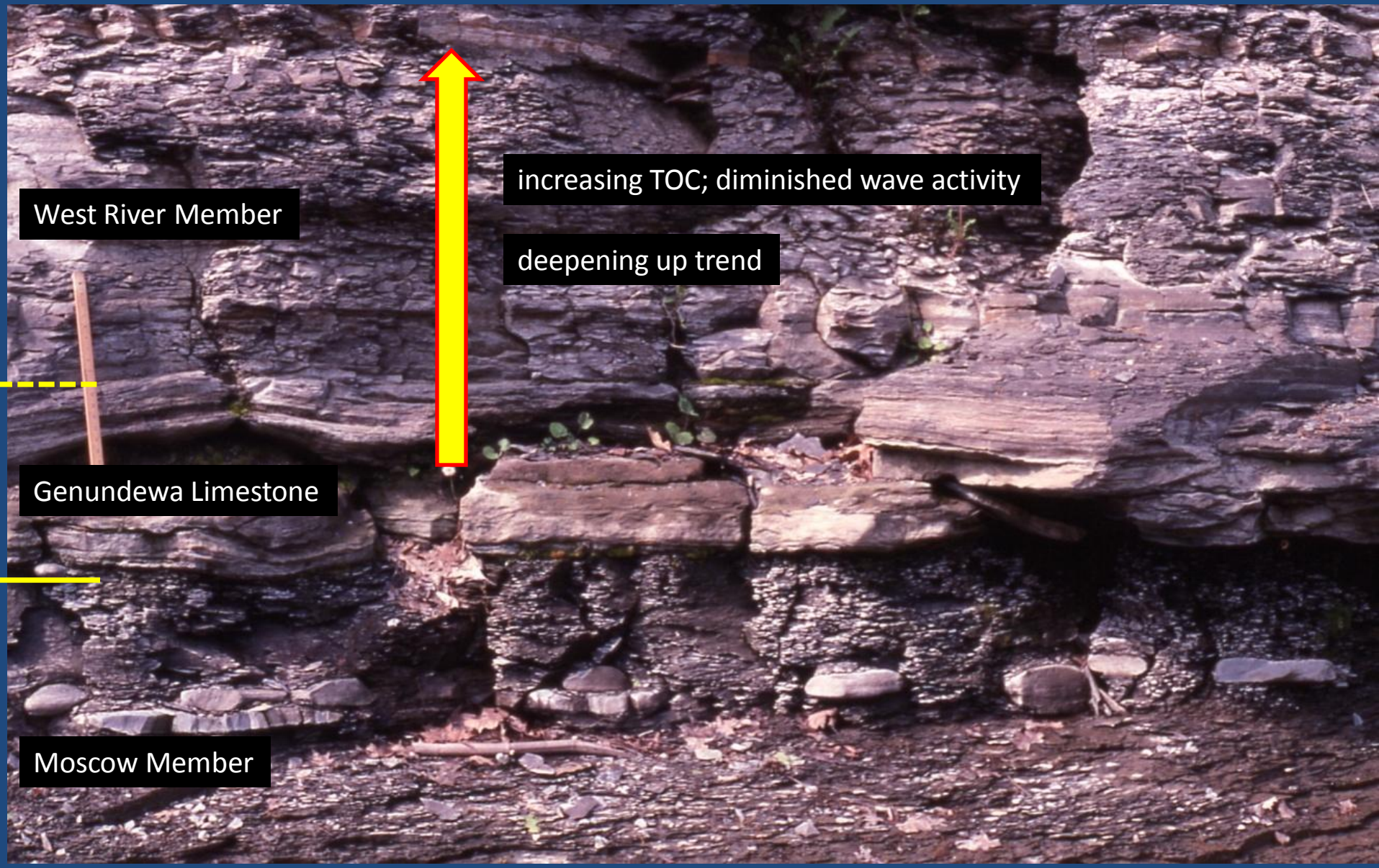


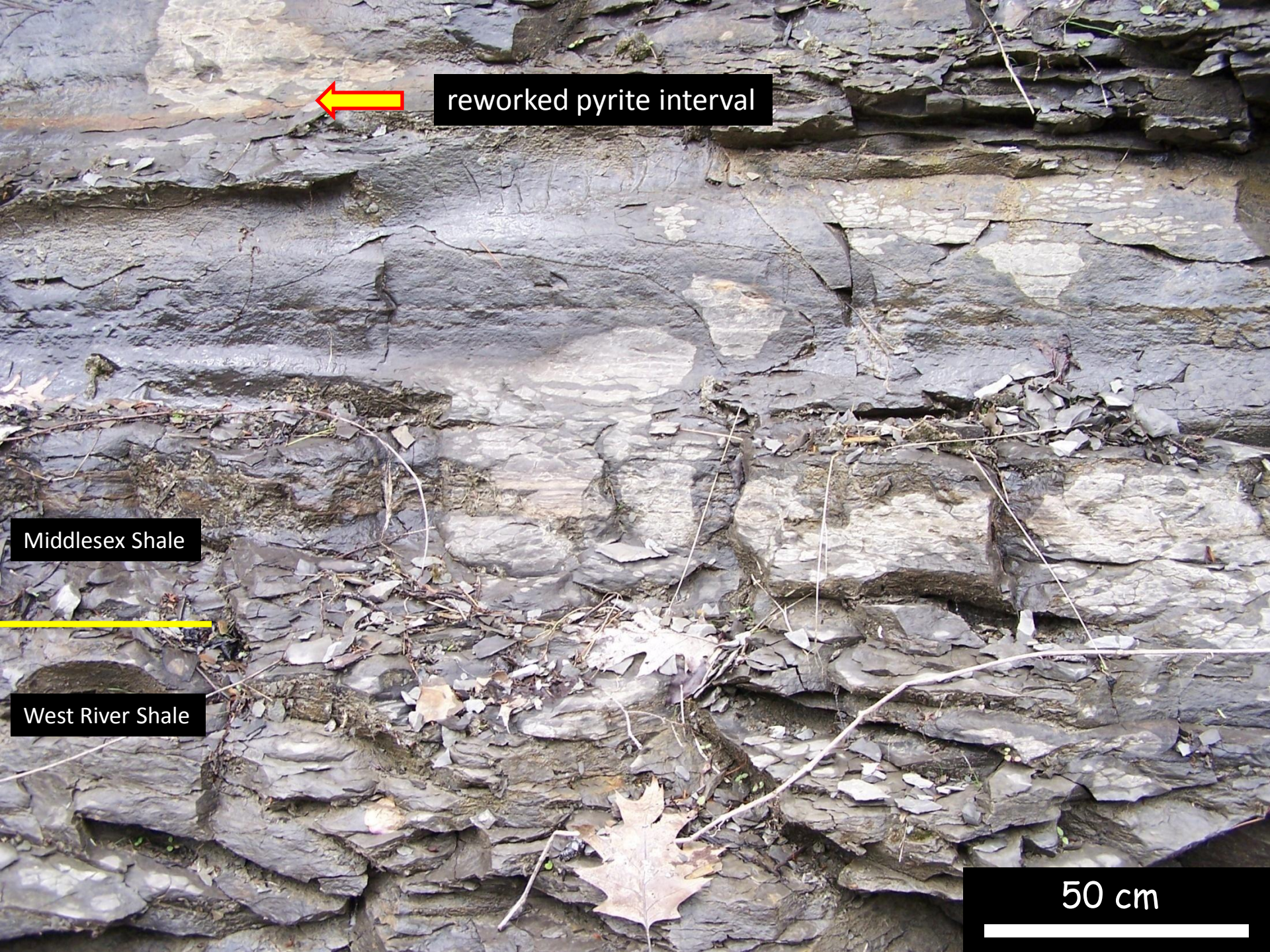
modified after Embry et al., 2007

T-R sequence … outcrop example

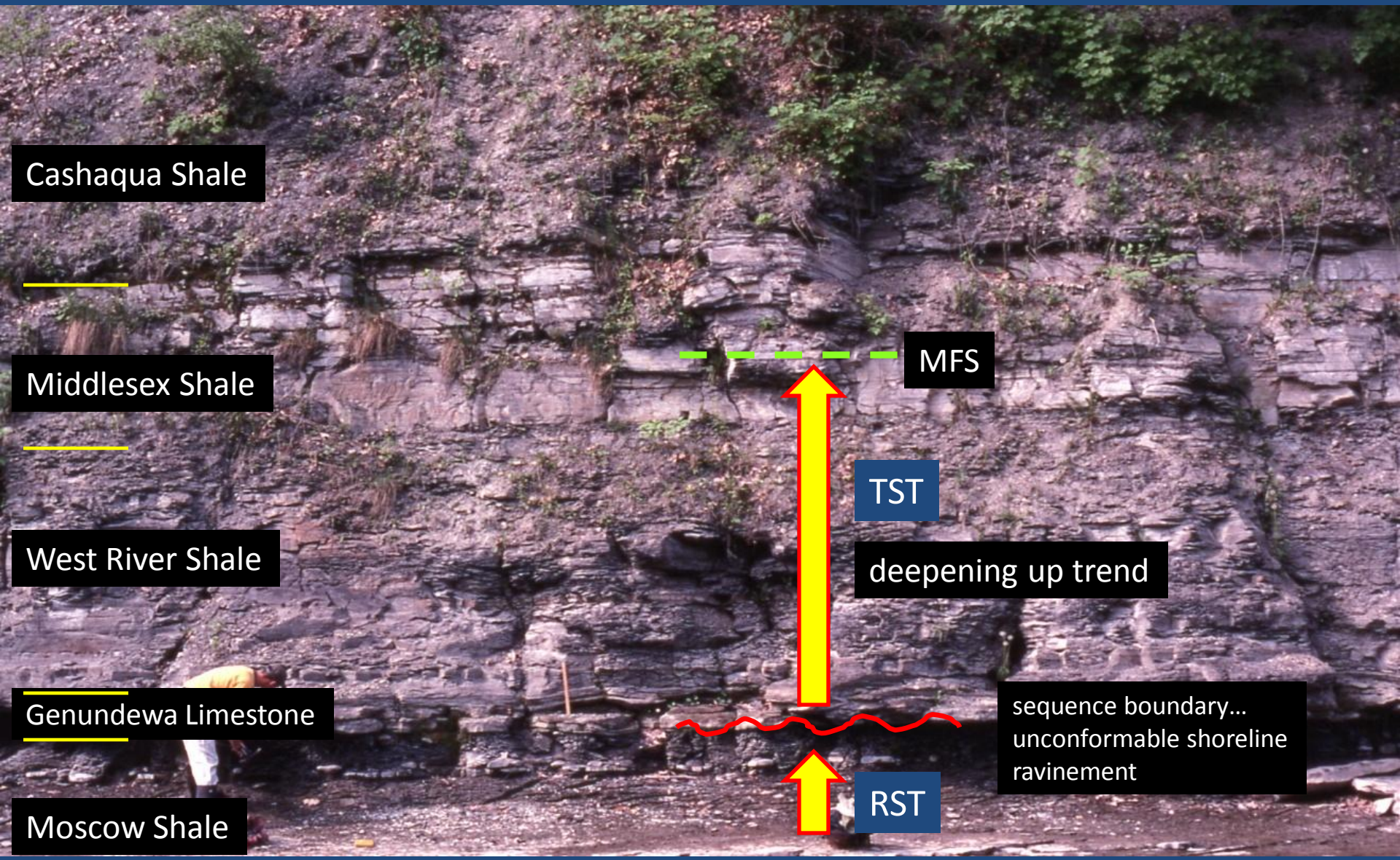
wave-worked arenaceous limestone unconformably overlying marine mudstone (Moscow Member) …

