Deep-Water Canyons in the Snug Harbor Siltstone and Pomeroy Arkose Members, Naknek Formation, Alaska—New Insights into the Sequence Stratigraphy of the Late Jurassic Cook Inlet Forearc Basin

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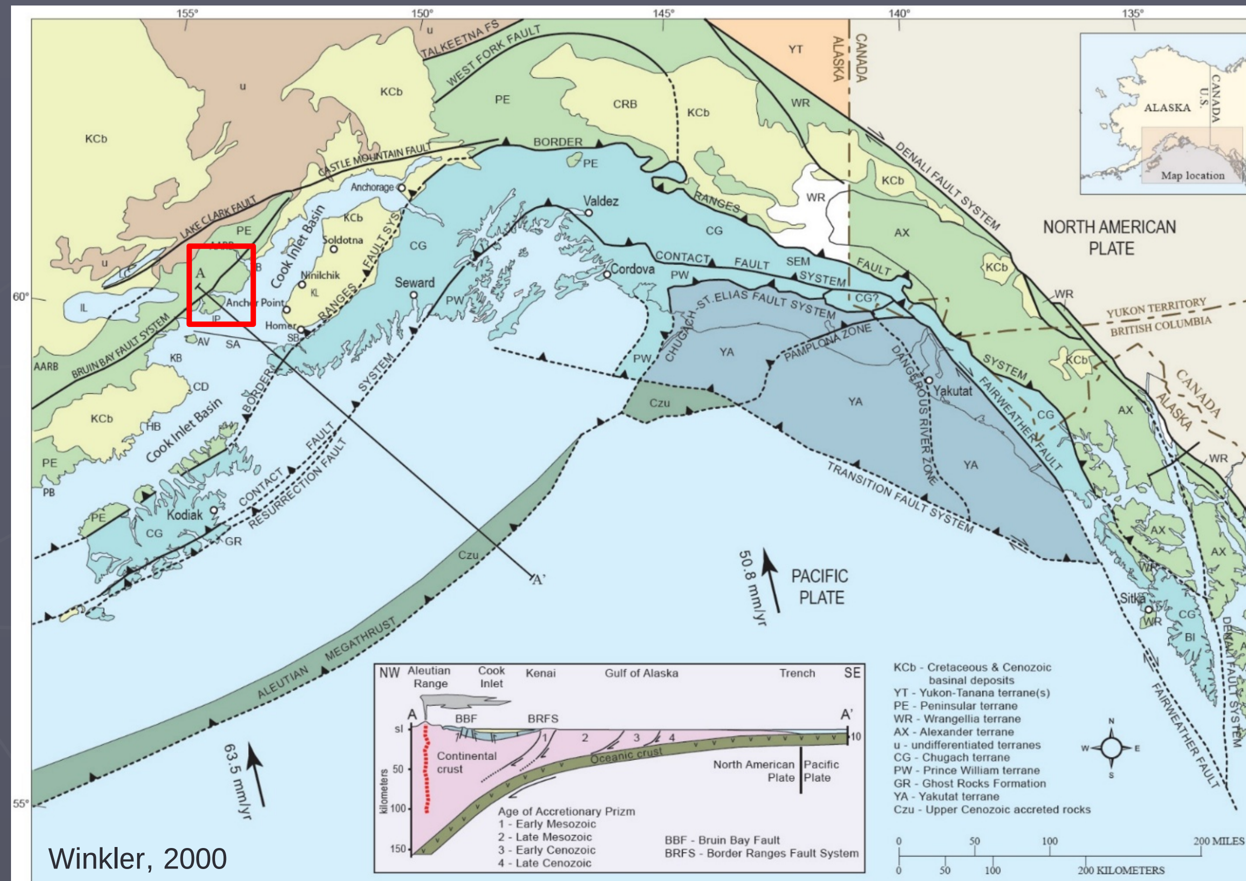
Abstract

Recent field studies of Upper Jurassic strata in lower Cook Inlet yield insights into the depositional environments, stacking architecture, and sequence stratigraphy of the forearc basin margin. In the Iniskin Peninsula area, the Naknek Formation is >1300 m thick, comprising four members (in ascending order): Chisik Conglomerate (fan delta), lower sandstone (shelf), Snug Harbor Siltstone (outer shelf and slope), and Pomeroy Arkose (base of slope to basin floor). Outcrop-based observations, including geologic mapping of an ~50-km-long outcrop belt, led to the discovery of two deep-water canyons in the Snug Harbor–Pomeroy interval. These km-scale canyons were incised into slope strata of Snug Harbor and host channelized to tabular fills of sandstone and mudstone to amalgamated sandstone successions that are hundreds of meters thick. The canyons—floored by unconformities overlain locally by boulder-bearing conglomerate—served as conduits through which sediment bypassed to the deep-water depositional system of the Pomeroy and were ultimately backfilled by onlapping elements of that system. We interpret the canyon floors as a sequence boundary that we tie to a correlative interval in inter-canyon areas; furthermore, candidate transgressive and maximum flooding surfaces are proposed at the base of and within Snug Harbor, respectively. These three surfaces envelope a transgressive systems tract (lower Snug Harbor) and a highstand systems tract (mid-Snug Harbor) and define the base of a deep-water lowstand systems tract (upper Snug Harbor and lower Pomeroy). The Snug Harbor transgressive surface caps the basal Naknek members—Chisik and lower sandstone (in part lateral equivalents)—that likely comprise a lowstand systems tract overlying the Middle Jurassic Chinitna Formation along a sequence boundary. Thus, a complete, probable third-order (m.y.-scale duration) stratigraphic sequence occurs in the lower three members of the Naknek, with record of a renewed accommodation succession cycle lying above the canyon sequence boundary. This new sequence stratigraphic framework sheds predictive light on facies distribution in this part of the basin's underexplored petroleum system and renders a new play concept for Cook Inlet—coarse-grained canyon fill encased, at least in part, by fine-grained slope strata.

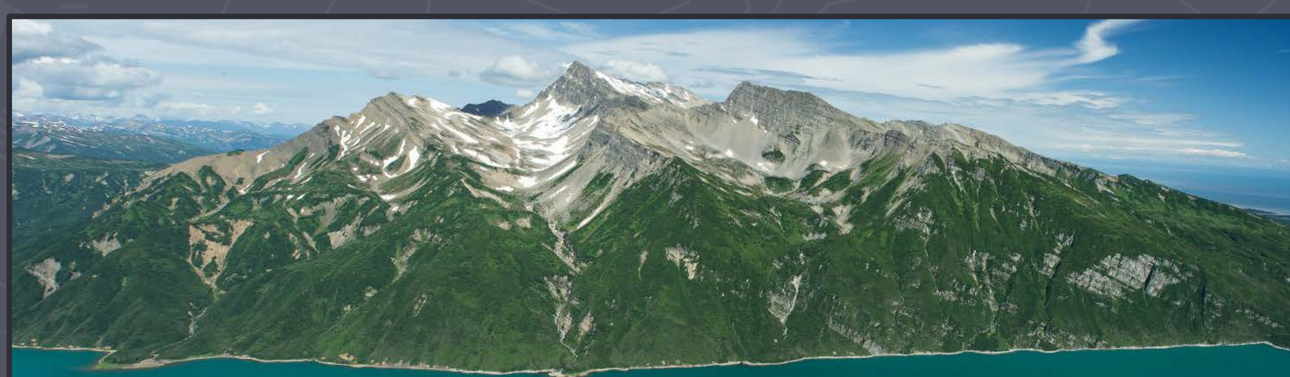
*Authors' note: these slides were presented at the Geological Society of America, Cordilleran Section Annual Meeting, 11–13 May 2015, Anchorage, Alaska.

