Using Geophysical Logs to Estimate Relative Uplift in Cook Inlet Basin, Alaska

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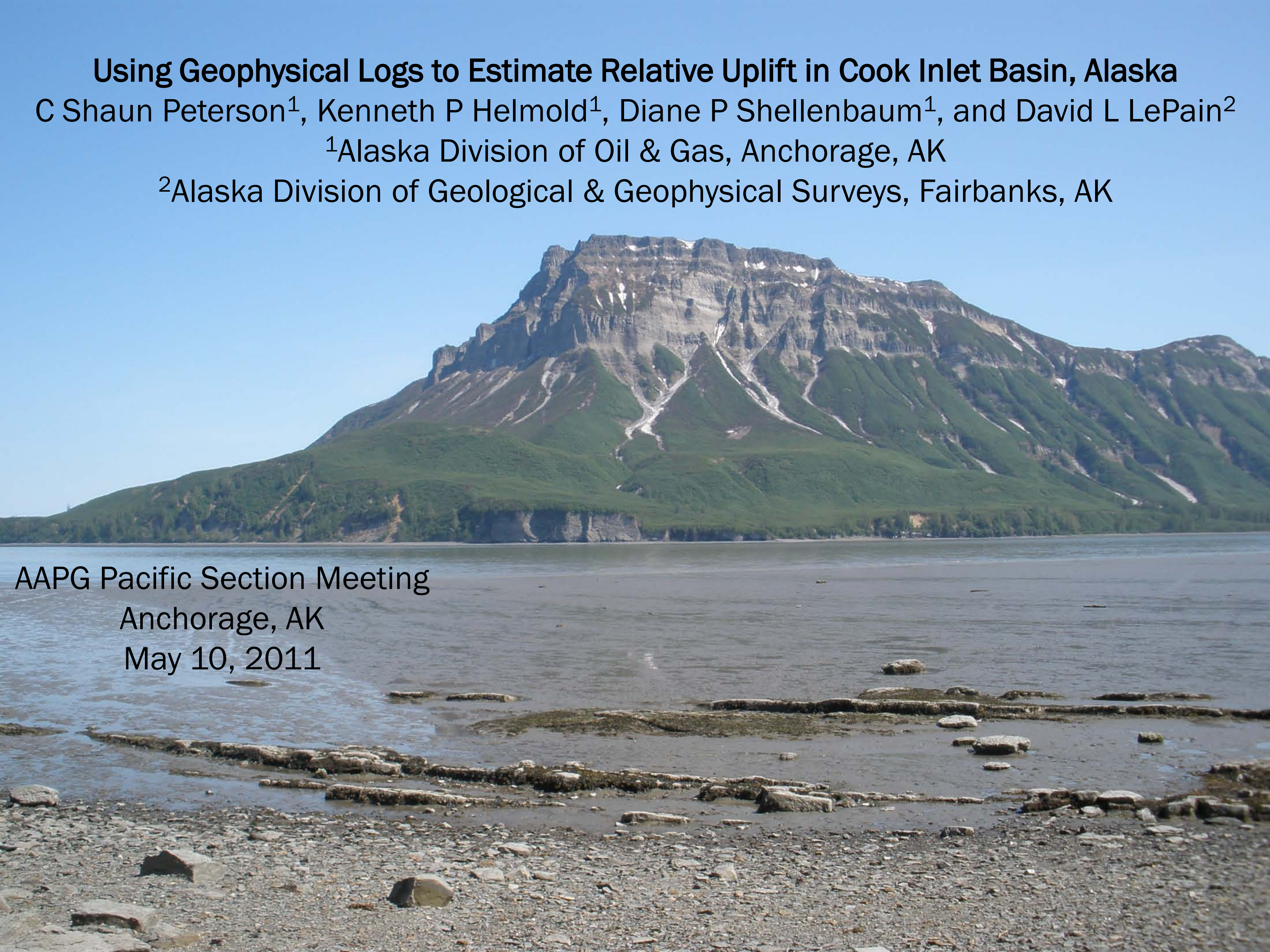

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Purposes of this Study

- To understand regional relative differences in Cook Inlet basin uplift history.
- To attempt, using public data sources, a Cook Inlet basin relative uplift model similar to other proprietary evaluations done in the past.
- To provide interpretation of distinctive patterns present in Cook Inlet basin compaction trends.
- To aid in the development of geohistory models for Upper Cook Inlet Basin wells.

Premises

- By use of shale compaction data (sonic logs) thicknesses of sedimentary sequences removed by erosion (i.e. uplift) can be estimated (Magara, 1976 & 1978).
- Compaction in sediments is a one-way street. Rebound does not occur when overburden is removed or pressure is reduced. The sonic log thus records the maximum compaction achieved at typically the greatest depth.

Preface to governing equation

- Porosity decreases with increasing depth.
- Rate of porosity decrease is exponential (faster at shallower depths, slower at greater depths).
- Porosity can be influenced by anomalously high subsurface fluid pressure (over-pressured zones) leading to greater than expected porosities.

(Magara, 1978)

Equation 1

Porosity/depth relationship (at hydrostatic fluid pressure)

$$\varphi = \varphi_o e^{-cZ} \qquad (1)$$

where φ = shale porosity at depth (Z)

φ_o = shale porosity at surface (Z=0)

e = base of the natural log

c = constant (length^{-1}) indicating slope of the normal compaction trend

Z = depth

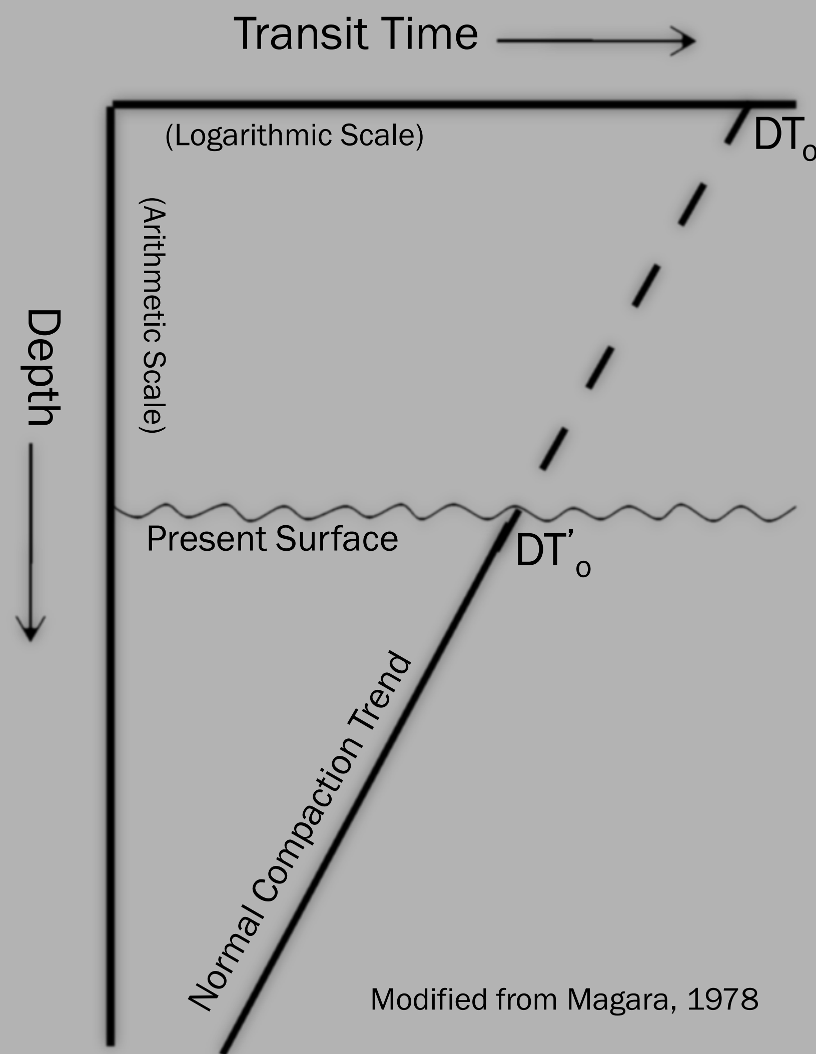
Because shale porosity (φ) at depth is difficult to obtain, sonic log transit time (DT) may act as a proxy for φ. Therefore substituting DT for φ in (1) above yields:

$$DT = DT'_o e^{-cZ} \qquad (1a)$$

where DT = sonic log transit time (μs/ft) at depth (Z)

DT'_o = extrapolated transit time (μs/ft) at surface (Z=0)

(Magara, 1978)



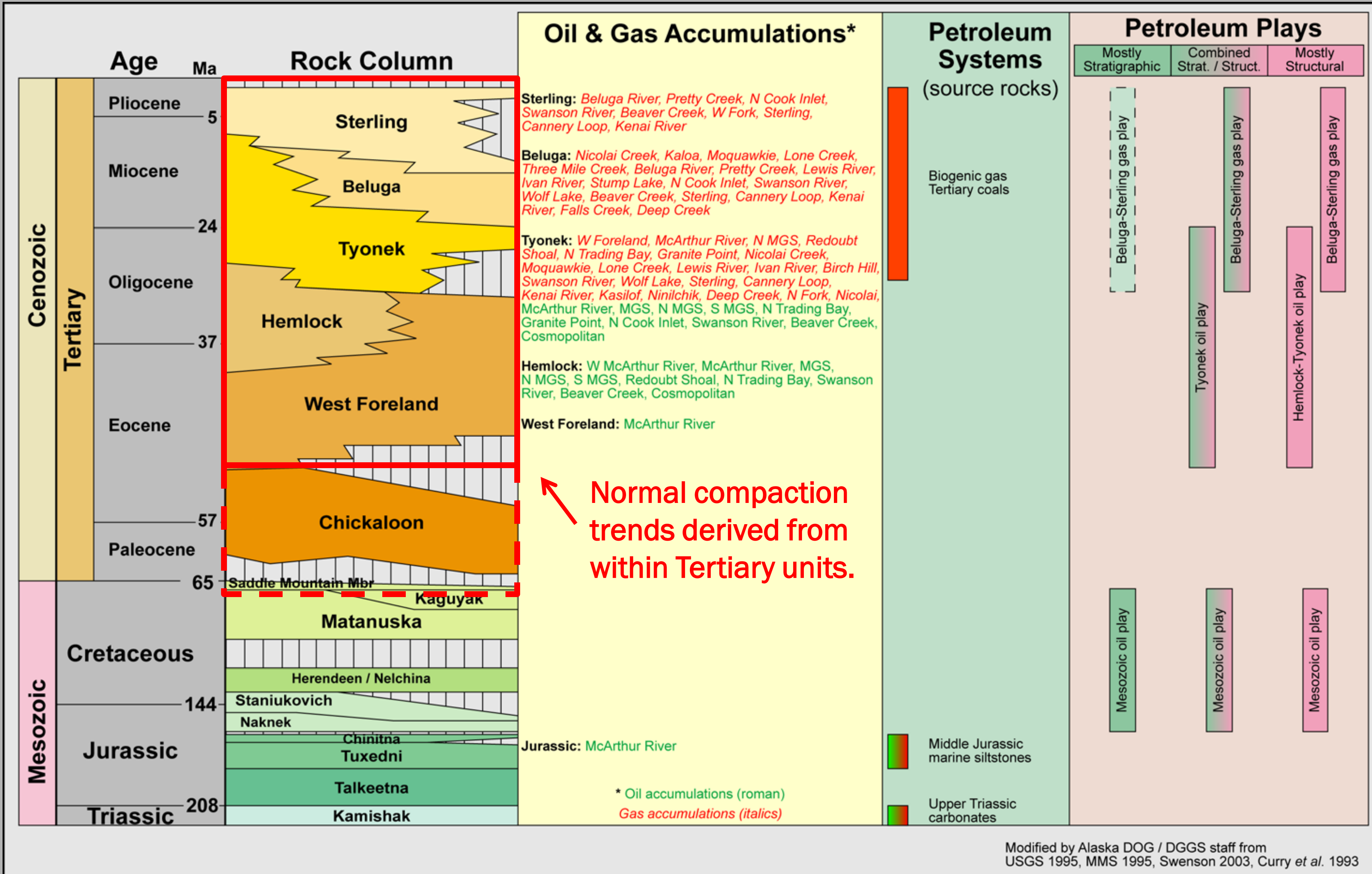
Relationship of DT_{log}, DT_o, and DT'_o