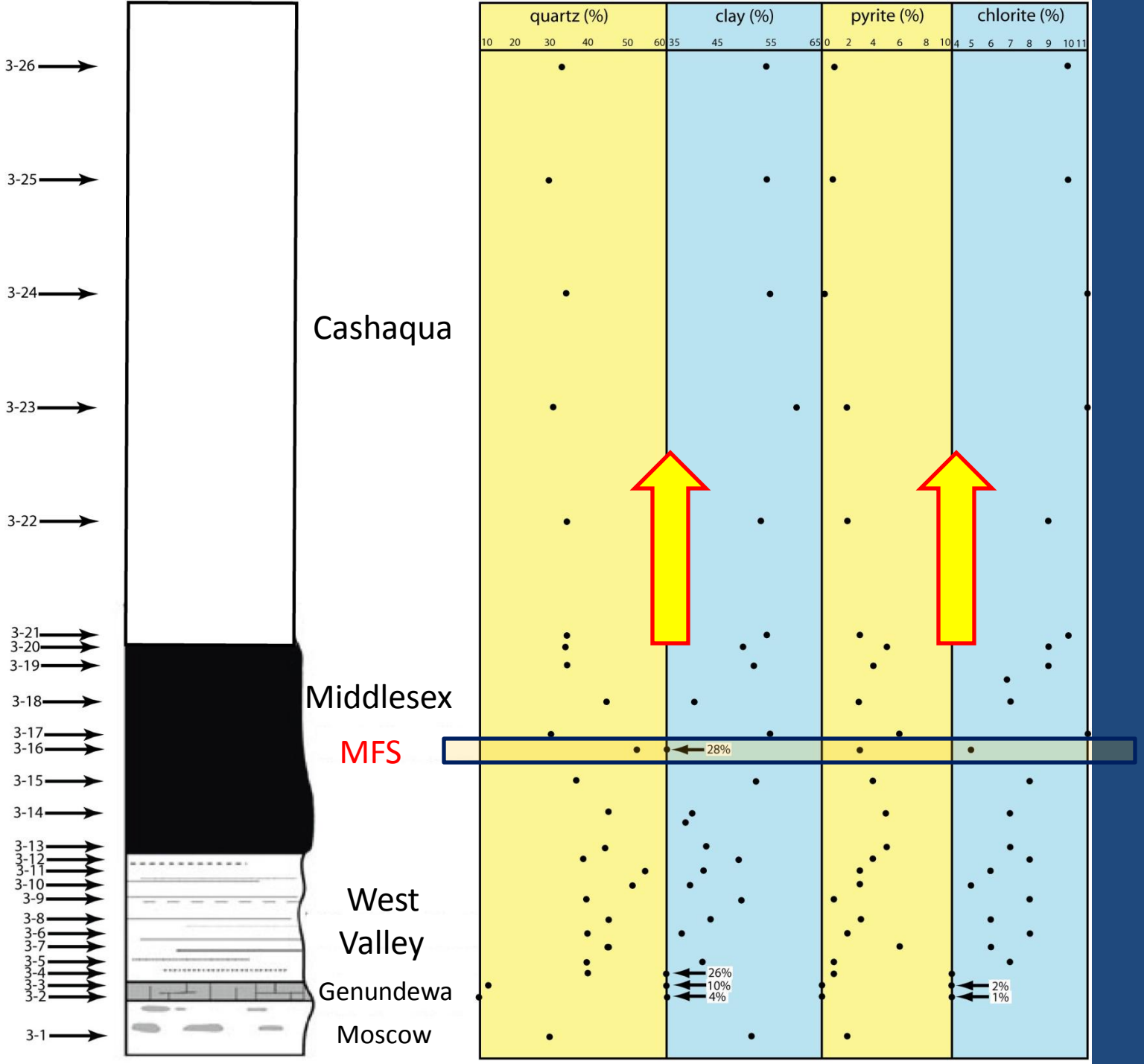

Genundewa Limestone
unconformable shoreline ravinement
Moscow Member

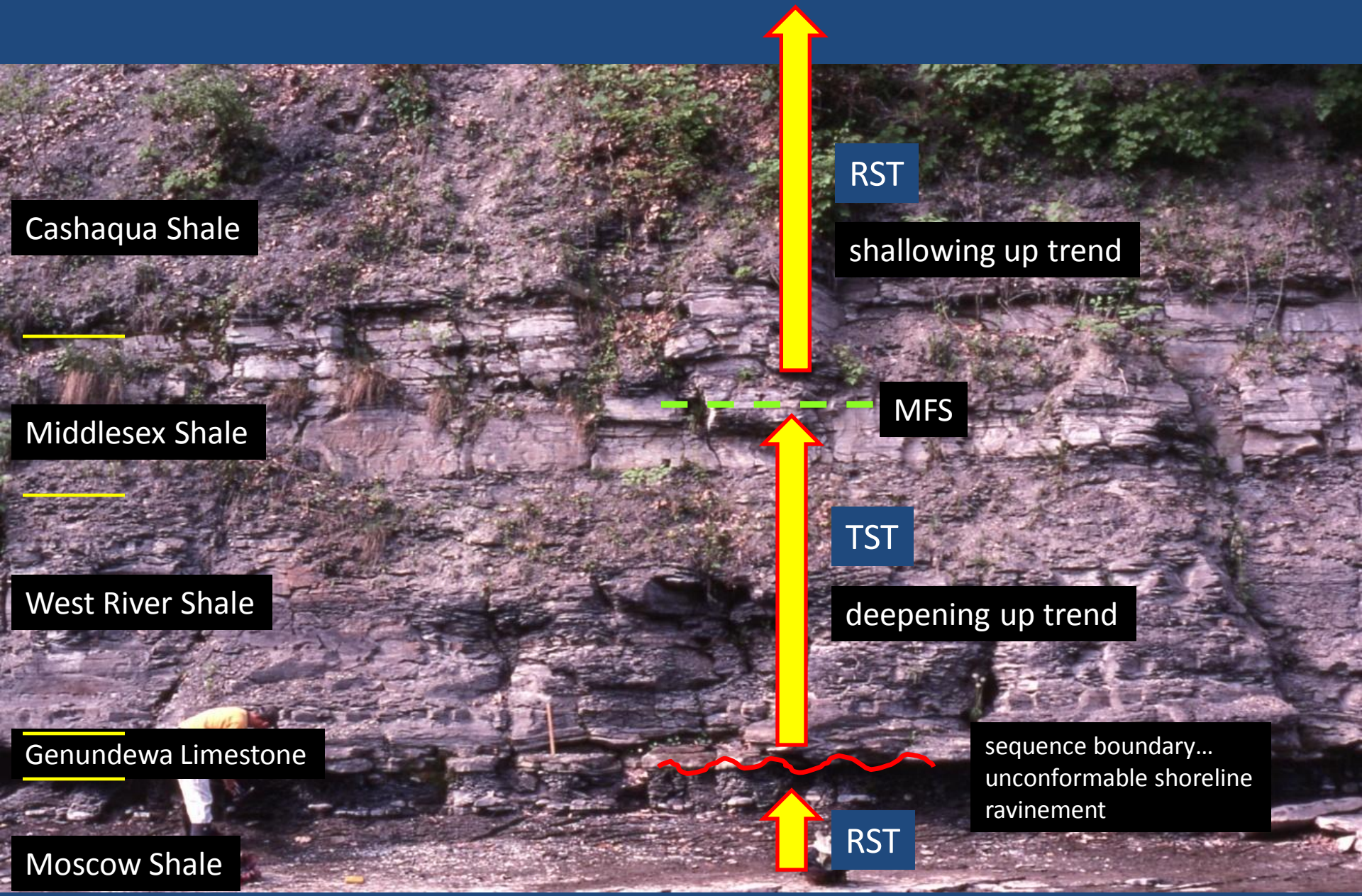

increasing TOC; diminished wave activity
West River Member
deepening up trend
Genundewa Limestone
Moscow Member

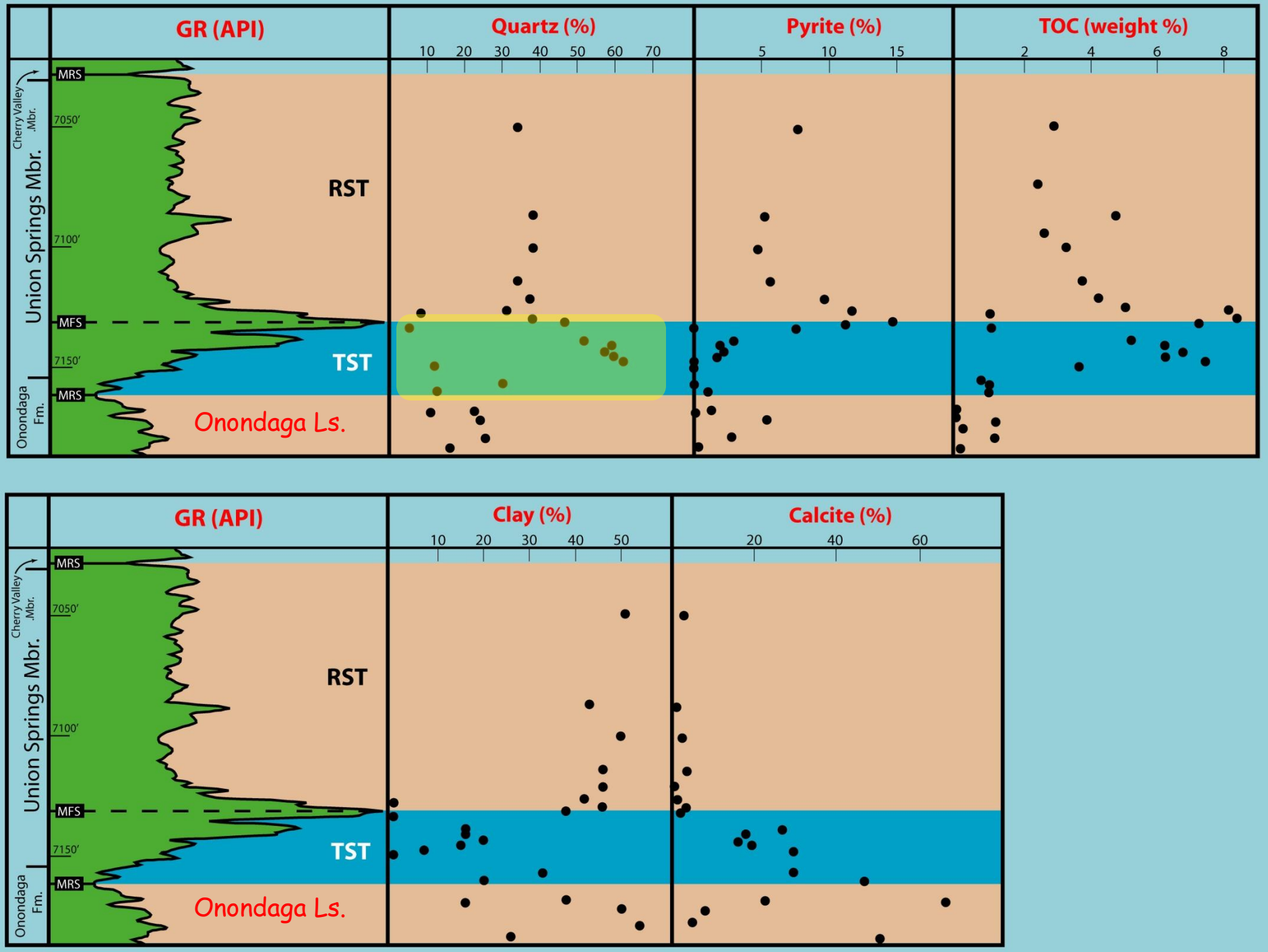

reworked pyrite interval
Middlesex Shale
West River Shale
50 cm

reworked pyrite interval

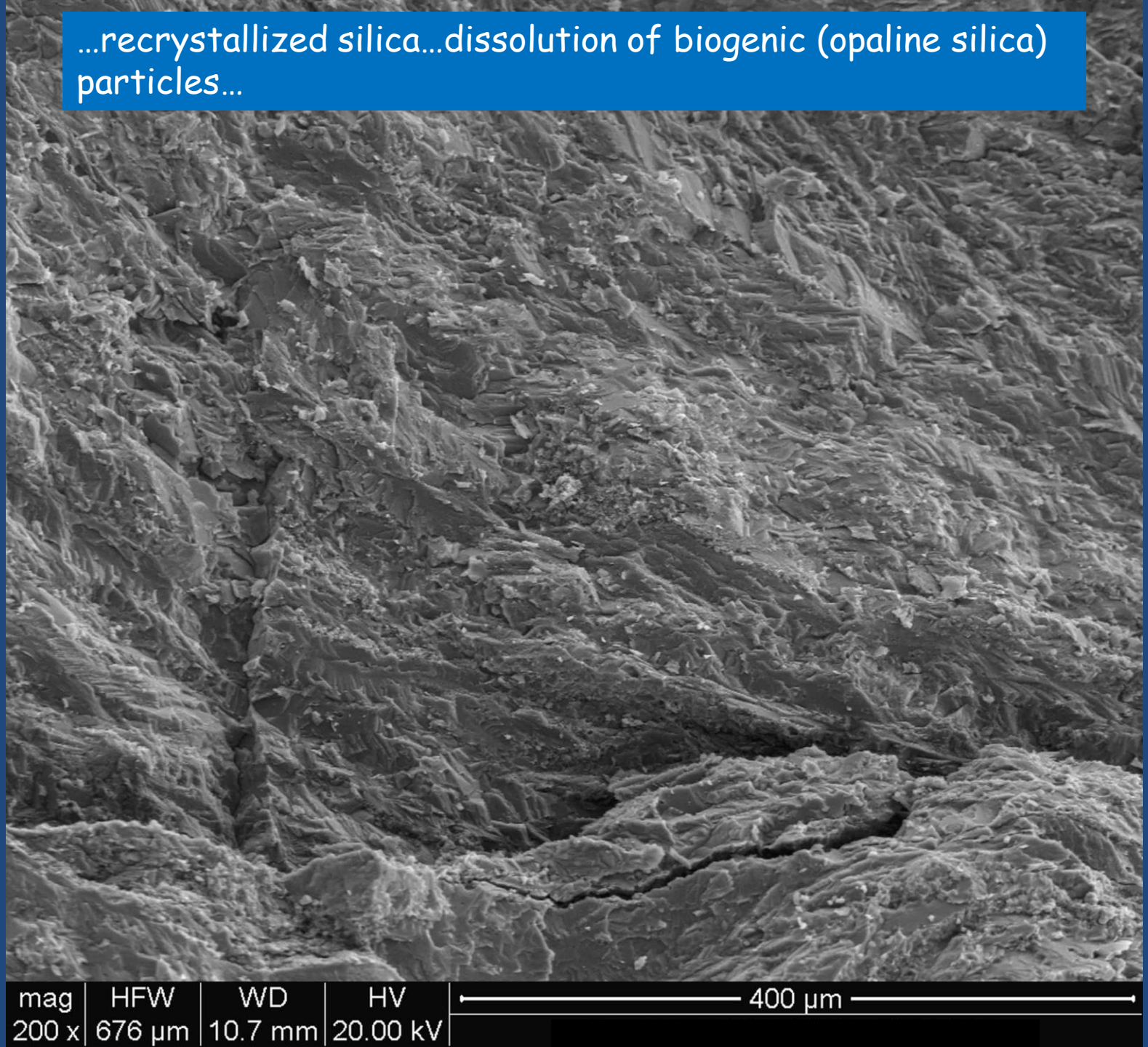

Cashaqua Shale
Middlesex Shale
West River Shale
Genundewa Limestone
Moscow Shale
MFS
TST
deepening up trend
sequence boundary…
unconformable shoreline
ravinement
RST

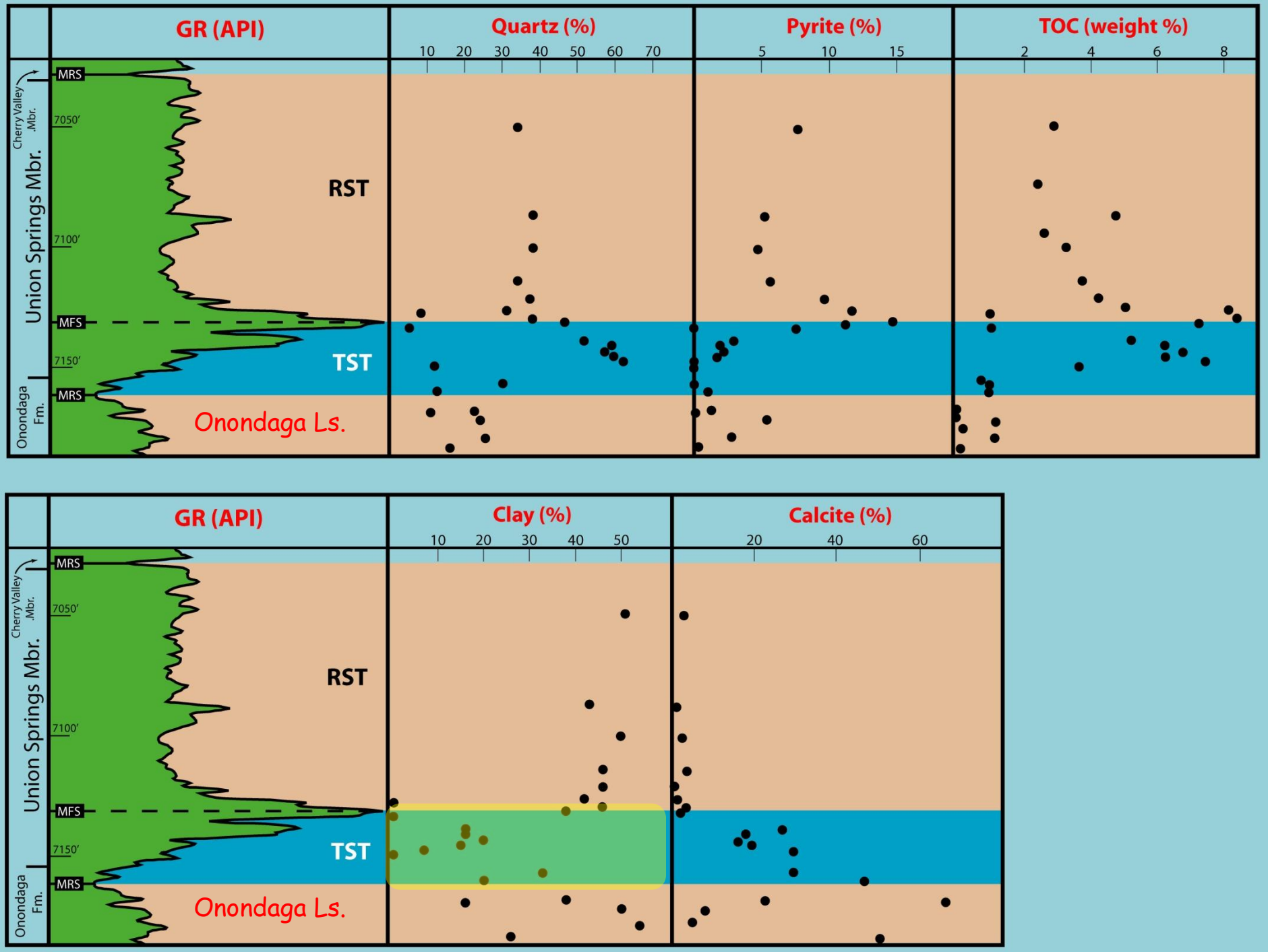

quartz (%)
clay (%)
pyrite (%)
chlorite (%)
10 20 30 40 50 60
35 45 55 65
0 2 4 6 8 10
4 5 6 7 8 9 10 11
3-26
3-25
3-24
3-23
3-22
3-21
3-20
3-19
3-18
3-17
3-16
3-15
3-14
3-13
3-12
3-11
3-10
3-9
3-8
3-6
3-7
3-5
3-4
3-3
3-2
3-1
Cashaqua
Middlesex
MFS
West Valley
Genundewa
Moscow
28%
26%
10%
4%
2%
1%


Cashaqua Shale
Middlesex Shale
West River Shale
Genundewa Limestone
Moscow Shale
RST
shallowing up trend
MFS
TST
deepening up trend
sequence boundary…
unconformable shoreline
ravinement
RST


GR (API)
Quartz (%)
10 20 30 40 50 60 70
Pyrite (%)
5 10 15
TOC (weight %)
2 4 6 8
Cherry Valley Mbr.
Union Springs Mbr.
Onondaga Fm.
MRS
7050′
7100′
MFS
7150′
MRS
RST
TST
Onondaga Ls.
GR (API)
Clay (%)
10 20 30 40 50
Calcite (%)
20 40 60
Cherry Valley Mbr.
Union Springs Mbr.
Onondaga Fm.
MRS
7050′
7100′
MFS
7150′
MRS
RST
TST
Onondaga Ls.