Geologic Setting—Cook Inlet Forearc Basin

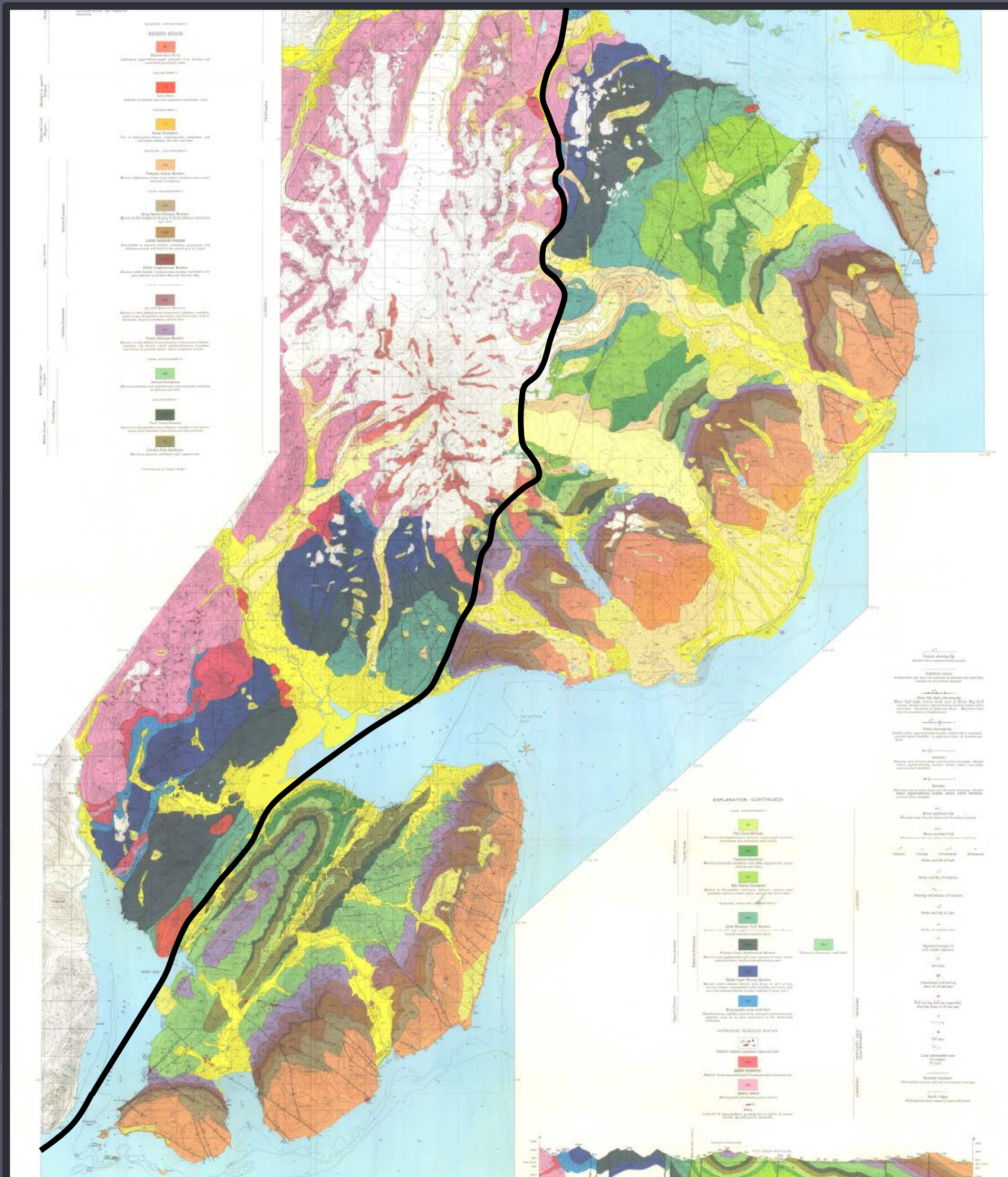
- Arc–forearc–accretionary wedge
- Cook Inlet forearc basin between BBFS and BRFS
  - ~200 m.y. record
- Jurassic stratigraphy exposed in the Iniskin–Tuxedni bays region
  - Naknek Formation
  - Chinitna Formation
  - Tuxedni Group
  - Talkeetna Formation



