Microbial-Dominated Carbonate Sedimentation in Oligo-Miocene Transtensional Basins of the Lake Mead (Nevada) Region*

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Abstract

The Oligo-Miocene Horse Spring Formation—exposed north of Lake Mead, Nevada—formed in restricted basins that pre-dated and accompanied complex transtensional tectonic activity. Such basins are normally buried and poorly exposed, but incision by the Colorado River provides world-class exposure and numerous volcanic tuffs allow for detailed sedimentological and stratigraphic analyses. A mixture of siliciclastic, evaporite, and carbonate facies, this formation contains four significant (~50-200 m-thick) lacustrine carbonate sequences that are dominated by microbial fabrics and textures. The oldest sequence, part of the Rainbow Gardens Member, is a laterally extensive, pre-extensional deposit comprised by oncolitic and massive carbonates with root traces, suggesting a palustrine depositional setting. Within the Thumb member, a 150 m thick carbonate unit thins rapidly to less than 10 m thick away from an exposed basin margin over less than 2 km, suggesting lake margin groundwater sources. The Bitter Ridge Limestone member is a laterally extensive (>25 km), thick (~200 m) unit with a tabular architecture. This sequence is characterized by stratiform microbialites, minor domal stromatolites, and extensive teepee structures that illuminate the paleoclimatic evolution of this large lake system. Finally, within the Lovell Wash Member, alluvial fan conglomerates can be traced laterally into a mixed carbonate/siliciclastic, lake margin sequence and, finally, into basinal facies dominated again by stromatolitic sedimentation. Stable isotope analyses of these marginal to basinal facies suggest a systematic δ13C enrichment toward the basin. Furthermore, we have been successful at using stable isotopic and geochemical signatures to correlate sequences throughout the region and across major transform faults, thereby allowing these lake sequences to serve as important constraints on the timing and nature of deformation in the region. These units can serve as excellent outcrop analogues for other rift-basin lacustrine carbonate.

References

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MICROBIAL-DOMINATED CARBONATE SEDIMENTATION IN OLIGO-MIOCENE TRANSTENSIONAL BASINS OF THE LAKE MEAD (NEVADA) REGION

NORTHERN ARIZONA UNIVERSITY

NSF

USGS science for a changing world

UNIVERSITY of ST. THOMAS

Motivation

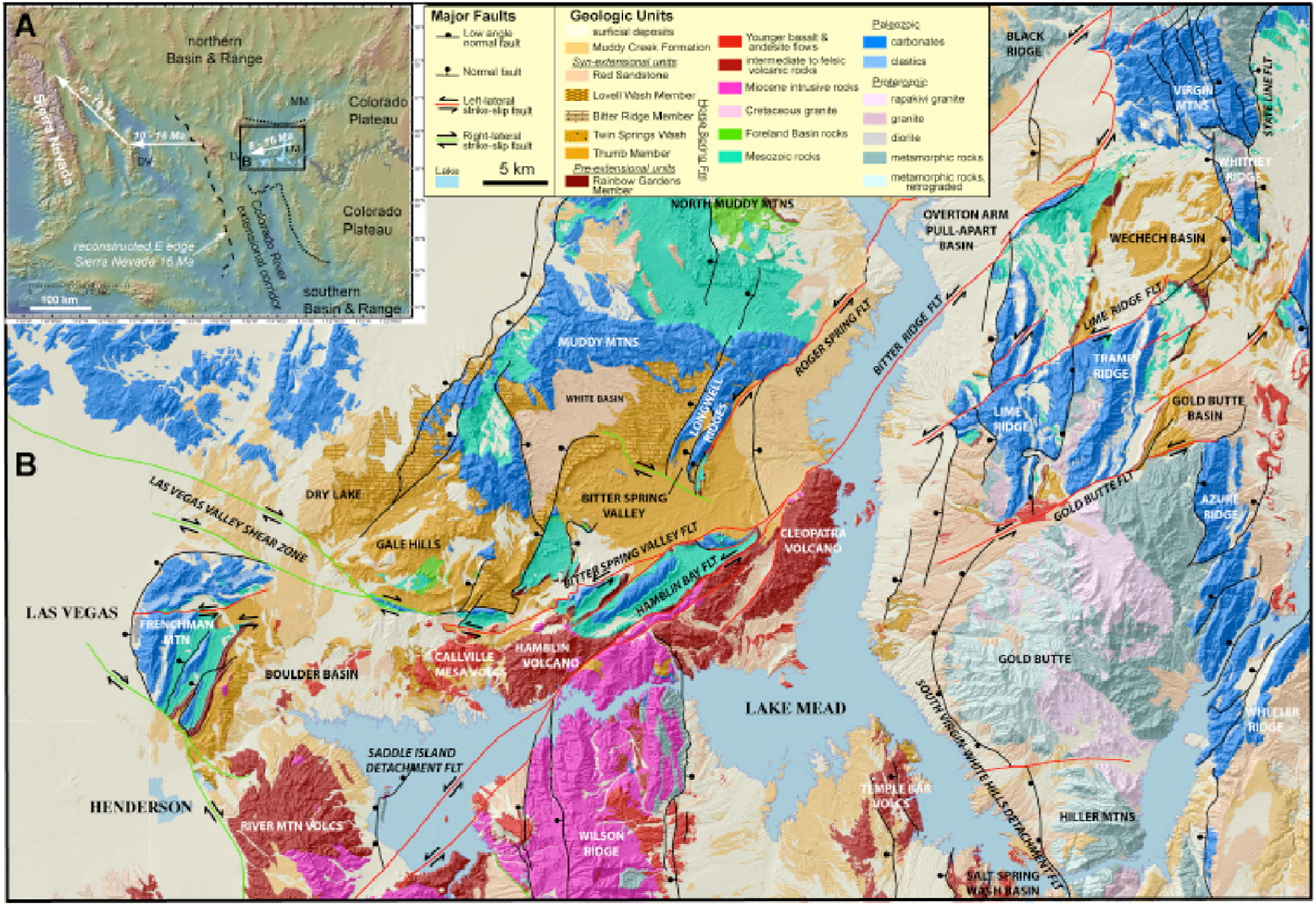
- The range of lacustrine carbonate reservoir geometries and heterogeneities needs further exploration.
- Lithofacies and associations within these systems should provide clues to these geometries
- The Horse Spring Fm. is a world-class outcrop analog for a carbonate-rich system

Stratigraphy

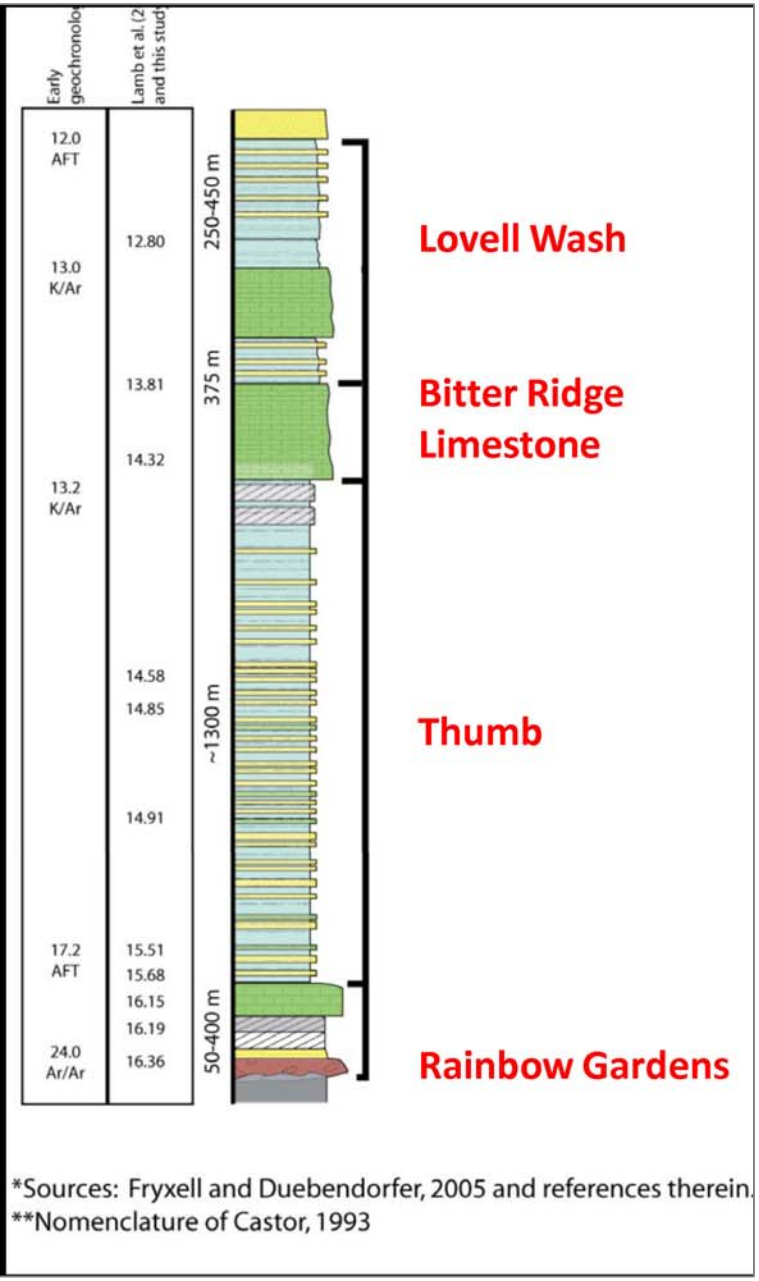
Tectonic Setting

Climatic Setting

THE HORSE SPRING FORMATION

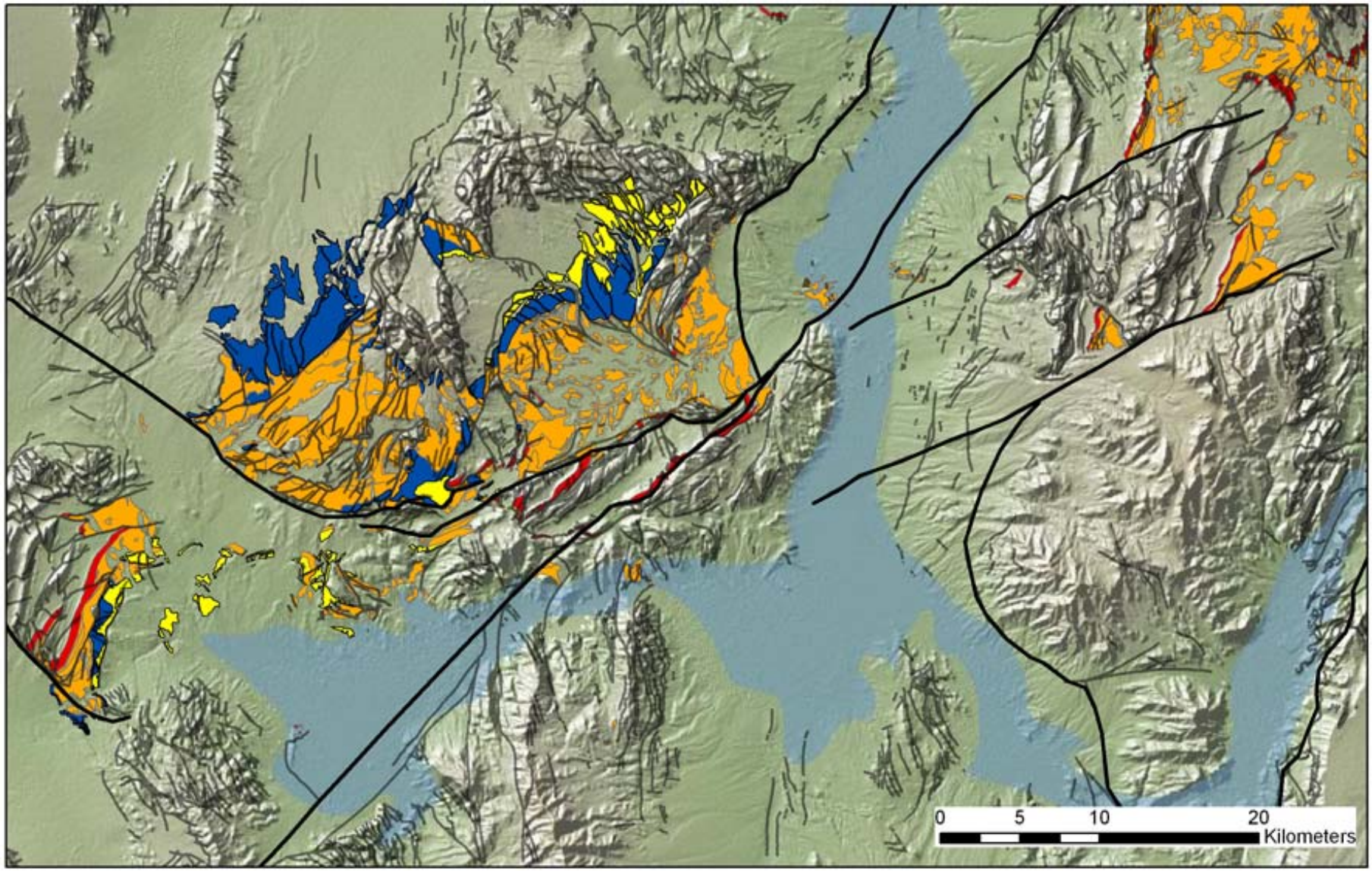

A
northern Basin & Rangeb
Colorado Plateau
Sierra Nevada
MM
LM
DV
B
reconstructed E edge Sierra Nevada 16 Ma
Colorado River extensional corridor
Colorado Plateau
southern Basin & Range
100 km
Major Faults
Low angle normal fault
Normal fault
Left-lateral strike-slip fault
Right-lateral strike-slip fault
Lake
5 km
Geologic Units
surficial deposits
Muddy Creek Formation
Syn-extensional units
Red Sandstone
Lovell Wash Member
Bitter Ridge Member
Twin Springs Wash
Thumb Member
Pre-extensional units
Rainbow Gardens Member
Younger basalt & andesite flows
Intermediate to felsic volcanic rocks
Miocene intrusive rocks
Cretaceous granite
Foreland Basin rocks
Mesozoic rocks
Paleozoic
carbonates
clastics
Proterozoic
rapakivi granite
granite
diorite
metamorphic rocks
metamorphic rocks, retrograded
Horse Spring Fm
B
NORTH MUDDY MTNS
MUDDY MTNS
WHITE BASIN
LONGWELL RIDGE
ROGER SPRING FLT
BITTER RIDGE FLT
OVERTON ARM PULL-APART BASIN
WECHECH BASIN
BLACK RIDGE
VIRGIN MTNS
STATE LINE FLT
WHITNEY RIDGE
LIME RIDGE FLT
TRAMP RIDGE
LIME RIDGE
GOLD BUTTE BASIN
GOLD BUTTE FLT
AZURE RIDGE
DRY LAKE
LAS VEGAS VALLEY SHEAR ZONE
GALE HILLS
BITTER SPRING VALLEY
BITTER SPRING VALLEY FLT
HAMBLIN BAY FLT
CLEOPATRA VOLCANO
LAS VEGAS
FRENCHMAN MTN
CALLVILLE MESA VOLCS
HAMBLIN VOLCANO
BOULDER BASIN
GOLD BUTTE
LAKE MEAD
SOUTH VIRGIN-WHITE HILLS DETACHMENT FLT
WHEELER RIDGE
SADDLE ISLAND DETACHMENT FLT
TEMPLE BAR VOLCS
HILLER MTNS
HENDERSON
RIVER MTN VOLCS
WILSON RIDGE
SALT SPRING WASH BASIN

Horse Spring Fm. Stratigraphy



Presenter's Notes: In particular, the Rainbow Gardens Mbr of the HSF:

1. Records earliest phase(s) of extension
2. Reconstruction of its basin is important initial condition in developing detailed models of Miocene extension

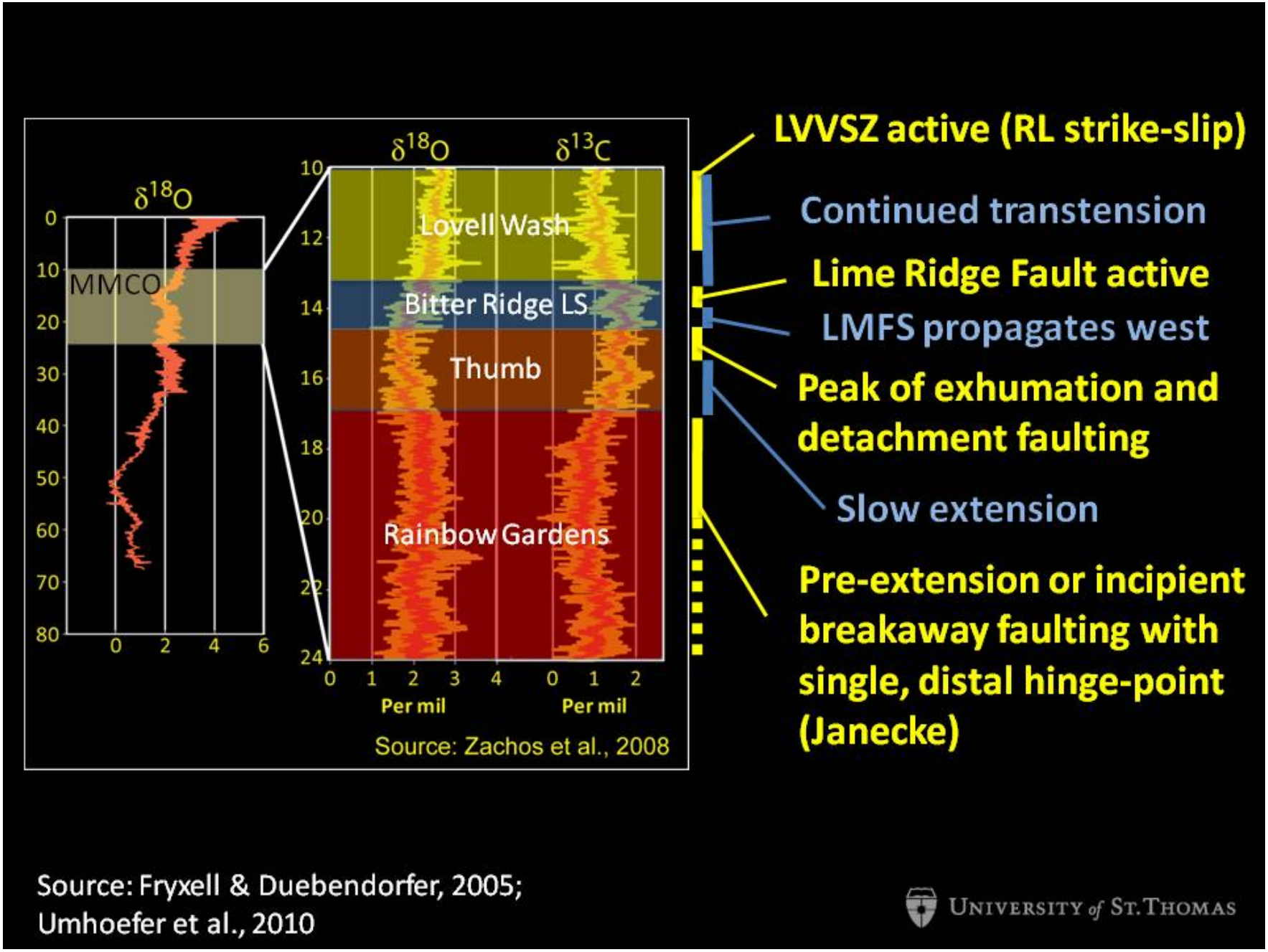


Rainbow Gardens Mbr.