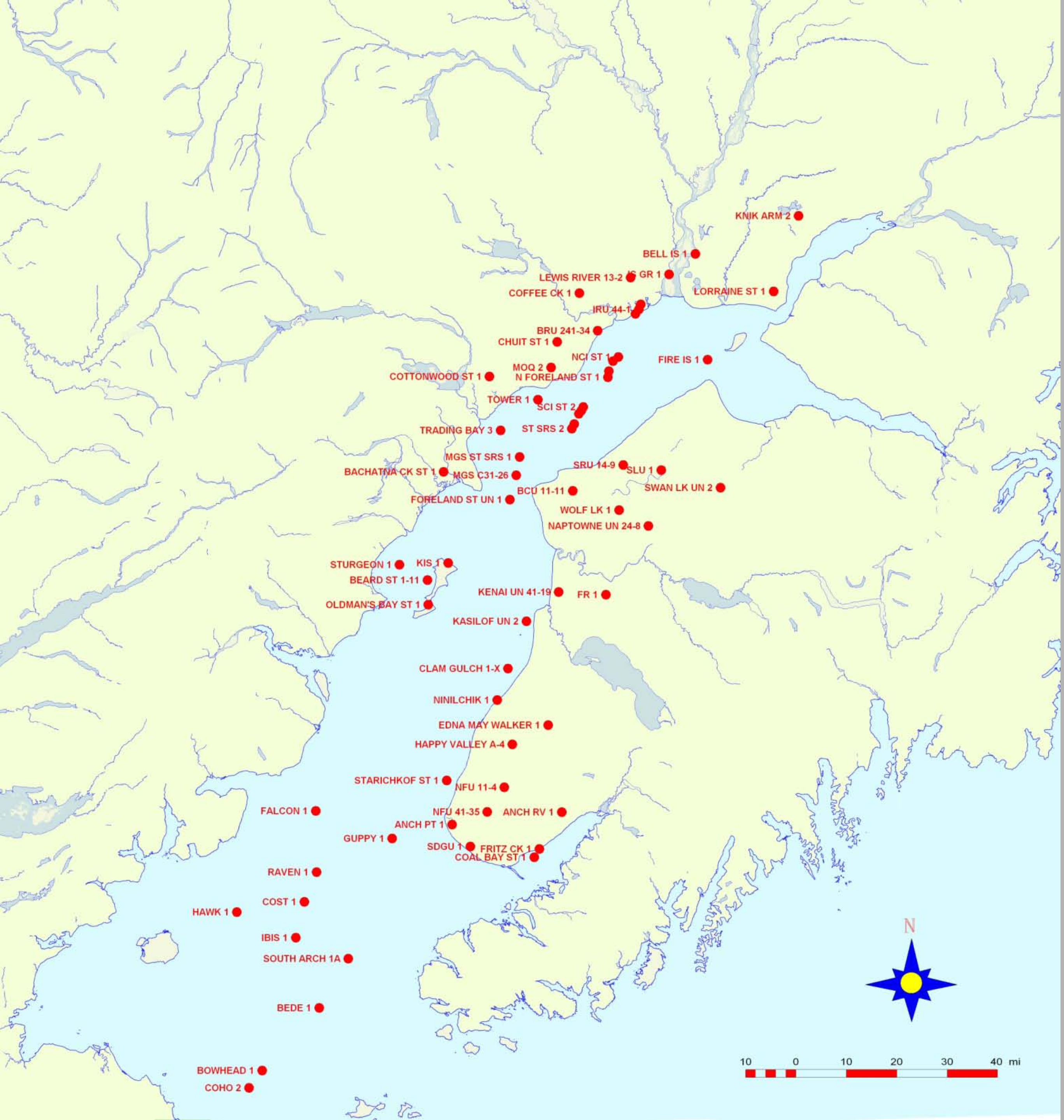
DT_{log} = sonic log transit times (μs/ft) from which normal compaction trend is regressed.

DT_o = extrapolated surface transit time (μs/ft) at original surface when significant uplift has not occurred.

DT'_o = extrapolated surface transit time (μs/ft) at present surface when uplift has occurred.

Cook Inlet Stratigraphy and Petroleum Plays





Well Distribution

64 Upper Cook Inlet wells analyzed (shown here).

26 wells retained for relative uplift analysis.

38 wells dropped due to data reliability concerns.

Methods

Sonic log (DT_{log}) editing workflow

- Edit DT_{log}

  Remove poor data quality zones, cycle skips, and coals.

- Apply Spontaneous Potential (SP) curve delimiter

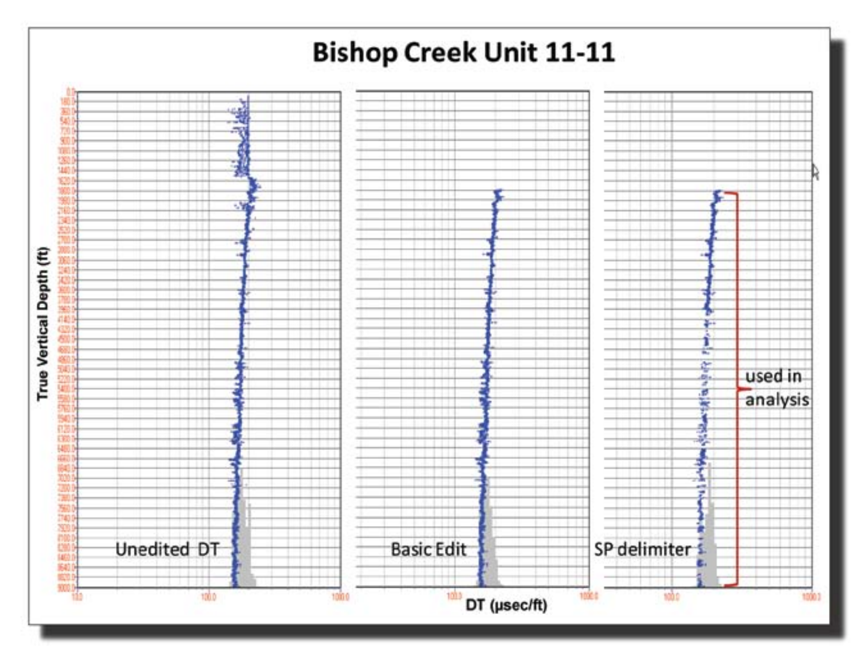
  Retain DT_{log} only where baseline shifted SP = 95-100mv in an attempt to model only the shaliest lithologies.

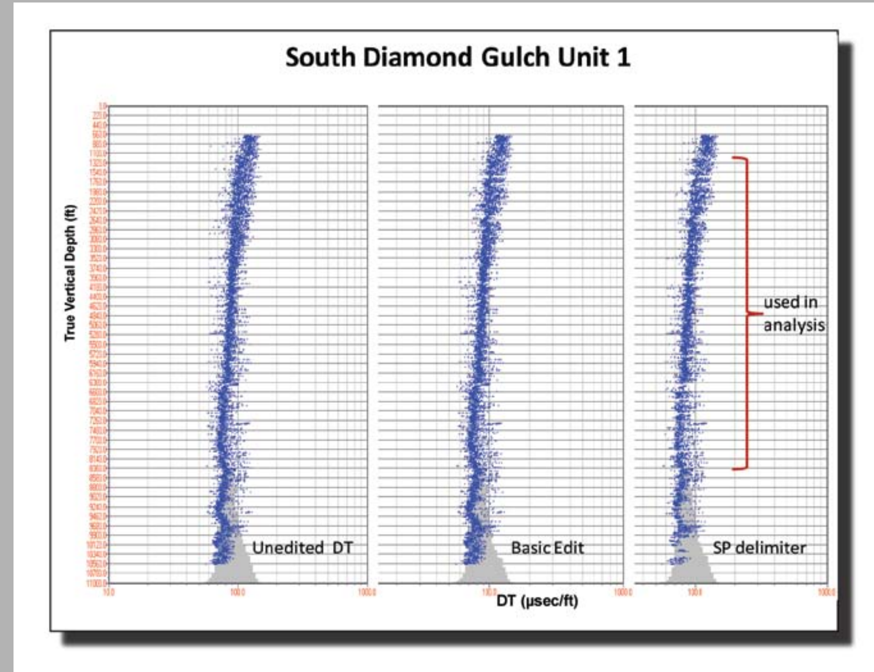
- Edit DT_{log} slope trends

  Remove effects of remnant non-shale lithologies, such as conglomerates and volcanics.

  Remove obvious fluid effects due to proximal gas fields.

  Remove over-pressured zones.