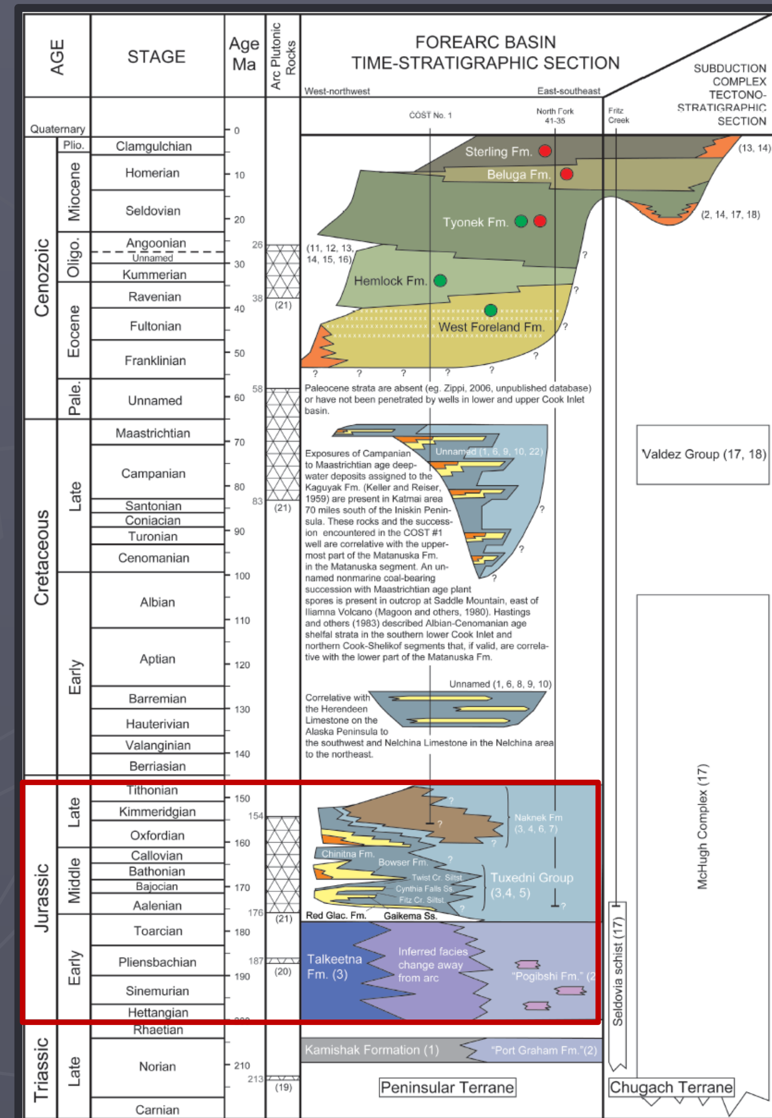
Winkler, 2000



Iniskin Bay–Tuxedni Bay Region—Study Area

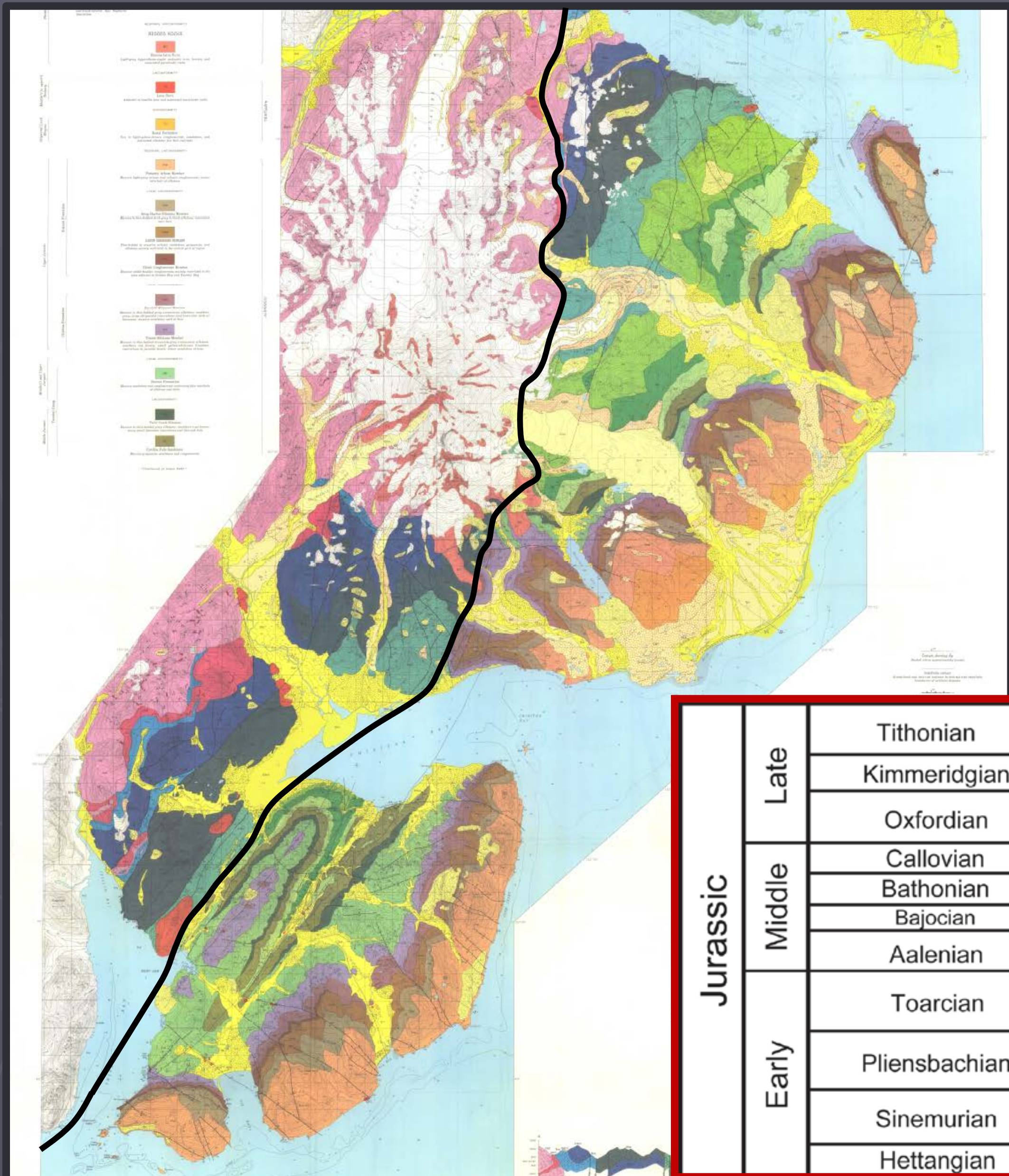


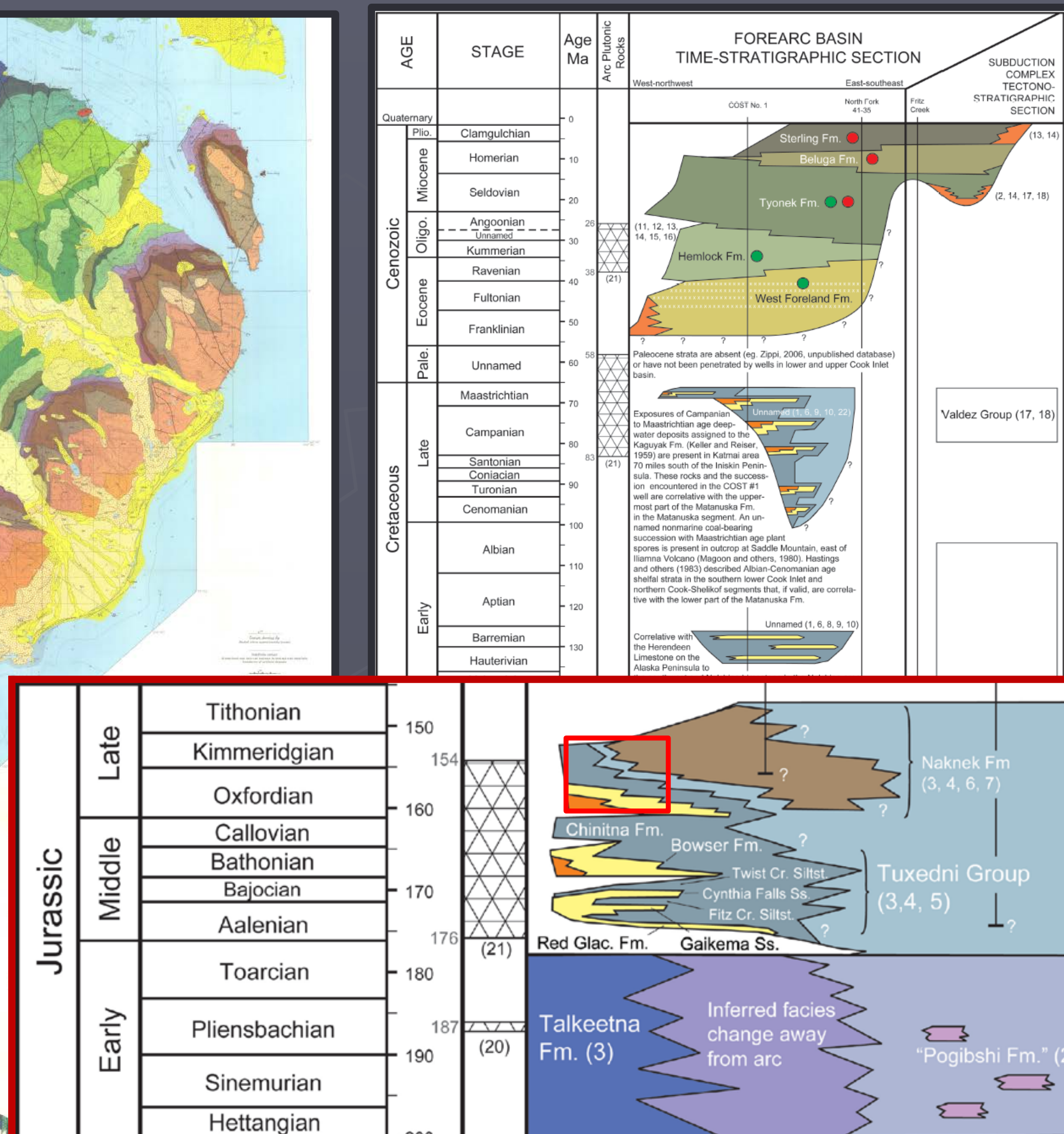
Detterman and Hartsock, 1966



LePain et al., 2013

Iniskin Bay–Tuxedni Bay Region—Study Area



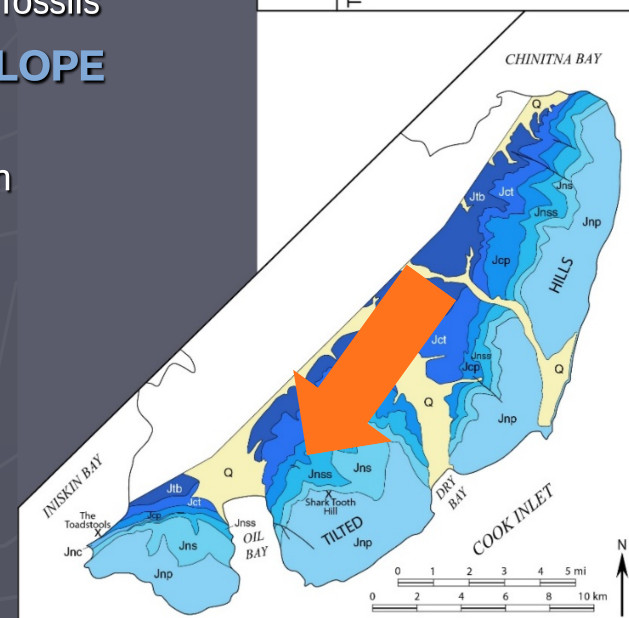


Naknek Formation

- Pomeroy Arkose (>900 m) : **BASE OF SLOPE and BASIN FLOOR**
  - Amalgamated sandstone and conglomerate, and siltstone
  - SGFD, DFD, MTD, locally channelized, dearth of trace and body fossils
- Snug Harbor Siltstone (~260 m): **OUTER SHELF and SLOPE**
  - Thin- to thick-bedded siltstone and very fine-grained sandstone
  - SGFD, DFD, locally channelized, moderate to sparse bioturbation
- lower sandstone (~240 m): **SHELF**
  - Thick-bedded, very fine- to fine-grained sandstone
  - HCS and SCS, diverse and abundant trace fossil assemblage