Bitter Ridge Limestone Mbr.

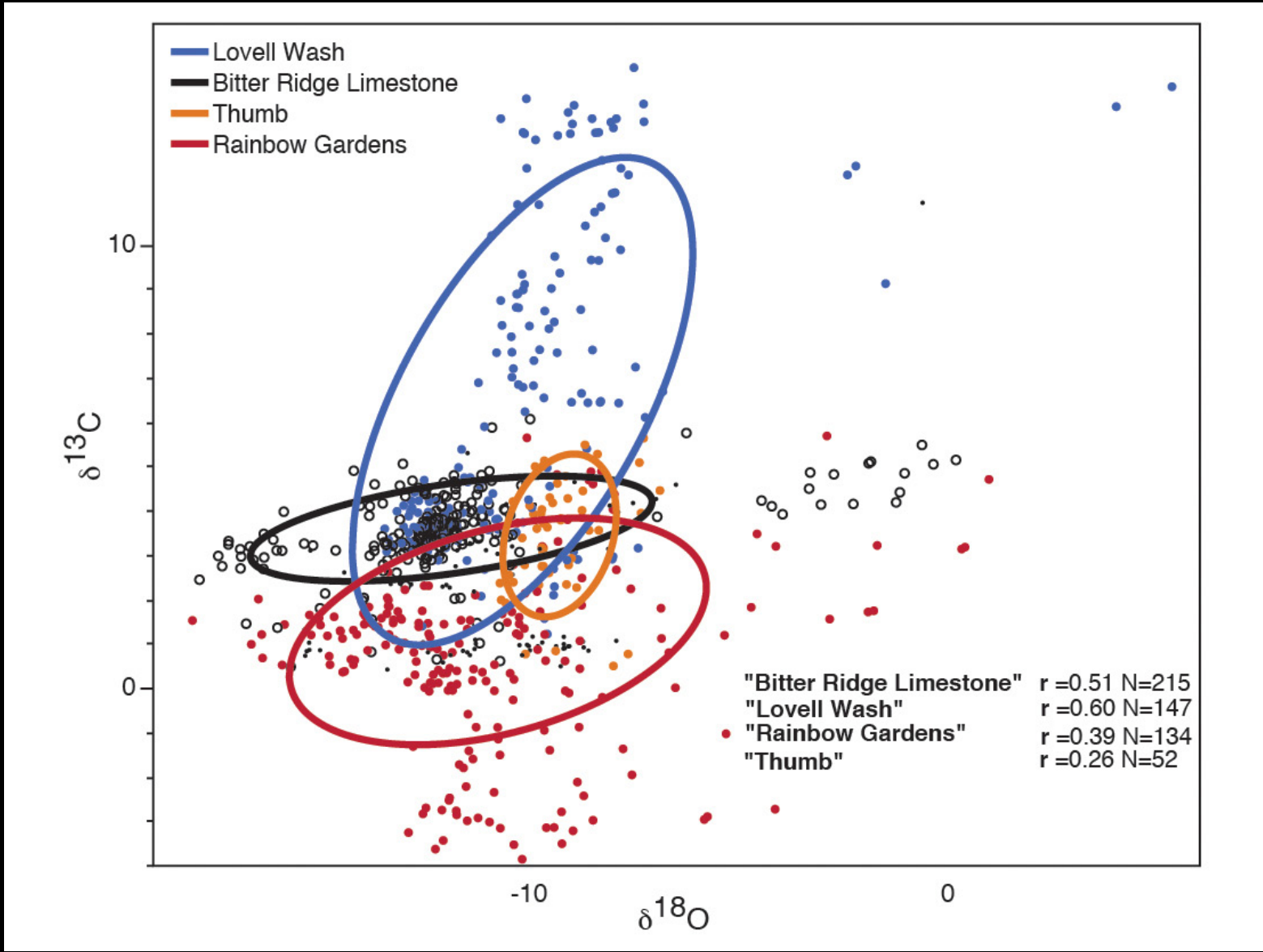
Thumb Mbr.

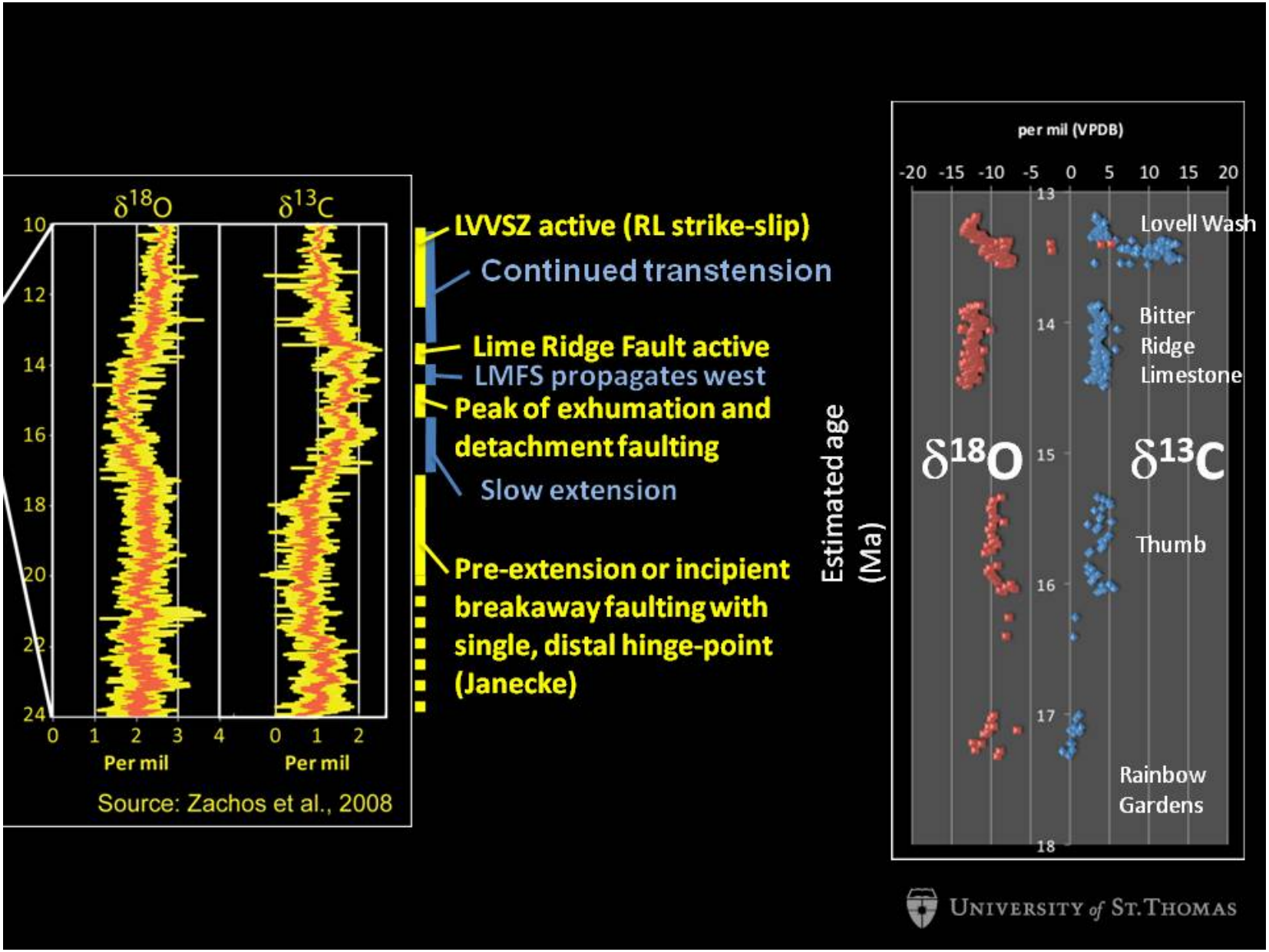
Lovell Wash Mbr.



Presenter's Notes: The HSF ranges between 24 and 10.

ISOTOPIC OVERVIEW


Lovell Wash
Bitter Ridge Limestone
Thumb
Rainbow Gardens
10
0
δ13C
-10
0
δ18O
"Bitter Ridge Limestone" r =0.51 N=215
"Lovell Wash" r =0.60 N=147
"Rainbow Gardens" r =0.39 N=134
"Thumb" r =0.26 N=52



Presenter's Notes: There is not a strong suggestion that the MMCO played a significant role in our record.

Possibilities:

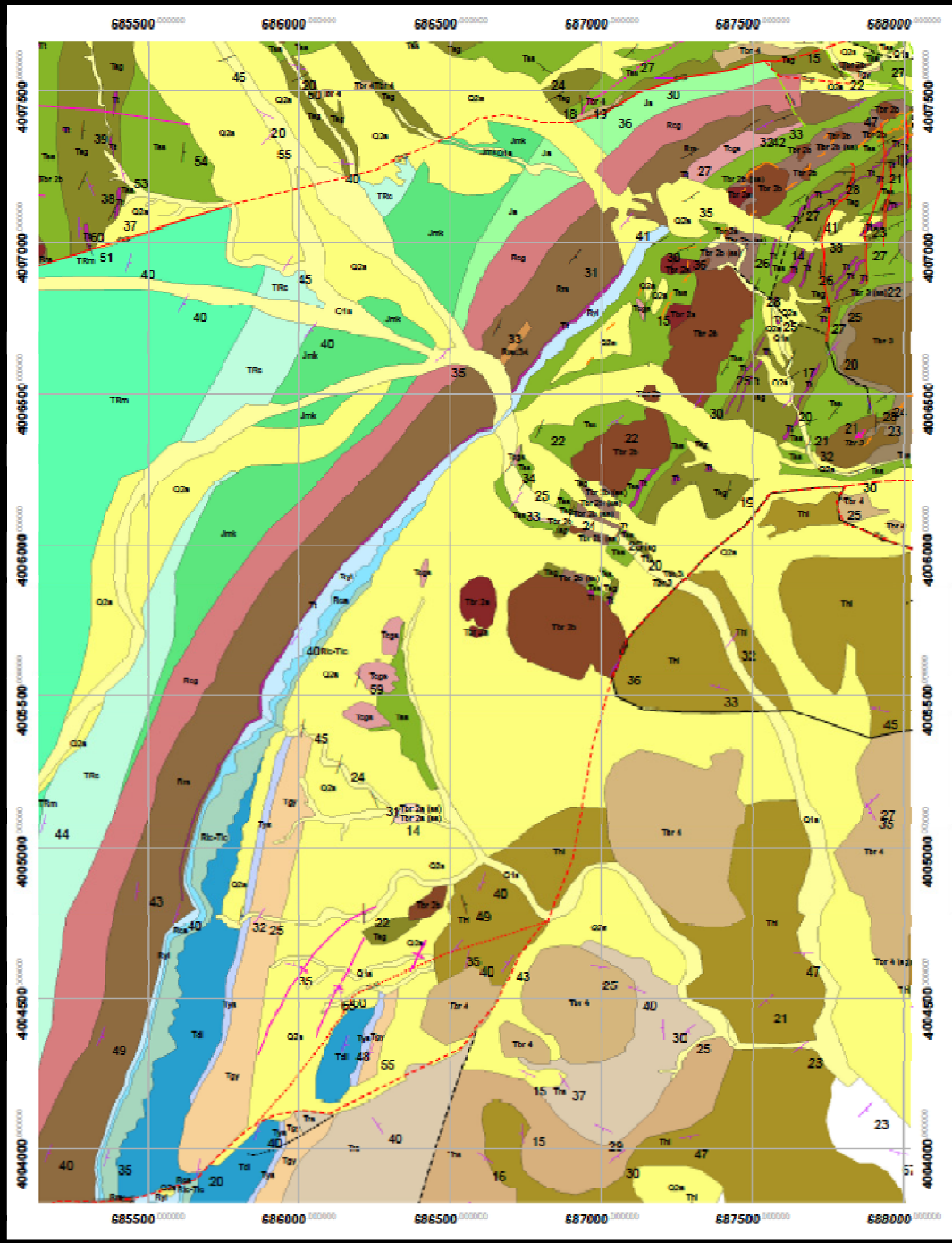
1. Drainage reorganization as Colorado Plateau begins to uplift, feeding new groundwater (water table reversal in the CO plateau)
2. Rapid extension leads to increased topographic corrugation, more rainshadow impact, more depletion.

Each member displays distinctive differences

CARBONATE LITHOFACIES AND FACIES ARCHITECTURE

Rainbow Gardens

- Pre-extensional
- Laterally continuous
- Tabular geometry
- Subaerial exposure and paleosol development
- Lacustrine to palustrine environments

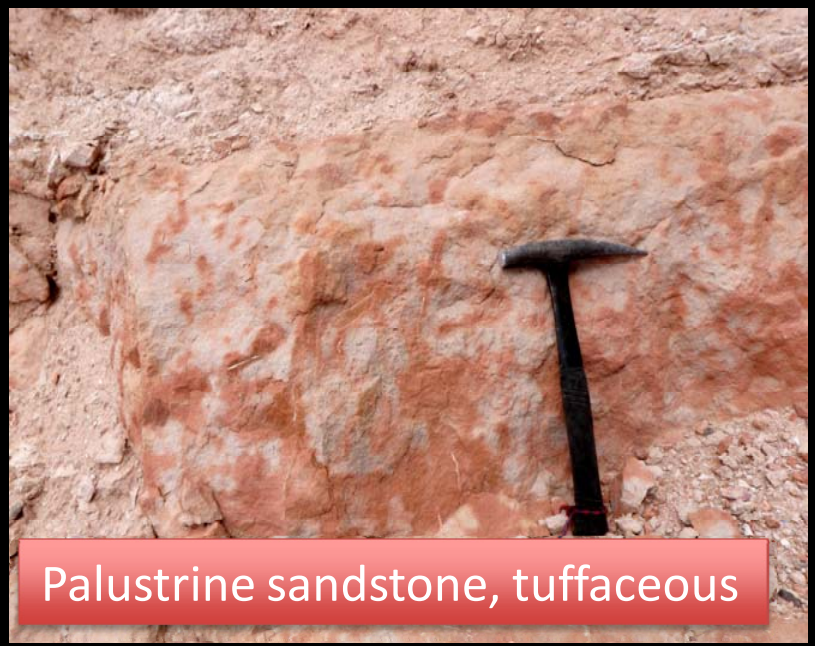


Rainbow Gardens Mbr.

