Petrology & Reservoir Quality of Cook Inlet Sandstones: Regional Perspective

Alaska Department of Natural Resources
Division of Geological & Geophysical Surveys
Division of Oil & Gas

Kenneth P. Helmold
Alaska Division of Oil & Gas

USGS Cook Inlet Resource Assessment
BP Energy Center
Anchorage, AK
September 21, 2010

Author and affiliation:

Kenneth P. Helmold
Alaska Division of Oil and Gas

Date presented:

September 22, 2010

Presentation forum:

U. S. Geological Survey Cook Inlet Resource Assessment
BP Energy Center, Anchorage, Alaska

Acknowledgements:

Dave Doherty (Renaissance Alaska, LLC)
Don Krouskop (Alaska Division of Oil and Gas)
Dave Lepain (Alaska Division of Geological and Geophysical Surveys)
Rick Stanley (U.S. Geological Survey, Menlo Park)
Shaun Peterson (Alaska Division of Oil and Gas)

Collaborative effort between DGGS, DOG, UAF, Purdue University and USGS

DGGS: Dave Lepain, Marwan Wartes, Bob Gillis, Paige Peapples
DOG: Diane Shellenbaum, Laura Silliphant, Ken Helmold, Shaun Peterson
UAF: Paul McCarthy, Jake Mongrain
Purdue: Ken Ridgway, Emily Finzel
USGS: Rick Stanley

Acknowledgements

- **Dave Doherty,** Renaissance Alaska
  - Provided routine core analyses and modal data collected from public domain

- **Don Krouskop,** AK Div. Oil & Gas
  - Provided routine core analyses filtered from DOG database

Outline

- Research questions
- Geologic setting
- Sample preparation
- Mineralogy and texture
- Provenance assessment
- Reservoir quality
- Petrology by formation

Questions

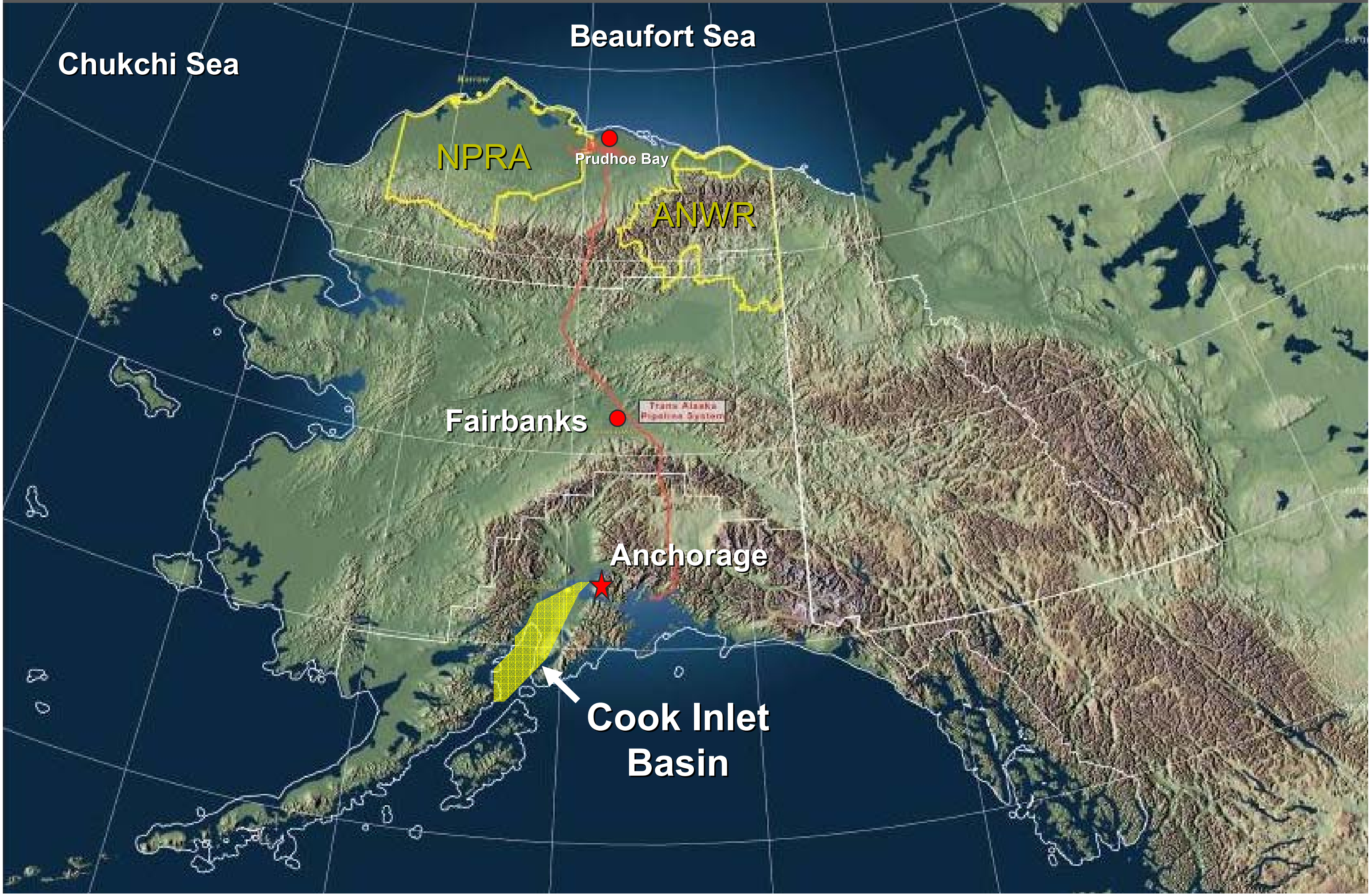
Dep. Sys.

Provenance

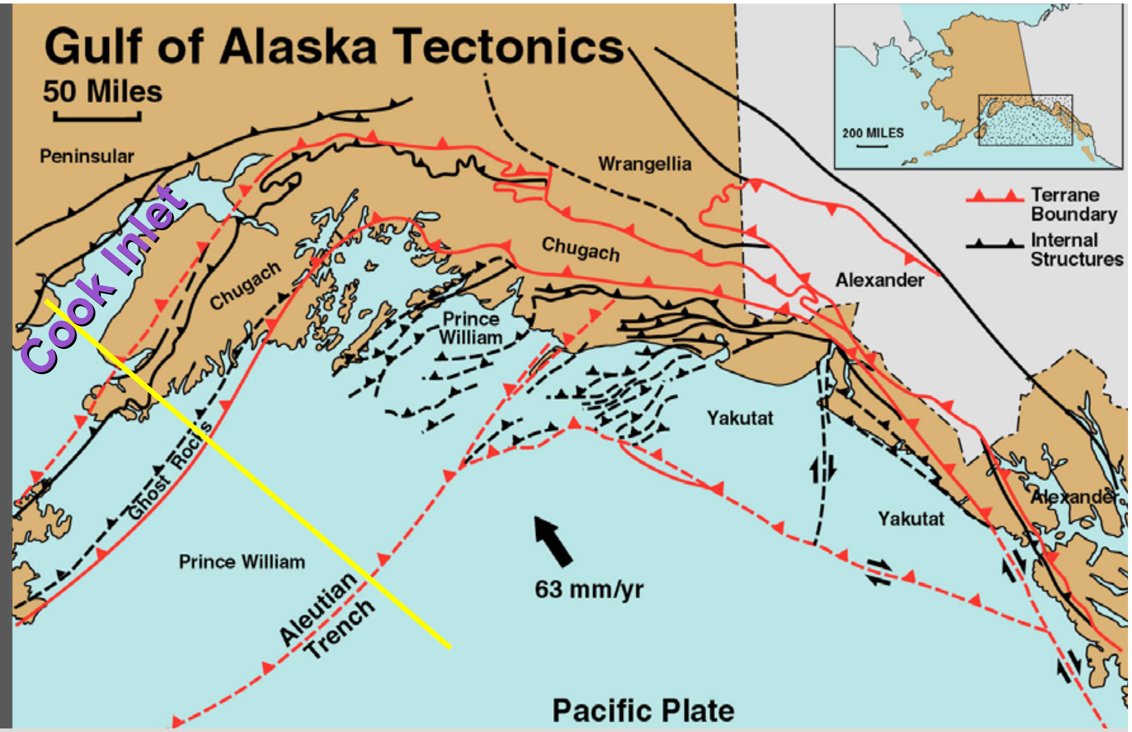
Diagenesis

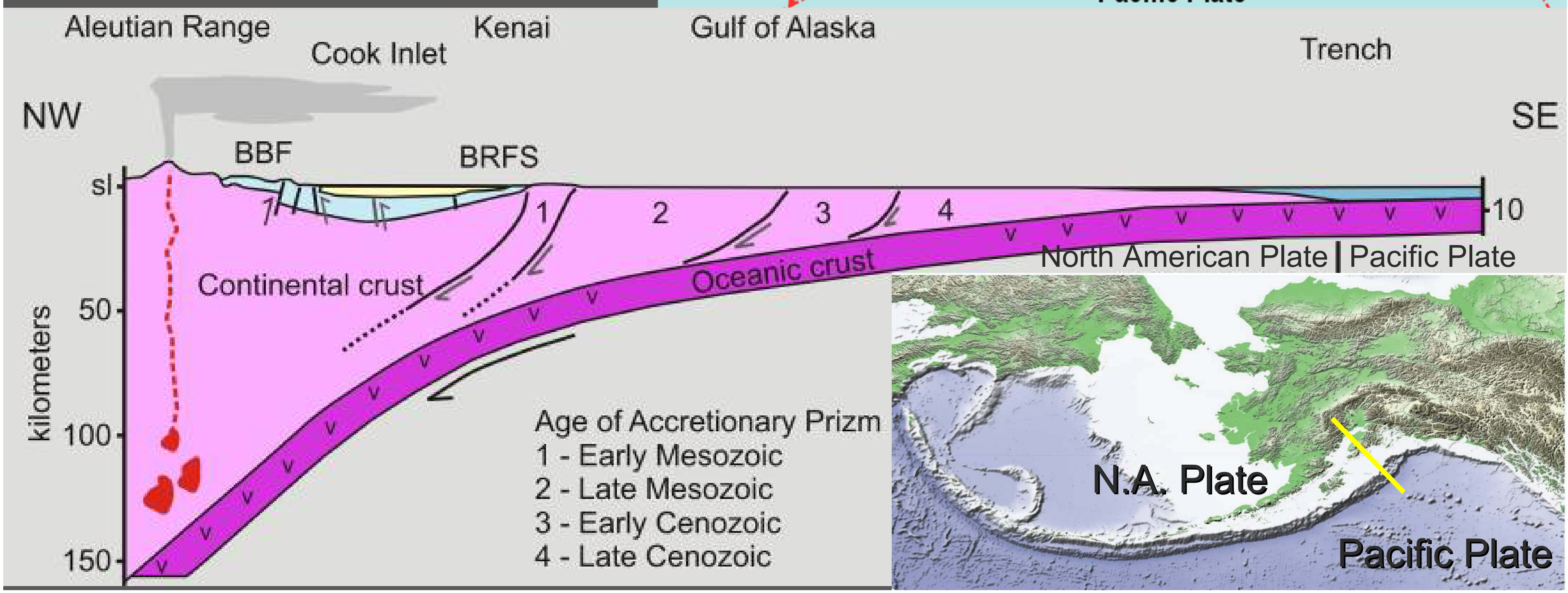
1. Do depositional systems in Tertiary strata occur in predictable distributions within the forearc basin?
2. How does depositional environment affect sandstone reservoir quality?
3. Are there spatial and temporal variations in sandstone composition across the basin, and how do they affect diagenetic history?
4. How does reservoir quality within a given unit vary across the basin as a function of burial?
5. Does the generation of zeolites precede hydrocarbon generation thereby condemning prospectivity?
6. Can reservoir quality of sandstones be predicted prior to drilling?

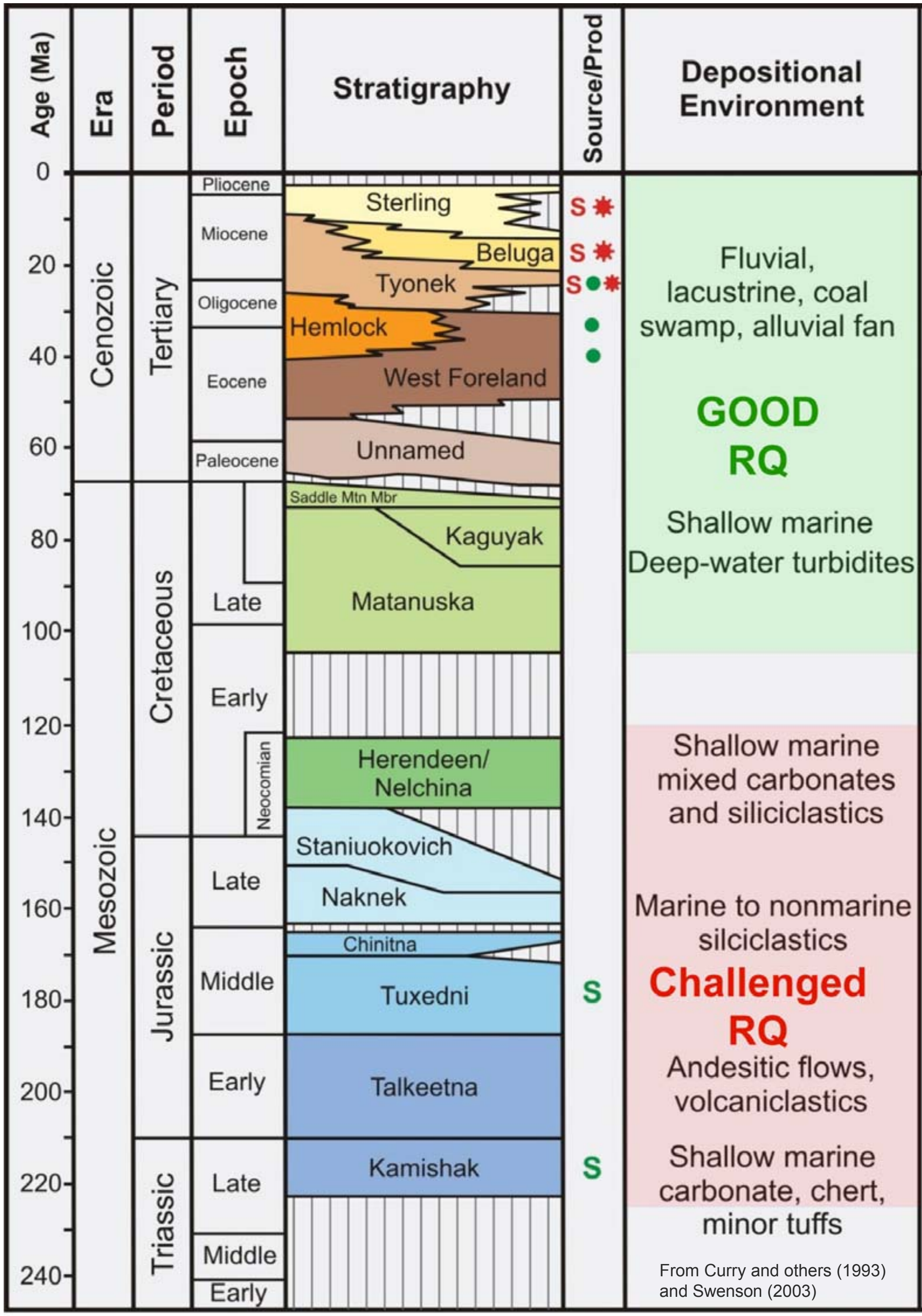
Location


Beaufort Sea
Chukchi Sea
NPRA
Prudhoe Bay
ANWR
Fairbanks
Anchorage
Cook Inlet
Basin

- **Collisional forearc basin filled with Mesozoic and Cenozoic marine and nonmarine strata**
- **Arc-trench system since latest Triassic**
- **Accretionary prism to E-SE**
- **Magmatic arc to W-NW**
- **Fault-bounded basin**

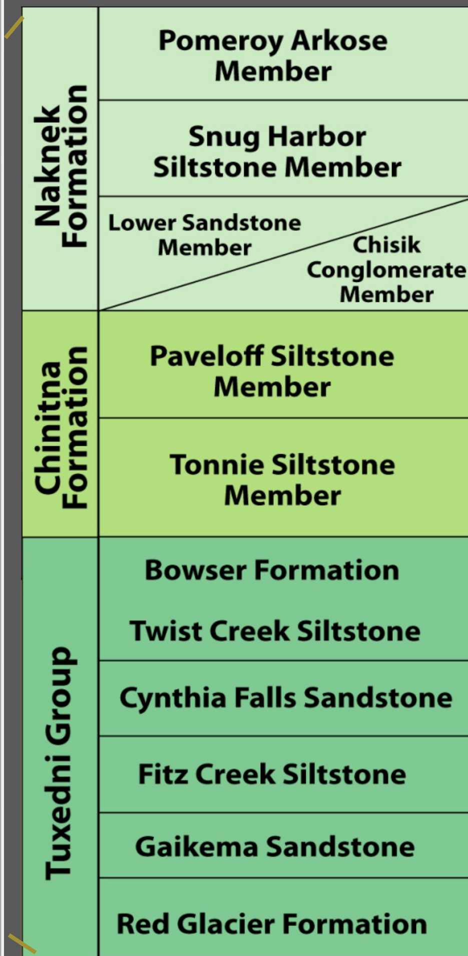






Stratigraphy

- Up to 30,000 ft of Mesozoic sedimentary rocks
- Up to 25,000 ft of Tertiary age nonmarine sedimentary rocks