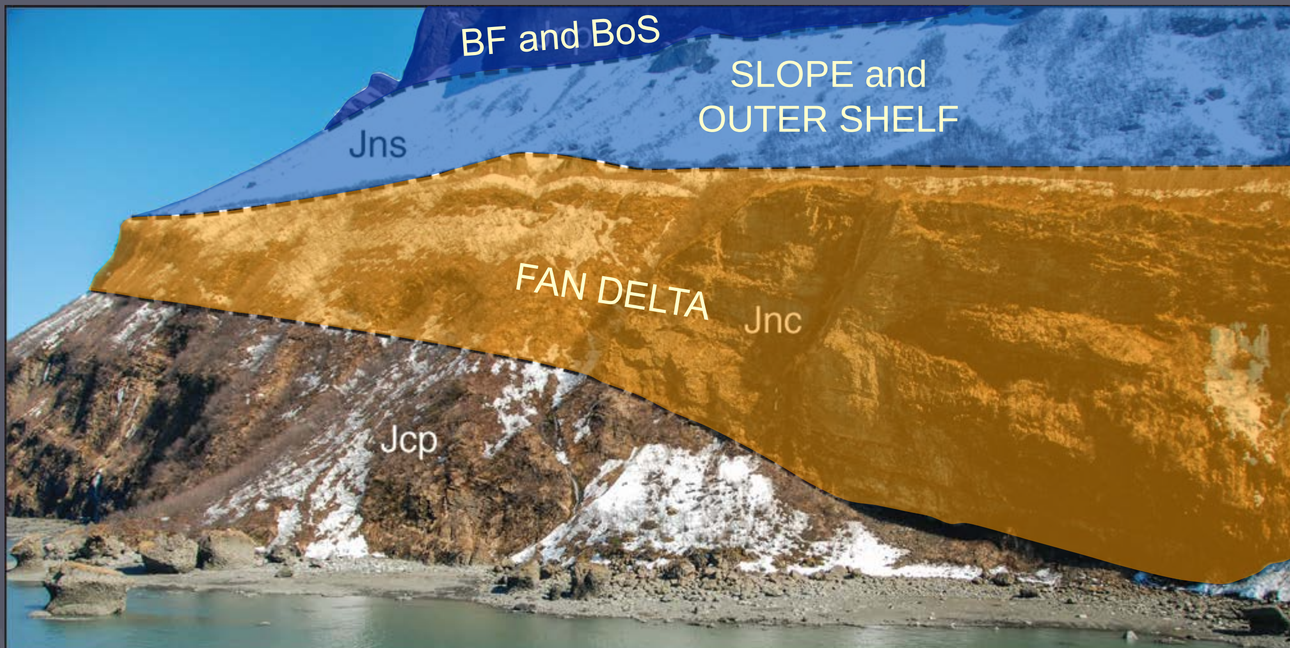
~~UNCONFORMITY~~

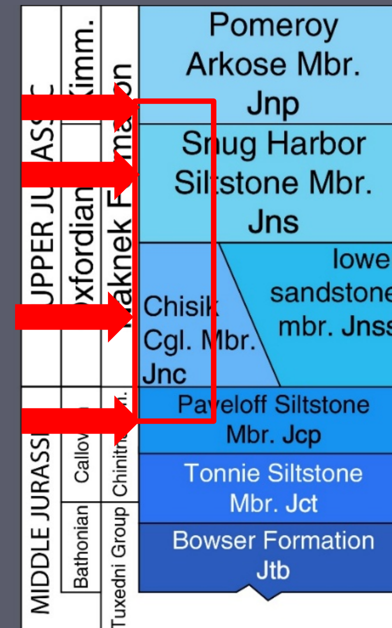
- Chinitna Formation

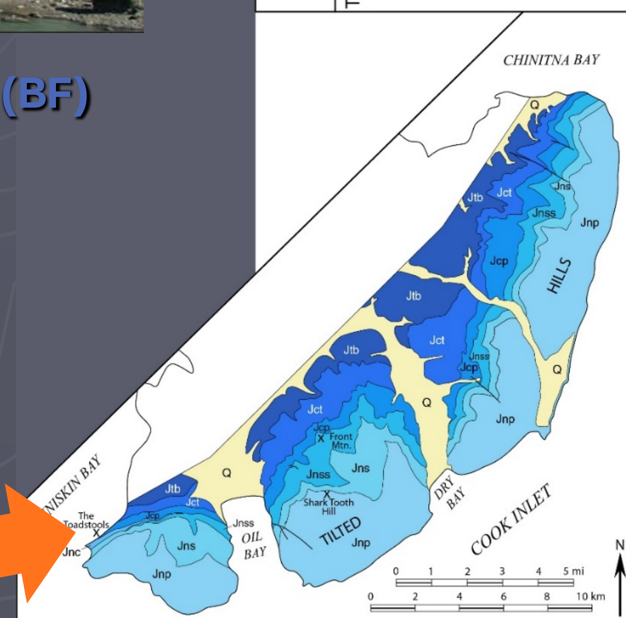


Naknek studies: Wartes et al., 2011, 2013, in press; LePain et al., 2013; Herriott and Wartes, 2014; Herriott et al., in preparation/this study

Naknek Formation







- Pomeroy: **BASE OF SLOPE (BoS)** and **BASIN FLOOR (BF)**
- Snug Harbor: **OUTER SHELF** and **SLOPE**
- Chisik (~100 m): **FAN DELTA**
  - Very thick-bedded conglomerate and sandstone
  - Locally cross-stratified, poorly sorted, belemnite-bearing

~~UNCONFORMITY~~

- Chinitna Formation

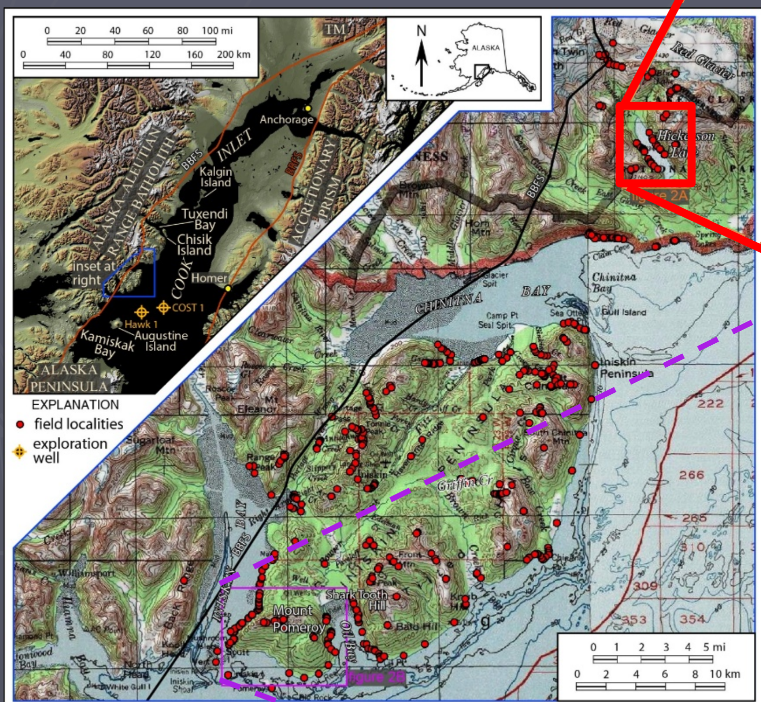
Naknek studies: Wartes et al., 2011, 2013, in press; LePain et al., 2013; Herriott and Wartes, 2014; Herriott et al., in preparation/this study

Snug Harbor Siltstone–Pomeroy Arkose Stacking: Typical

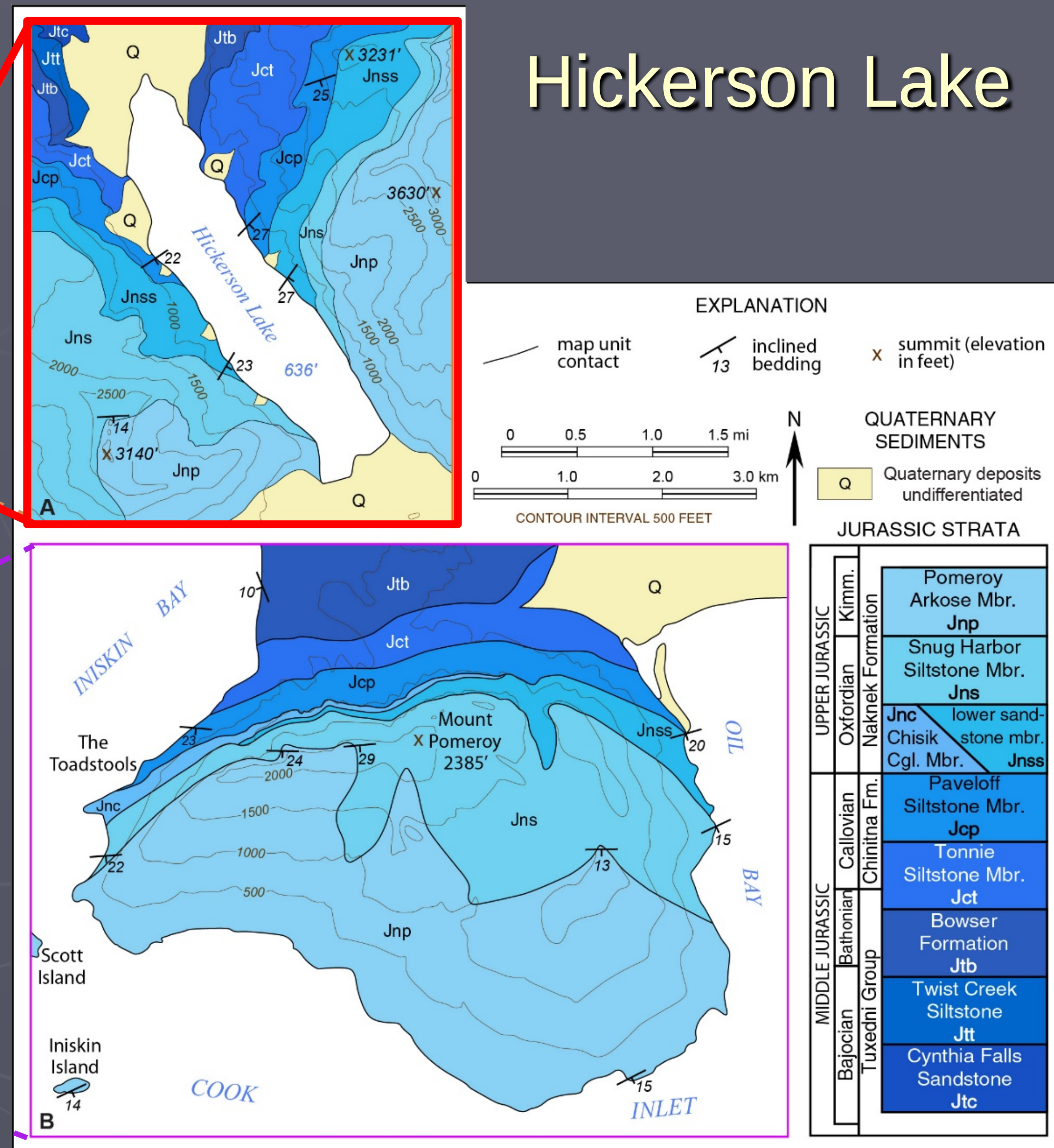
- Uppermost Snug Harbor is lithologically gradational to Pomeroy
  - Very thick arkoses are Pomeroy facies, but subordinate to Snug Harbor facies
- Contact is abrupt and conformable
  - Mapped at onset of amalgamated arkosic sandstone
  - Stratal onlap not observed