Sonic log transit time (DT) vs Depth Plots

Basic Edit

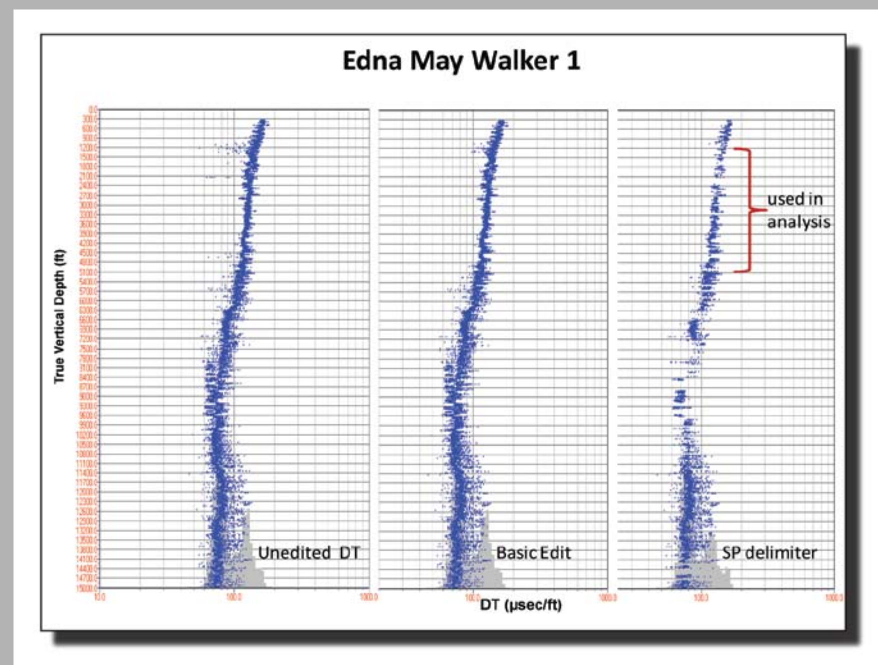
- Erroneous data removed.
- Obvious cycle skips removed.

SP delimiter

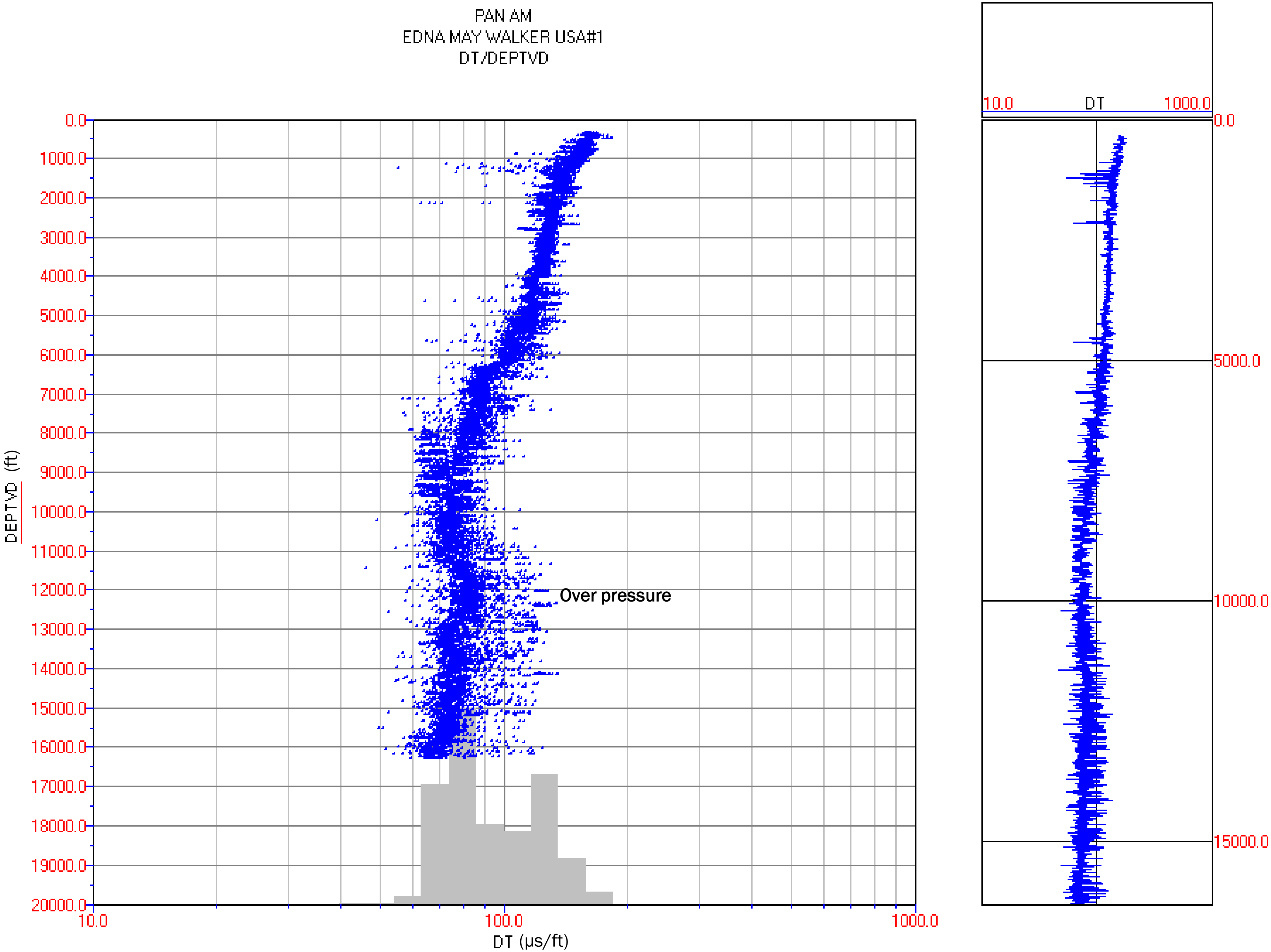
- Data cloud narrowed (and segmented).

In general

- Non-shale lithologies ignored.
- Over pressured zones ignored.

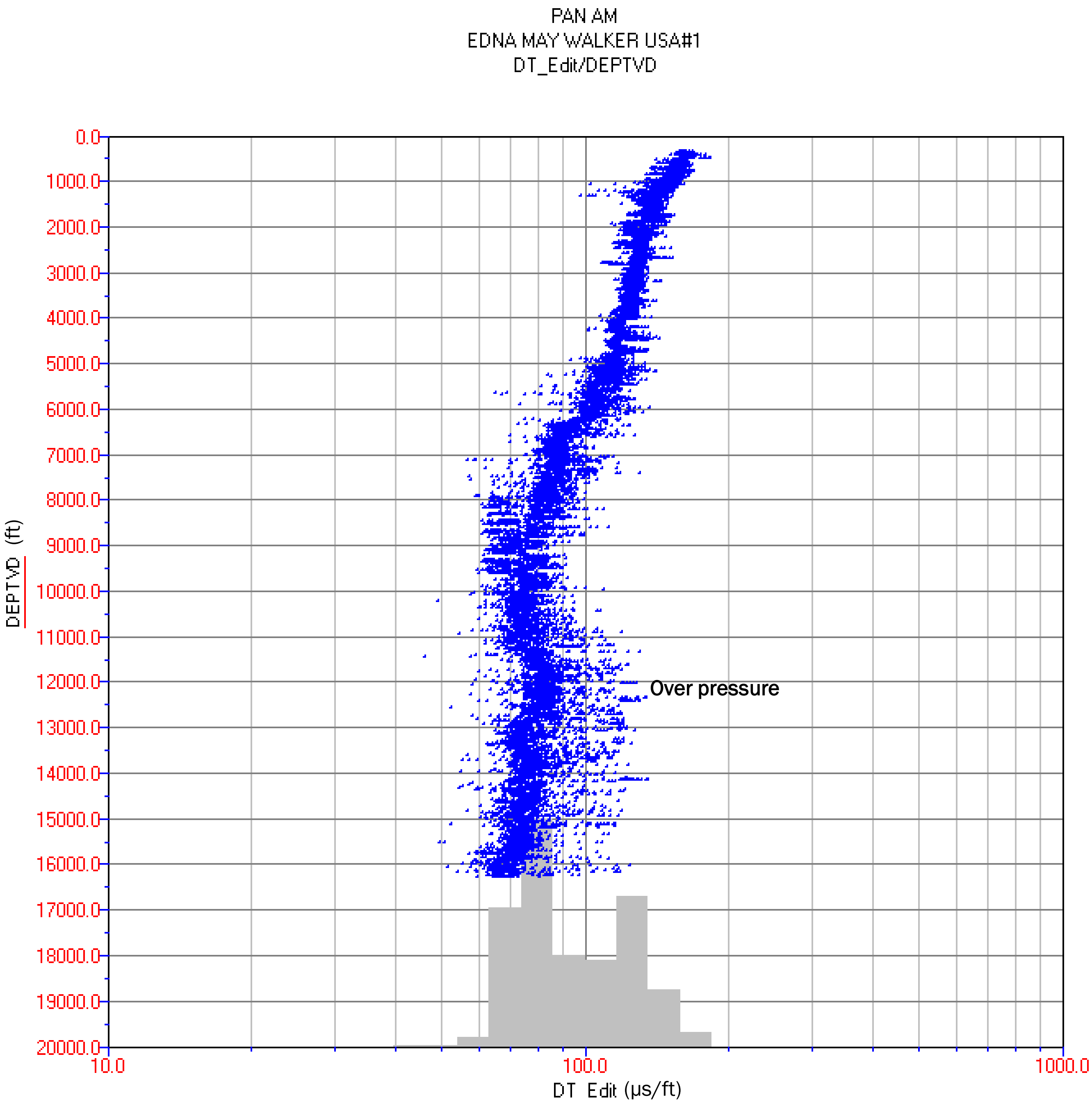


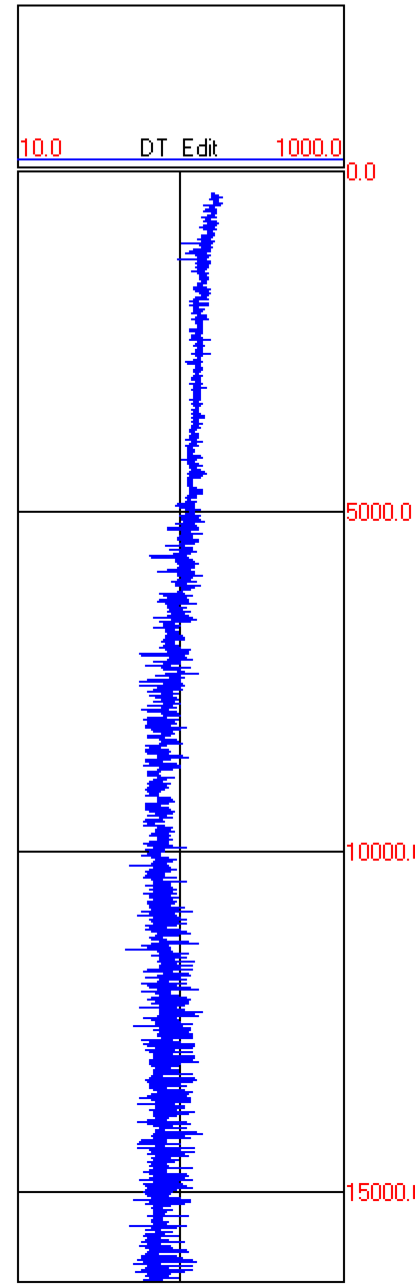
Raw data



Note: A decrease in DT (sonic log transit time) is equivalent to an increase in velocity.