…recrystallized silica…dissolution of biogenic (opaline silica) particles…

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TOC (weight %)
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7150′
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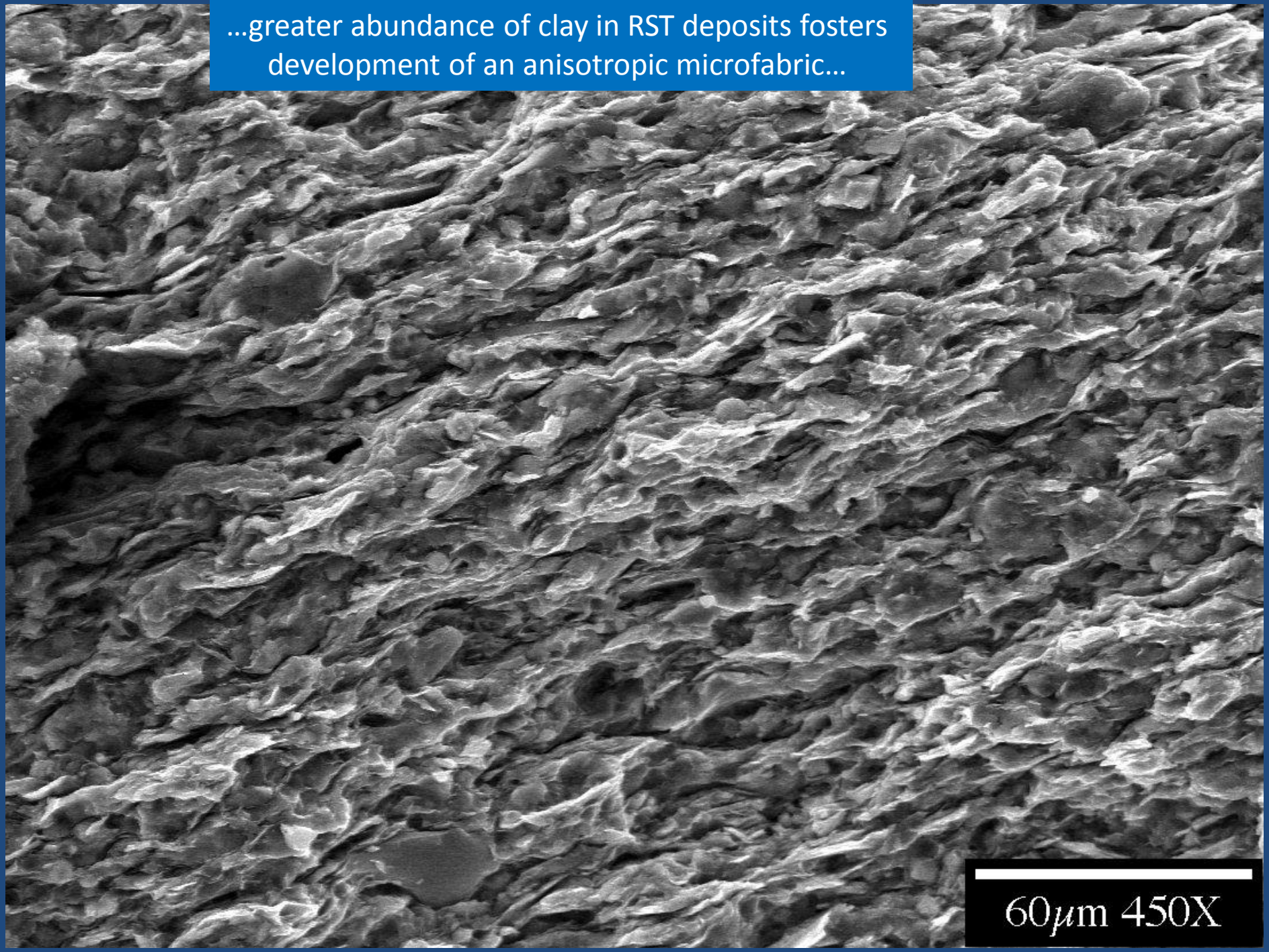
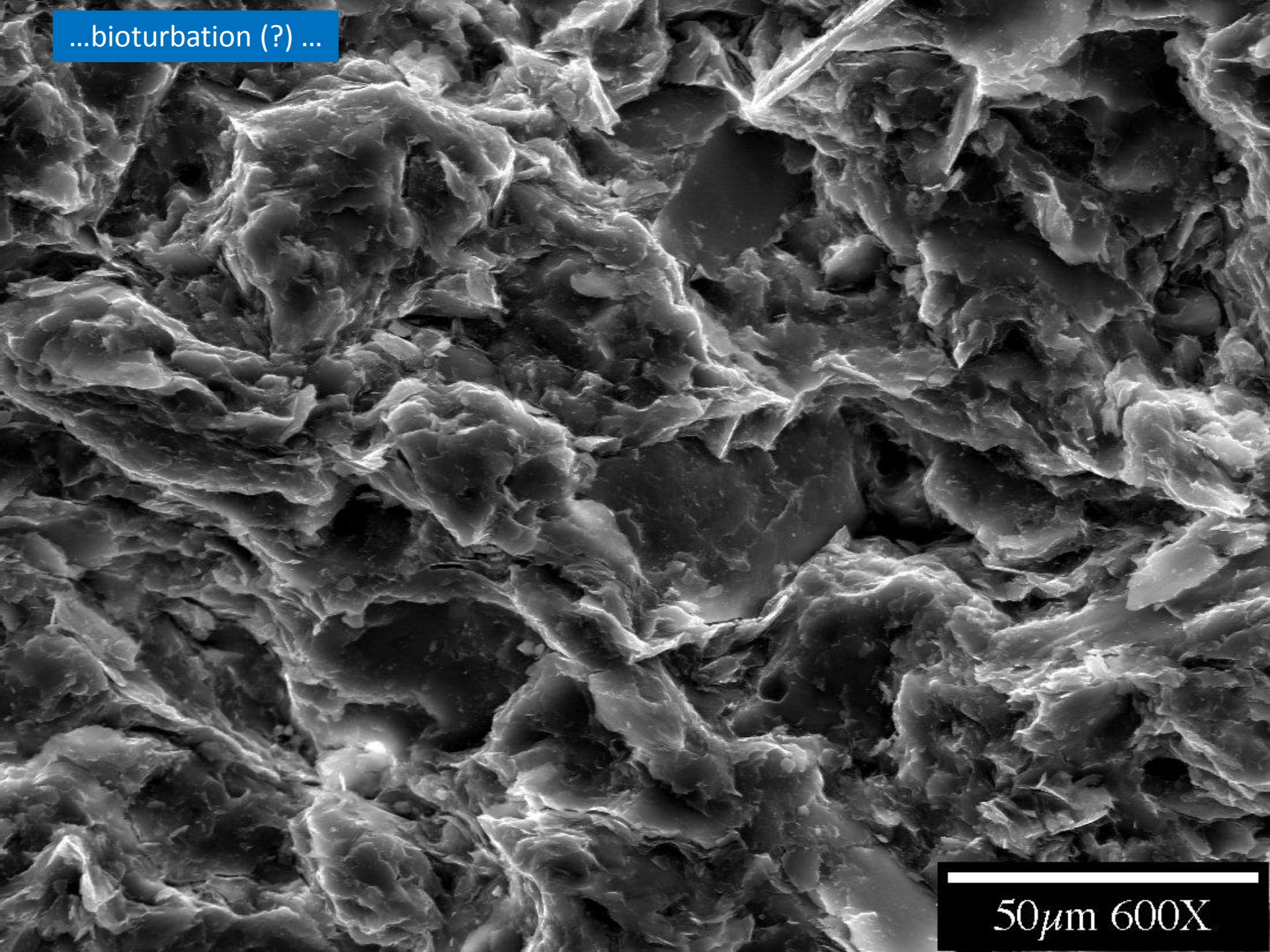
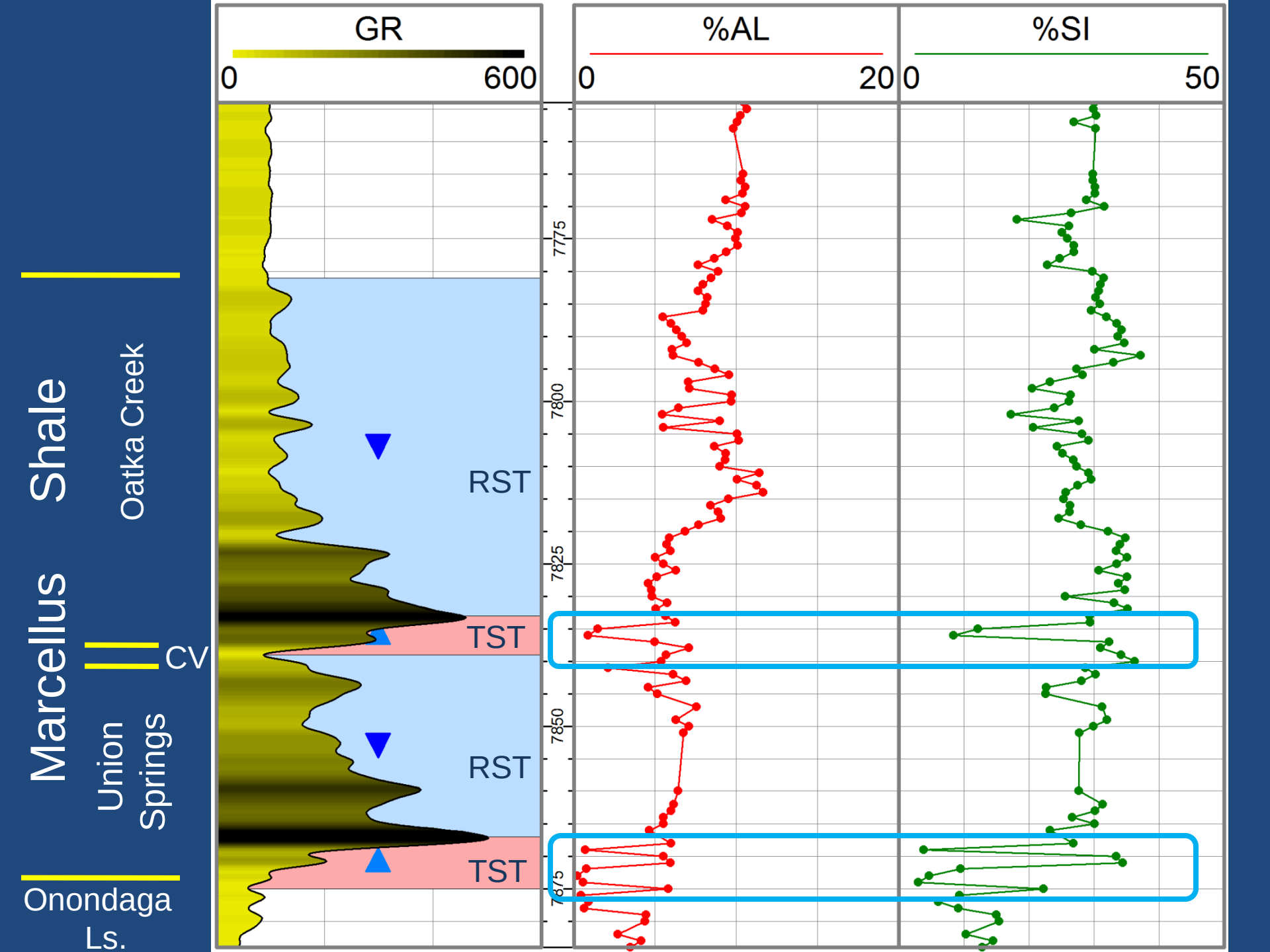
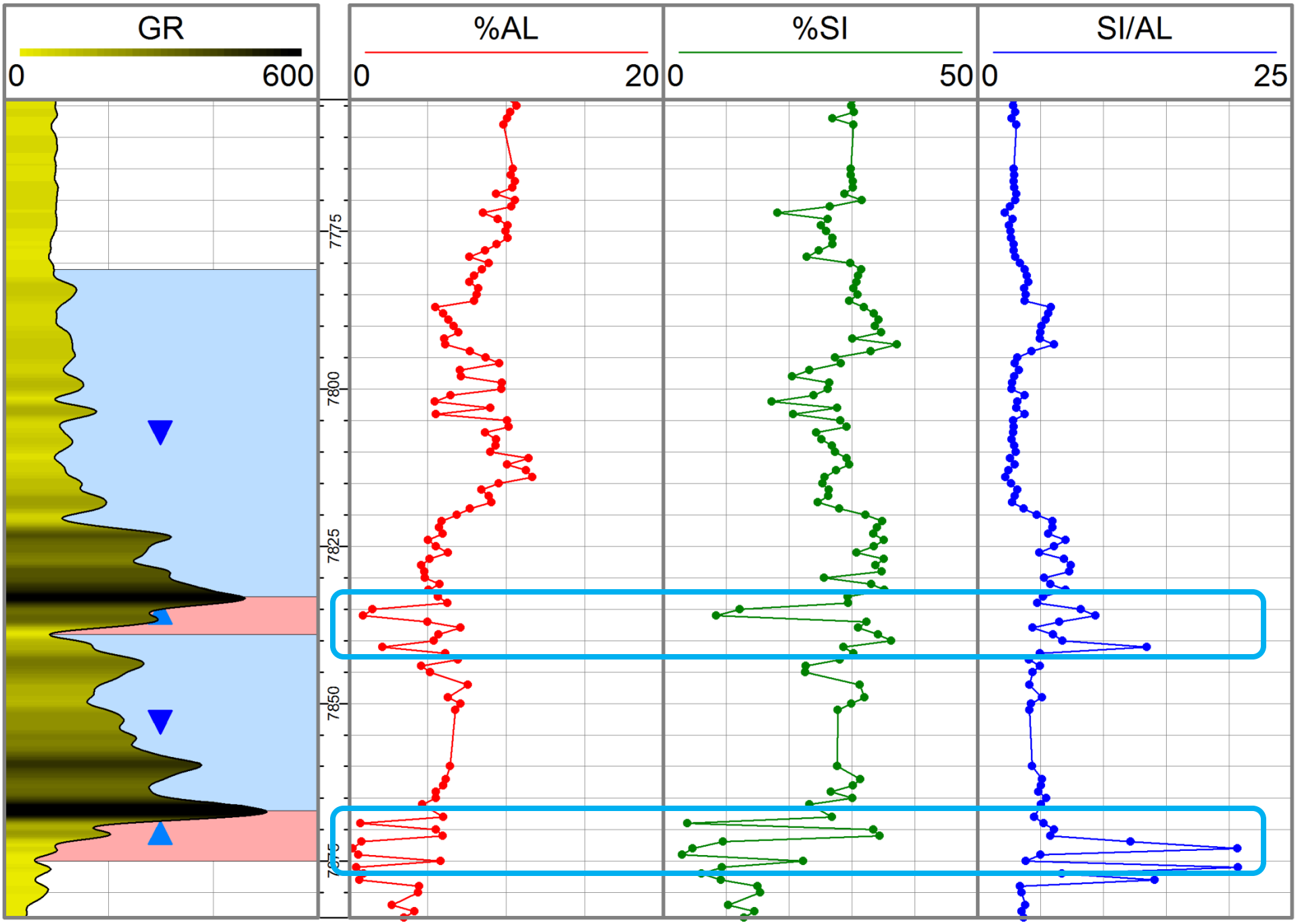
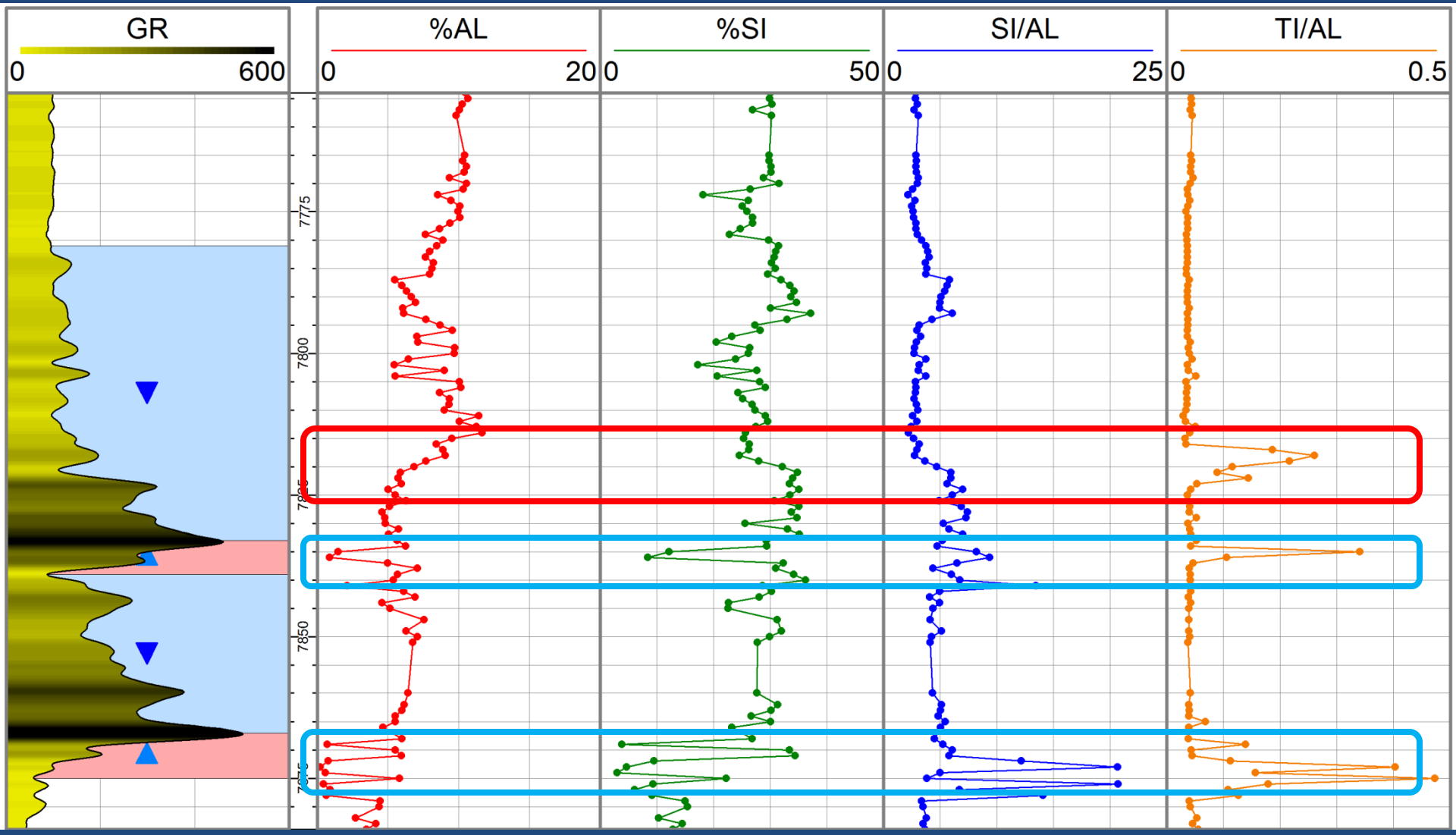
Onondaga Ls.