Snug Harbor Siltstone–Pomeroy Arkose Stacking: Atypical

Lithostratigraphic "containers" at Hickerson Lake & Mount Pomeroy

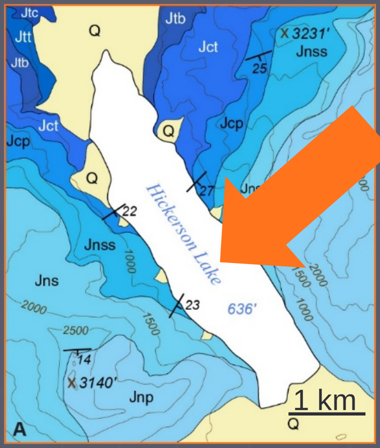


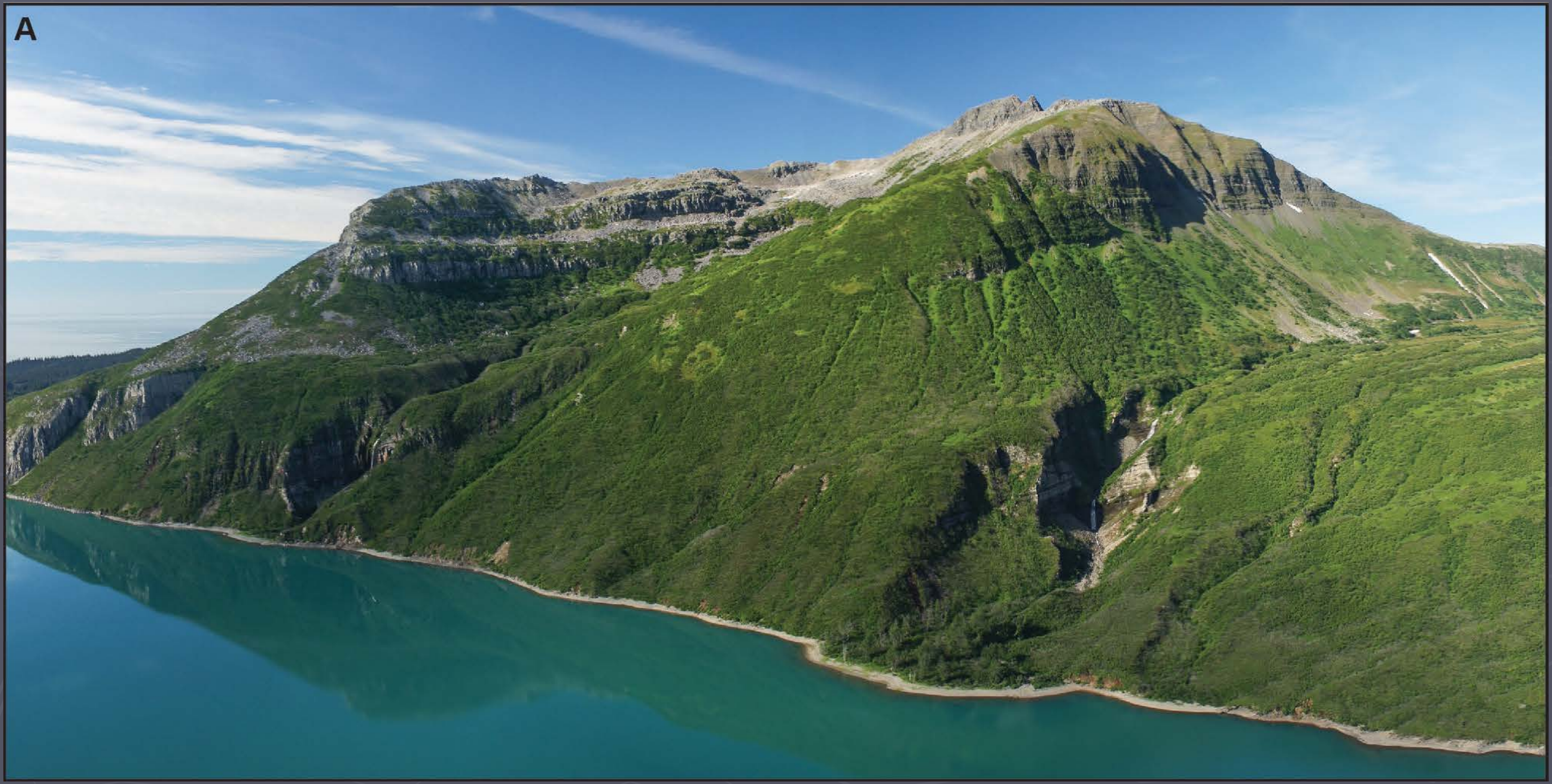
Hickerson Lake



Hickerson Lake Area

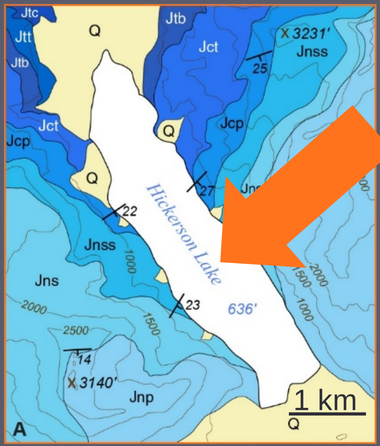
- Approximately strike-parallel view
- Snug Harbor "transitions" into Pomeroy

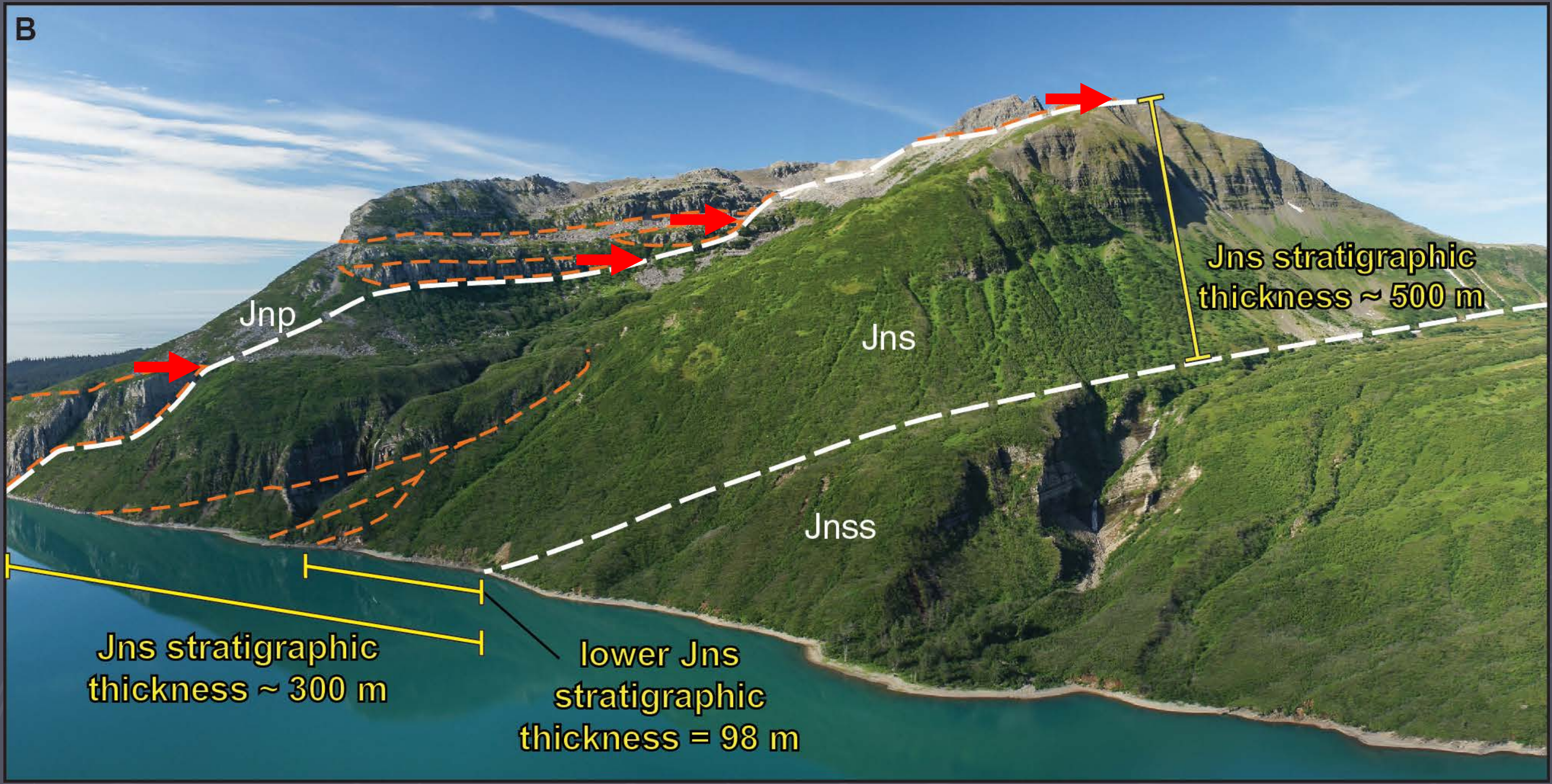




Hickerson Lake Area

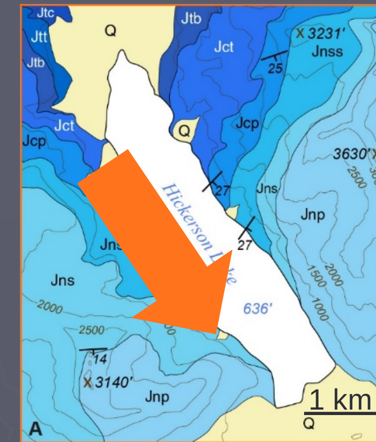
- ~200 m of lithostratigraphic relief at Jns–Jnp contact
  - Onlap of Jnp channelform strata onto Jns
- Upper ~200 m of Jns:
  - Channelform in part; coarser-grained and thicker-bedded than typical Jns