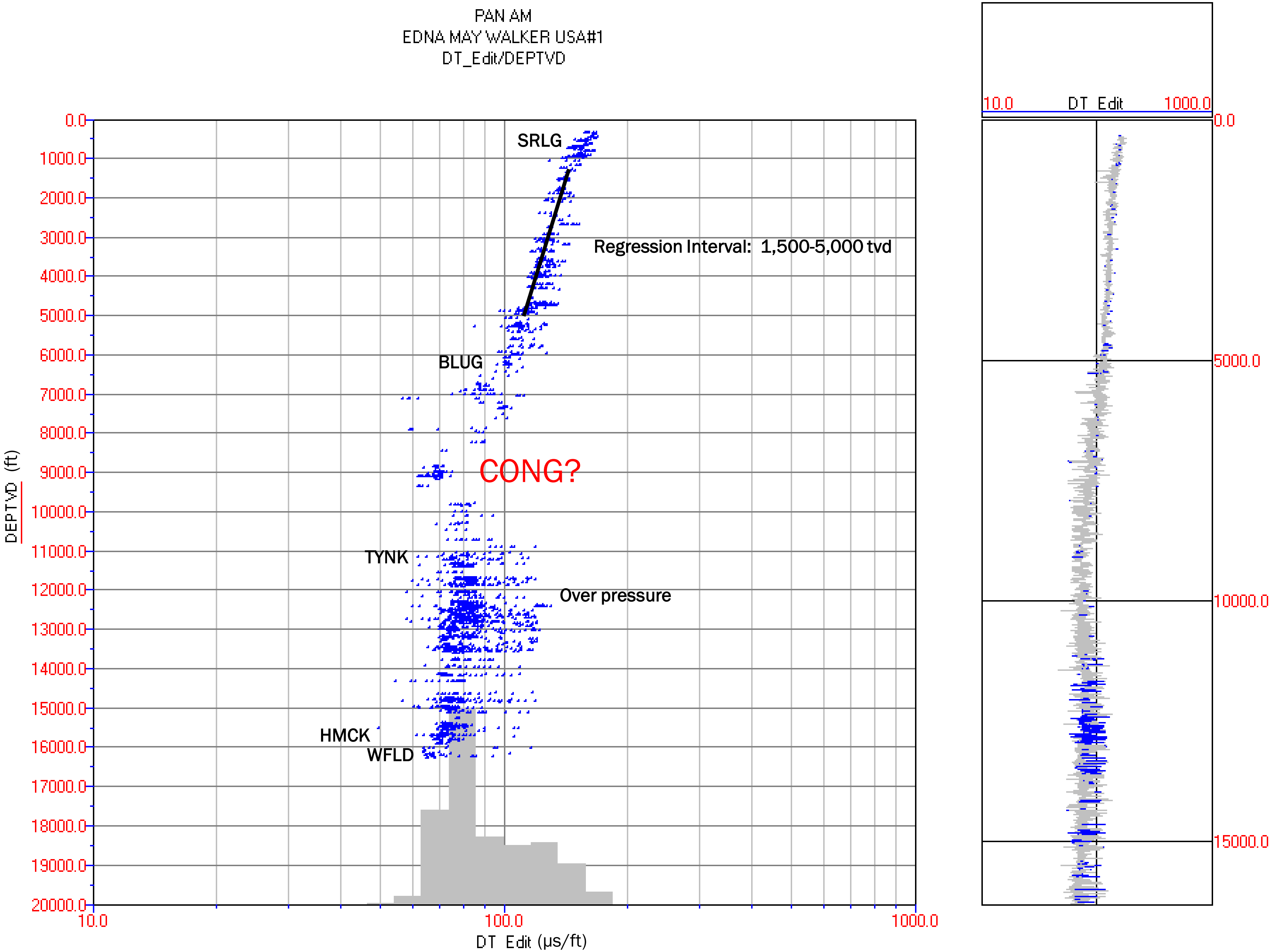
Basic edit





Note: A decrease in DT (sonic log transit time) is equivalent to an increase in velocity.

SP delimiter >97 mv

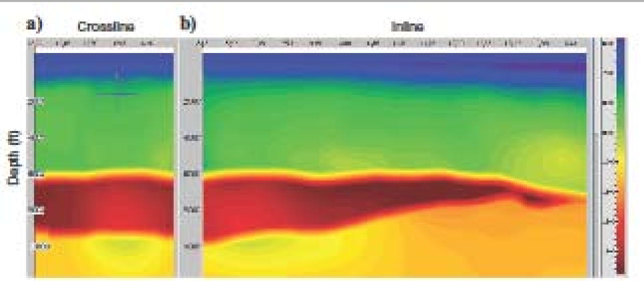


Note: A decrease in DT (sonic log transit time) is equivalent to an increase in velocity.

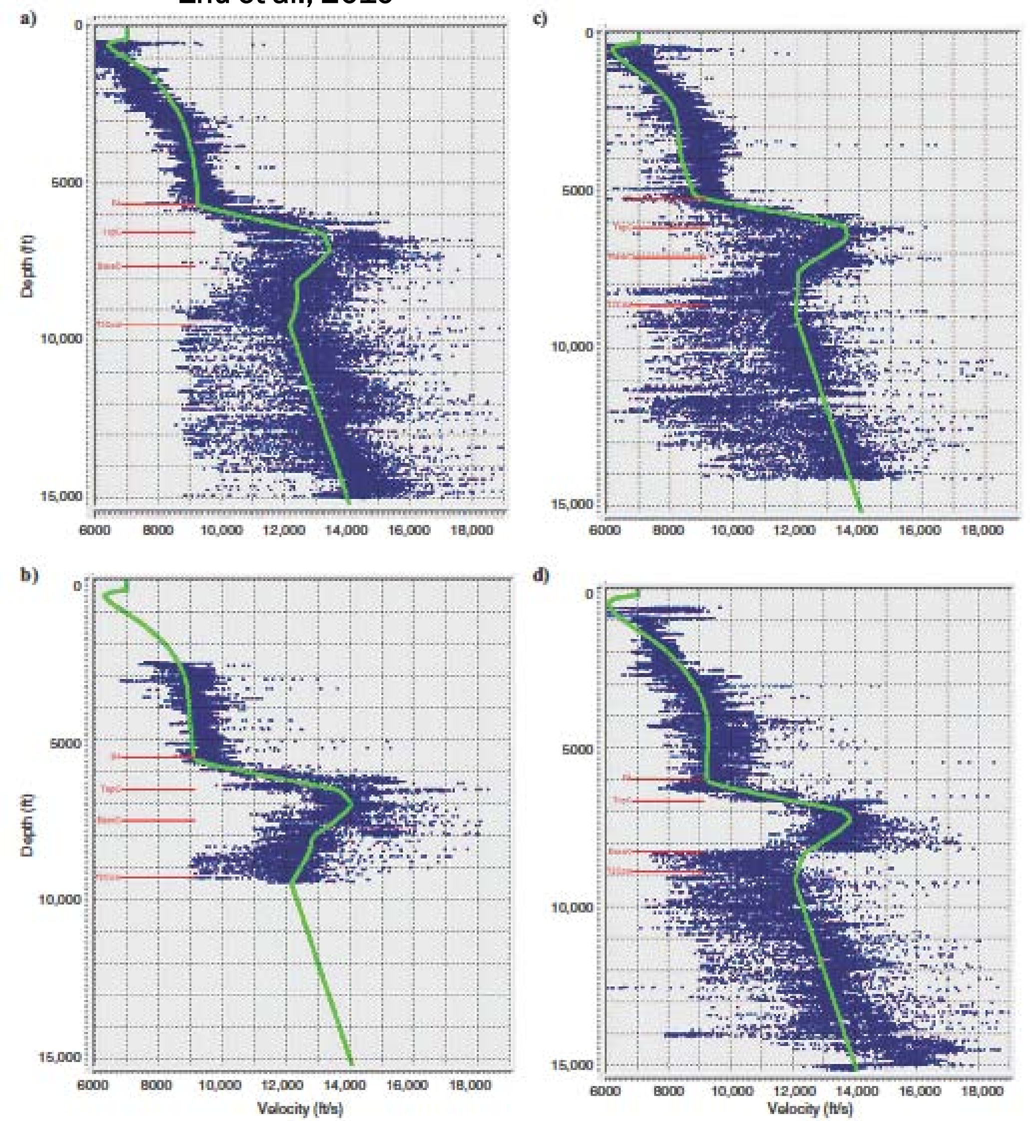
Velocity vs. Depth Plots

Conglomerates within the Beluga are typically indicated by marked increase in sonic velocity.

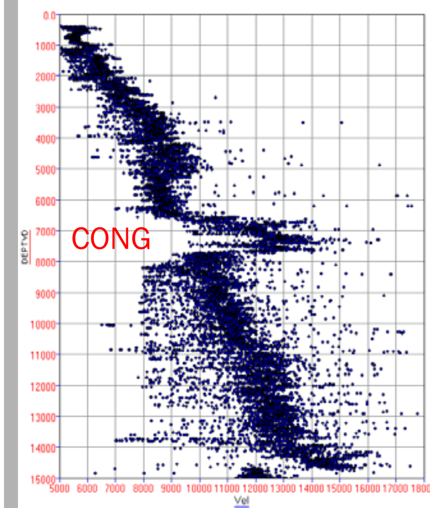
Units manipulation: Transit time (µs/ft) vs. velocity (ft/s)



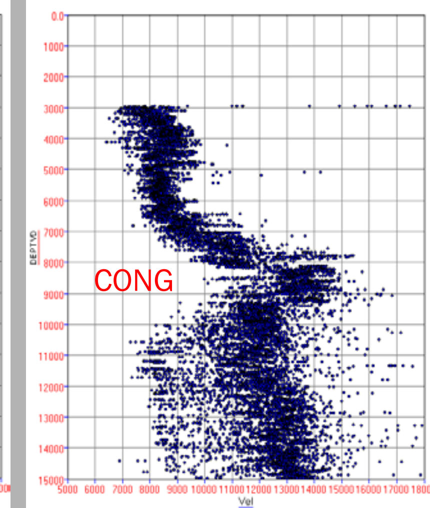
Zhu et al., 2010



Naptowne Unit 24-08



Funny River 1

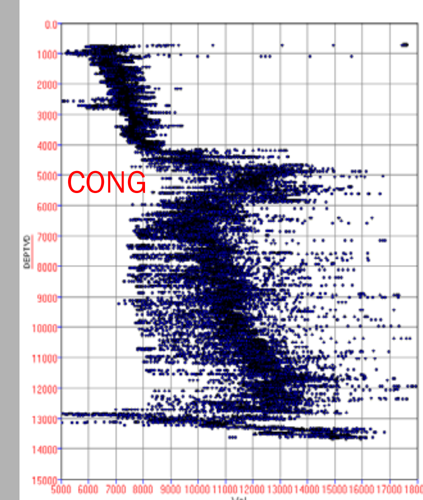


From Zhu et al., 2010
Four wells in the Kenai Peninsula (Sterling area) show a sonic velocity spike across a distinctive conglomerate zone.