Rainbow Gardens Member


Conglomerate

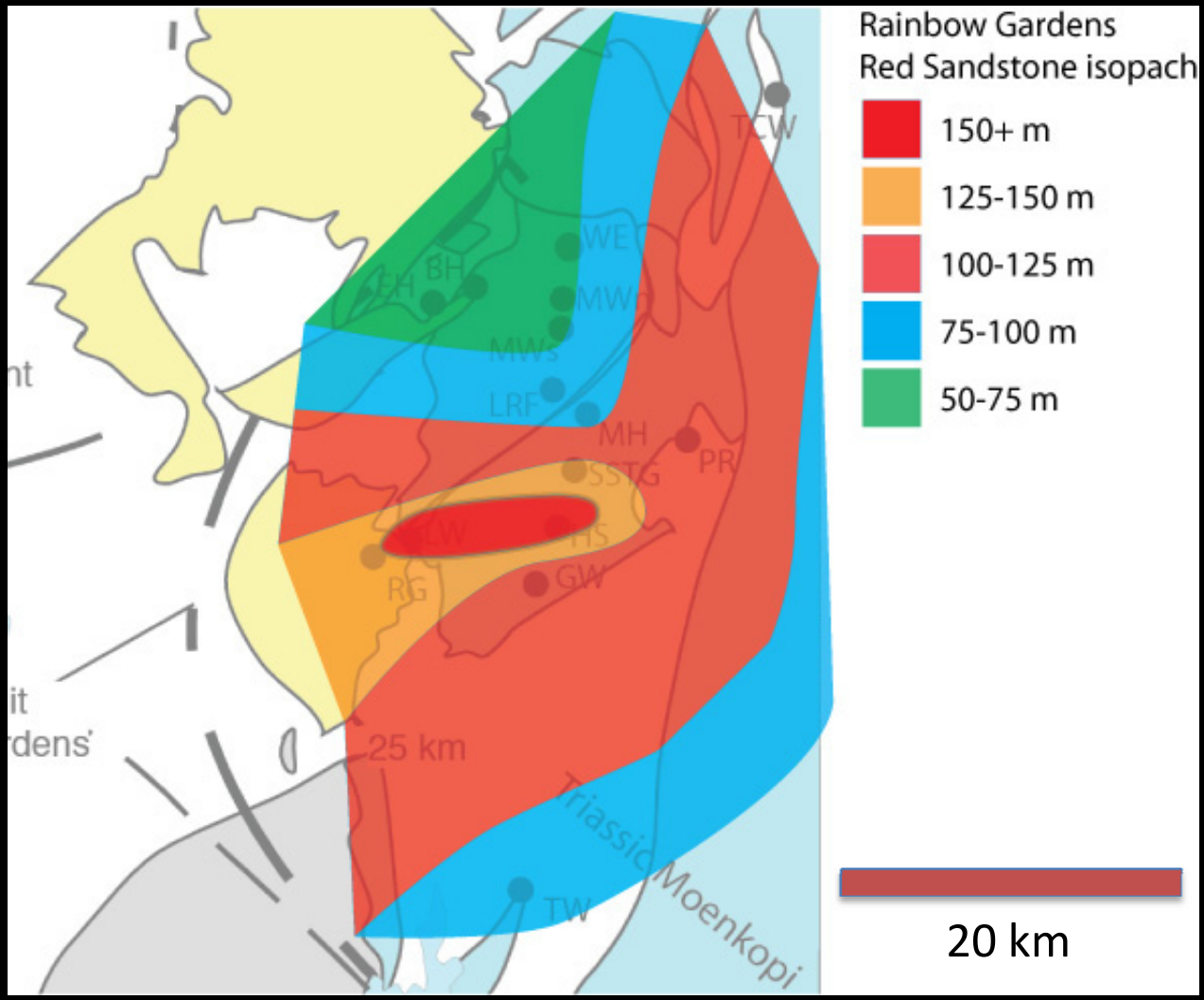

Palustrine sandstone

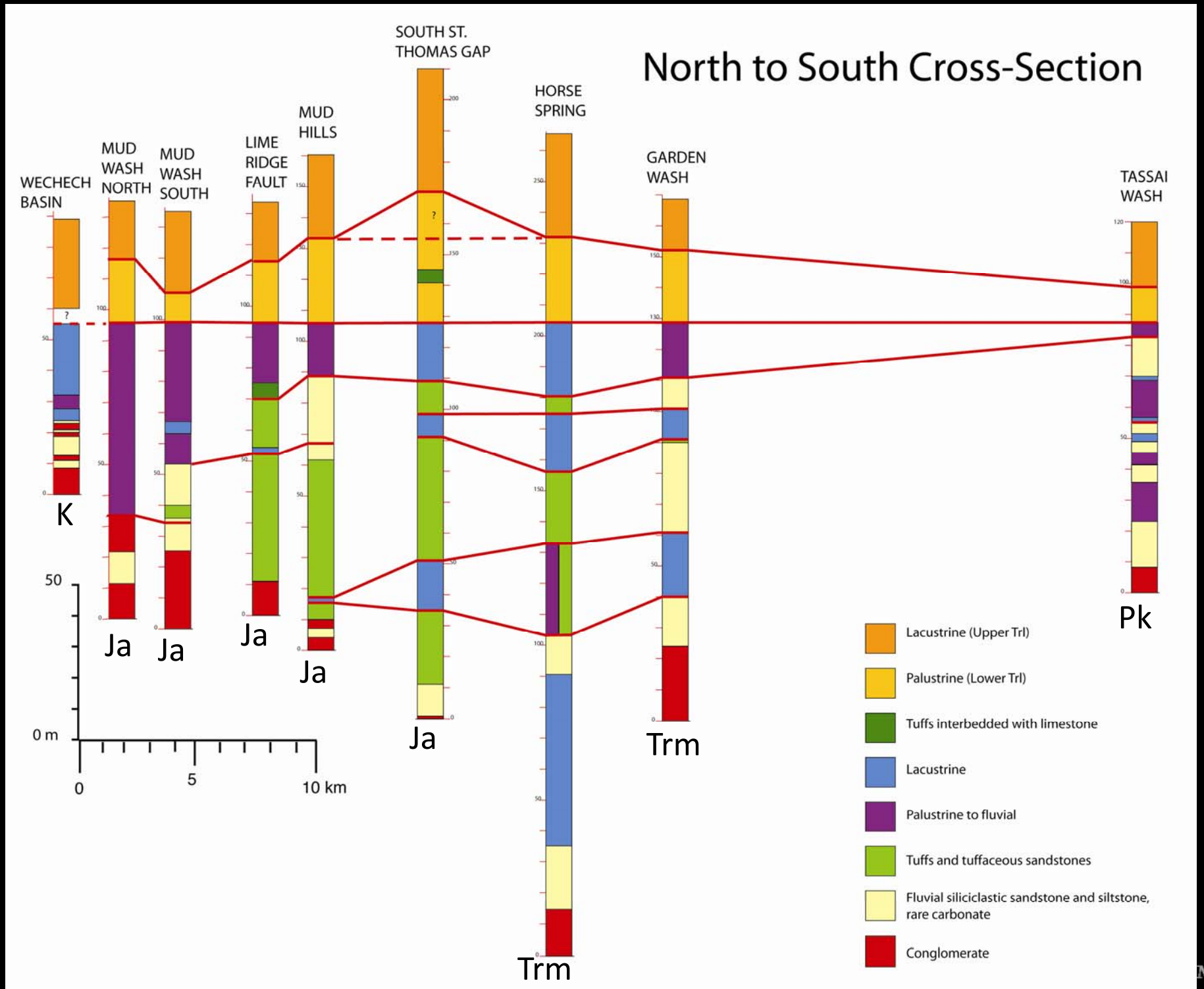

Palustrine sandstone, tuffaceous


Limestone, stratiform stromatolite

OMAS

Isopachs: Red Sandstone

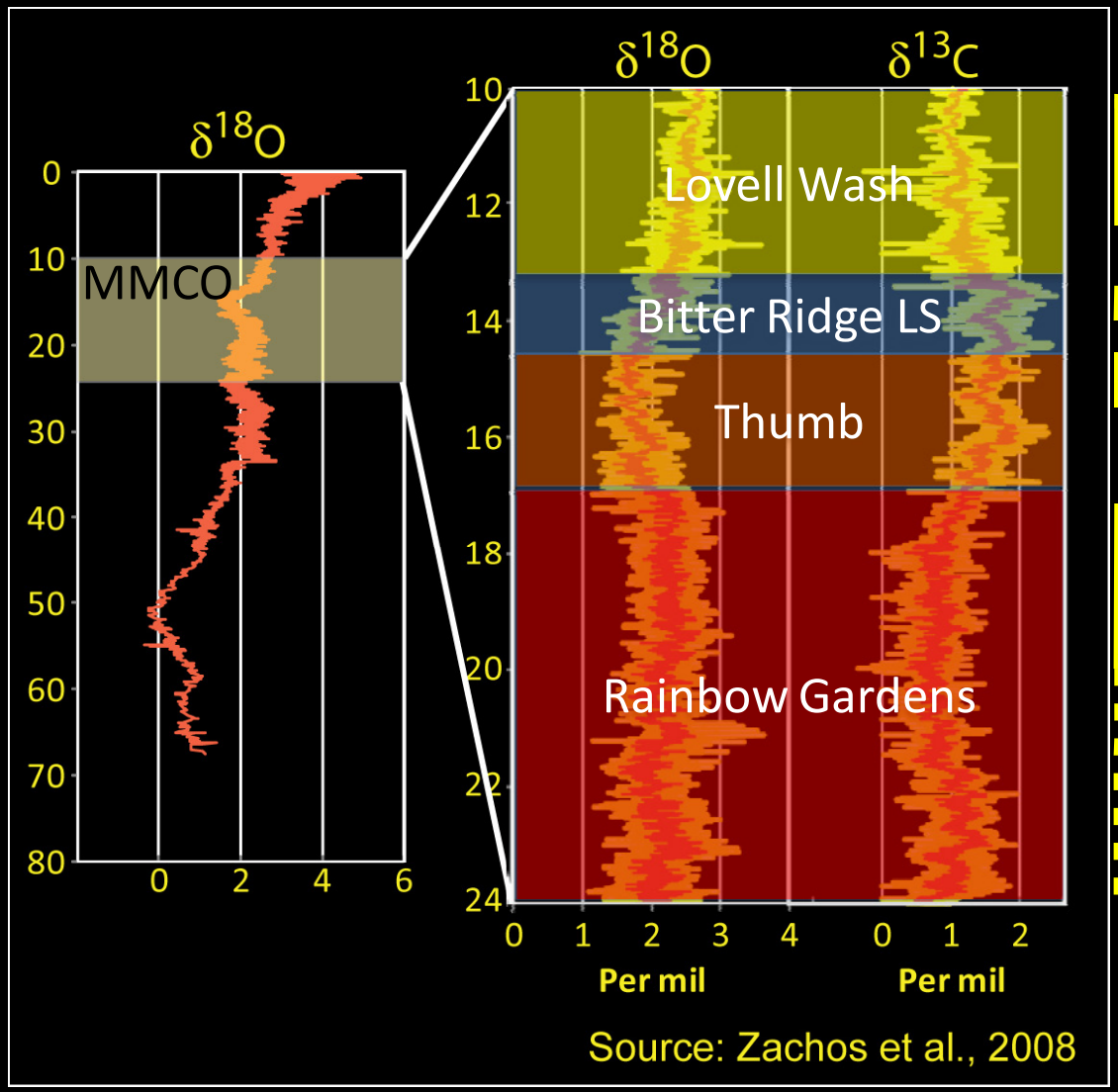



North to South Cross-Section
WECHECH BASIN
MUD WASH NORTH
MUD WASH SOUTH
LIME RIDGE FAULT
MUD HILLS
SOUTH ST. THOMAS GAP
HORSE SPRING
GARDEN WASH
TASSAI WASH
K
Ja
Ja
Ja
Ja
Ja
Trm
Trm
Pk
50
0 m
0
5
10 km
Lacustrine (Upper Trl)
Palustrine (Lower Trl)
Tuffs interbedded with limestone
Lacustrine
Palustrine to fluvial
Tuffs and tuffaceous sandstones
Fluvial siliciclastic sandstone and siltstone, rare carbonate
Conglomerate

Thumb Member

Thumb Member

- Syn-extensional (encompasses peak extension)
- Mainly clastic
- Laterally and vertically discontinuous carbonate packages
- Facies similar to Rainbow Gardens



LVVSZ active (RL strike-slip)

Continued transtension

Lime Ridge Fault active

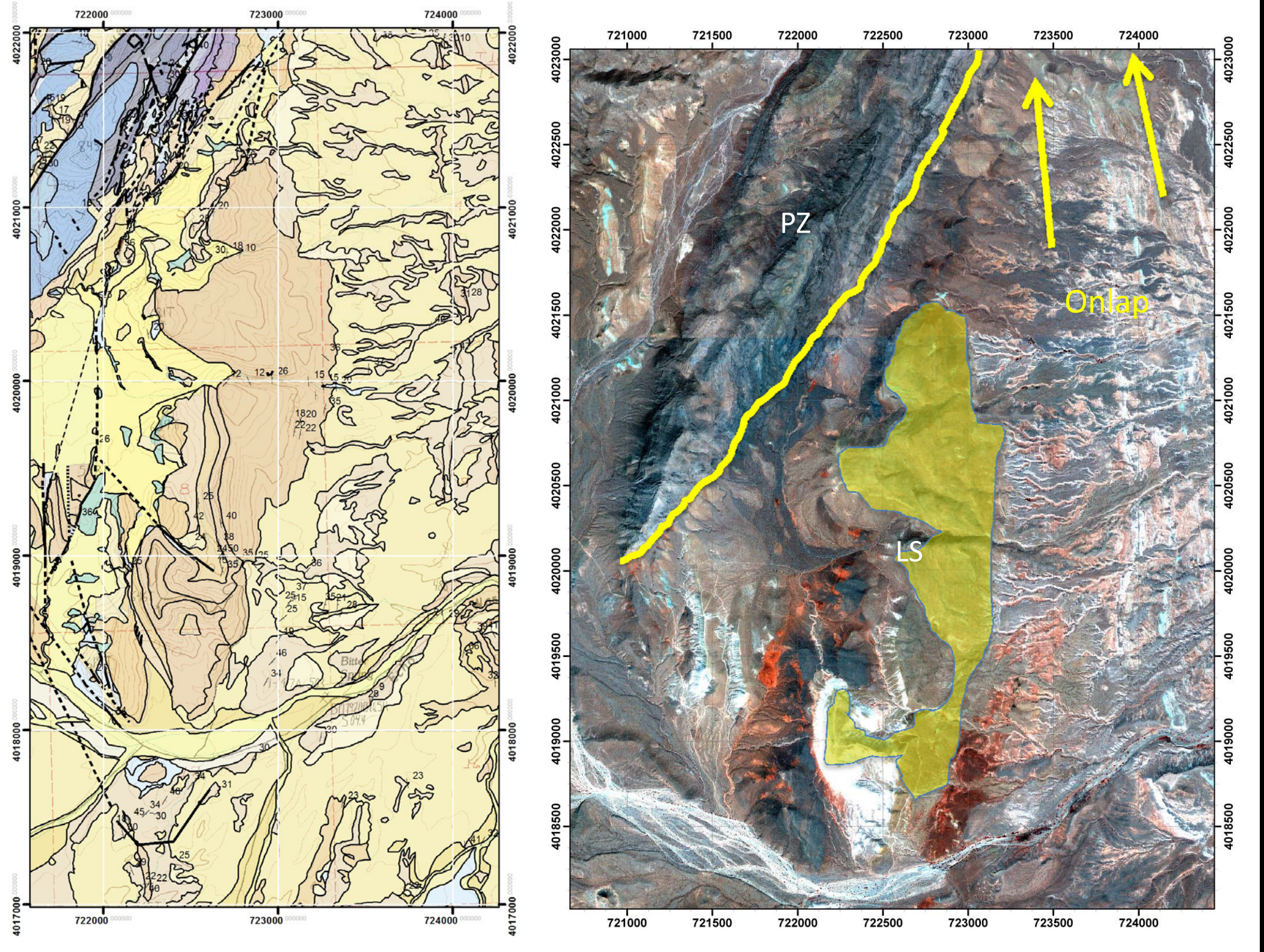
LMFS propagates west

Peak of exhumation and detachment faulting

Slow extension

Pre-extension or incipient breakaway faulting with single, distal hinge-point (Janecke)

