Reservoir Potential of Tertiary and Mesozoic Sandstones, Cook Inlet, Alaska

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AAPG Pacific Section
Anchorage, AK
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Collaborative effort between DGGS, DOG, UAF, Purdue University and USGS

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DOG: Diane Shellenbaum, Laura Silliphant, Ken Helmold, Shaun Peterson
UAF: Paul McCarthy, Jake Mongrain
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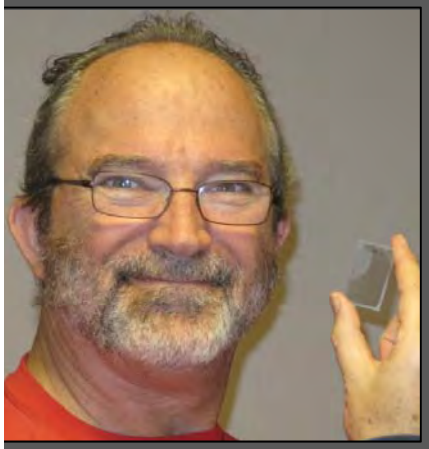
Provided routine core analyses and modal data collected from public domain



Jim Hickey, DeGolyer & MacNaughton

Provided interpretation of MICP analyses

Don Krouskop, AK Division Oil & Gas

Provided routine core analyses from DOG database

Outline

Workflow

Geologic setting

Sample preparation

Framework mineralogy

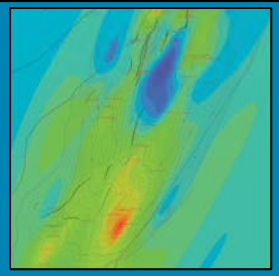
Provenance assessment

Overall Reservoir quality

Petrology & RQ by formation

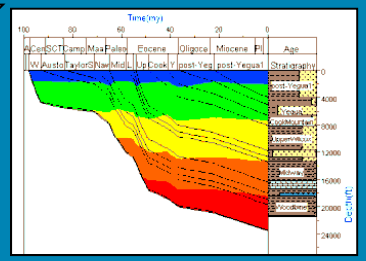
Workflow

Tertiary erosion

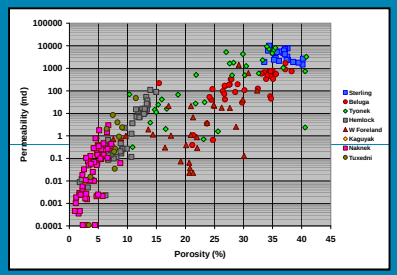


Petrographic data

1D burial histories



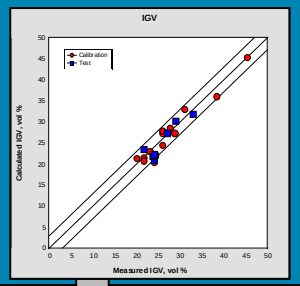
Petrophysical data

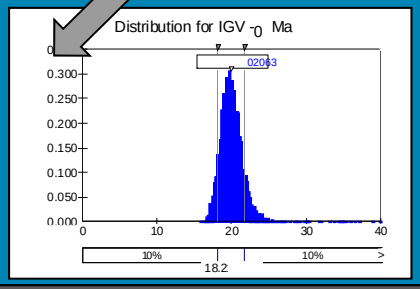


time, temp. & effective stress

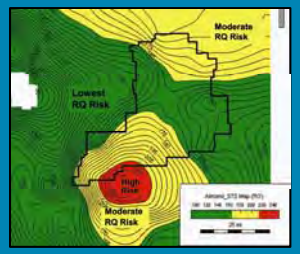
rock composition, Φ & K

Diagenetic models

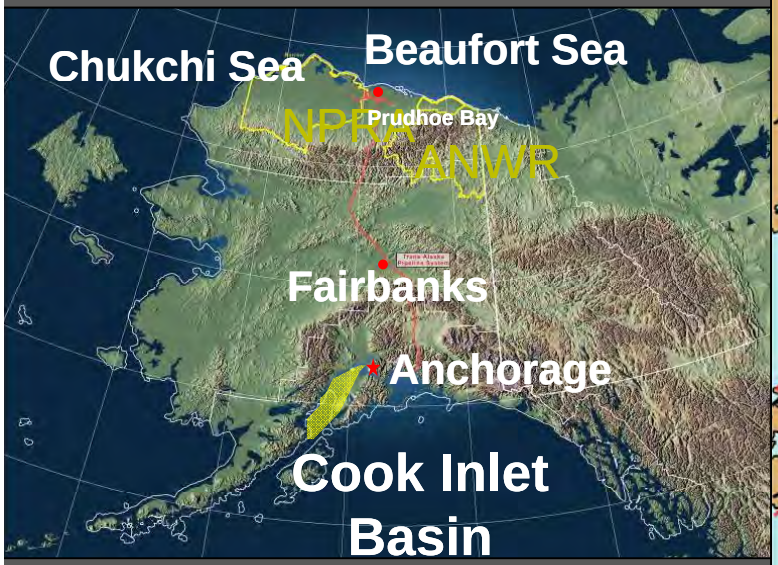


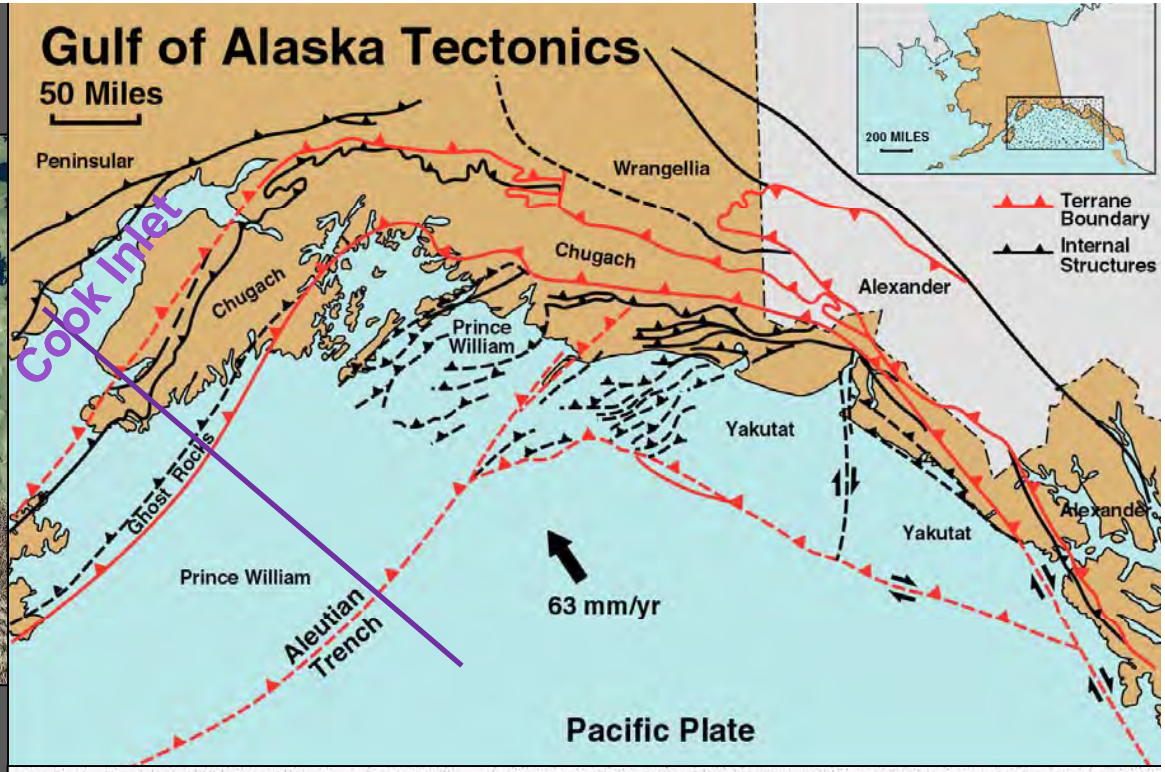


Predictive RQ maps

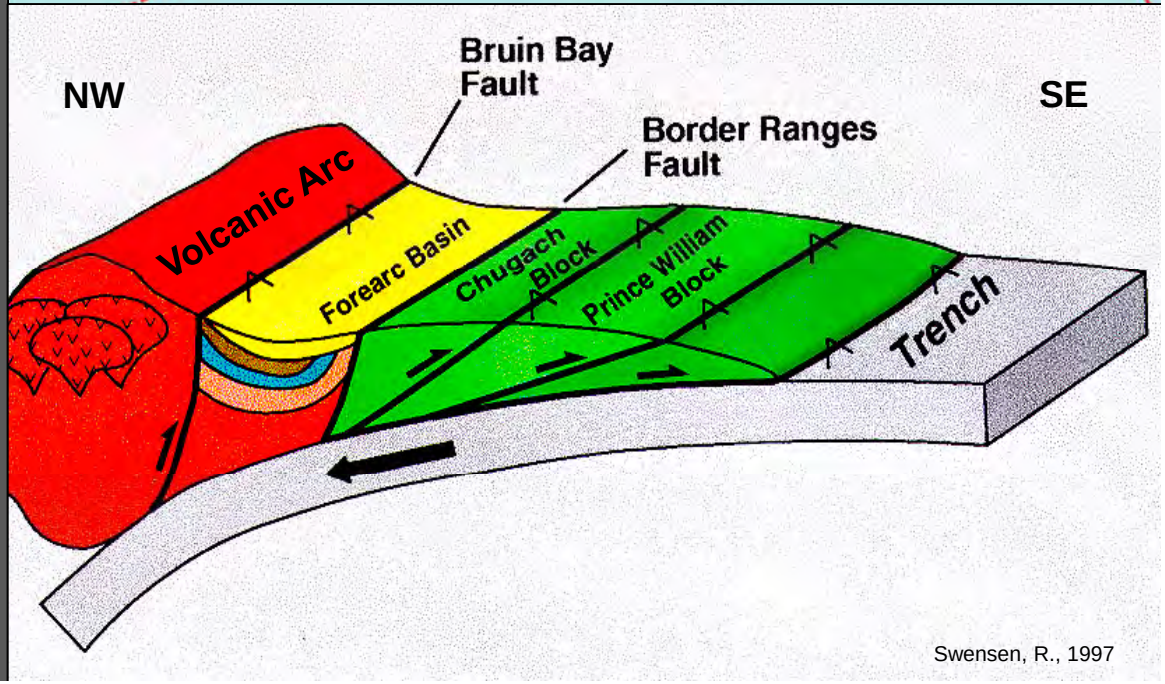


Regional Geology





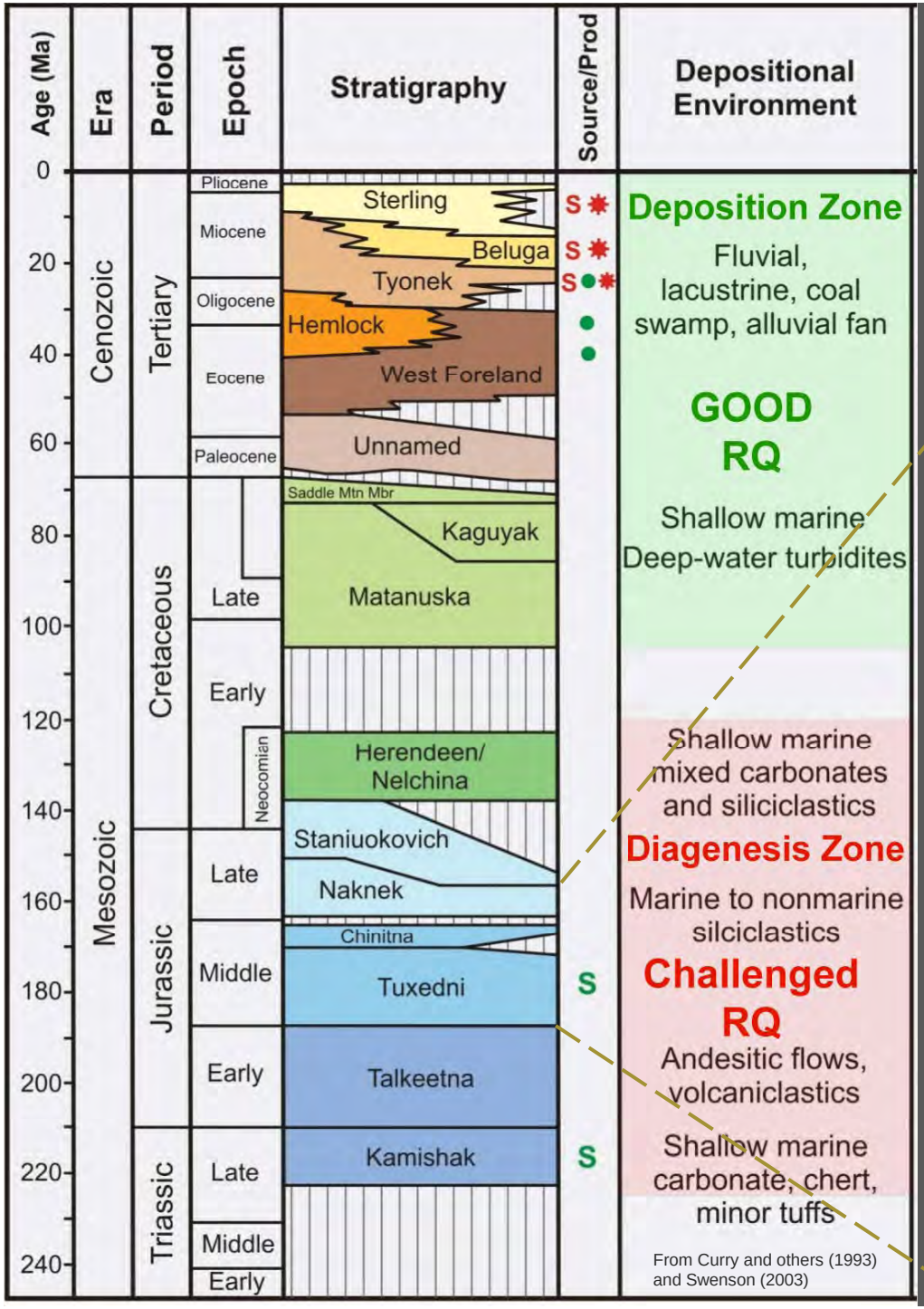
- Collisional forearc basin filled with Mesozoic and Cenozoic marine and nonmarine strata
- Arc-trench system since latest Triassic
- Accretionary prism to SE
- Magmatic arc to NW
- Fault-bounded basin