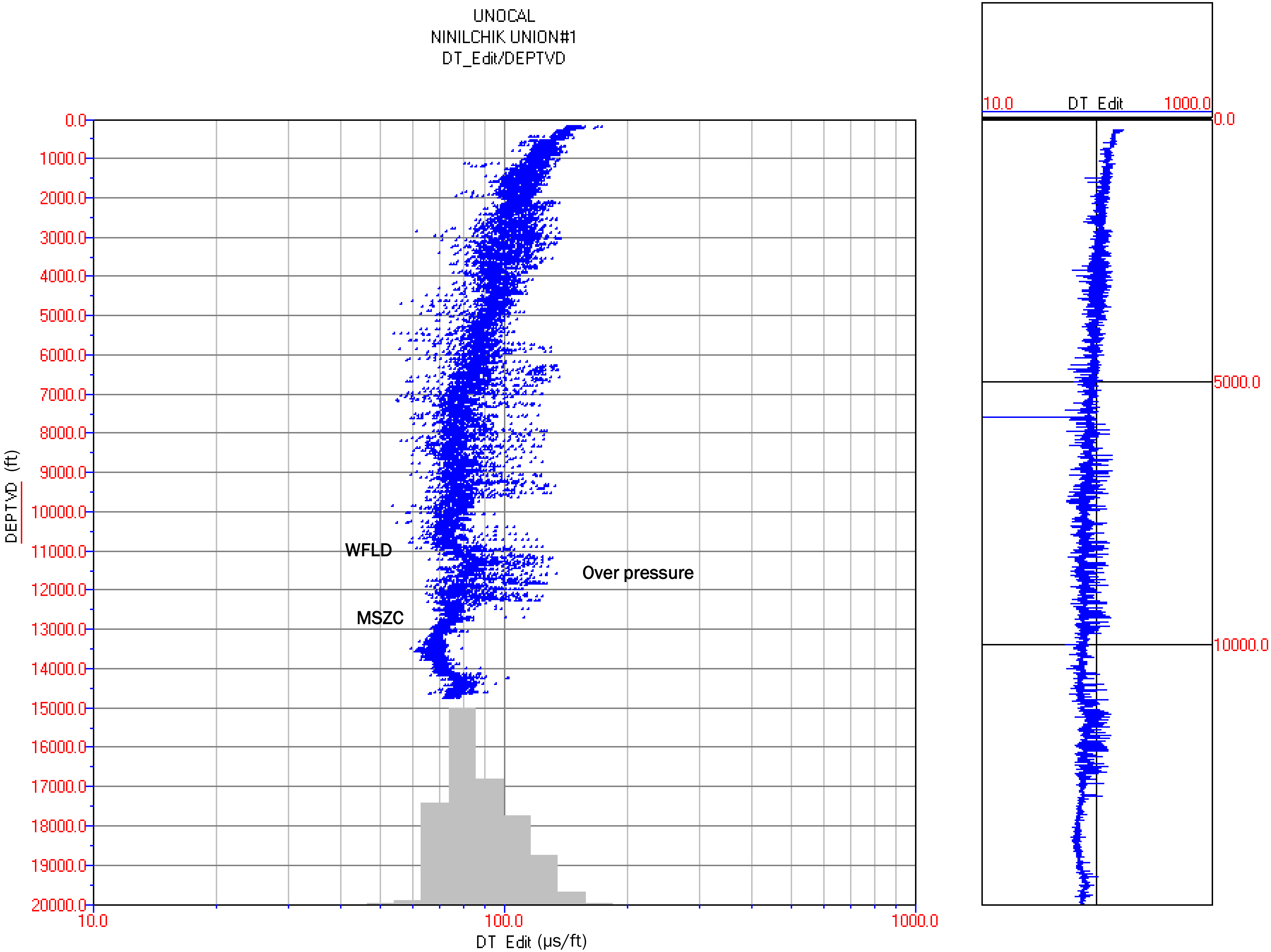
←

Representative plots for Sterling area wells from this study show similar spikes. →

Wolf Lake 1



Basic edit



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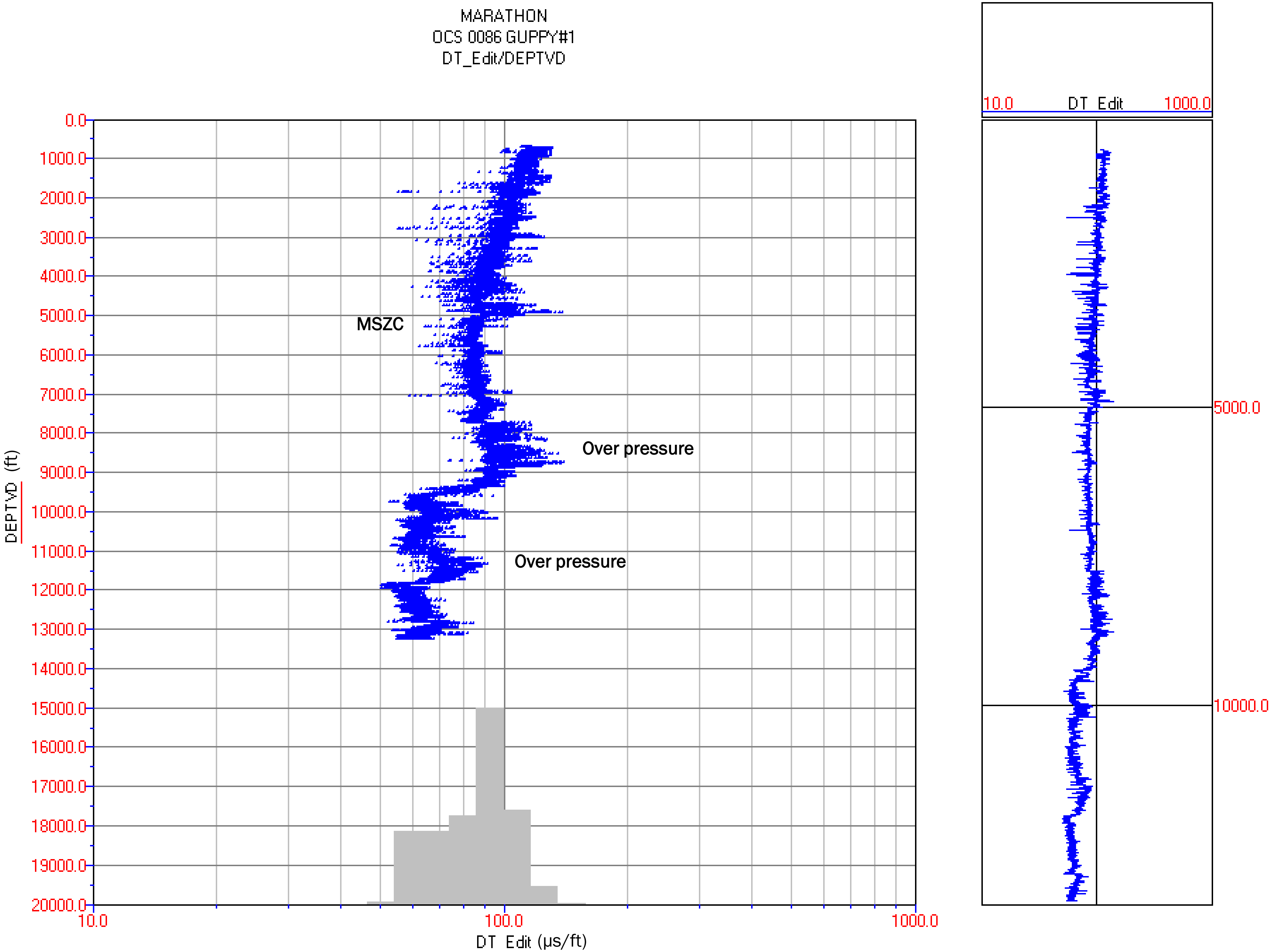
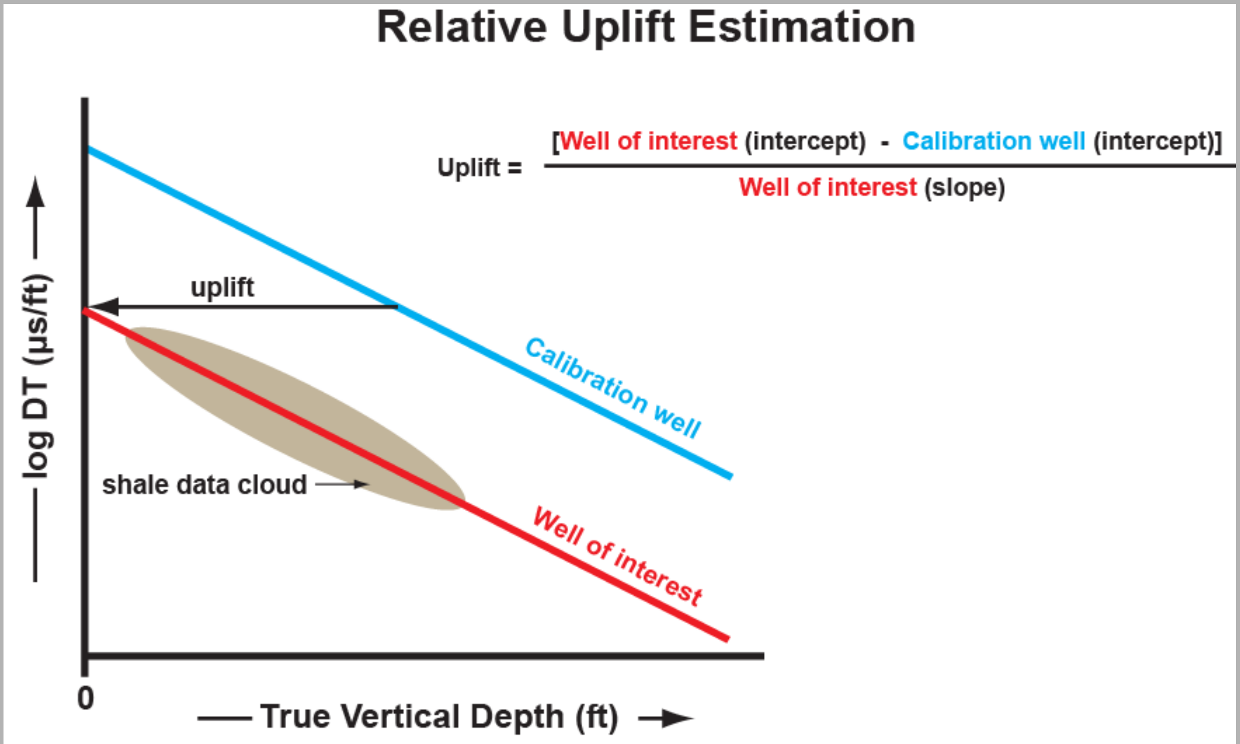