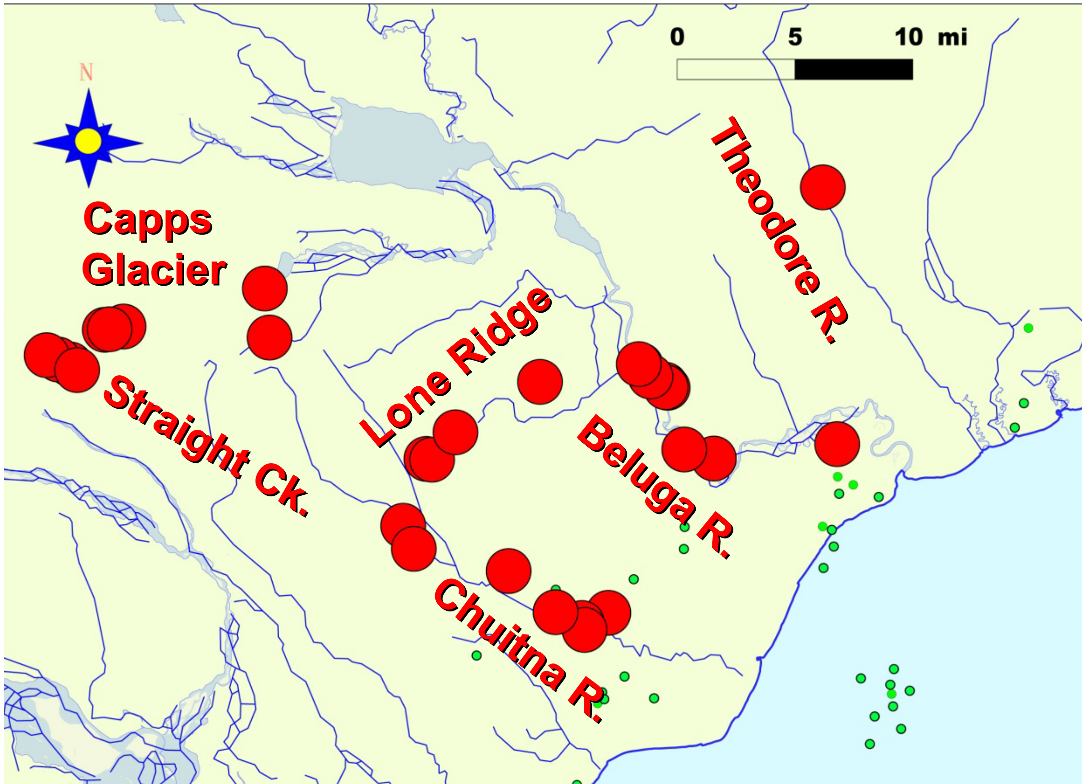


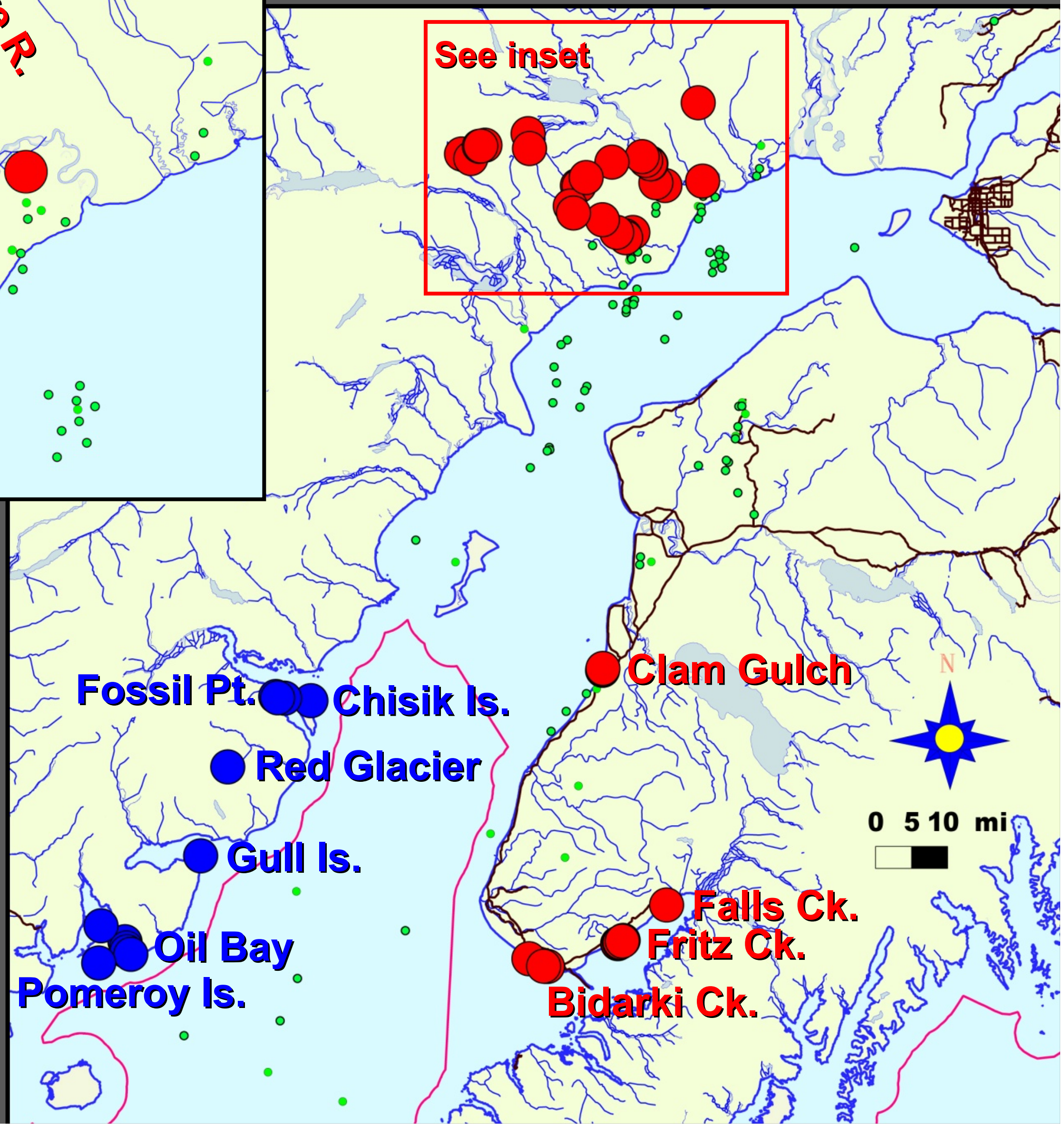
Basin fill has been modified by folding and faulting to form structural traps

Lithologies interfinger within formations

Interfingering is the basis for stratigraphic traps

Outcrop Sample Distribution





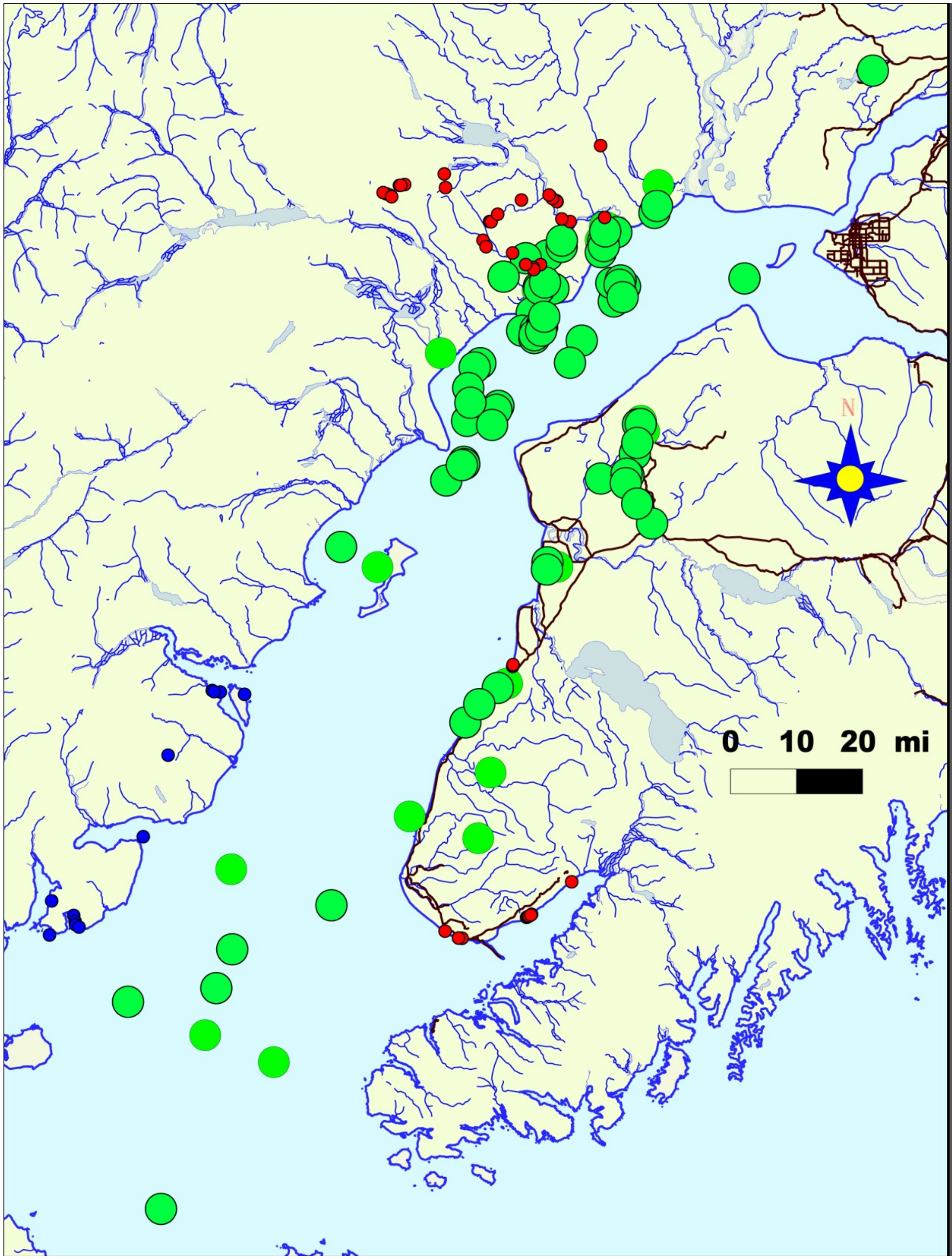
Samples by Formation

Tertiary (37 measured sections)

- 24 Sterling
- 52 Beluga
- 21 Tyonek
- 46 West Foreland

Mesozoic (5 measured sections)

- 19 Naknek
- 5 Tuxedni



Well Distribution

- 98 Wells from upper & lower Cook Inlet
- 5779 Subsurface samples

Samples by Formation:

334	Sterling
440	Beluga
2134	Tyonek
2070	Hemlock
74	West Foreland
430	Kaguyak
68	Herendeen
164	Naknek
65	Tuxedni

- Subsurface samples
- Tertiary outcrop samples
- Mesozoic outcrop samples

Collecting Friable Sands - Theory


Collecting Friable Sands - Practical
1.Ascend....
2. Excavate....
3. Wrap....
4. Back to camp


Preparing Friable Sands
1. Mix….
2. Pour….
3. Cure….
4. Box….
5. Transport

Routine Ø-K Core Analysis

Core Plugs Drilled in Anchorage

- Slab epoxy blocks across top
- Check degree of lithification

Very Friable

- Saturated in KCL solution
- Placed in freezer
- Plugged with nitrogen
- Core plugs returned to freezer
- Frozen plugs shipped to Houston

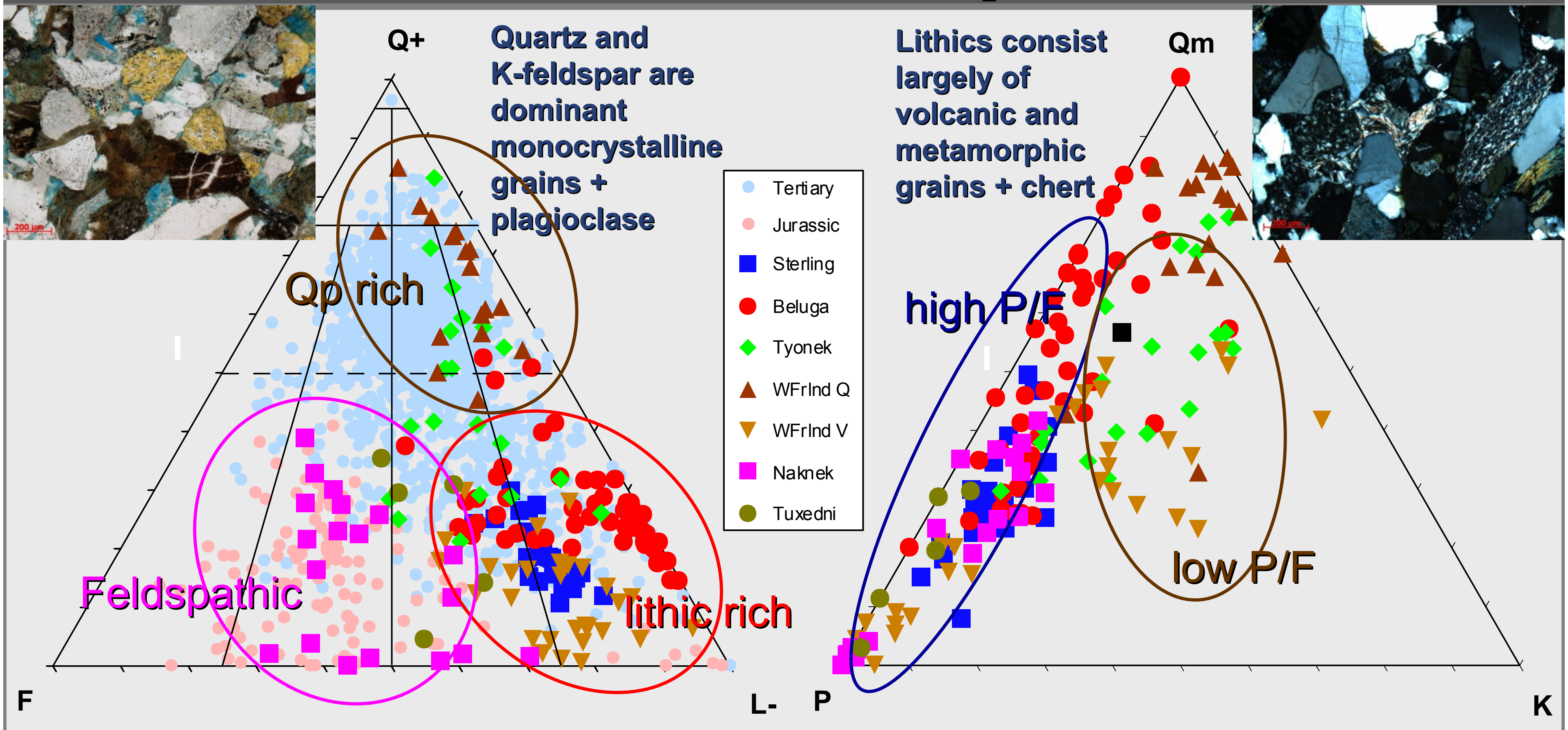
Moderately Lithified

- Kept at ambient state
- Plugged with water
- Shipped to Houston

Sandstone Provenance

- **Magmatic arc (Alaska Range)**
  - Volcanic cover (Jurassic – Tertiary)
    - Basalt, andesite, tuff, breccia
  - Plutonic roots (Jurassic – Cretaceous)
    - Granodiorite, quartz monzonite, diorite, syenite
- **Accretionary prism (Chugach Terrane)**
  - Valdez Group (Upper Cretaceous)
    - Sandstone, siltstone, shale
    - Schist, phyllite (greenschist facies)
  - McHugh Complex (Jurassic – Cretaceous)
    - Argillite, graywacke, limestone, chert
    - Tuff, gabbro, basalt (prehnite - pumpellyite facies)

