Origin of Petroliferous Dolomitic Beds in the Uteland Butte Member, Lower Green River Formation, Uinta Basin, Utah*

Federico Rueda[1], Hans G. Machel[1], and Michael D. Vanden Berg[2]

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Abstract

The lacustrine Green River Formation is an important oil-producing formation in the Uinta Basin, Utah. Of particular interest for horizontal drilling are three beds with up to 100% dolomite in the Uteland Butte member (UBM) of the lower Green River Formation. These beds are 1.5 to 8 feet in thickness and interbedded with organic-rich limestones and shales. They have up to 30% porosity but only max 0.1 mD permeability, thus forming an unconventional reservoir. However, not all dolomitized layers, of which there are several more in the UBM, are of reservoir quality. This study attempts to determine the role of dolomitization and other diagenetic processes in reservoir development, i.e., when and how were the abnormally high porosities paired with low permeabilities created. Furthermore, delineating the regional geometry of the dolomite layers is critical for the understanding the petroleum production potential. Methods of investigation include outcrop and core petrography, thin section microscopy, SEM, XRD, CL, and isotopic analyses. Deposition of the UBM took place during three transgressive-regressive cycles that were driven by climate variations. The lake level was high during cooler and wetter periods that alternated with warmer and drier periods, which led to lower lake levels from reduced fluvial input and/or evaporation. The three reservoir layers were deposited during the first of these cycles as lime muds in lacustrine littoral to sublittoral environments as intraclastic, peloidal grainstones, and silty peloidal packstones, and in shallow littoral environments as peloidal, bioturbated mudstones and wackestones The dolomite-bearing layers are greenish to beige in hand specimen and outcrop. Crystal sizes are <15 µm and porosity is mainly intercrystal. There is no discernible relationship between dolomitization and depositional environments. Permeability is low due to irregular and commonly disconnected pore throats. In addition, post-dolomitization silicification commonly formed nodules and layers of length-slow chalcedony and equigranular quartz, as well as blocky ferroan calcite and equant to blocky calcite cement, which reduced secondary porosity and permeability. Dolomitization took place very early, i.e., almost syndepositionally, from lake water that was moderately evaporated and probably enriched in Mg during drier periods. Increased fresh water input during more humid climate periods stopped dolomitization and facilitated further deposition of lime mud layers that are now interbedded with the dolomitized beds. The origin of the microporosity - or lack thereof - is as yet undetermined.

References Cited

Logan, S.K., J.F. Sarg, and M.D. Vanden Berg, 2016, Lithofacies, deposition early diagenesis, and porosity of the Uteland Butte member, Green River Formation, Eastern Uinta Basin, Utah and Colorado: Open File report 652, Utah Geological Survey.

Sibley, D.F., and J.M. Gregg, 1987, Classification of Dolomite Rock Textures: Journal of Sedimentary Petrology, v. 57/6, p. 967-975.

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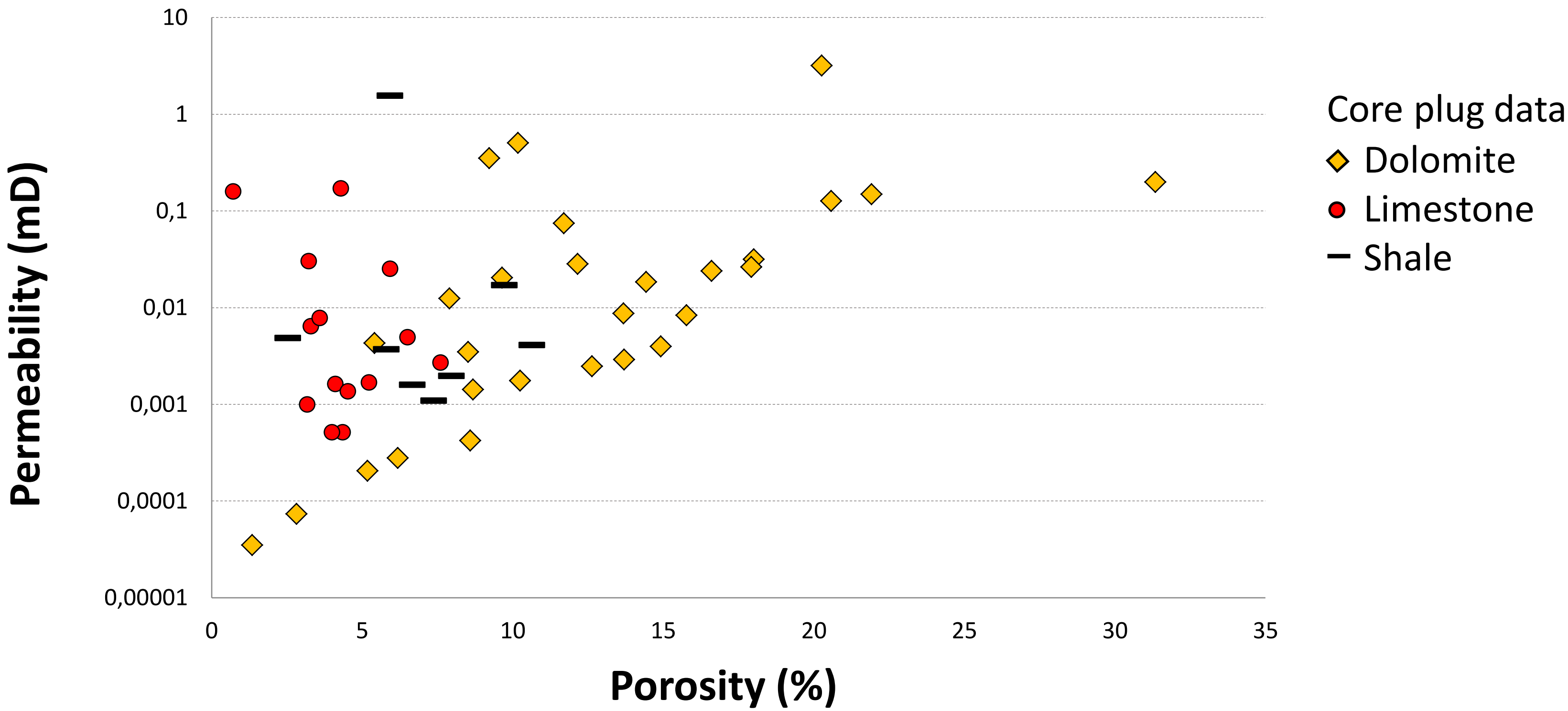
UNIVERSITY OF ALBERTA

UTAH DNR GEOLOGICAL SURVEY

1. **Dolomite Reservoirs Characteristics**
2. Objectives
3. Methodology
4. Study Area
5. Stratigraphy
6. Facies - Depositional Environments
7. Cyclicity
8. Dolomite Textures
9. Geochemistry
10. Interpretations
11. Conclusions

DOLOMITE RESERVOIR CHARACTERISTICS



- ✓ Unconventional reservoirs
- ✓ Estimated resources: **177 MMOB** / **218 BCFG**
- ✓ Depth: North: ~8200 ft (~2700 m) / South: ~5500 ft (~ 1700 m)
- ✓ Dolomite bed thickness: ~**1.2 – 7.5 ft** (~0.5 m – 2.5 m)
- ✓ BHT: 200°-140°F (90 – 60 °C)

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OBJECTIVES

1. Origin of the Uteland Butte member dolomites?
2. Implications for reservoir geology?

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METHODOLOGY

- ✓ Core + well logs + Outcrops
- ✓ Petrography, CL, SEM
- ✓ XRD, EMP

  Trace Elements
- ✓ Conventional stable isotopes

  Clumped isotopes

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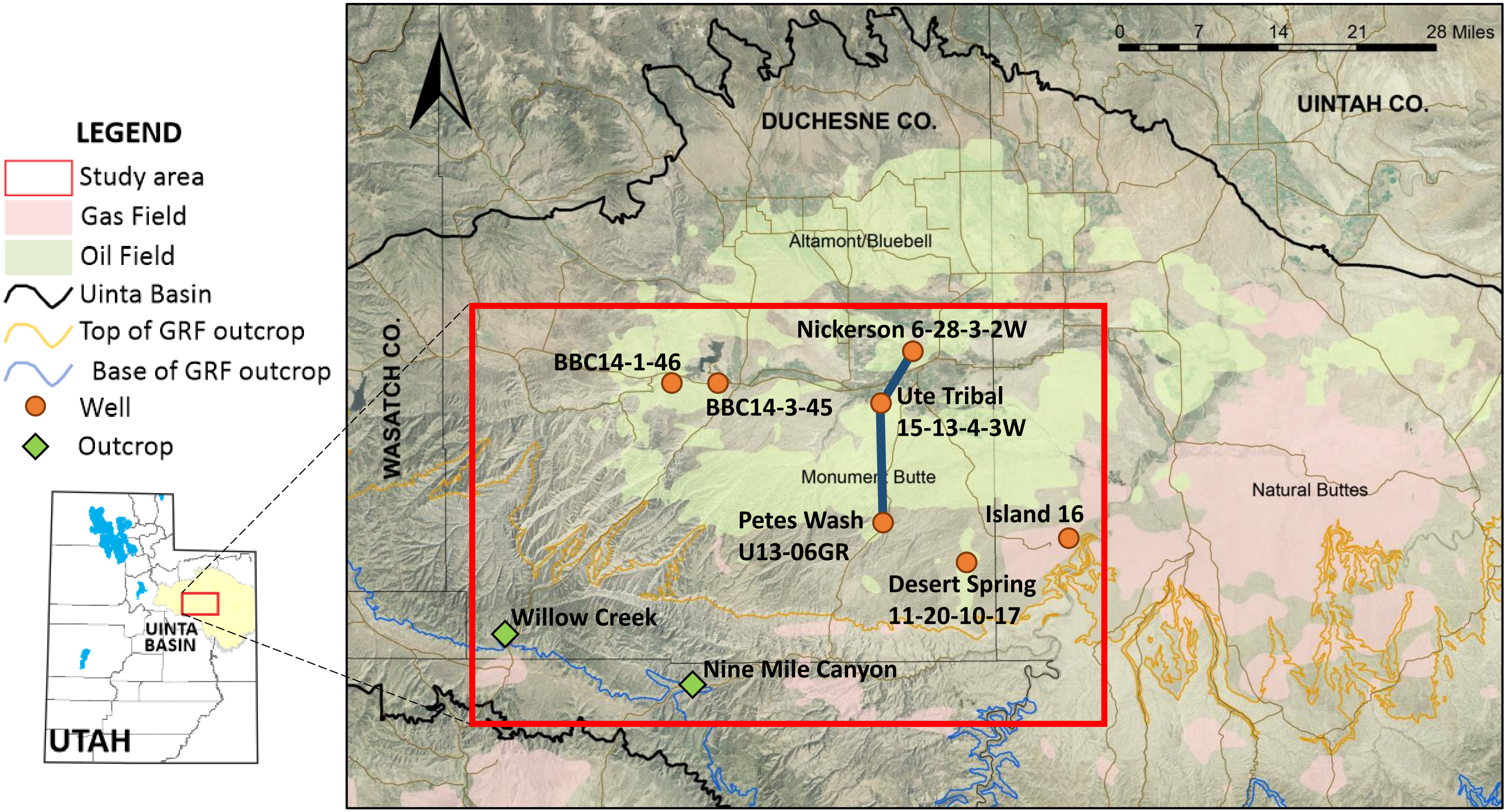
STUDY AREA



LEGEND
Study area
Gas Field
Oil Field
Uinta Basin
Top of GRF outcrop
Base of GRF outcrop
Well
Outcrop
UINTA BASIN
UTAH
0 7 14 21 28 Miles
DUCHESNE CO.
UINTAH CO.
WASATCH CO.
Altamont/Bluebell
Nickerson 6-28-3-2W
BBC14-1-46
BBC14-3-45
Ute Tribal 15-13-4-3W
Monument Butte
Natural Buttes
Petes Wash U13-06GR
Island 16
Desert Spring 11-20-10-17
Willow Creek
Nine Mile Canyon

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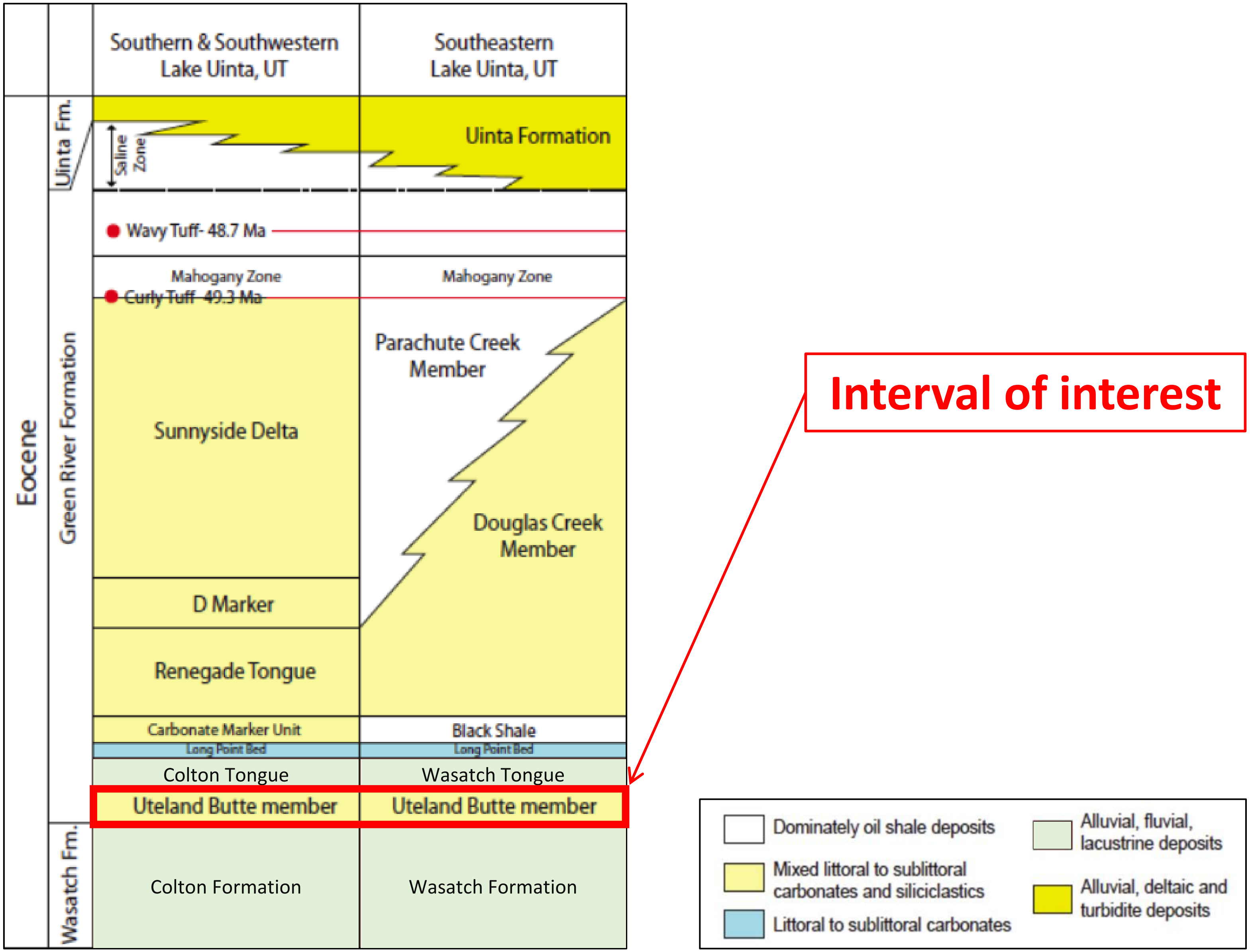
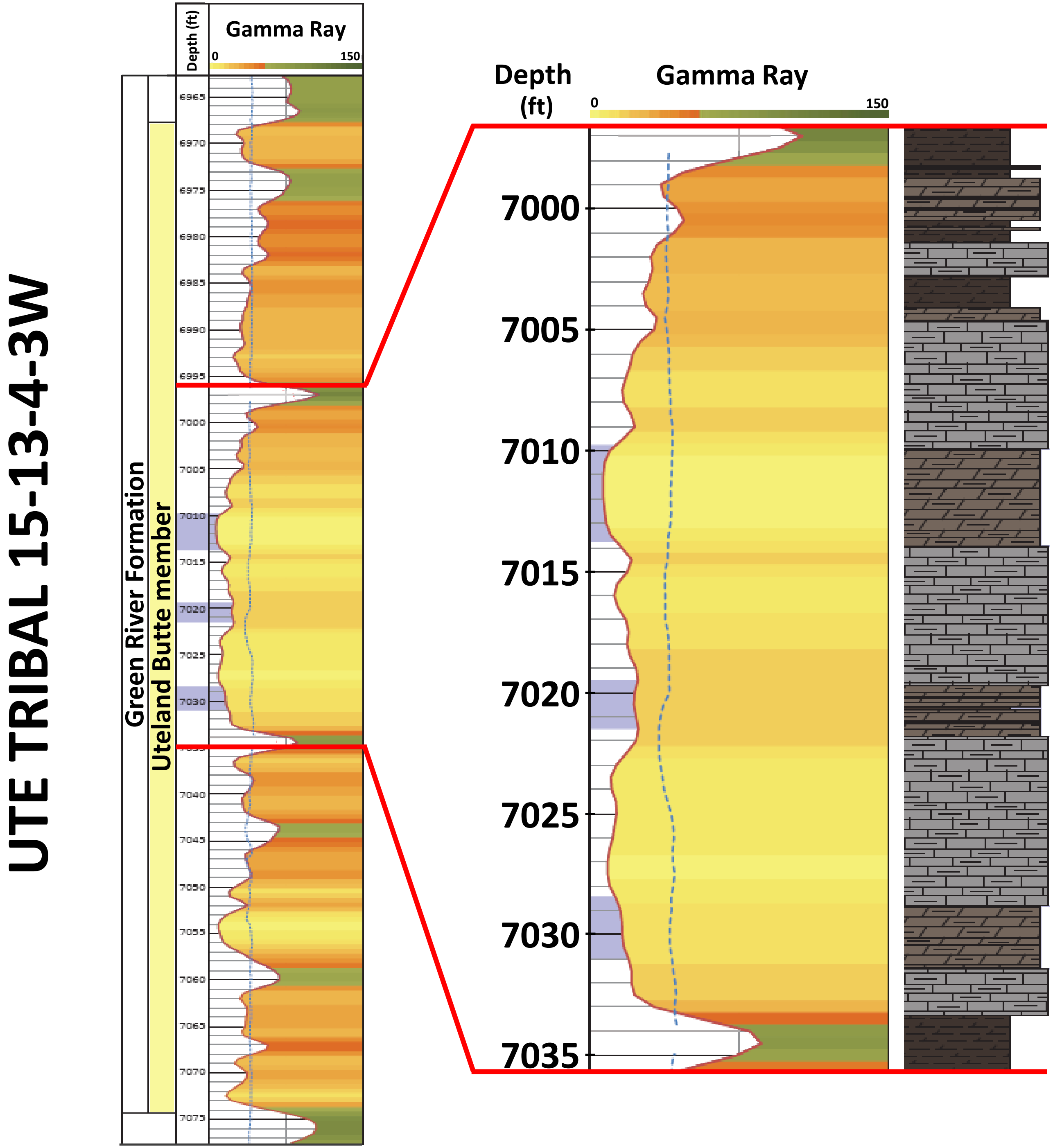
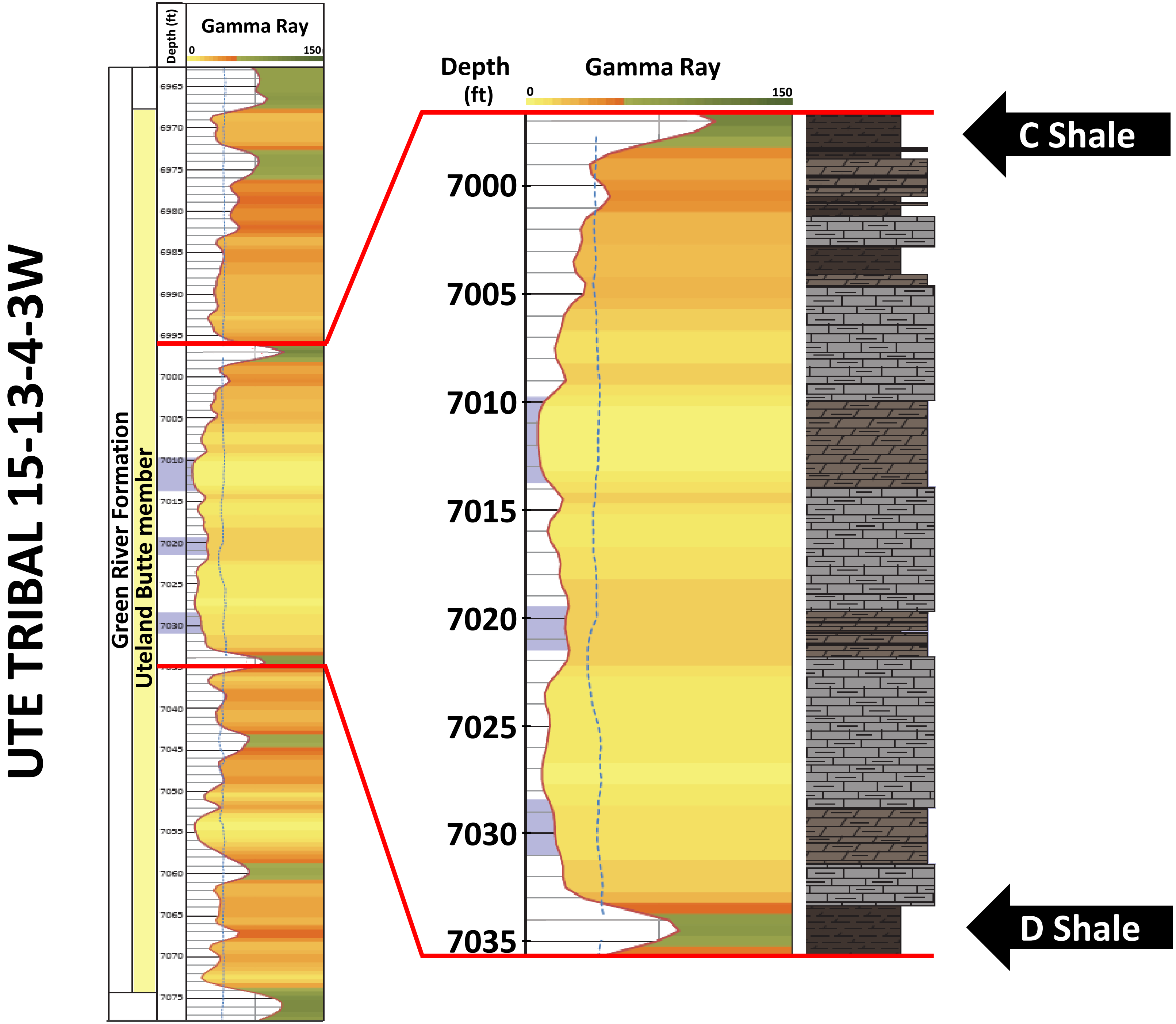
Generalized stratigraphic column for Uinta Basin