…greater abundance of clay in RST deposits fosters development of an anisotropic microfabric…
60μm 450X


…bioturbation (?) …
50μm 600X


Marcellus Shale
Oatka Creek
CV
Union Springs
Onondaga Ls.
GR
0
600
%AL
0
20
%SI
0
50
7775
7800
7825
7850
7875
RST
TST
RST
TST

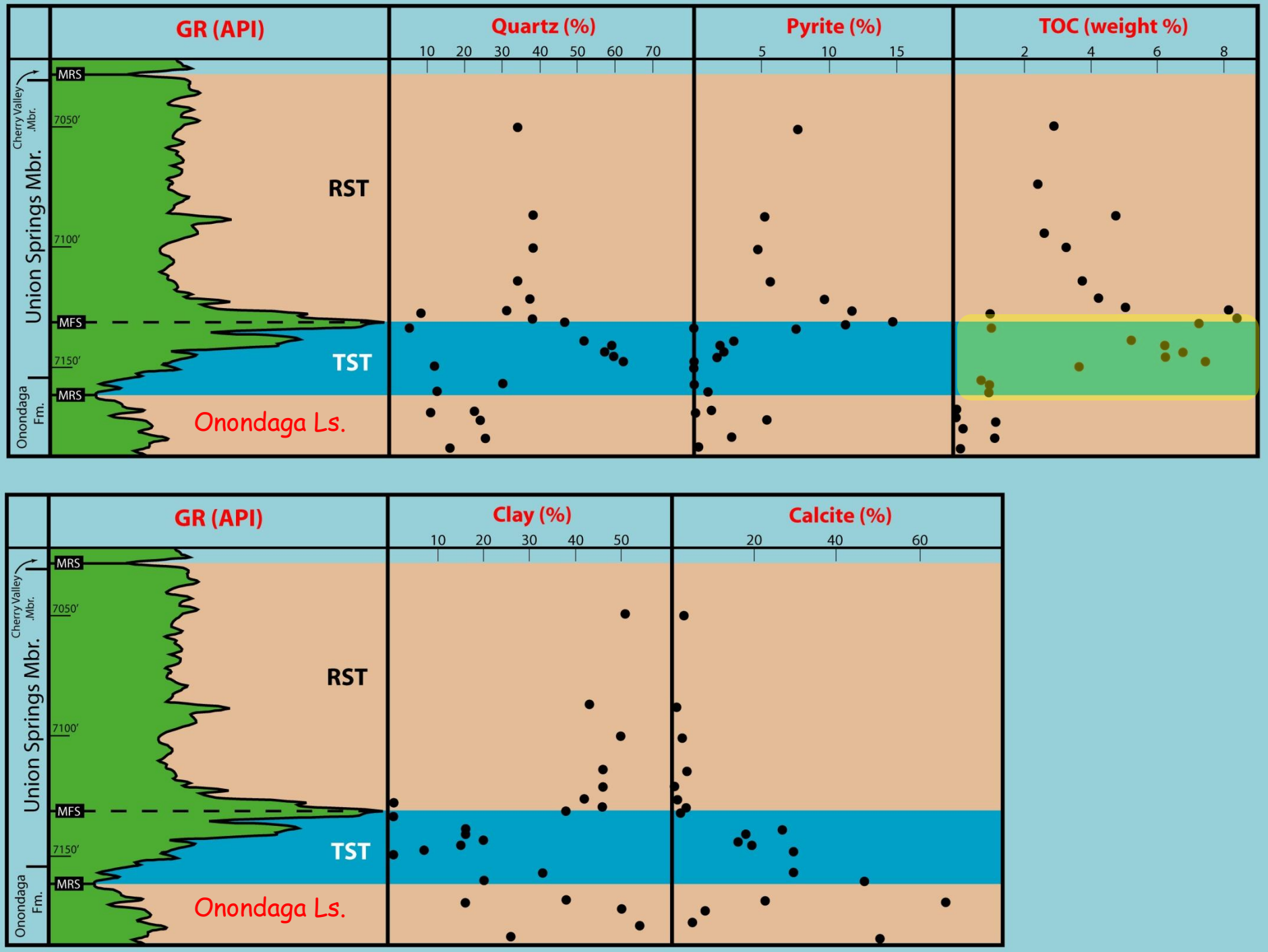

GR
0
600
%AL
0
20
%SI
0
50
SI/AL
0
25
7775
7800
7825
7850


GR
0
600
%AL
0
20
%SI
0
50
SI/AL
0
25
TI/AL
0
0.5
7775
7800
7850

…TST… increasing base level and related landward shift of depositional environments leads to 1) reduced clastic flux (clay and detrital quartz) and 2) increased abundance (*concentration*) of bioclastic particles (Si) and eolian (Si, Ti) detritus…

…elevated (diagenetic) quartz and reduced clay

>>>> **enhanced brittleness**…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Pyrite (%)
5 10 15
TOC (weight %)
2 4 6 8
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Union Springs Mbr.
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MFS
7150′
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10 20 30 40 50
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20 40 60
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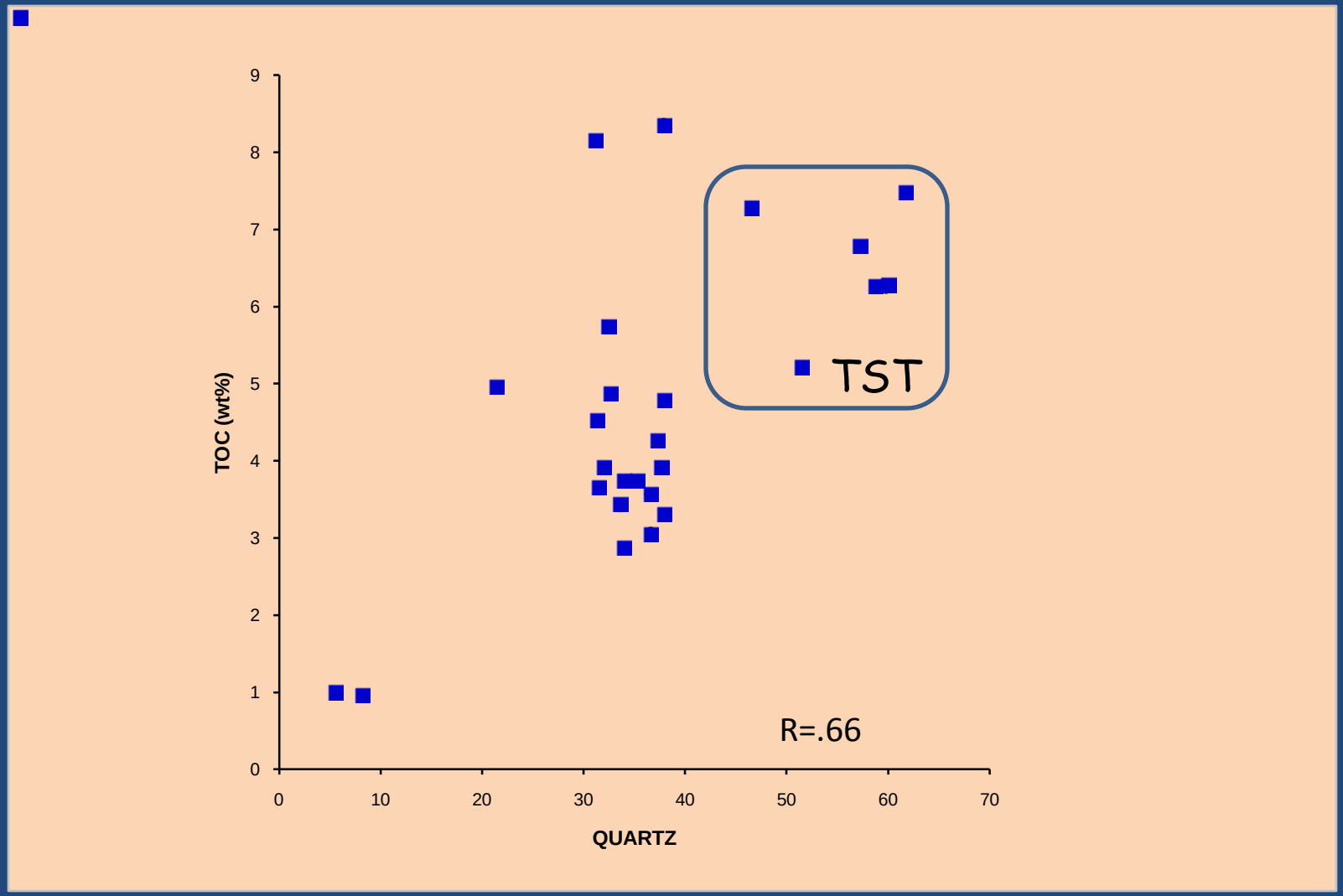
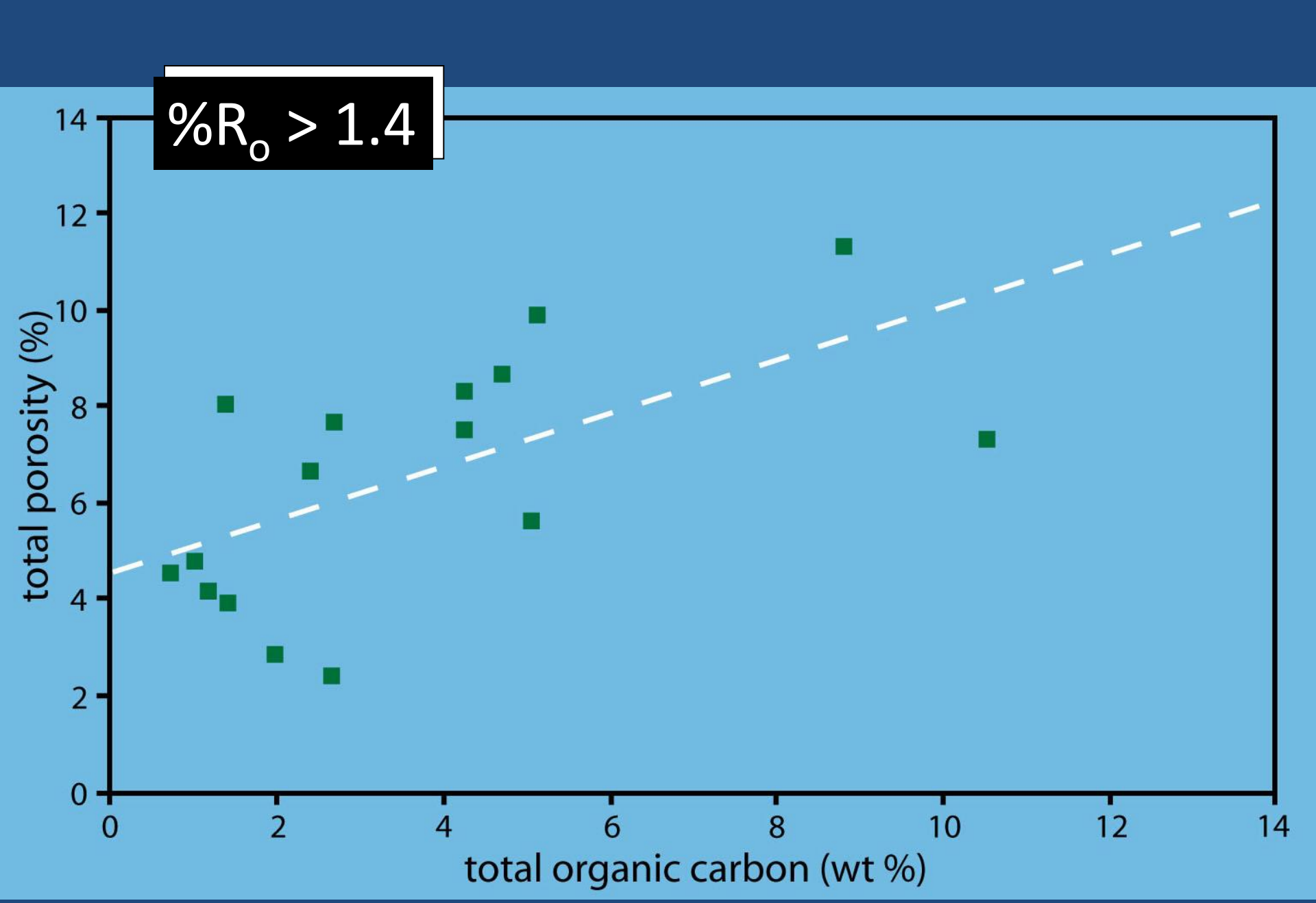
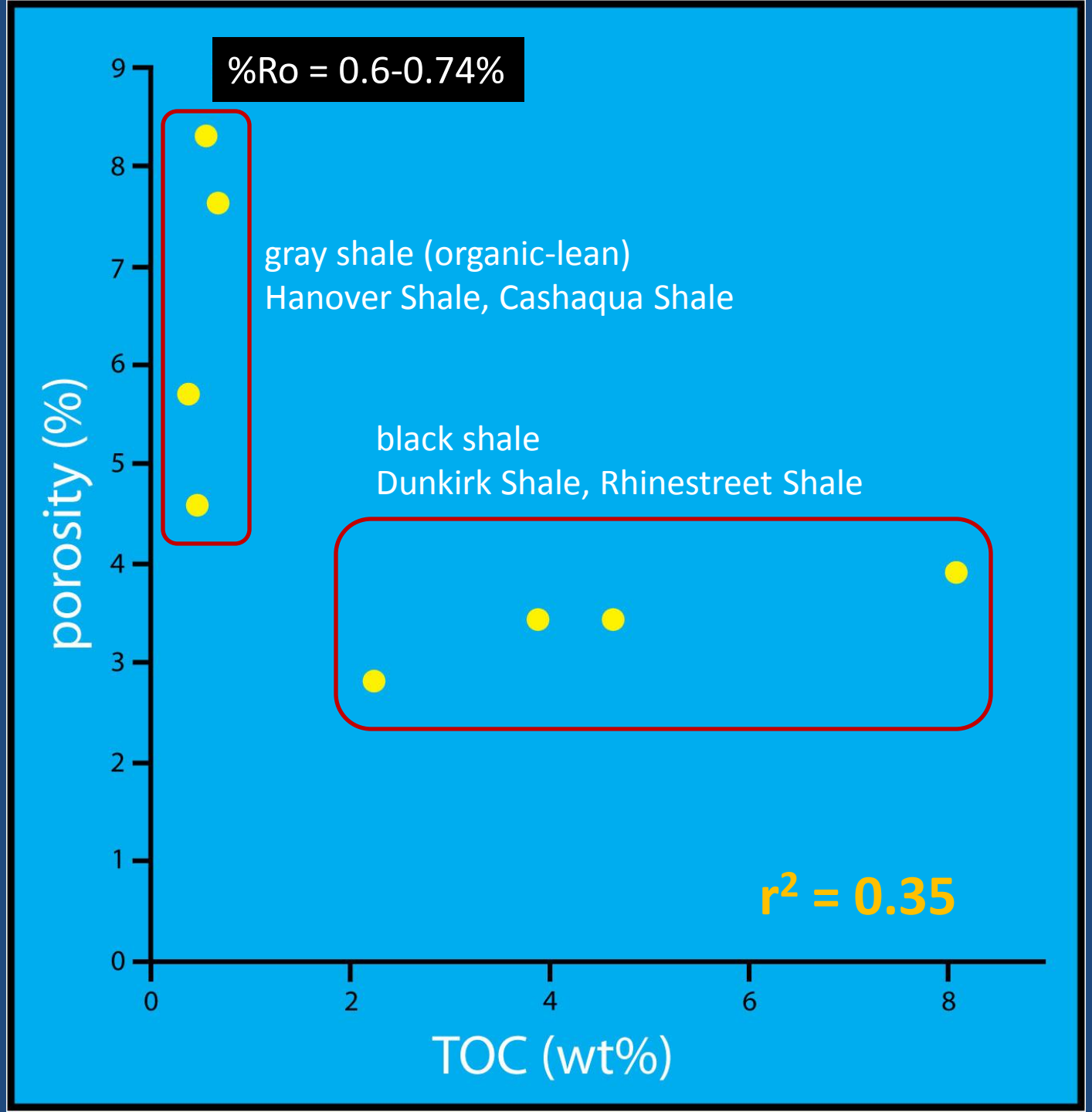
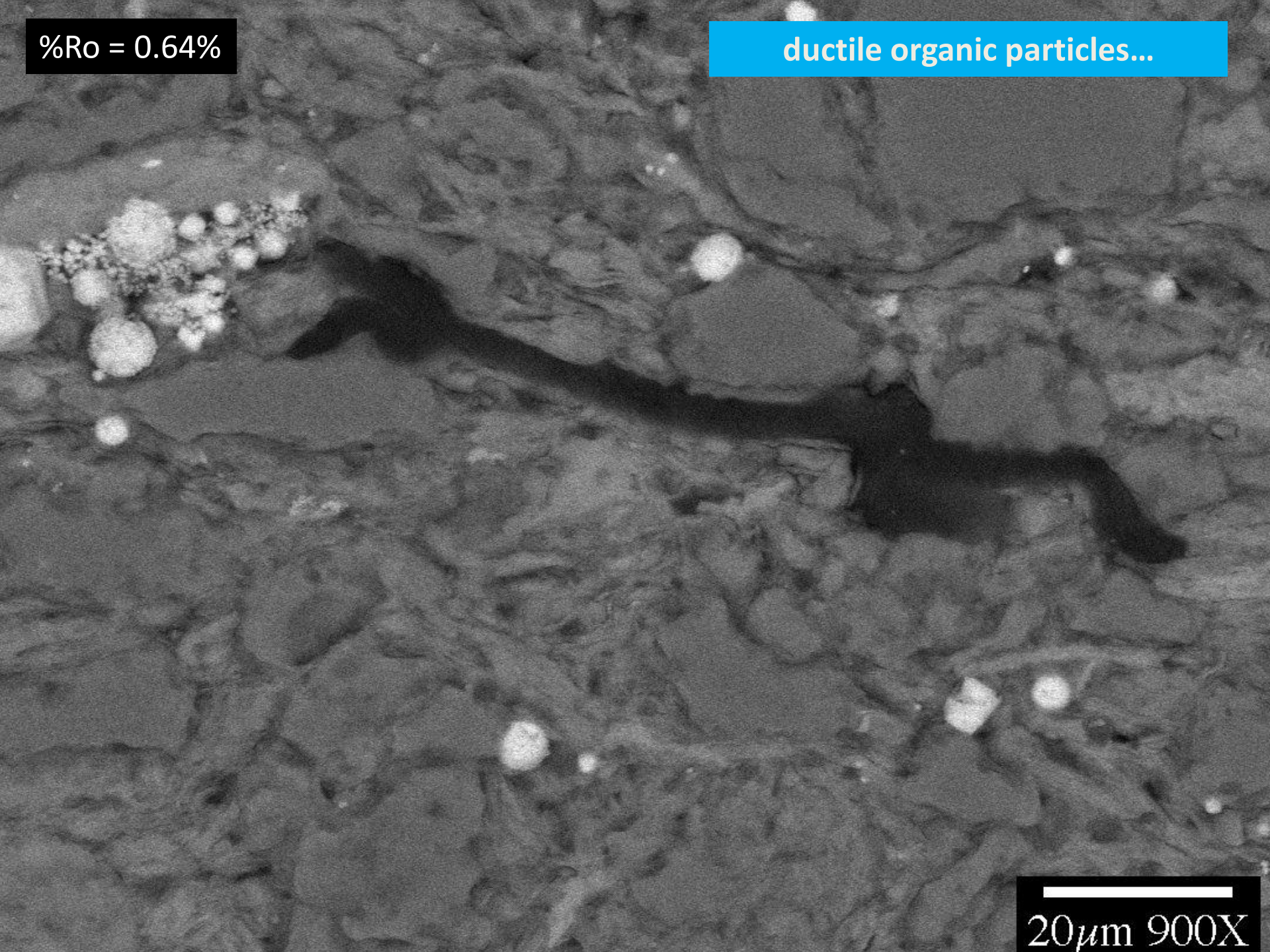
Onondaga Fm.
MRS
7050′
7100′
MFS
7150′
MRS
RST
TST
Onondaga Ls.