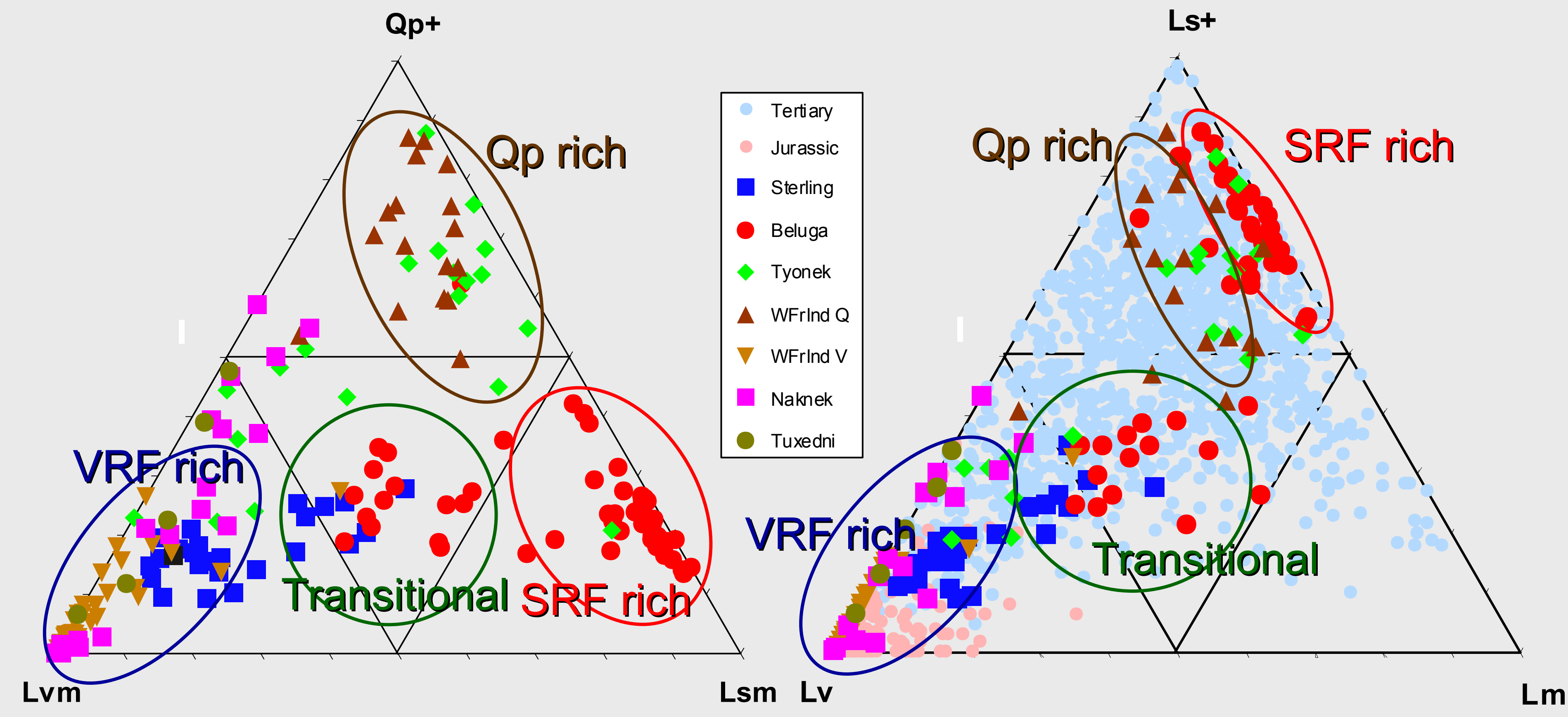
Framework Composition



1. Sterling, Beluga & W Foreland-v are lithic rich
2. Tyonek & W Foreland-q are relatively quartz rich
3. Naknek & Tuxedni are feldspathic

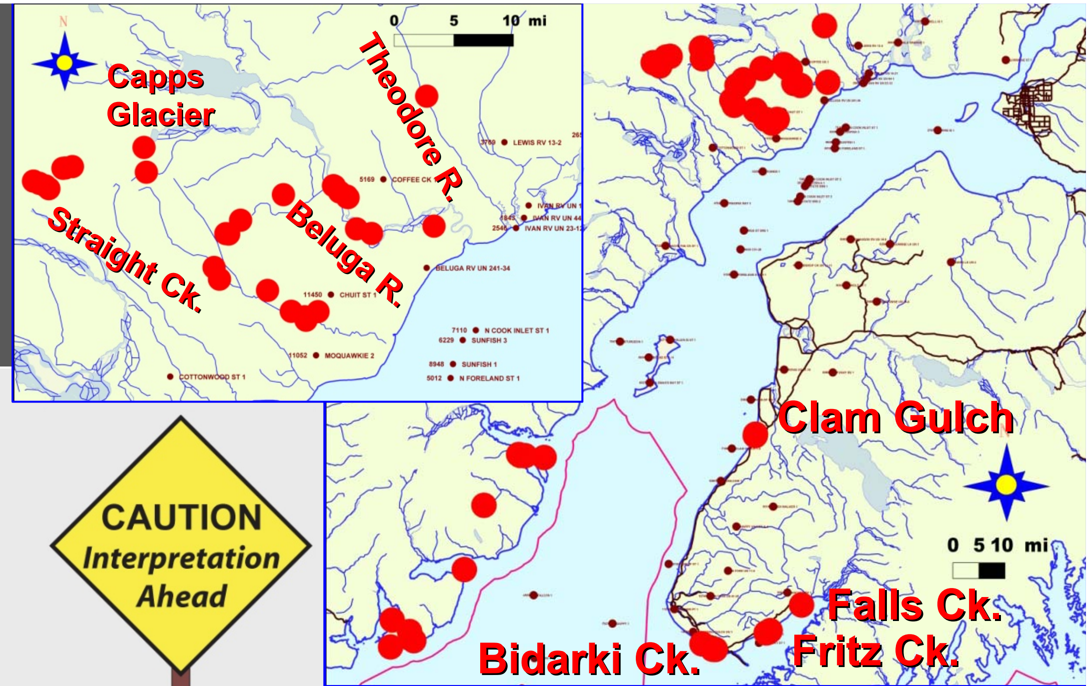
1. Sterling, W Foreland-v & Naknek have high P/F indicating intermediate igneous provenance
2. Tyonek & W Foreland-q have lower P/F indicating “granitic” provenance

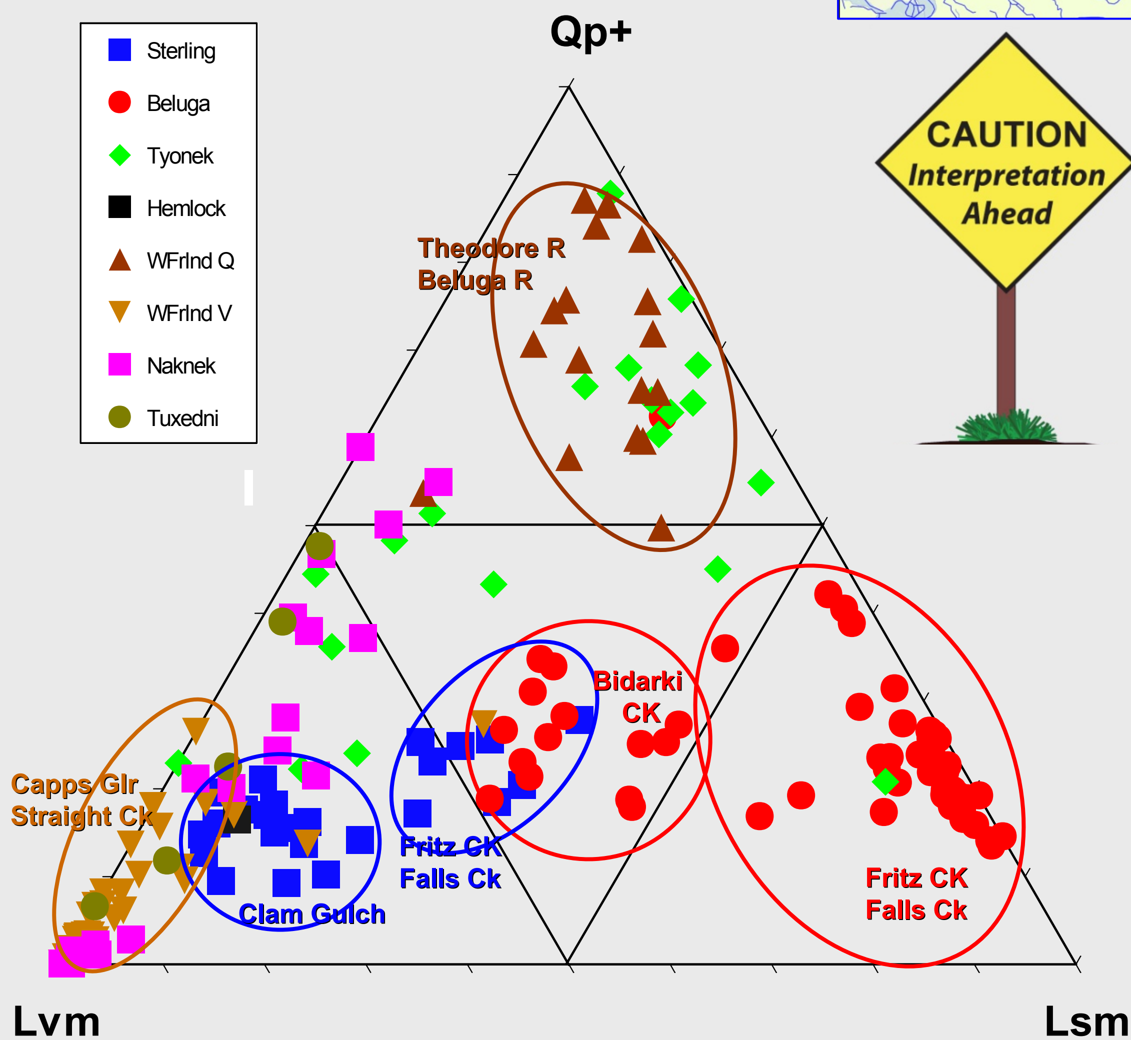
Lithic Composition



1. Most Beluga are rich in argillaceous SRF
2. Tyonek & W Foreland-q are rich in Qp and chert (common provenance ?)
3. Sterling, W Foreland-v, Naknek & Tuxedni VRF-rich
4. Some Sterling & Beluga are transitional (changing provenance ?)

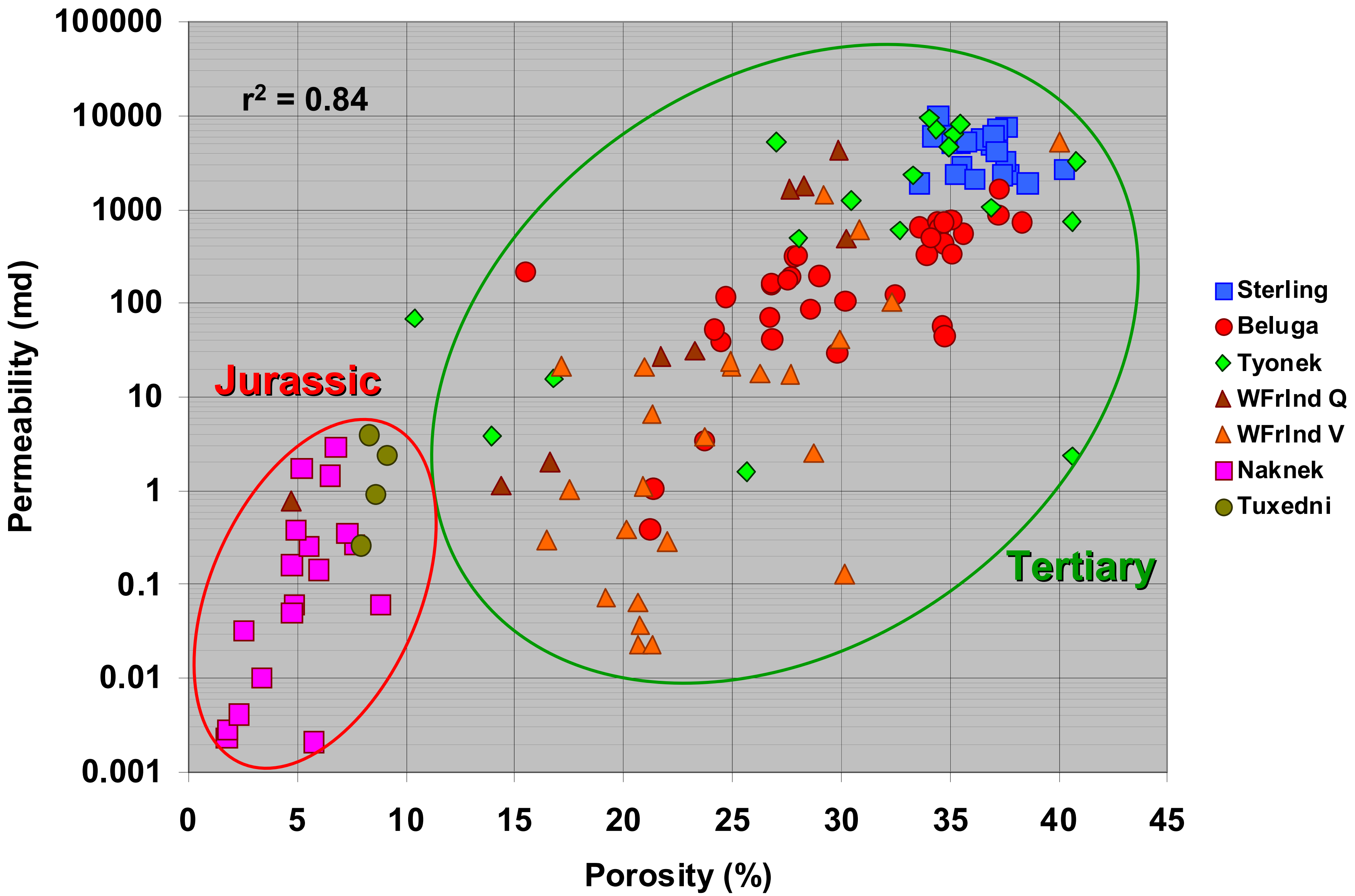
Provenance Implications



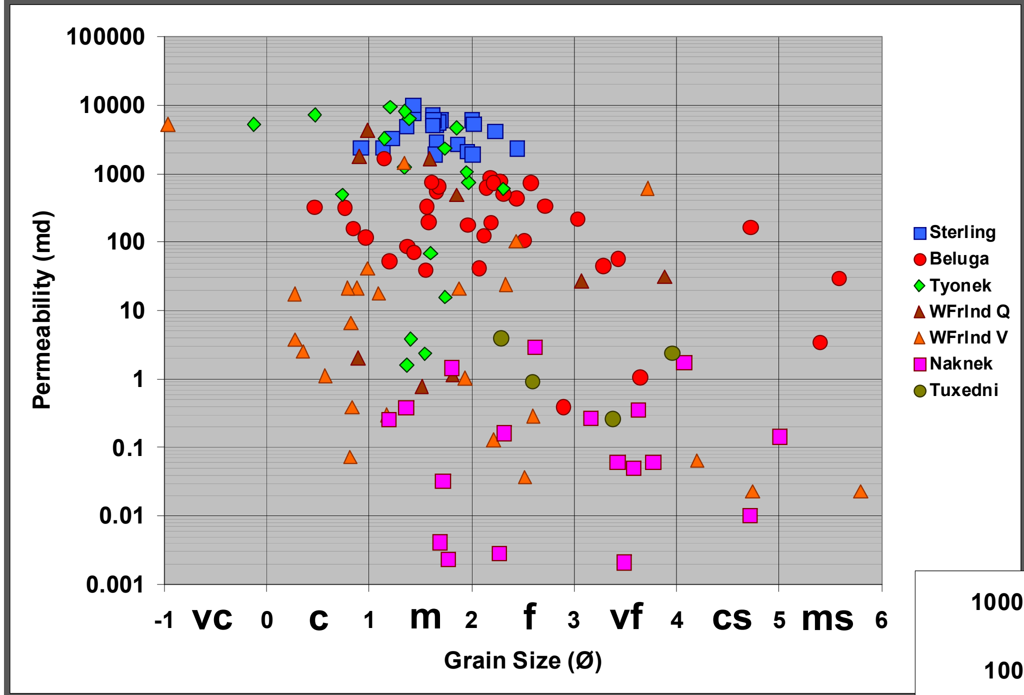


1. Sterling & Beluga at Fritz & Falls Cks show vertical transition from accretionary prism to volcanic arc provenance
2. Beluga shows lateral provenance transition from Fritz to Bidarki Ck
3. Sterling shows lateral provenance transition from Fritz Ck to Clam Gulch
4. West Foreland has two distinct provenances (could some be Hemlock ?)