Source: Fryxell & Duebendorfer, 2005; Umhoefer et al., 2010


722000
723000
724000
4022000
4021000
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4018000
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721500
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724000
4023000
4022500
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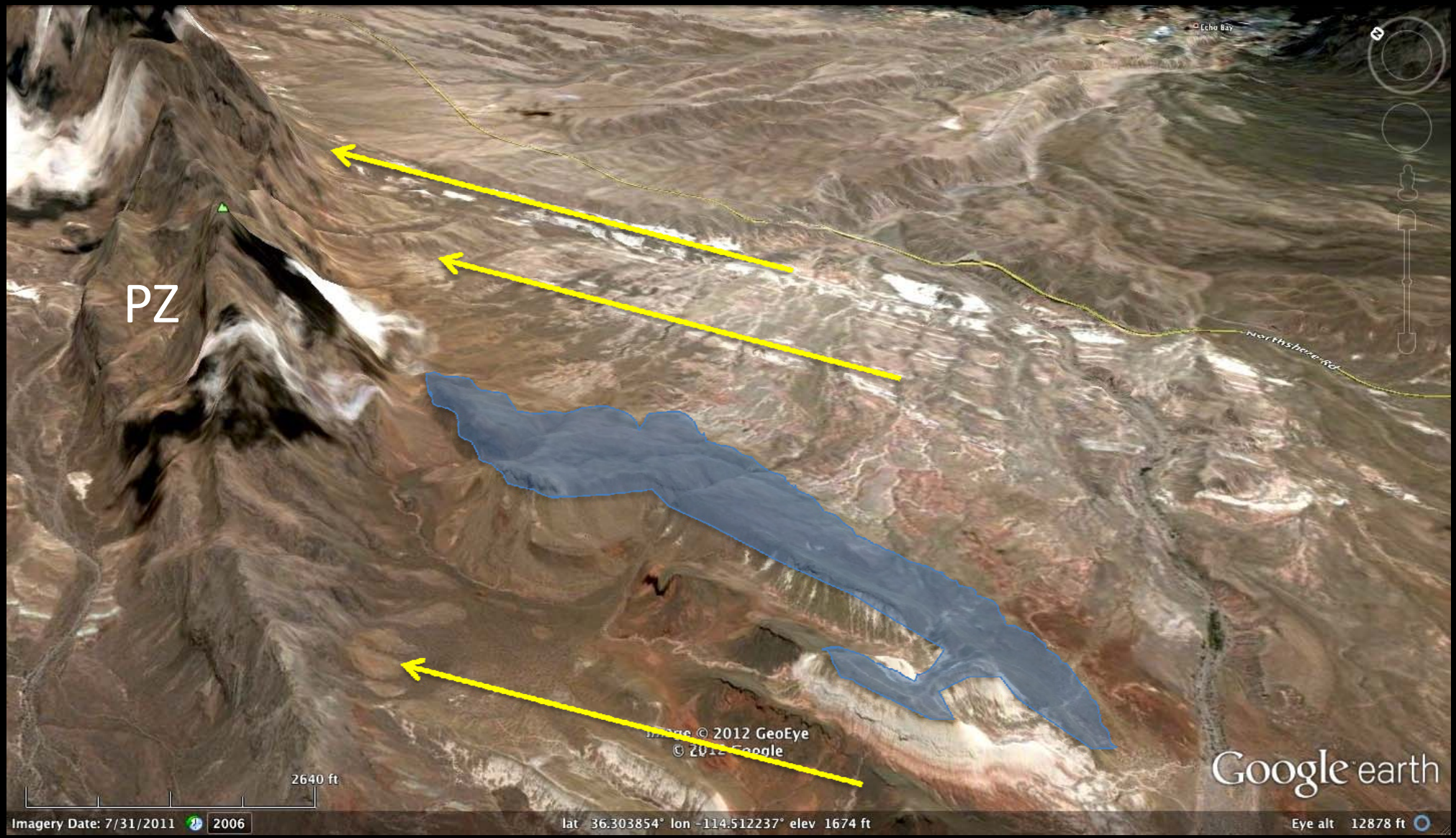
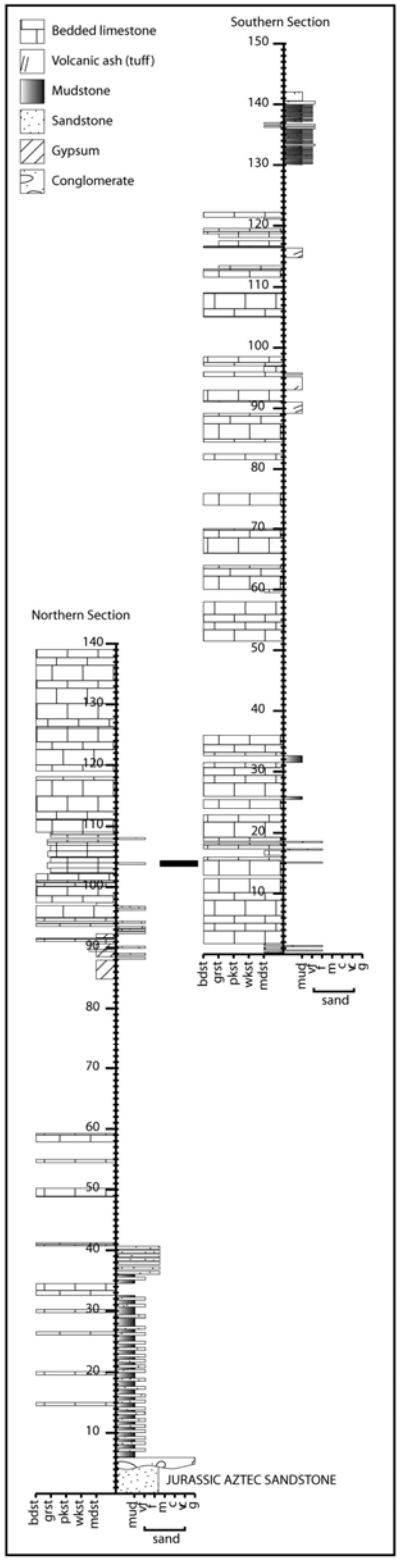
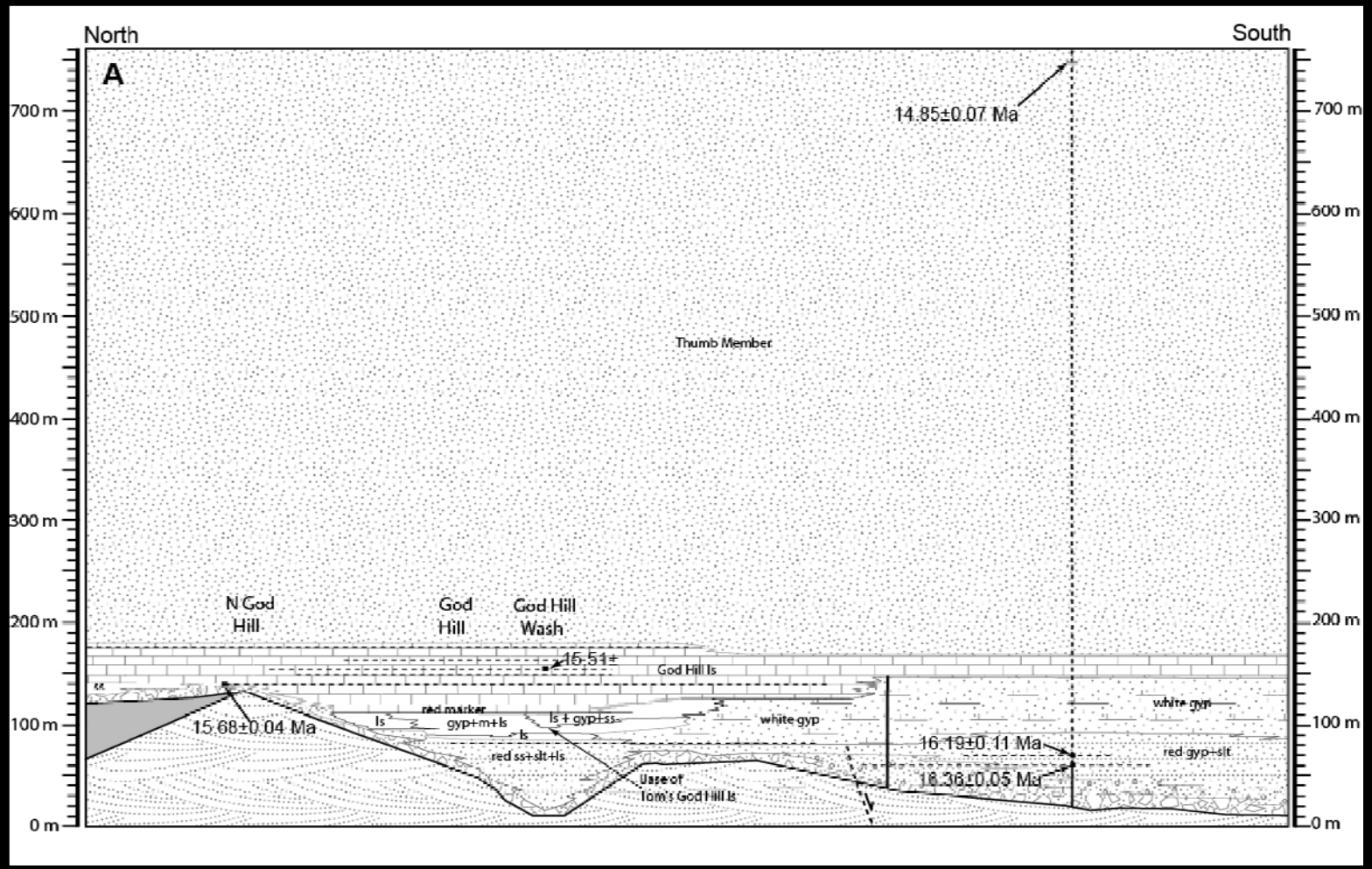
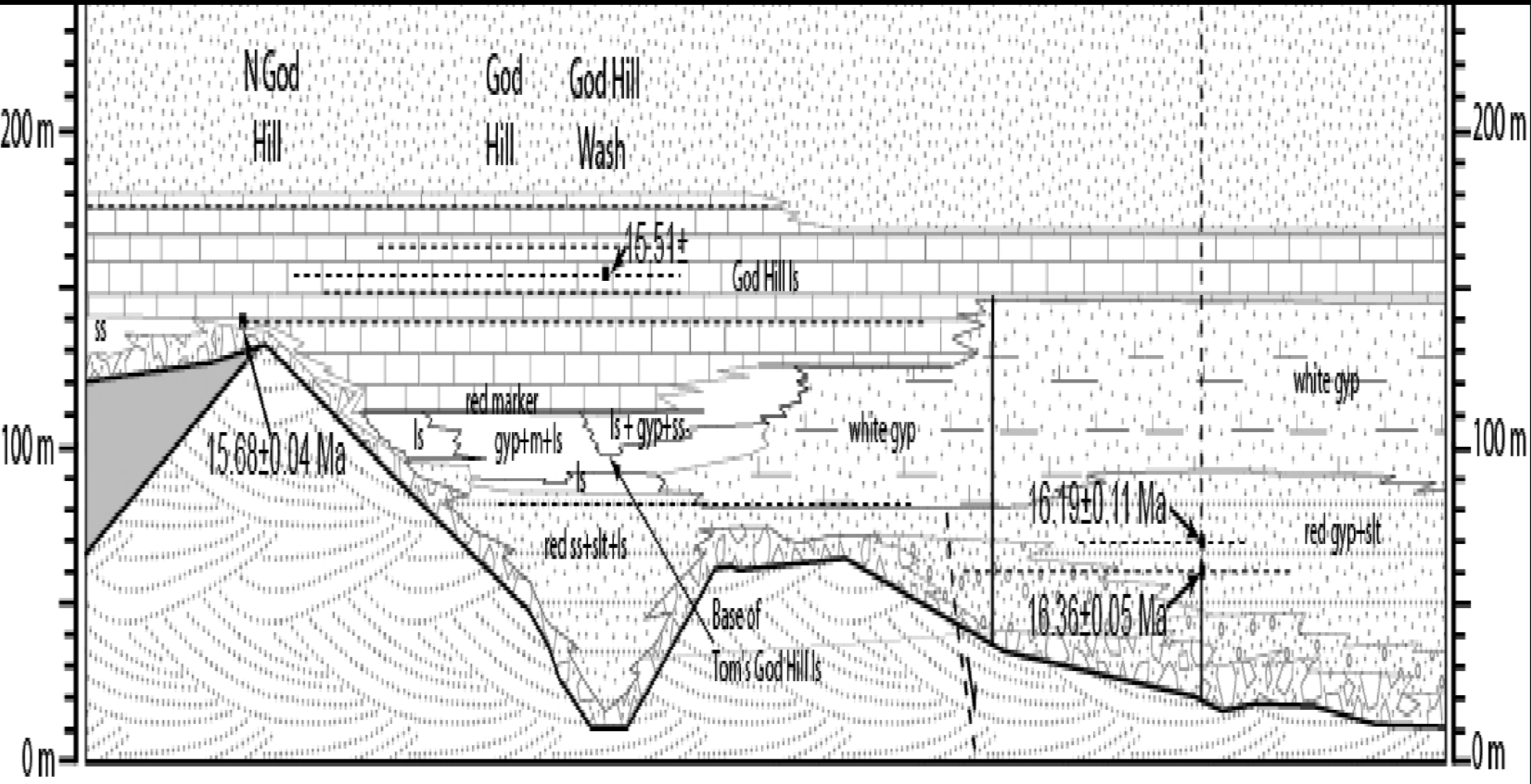
4021500
4021000
4020500
4020000
4019500
4019000
4018500
PZ
Onlap
LS

Thumb basin margin





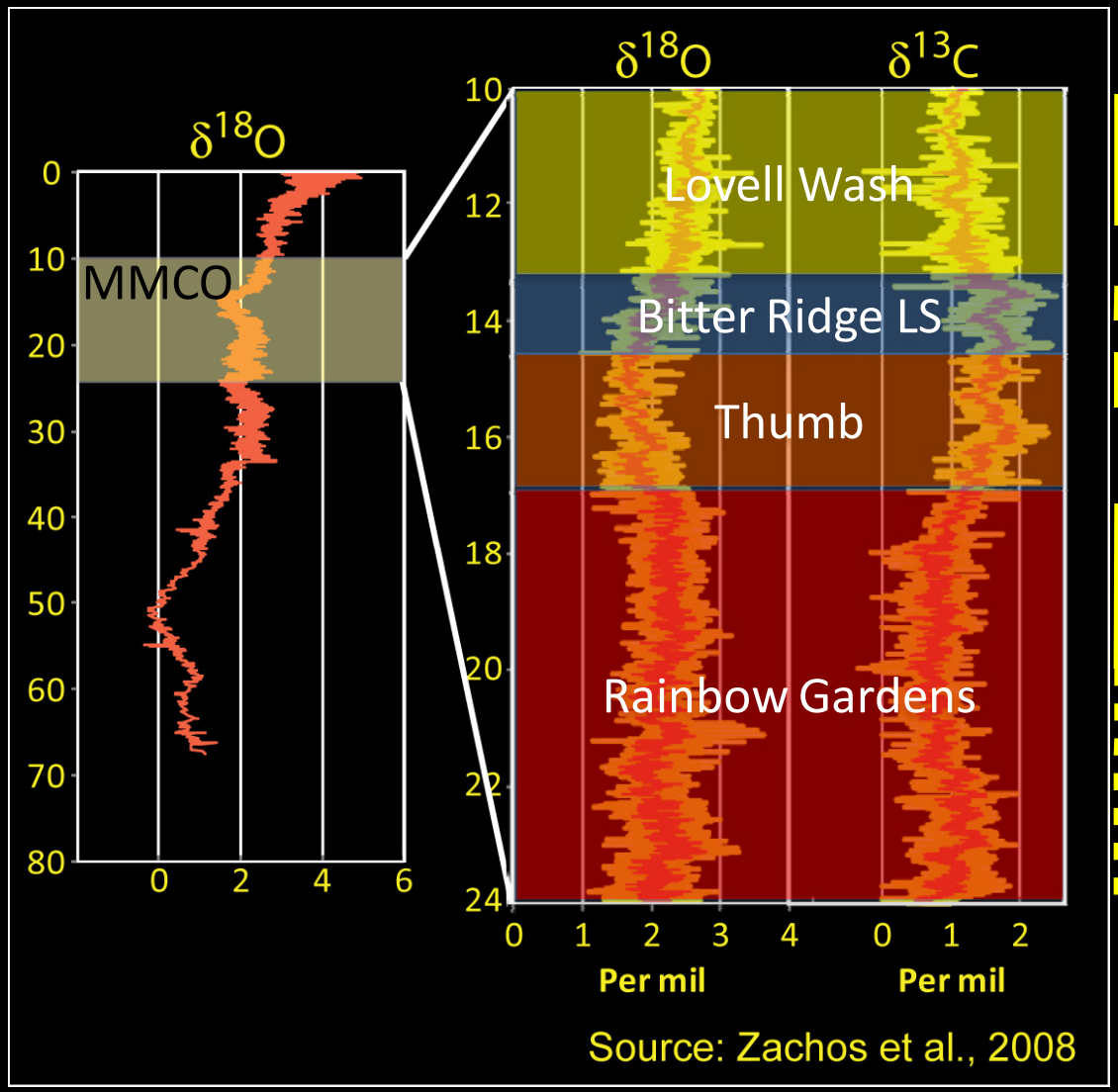



N God Hill
God Hill
God Hill Wash
200 m
100 m
0 m
15.51±
God Hill ls
ss
red marker
ls
gyp+m+ls
ls + gyp+ss
ls
white gyp
white gyp
15.68±0.04 Ma
16.19±0.11 Ma
red gyp+slt
red ss+slt+ls
16.36±0.05 Ma
Base of
Tom's God Hill ls

Bitter Ridge Limestone

Bitter Ridge Limestone

- Syn-extensional with transform faulting
- Laterally very continuous (~35 km X ?)
- Mostly tabular, layer-cake geometry (200 m thick)
- Internally heterogeneous
- Shallow, quasi-perennial saline to hypersaline lake system
- Rapid sedimentation rates (200-600 m/my)