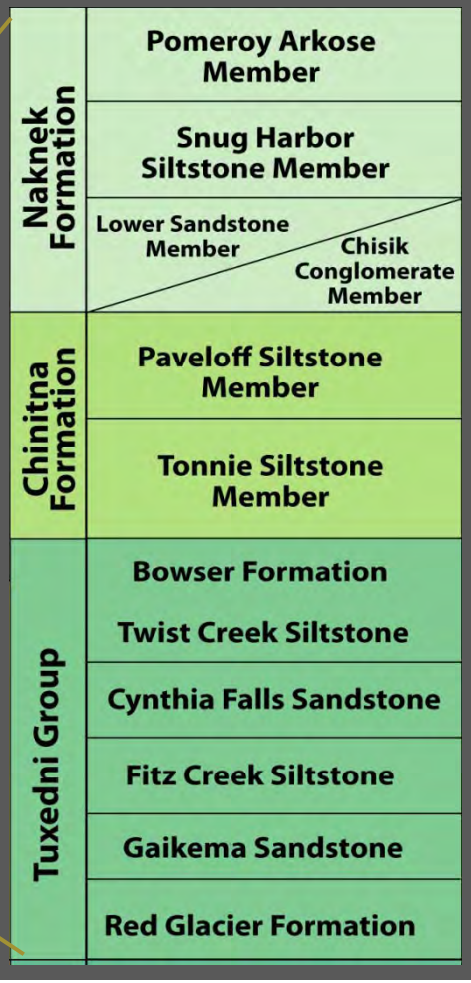
Swensen, R., 1997

Stratigraphy

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



From Curry and others (1993) and Swenson (2003)

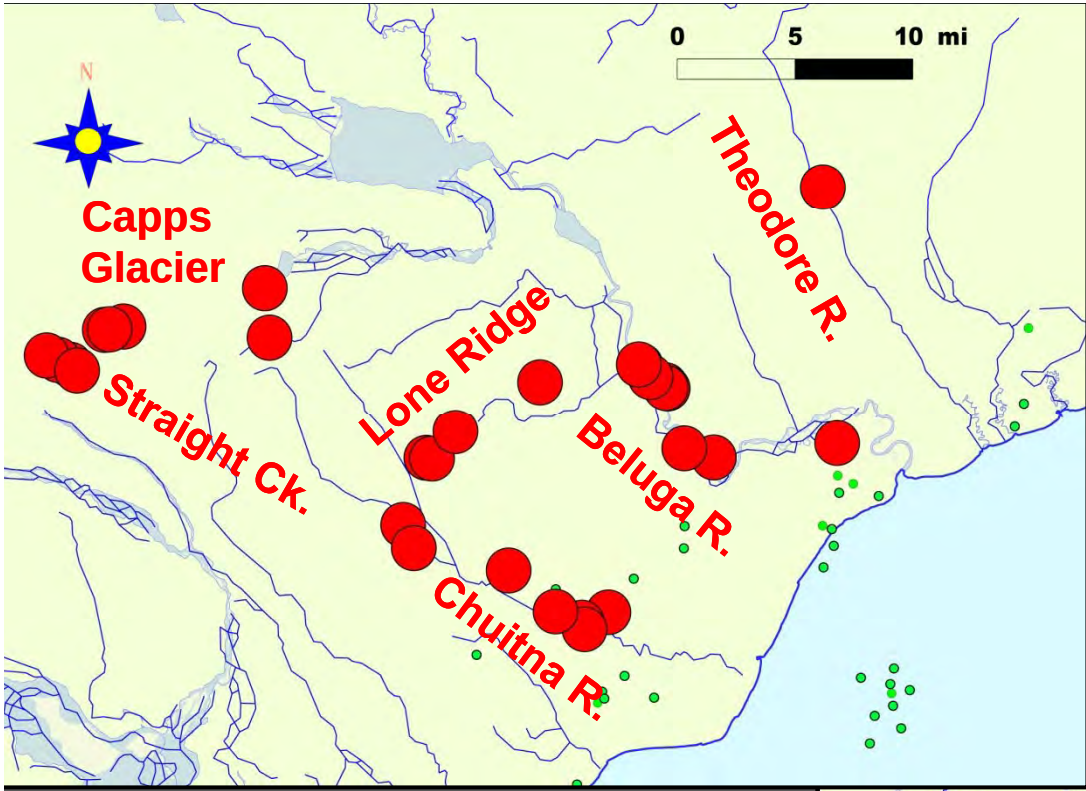


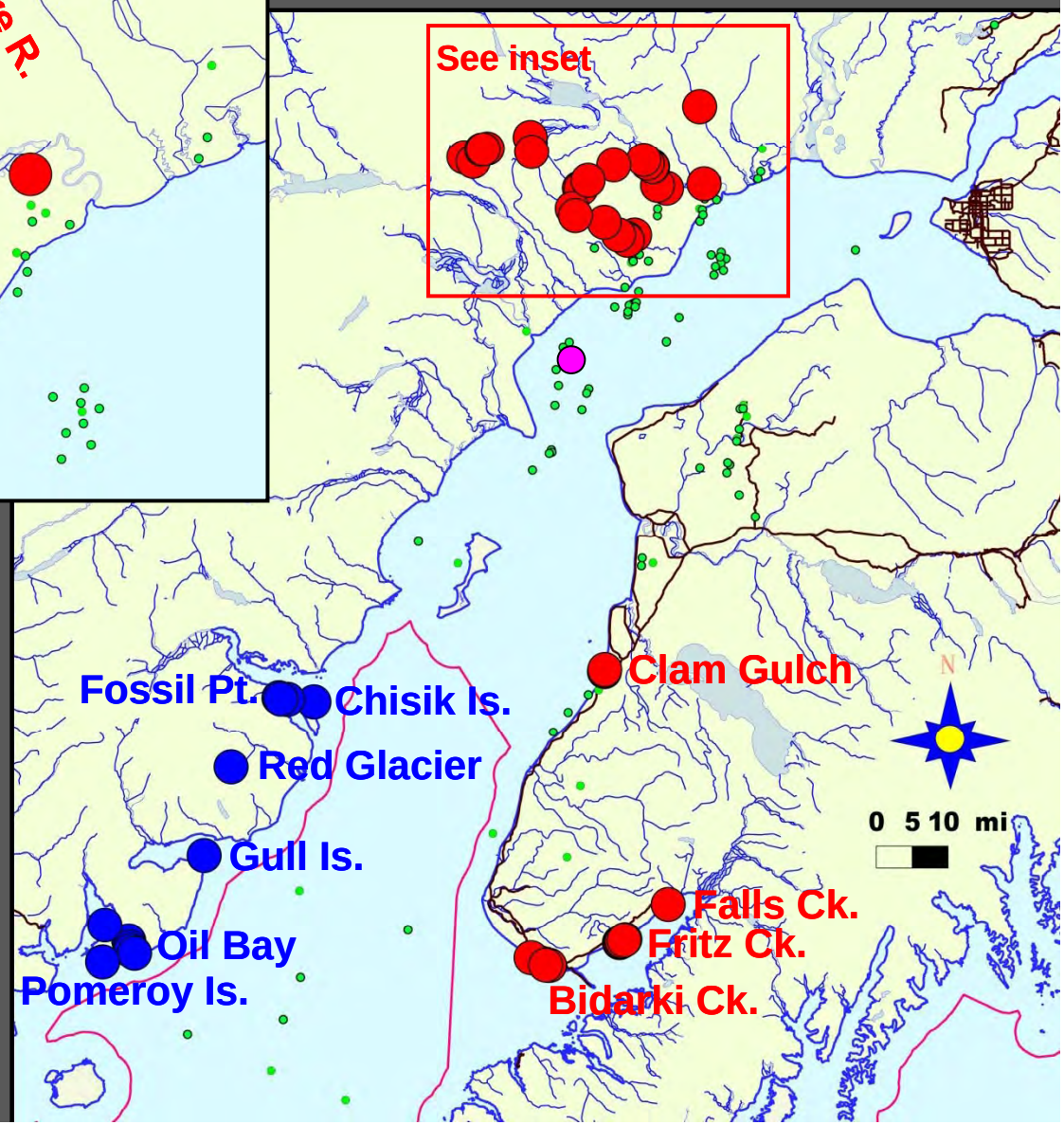
Basin fill has been modified by folding and faulting to form structural traps

Lithologies interfinger within formations

Interfingering is the basis for stratigraphic traps

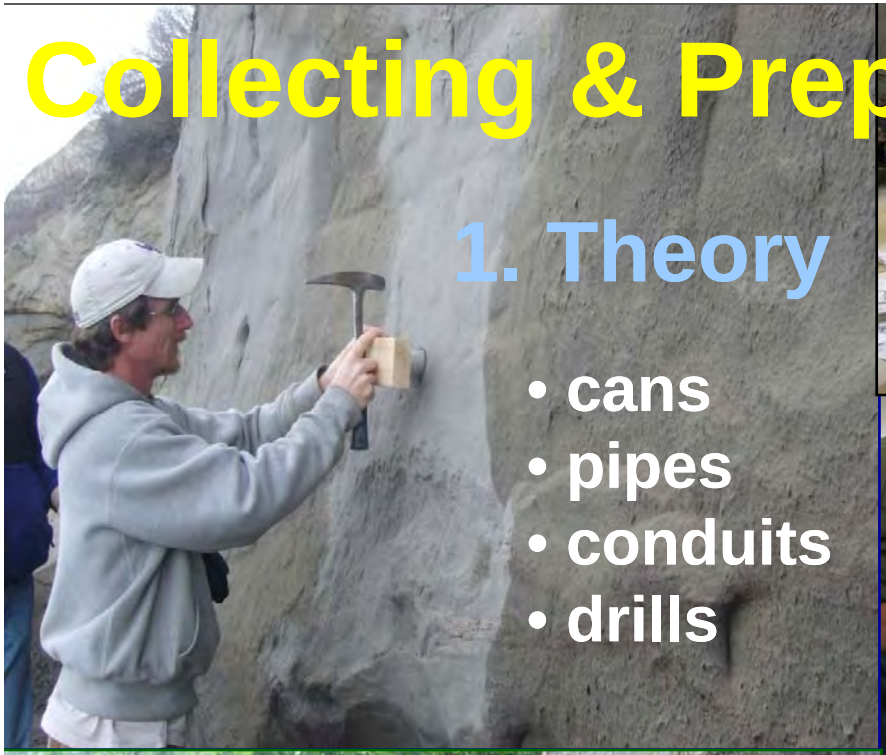
Sample Distribution





- **Tertiary outcrops**
  144 samples from 37 sections
- **Mesozoic outcrops**
  64 samples from 14 sections
- **Tertiary well**
  61 samples from 1 well
- **Tertiary & Mesozoic wells (Φ – K data only)**
  5779 samples from 98 wells

Collecting & Preparing Friable Sands



1. Theory

- cans
- pipes
- conduits
- drills

3. "Epoxy Party"

2. Practical

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

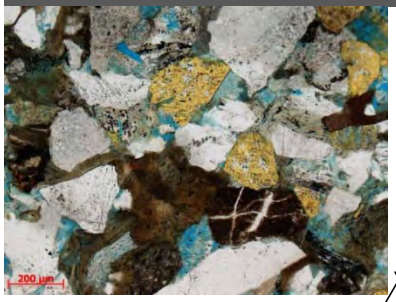
Schist, phyllite (greenschist facies)