Outcrop Reservoir Quality

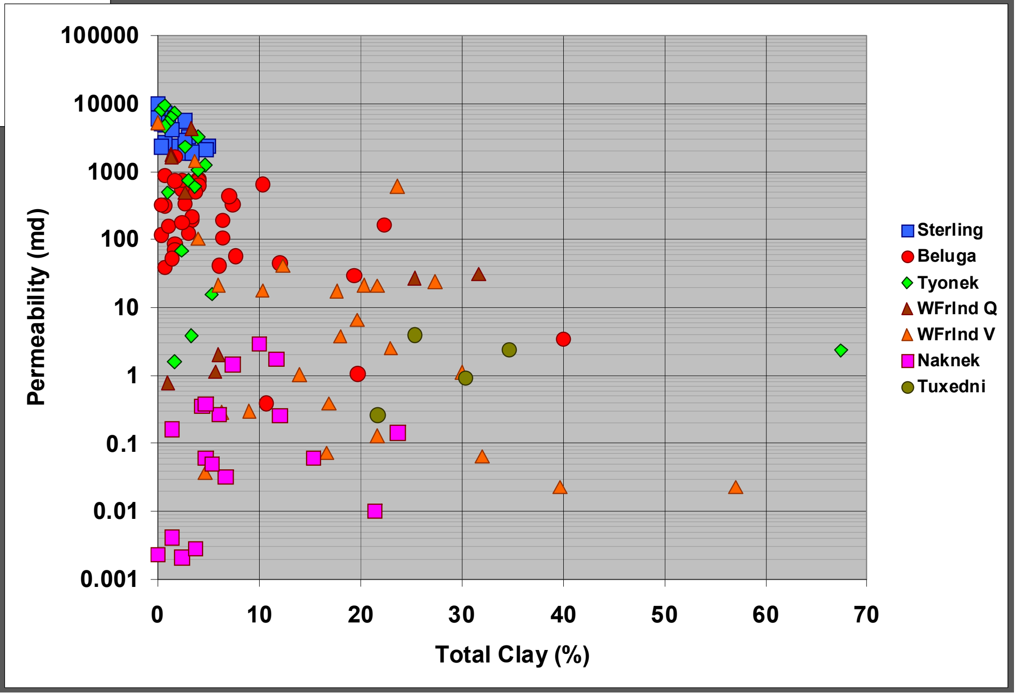


Textural Control on RQ

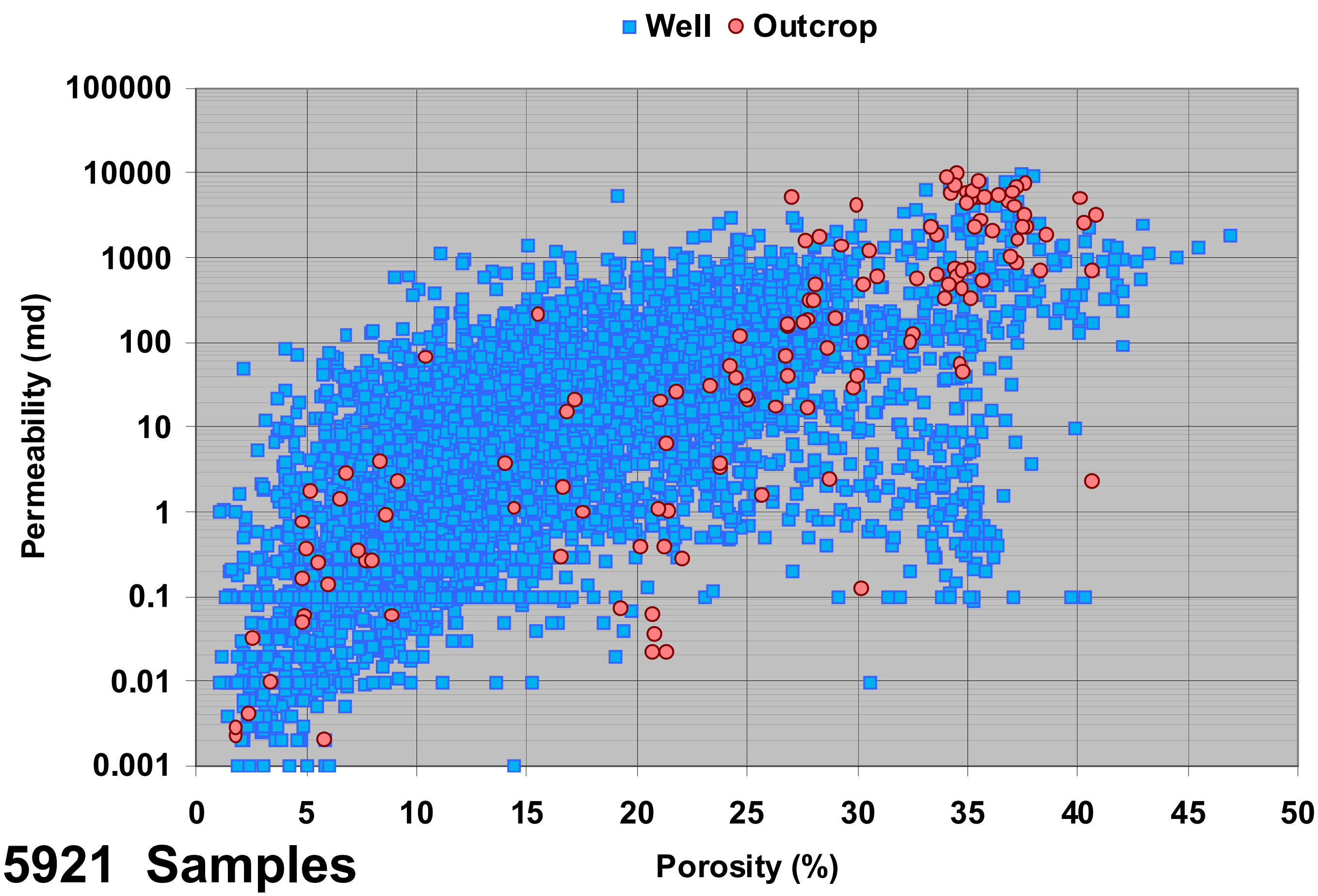


Moderate correlation between grain size and permeability (r^2 = - 0.4)

Moderate correlation between total clay and permeability (r^2 = - 0.5)



Routine Core Analysis Data



5921 Samples

1. Core and outcrop data occupy similar Φ-K fields
2. Low-permeability Sterling sands plot off regional trend (facies or texture)
3. Artificial linear trends (constant K)
4. Well data include conventional and sidewall core data
5. Does not include all older exploration wells
6. Few development wells

5779 Subsurface samples

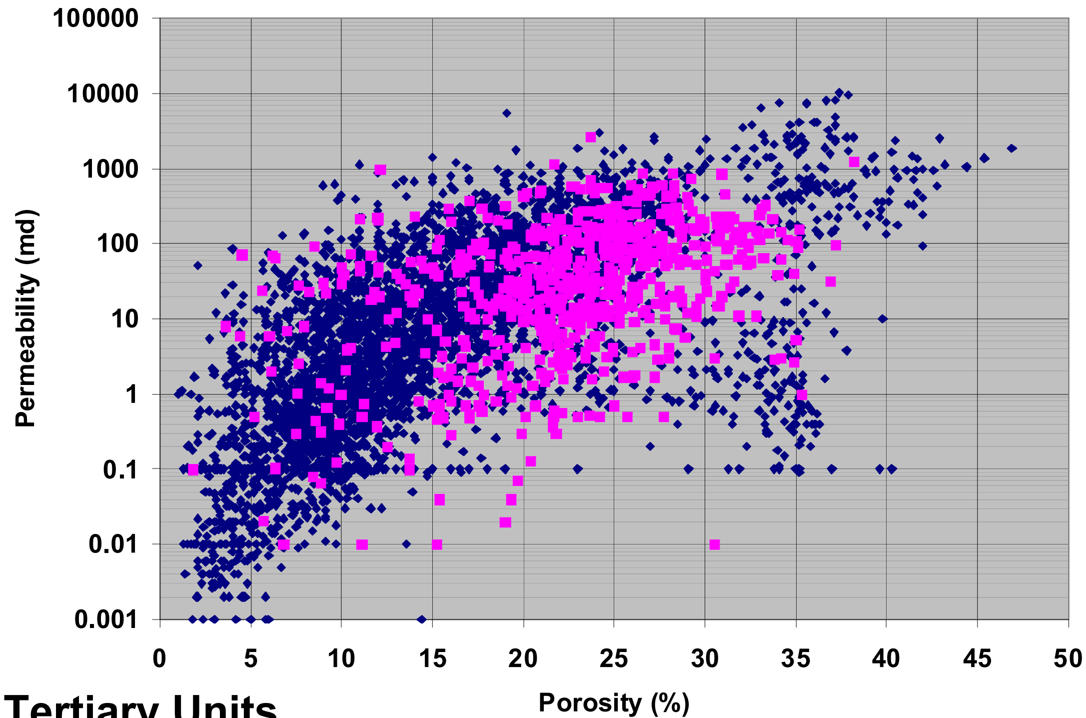
5052	Tertiary
430	Upper Cretaceous
297	Neocomian - Jurassic

142 Outcrop samples

118	Tertiary
24	Jurassic

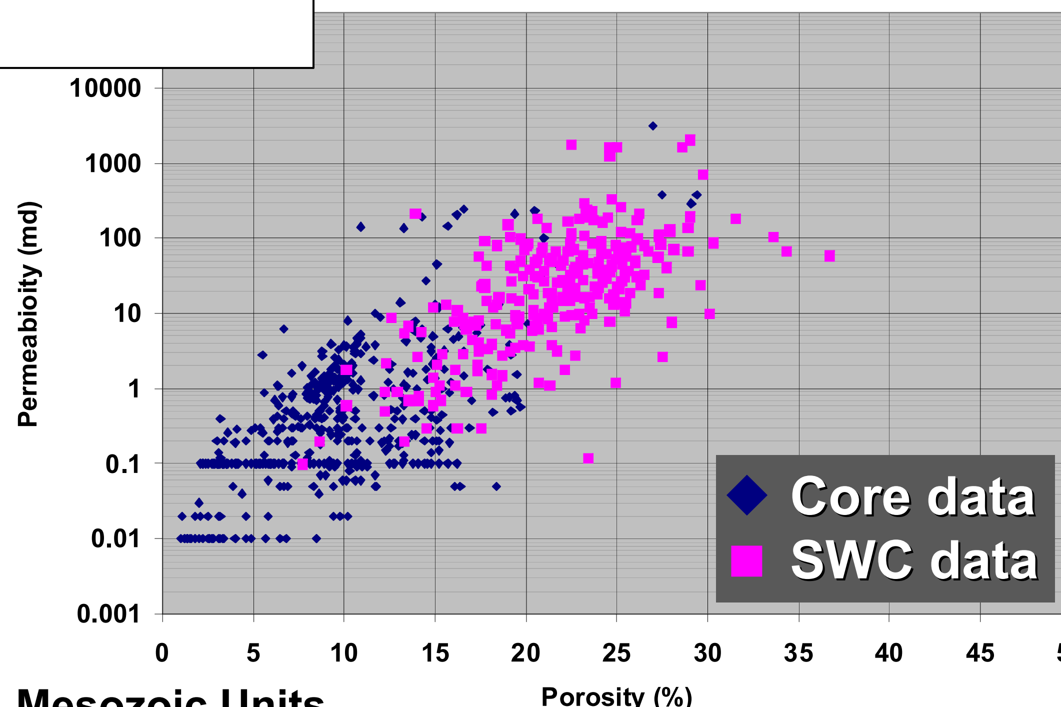
Core vs. SWC Φ-K Data

1. SWC were purposely taken in the best reservoir facies
2. SWC are artificially enhanced



Tertiary Units

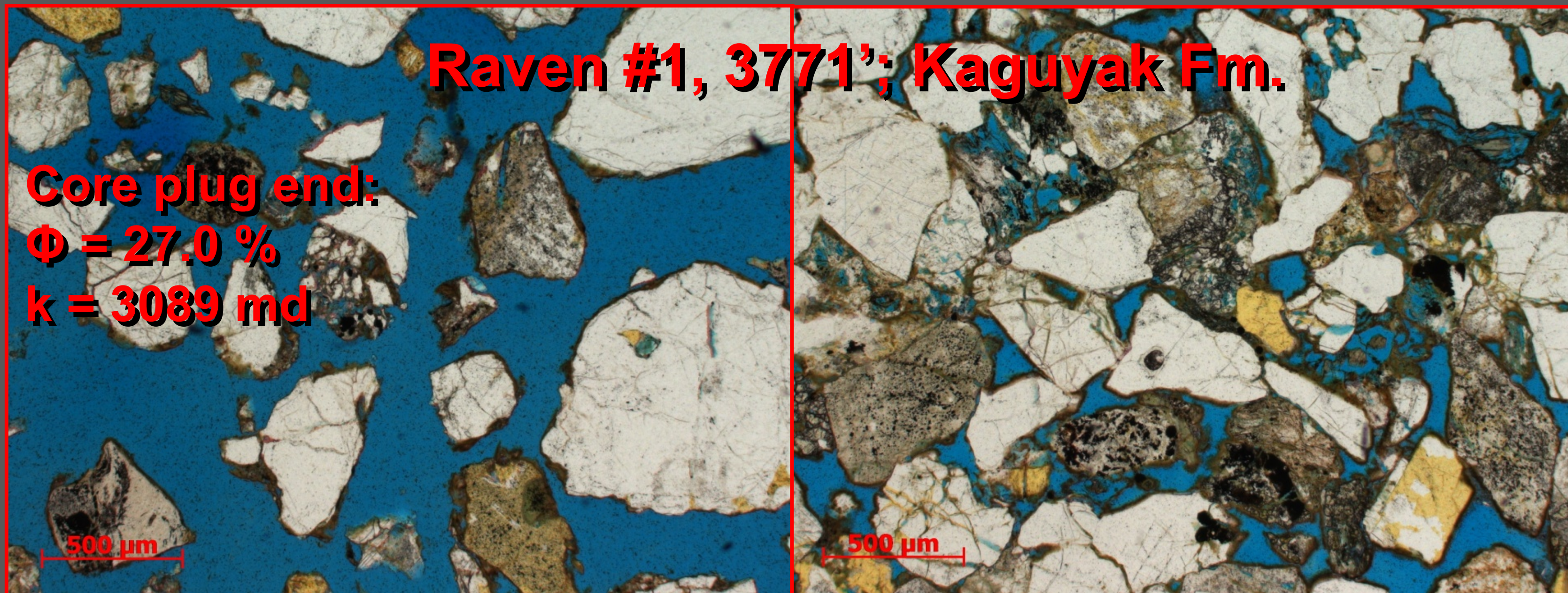
1. Mesozoic core + SWC data overlie Tertiary data
2. Few very-high Φ-K Tertiary SWC data
3. Fair – moderate overlap between Tertiary core and SWC data
4. Poor overlap between Mesozoic core and SWC data