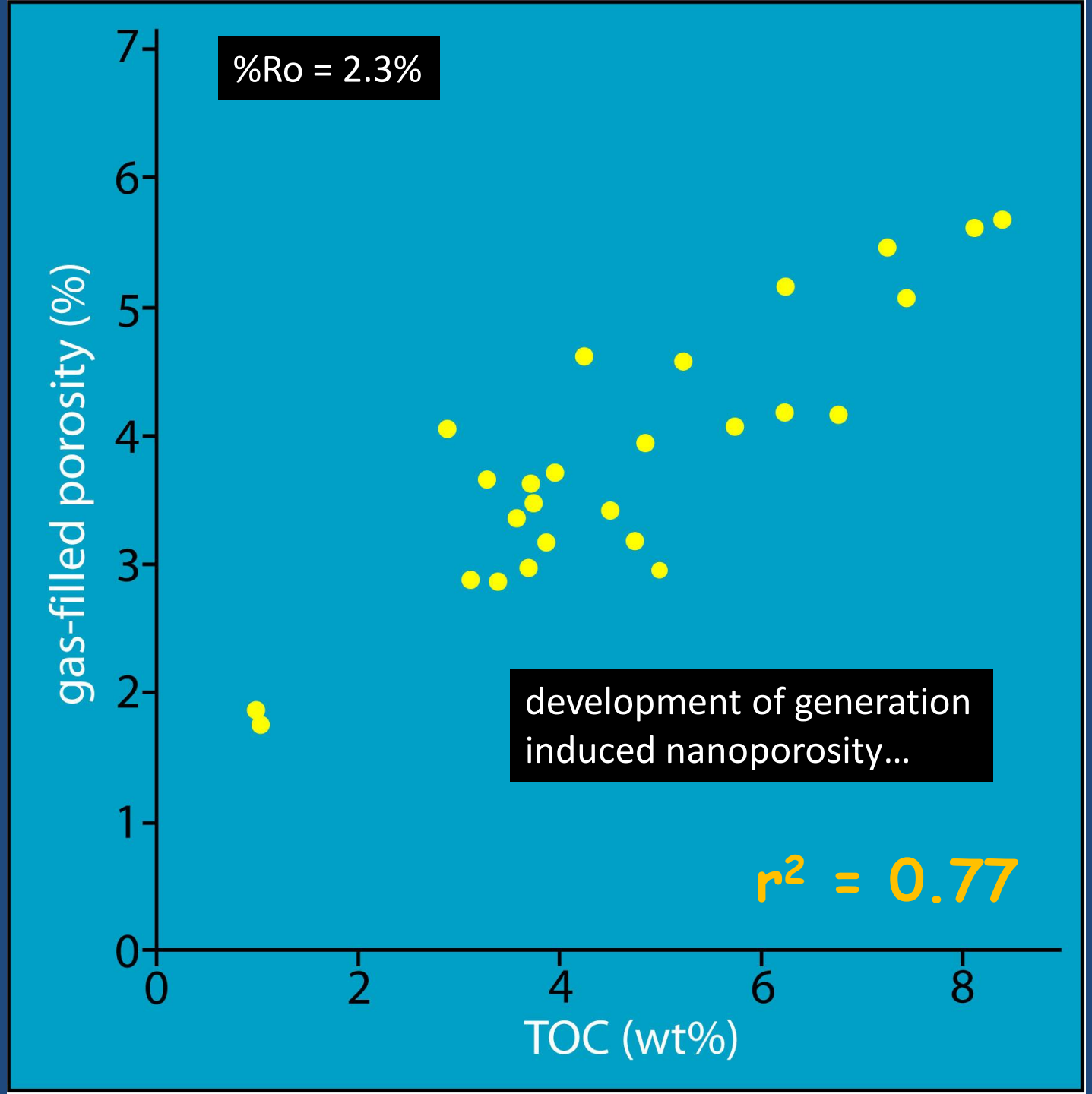
TOC vs. quartz

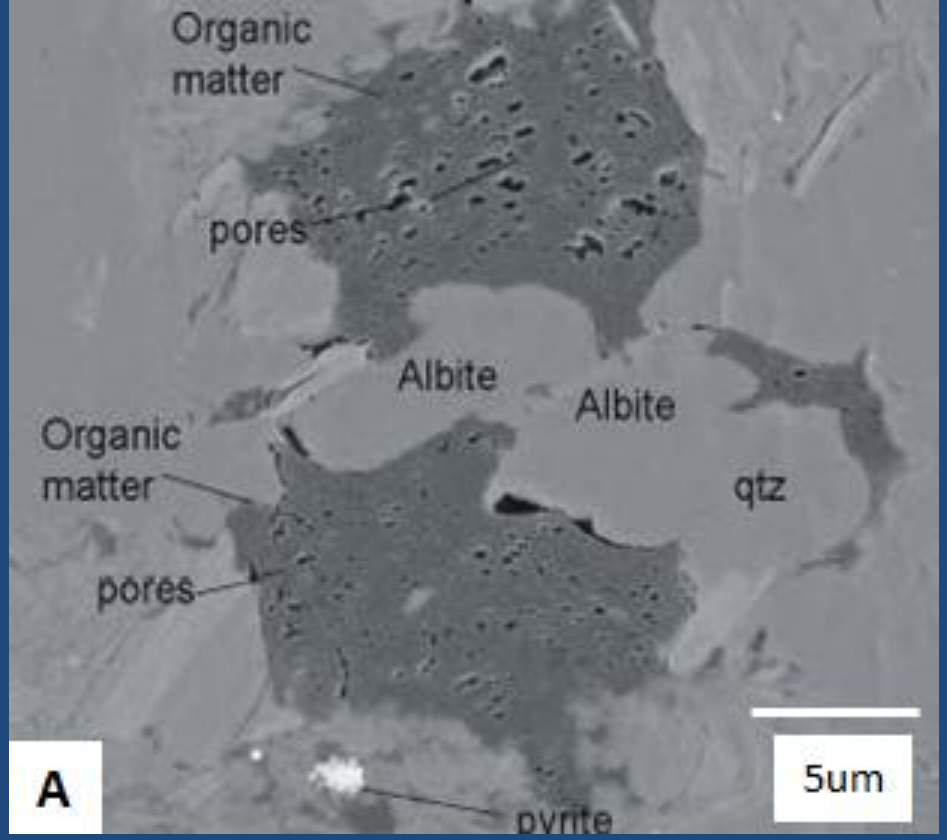


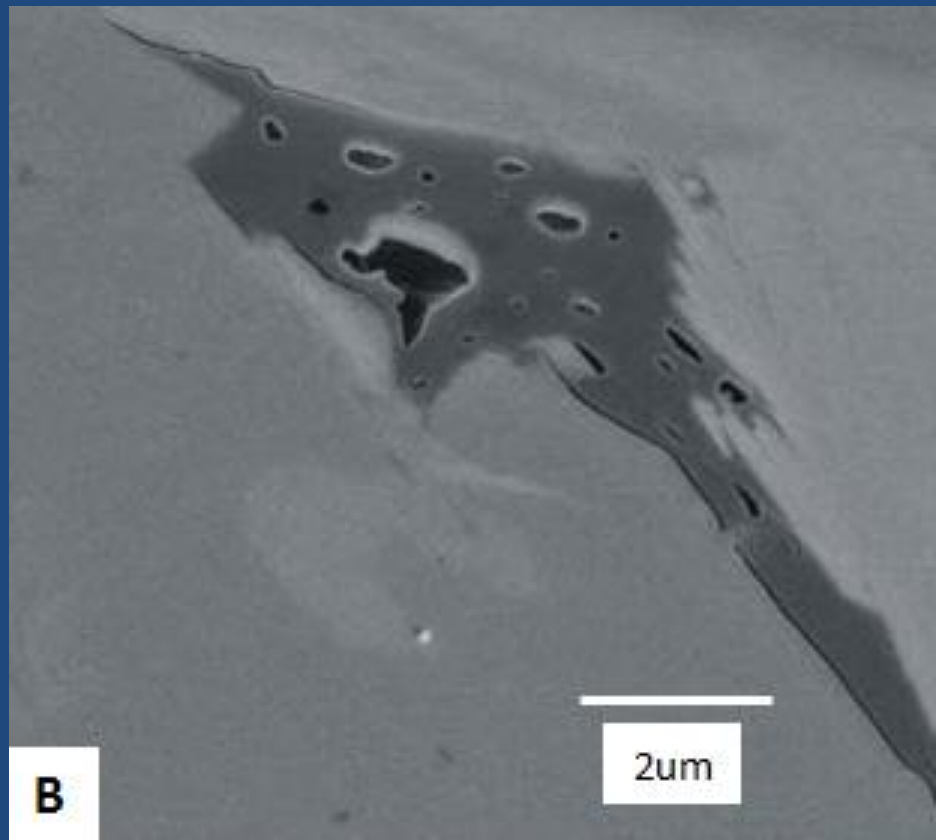

%Ro > 1.4
total porosity (%)
0
2
4
6
8
10
12
14
total organic carbon (wt %)
0
2
4
6
8
10
12
14