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Continued transtension

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LMFS propagates west

Peak of exhumation and detachment faulting

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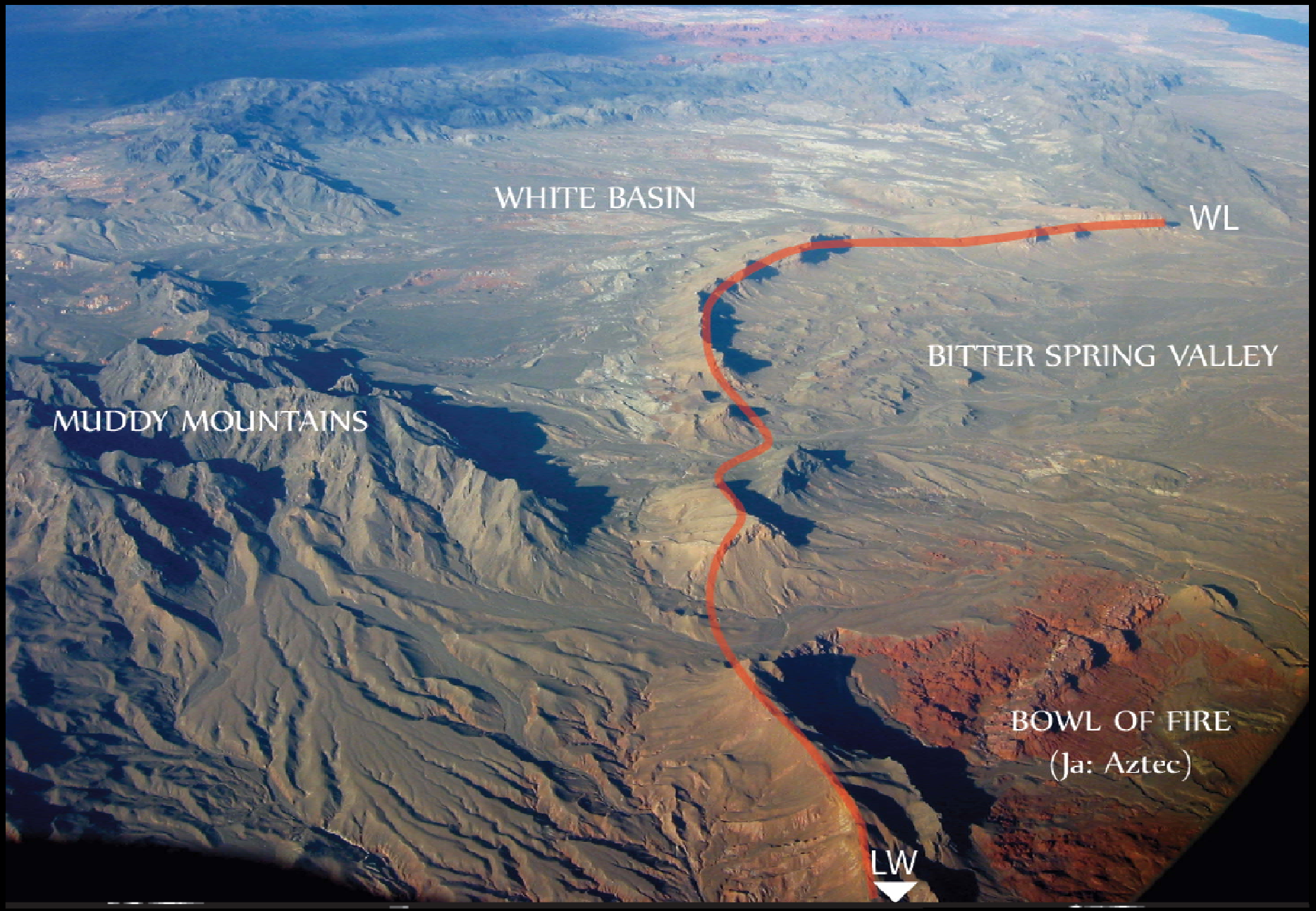
Pre-extension or incipient breakaway faulting with single, distal hinge-point (Janecke)

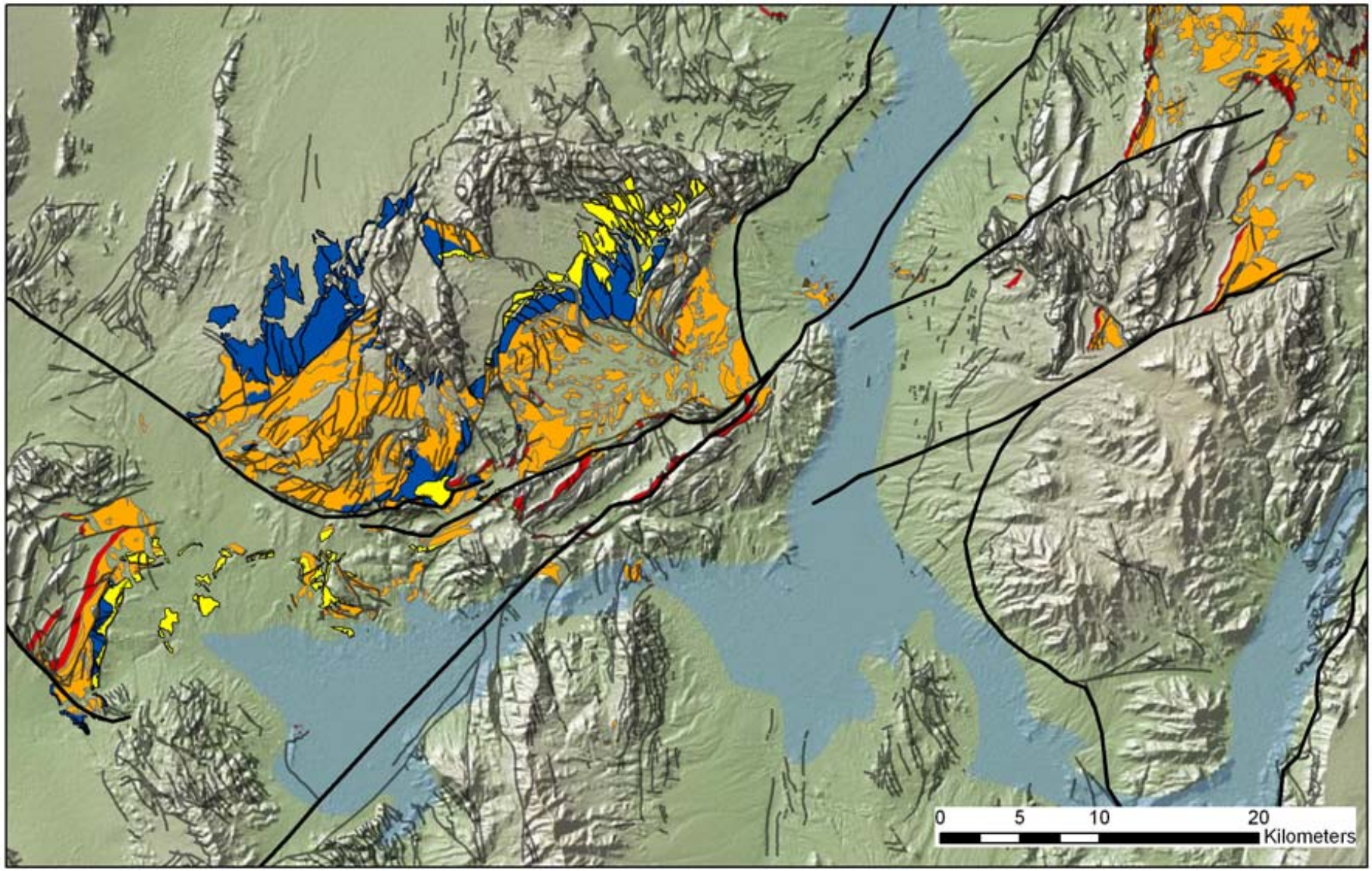
Source: Fryxell & Duebendorfer, 2005; Umhoefer et al., 2010

Presenter's Notes: 28Quality of exposure is excellent. One section in the Slot Canyon (part of the Anniversary Mine locality) is 100% exposed for over 200 m, with polished rock walls. The entire exposed thickness here is close to 500 m.
These images are from the Bitter Ridge Limestone, the thickest and most extensive unit.
The lower granular limestone is tabular and correlative over 15 km
An intervening redbed interval and the overlying Anniversary Mine limestone is less laterally extensive, with lateral facies changes into marls and clastics. Here is an interval that was mined for borates in the 1920s, the actual "Anniversary Mine".


CENTIMETRE
Institute on Lake Superior Geology


etrex
VISTA
GARMIN


WHITE BASIN
WL
BITTER SPRING VALLEY
MUDDY MOUNTAINS
BOWL OF FIRE
(Ja: Aztec)
LW

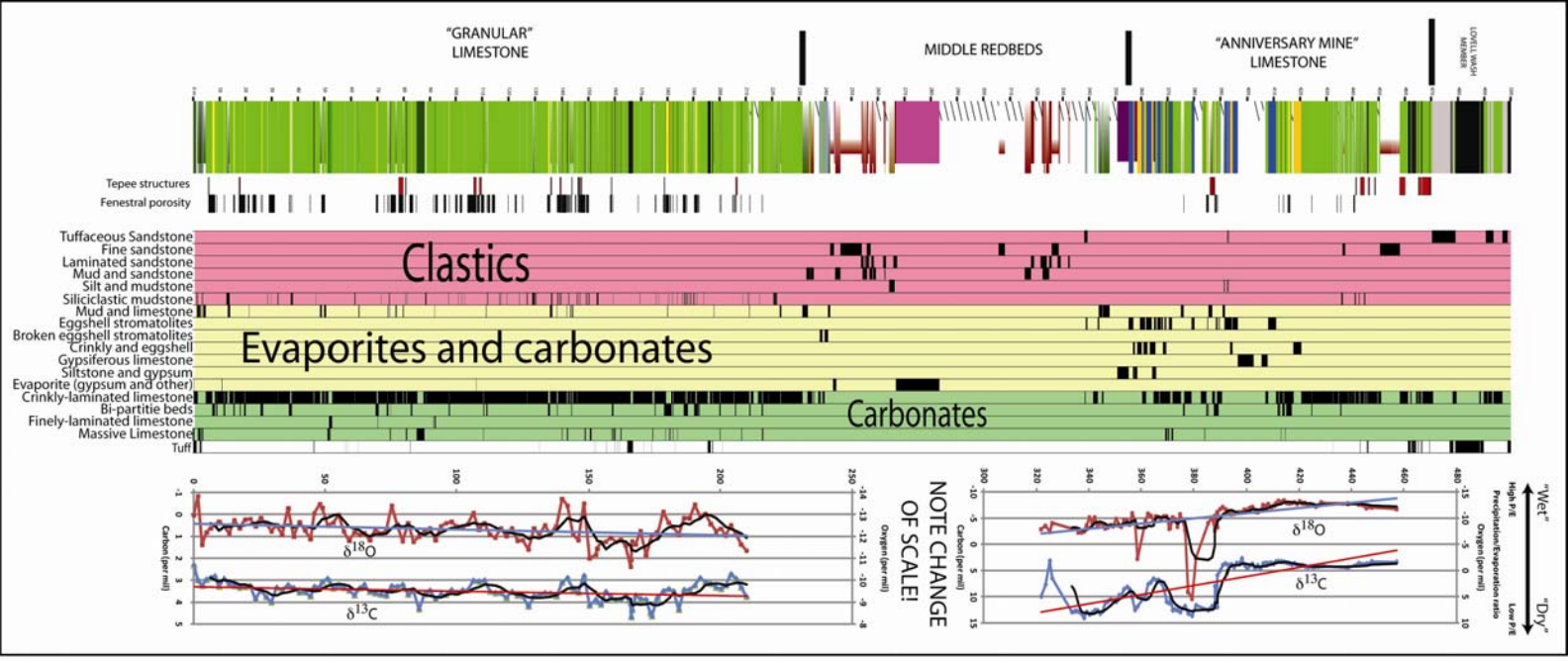


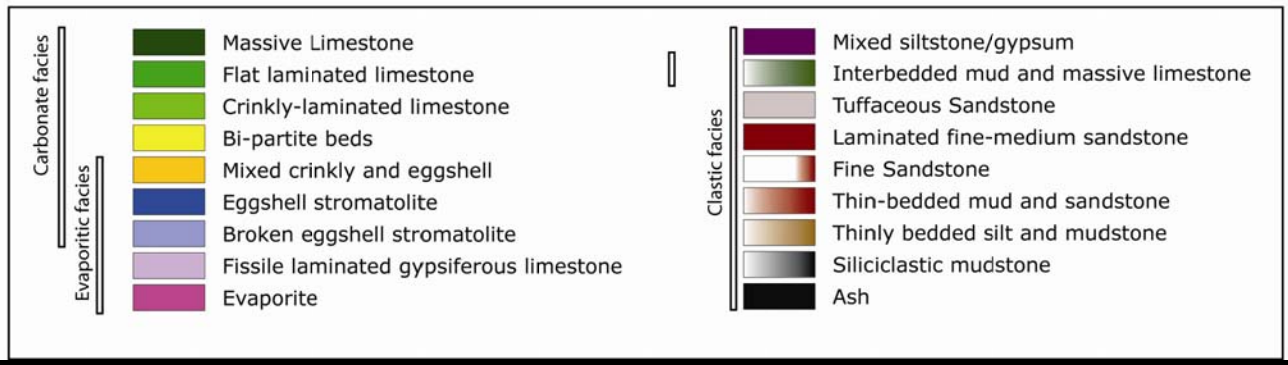
Rainbow Gardens Mbr.

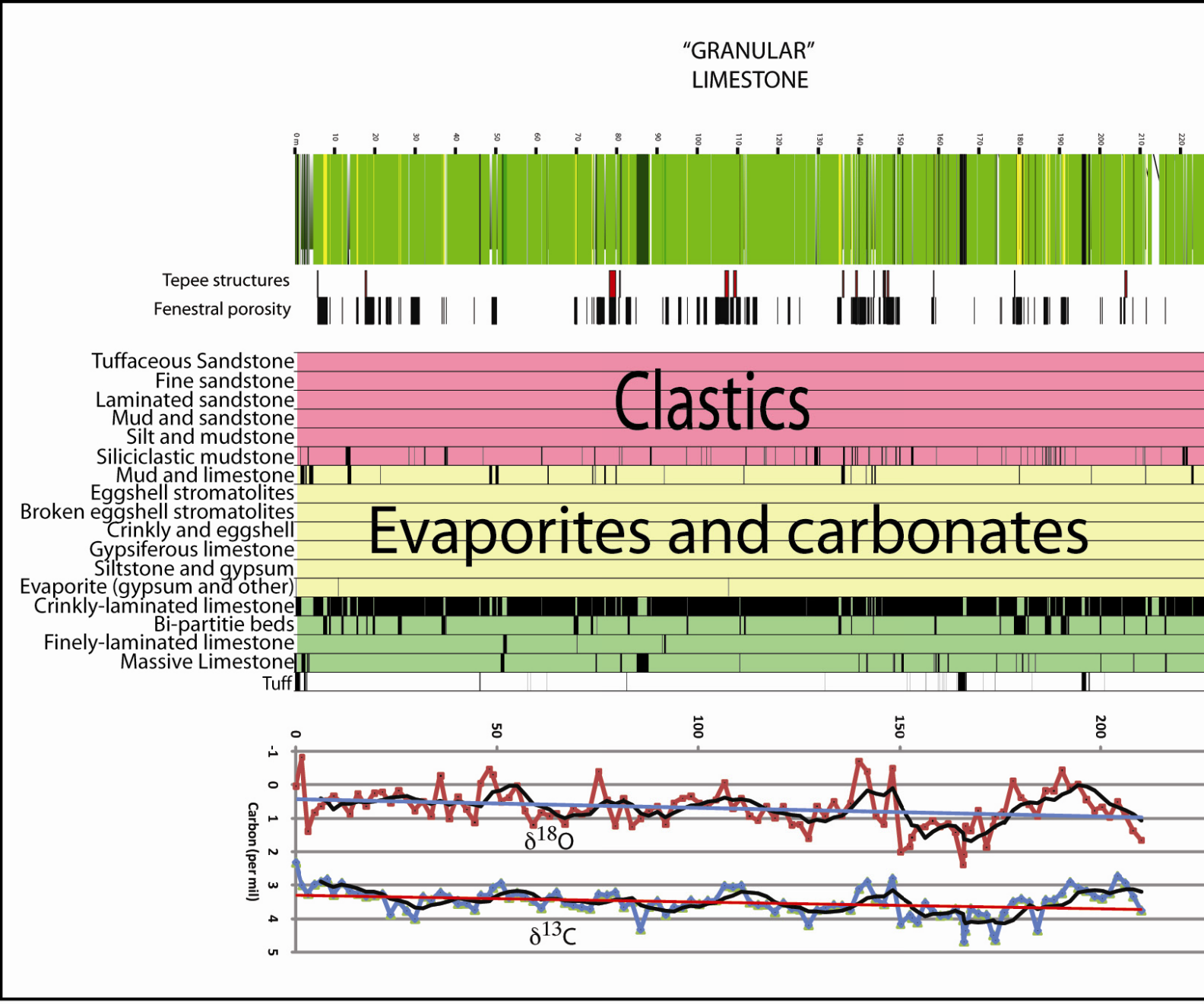
Bitter Ridge Limestone Mbr.

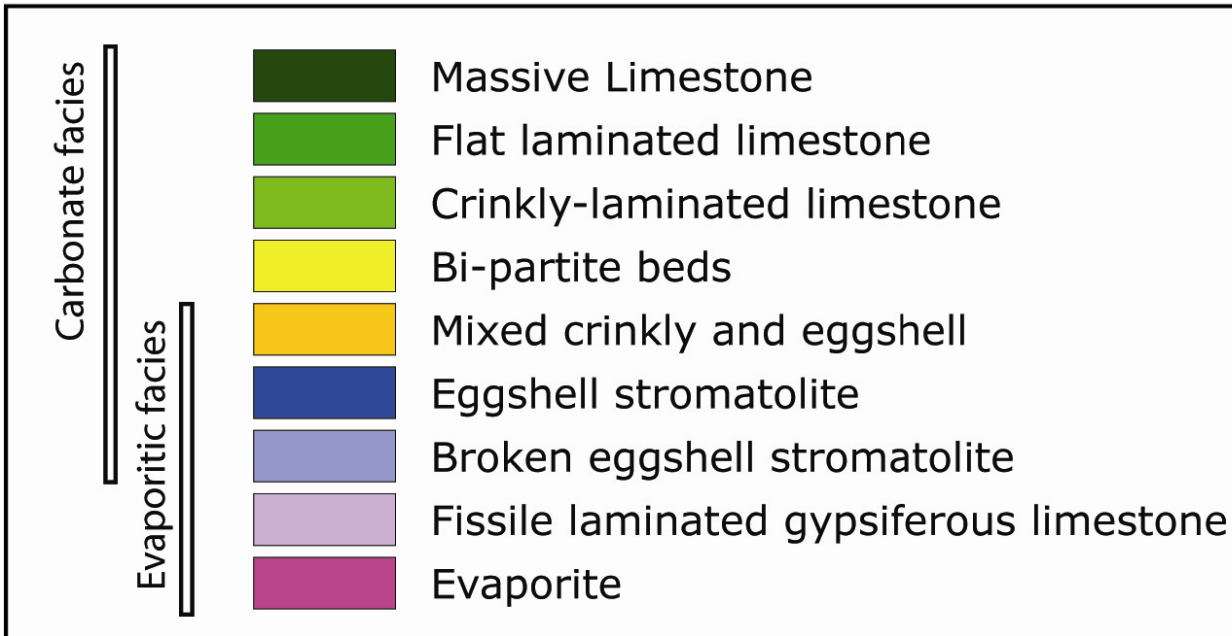
Thumb Mbr.