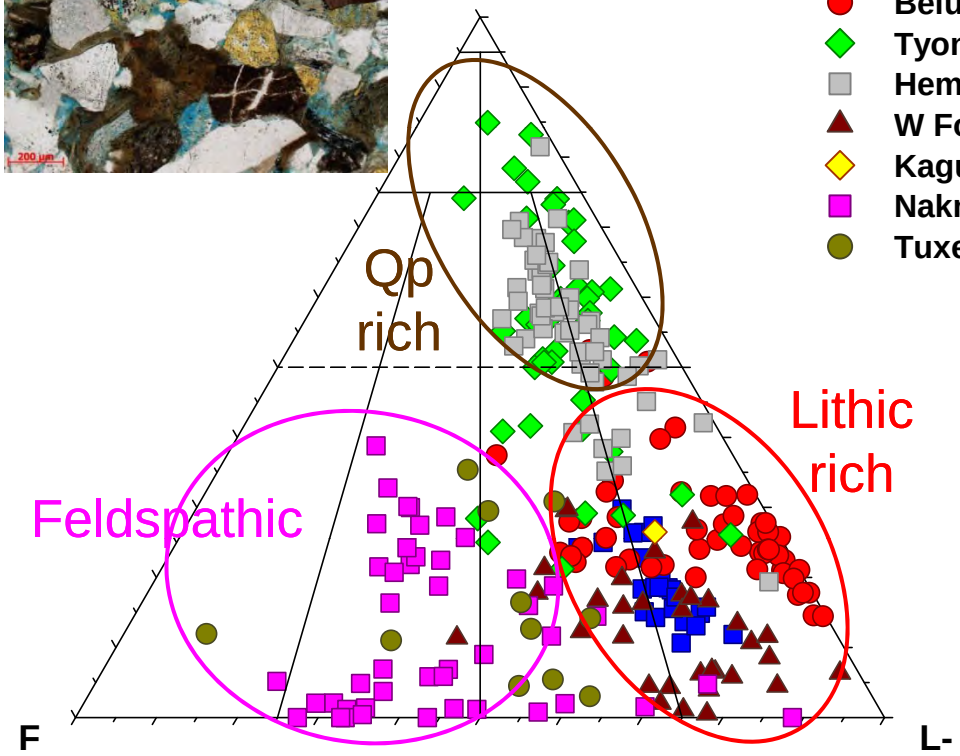
McHugh Complex (Jurassic – Cretaceous)

Argillite, graywacke, limestone, chert

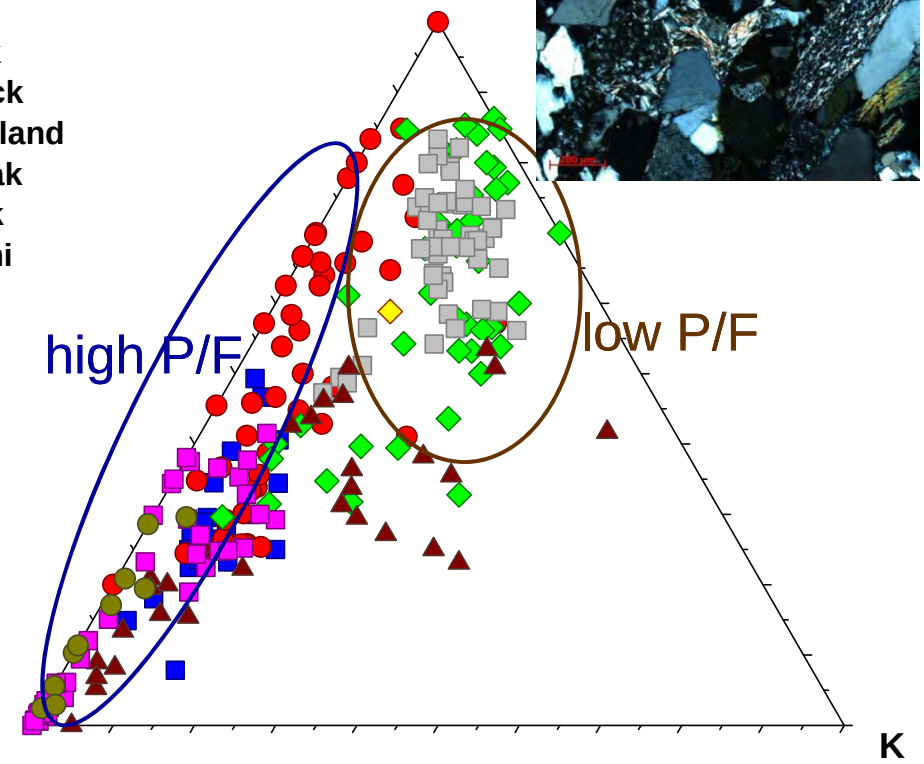
Tuff, gabbro, basalt (prehnite-pumpellyite facies)

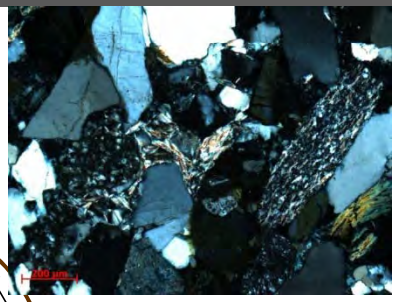
Framework Composition





Sterling
Beluga
Tyonek
Hemlock
W Foreland
Kaguyak
Naknek
Tuxedni

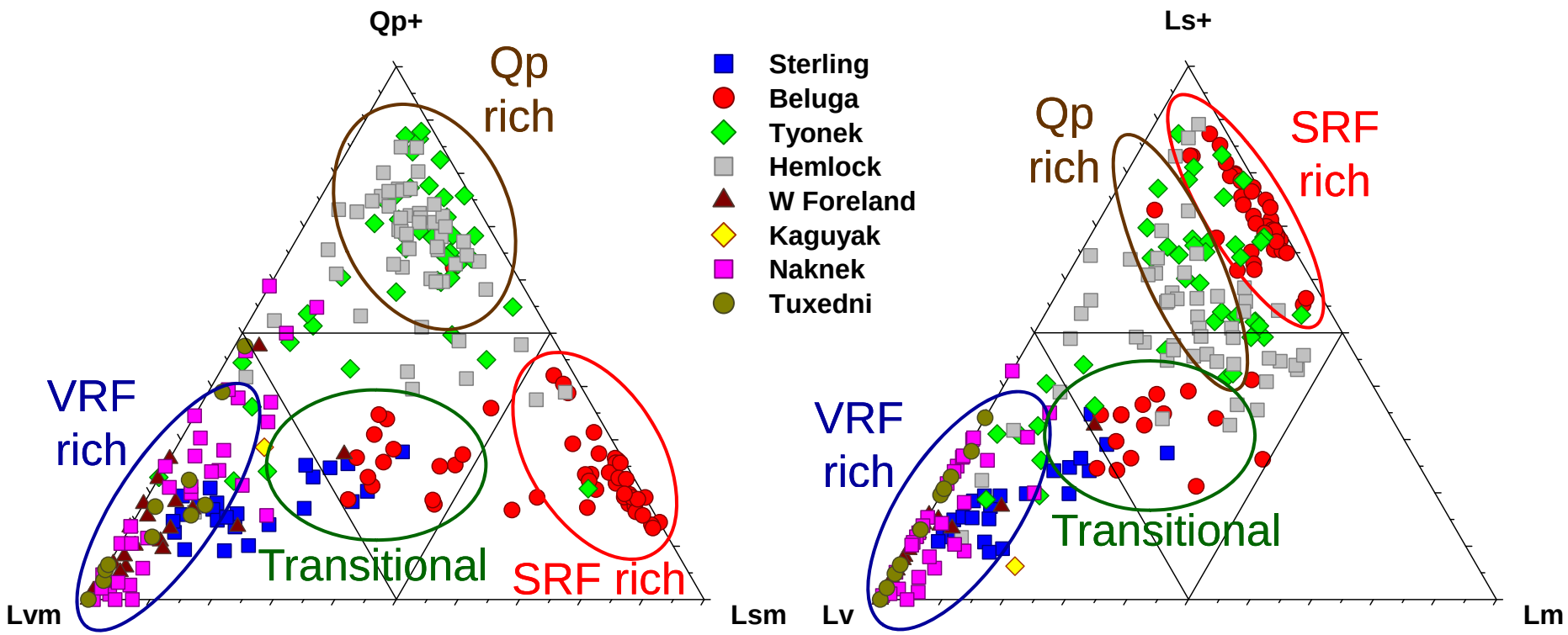




1. Sterling, Beluga & W Foreland are lithic rich
2. Tyonek & Hemlock are relatively quartz rich
3. Naknek & Tuxedni are feldspathic

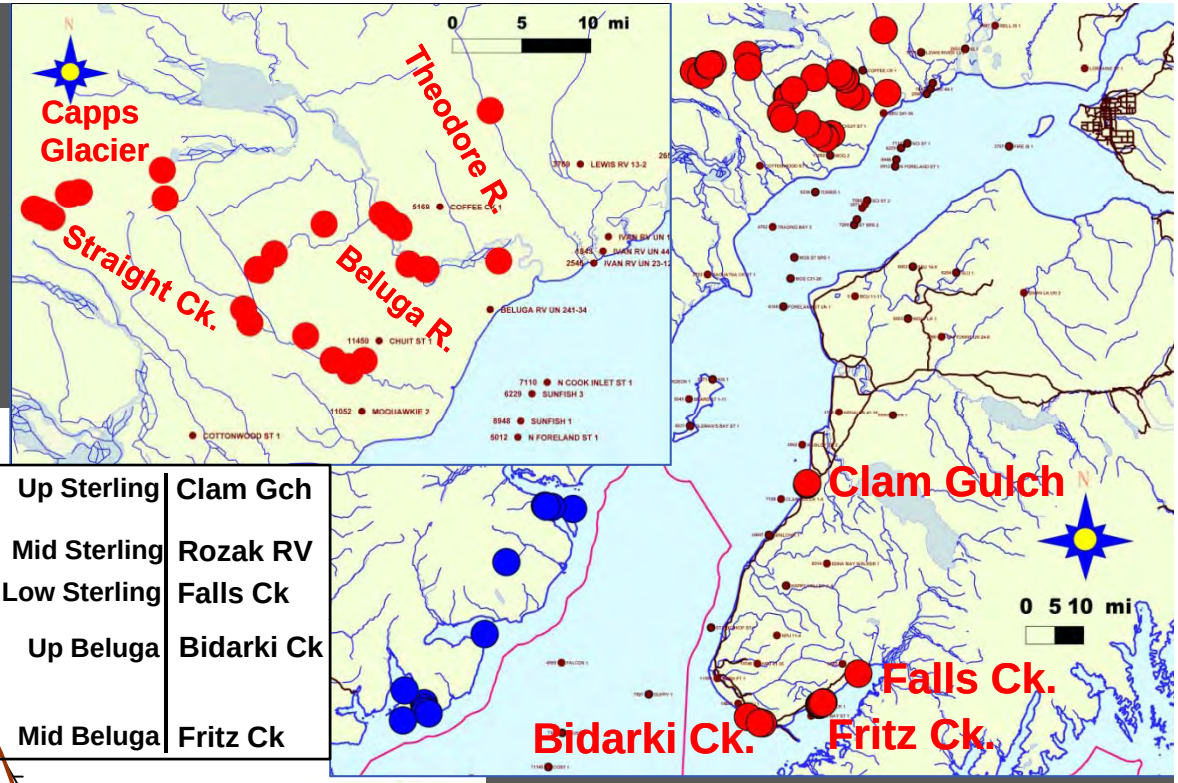
1. Sterling, W Foreland & Naknek have high P/F - intermediate igneous provenance
2. Tyonek & Hemlock have lower P/F - “granitic” provenance