%Ro = 0.6-0.74%
gray shale (organic-lean)
Hanover Shale, Cashaqua Shale
black shale
Dunkirk Shale, Rhinestreet Shale
r2 = 0.35
porosity (%)
TOC (wt%)
0
1
2
3
4
5
6
7
8
9
0
2
4
6
8

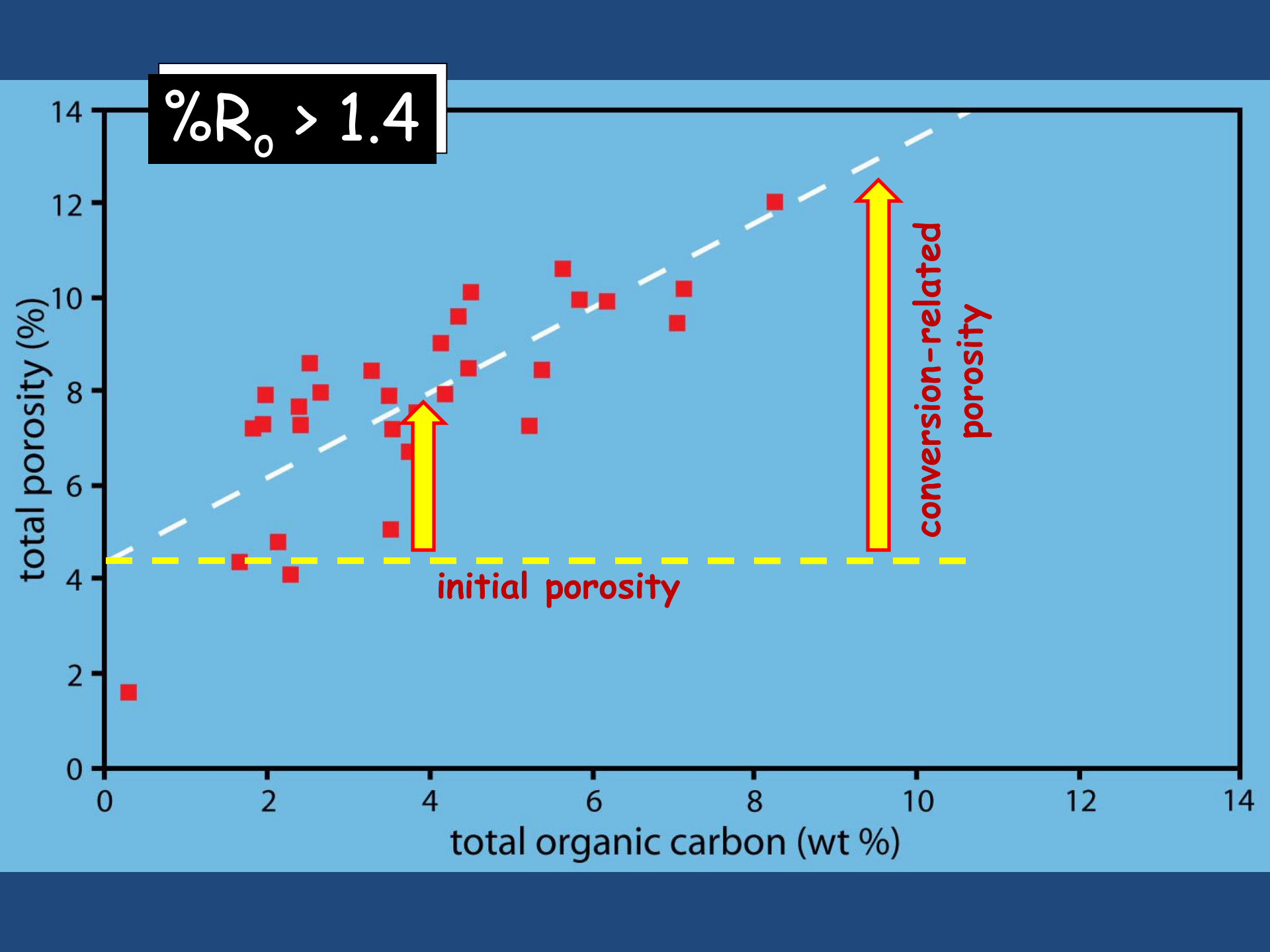

%Ro = 0.64%
ductile organic particles…
20μm 900X


%Ro = 2.3%
gas-filled porosity (%)
TOC (wt%)
0
1
2
3
4
5
6
7
0
2
4
6
8
development of generation induced nanoporosity…
r2 = 0.77

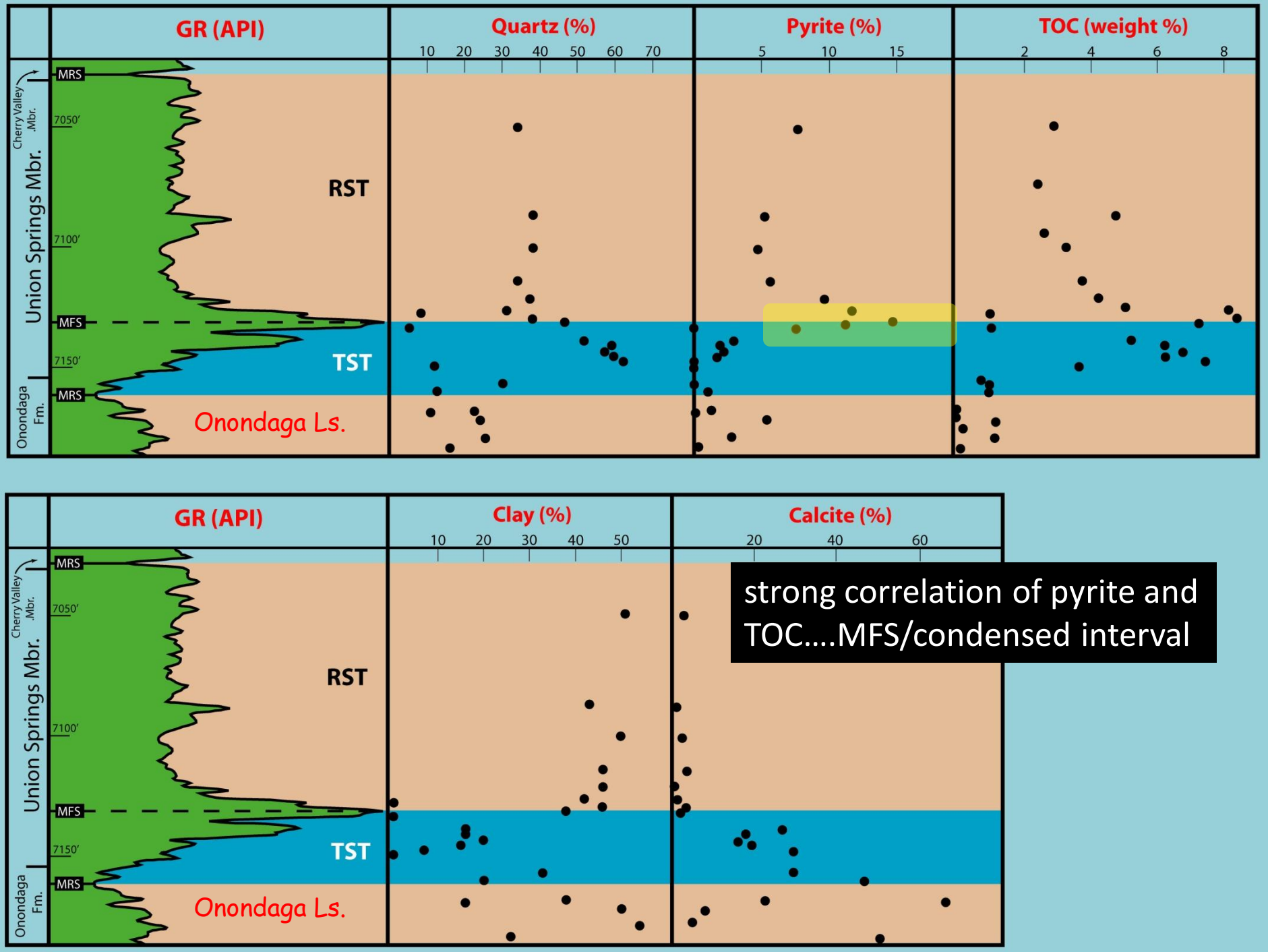




from Slatt and O'Brien (in press),
provided by M. Zheng


%R0 > 1.4
total porosity (%)
total organic carbon (wt %)
0
2
4
6
8
10
12
14
initial porosity
conversion-related porosity

…TST… depending on thermal stress (%Ro), porosity and permeability may increase from the base to top of the TST (base of the RST) in response to increasing TOC…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10 20 30 40 50 60 70
Pyrite (%)
5 10 15
TOC (weight %)
2 4 6 8
Cherry Valley Mbr.
Union Springs Mbr.
Onondaga Fm.
MRS
7050′
7100′
MFS
7150′
MRS
RST
TST
Onondaga Ls.
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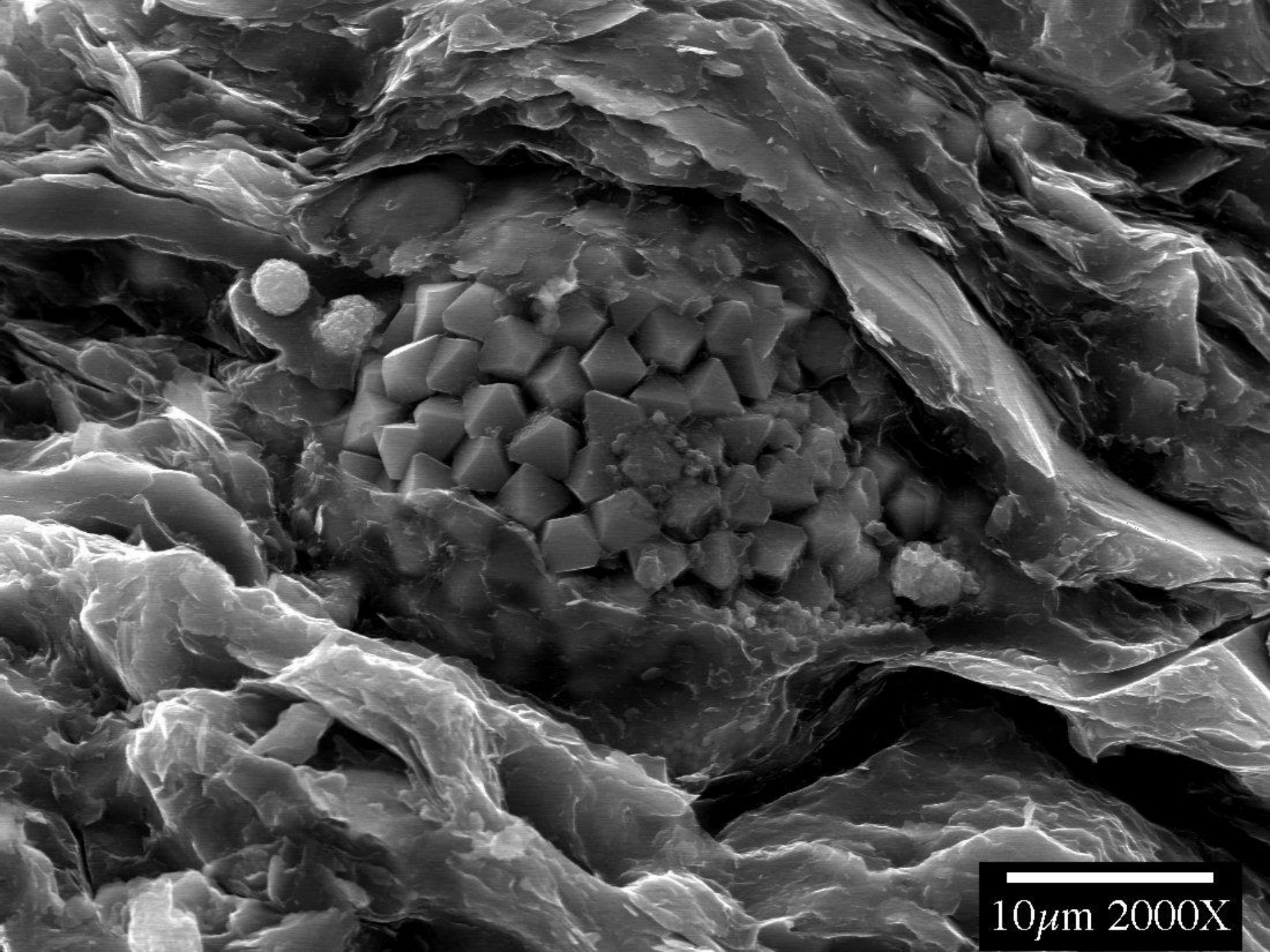
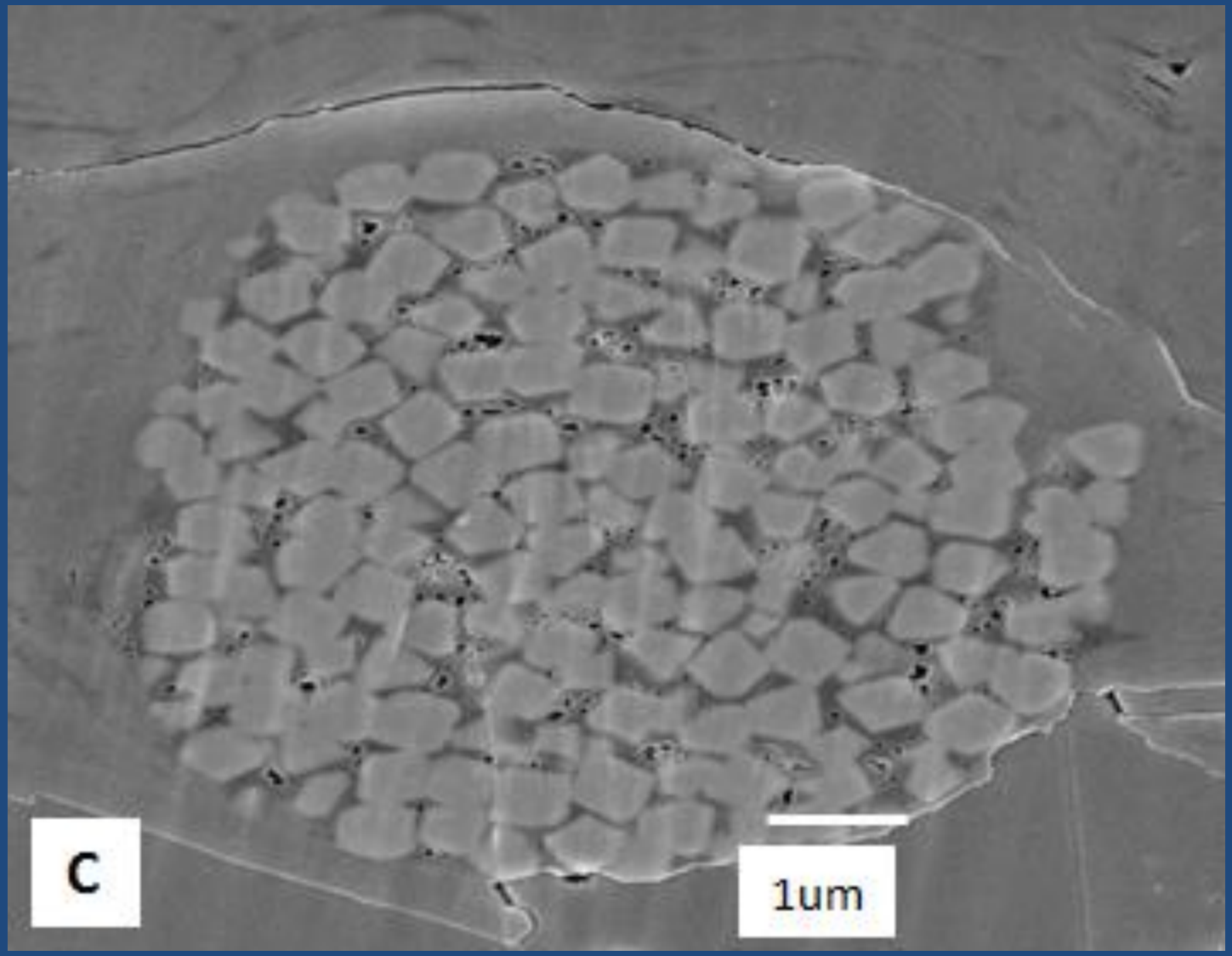
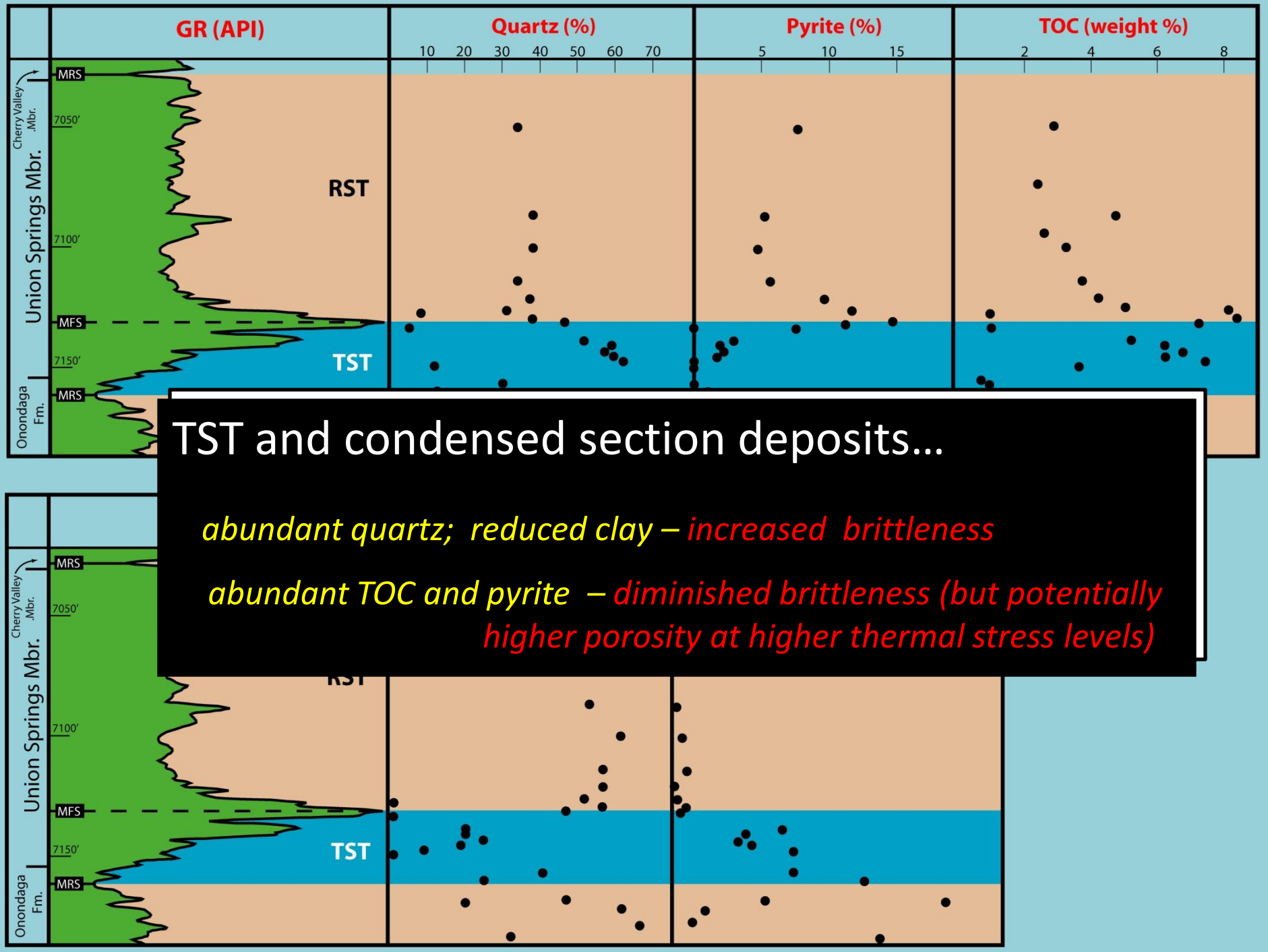
Onondaga Fm.
MRS
7050′
7100′
MFS
7150′
MRS
RST
TST
Onondaga Ls.
strong correlation of pyrite and TOC….MFS/condensed interval