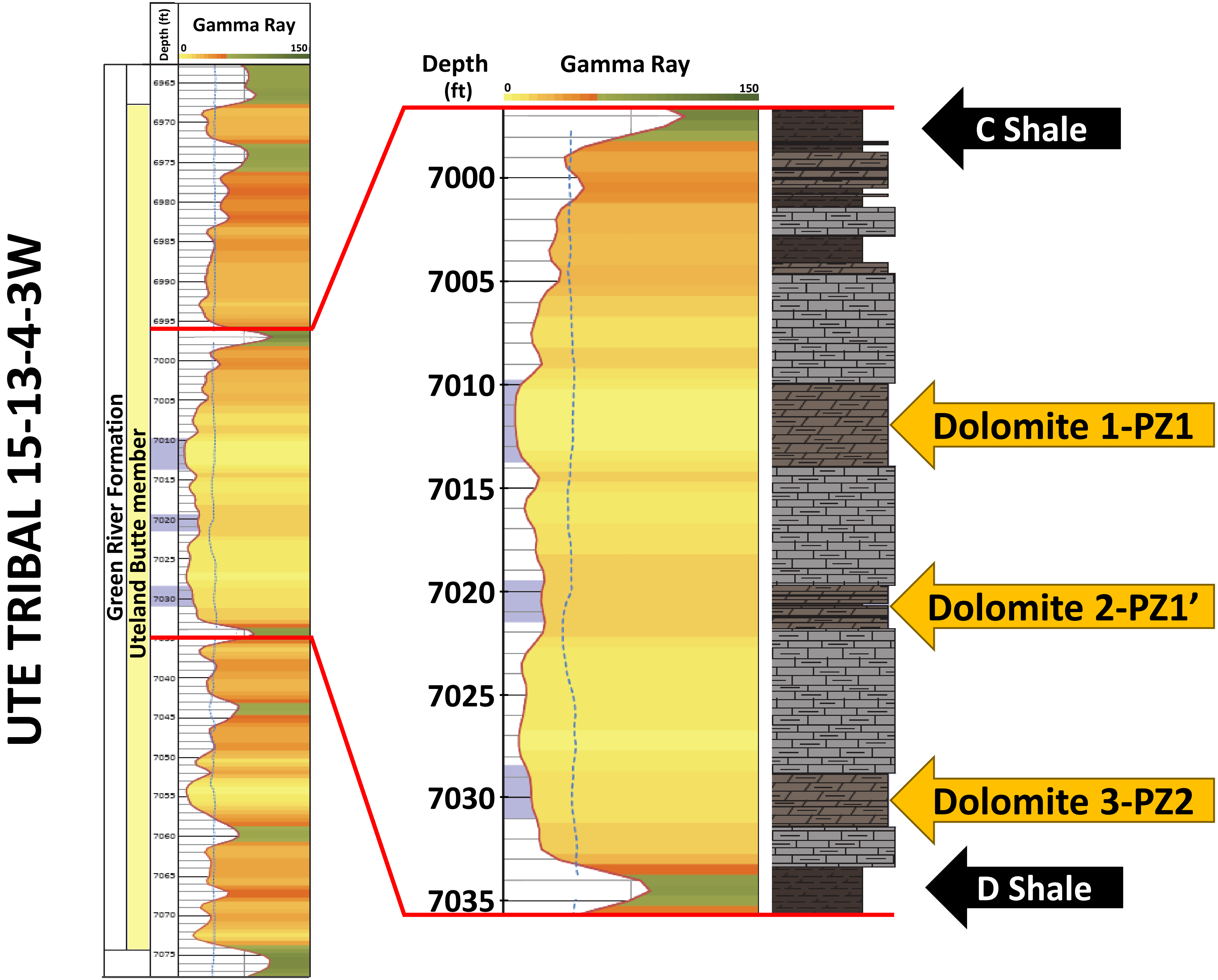


Modified from Logan, S.K., et al (2016)


UTE TRIBAL 15-13-4-3W
Green River Formation
Uteland Butte member
Depth (ft)
Gamma Ray
0
150
6965
6970
6975
6980
6985
6990
6995
7000
7005
7010
7015
7020
7025
7030
7040
7045
7050
7055
7060
7065
7070
7075
Depth (ft)
Gamma Ray
0
150
7000
7005
7010
7015
7020
7025
7030
7035



UTE TRIBAL 15-13-4-3W
Green River Formation
Uteland Butte member
Depth (ft)
Gamma Ray
0
150
C Shale
D Shale
7000
7005
7010
7015
7020
7025
7030
7035


UTE TRIBAL 15-13-4-3W
Green River Formation
Uteland Butte member
Depth (ft)
Gamma Ray
0
150
6965
6970
6975
6980
6985
6990
6995
7000
7005
7010
7015
7020
7025
7030
7040
7045
7050
7055
7060
7065
7070
7075
Depth (ft)
Gamma Ray
0
150
7000
7005
7010
7015
7020
7025
7030
7035
C Shale
Dolomite 1-PZ1
Dolomite 2-PZ1’
Dolomite 3-PZ2
D Shale

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6. **Facies - Depositional Environments**
7. Cyclicity
8. Dolomite Textures
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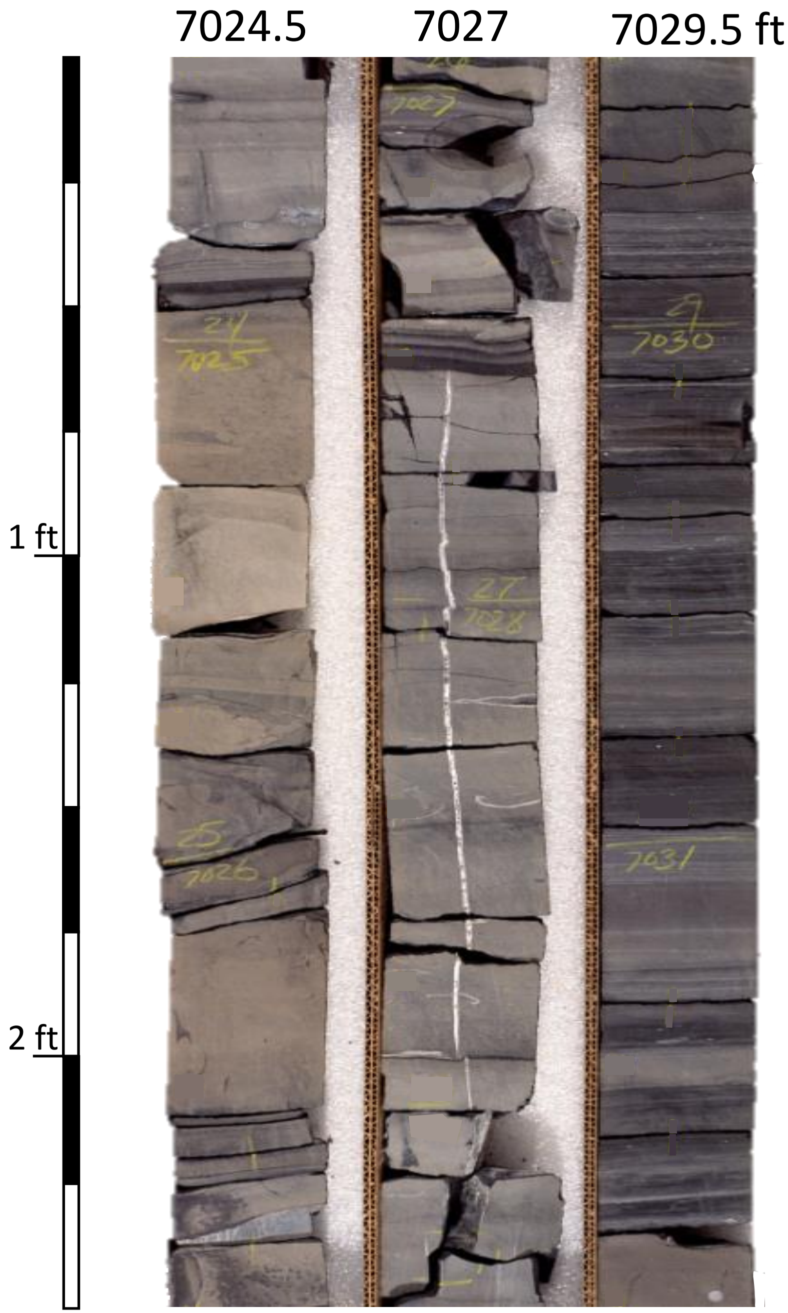
FACIES