Lovell Wash Mbr.





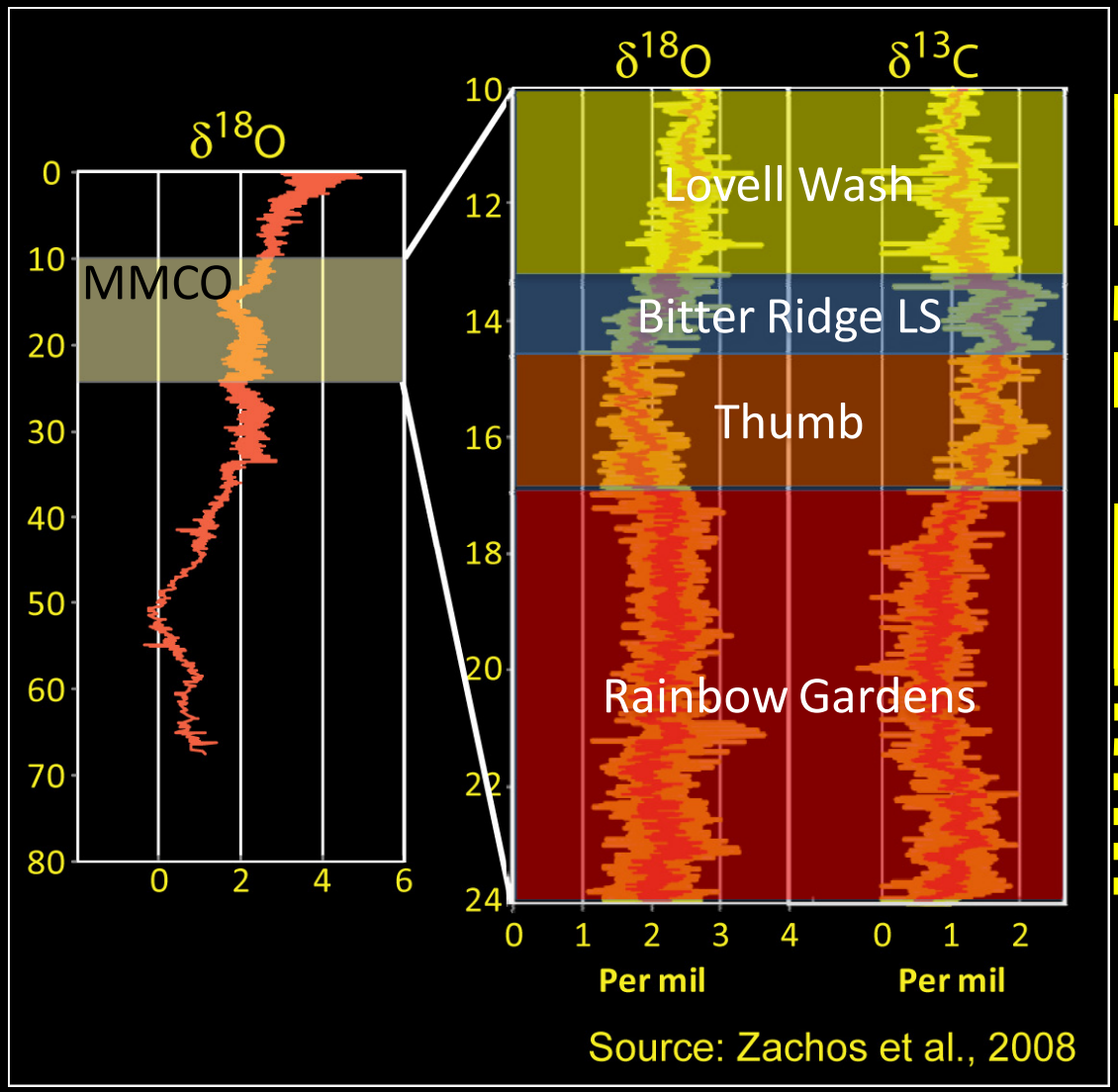

"GRANULAR"
LIMESTONE
Tepee structures
Fenestral porosity
Tuffaceous Sandstone
Fine sandstone
Laminated sandstone
Mud and sandstone
Silt and mudstone
Siliciclastic mudstone
Clastics
Mud and limestone
Eggshell stromatolites
Broken eggshell stromatolites
Crinkly and eggshell
Gypsiferous limestone
Siltstone and gypsum
Evaporite (gypsum and other)
Evaporites and carbonates
Crinkly-laminated limestone
Bi-partitie beds
Finely-laminated limestone
Massive Limestone
Tuff
Carbon (per mil)
δ18O
δ13C


Carbonate facies
Evaporitic facies
Massive Limestone
Flat laminated limestone
Crinkly-laminated limestone
Bi-partite beds
Mixed crinkly and eggshell
Eggshell stromatolite
Broken eggshell stromatolite
Fissile laminated gypsiferous limestone
Evaporite

Lovell Wash

Lovell Wash Member

- On-going transtension
- Rapid lateral and vertical facies changes
- Isolated carbonate build-ups within marls and clastics: some up to 100 m thick but less laterally continuous than BRL
- Intimately associated with evaporites
- Stromatolitic fabrics more diverse
- Isotopically more diverse: hydrothermal input



LVVSZ active (RL strike-slip)

Continued transtension

Lime Ridge Fault active

LMFS propagates west

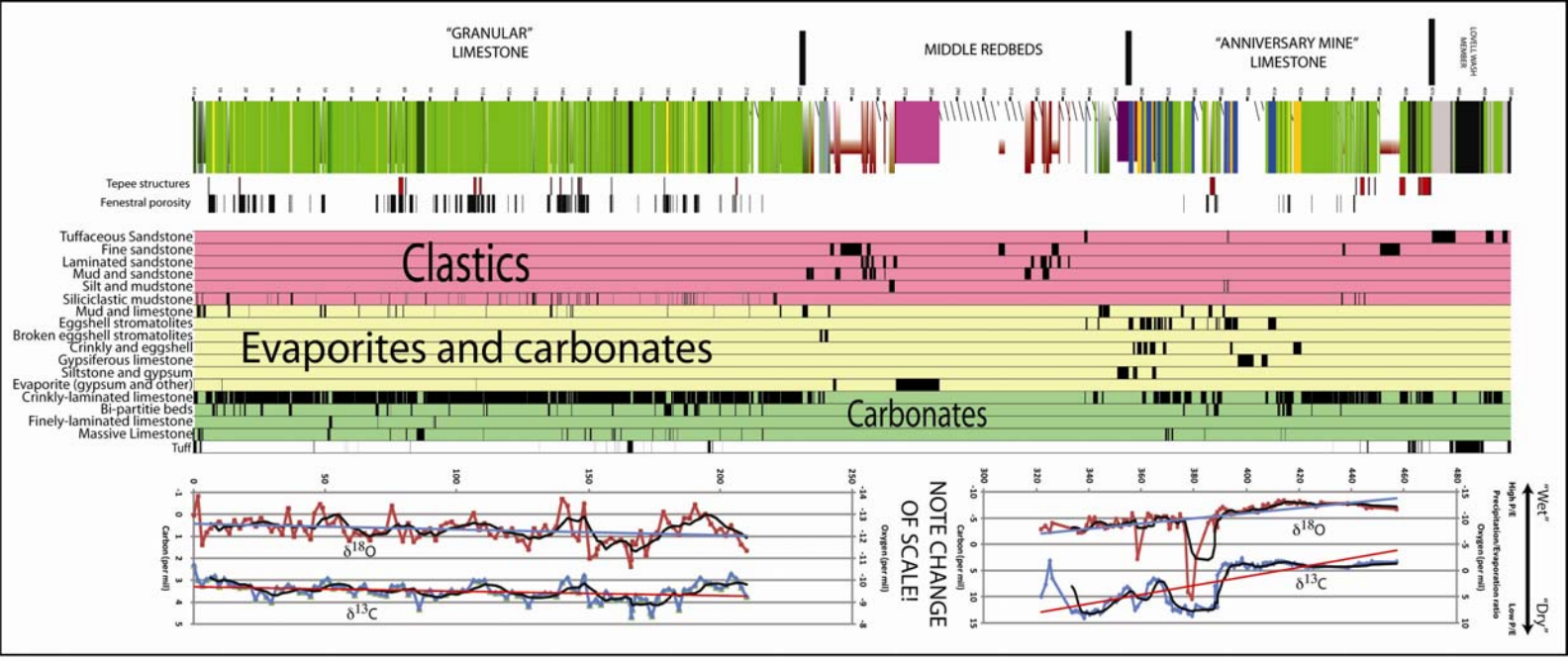
Peak of exhumation and detachment faulting

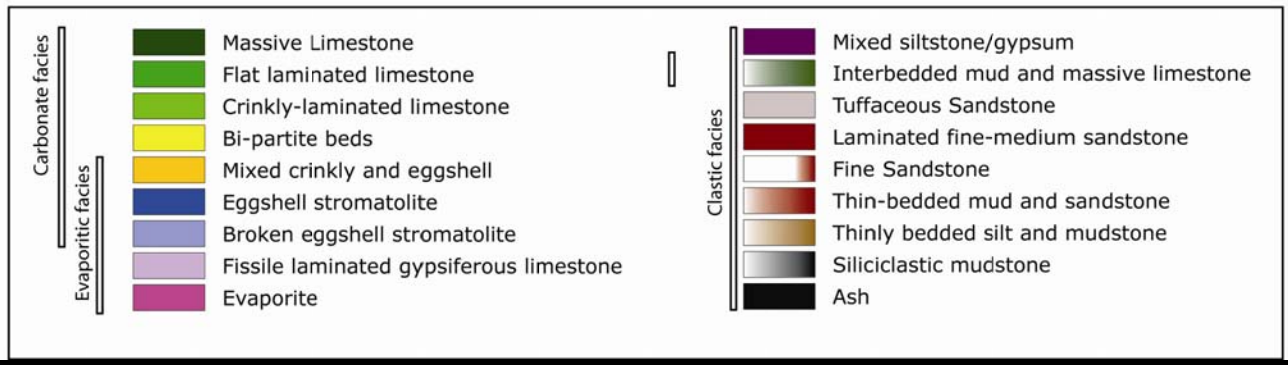
Slow extension

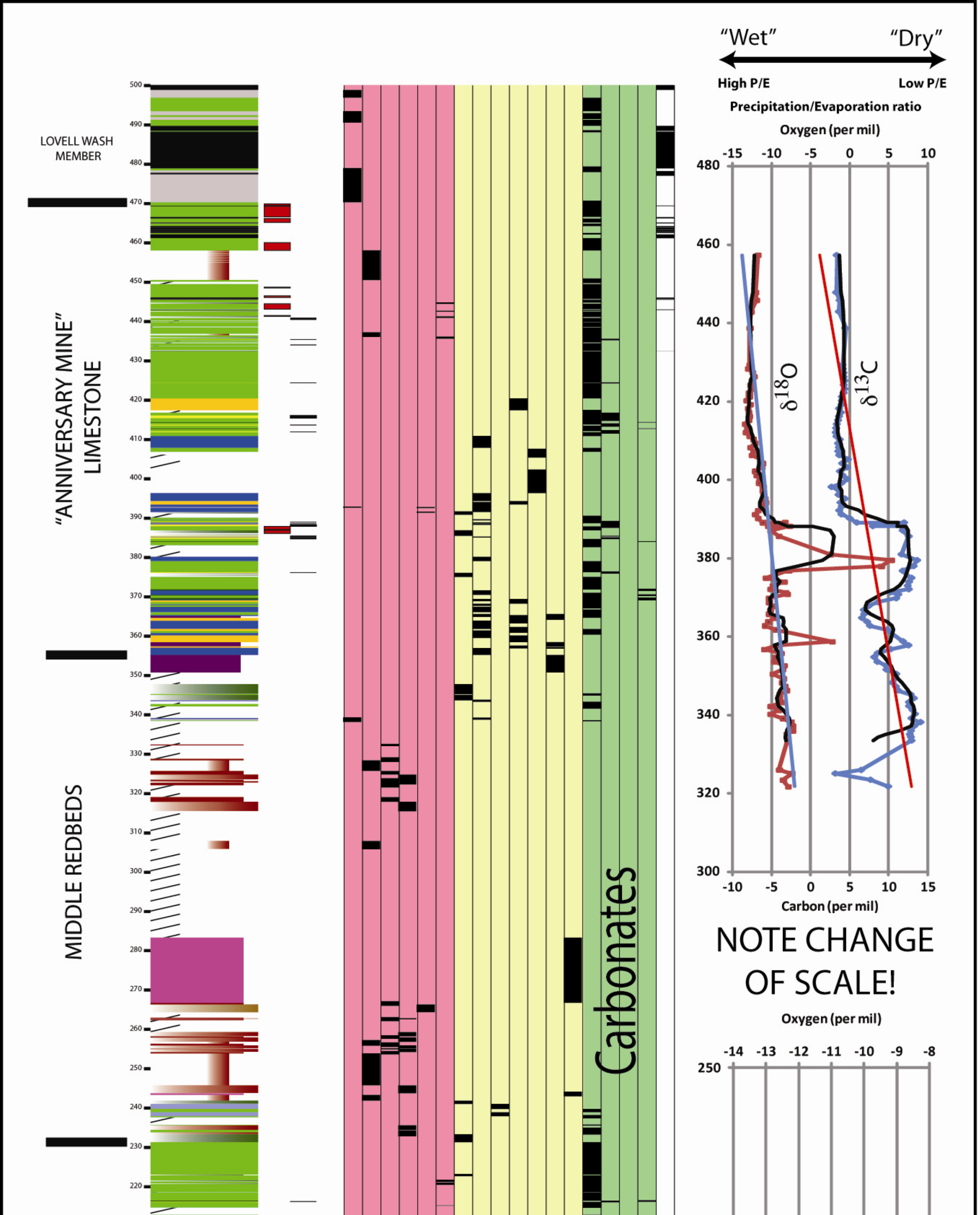
Pre-extension or incipient breakaway faulting with single, distal hinge-point (Janecke)

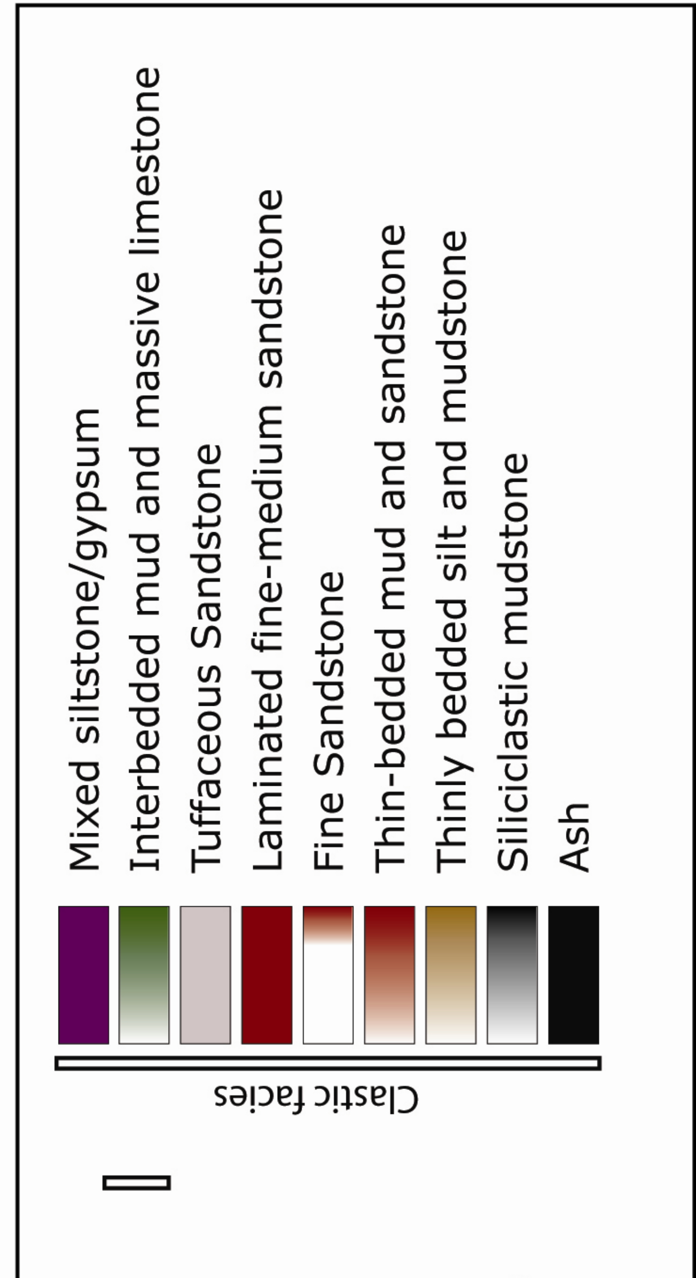
Source: Fryxell & Duebendorfer, 2005; Umhoefer et al., 2010