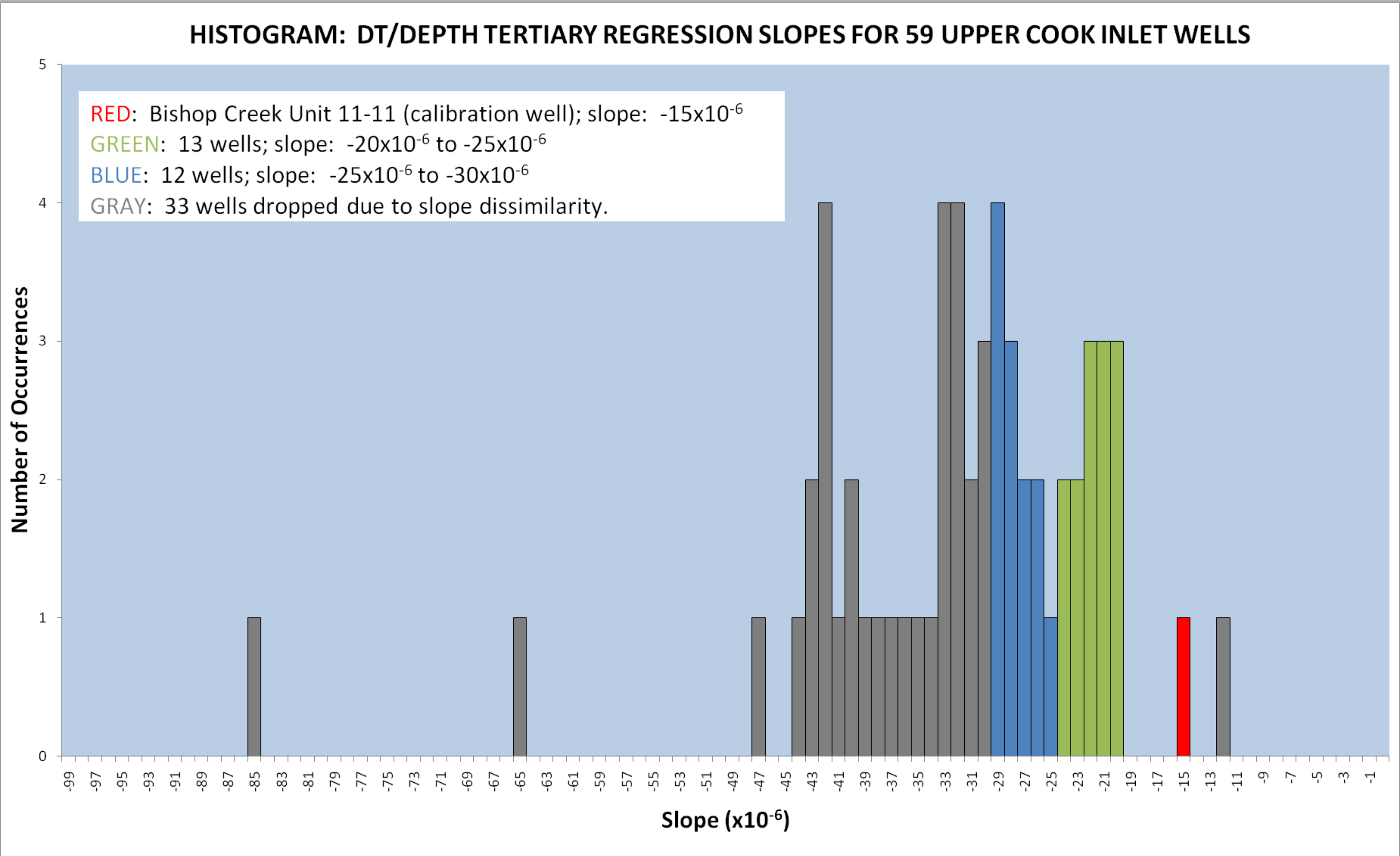
Note: A decrease in DT (sonic log transit time) is equivalent to an increase in velocity.

Methods cont.

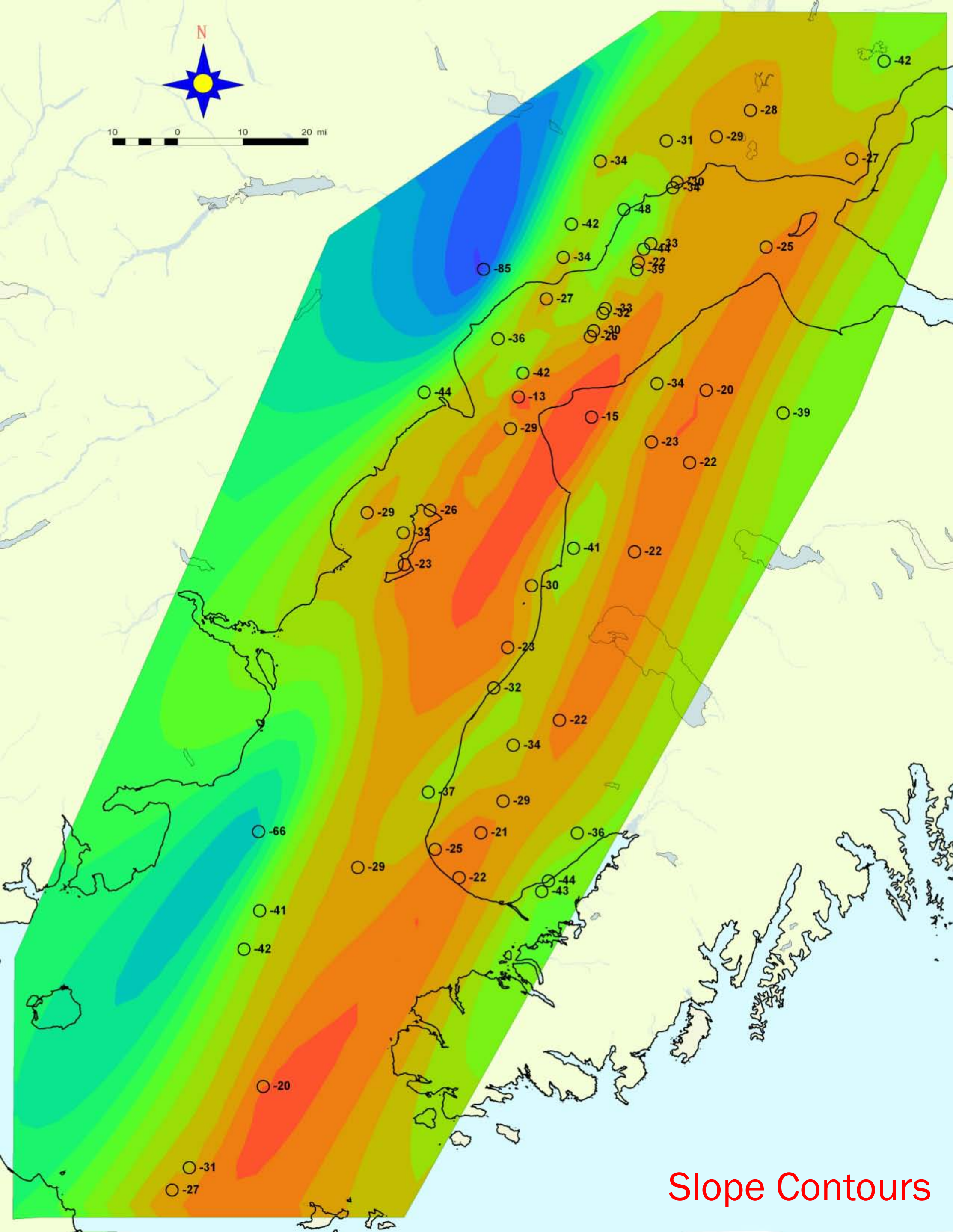
Determine normal compaction trends for 64 Cook Inlet wells

1) Plot log DT vs Depth (TVD) for all wells.
2) Regress trends back to surface (TVD=0) to determine DT'_o (with erosion).
3) The largest DT'_o is defined as the value closest to DT_o (without significant erosion).
4) The trend having the largest DT'_o serves as the "calibration well".
5) "Relative" uplift in other wells determined by comparison to calibration well.
6) Slope similarity between well of interest and calibration well is required.





HISTOGRAM: DT/DEPTH TERTIARY REGRESSION SLOPES FOR 59 UPPER COOK INLET WELLS
RED: Bishop Creek Unit 11-11 (calibration well); slope: -15x10-6
GREEN: 13 wells; slope: -20x10-6 to -25x10-6
BLUE: 12 wells; slope: -25x10-6 to -30x10-6
GRAY: 33 wells dropped due to slope dissimilarity.
Number of Occurrences
Slope (x10-6)
0
1
2
3
4
5
-99 -97 -95 -93 -91 -89 -87 -85 -83 -81 -79 -77 -75 -73 -71 -69 -67 -65 -63 -61 -59 -57 -55 -53 -51 -49 -47 -45 -43 -41 -39 -37 -35 -33 -31 -29 -27 -25 -23 -21 -19 -17 -15 -13 -11 -9 -7 -5 -3 -1



Slope Contour Map

All slope values are ($x10^{-6}$)