Three basic rock types:
Shale – Limestone – Dolostone

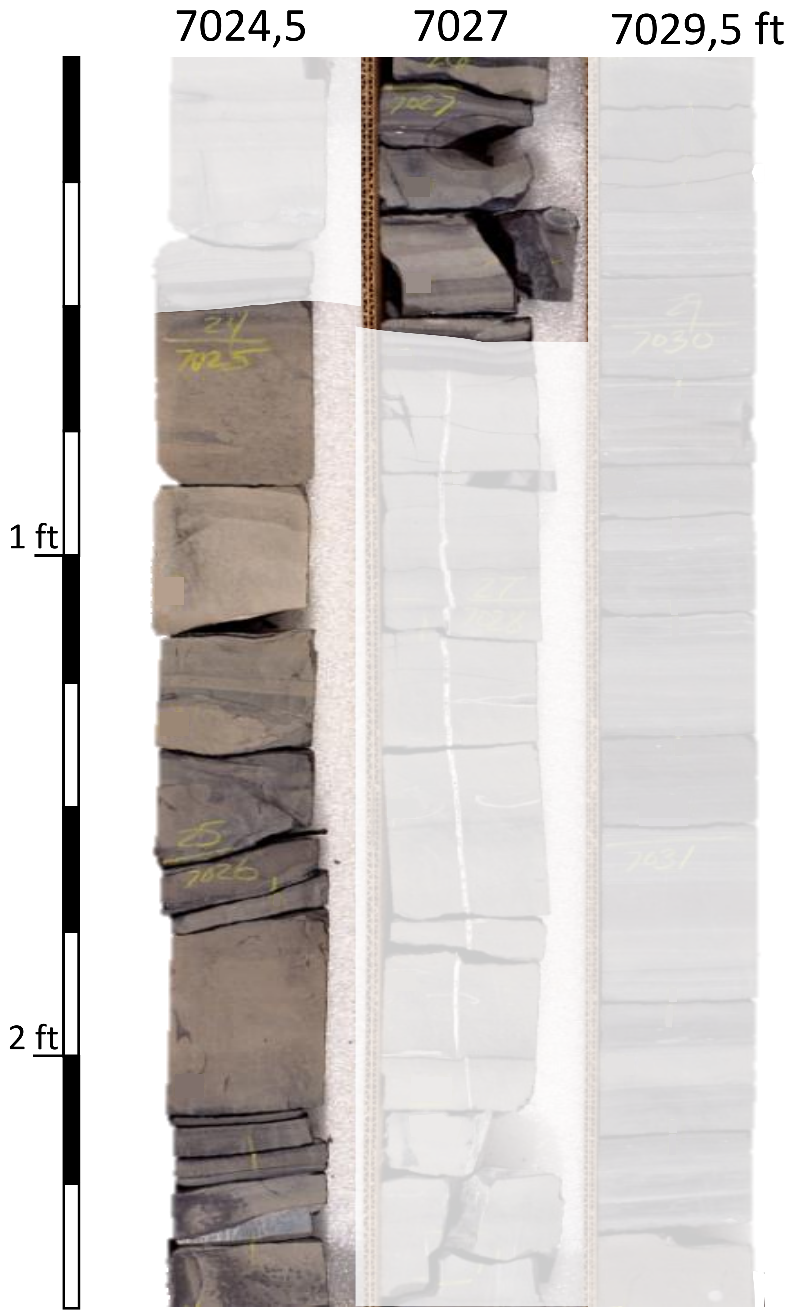
FACIES

At the base:
Shale

FACIES

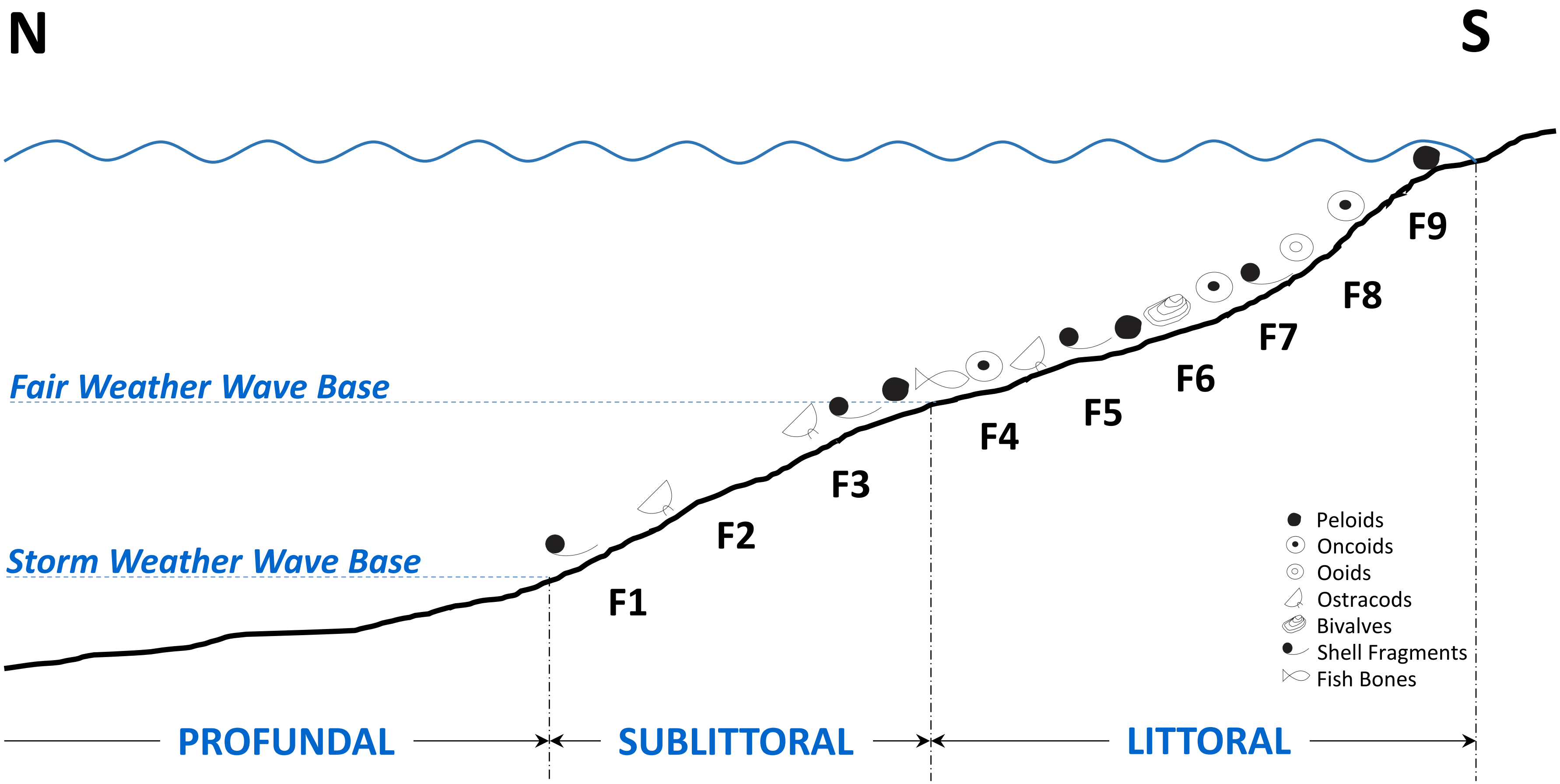
In the middle:
Molluscan limestone

FACIES



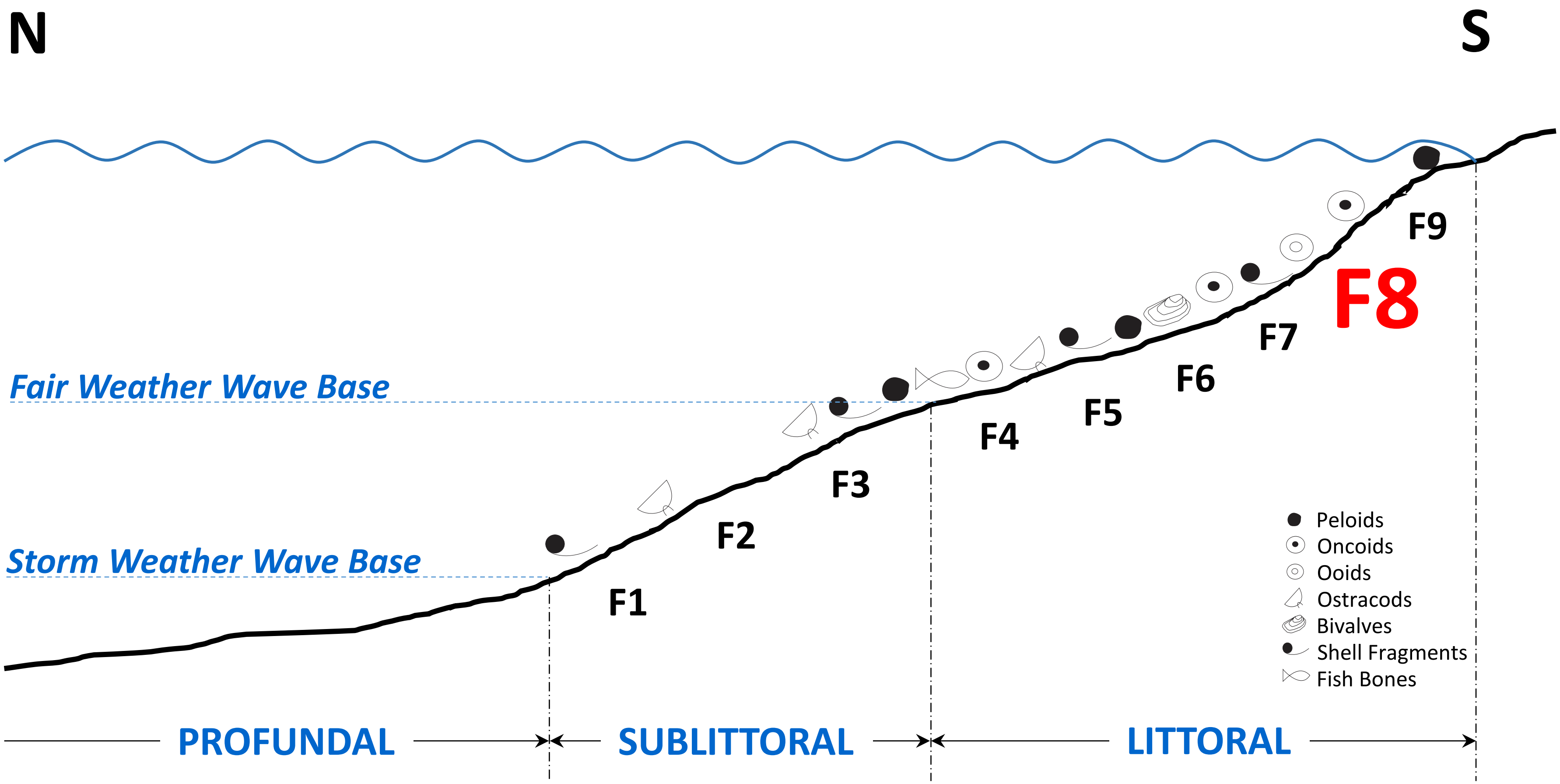
At the top:
Wackestone coarsening upward to packstone - grainstone

DEPOSITIONAL ENVIRONMENTS



Schematic profile of lake basin with lateral facies distribution
Water levels agitation (*FWWB-SWB*) define environments

DEPOSITIONAL ENVIRONMENTS



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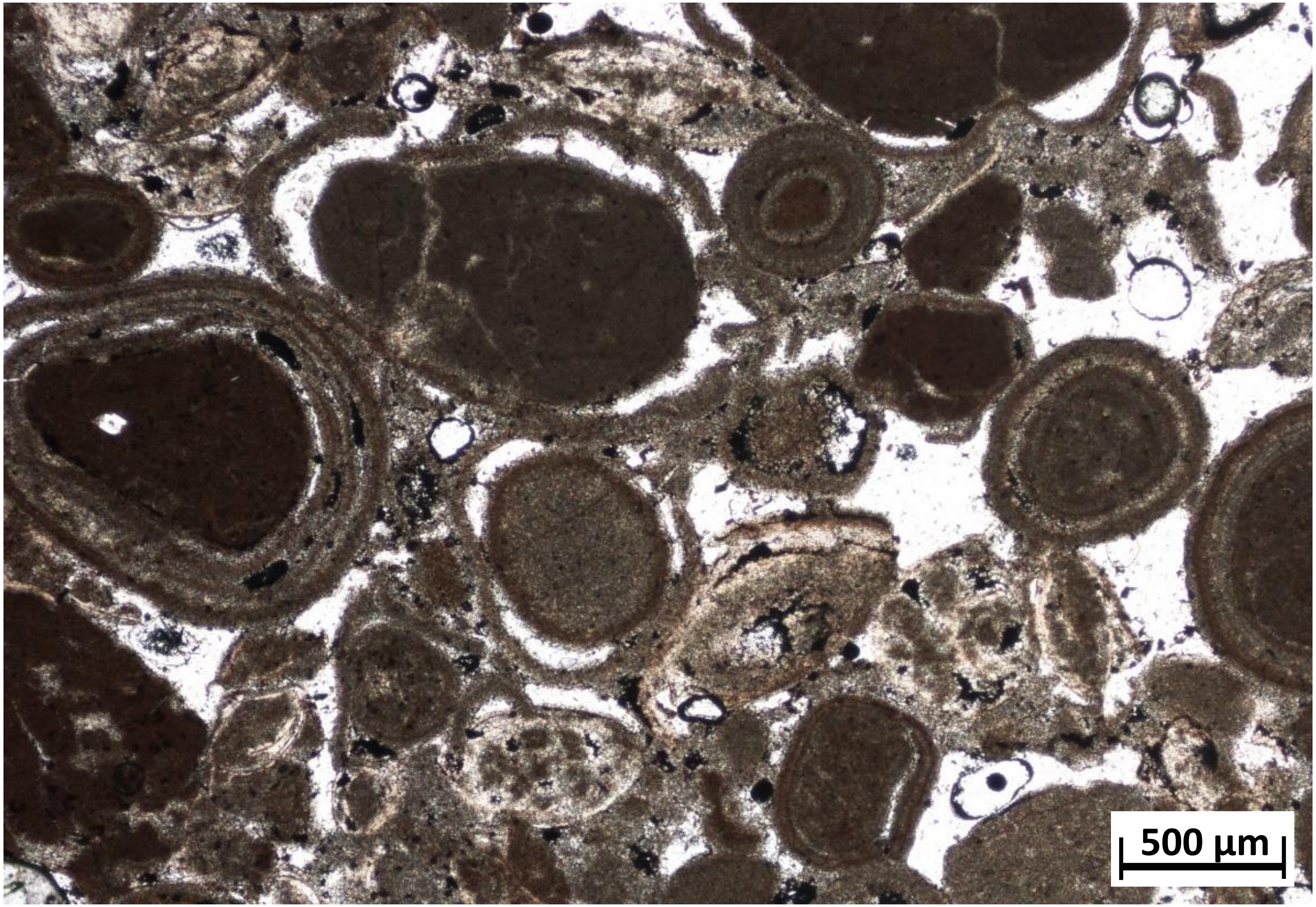
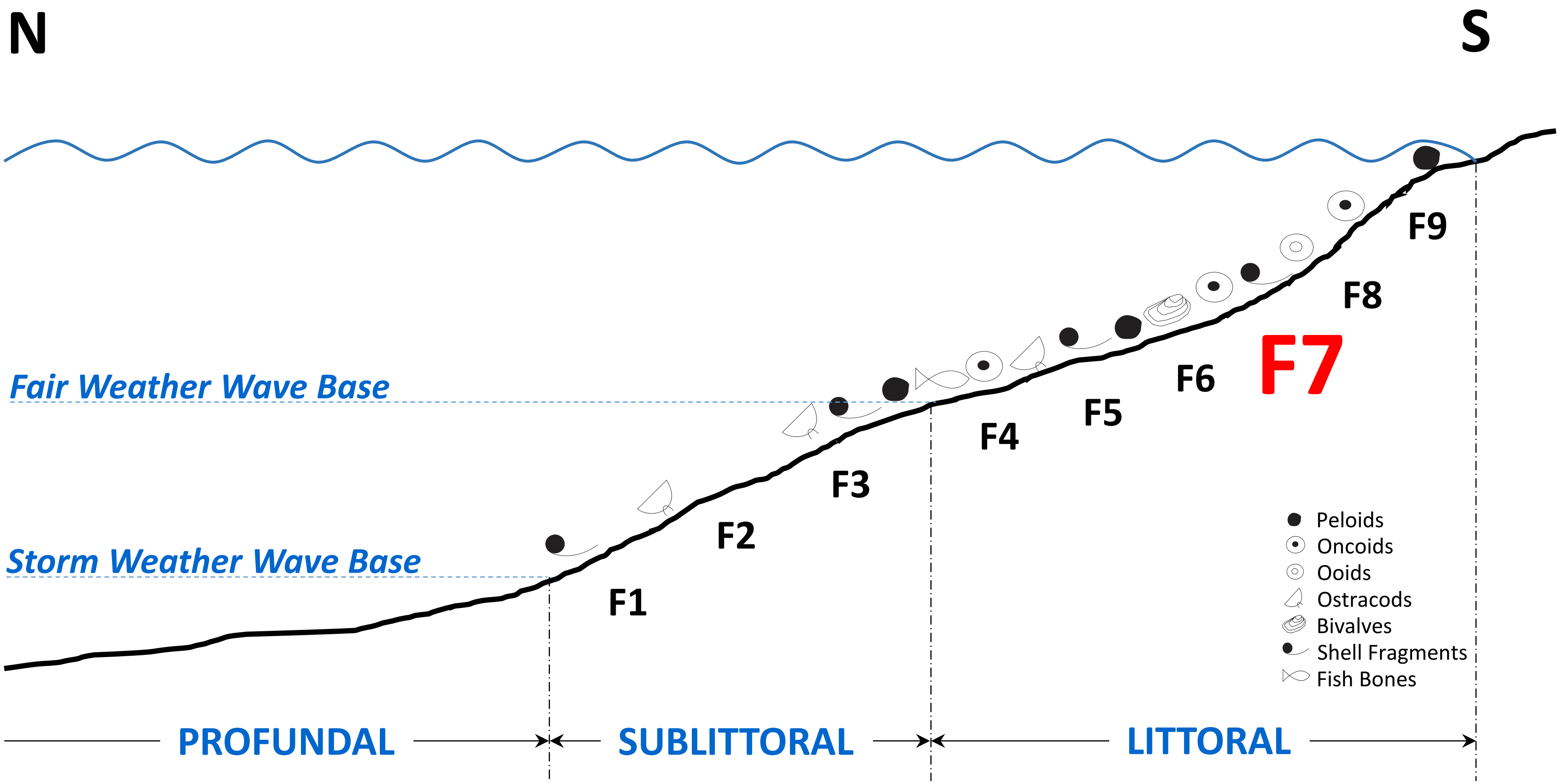


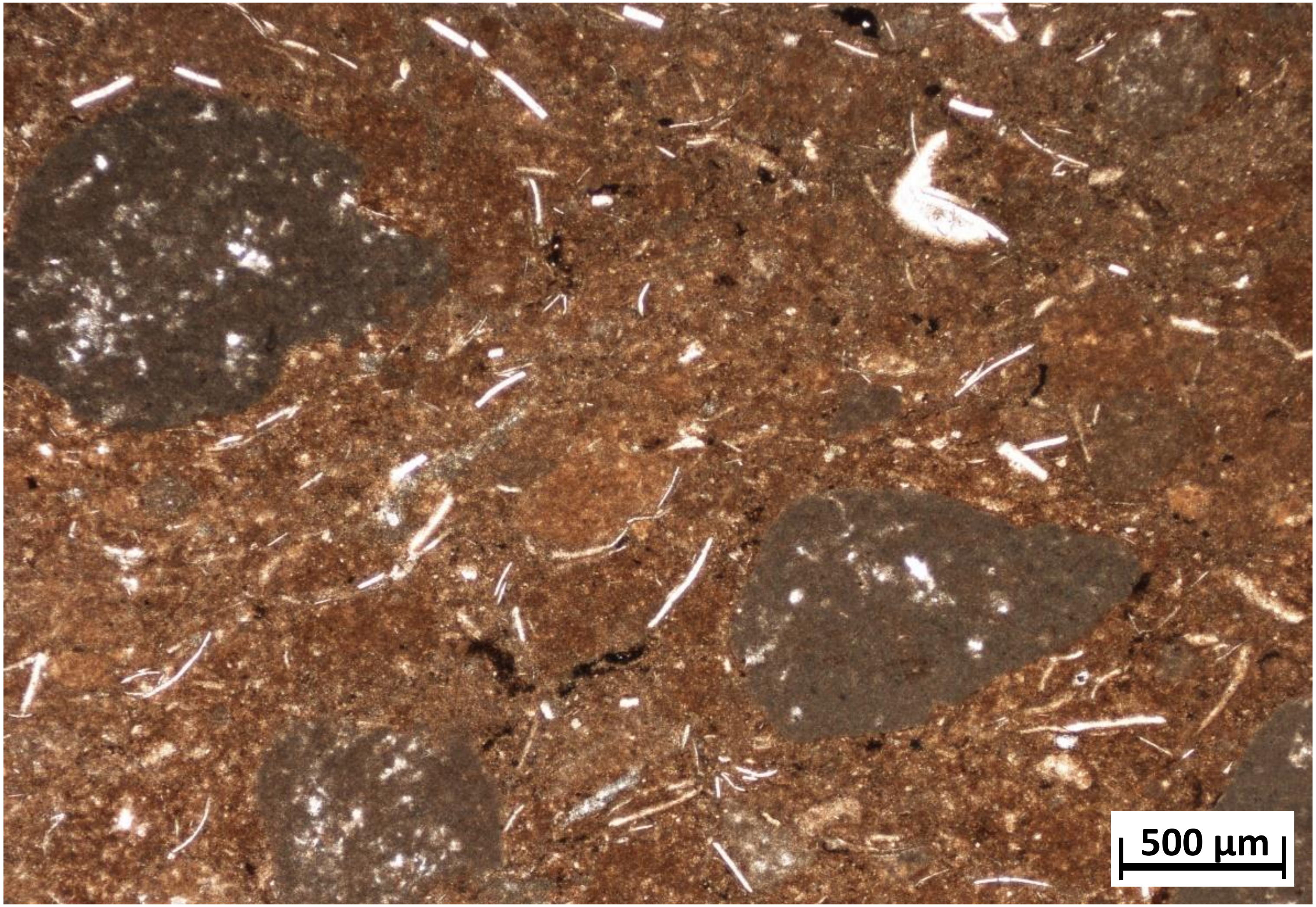
Facie 8. Ooid grainstone

Subspherical, dolomitized, and partially dissolved ooids

DEPOSITIONAL ENVIRONMENTS



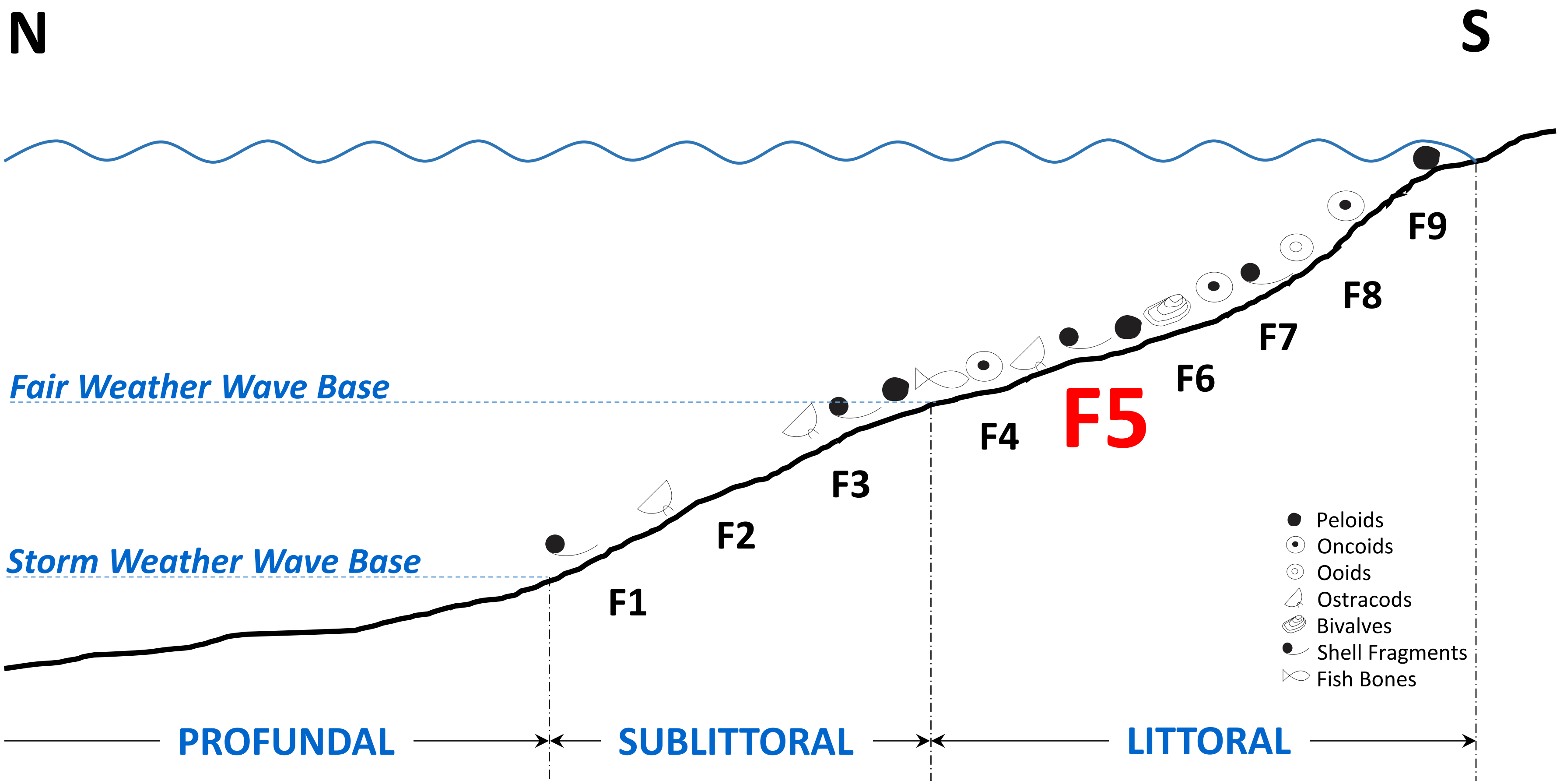
Schematic profile of lake basin with lateral facies distribution
Water levels agitation (*FWWB-SWB*) define environments