Lithic Composition

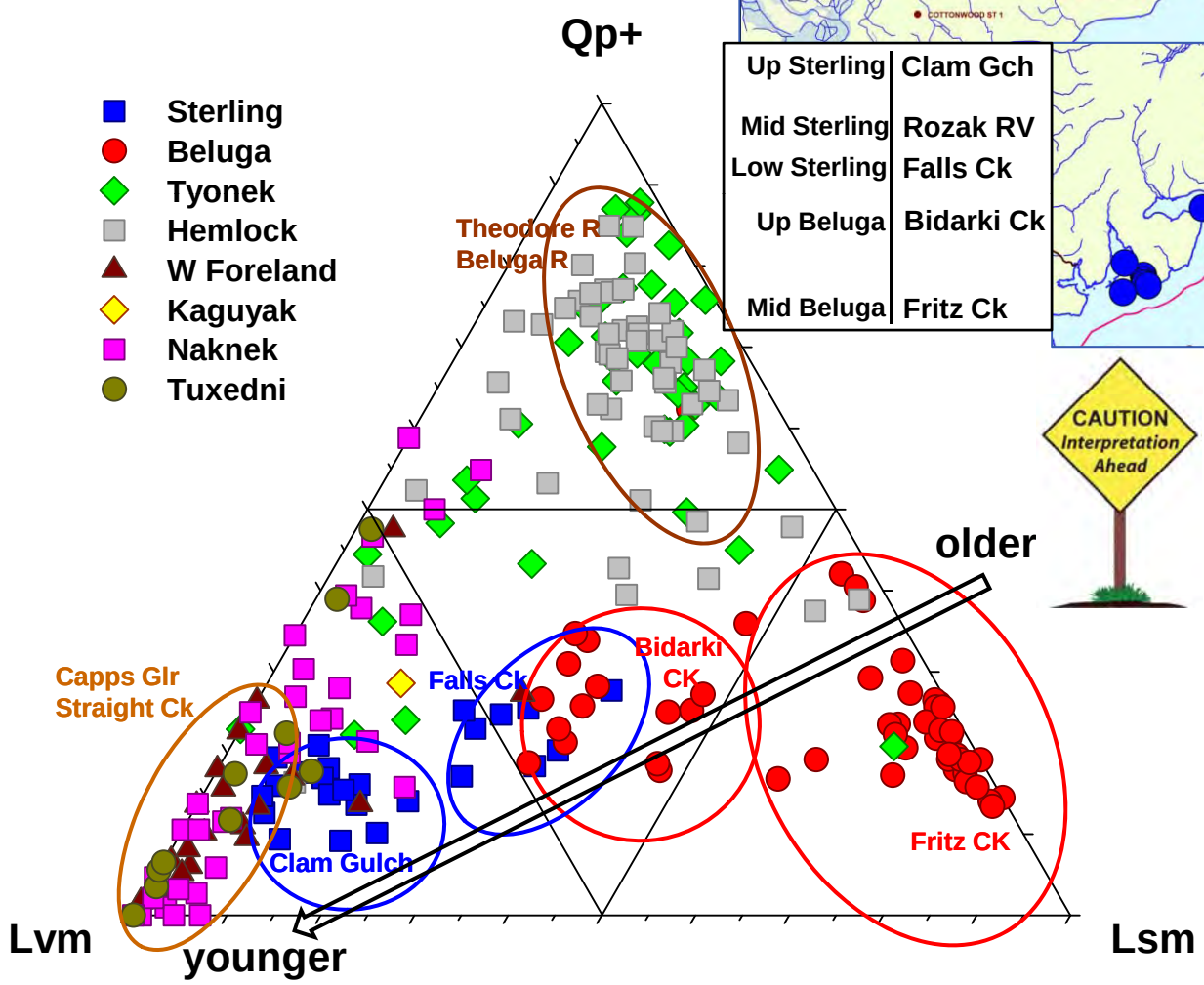


1. Most Beluga are rich in argillaceous SRF
2. Tyonek & Hemlock are rich in Qp and chert (common provenance ?)
3. Sterling, W Foreland & Tuxedni are rich in VRF's
4. Some Sterling & Beluga are transitional (changing provenance ?)

Provenance Implications

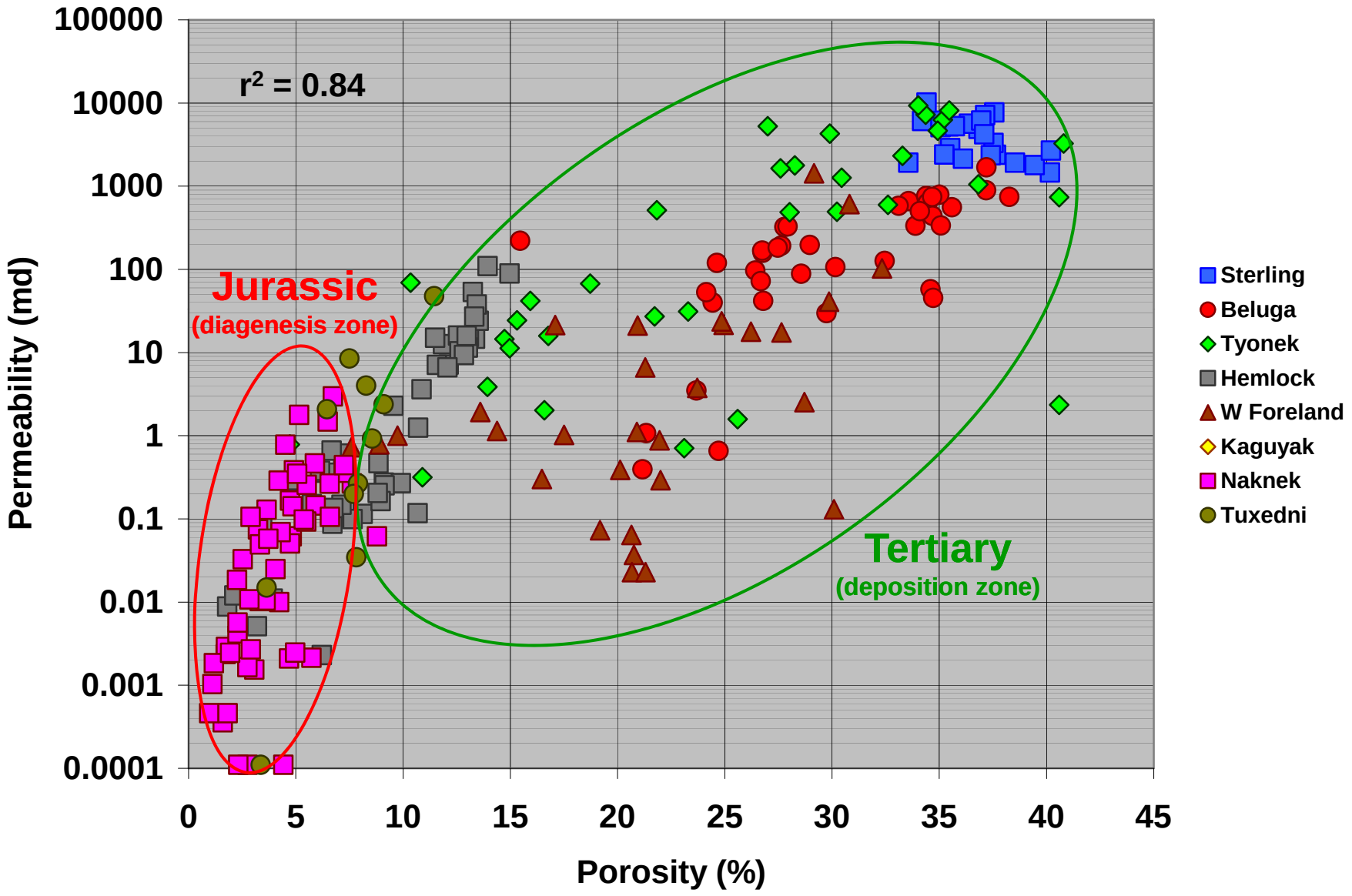


Up Sterling	Clam Gch
Mid Sterling	Rozak RV
Low Sterling	Falls Ck
Up Beluga	Bidarki Ck
Mid Beluga	Fritz Ck

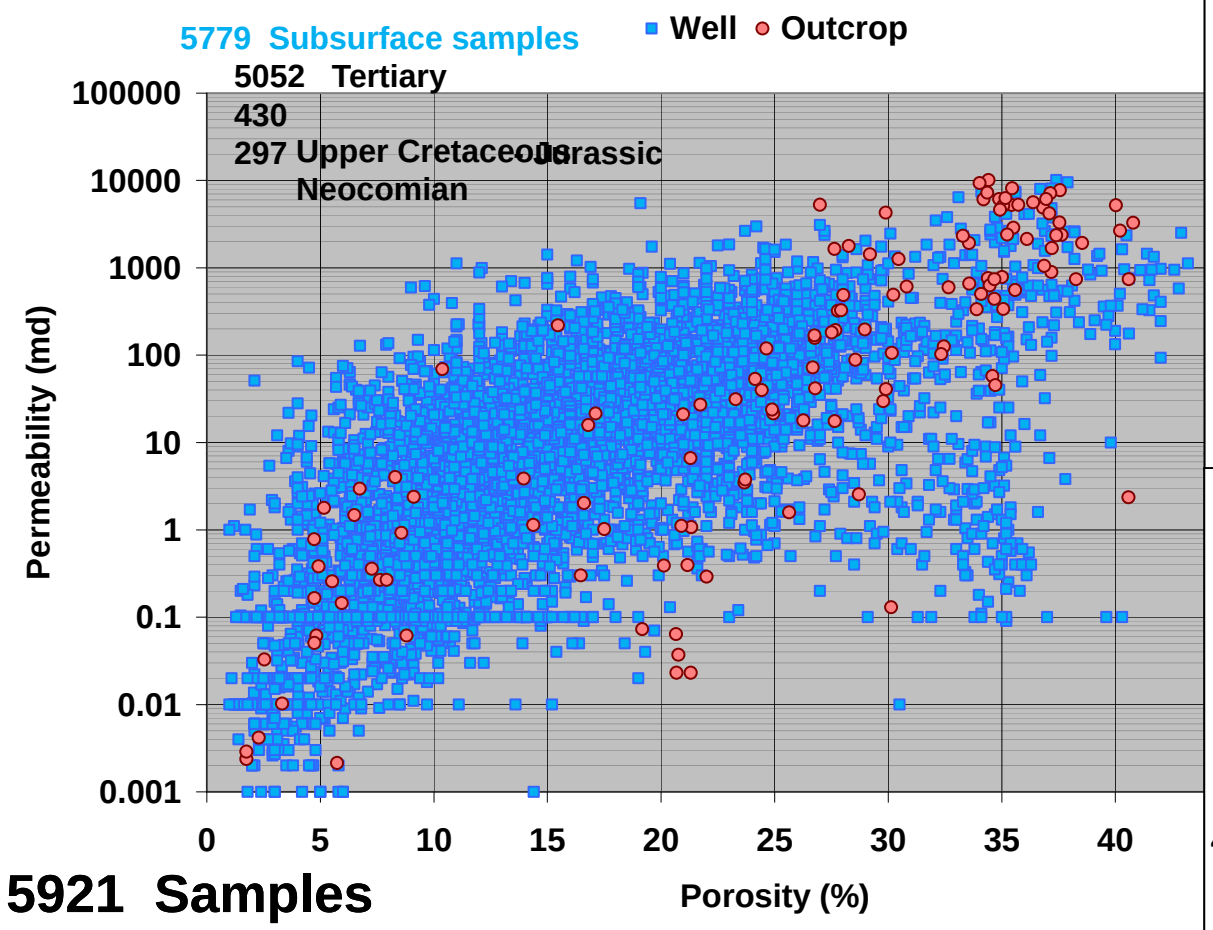


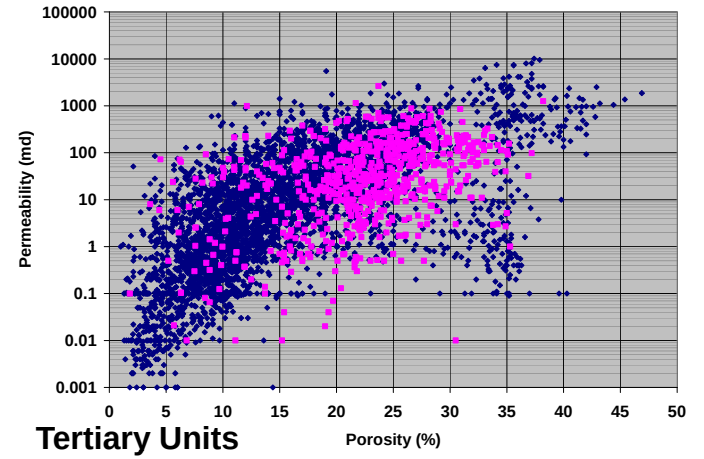
1. Beluga Fm. shows vertical provenance transition from SRF-rich Middle Beluga (Fritz CK) to mixed SRF-VRF Upper Beluga (Bidarki Ck)
2. Sterling Fm. shows vertical provenance transition from mixed SRF-VRF lower Sterling (Falls Ck) to VRF-rich upper Sterling (Clam Gulch)