10μm 2000X



from Slatt and O'Brien (in press), provided by M. Zheng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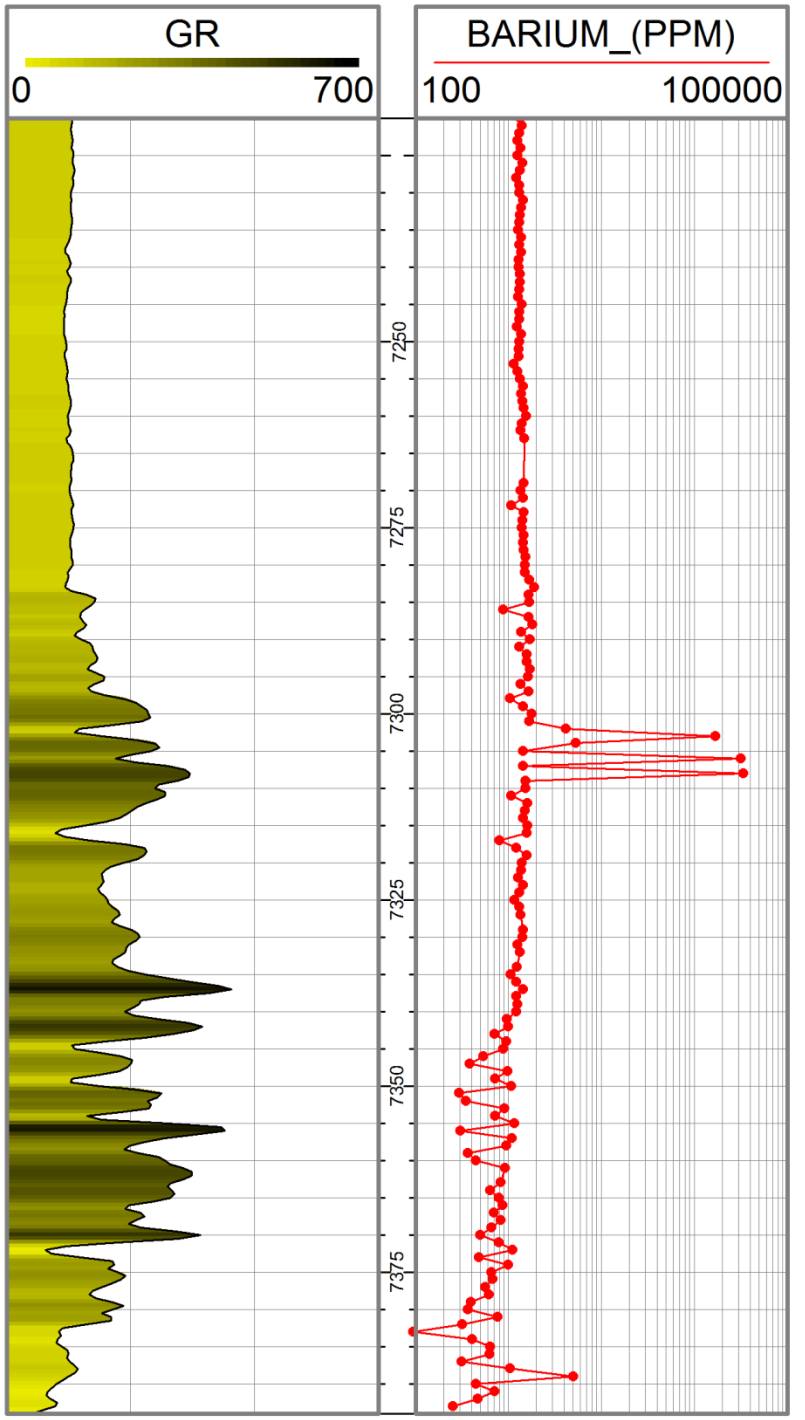
7150′
MRS
RST
TST
TST and condensed section deposits…
abundant quartz; reduced clay – increased brittleness
abundant TOC and pyrite – diminished brittleness (but potentially higher porosity at higher thermal stress levels)

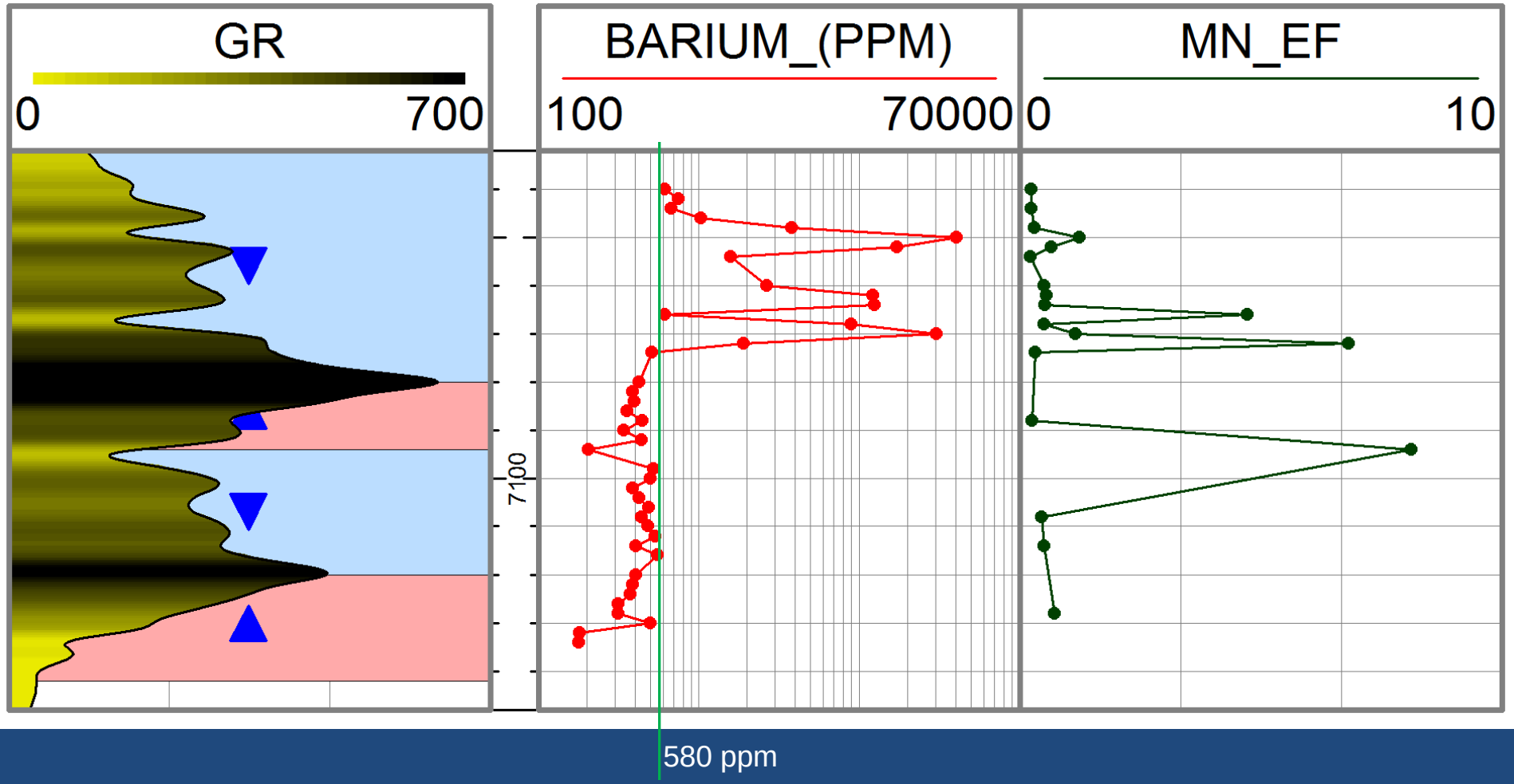
elevated barium levels

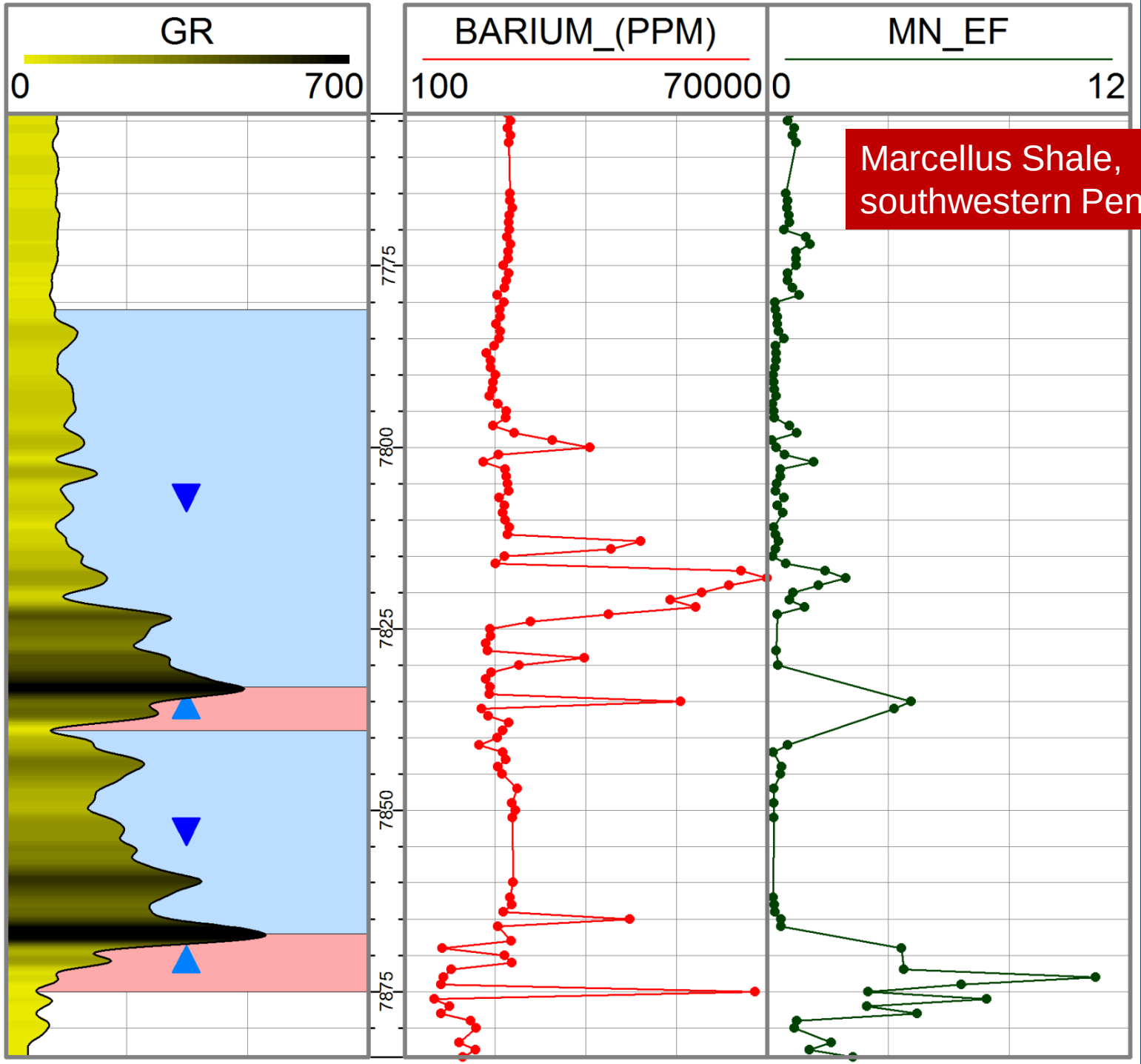
Marcellus Shale, northern central West Virginia