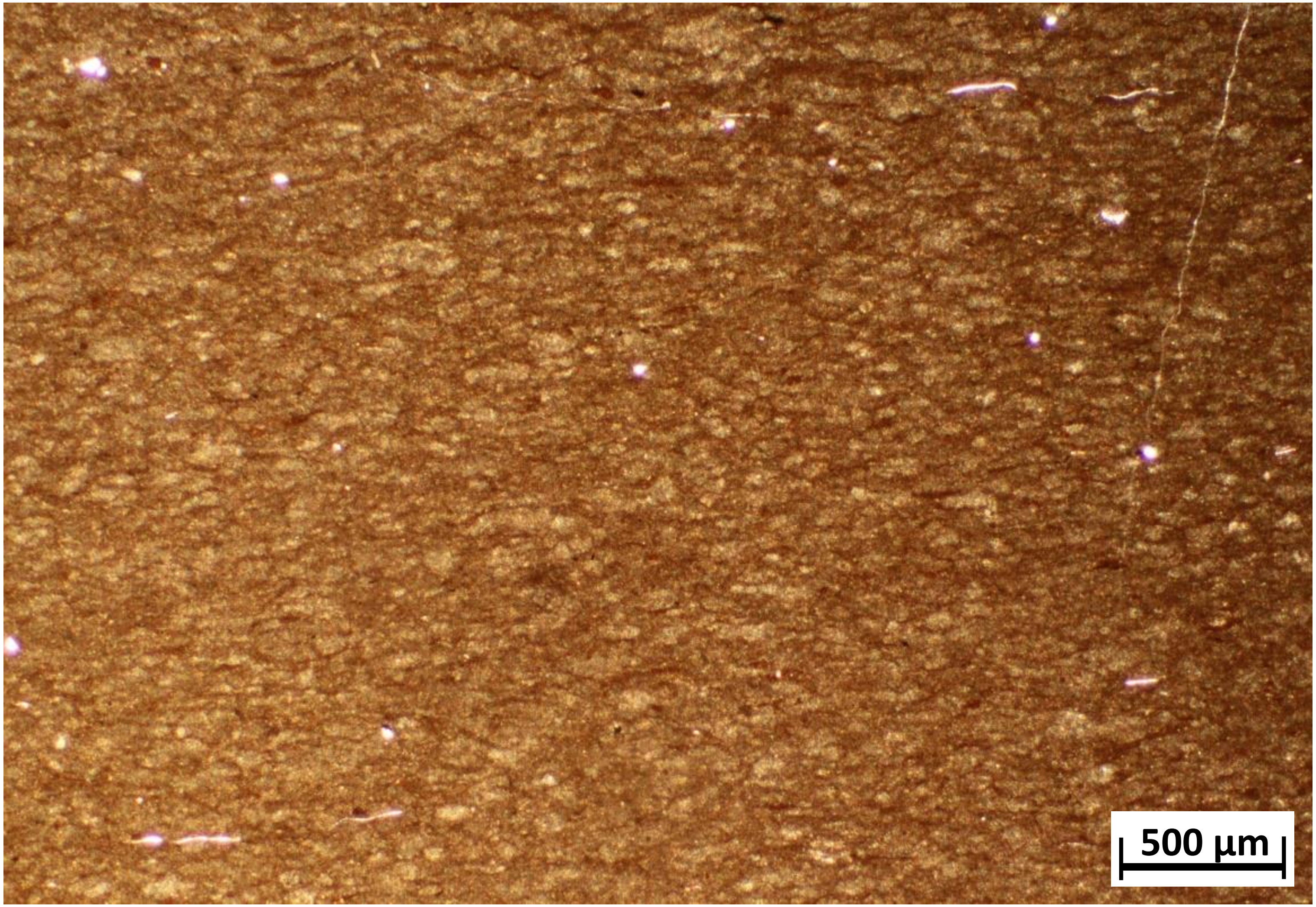
Facie 7. Intraclastic packstone

Poorly sorted, subangular, sand to gravel sized dolomitized intraclast, and molluscan shell fragments

DEPOSITIONAL ENVIRONMENTS



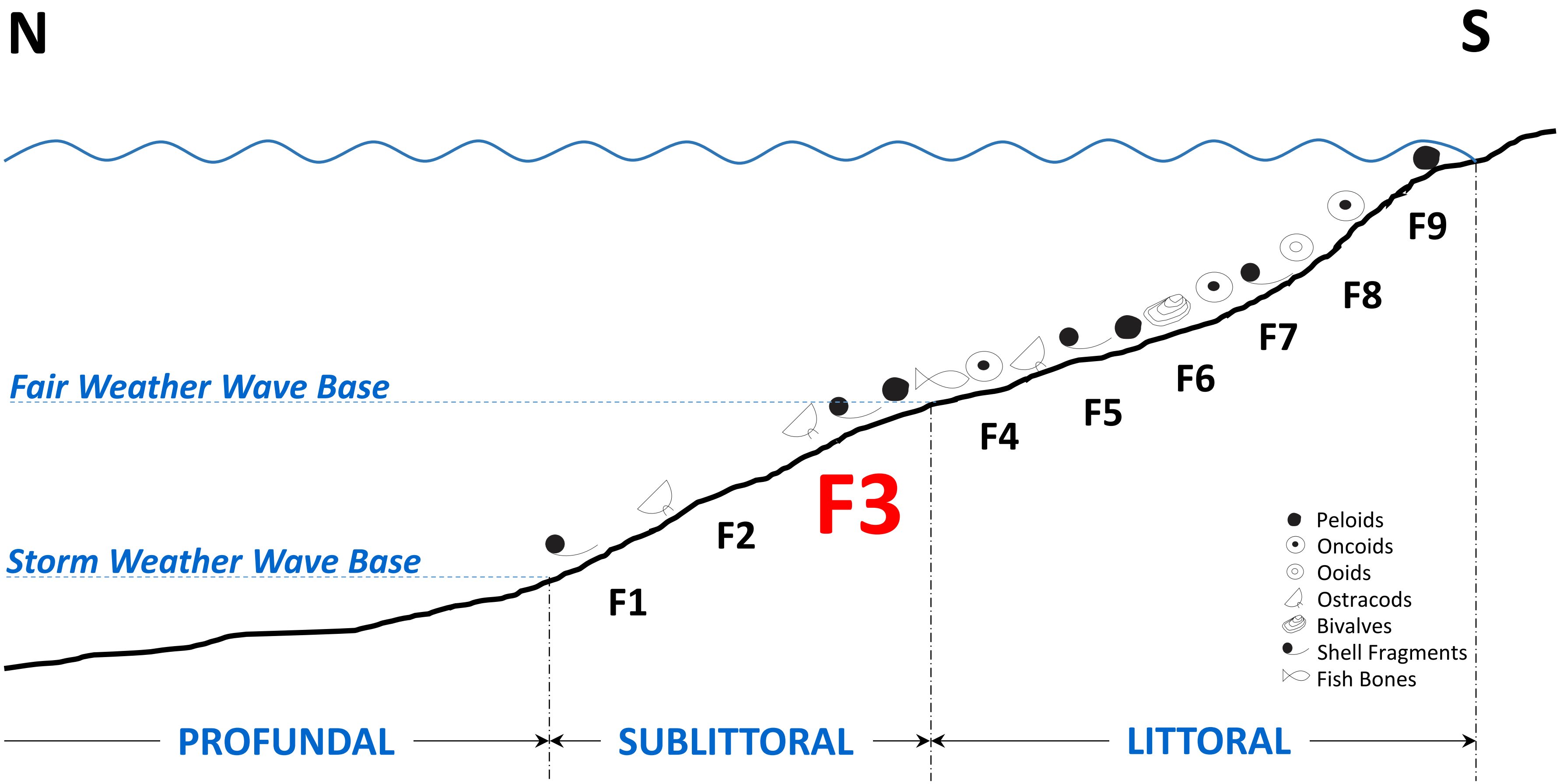
Schematic profile of lake basin with lateral facies distribution
Water levels agitation (*FWWB-SWB*) define environments



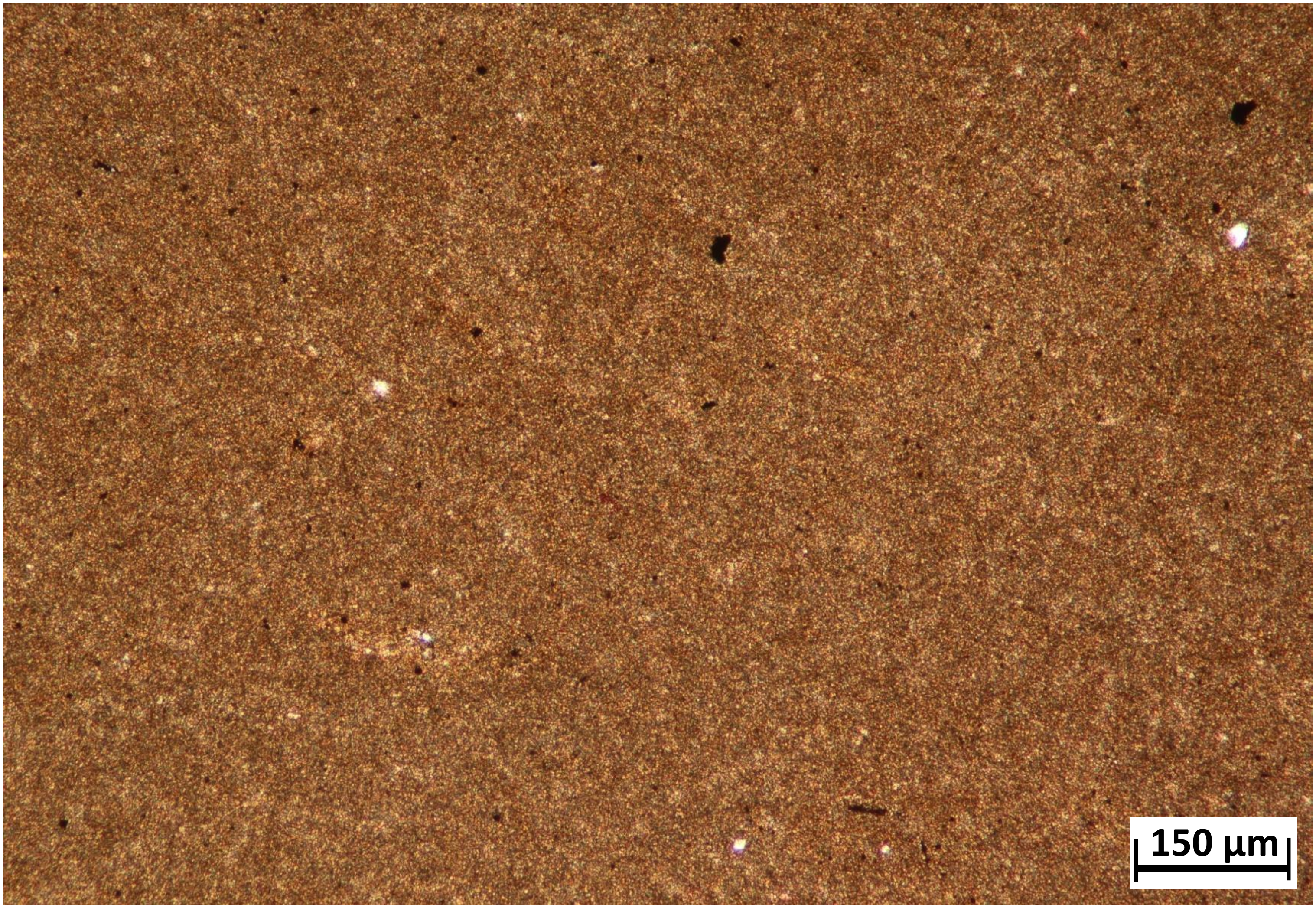
Facie 5. Peloidal wackestones/packstone

Microcrystalline dolomite matrix with abundant peloids and ostracods shell fragments

DEPOSITIONAL ENVIRONMENTS



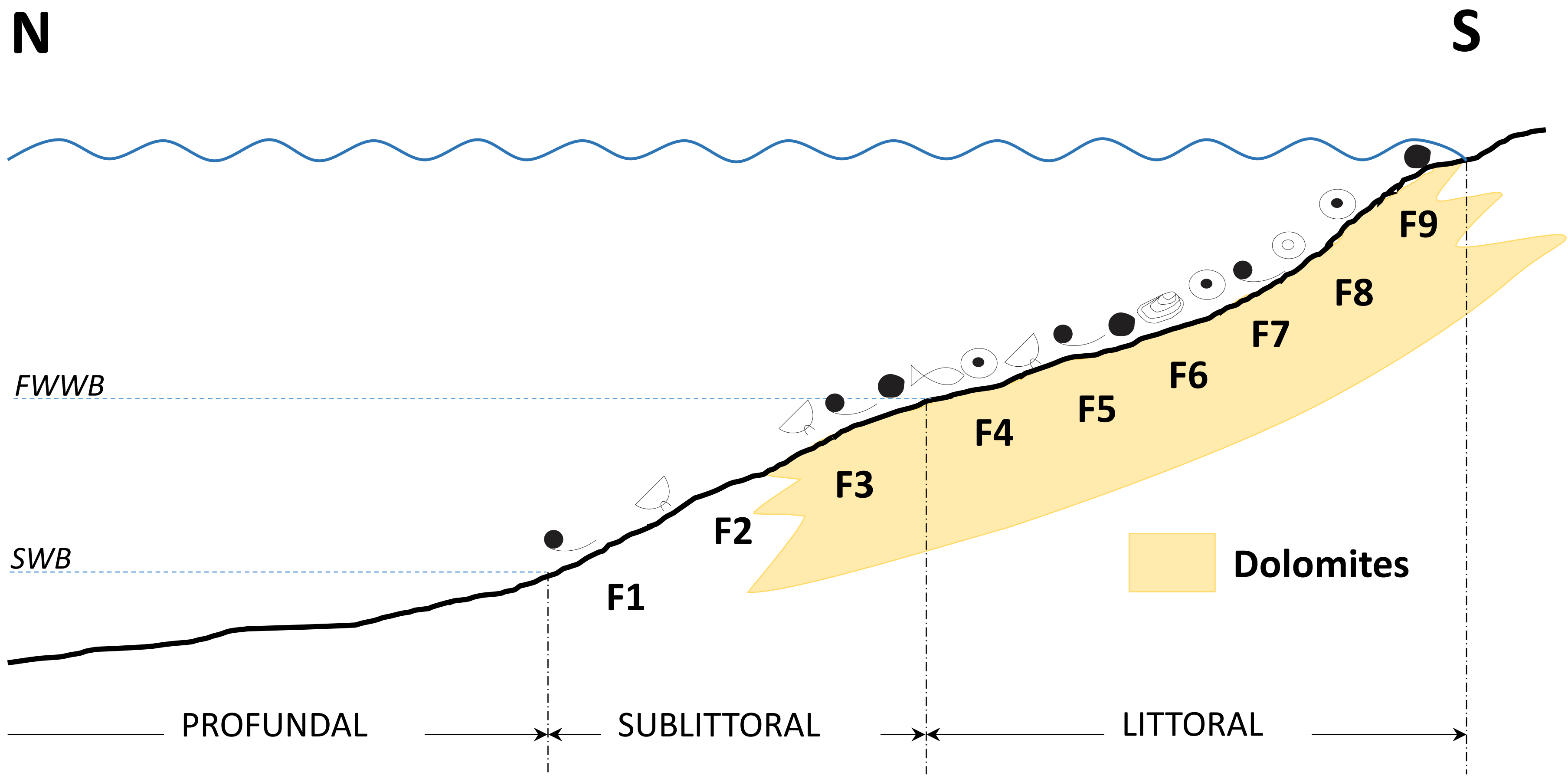
Schematic profile of lake basin with lateral facies distribution
Water levels agitation (*FWWB-SWB*) define environments



Facie 3. Mudstone

Microcrystalline dolomite matrix with scarce ostracods shell fragments

DEPOSITIONAL ENVIRONMENTS



1. Dolomitization (yellow) cross-cut facies boundaries
2. Replaced micritic matrix from littoral to sublittoral environments
3. Excellent fabric preservation

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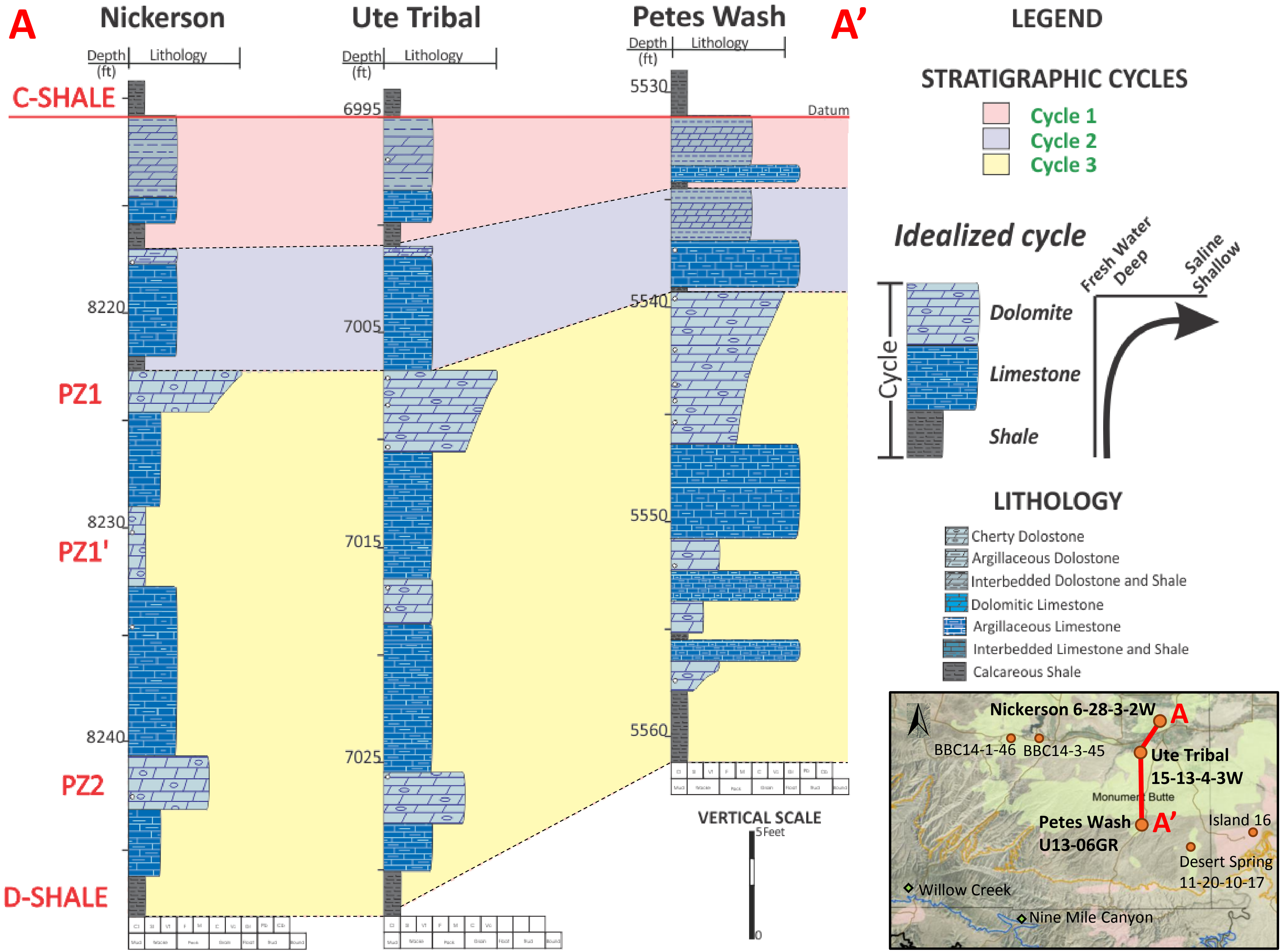
CYCLICITY