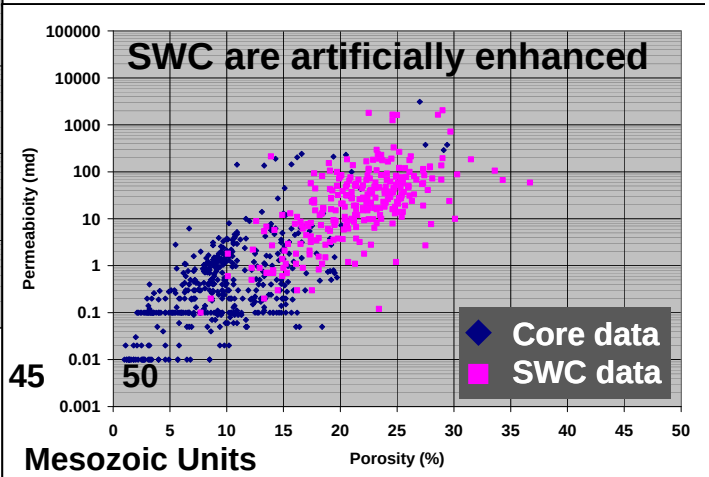
Outcrop Reservoir Quality



Routine Core Analysis



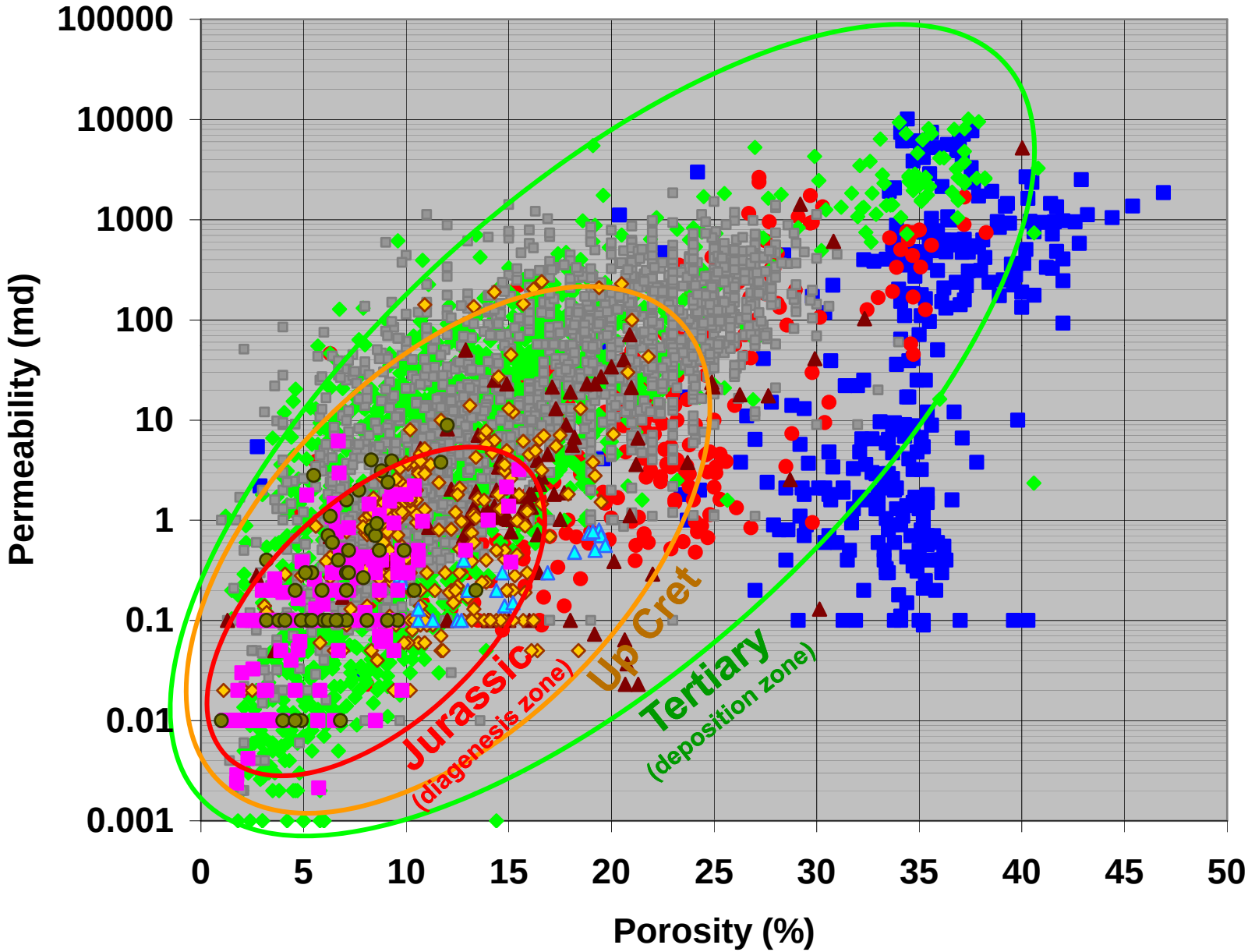




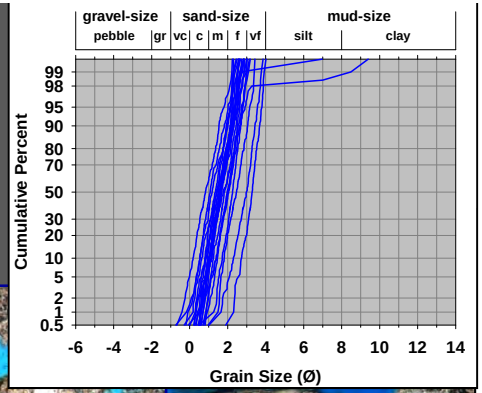
1. Core and outcrop data occupy similar Φ-K fields
2. Low-permeability Sterling sands plot off regional trend (facies or texture ?)
3. Well data include conventional and sidewall core data

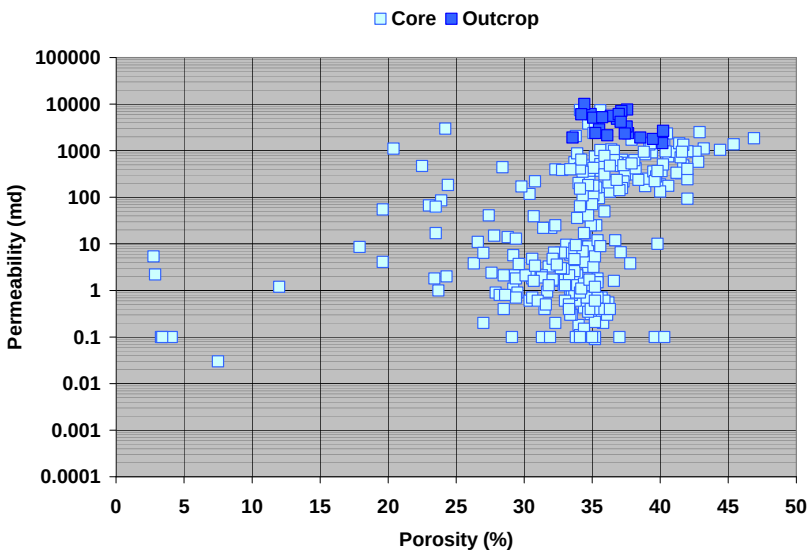
1. Mesozoic core + SWC data overlie Tertiary data
2. Fair – moderate overlap between Tertiary core and SWC data
3. Poor overlap between Mesozoic core and SWC data