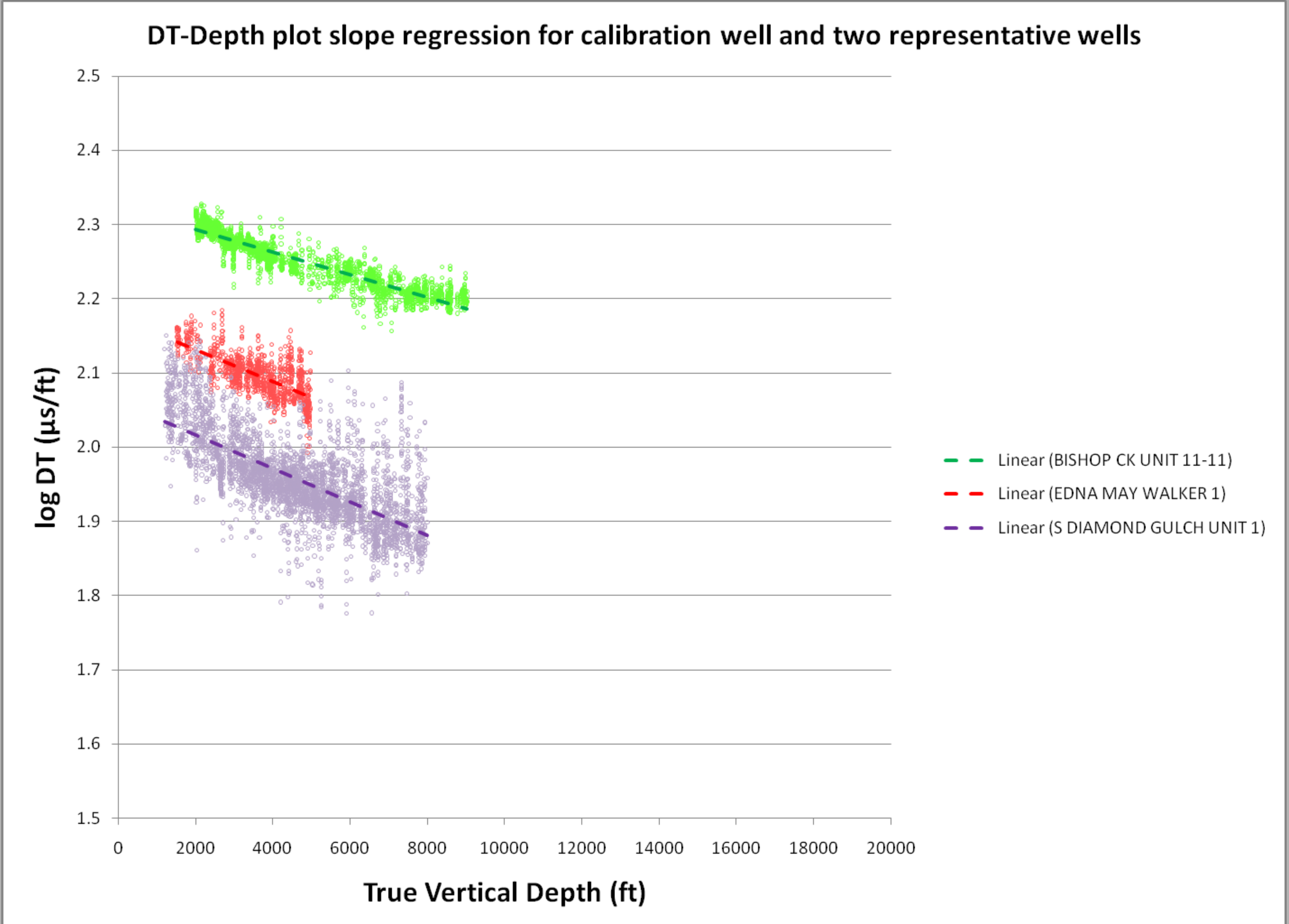
Hot colors indicate slopes more similar to BCU 11-11 ($-15x10^{-6}$).

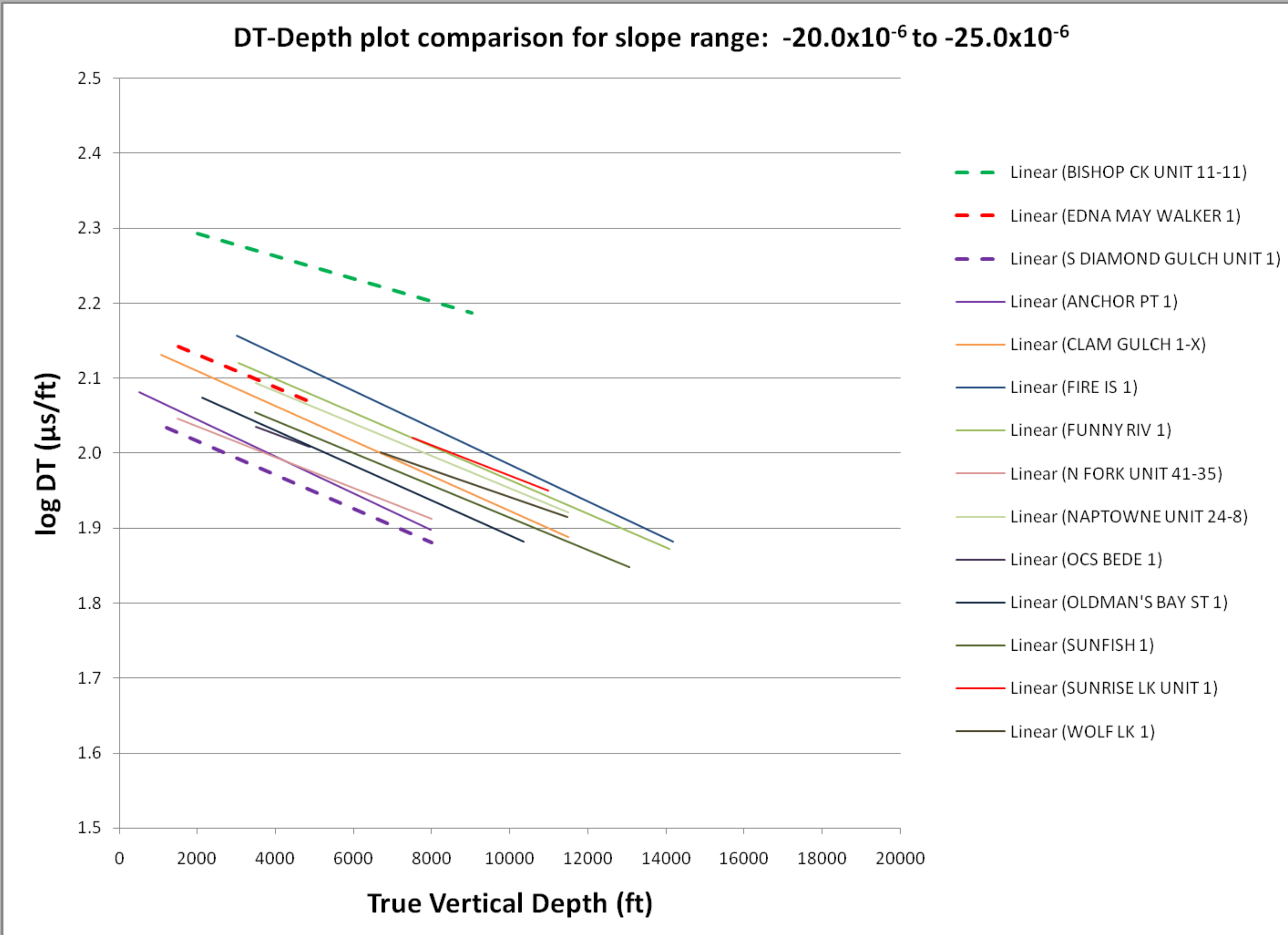
Cool colors indicate slopes less similar to BCU 11-11.

In general basin center slopes are greater than basin edge slopes.

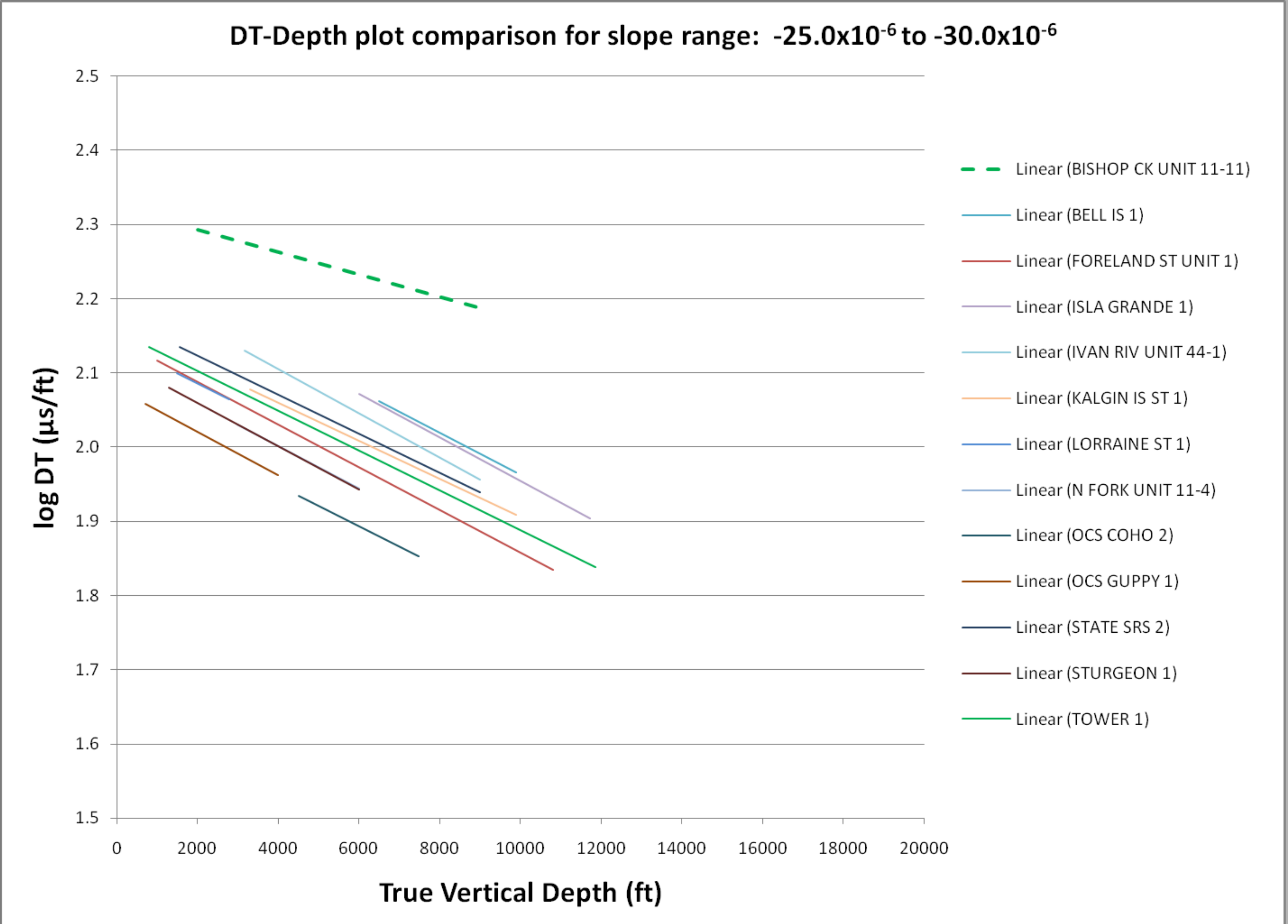
Slope variability may indicate differences in sediment source, lithology, or depositional history.