A
Nickerson
Ute Tribal
Petes Wash
A'
Depth (ft)
Lithology
C-SHALE
Datum
PZ1
PZ1'
PZ2
D-SHALE
8220
8230
8240
6995
7005
7015
7025
5530
5540
5550
5560
VERTICAL SCALE
5 Feet
0
LEGEND
STRATIGRAPHIC CYCLES
Cycle 1
Cycle 2
Cycle 3
Idealized cycle
Cycle
Dolomite
Limestone
Shale
Fresh Water
Deep
Saline
Shallow
LITHOLOGY
Cherty Dolostone
Argillaceous Dolostone
Interbedded Dolostone and Shale
Dolomitic Limestone
Argillaceous Limestone
Interbedded Limestone and Shale
Calcareous Shale
Nickerson 6-28-3-2W
A
BBC14-1-46
BBC14-3-45
Ute Tribal
15-13-4-3W
Monument Butte
Petes Wash
U13-06GR
A'
Island 16
Desert Spring
11-20-10-17
Willow Creek
Nine Mile Canyon

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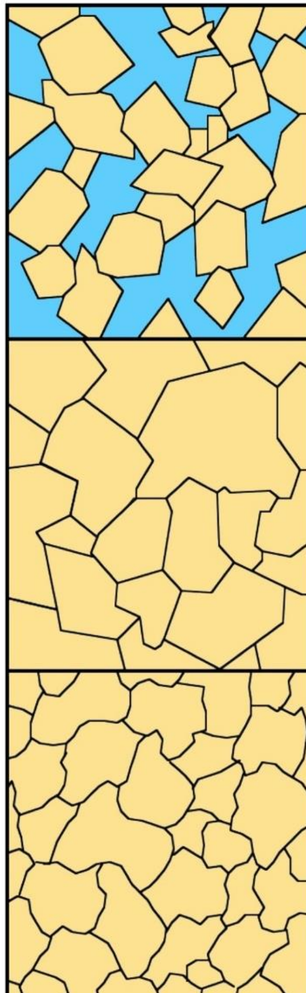
TEXTURES



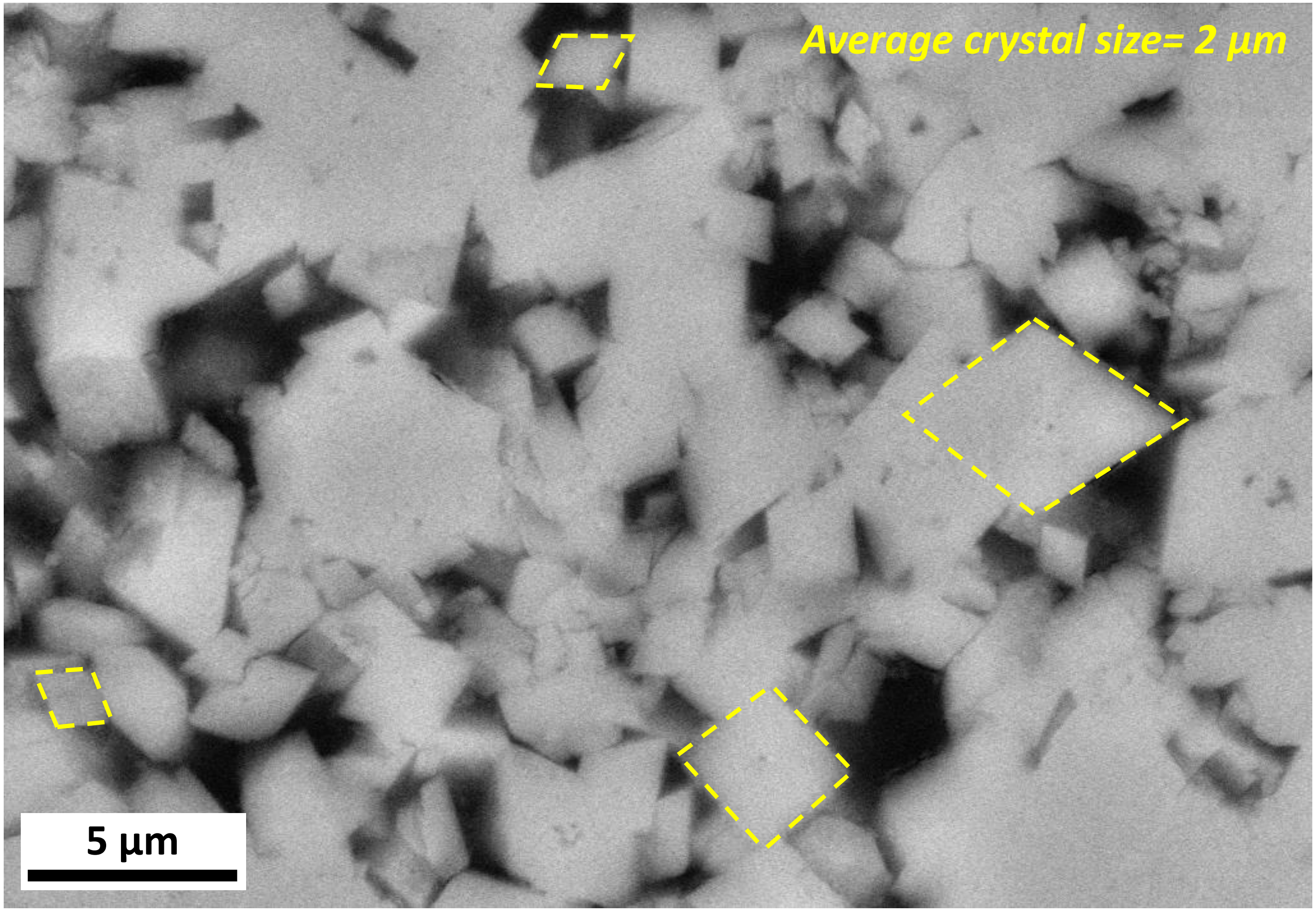
Planar-e (euhedral): most dolomite crystals are euhedral; crystal supported with intercrystalline area filled by another mineral or porous (as in sucrose texture).

Planar-s (subhedral): most dolomite crystals are subhedral to anhedral with straight, compromise boundaries and many crystal-face junctions. Low porosity and/or low intercrystalline matrix.

Nonplanar: closely packed anhedral crystals with mostly curved, lobate, serrated, or otherwise irregular intercrystalline boundaries. Few crystal face junctions and crystals often display undulatory extinction.

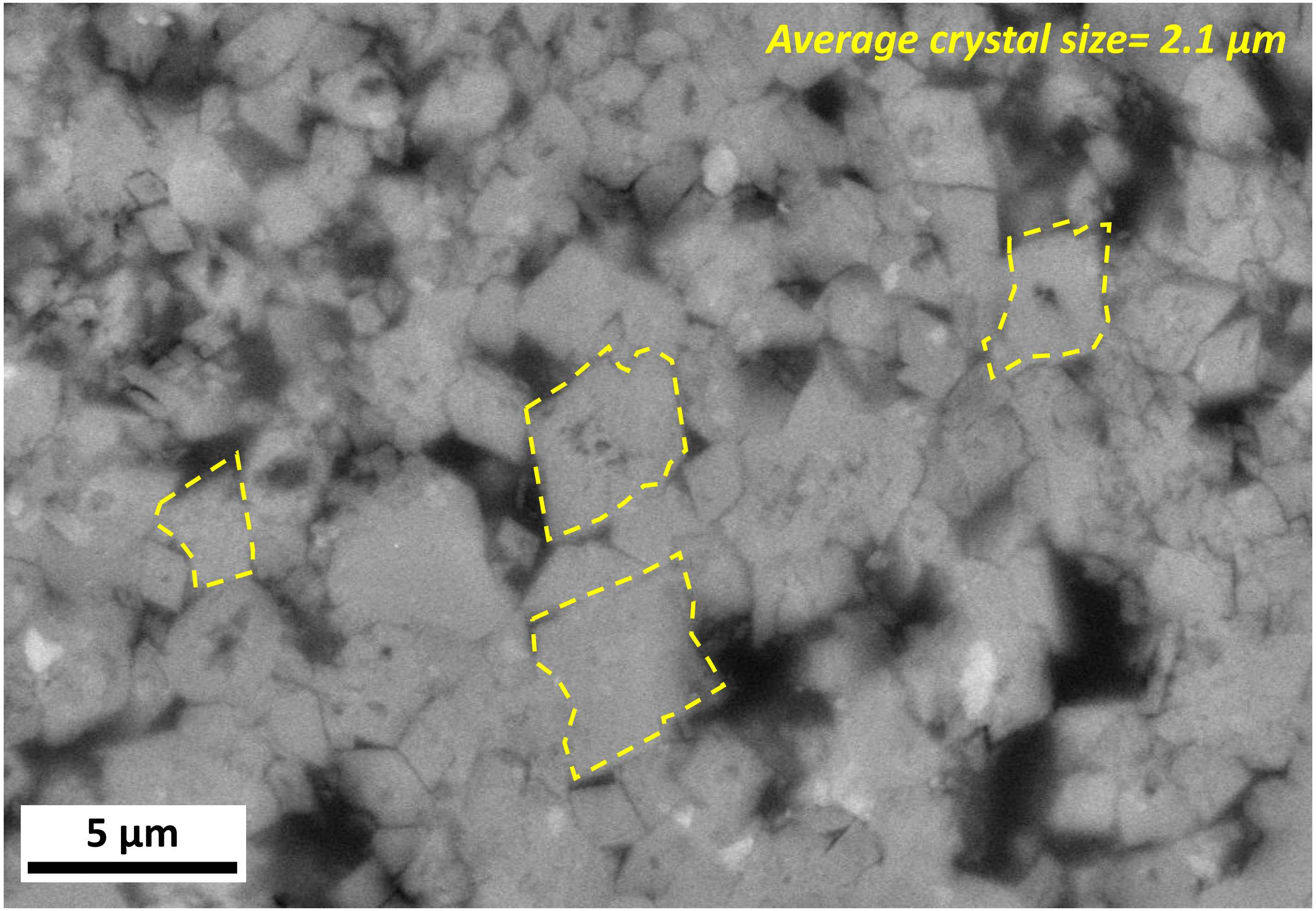
Dolomite textural classification (Sibley & Gregg, 1987)

TEXTURES



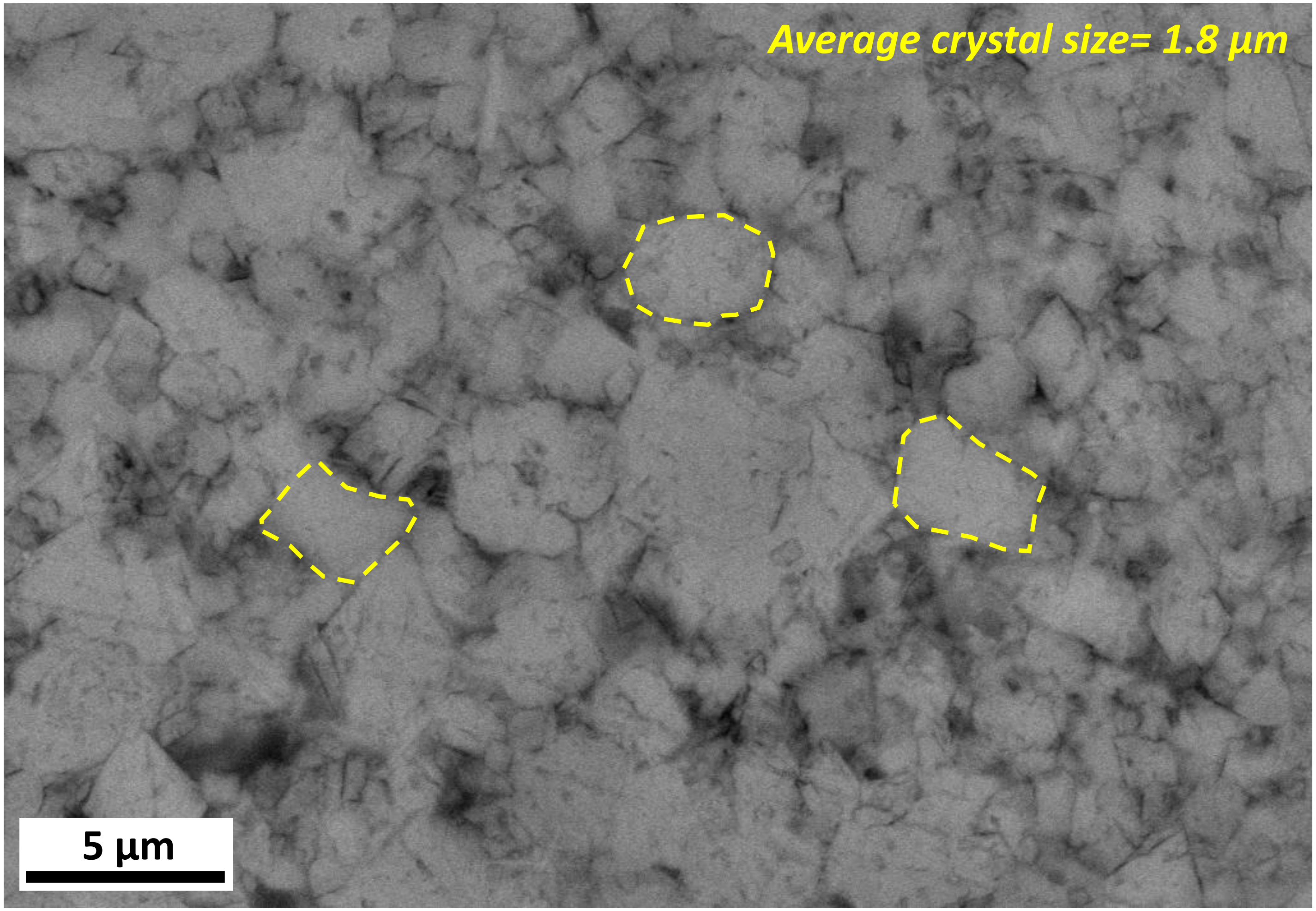
SEM image of **planar-e** dolomite texture of PZ1', well Nickerson.
Porosity: **21%** (data from image analysis software)

TEXTURES



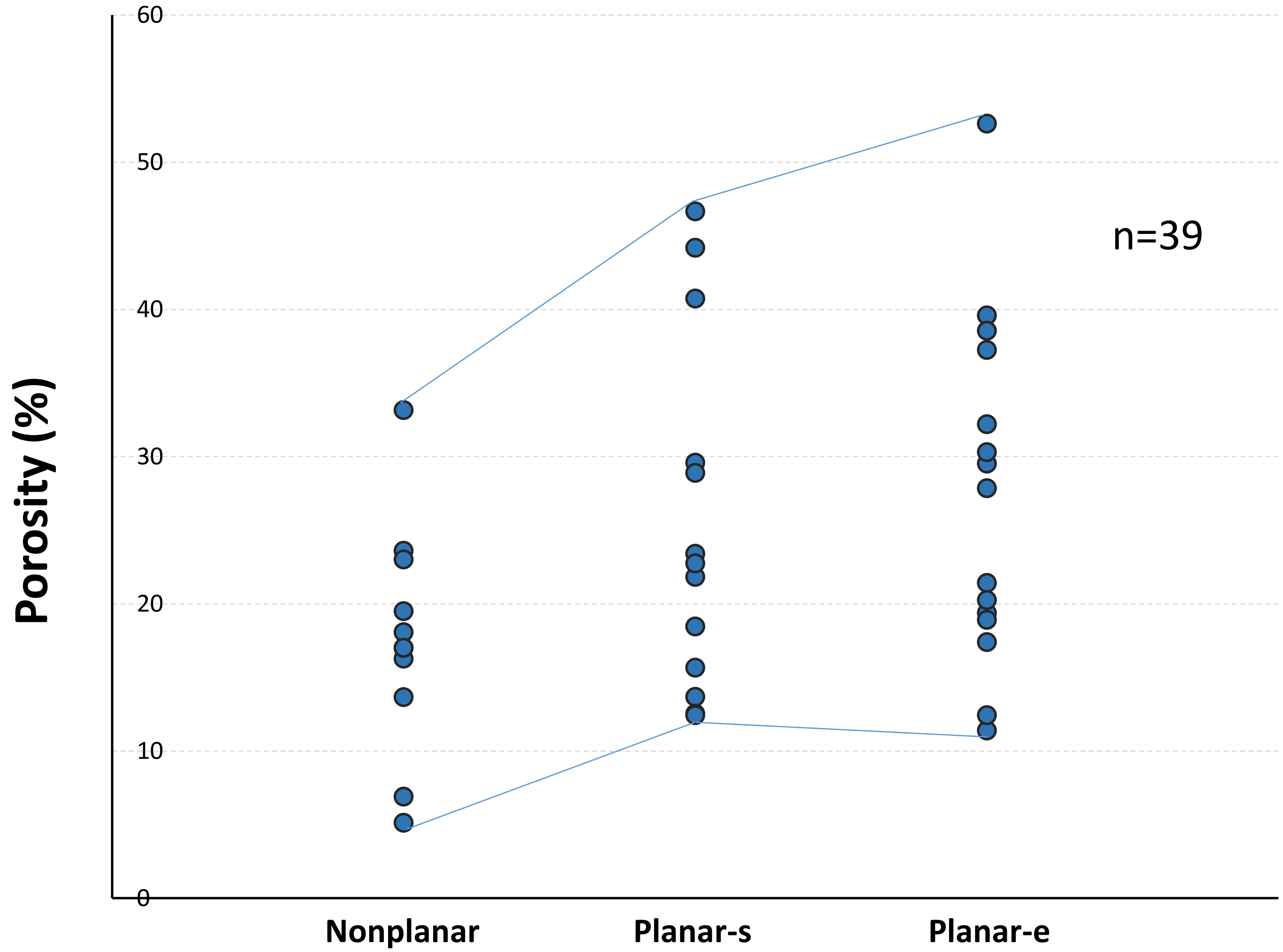
SEM image of **planar-s** dolomite texture of PZ2, well Nickerson.
Porosity: **18%** (data from image analysis software)

TEXTURES



SEM image of **nonplanar** dolomite texture at the base of PZ1, well Ute Tribal. Porosity: **14%** (data from image analysis software)

TEXTURES Vs POROSITY



High porosity values (data from image analysis software) are associated with planar-e to planner-s textures