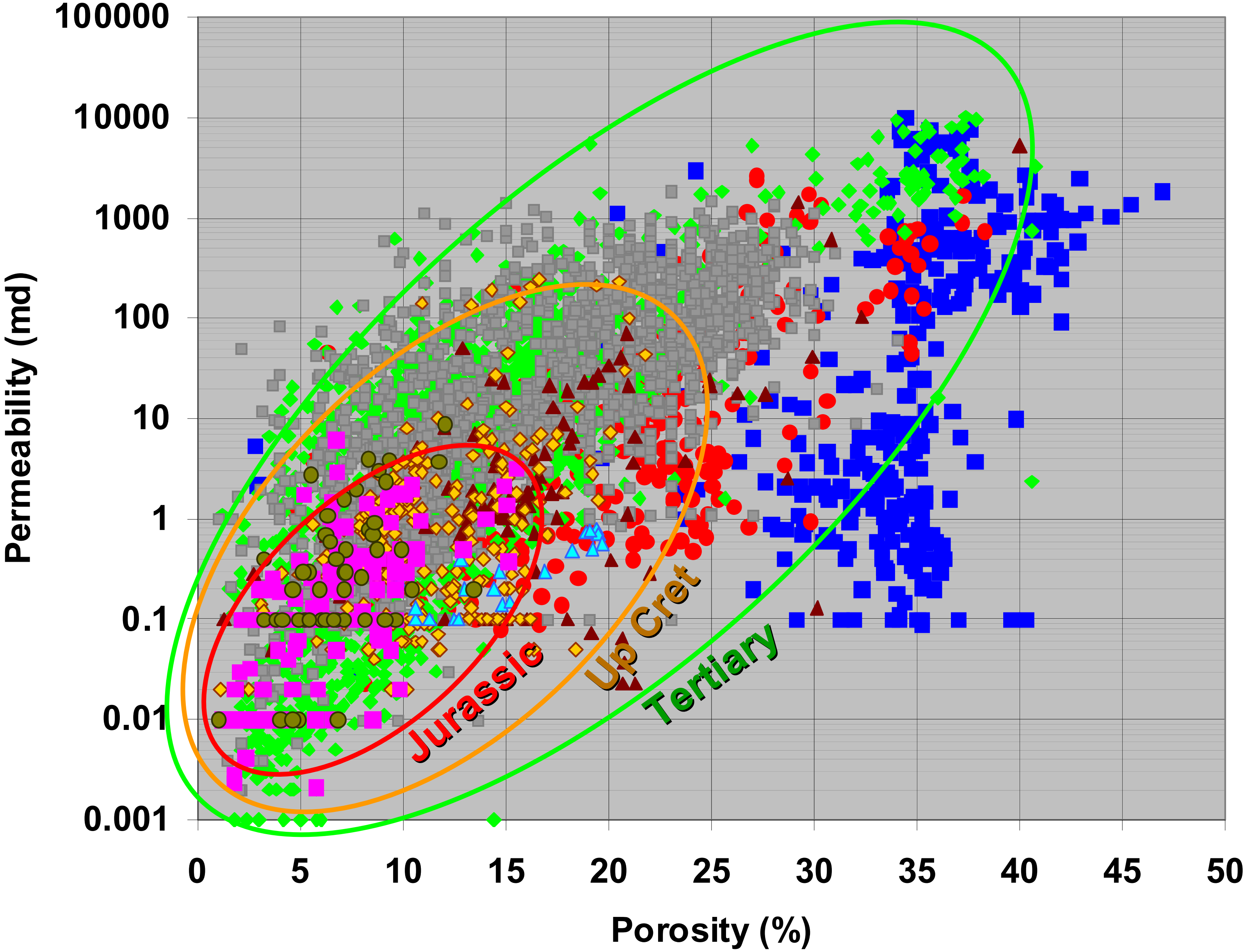
Mesozoic Units

Nilla SWC Analog

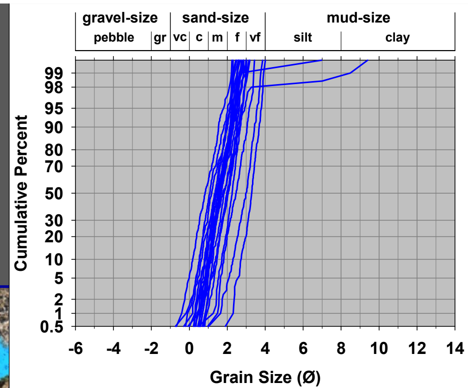
Questionable Core Data

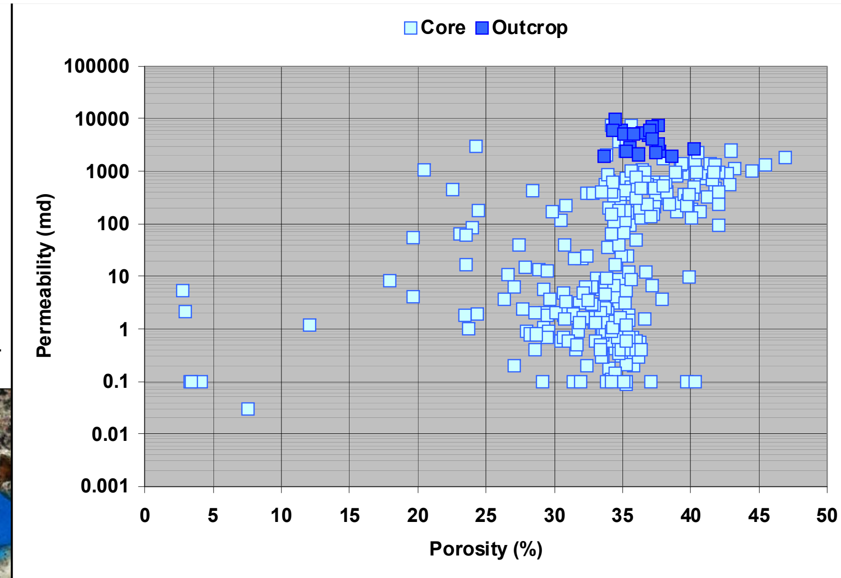


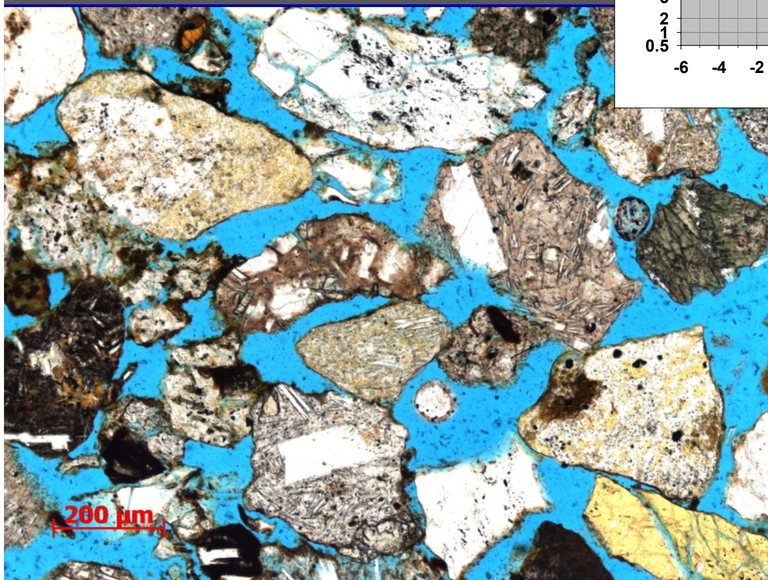
Reservoir Quality by Formation

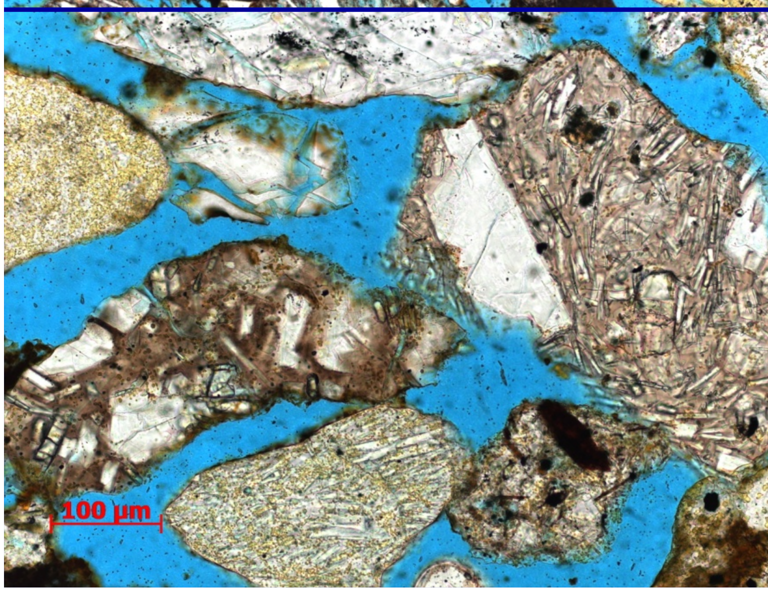


Sterling Formation



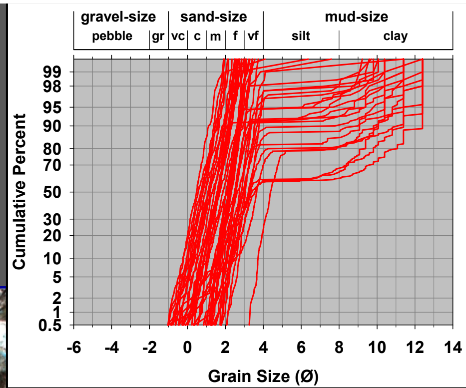


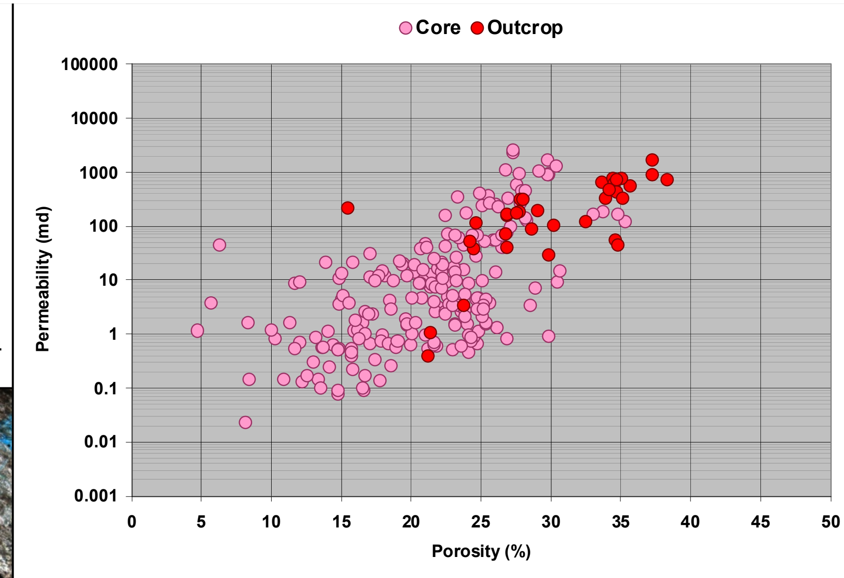


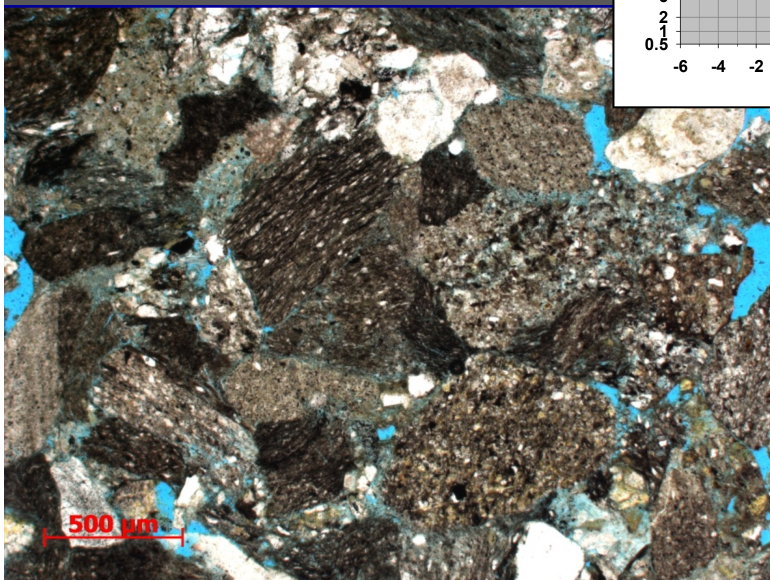


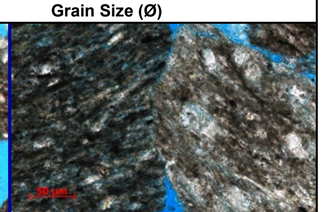
Grain Size:	0.31 mm (mL)
Sorting:	0.55 (mod)
Porosity:	36.3 %
Permeability:	4,548 md
Intergran vol:	30.6 %
Total Clay:	1.7 %
Mineralogy:	volcanic RF (interm – mafic), plag, K-spar , hornblende, basaltic hornblende, quartz
Diagenesis:	Very good RQ, potential problems with mod – deep burial
Provenance:	volcanic arc ?

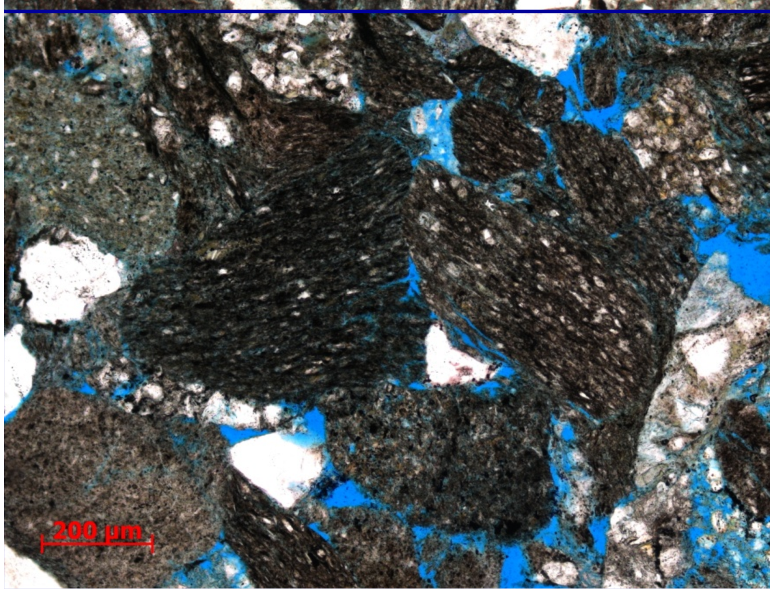
Beluga Formation





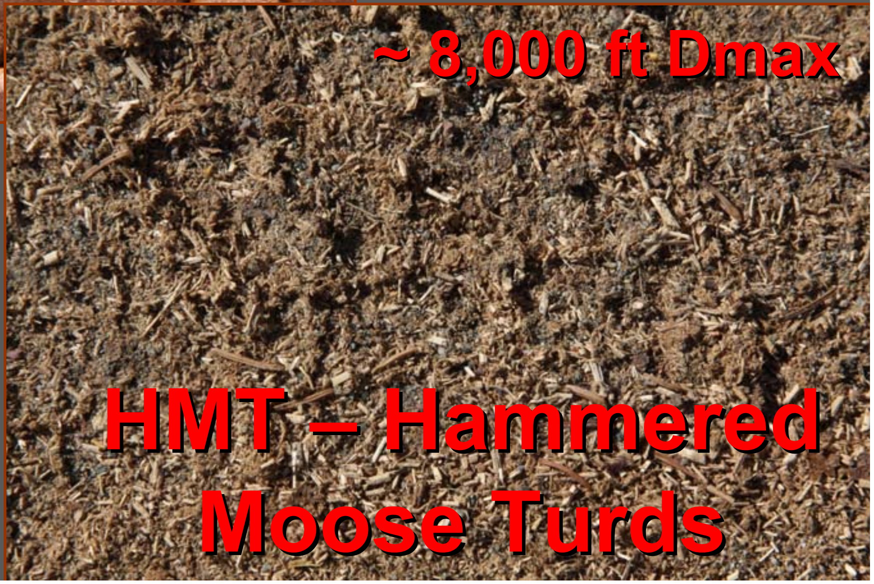




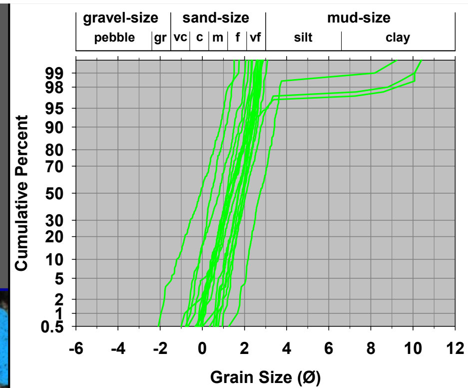


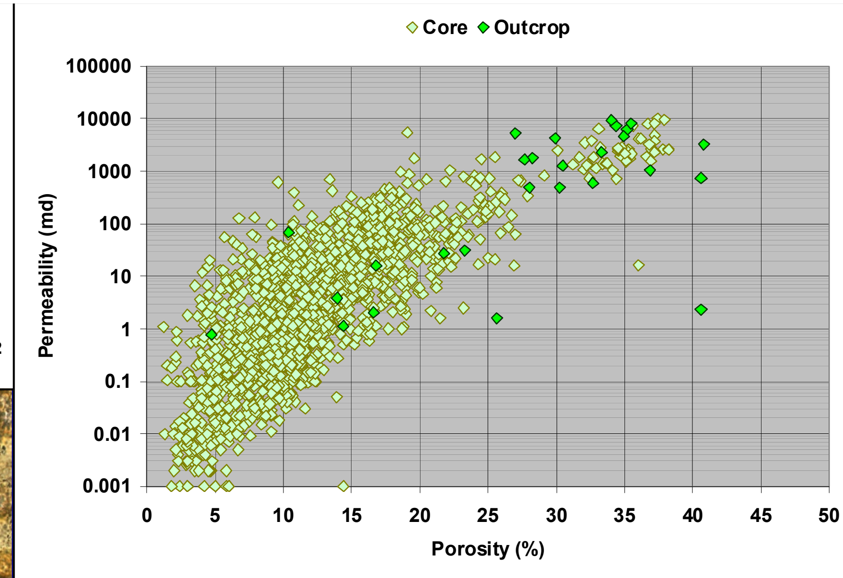
Grain Size:	0.26 mm (mL)
Sorting:	1.27 (poor)
Porosity:	30.0 % (not all effective)
Permeability:	331.8 md
Intergran vol:	22.0 %
Total Clay:	7.7 %
Mineralogy:	Argillaceous SRF & MRF, minor quartz, K-spar, chert, plagioclase
Diagenesis:	potential for mega ductile grain deformation, little cement, fair RQ
Provenance:	accretionary prism