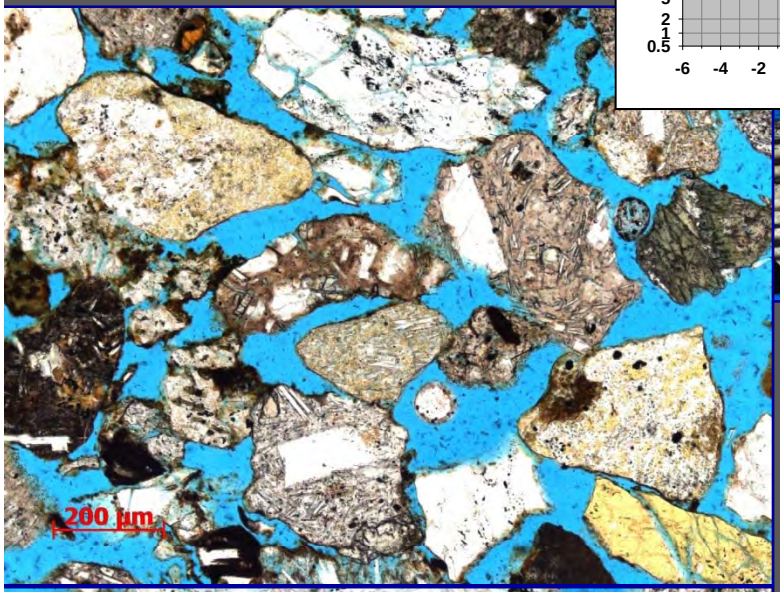
Reservoir Quality by Formation

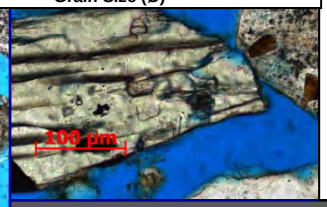


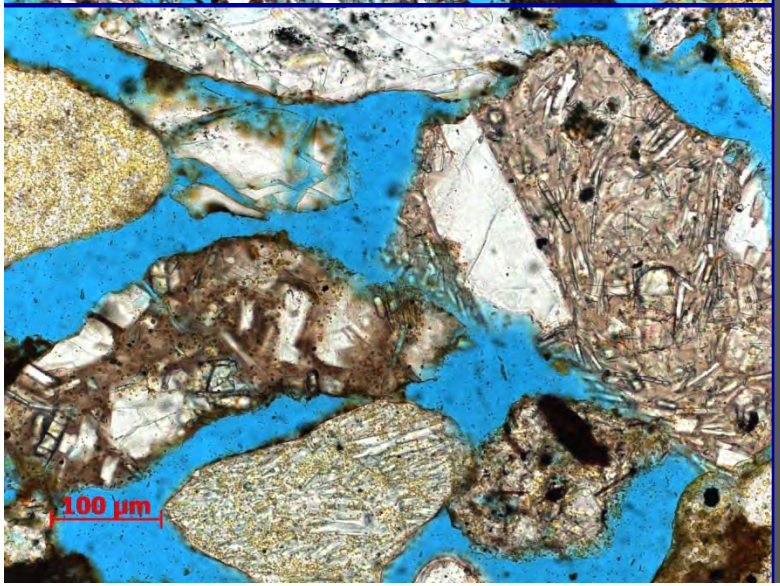
Sterling Formation





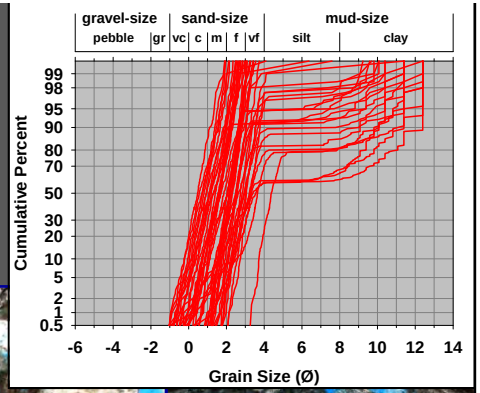


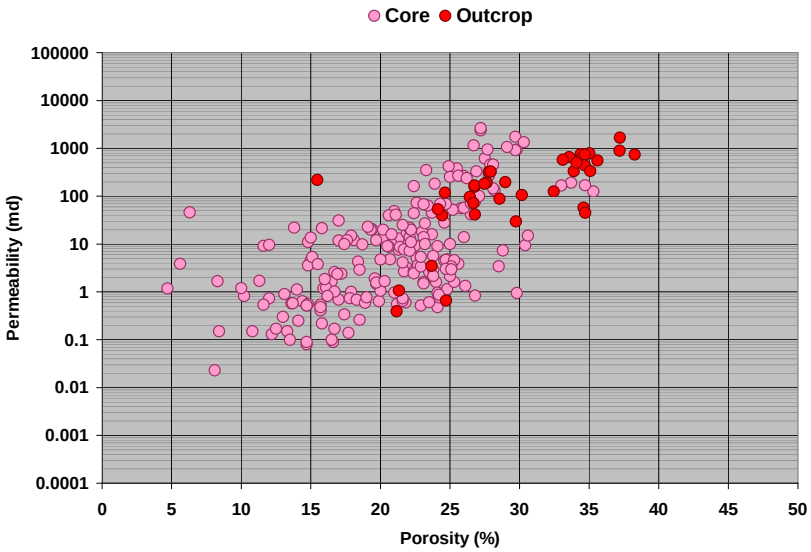


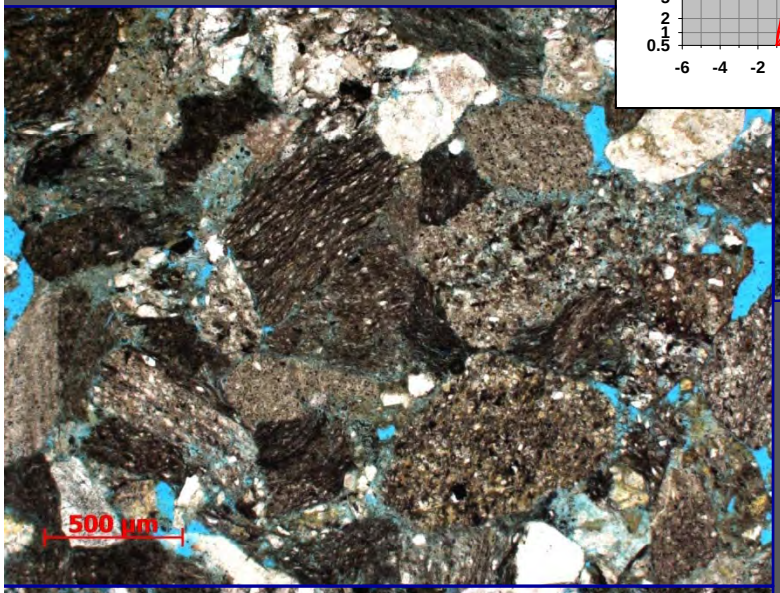


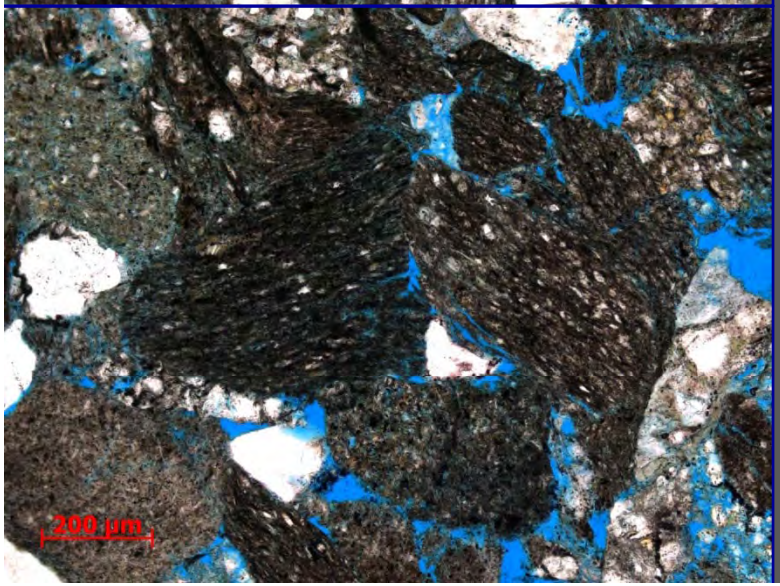
Grain Size:	0.31 mm (mL)
Sorting:	0.55 (mod)
Porosity:	36.3 %
Permeability:	4,548 md
Intergran vol:	30.6 % (minor compaction)
Total Clay:	1.7 %
Total Cement:	0.8%
Mineralogy:	volcanic RF (interm – mafic), plag, K-spar , hornblende, basaltic hornblende, little qtz.
Provenance:	volcanic arc ?
Diagenesis:	Very good RQ, potential problems with mod – deep burial

Beluga Formation



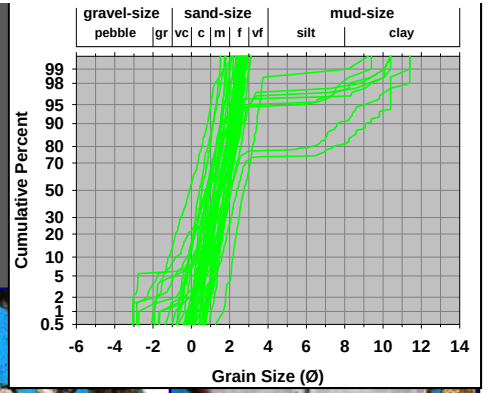


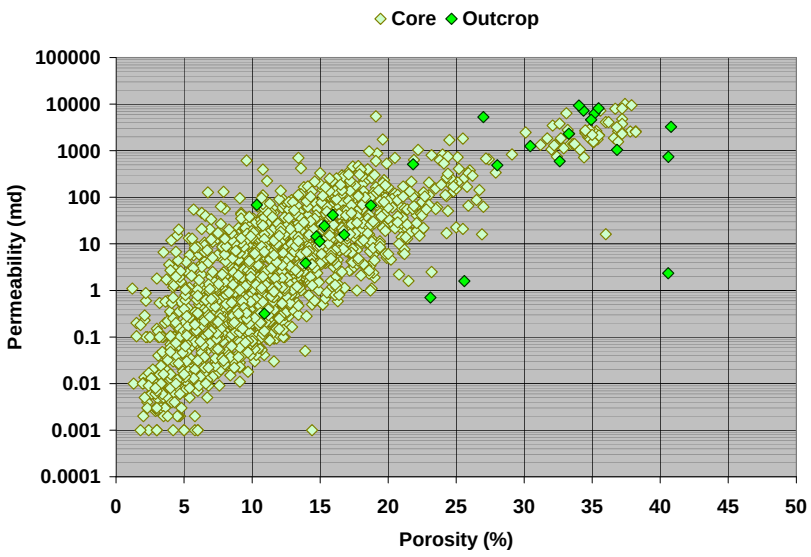


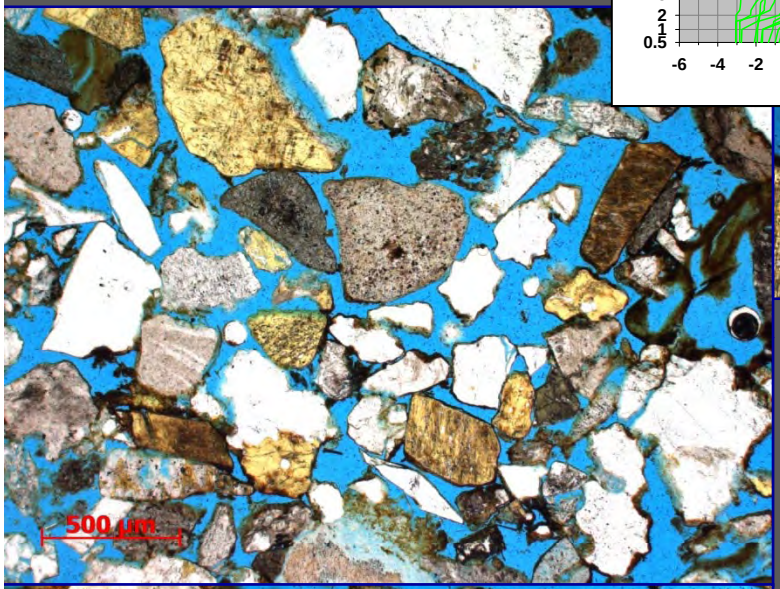


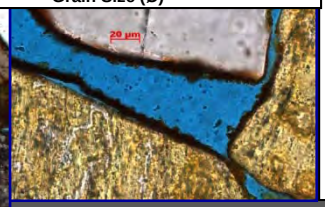
Grain Size:	0.26 mm (mL)
Sorting:	1.27 (poor)
Porosity:	30.0 % (not all effective)
Permeability:	331.8 md
Intergran vol:	22.0 % (mod. Compaction)
Total Clay:	7.7 %
Total Cement:	1.7 %
Mineralogy:	Argillaceous SRF & MRF, minor quartz, K-spar, chert, plagioclase
Provenance:	accretionary prism
Diagenesis:	potential for mega ductile grain deformation, little cement, fair RQ

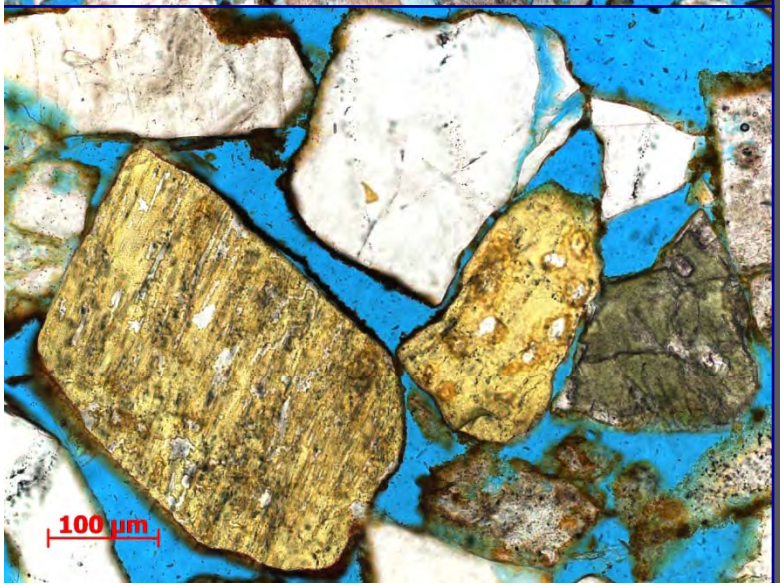
Tyonek Formation





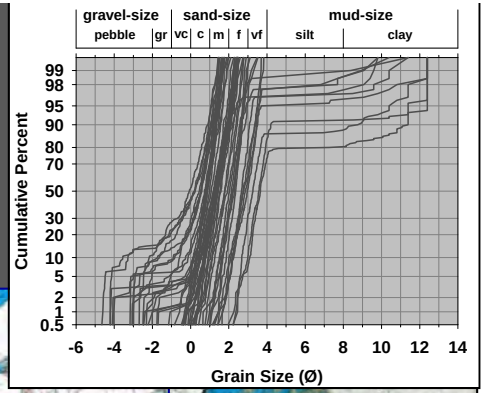


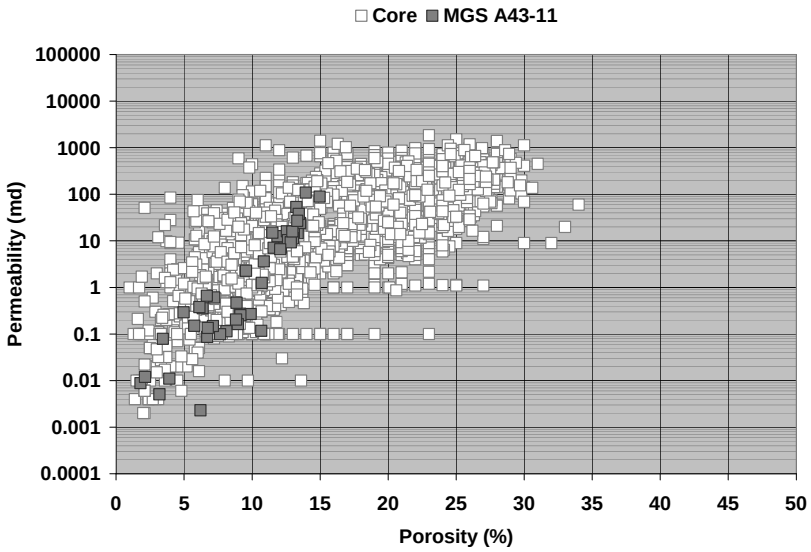


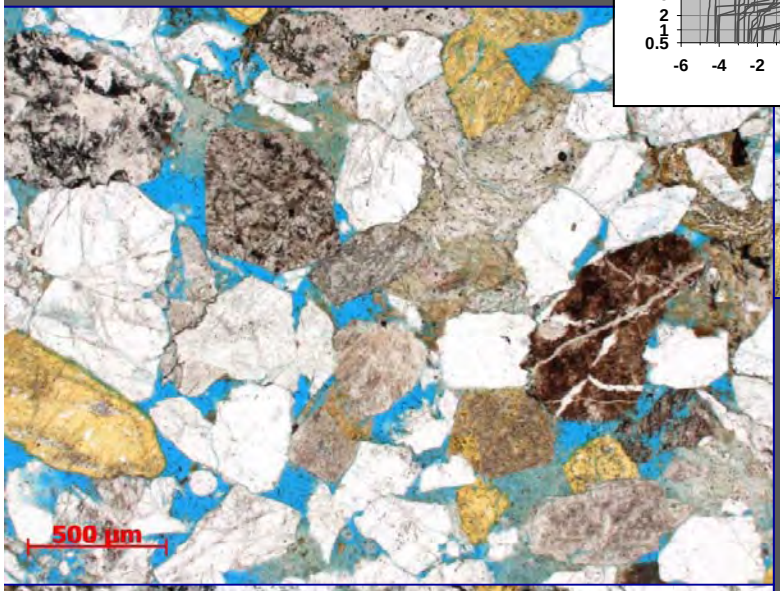


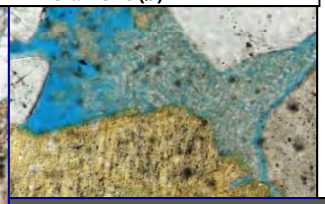
Grain Size:	0.39 mm (mU)
Sorting:	0.82 (mod)
Porosity:	25.3 %
Permeability:	1,755 md
Intergran vol:	23.2 % (mod. compaction)
Total Clay:	6.0 %
Total Cement:	3.0 %
Mineralogy:	quartz, K-spar, plagioclase, PRF, chert, argillaceous SRF & MRF, biotite
Provenance:	dissected arc plutons, metamorphic cover
Diagenesis:	good RQ, chlorite/smectite rims, kaolinite pore-fills, little cement