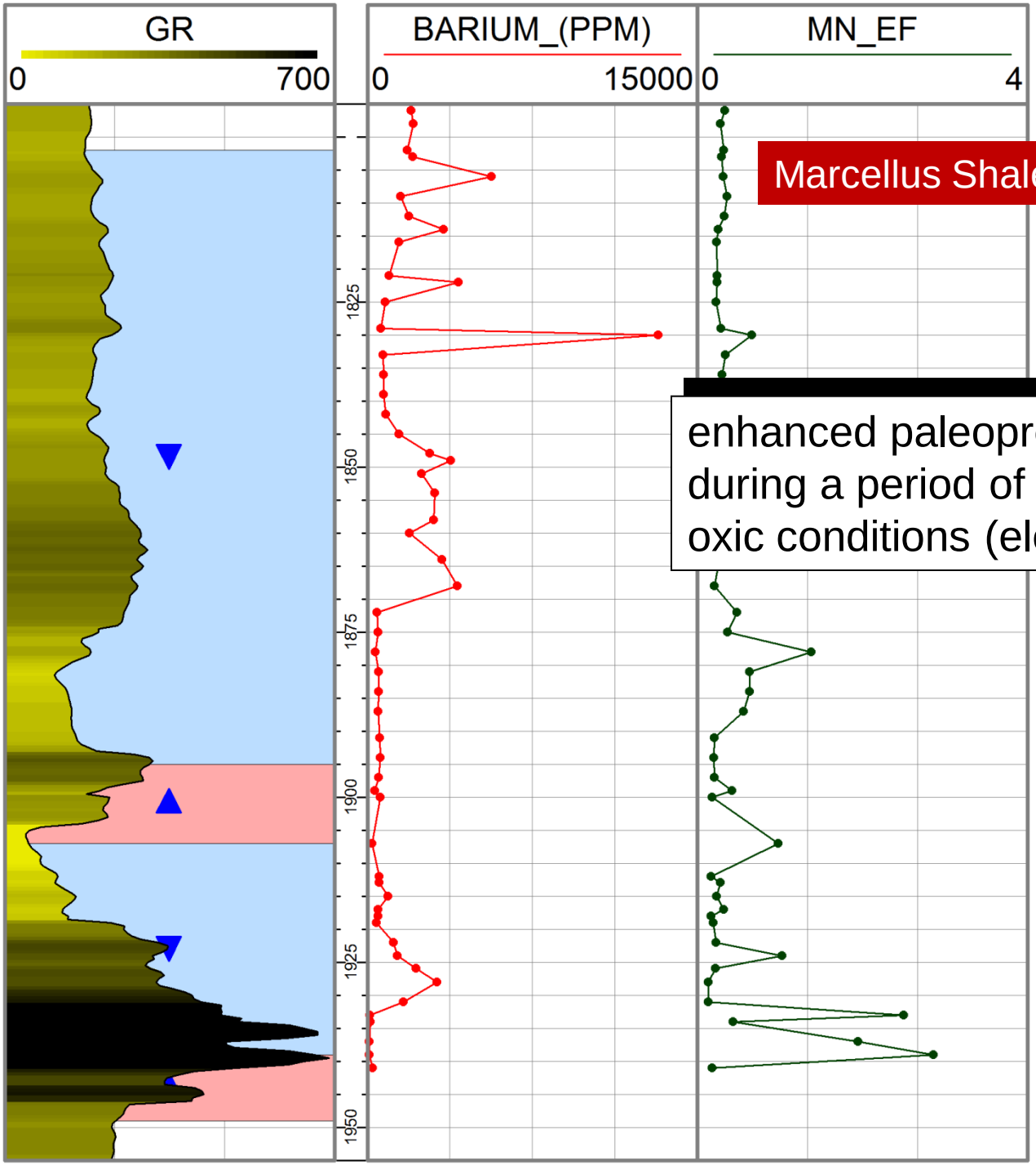


580 ppm; “average” shale (Wedepohl, 1971)

Marcellus Shale, northern West Virginia



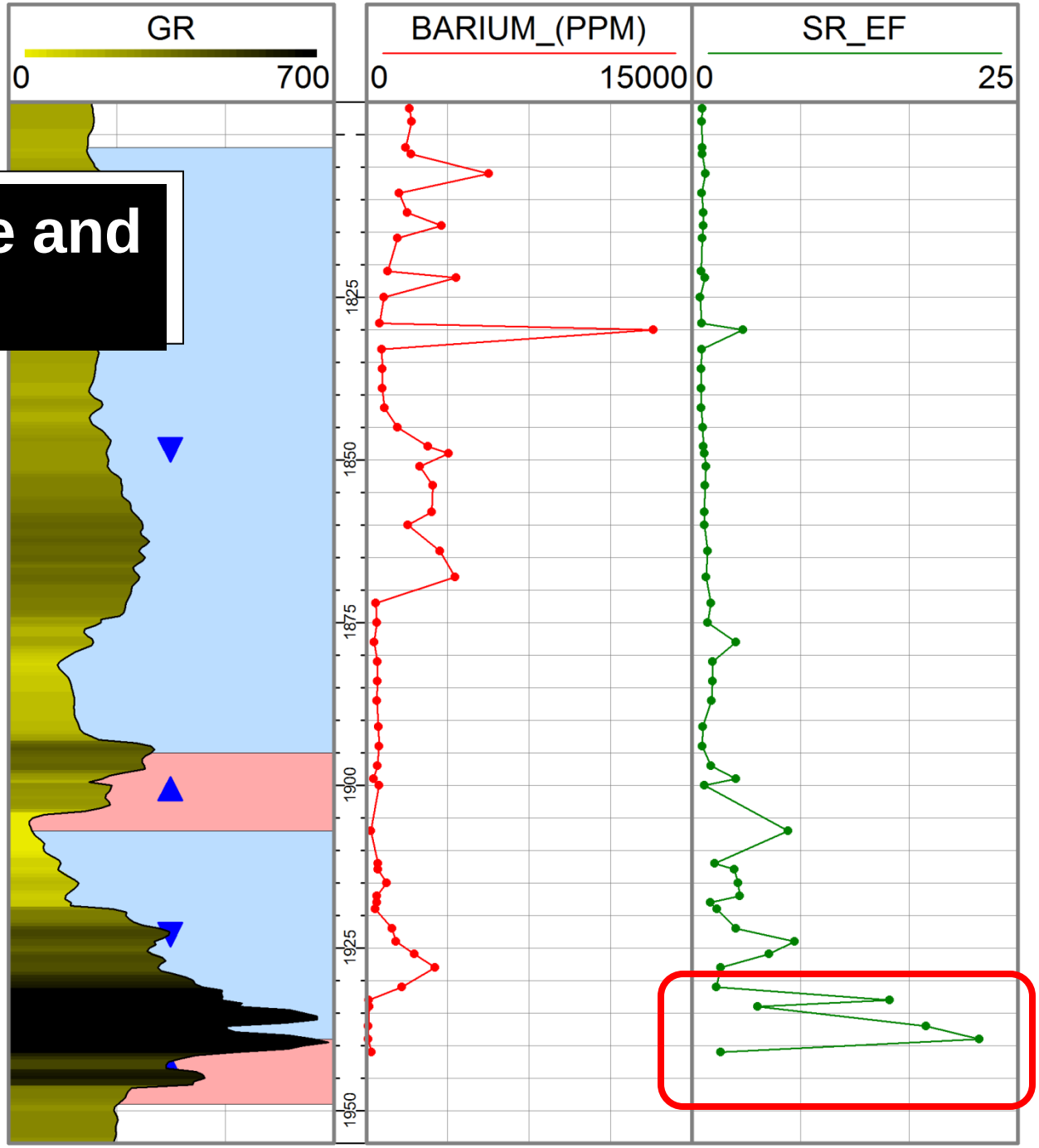

GR
0
700
BARIUM_(PPM)
100
70000
MN_EF
0
12
7775
7800
7825
7850
7875
Marcellus Shale,
southwestern Pennsylvania



Marcellus Shale, eastern New York

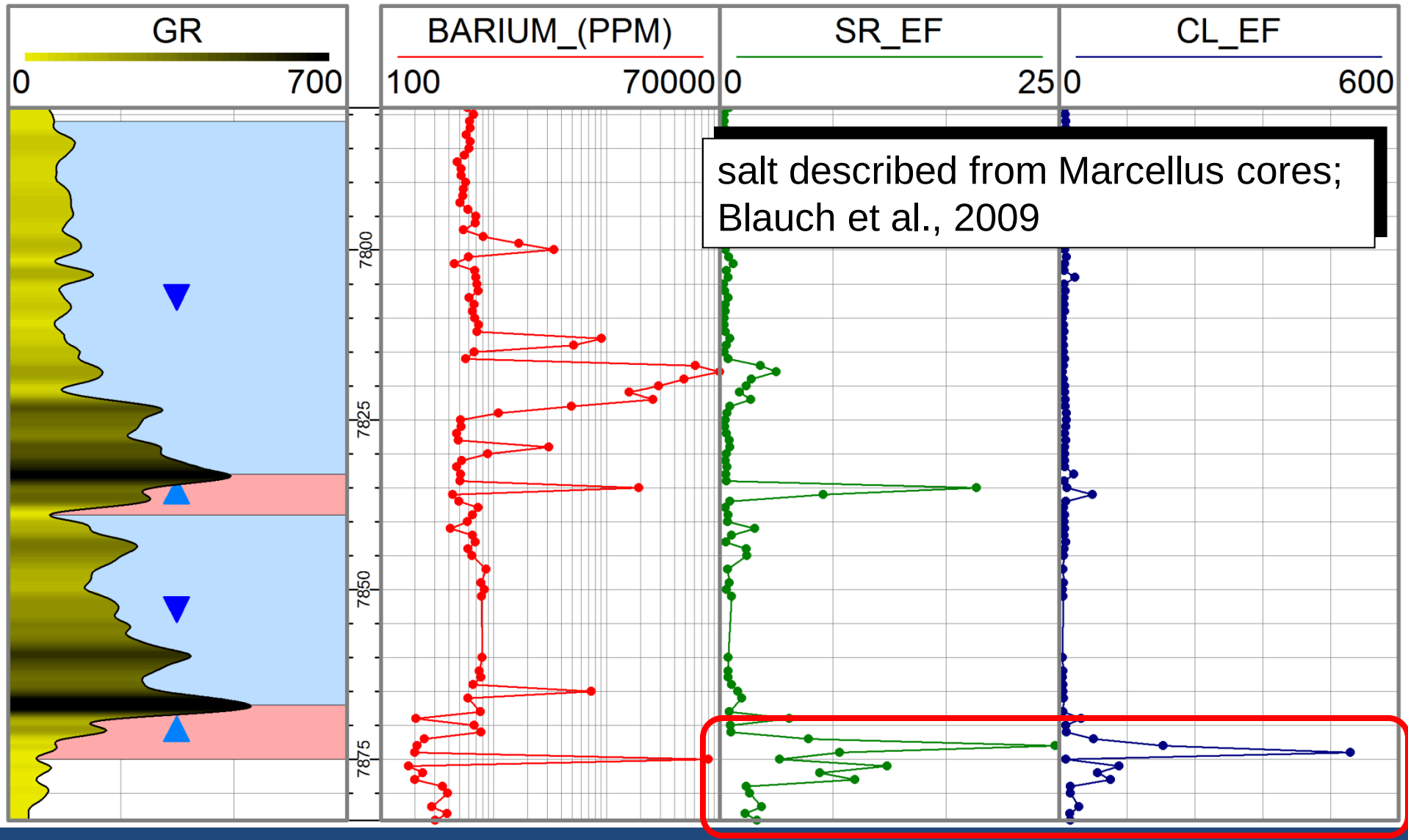
enhanced paleoproductivity perhaps during a period of increasingly oxic conditions (elevated Mn)

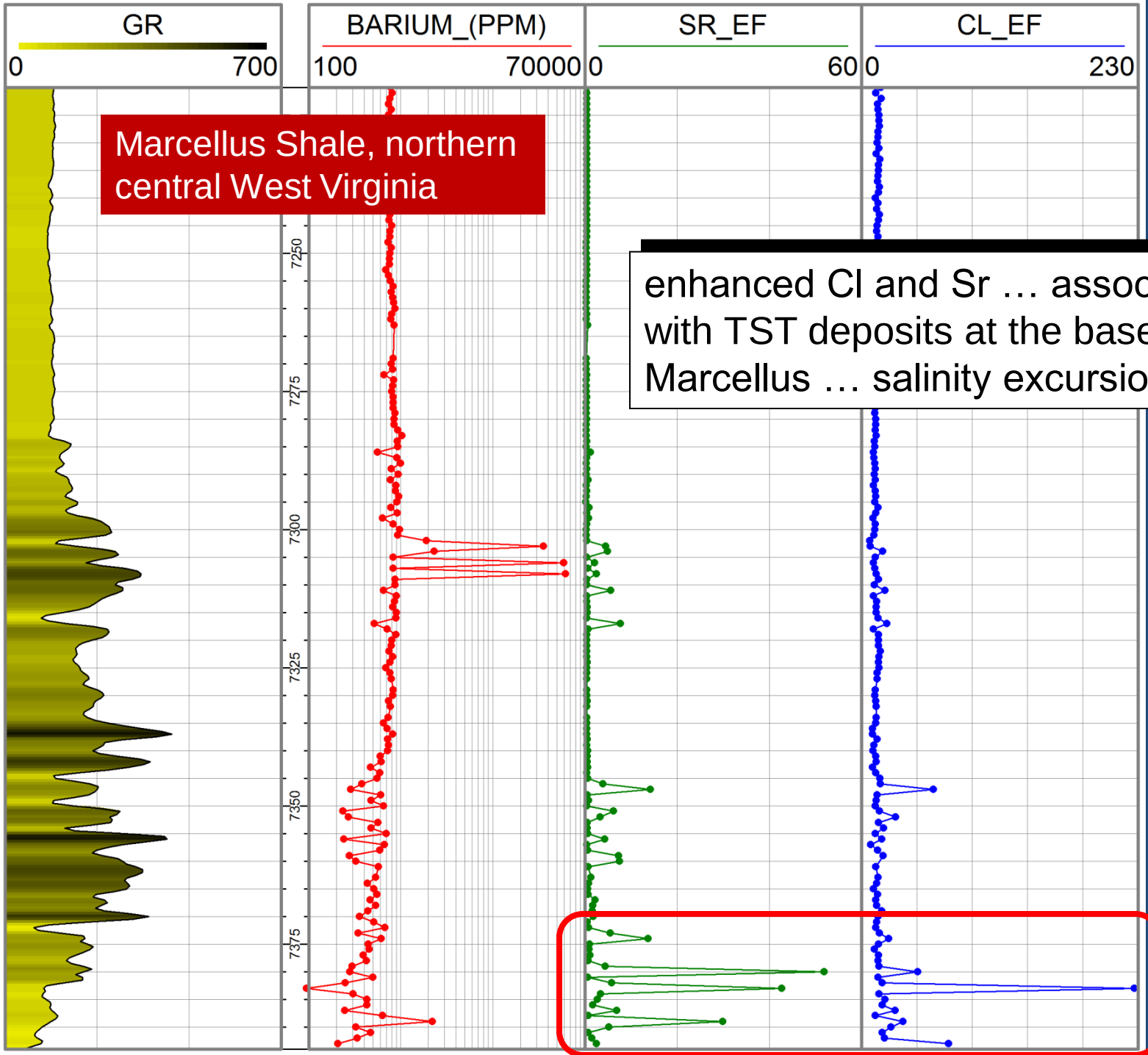
elevated chloride and strontium levels



eastern New York

Marcellus Shale, southwestern Pennsylvania




GR
0
700
BARIUM_(PPM)
100
70000
SR_EF
0
60
CL_EF
0
230
7250
7275
7300
7325
7350
7375
Marcellus Shale, northern central West Virginia
enhanced Cl and Sr … associated with TST deposits at the base of the Marcellus … salinity excursions…

Acknowledgements