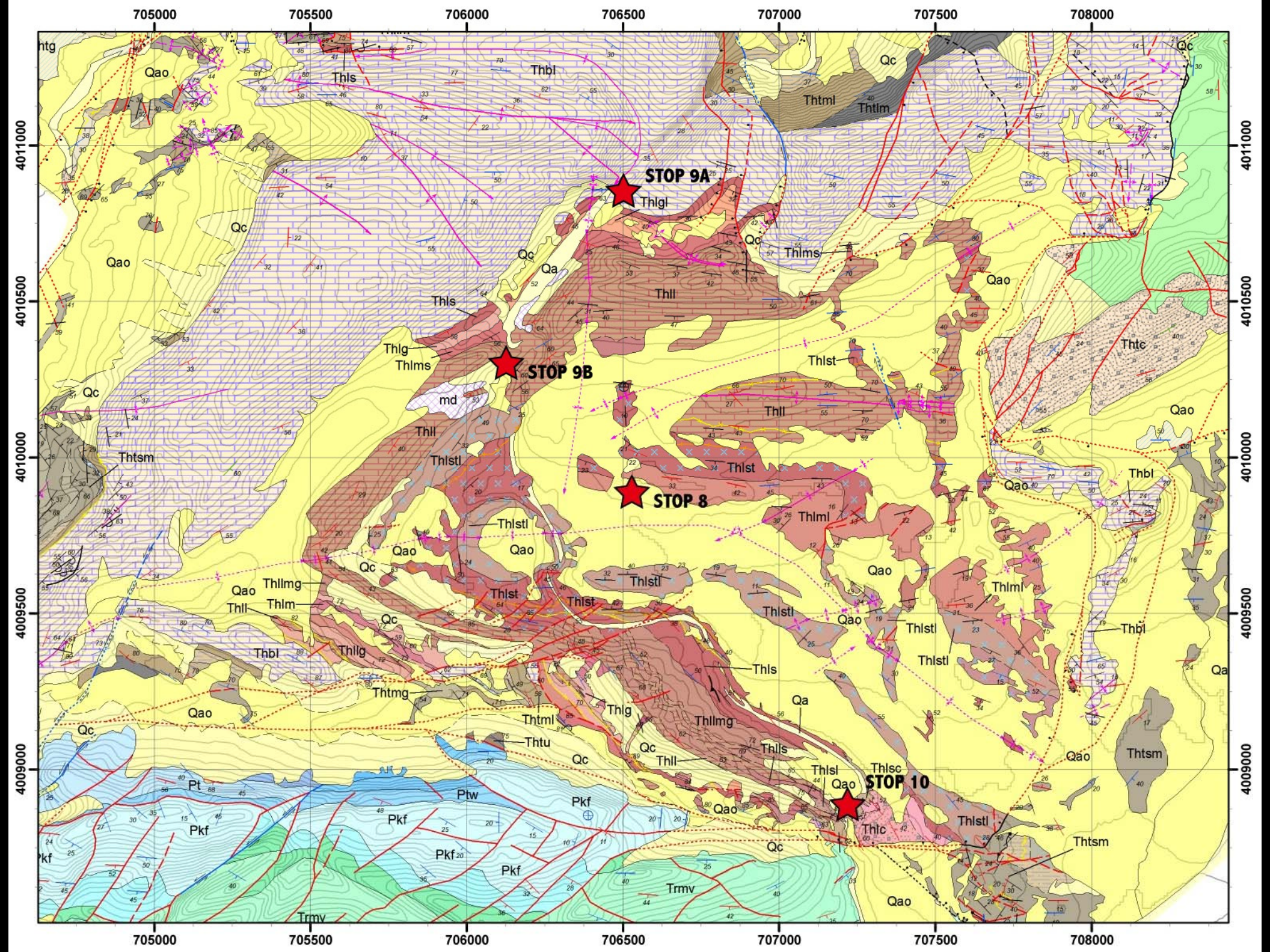
1-2 m stromatolitic bioherm interval



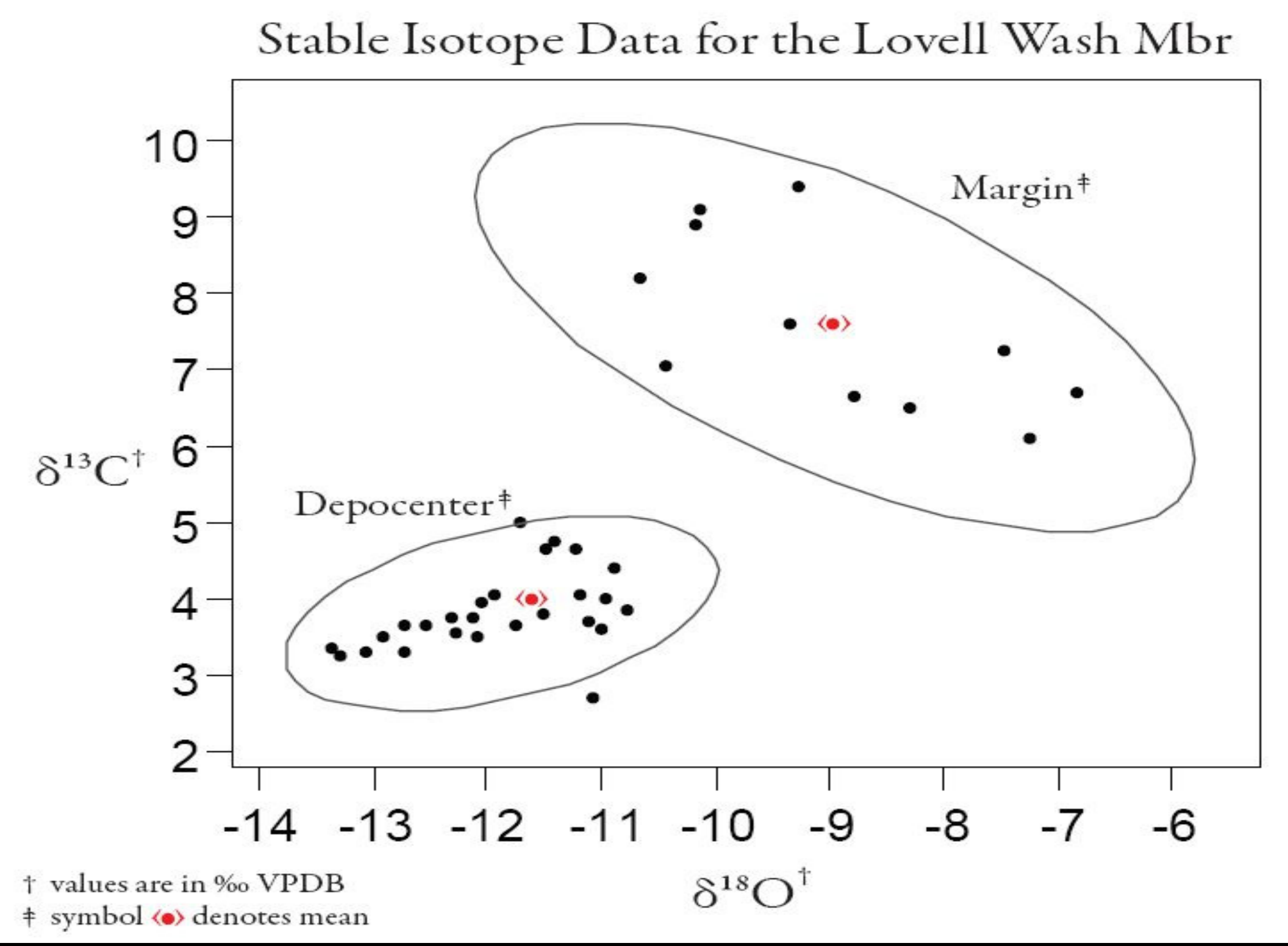


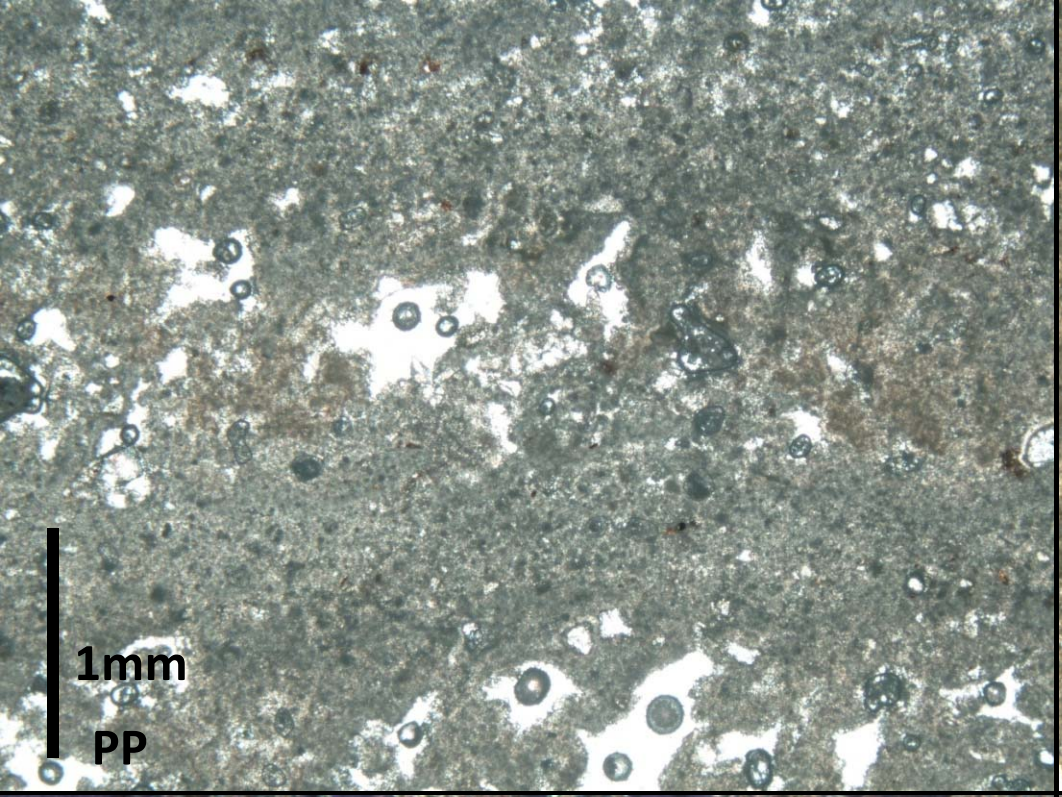

"Wet"
"Dry"
High P/E
Low P/E
Precipitation/Evaporation ratio
Oxygen (per mil)
Carbon (per mil)
NOTE CHANGE OF SCALE!
Oxygen (per mil)
δ18O
δ13C
LOVELL WASH MEMBER
"ANNIVERSARY MINE" LIMESTONE
MIDDLE REDBEDS
Carbonates

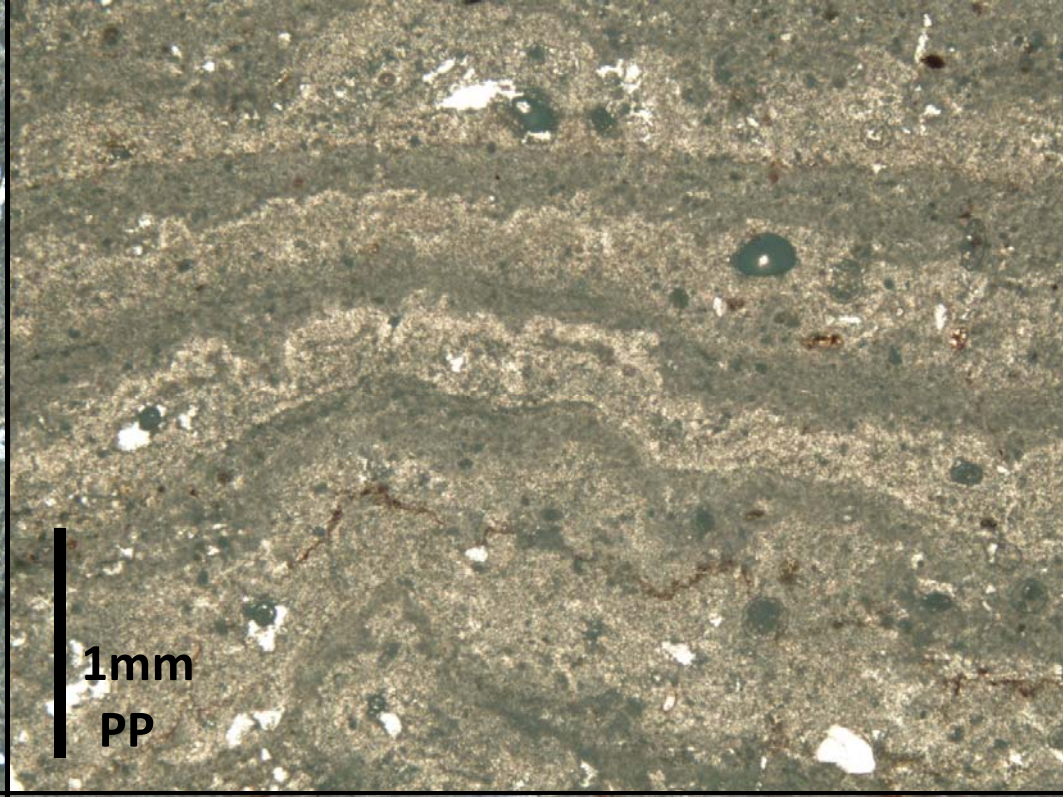

Mixed siltstone/gypsum
Interbedded mud and massive limestone
Tuffaceous Sandstone
Laminated fine-medium sandstone
Fine Sandstone
Thin-bedded mud and sandstone
Thinly bedded silt and mudstone
Siliciclastic mudstone
Ash
Clastic facies

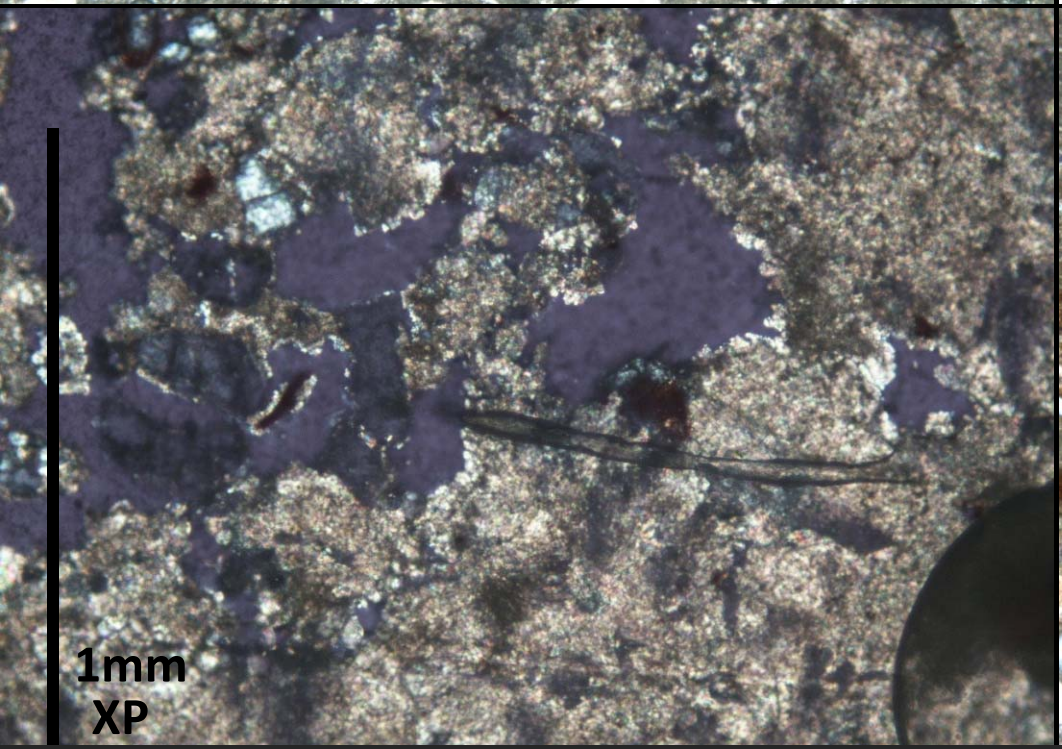

705000
705500
706000
706500
707000
707500
708000
4011000
4010500
4010000
4009500
4009000
STOP 9A
STOP 9B
STOP 8
STOP 10
Qao
Qc
Qa
Thls
Thbl
Thtml
Thtlm
Thlms
Thll
Thlg
Thlgl
Thtc
Thlst
Thlstl
Thtsm
Thlml
Thllmg
Thlm
Thllg
Thtmg
Thtml
Thtu
Thlsl
Thlsc
Thlc
md
Pt
Ptw
Pkf
Trmv