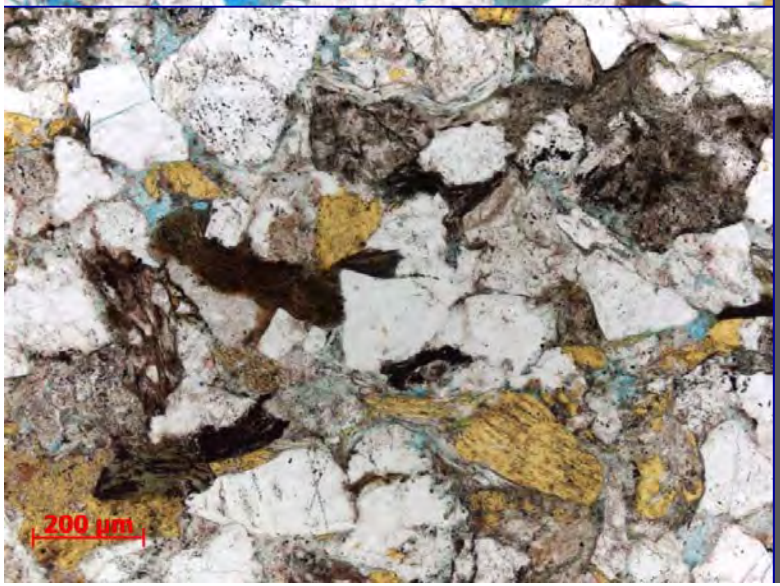
Hemlock Formation





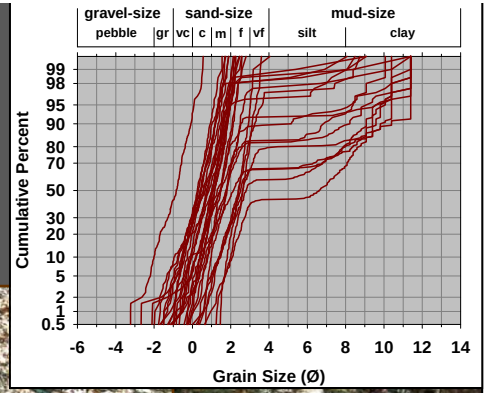


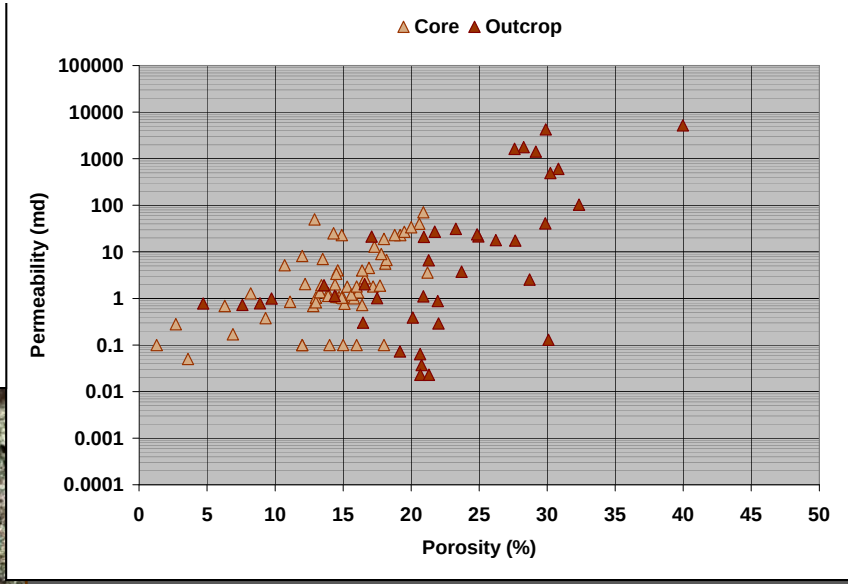




Grain Size:	0.45 mm (mU)
Sorting:	1.04 (poor)
Porosity:	16.0 %
Permeability:	94 md
Intergran vol:	11.5 % (significant compaction)
Total Clay:	5.1 %
Total Cement:	2.9 %
Mineralogy:	quartz, K-spar, plagioclase, PRF, chert, argillaceous SRF & MRF, biotite
Provenance:	dissected arc plutons, metamorphic cover
Diagenesis:	mod. - good RQ, compaction, chlorite/smectite rims, kaolinite

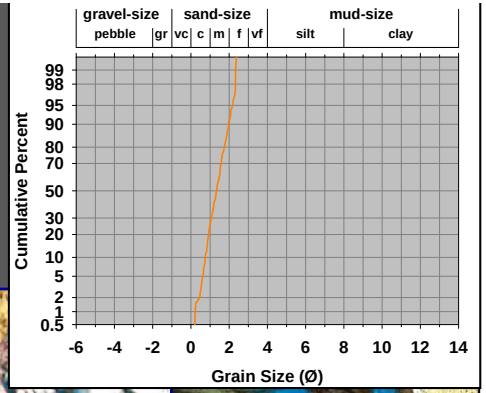
W Foreland Formation

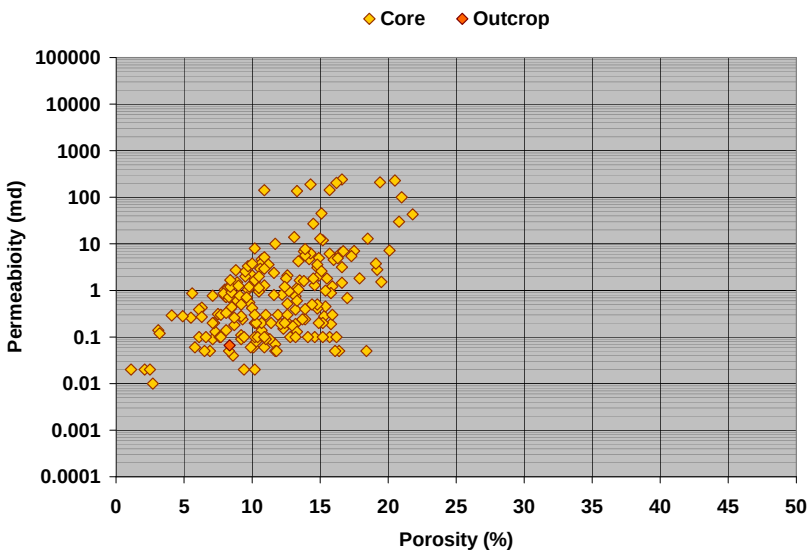


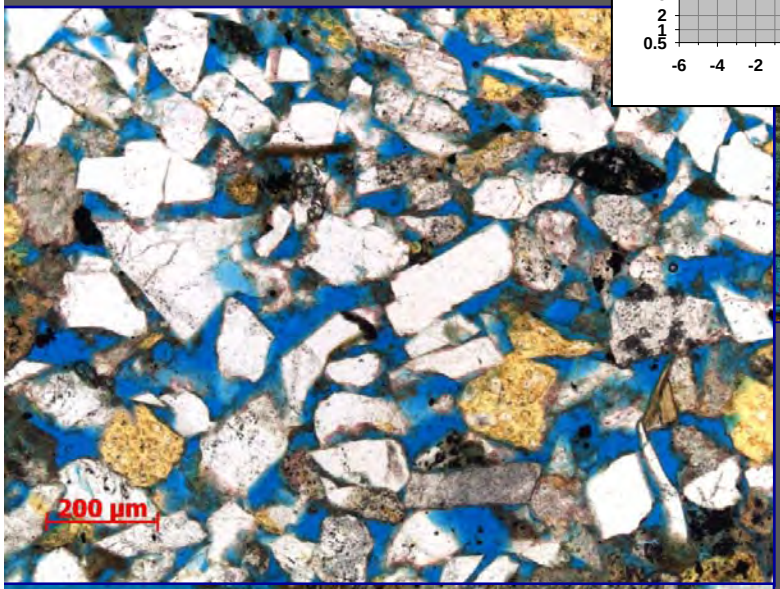


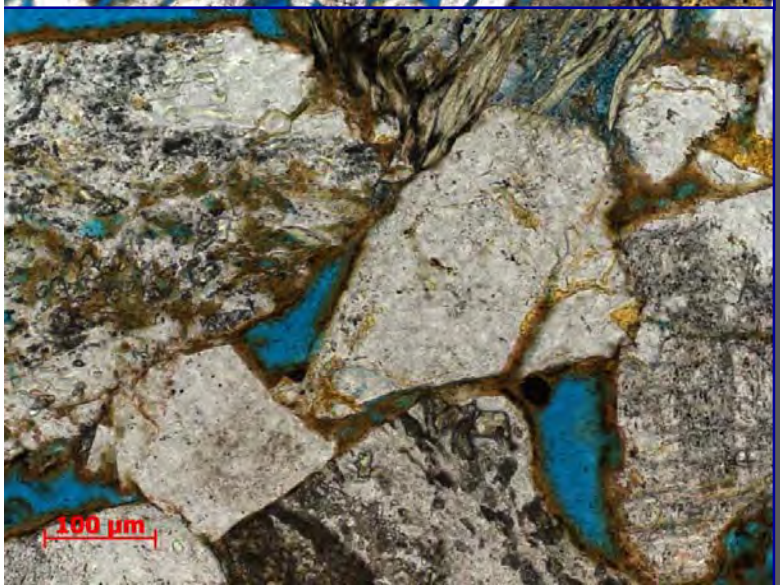
Grain Size:	0.45 mm (mU)
Sorting:	1.41 (poor)
Porosity:	21.9 % (not all effective)
Permeability:	259 mm d
Intergran vol:	28.0 % (early clays & zeolites)
Total Clay:	17.3 %
Total Cement:	7.7 % (zeolites)
Mineralogy:	VRF (interm - mafic), plag, hornblende, basaltic Hb, biotite, pumice, shards, minor qtz
Provenance:	volcanic arc
Diagenesis:	clinoptilolite, chlorite/smectite rims and pore fills