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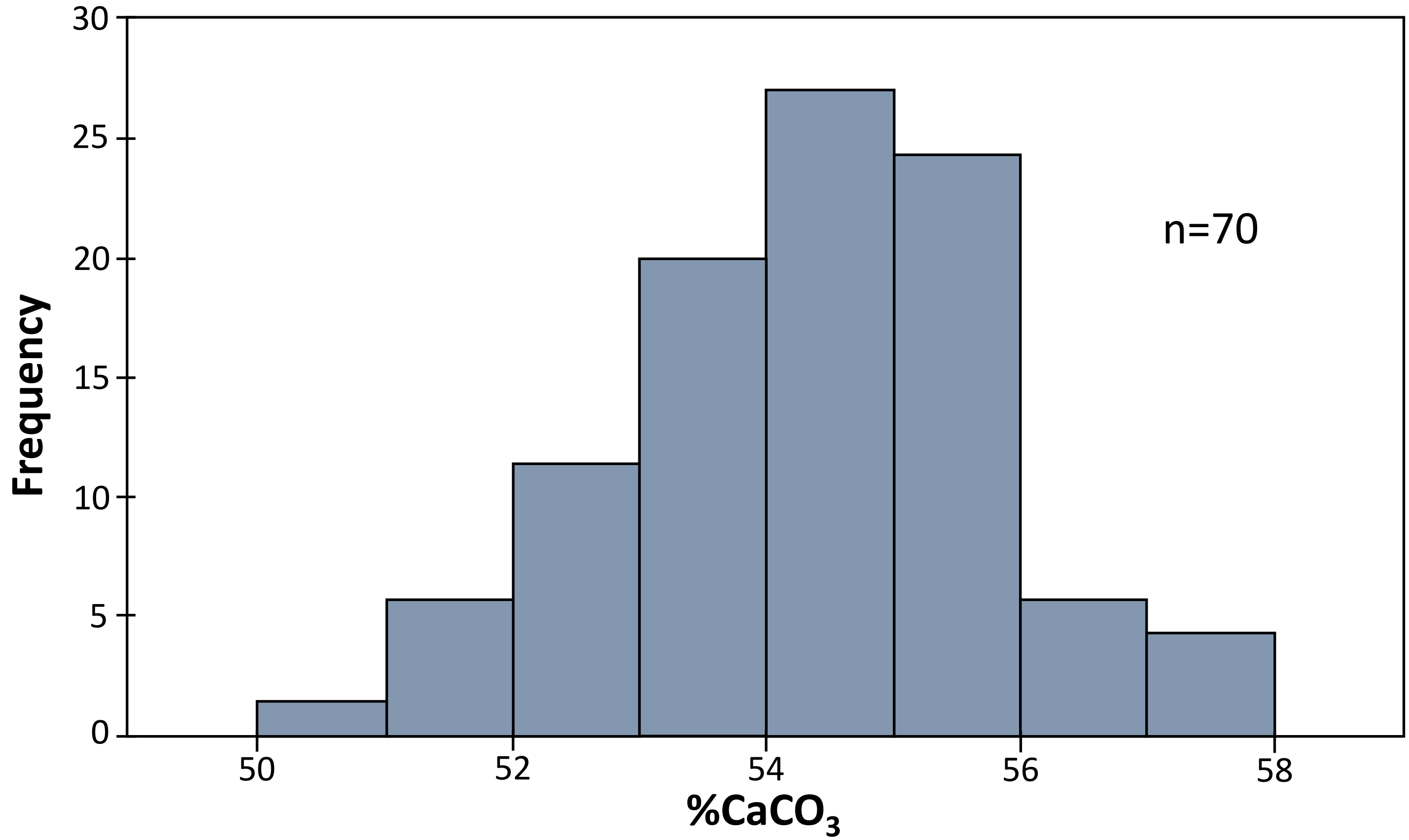
STOICHIOMETRY

XRD / All wells



%$CaCO_3$ dolomite distribution suggests changes in lake water chemistry and/or variable degrees of recrystallization

%$CaCO_3$ Vs DEPTH

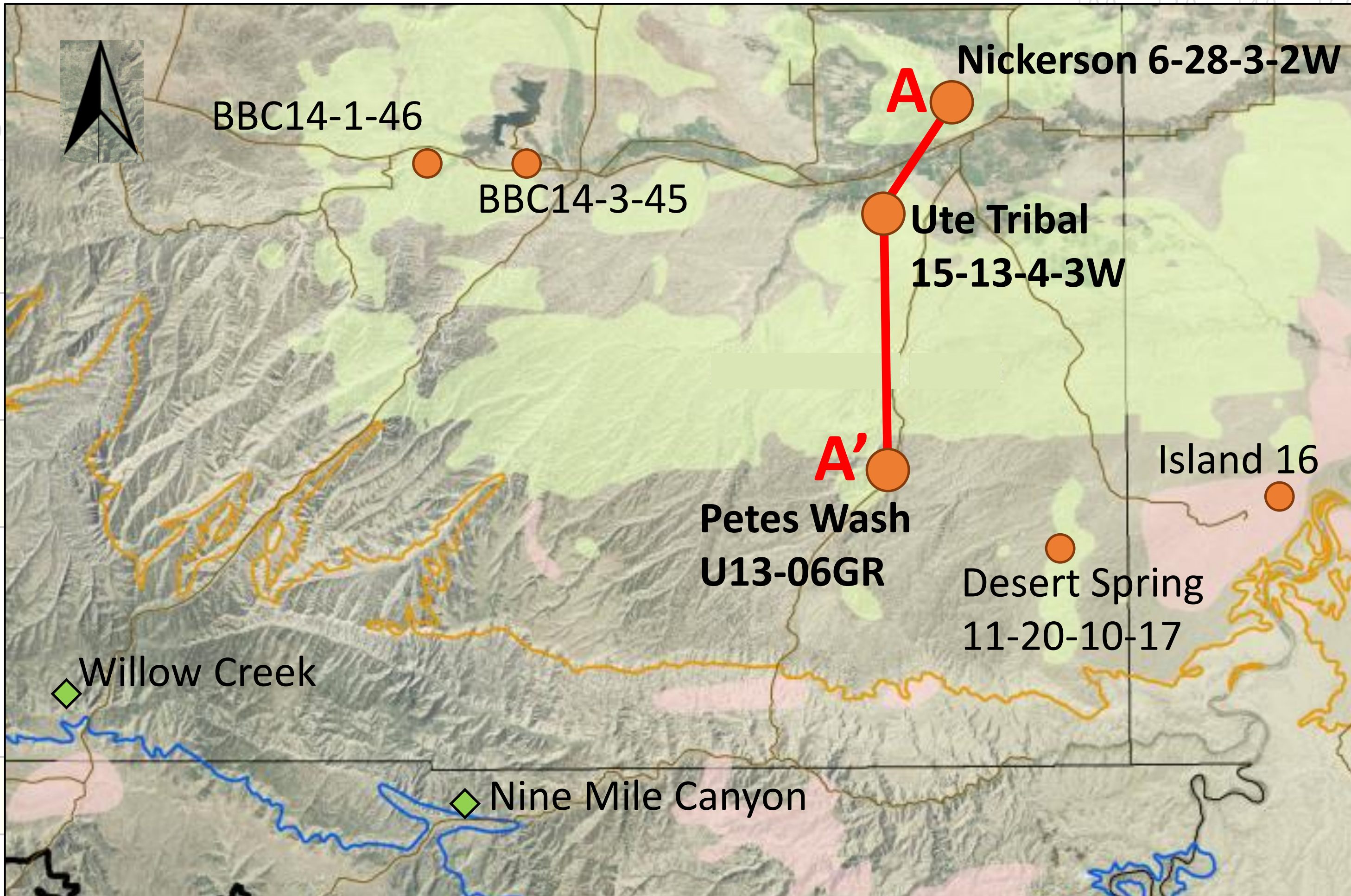
XRD data, A-A’

A A’

Petes Wash

%Ca

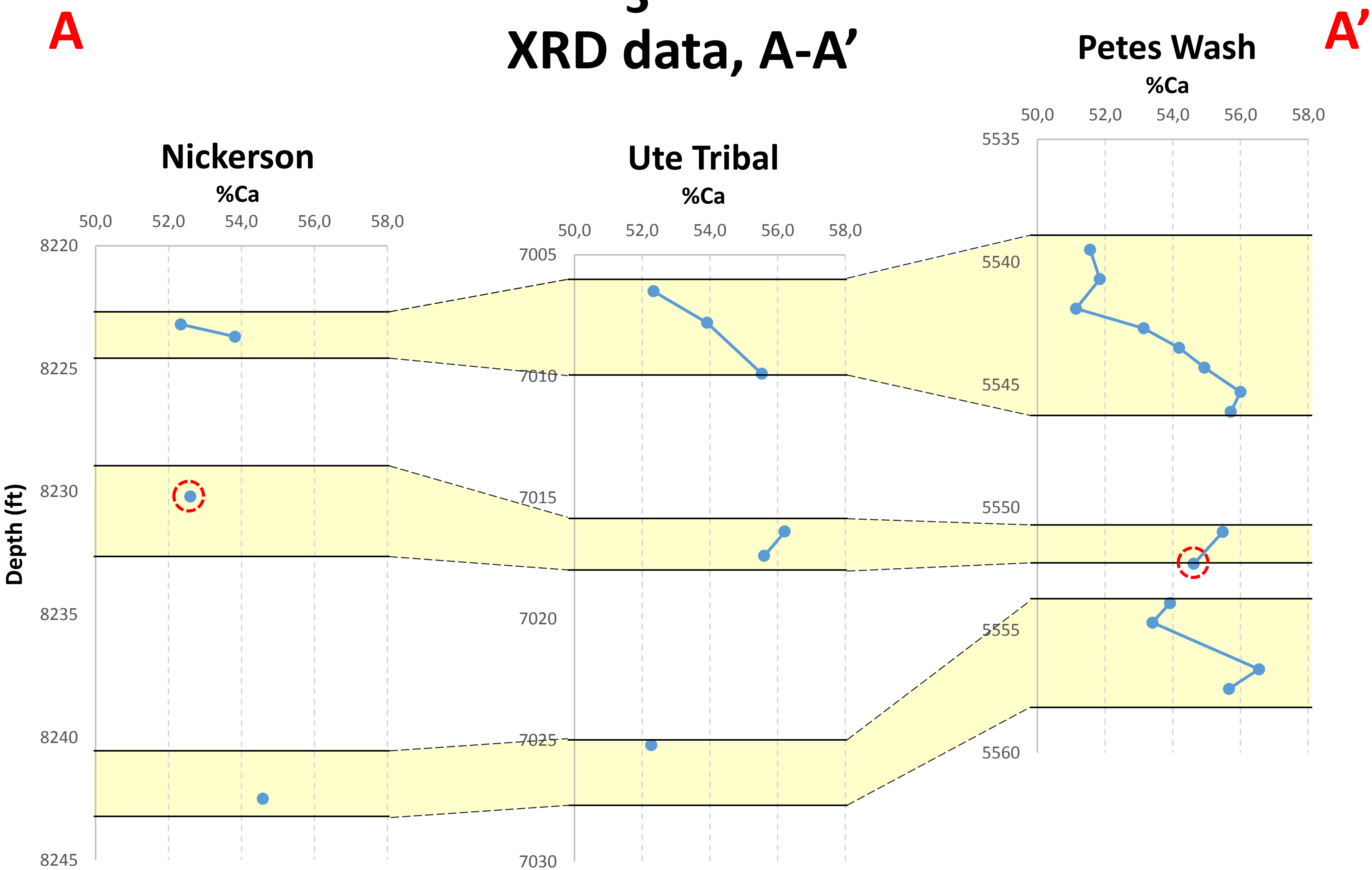
Depth (ft)



%Ca (data from XRD) varies with depth changing from nearly stoichiometric dolomite (top) to calcium rich dolomite (bottom)

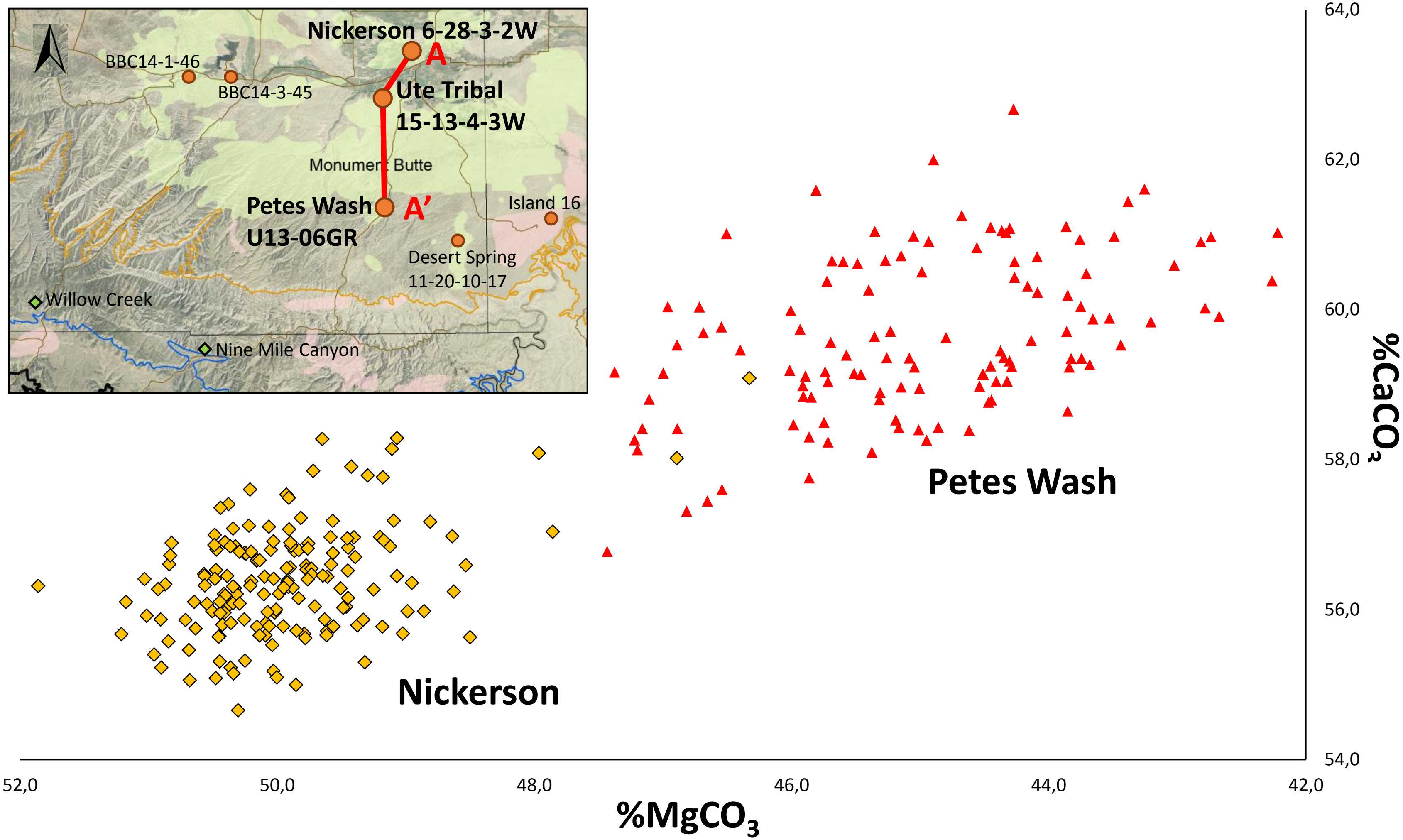
%$CaCO_3$ Vs DEPTH

XRD data, A-A’



%Ca (data from XRD) varies with depth changing from nearly stoichiometric dolomite (top) to calcium rich dolomite (bottom)

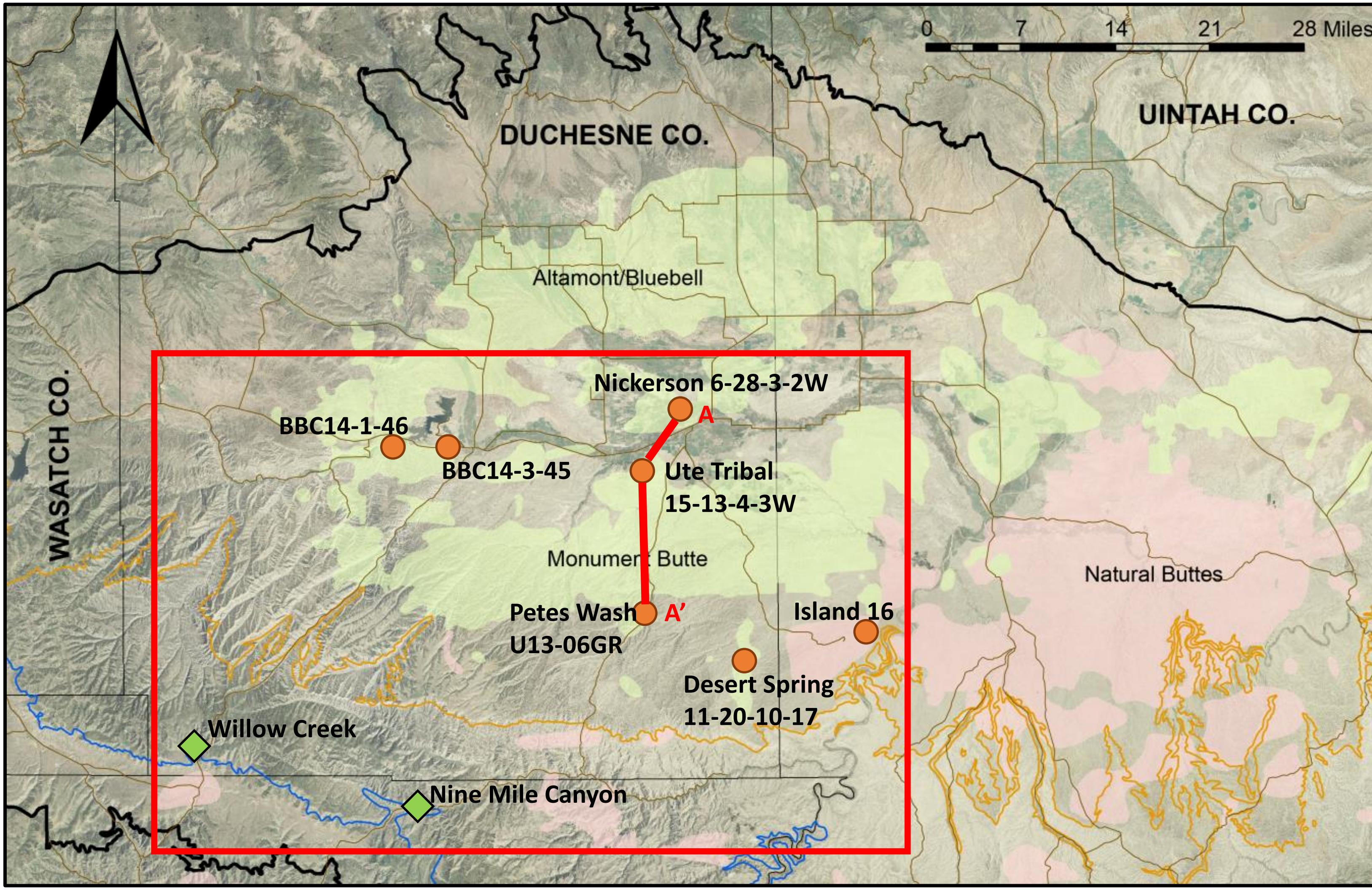
%$CaCO_3$ REGIONAL TREND
EMP data / PZ1'



Ca:Mg ratio (data from EMP) exhibits a regional trend N – S regardless of depth (PZ1')