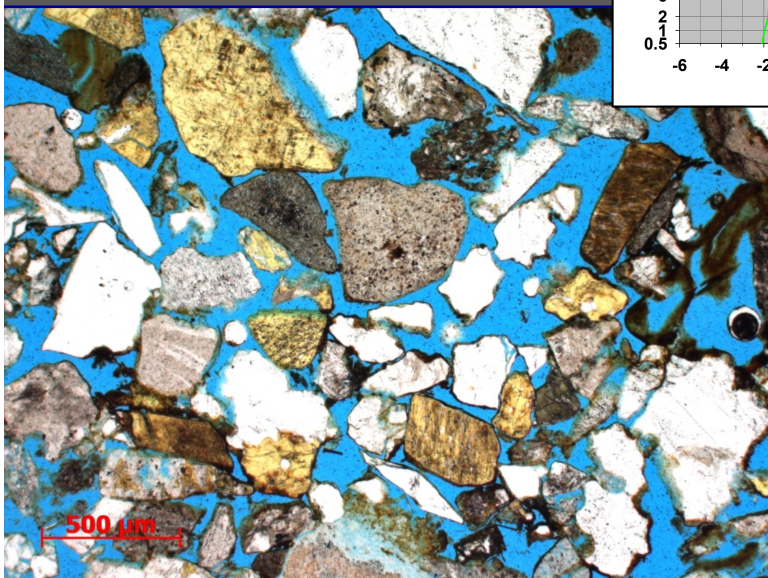
Ductile Deformation Alaska-Style

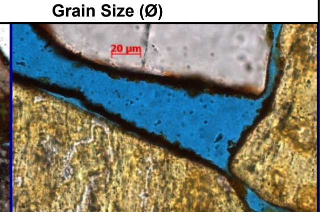


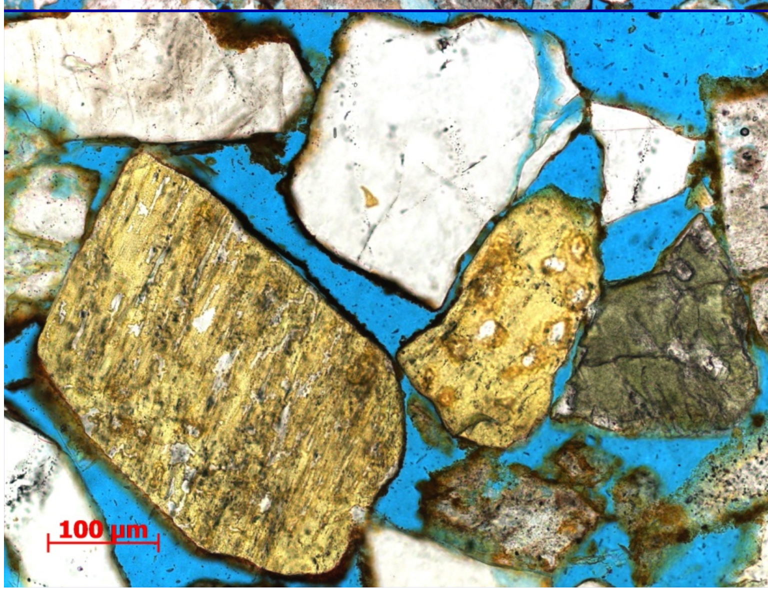
Tyonek Formation





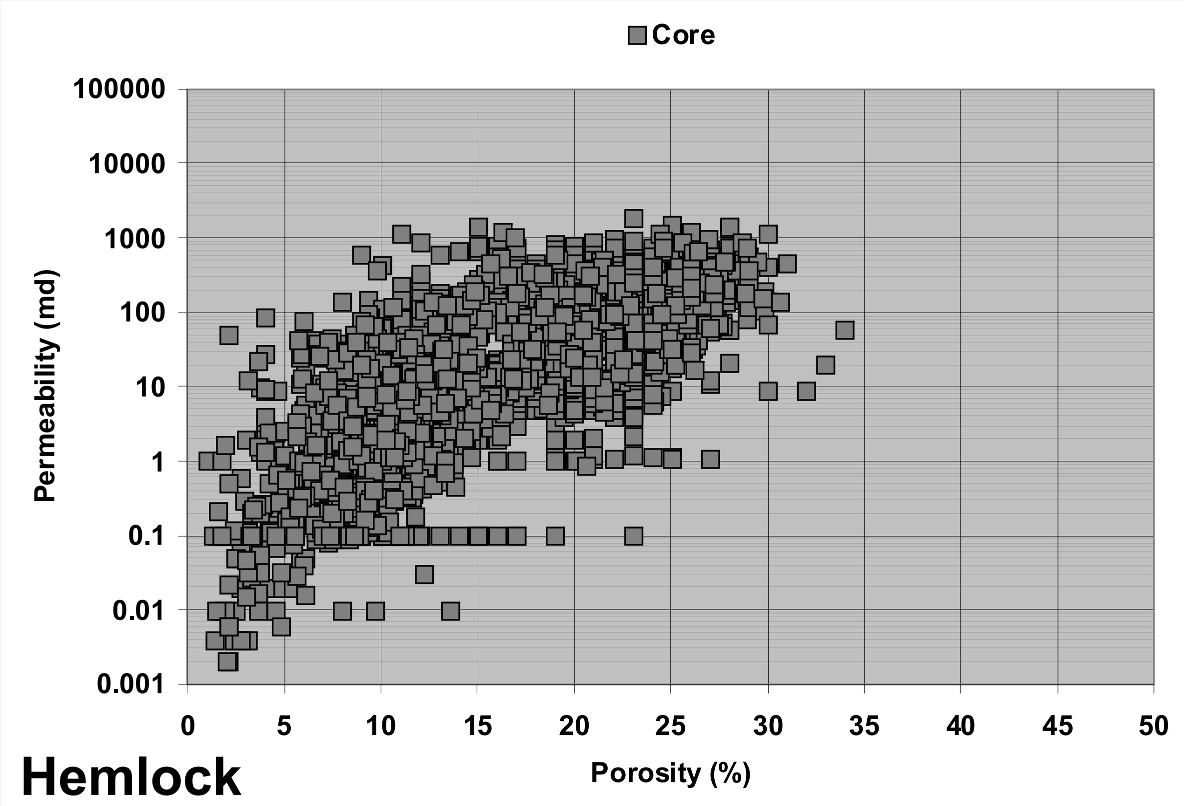




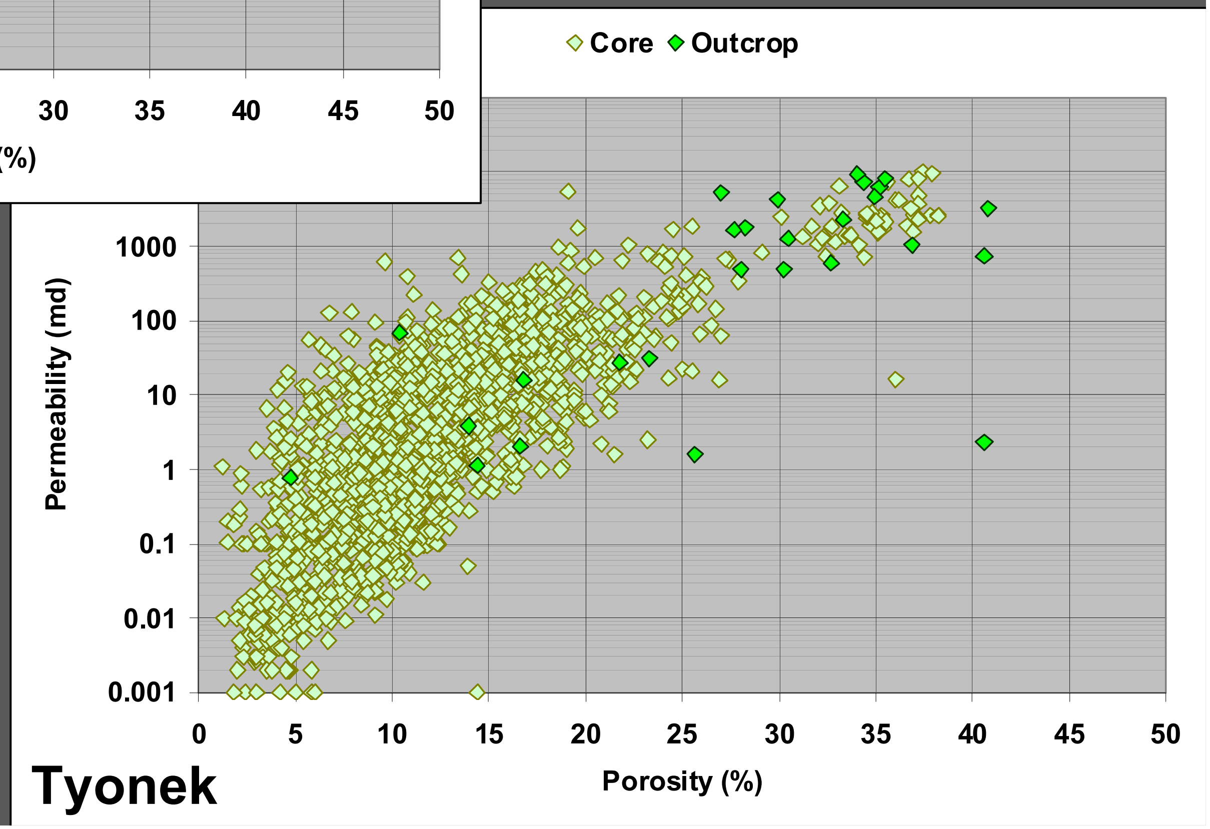


Grain Size:	0.40 mm (mU)
Sorting:	0.66 (mod)
Porosity:	30.6 %
Permeability:	2,820 md
Intergran vol:	28.9 %
Total Clay:	5.8 %
Mineralogy:	quartz, K-spar, plagioclase, PRF, chert, argillaceous SRF & MRF, biotite
Diagenesis:	good RQ, clay rims - possibly authigenic chlorite/smectite, little cement
Provenance:	dissected arc plutons, metamorphic cover

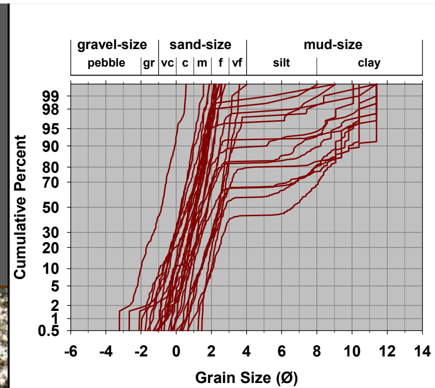
Hemlock Formation

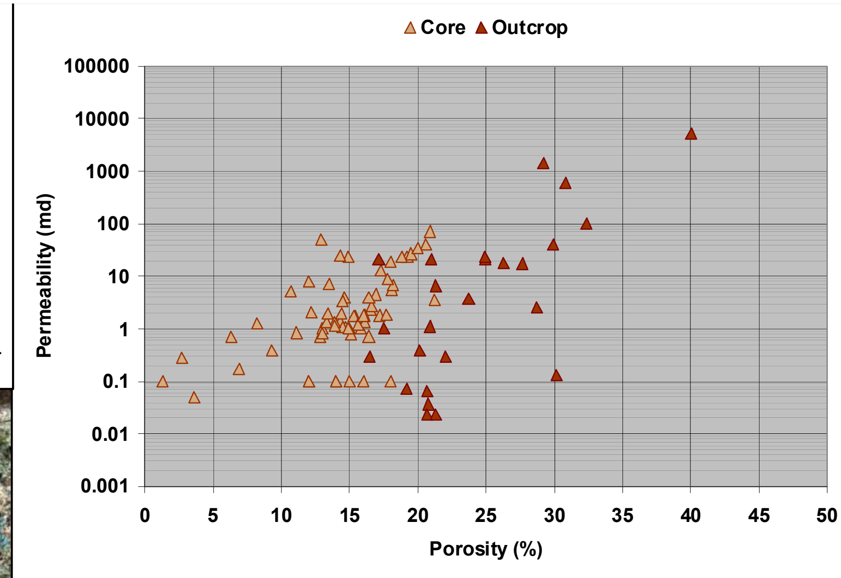


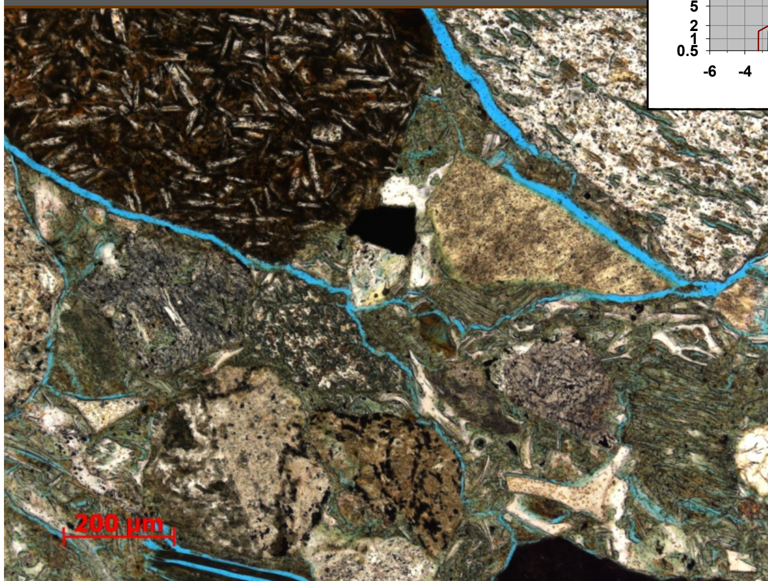
1. Hemlock largely overlaps Tyonek
2. No outcrop data to compare