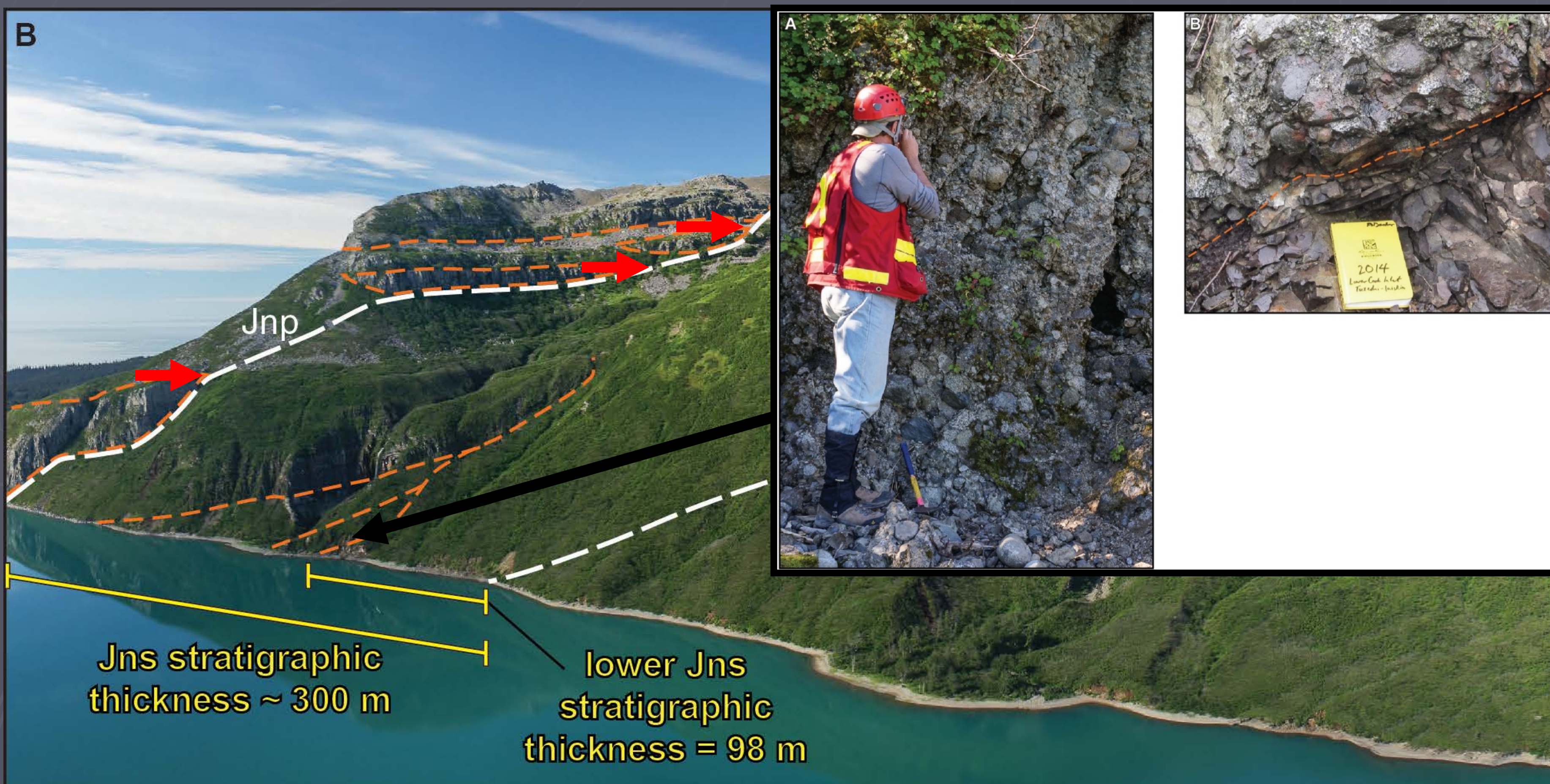




Hickerson Lake Area

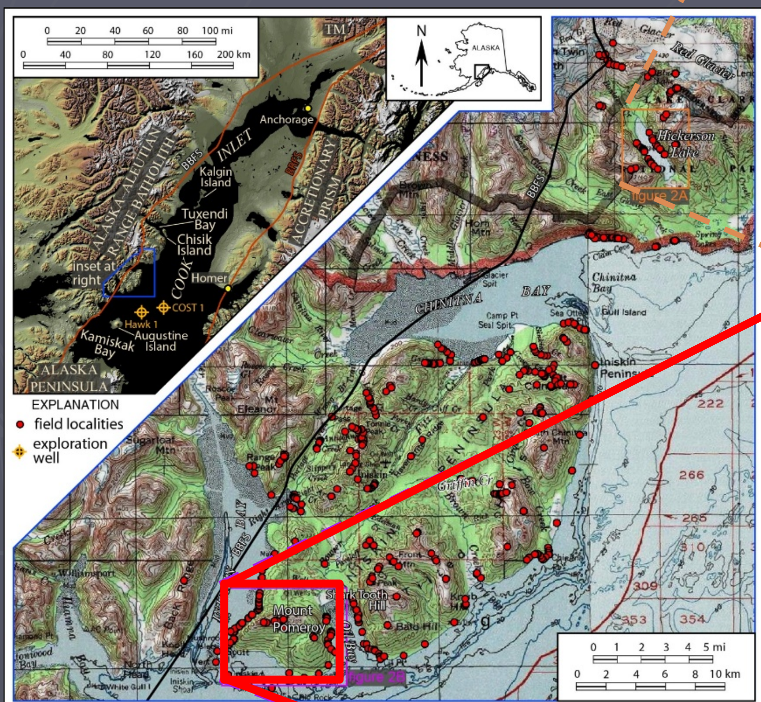
- ~200 m of lithostratigraphic relief at Jns–Jnp contact
  - Onlap of Jnp channelform strata onto Jns
- Upper ~200 m of Jns:
  - Channelform in part; coarser-grained and thicker-bedded than typical Jns
  - Conglomerate at base
- Complex "container" margin