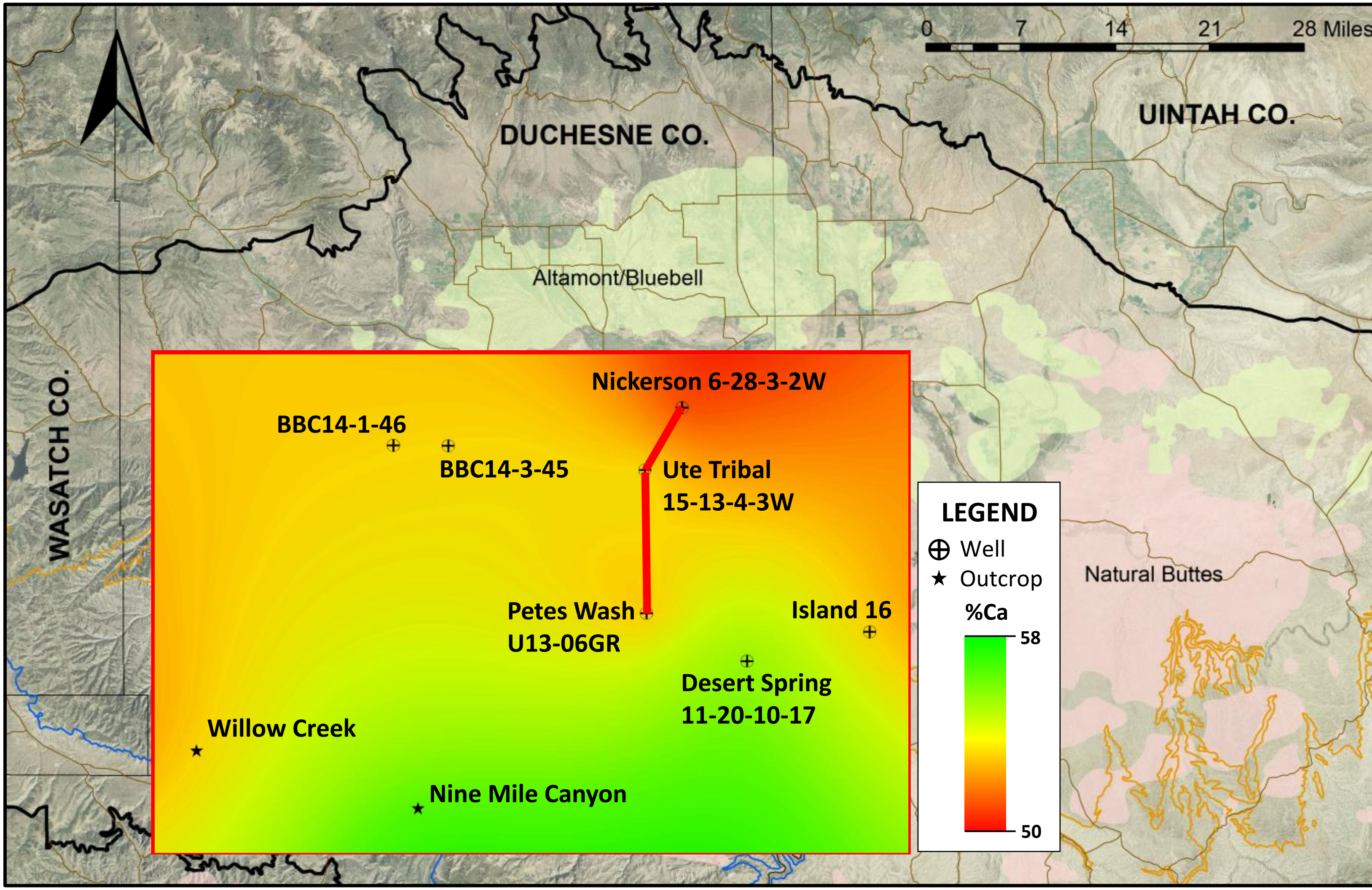
%$CaCO_3$ REGIONAL TREND

XRD Data, all wells for PZ1'

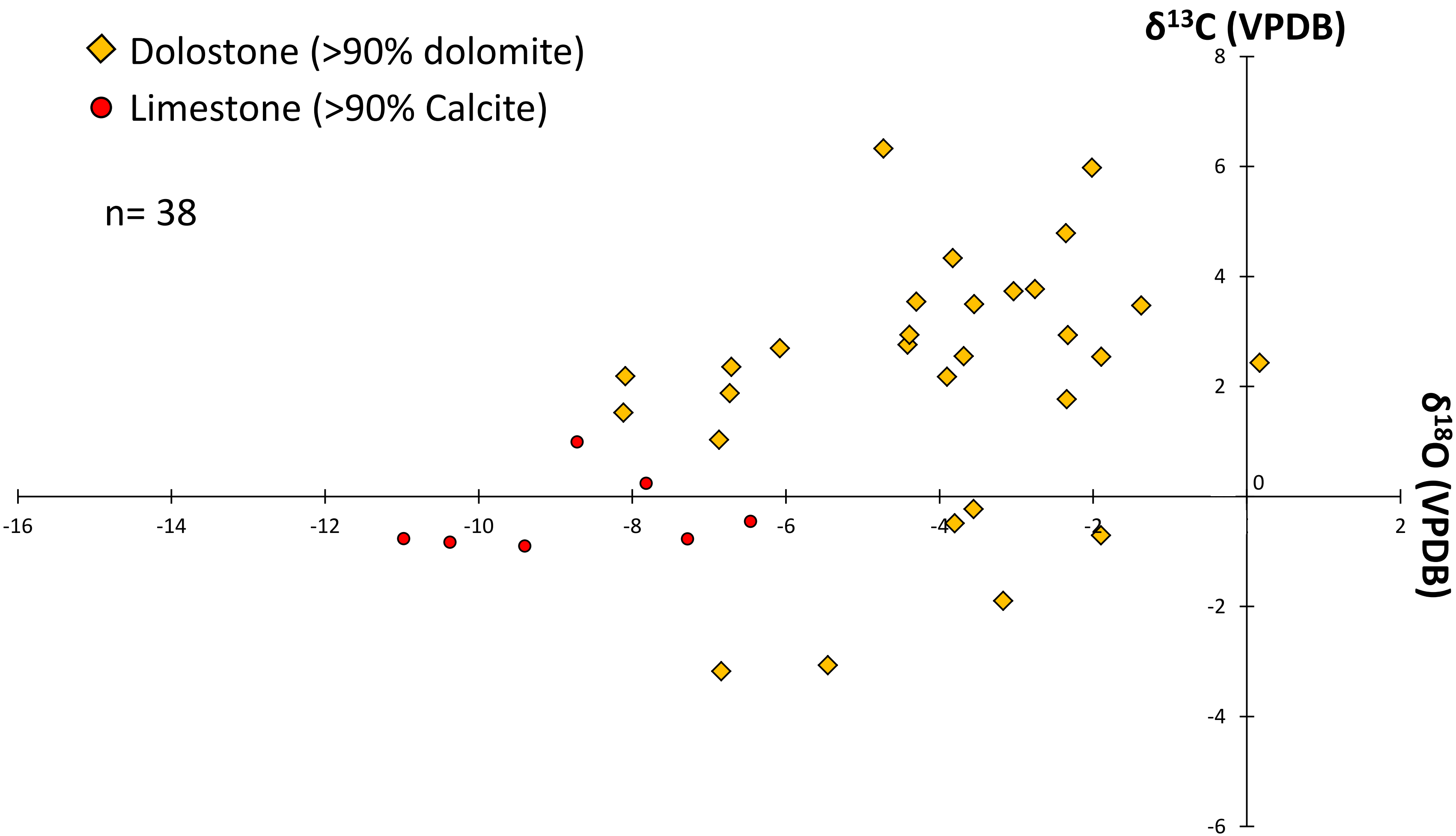


%$CaCO_3$ REGIONAL TREND

XRD Data, all wells for PZ1'

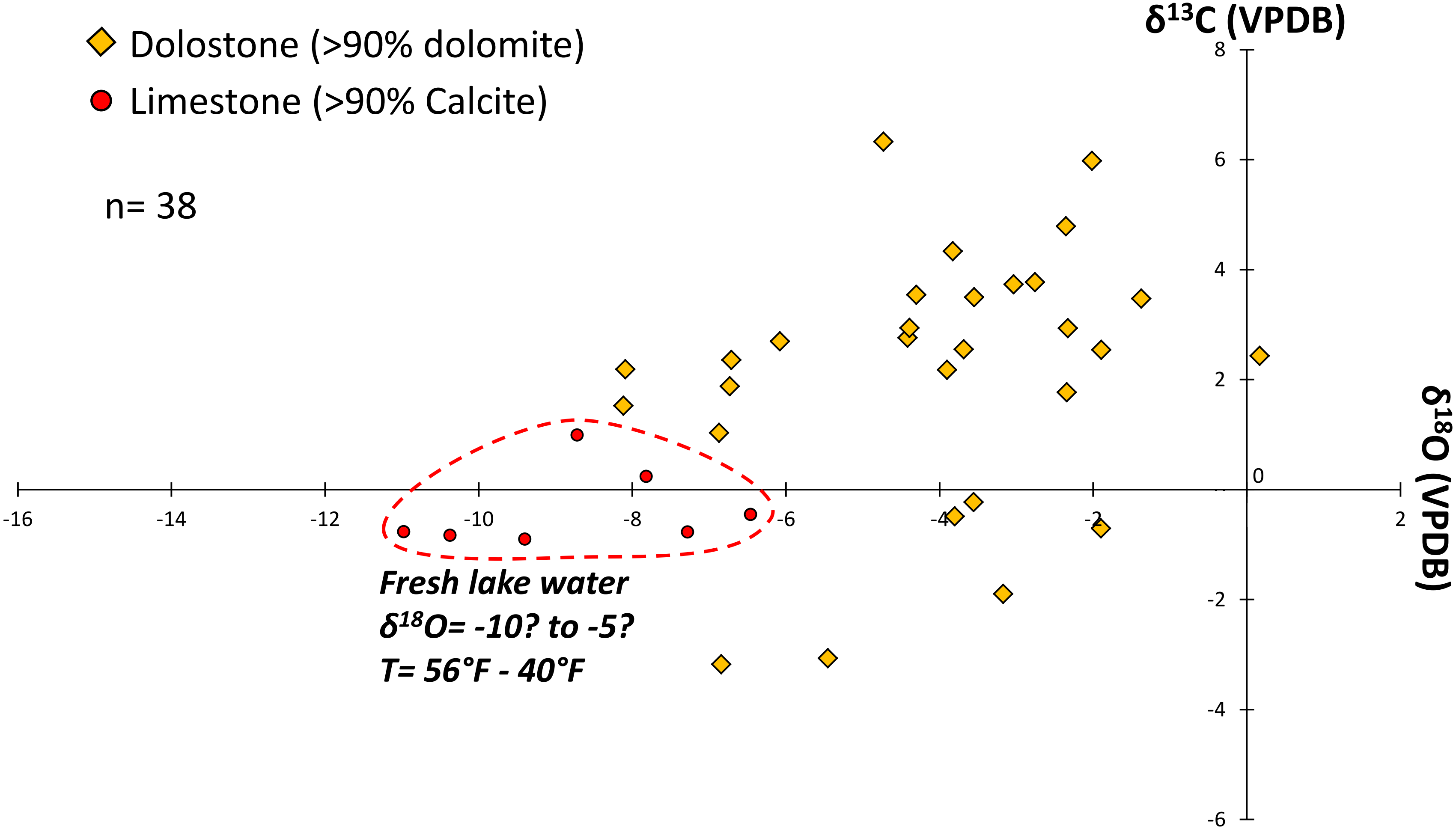


ISOTOPIC SIGNATURE



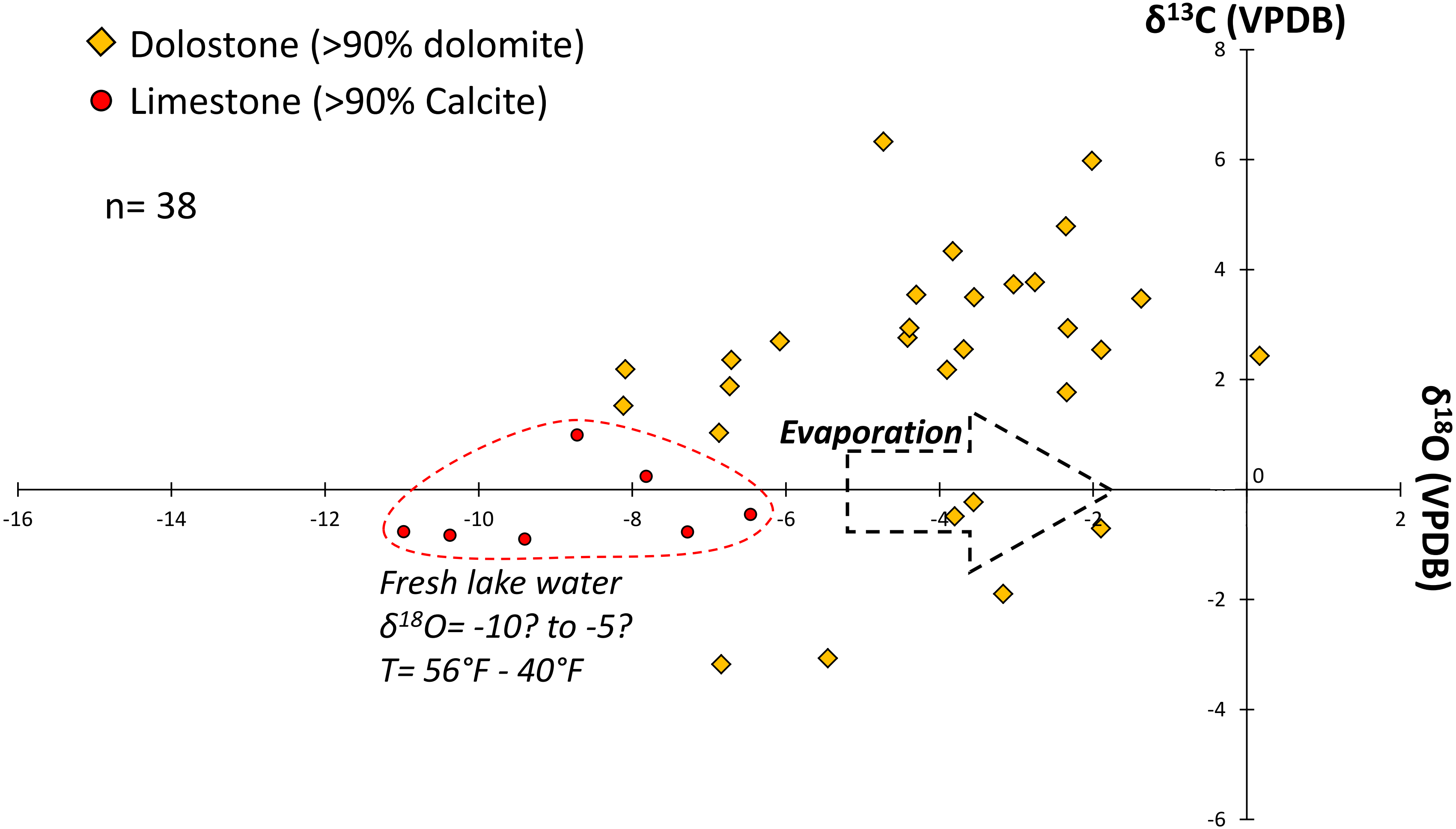
^{13}C and ^{18}O of dolomite for PZ1, PZ1', and PZ2 and interbedded molluscan limestones

ISOTOPIC SIGNATURE



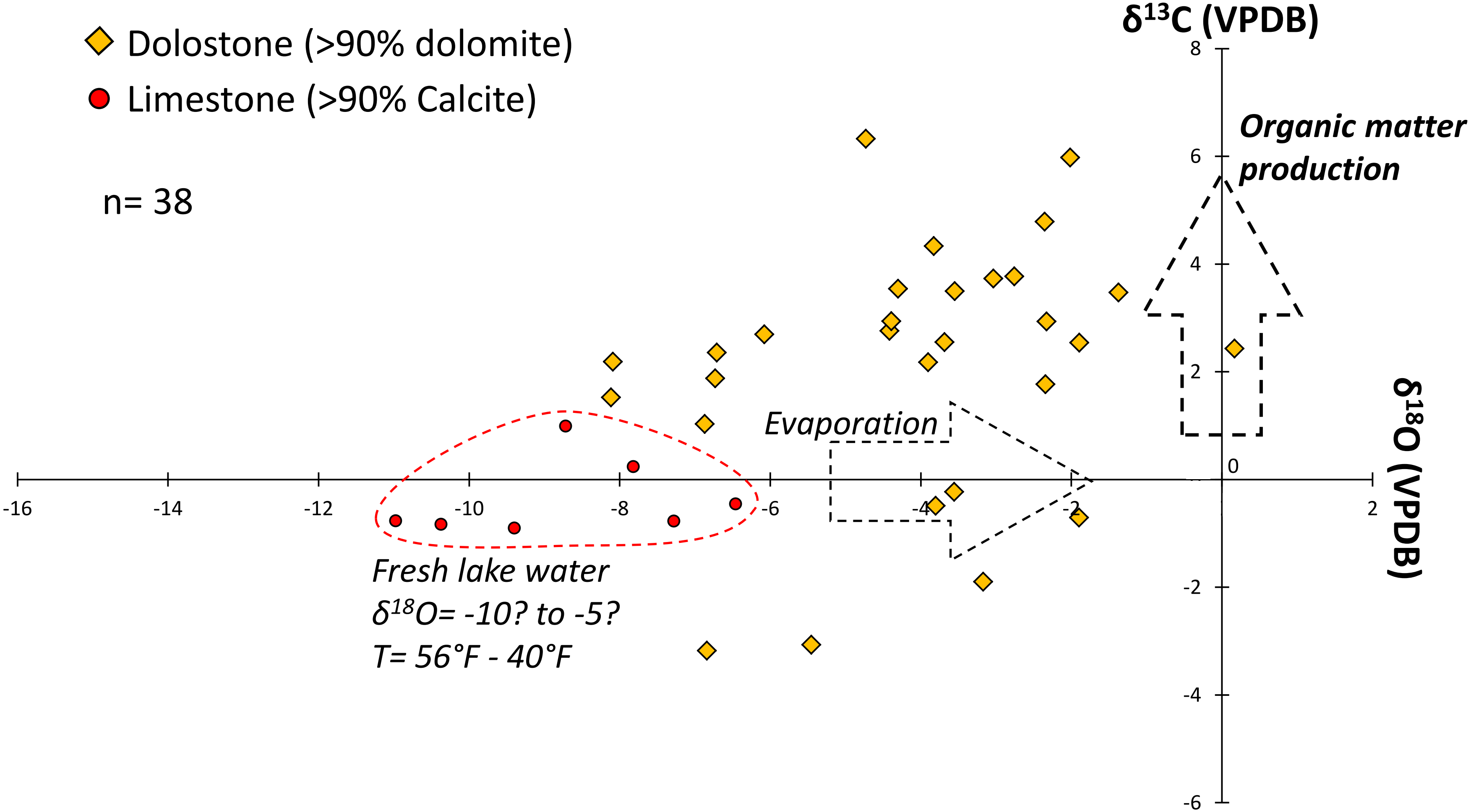
Pre-dolomite composition of lacustrine calcite, probably representing lake water chemistry