Kaguyak Formation



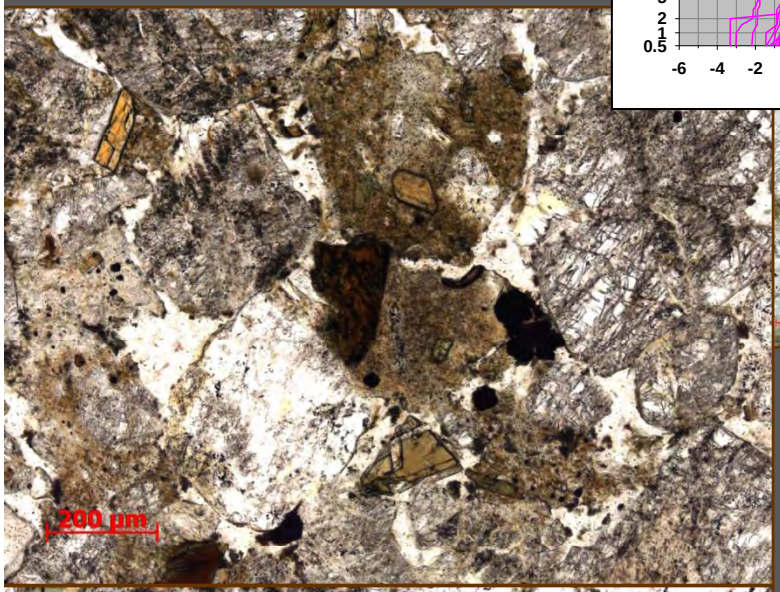


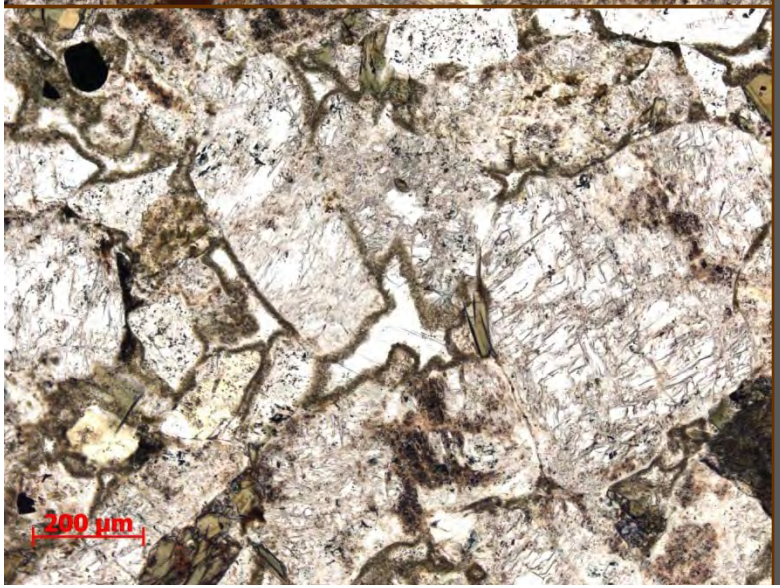


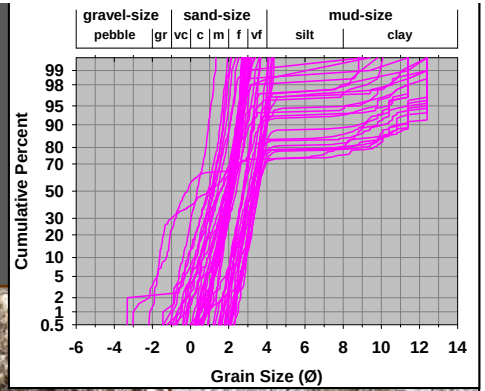


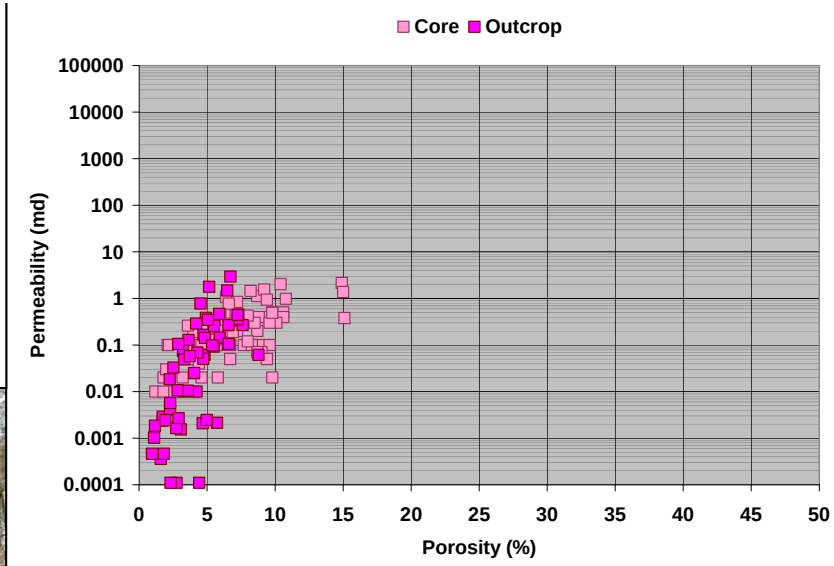
Grain Size:	0.49 mm (mU)
Sorting:	1.25 (poor)
Porosity:	11.4 %
Permeability:	8.2 md
Intergran vol:	27.0 % (mod. compaction)
Total Clay:	12.0 %
Total Cement:	3.6 %
Mineralogy:	quartz, plagioclase, K-spar hornblende, VRF, PRF
Provenance:	dissected arc plutons and overlying volcanics
Diagenesis:	kaolinite, chlorite/smectite, ductile VRF's, fair - mod RQ

Naknek Formation



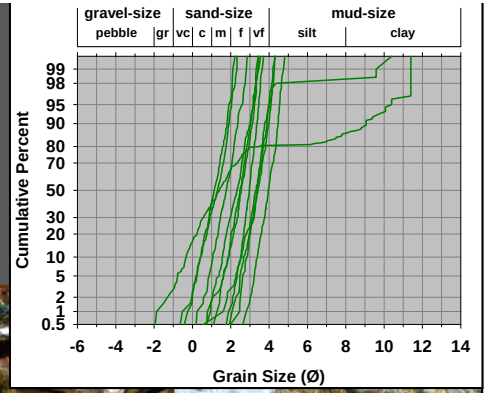


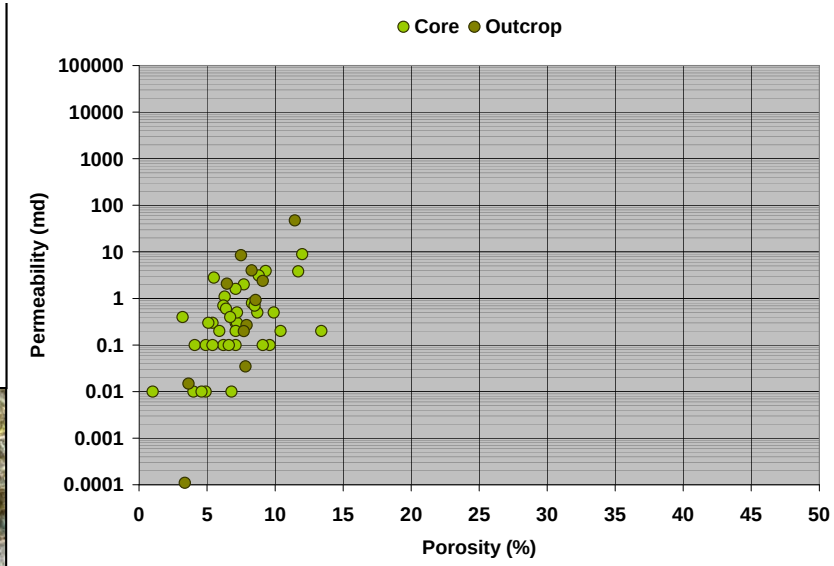


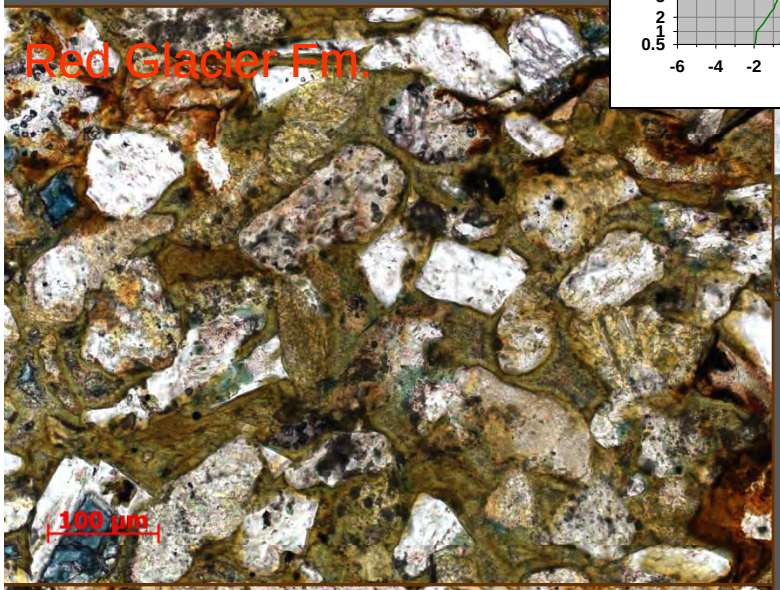


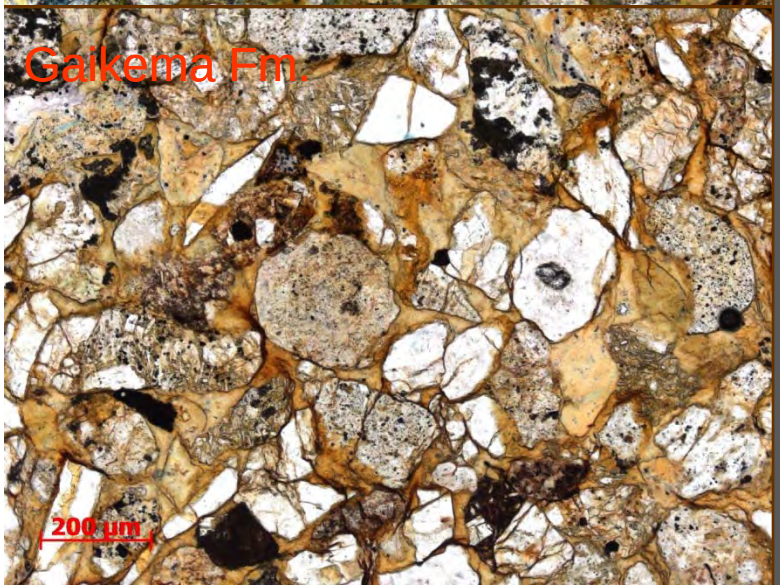
Grain Size:	0.22 mm (fU)
Sorting:	1.23 (poor)
Porosity:	4.1 %
Permeability:	0.21 md
Intergran vol:	24.2 % (extensive zeolites)
Total Clay:	6.5 %
Total Cement:	18.2 % (zeolites)
Mineralogy:	plagioclase, hornblende, bas. Hb, ilmenite/magnetite, little quartz
Provenance:	dissected arc plutons
Diagenesis:	laumontite, heulandite, authigenic chlorite/smectite or chlorite, poor RQ

Tuxedni Group









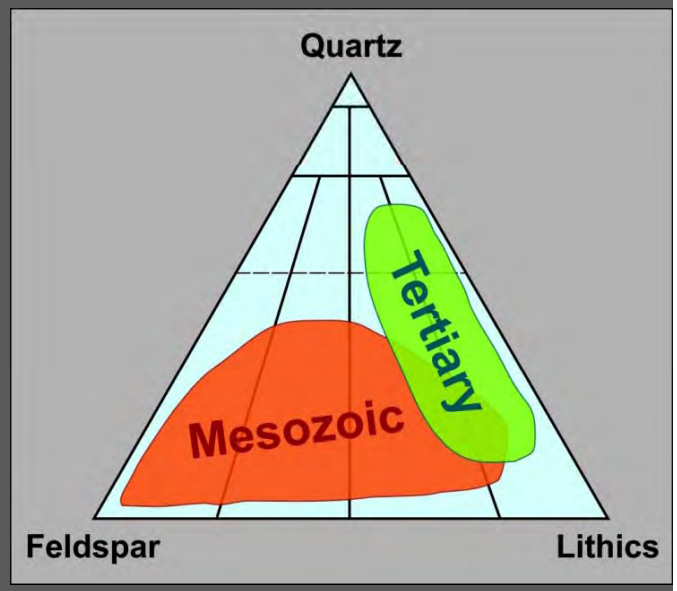
Grain Size:	0.20 mm (fU)
Sorting:	0.81 (mod)
Porosity:	7.5 % (little effective ϕ)
Permeability:	5.9 md
Intergran vol:	35.6 % (extensive clay cement)
Total Clay:	21.9 %
Total Cement:	16.7 % (zeolites)
Mineralogy:	volcanic RF (felsic - interm), altered VRF, plagioclase, min. qtz
Provenance:	volcanic arc
Diagenesis:	Authigenic pore-filling clay, chlorite/smectite, chlorite, laumontite, heulandite, poor RQ

The Rich Get Richer...

R.G. Loucks, TX BEG

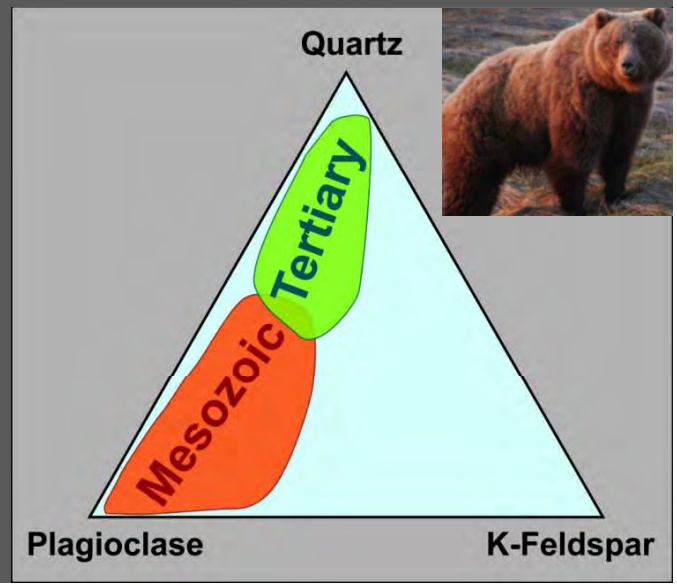
Tertiary & Up. Cret. Sandstones – Rich guys (deposition zone)

- Young age (< 65 million years old)
- Shallow burial (< 10,000 feet)
- Chemically stable mineralogy (Quartz + K-feldspar)



Mesozoic Sandstones – Poor guys (diagenesis zone)

- Old age (> 65 million years old)
- Deep burial (> 10,000 feet)
- Chemically unstable mineralogy (Plagioclase + VRF's)
- Enhanced potential for unconventional reservoirs



Conclusions

- Tertiary & Mesozoic sandstones have distinct differences in mineralogy due to variations in provenance (accretionary prism vs. arc)
- Vertical and possible lateral variations in provenance exist in the Tertiary sandstones
- 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

- Continue collecting petrographic data from outcrops and the subsurface
- Construct 1D burial histories for subsurface samples using Tertiary erosion estimates
- Combine time-temperature-pressure and modal data to construct forward diagenetic models
- Combine static diagenetic models to produce regional maps of reservoir quality (porosity, permeability, IGV, cement)

The End