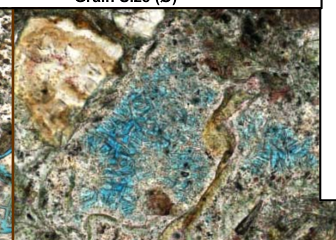


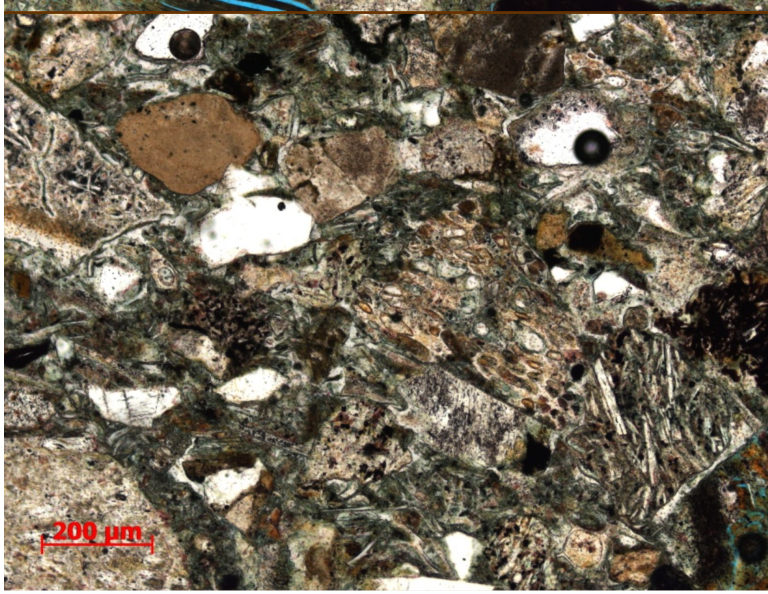
W Foreland Formation





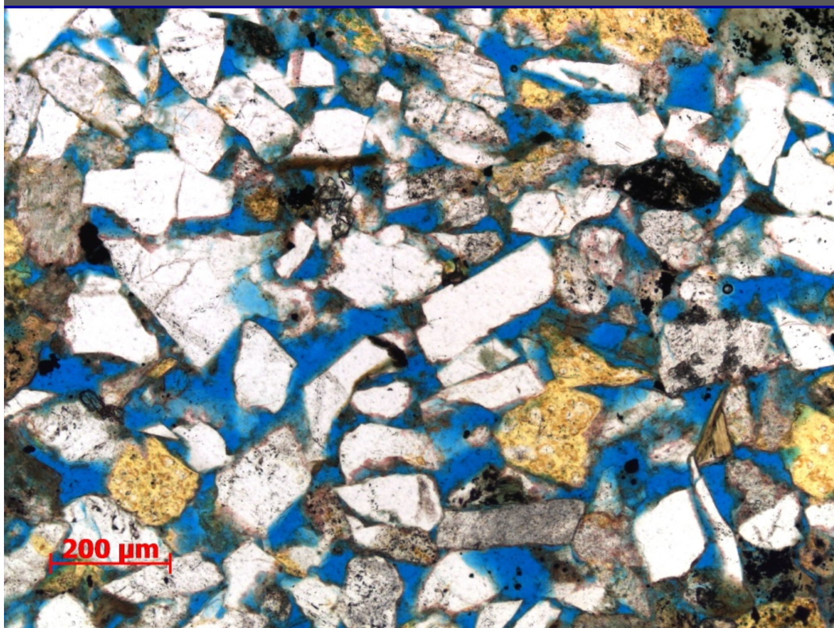


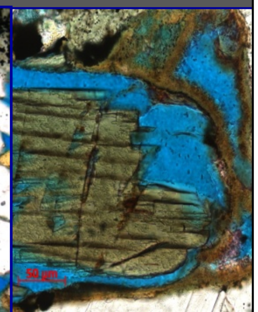


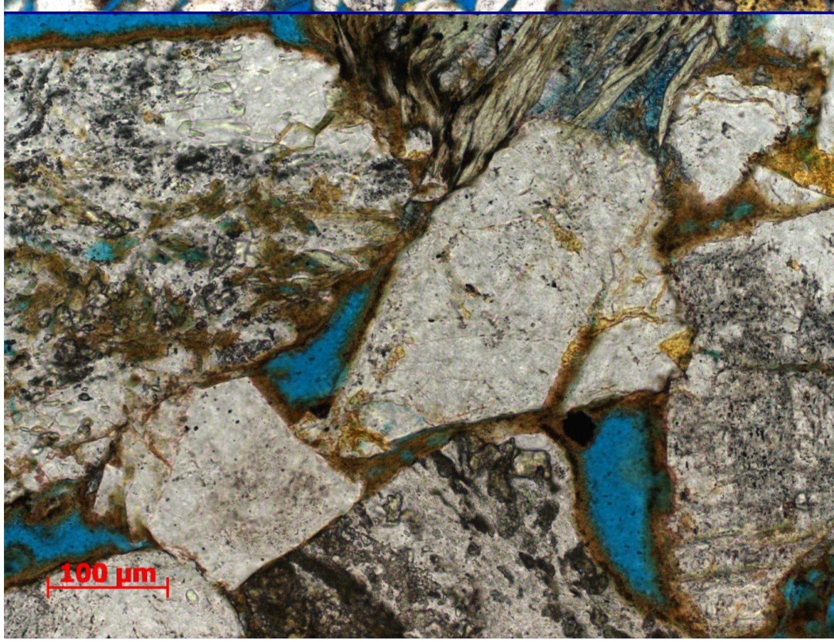


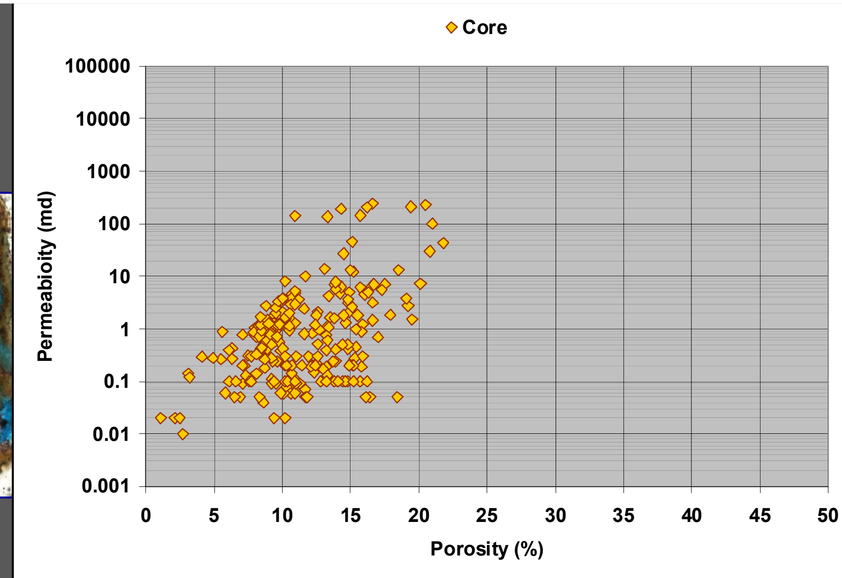
Grain Size:	0.43 mm (mU)
Sorting:	1.48 (poor)
Porosity:	23.7 %
Permeability:	301 md
Intergran vol:	29.4 %
Total Clay:	18.2 %
Mineralogy:	VRF (interm - mafic), plag, hornblende, basaltic Hb, biotite, pumice, shards, minor quartz
Diagenesis:	clinoptilolite (Na, K, Ca), authigenic chlorite/smectite
Provenance:	volcanic arc

Kaguyak Formation



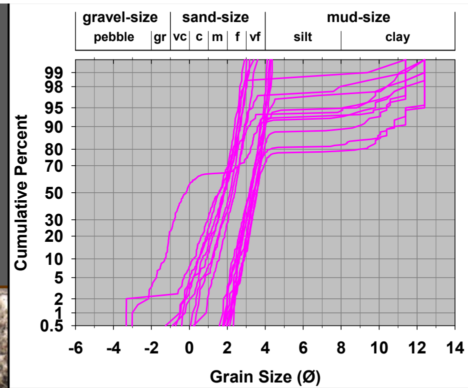


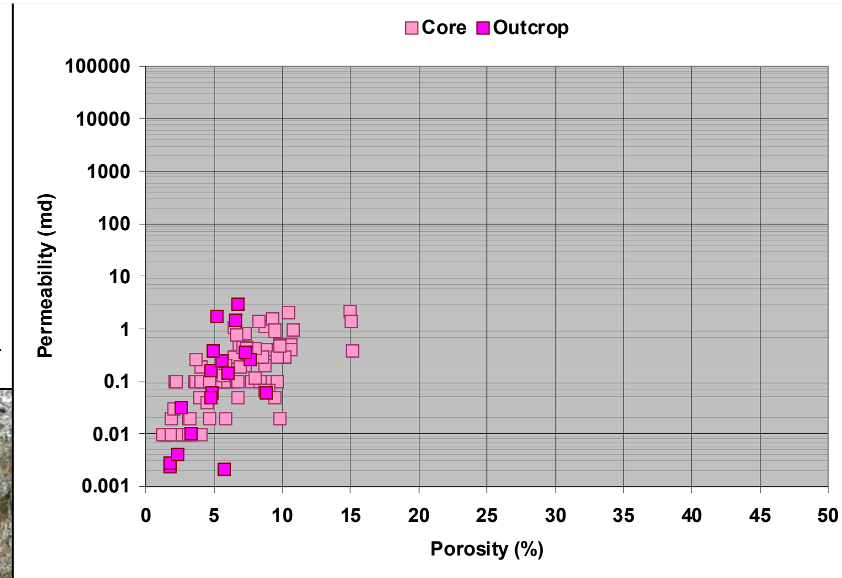


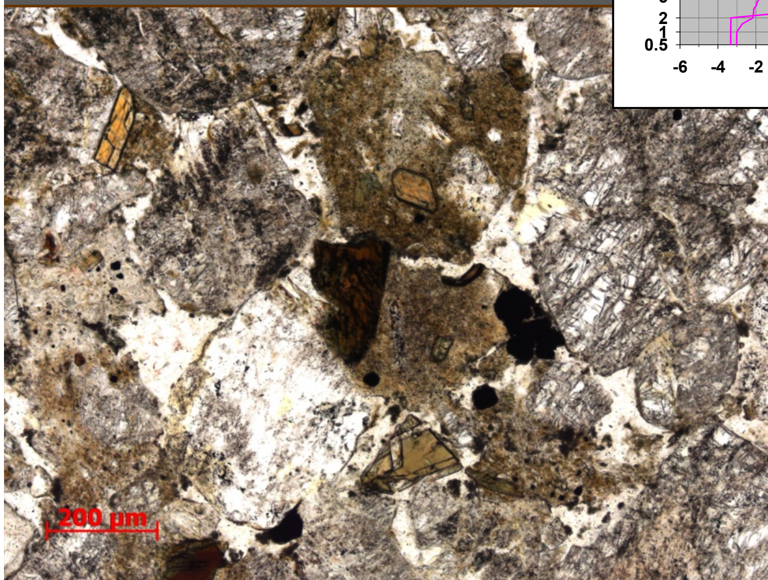


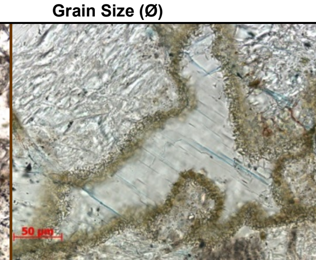
Grain Size:	0.49 mm (mU)
Sorting:	1.25 (poor)
Porosity:	11.4 %
Permeability:	8.2 md
Intergran vol:	27.0 %
Total Clay:	12.0 %
Mineralogy:	quartz, plagioclase, K-spar hornblende, VRF, PRF
Diagenesis:	authigenic chlorite/smectite or chlorite, ductile VRF's, fair - mod RQ.
Provenance:	dissected arc plutons and overlying volcanics

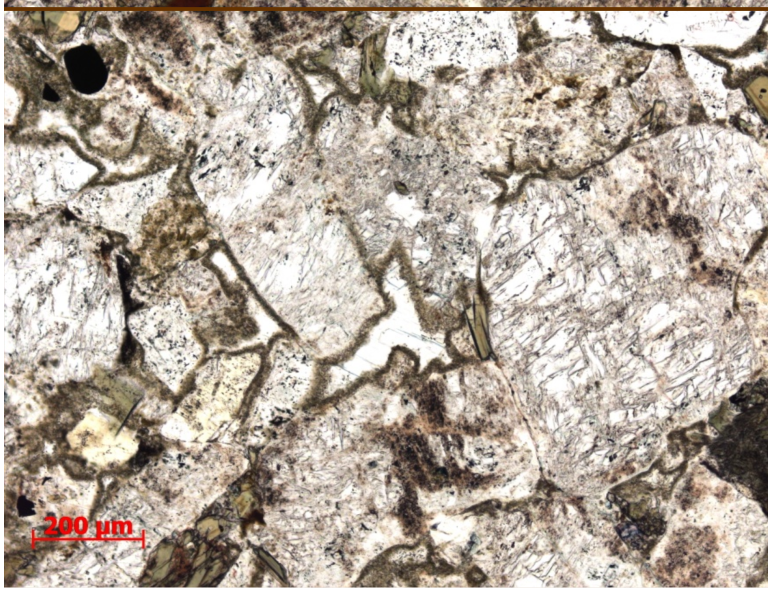
Naknek Formation











Grain Size:	0.18 mm (fU)
Sorting:	1.47 (poor)
Porosity:	5.0 %
Permeability:	0.45 md
Intergran vol:	25.9 %
Total Clay:	7.6 %
Mineralogy:	plagioclase, hornblende, basaltic hornblende, quartz
Diagenesis:	laumontite, heulandite, authigenic chlorite/smectite or chlorite, poor RQ. When did zeolites form?
Provenance:	dissected arc plutons

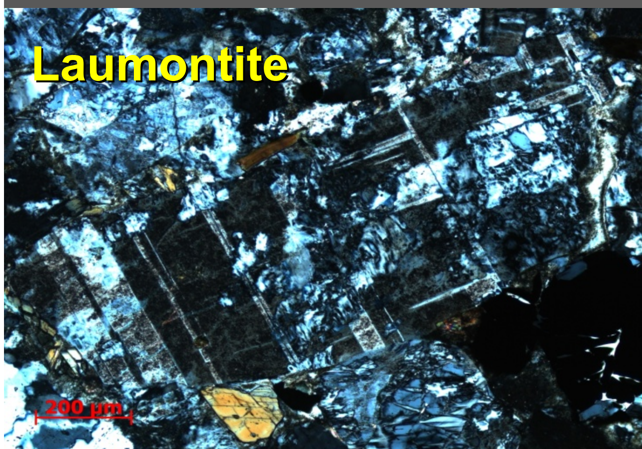
Albitization Reactions

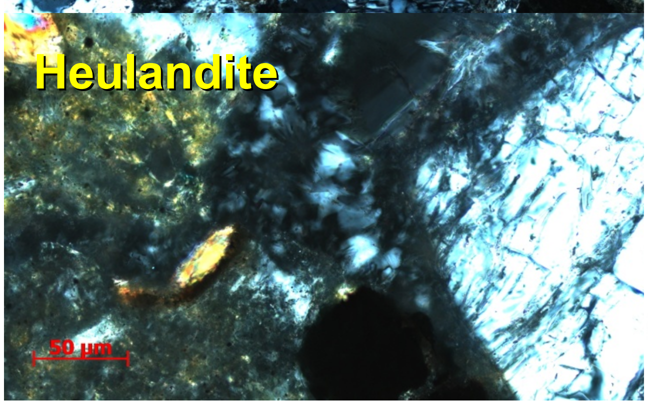
$$NaAlSi_3O_8 \cdot CaAl_2Si_2O_8 + 2SiO_2 + 4H_2\,0 = NaAlSi_3O_8 + CaAl_2Si_4O_{12} \cdot 4H_2O$$

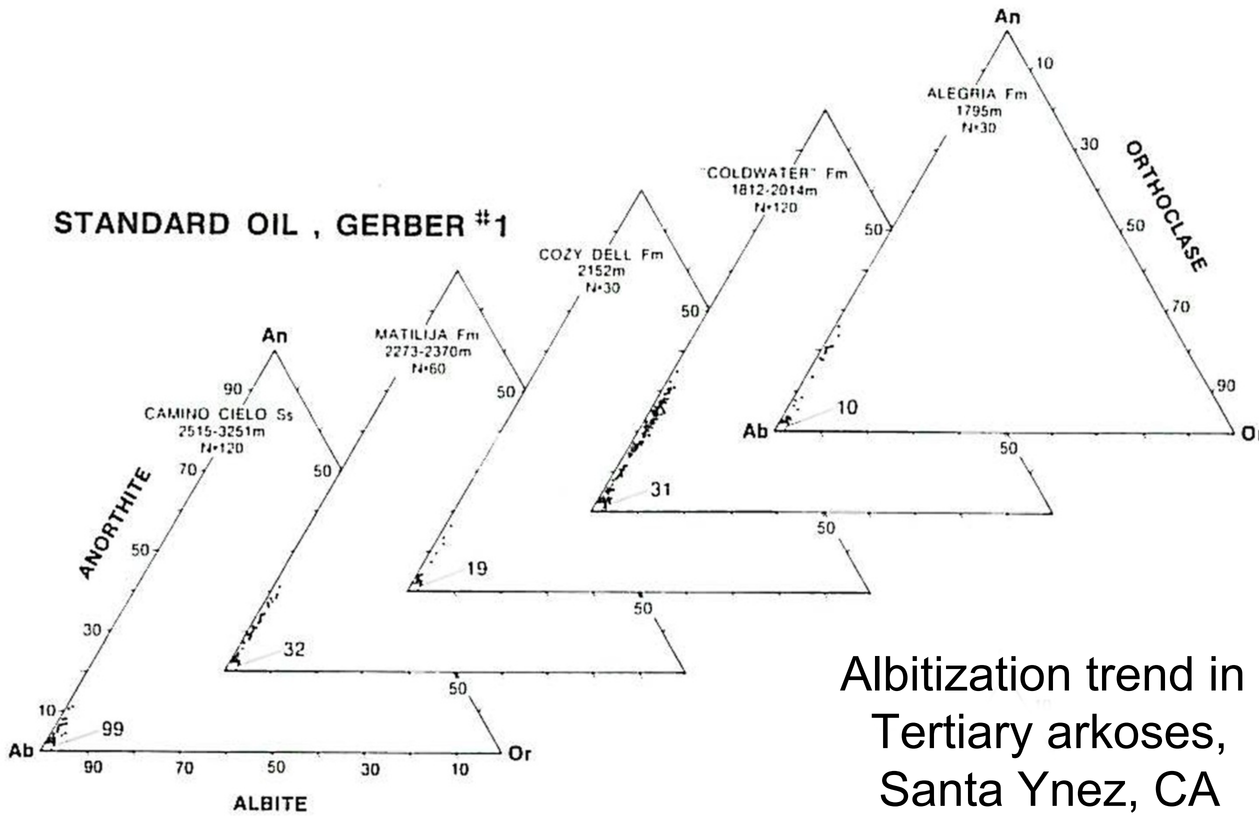
Plagioclase | **Quartz** | **Albite** | **Laumontite**

$$NaAlSi_3O_8 \cdot CaAl_2Si_2O_8 + 5SiO_2 + 6H_2\,0 = NaAlSi_3O_8 + CaAl_2Si_7O_{18} \cdot 6H_2O$$