ISOTOPIC SIGNATURE



Evaporation of lake water increased ^{18}O dolomite values

ISOTOPIC SIGNATURE



High organic matter production increased ^{13}C dolomite values

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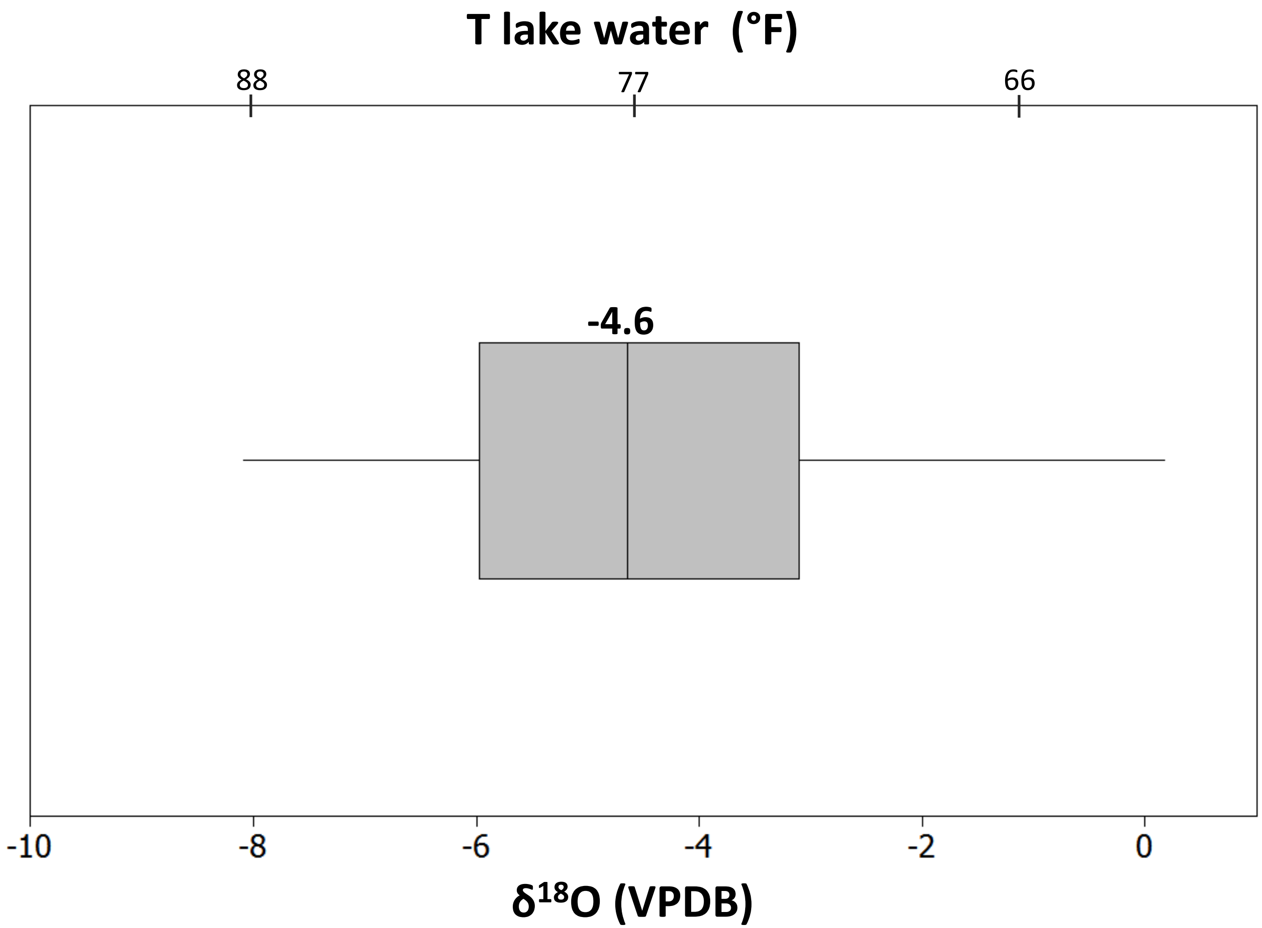
TEMPERATURE OF DOLOMITIZATION



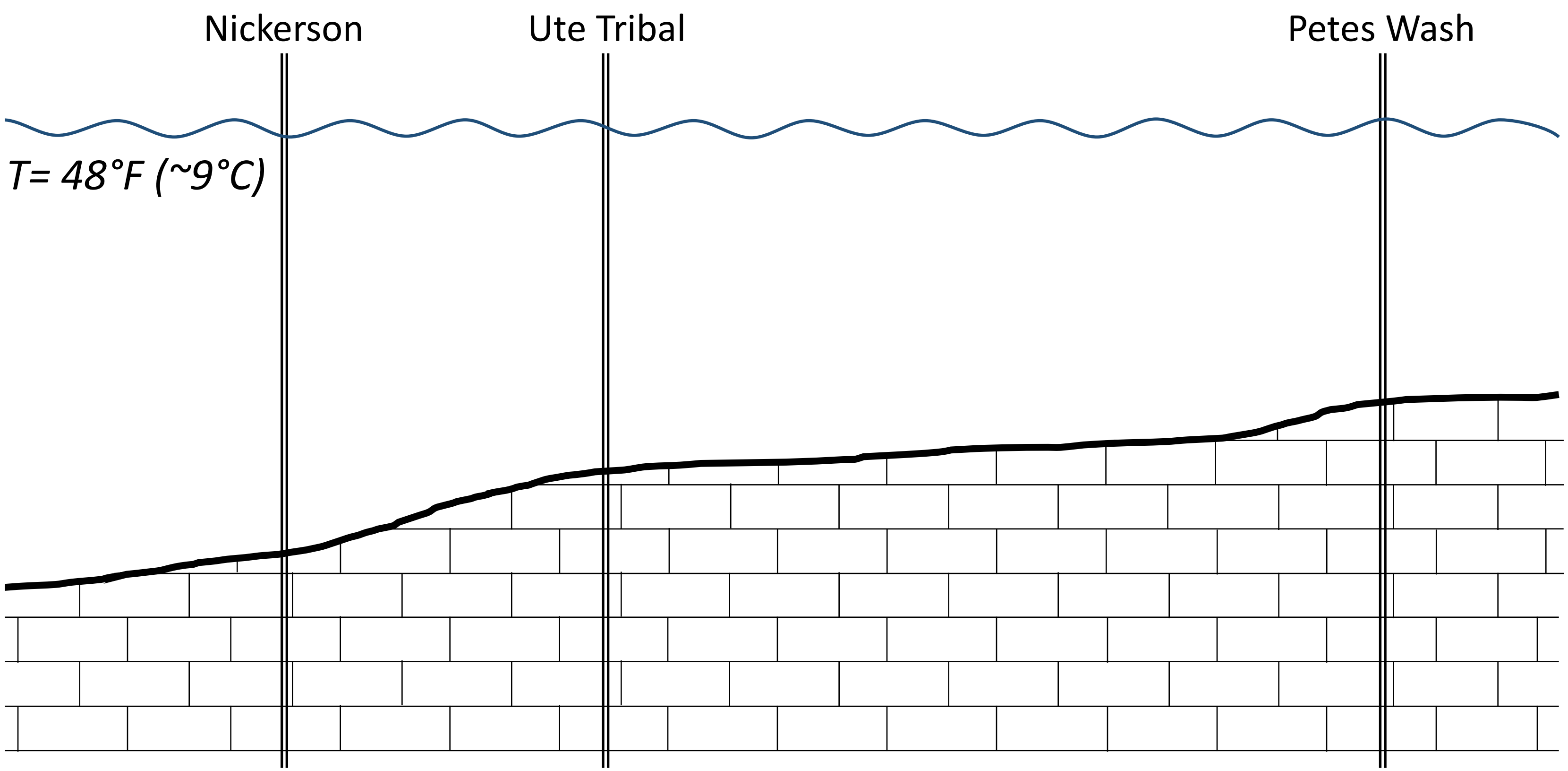
$\delta^{18}O$ dolomite: -3.1 to -5.9

$\delta^{18}O$ lake water: -10? to -5?

Calculated lake water temperature: 66 °to 88°F

DOLOMITIZATION DRIVEN BY CLIMATE CHANGE

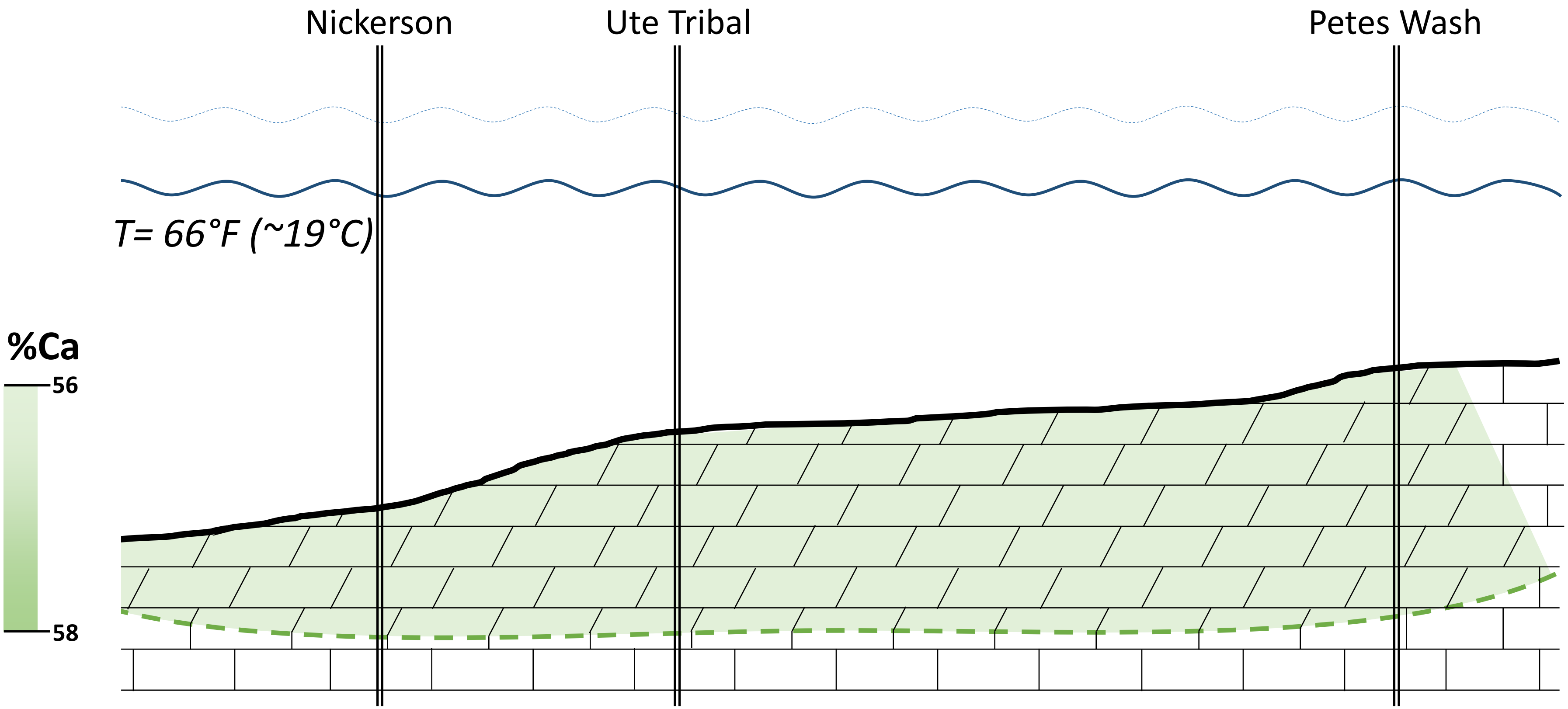
Stage 0:



Fresh water input - humid climate - favored deposition of wackestones/floatstone with bivalves, gastropods, and ostracods

DOLOMITIZATION DRIVEN BY CLIMATE CHANGE

Stage 1:



Climate changes (high evaporation + reduced fresh water input) changed lake water chemistry that promoted replacement of micrite (matrix) by high calcium dolomite

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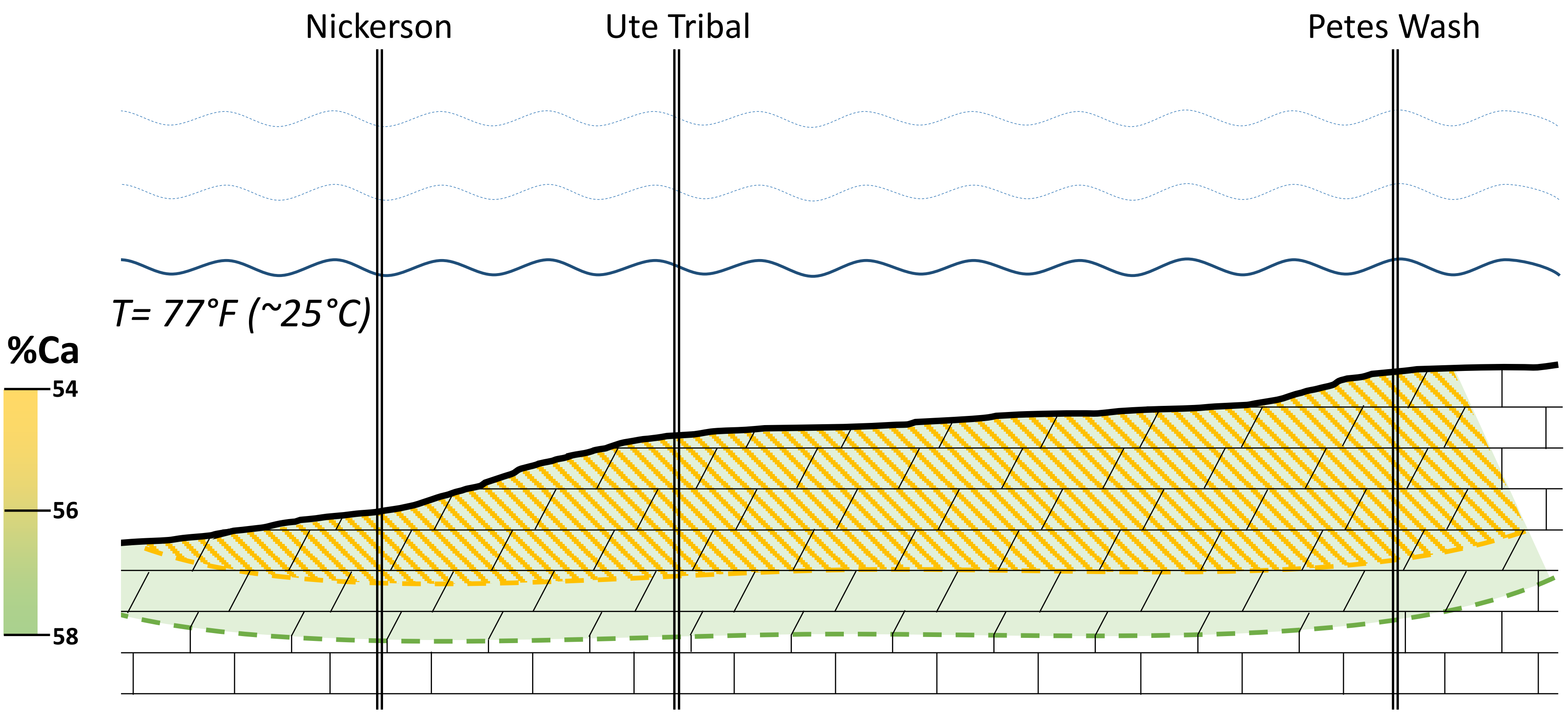
Stage 2:



Higher evaporation favoured dolomite recrystallization (*stage 1*) and/or micrite replacement by calcium dolomite

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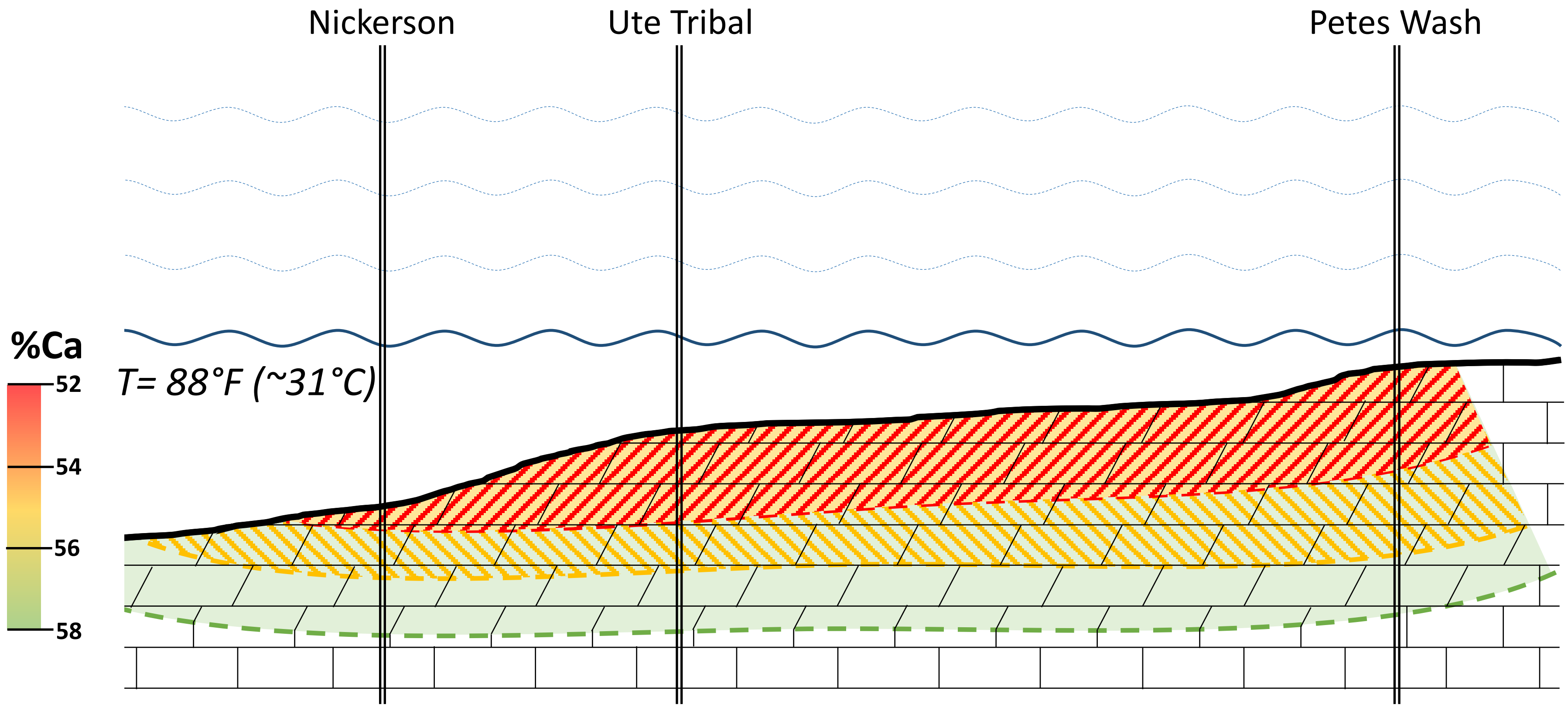
Stage 3:



At highest temperature, dolomite recrystallization (stages 1-2) persisted developing nearly stoichiometric dolomite (top). This cycle was repeated several times

1. Dolomite Reservoirs Characteristics
2. Objectives
3. Methodology
4. Study Area
5. Stratigraphy
6. Facies - Depositional Environments
7. Cyclicity
8. Dolomite Textures
9. Geochemistry
10. Interpretations
11. **Conclusions**

Origin of the Uteland Butte member dolomites

Dolomitization was driven by climate changes:

- ✓ Took place in cyclically warmer climates
- ✓ Enhanced evaporation
- ✓ Reduced fresh water input
- ✓ Shallower lake water levels

Implications for reservoir geology

- ✓ Dolomite planar-e and planar-s textures are slightly correlated with higher porosity values
- ✓ Spatial distribution of dolomite textures?
- ✓ Spatial distribution of %Ca vs Porosity?

REFERENCES

Logan, S. K.; Sarg, J. F.; & Vanden Berg, M. D. (2016) Lithofacies, deposition early diagenesis, and porosity of the Utelan Butte member, Green River Formation, Eastern Uinta Basin, Utah and Colorado. Open-file report 652. Utah Geological Survey

Sibley, D. F.; & Gregg, J. M. (1987). Classification of Dolomite Rock Textures. *Journal of Sedimentary Petrology, 57* (6), 967-975