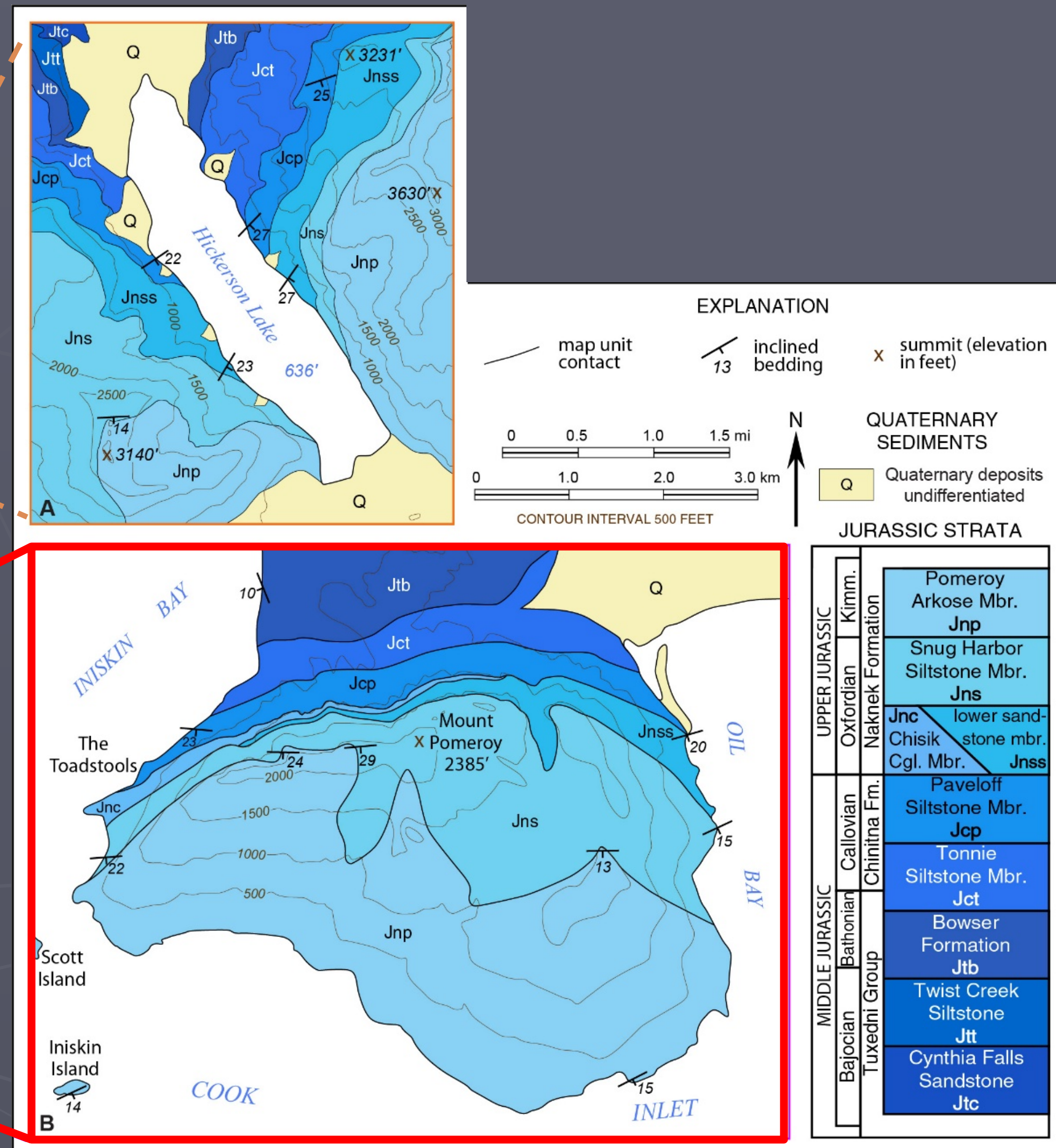




Snug Harbor Siltstone–Pomeroy Arkose Stacking: Atypical

Lithostratigraphic "containers" at Hickerson Lake & Mount Pomeroy

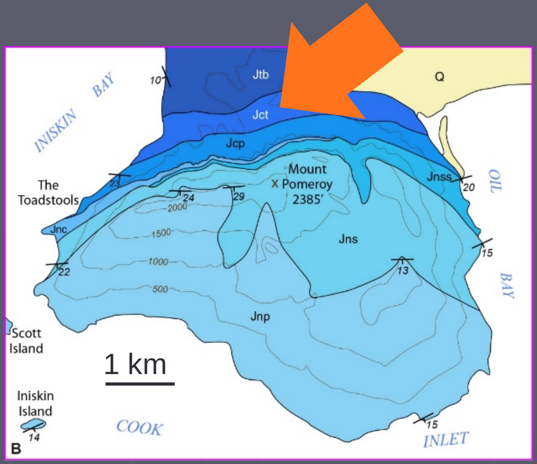


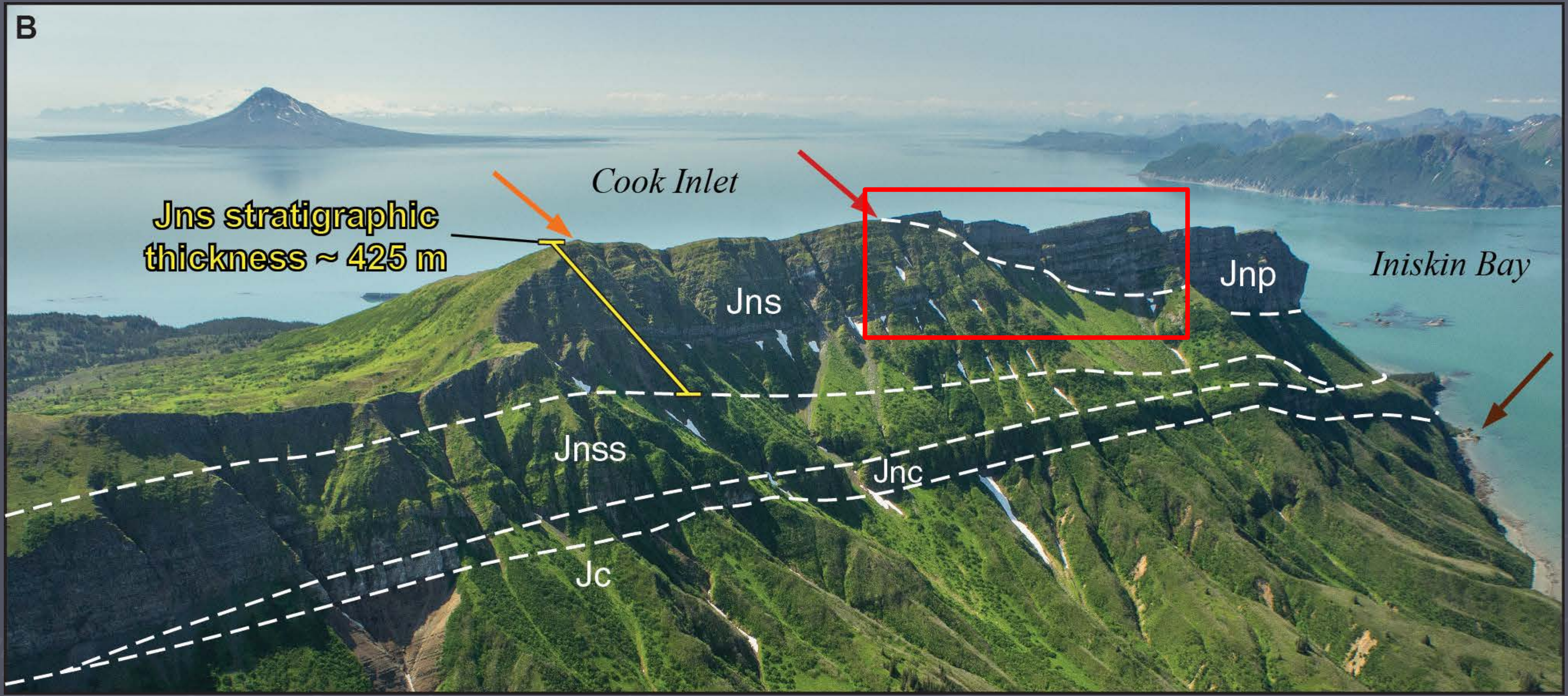


Mount Pomeroy

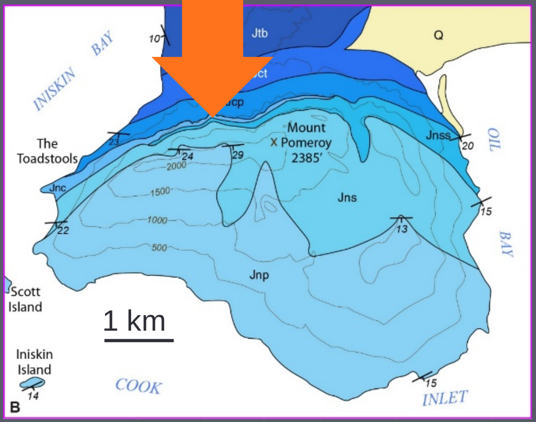
Mount Pomeroy Area

- ~425 m of Jns at Mount Pomeroy
- Jns "transitions" along strike into Jnp
- Marked lithostratigraphic relief along Jns–Jnp contact