Plagioclase | **Quartz** | **Albite** | **Heulandite**

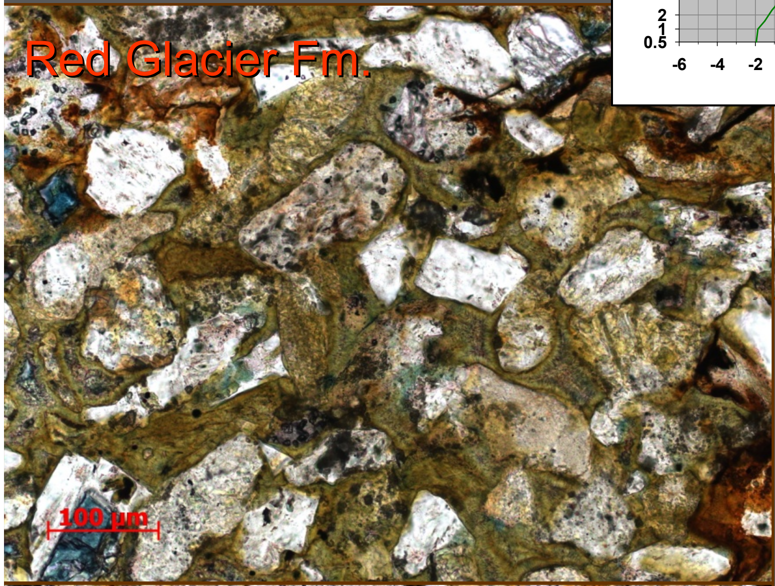


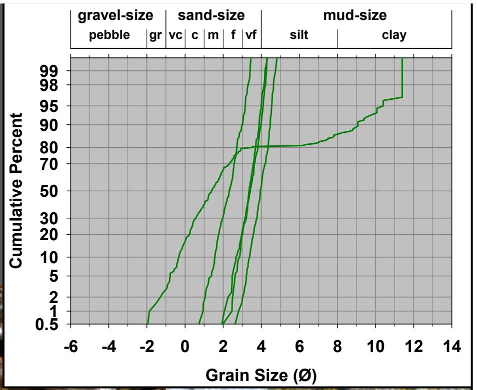


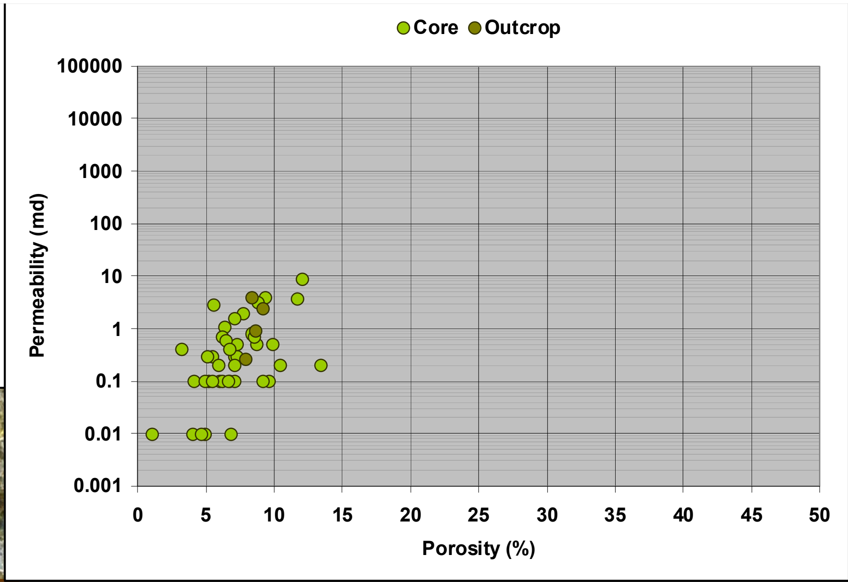


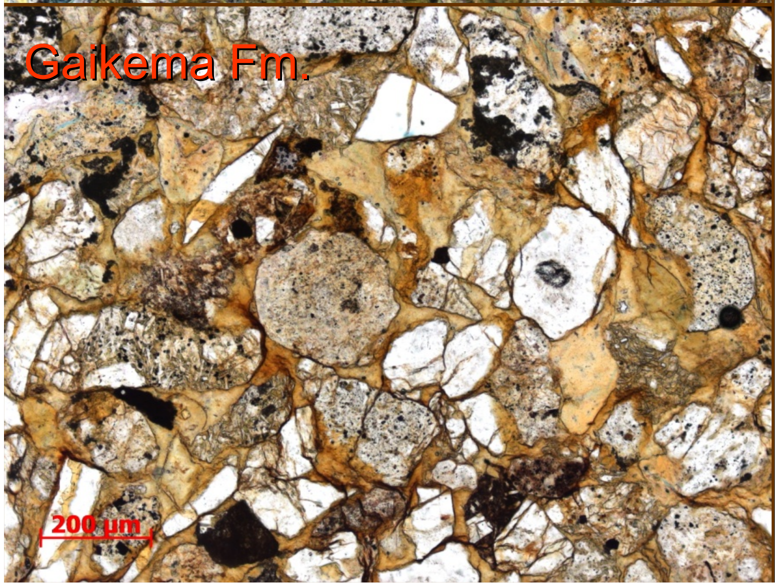
Albitization trend in Tertiary arkoses, Santa Ynez, CA

Tuxedni Group



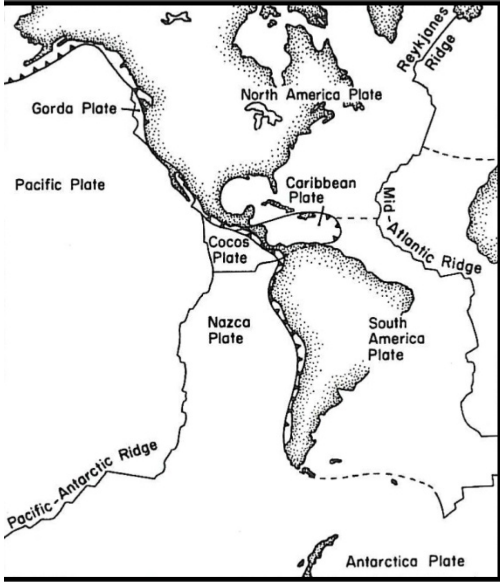




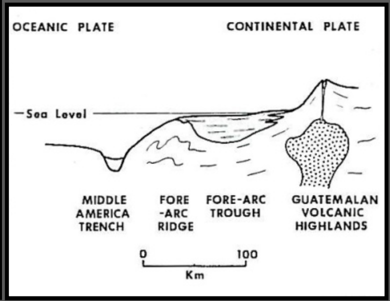


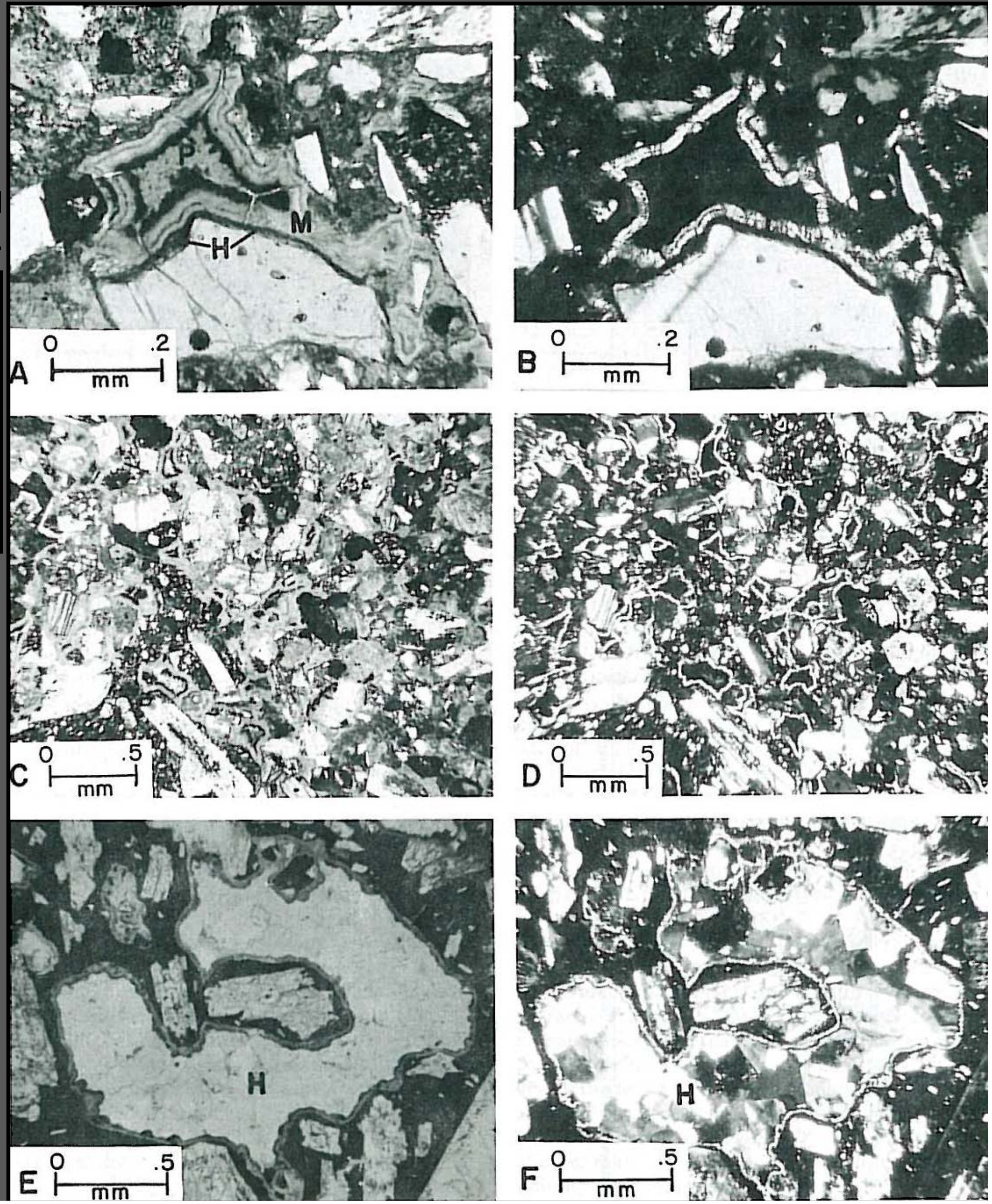
Grain Size:	0.13 mm (fL)
Sorting:	1.12 (poor)
Porosity:	8.5 %
Permeability:	1.90 md
Intergran vol:	39.2 %
Total Clay:	29.6 %
Mineralogy:	volcanic RF (felsic - interm), altered VRF, plagioclase, quartz
Diagenesis:	Authigenic pore-filling clay, probably chlorite/smectite or chlorite, potential zeolites, poor RQ
Provenance:	volcanic arc

Tuxedni Diagenesis Analog



1979, D.K. Davis, W.R. Almon, S.B. Bonis & B.E. Hunter, Deposition and diagenesis of Tertiary-Holocene volcaniclastics, Guatemala, SEPM Special Publication 26, p. 281-306.

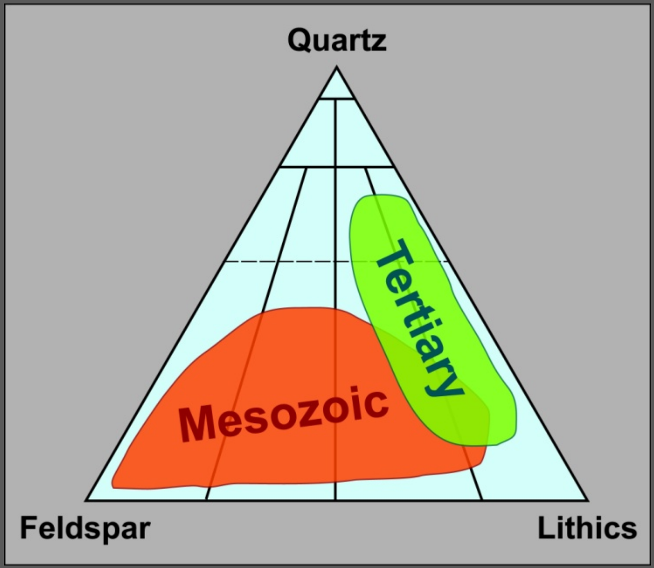


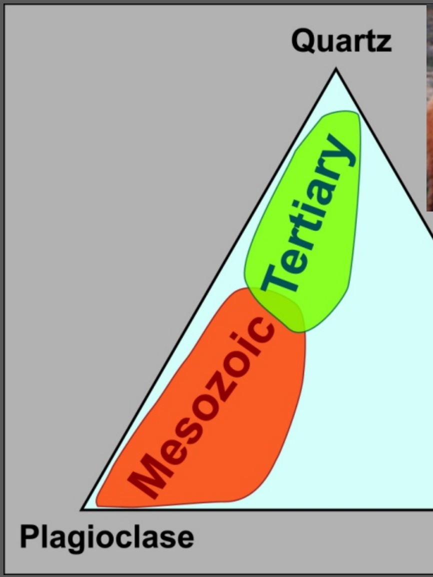


1. Three episodes of cements:
   - Hematite-Goethite
   - Smectite + Hematite
   - Smectite + Heulandite
2. Pore fluid chemistry has the most control on cementation
3. All porosity is occluded within 2,000 years of deposition

The Rich Get Richer...

- **Tertiary Sandstones – Good guys**
  - Young age (< 65 million years old)
  - Shallow burial (< 10,000 feet)
  - Chemically stable mineralogy (Quartz + K-feldspar)
- **Mesozoic Sandstones – Reservoir challenged**
  - Old age (> 65 million years old)
  - Deep burial (> 10,000 feet)
  - Chemically unstable mineralogy (Plagioclase + VRF’s)
  - Enhanced potential for unconventional reservoirs

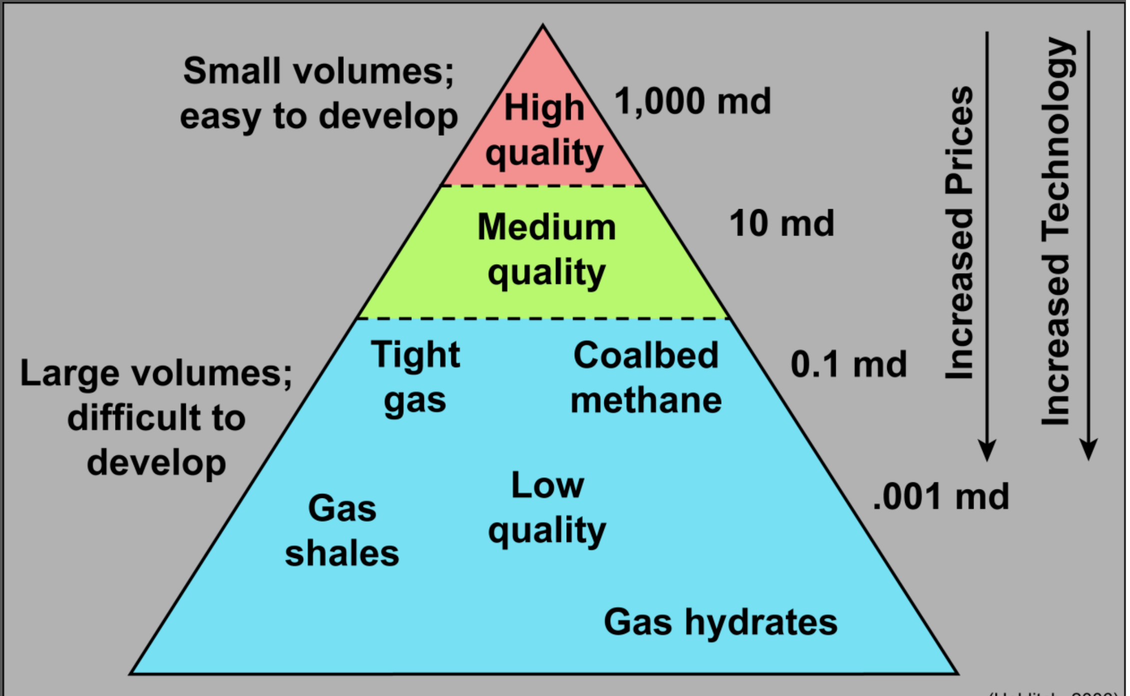




Tight Gas Sand

- Sandstone reservoir with permeability to flow gas of less than 0.1 md
- Sandstone reservoir that cannot be produced at economic flow rates without stimulation by hydraulic fracture treatment

- Geologic Considerations
  - Depositional facies
  - Reservoir geometry
  - Textural maturity
  - Mineralogy
  - Diagenetic processes
  - Porosity & permeability
  - Natural fractures



(Holditch, 2006)

Conclusions

- Tertiary sandstones have distinct differences in mineralogy due to variations in provenance (accretionary prism vs. arc)
- Both vertical and lateral variations in provenance may exist
- Mineralogy exerts a strong control on diagenesis and reservoir quality
- Tertiary & Upper Cretaceous have substantial potential for conventional reservoirs
- Jurassic has potential for unconventional reservoirs

The Way Forward

- Provide digital data from routine core analyses from outcrop and subsurface samples – both raw and interpreted
- Provide digital compositional and grain size data from outcrop samples
- Continue compilation of routine core analyses and petrographic data from public domain


The End
DANGER
N206PA