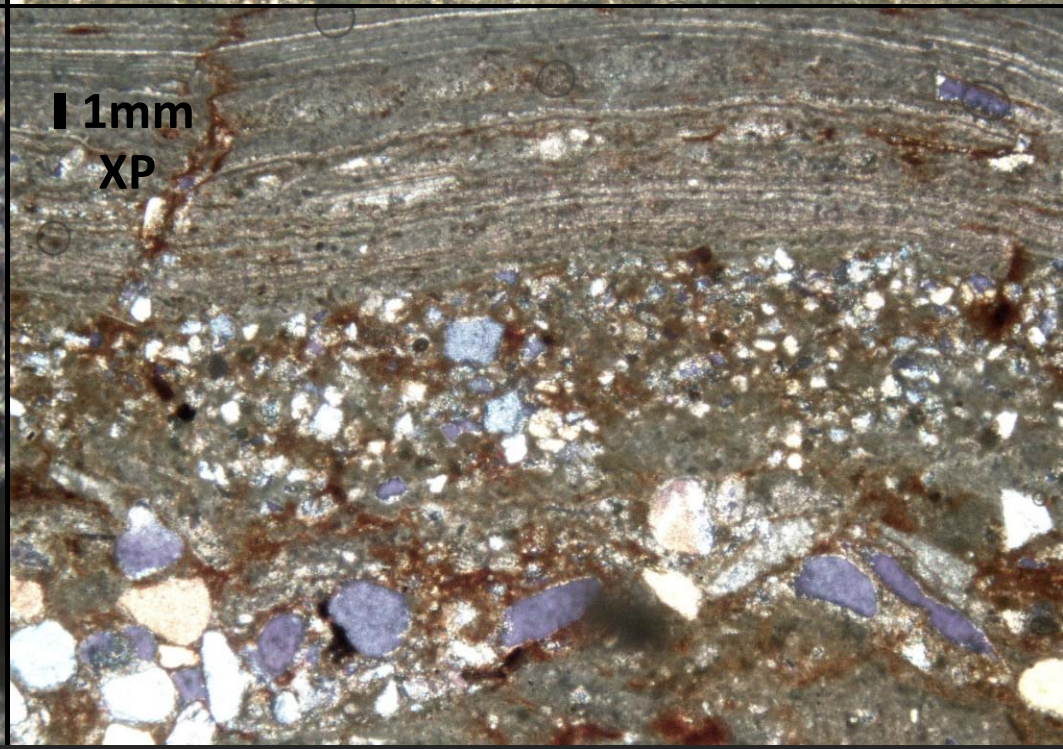
Study Area


Stable Isotope Data for the Lovell Wash Mbr
Margin‡
Depocenter‡
δ13C†
δ18O†
10
9
8
7
6
5
4
3
2
-14
-13
-12
-11
-10
-9
-8
-7
-6
† values are in ‰ VPDB
‡ symbol ⟨●⟩ denotes mean



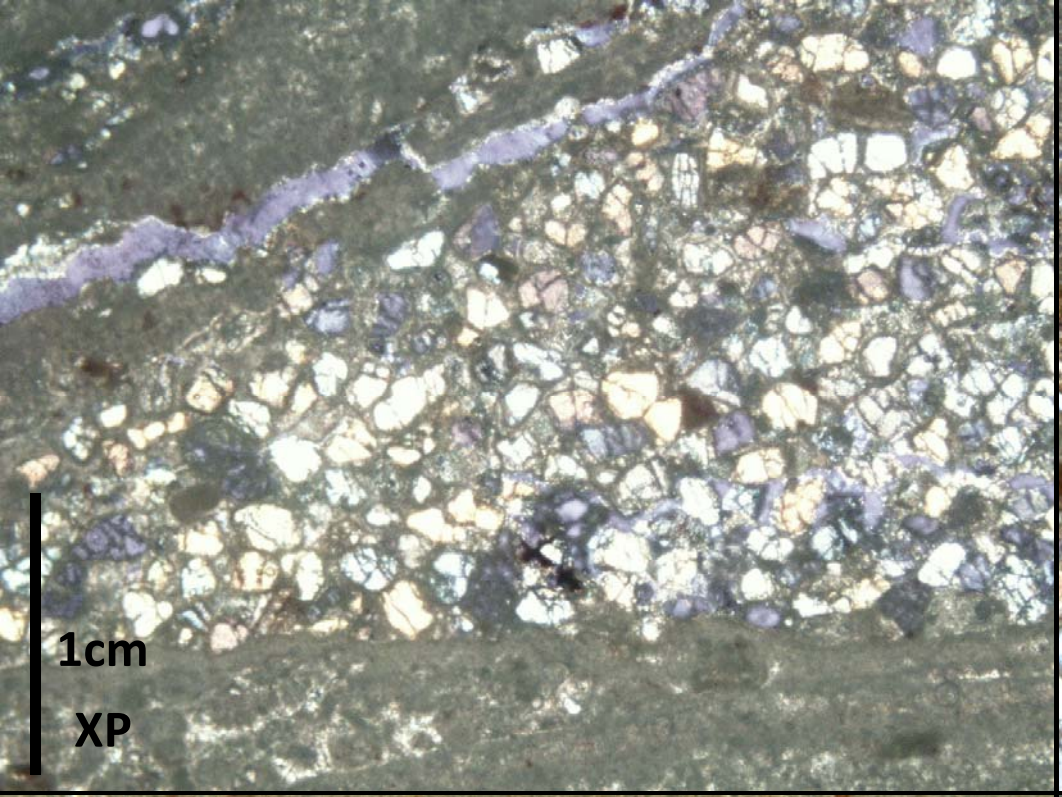


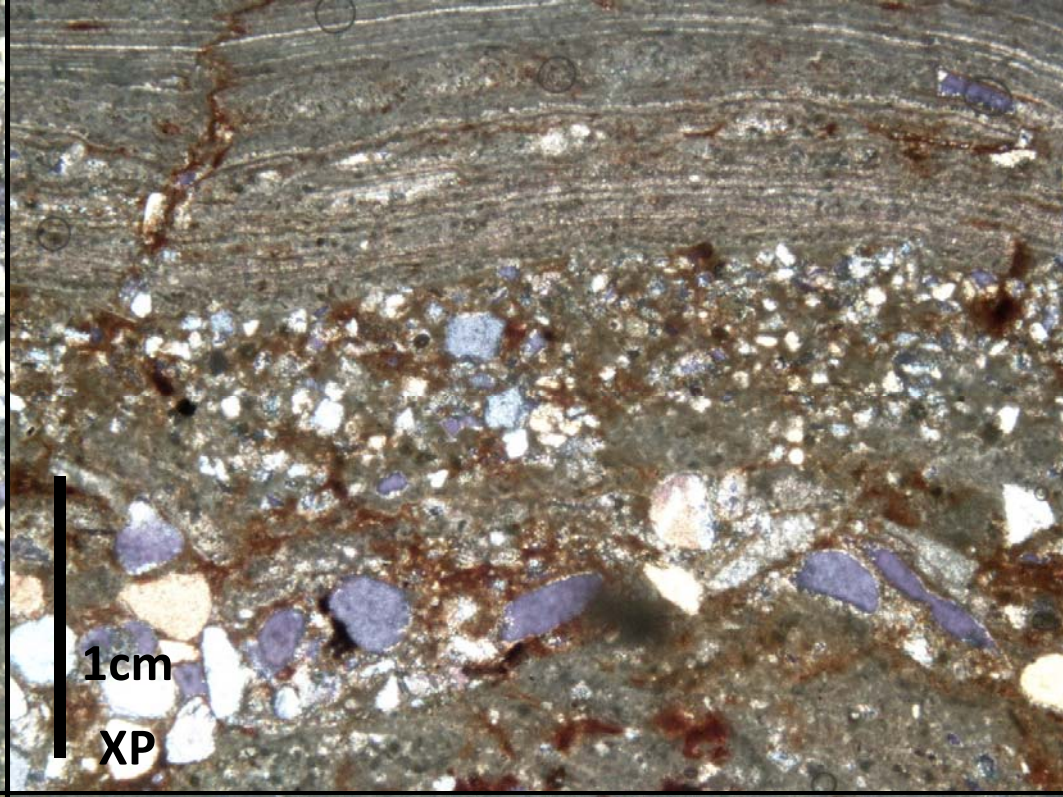


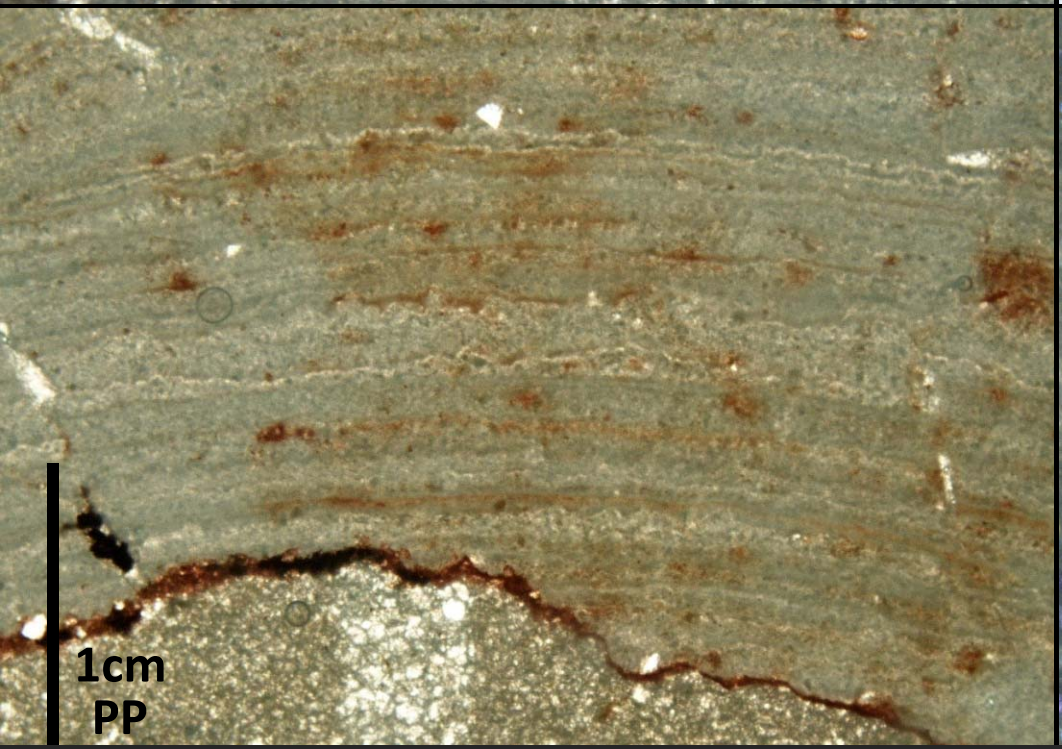


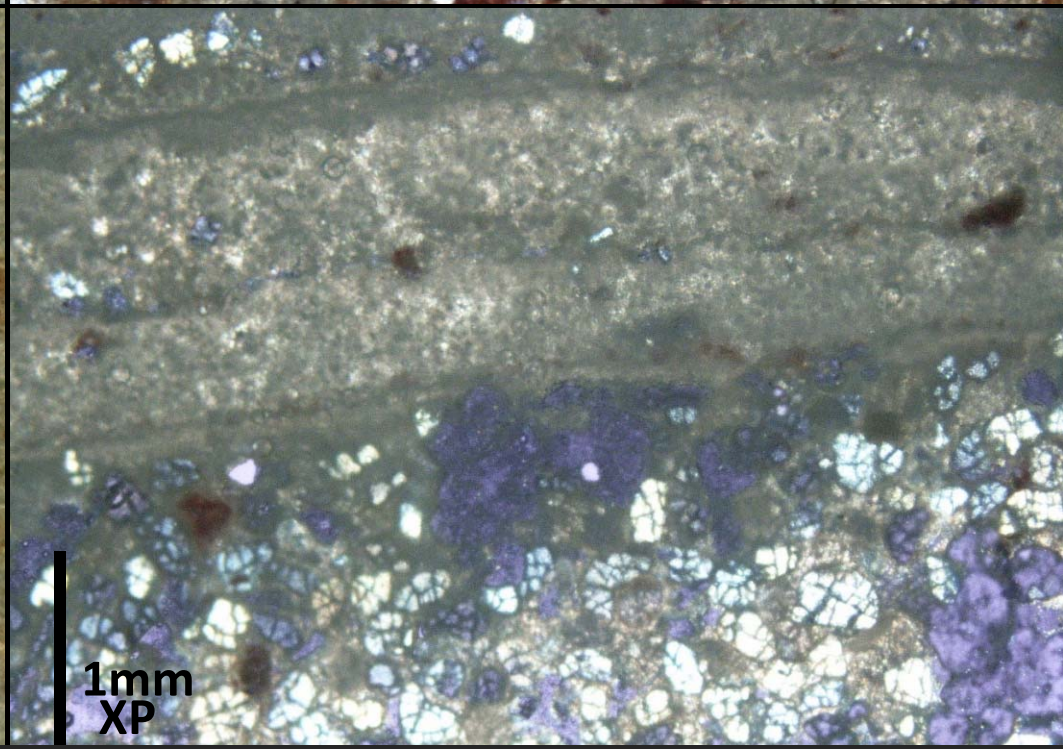
Observations

Presenter's Notes: 48Here we have an outcrop photo of the Marginal Wave Zone, looking from underneath the beds. We can see the underside of oscillatory wave rippled sandstones whose bedforms are preserved by the microbialites.



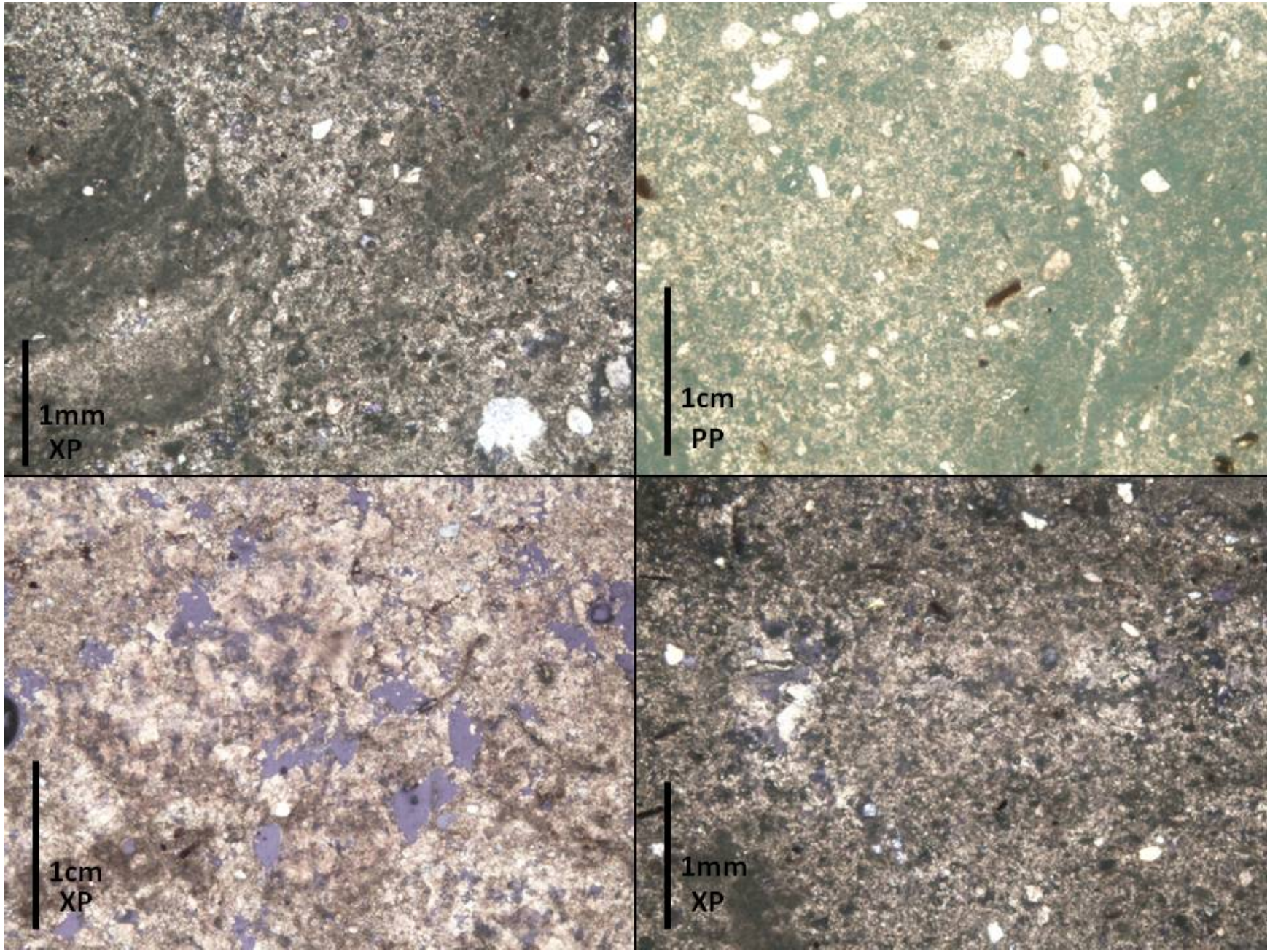






Observations

Presenter's Notes: 50This photo shows the microbial carbonates at the basinal site. We have meter scale packages of centimeter bedded stratiform carbonates. There are no other witnessed morphologies at this scale.



Presenter's Notes: 51The lack of internal structure and morphological features is immediately evident in the basinal samples. These are typical examples of the wispy and discontinuous laminations seen in basinal samples under close examination in hand sample and thin section. Random orientation of small detrital material. Overall, there is a lack of morphological diversity at this scale.

Conclusions

- HSF carbonates show a wide range of microbially mitigated facies
- These facies formed under lacustrine and palustrine conditions
- Formed in both laterally extensive and restricted settings, leading to a varied facies architecture
- Indicate a very unique paleogeography in the Lake Mead region during the Miocene

Mid-Miocene Climatic Optimum

+

Variable styles and rates of extensional faulting

+

Exclusively Pz carbonate provenance =

Thick, nearly pure carbonate alkaline lakes with high microbial primary productivity