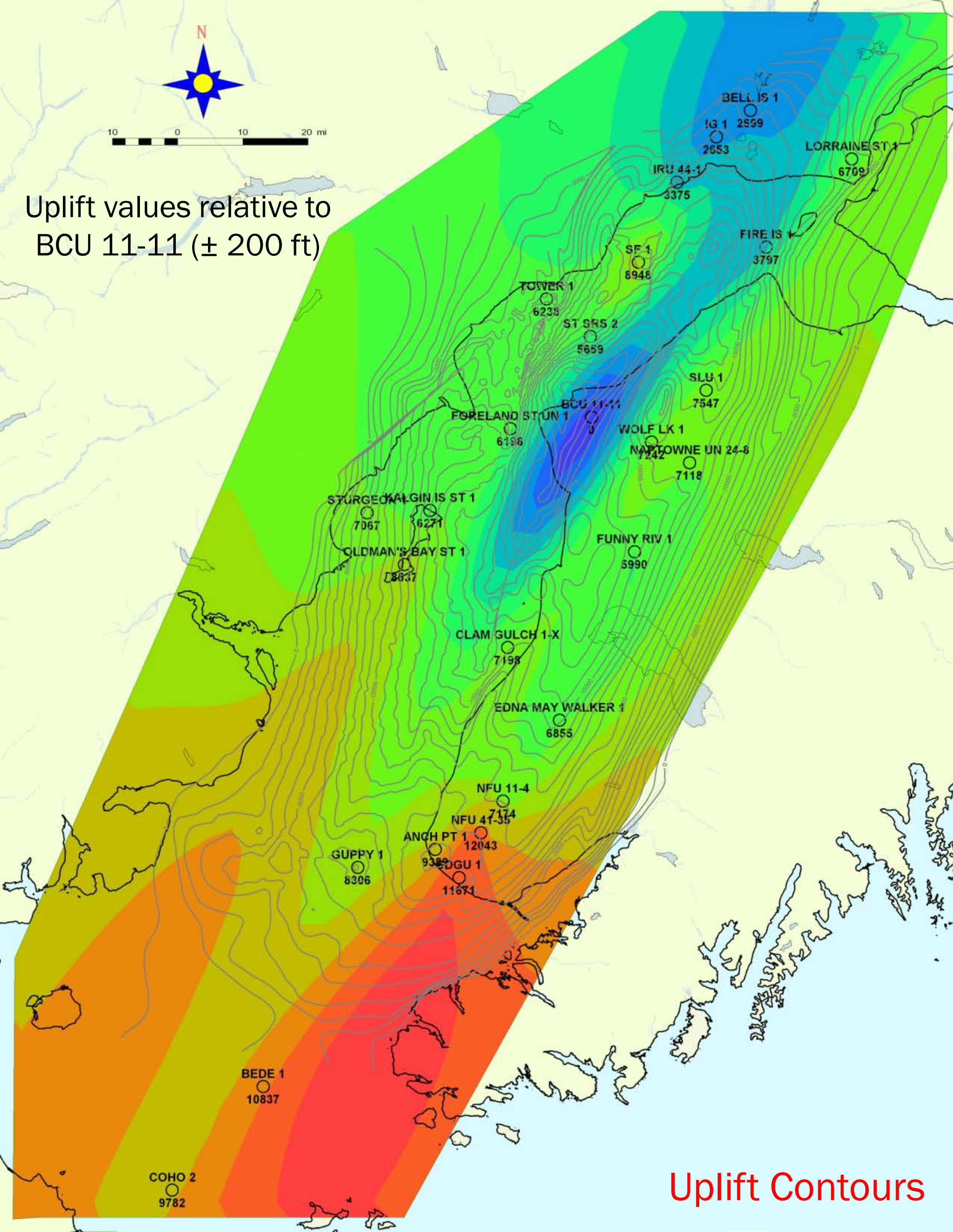
25 wells with slopes <2x the BCU 11-11 slope ($-15x10^{-6}$) were retained. All other wells deemed too dissimilar to warrant further comparison.


DT-Depth plot slope regression for calibration well and two representative wells
log DT (µs/ft)
2.5
2.4
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
True Vertical Depth (ft)
Linear (BISHOP CK UNIT 11-11)
Linear (EDNA MAY WALKER 1)
Linear (S DIAMOND GULCH UNIT 1)



DT-Depth plot comparison for slope range: -20.0x10-6 to -25.0x10-6
log DT (µs/ft)
2.5
2.4
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
True Vertical Depth (ft)
Linear (BISHOP CK UNIT 11-11)
Linear (EDNA MAY WALKER 1)
Linear (S DIAMOND GULCH UNIT 1)
Linear (ANCHOR PT 1)
Linear (CLAM GULCH 1-X)
Linear (FIRE IS 1)
Linear (FUNNY RIV 1)
Linear (N FORK UNIT 41-35)
Linear (NAPTOWNE UNIT 24-8)
Linear (OCS BEDE 1)
Linear (OLDMAN'S BAY ST 1)
Linear (SUNFISH 1)
Linear (SUNRISE LK UNIT 1)
Linear (WOLF LK 1)


DT-Depth plot comparison for slope range: -25.0x10-6 to -30.0x10-6
log DT (µs/ft)
2.5
2.4
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
True Vertical Depth (ft)
Linear (BISHOP CK UNIT 11-11)
Linear (BELL IS 1)
Linear (FORELAND ST UNIT 1)
Linear (ISLA GRANDE 1)
Linear (IVAN RIV UNIT 44-1)
Linear (KALGIN IS ST 1)
Linear (LORRAINE ST 1)
Linear (N FORK UNIT 11-4)
Linear (OCS COHO 2)
Linear (OCS GUPPY 1)
Linear (STATE SRS 2)
Linear (STURGEON 1)
Linear (TOWER 1)



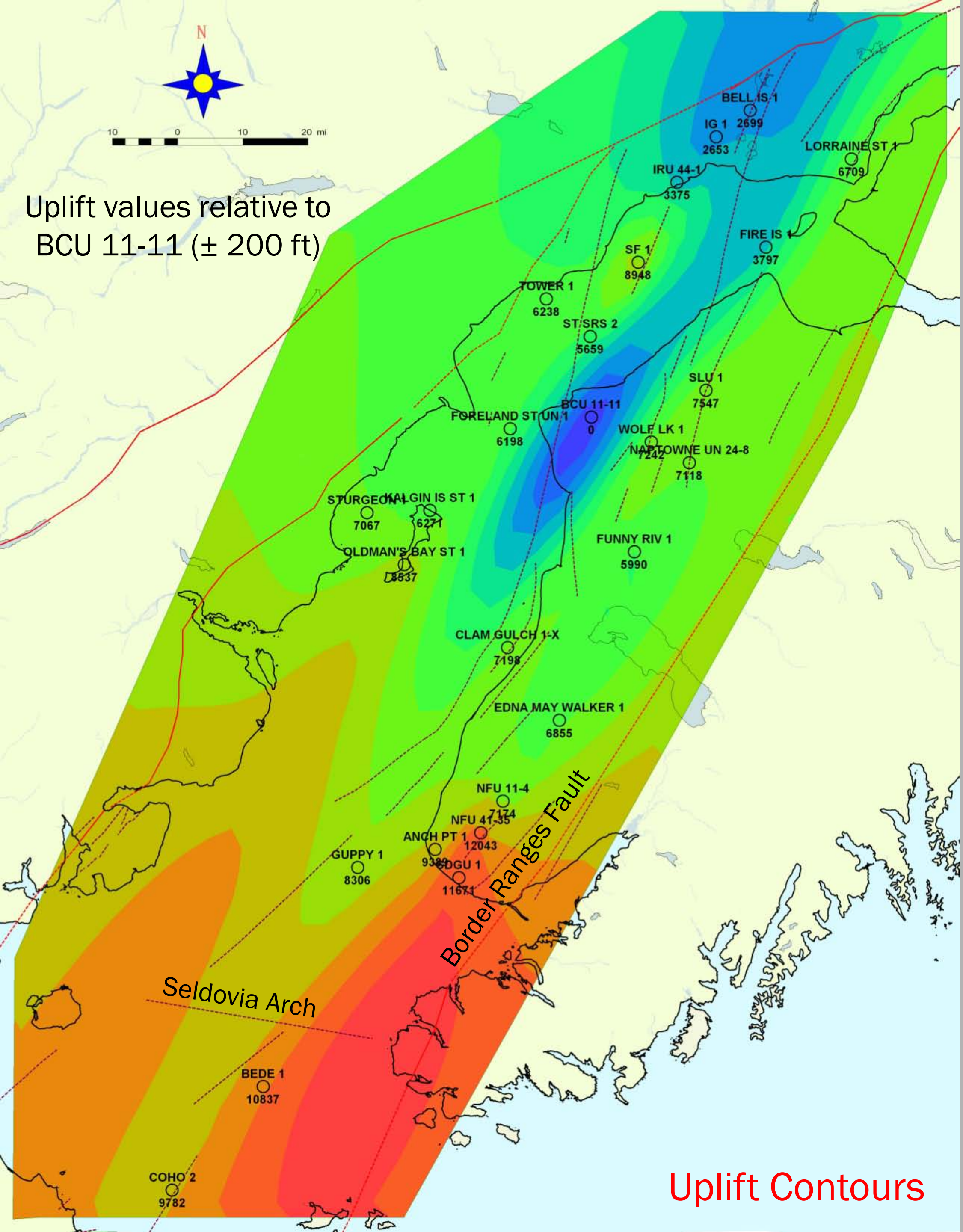
Relative Uplift Contour Map

Calibration well:
- Bishop Creek Unit 11-11 (BCU 11-11)
- Slope: -15.2×10^{-6}
- Relative uplift: 0 ft

Well with largest relative uplift:
- North Fork Unit 41-35 (NFU 41-35)
- Slope: -20.5×10^{-6}
- Relative uplift: 12,043 ft (± 200 ft)
- ΔSlope wrt calib. well: 5.3×10^{-6}

Well with smallest relative uplift:
- Isla Grande 1 (IG 1)
- Slope: -29.2×10^{-6}
- Relative uplift: 2,653 ft (± 200 ft)
- ΔSlope wrt calib. well: 14.0×10^{-6}

Note: Similarities between uplift contours (colors) and base Tertiary contours (lines) suggests a possible link between relative uplift and base Tertiary depth.



Relative Uplift Contour Map with faults and folds

A NE-SW trending "uplift high" defined by NFU 41-35 (~12,000 ft), SDGU 1 (~11,500 ft), and Bede 1 (~11,000 ft) runs roughly parallel to but west of the Border Ranges Fault.

Bede 1 is located on the south shoulder of the ESE-WNW trending Seldovia Arch.

Seismic data suggest coeval Seldovia Arch uplift and Sterling, Beluga, and upper Tyonek Formation deposition.

Bede 1 well (~11,000 ft relative uplift) is missing Sterling and Beluga section suggesting >11,000 ft relative uplift has occurred along the Seldovia Arch.

Conclusions

1) Differential uplift throughout Upper Cook Inlet basin has occurred.

2) BCU 11-11 serves as the calibration well against which relative uplifts are measured. It's location is the area of least uplift (corroborated by base-Tertiary map).

3) A NE-SW oriented trend averaging ~11,500 ft relative uplift is located west of and sub-parallel to the Border Ranges Fault and could be related.

4) IG 1 and Bell Is 1 are located in the area of least relative uplift (~2,700 ft).

5) The average relative uplift of the 25 wells analyzed is 7,200 ft.

6) 12,000 ft of relative uplift has occurred in NFU 41-35. Assuming layer-cake stratigraphy 8,900 ft (~75%) can be attributed to missing section: unconsolidated, Sterling (SRLG), and some Beluga (BLUG).

BCU 11-11:	SRLG top 4,476' tvd	BLUG top 8,918' tvd	--
NFU 41-35:	--	BLUG top 1,545' tvd	TYNK top 4,835' tvd

Next Step

Incorporate uplift estimates into geohistory models for Upper Cook Inlet wells in order to estimate petroleum migration pathways and reservoir potential.


The End