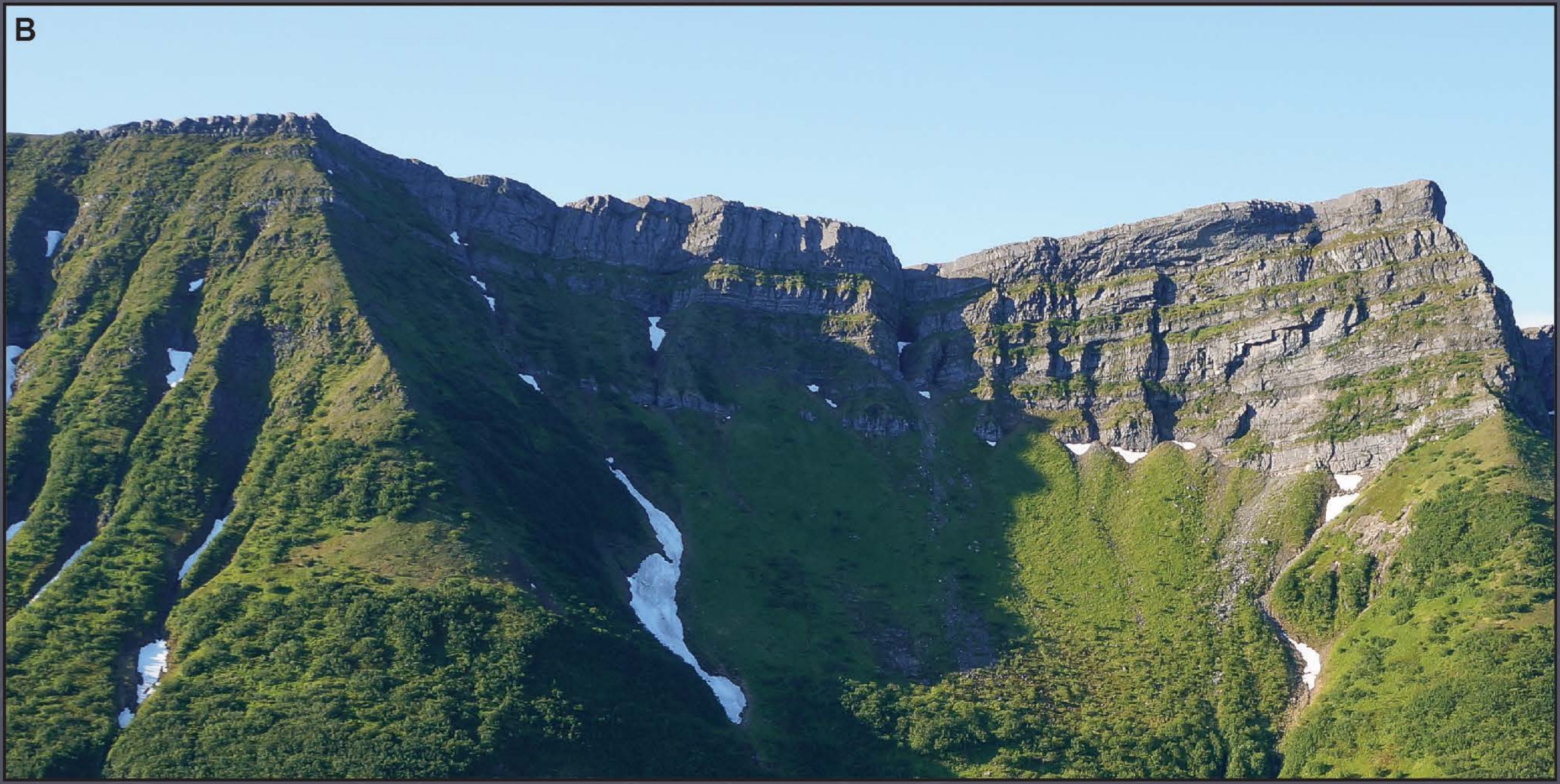




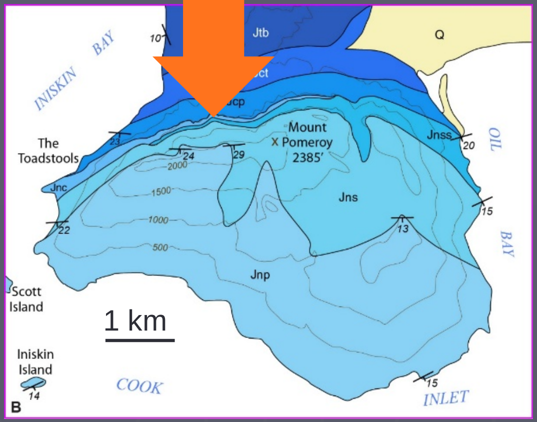
Mount Pomeroy Area



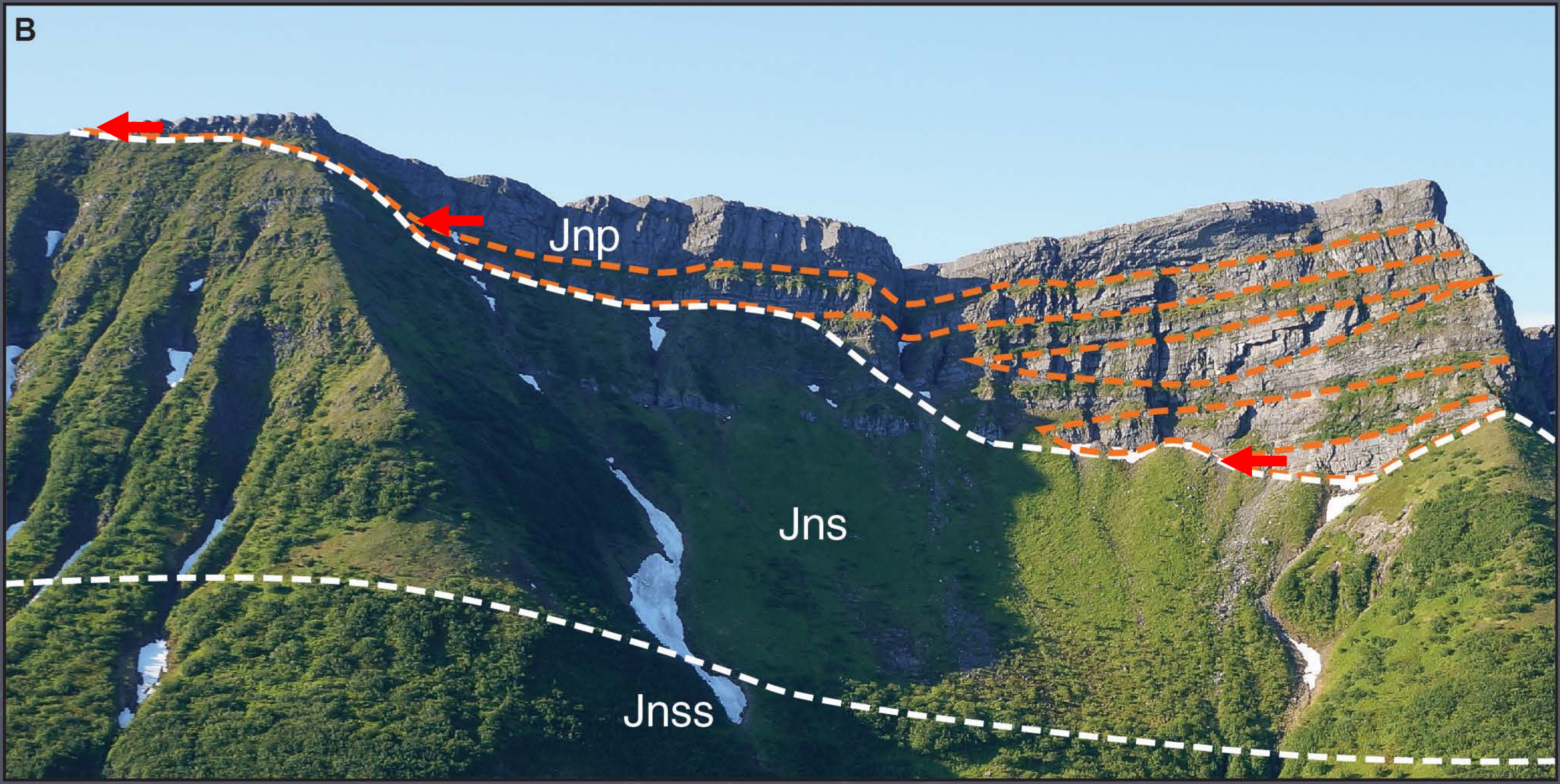
- Approximately dip-direction-parallel view of Jns "transitioning" along strike into Jnp



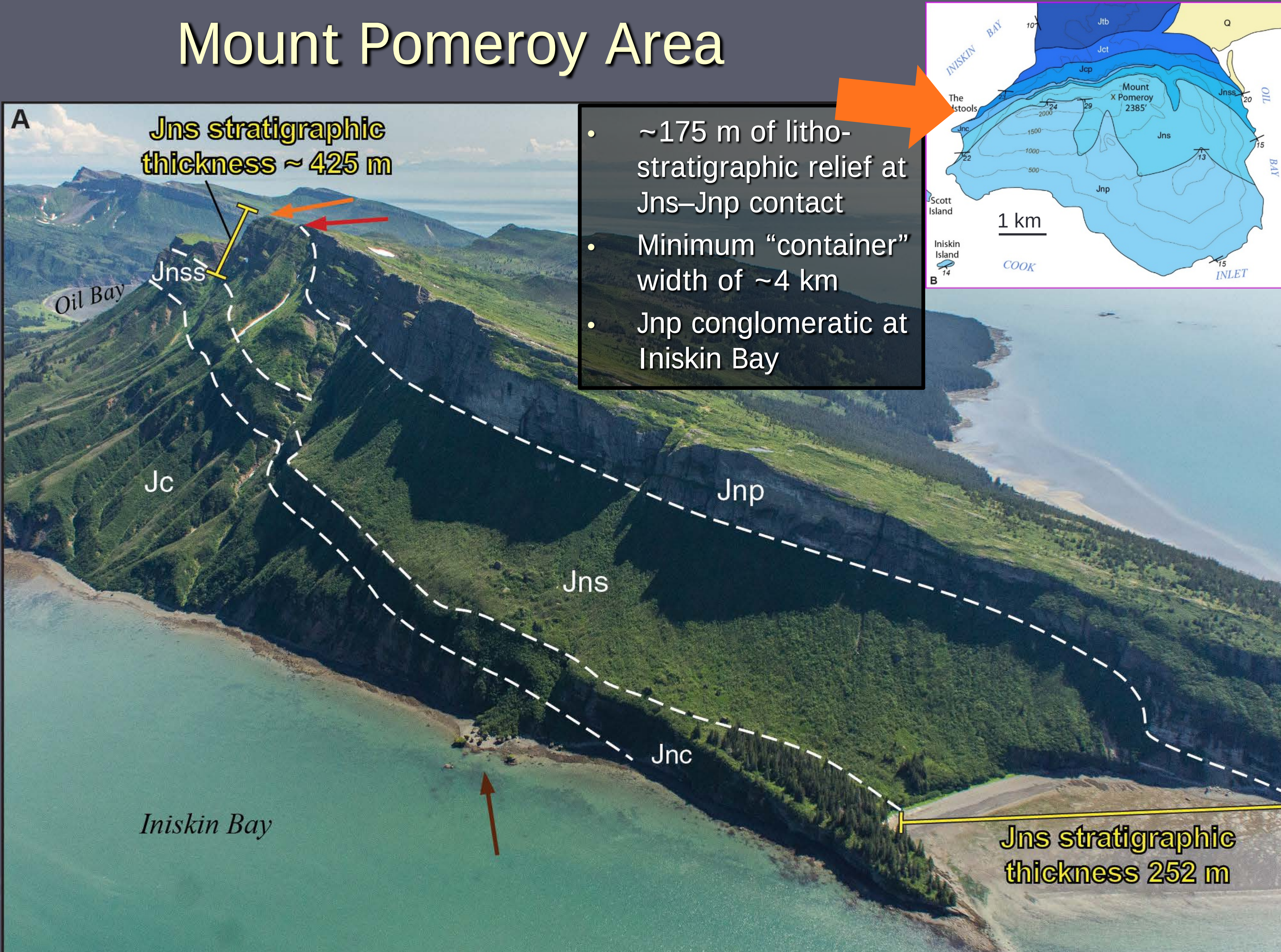
Mount Pomeroy Area



- ~100 m of local lithostratigraphic relief at Jns–Jnp contact
  - Onlapped by channelform strata of Jnp

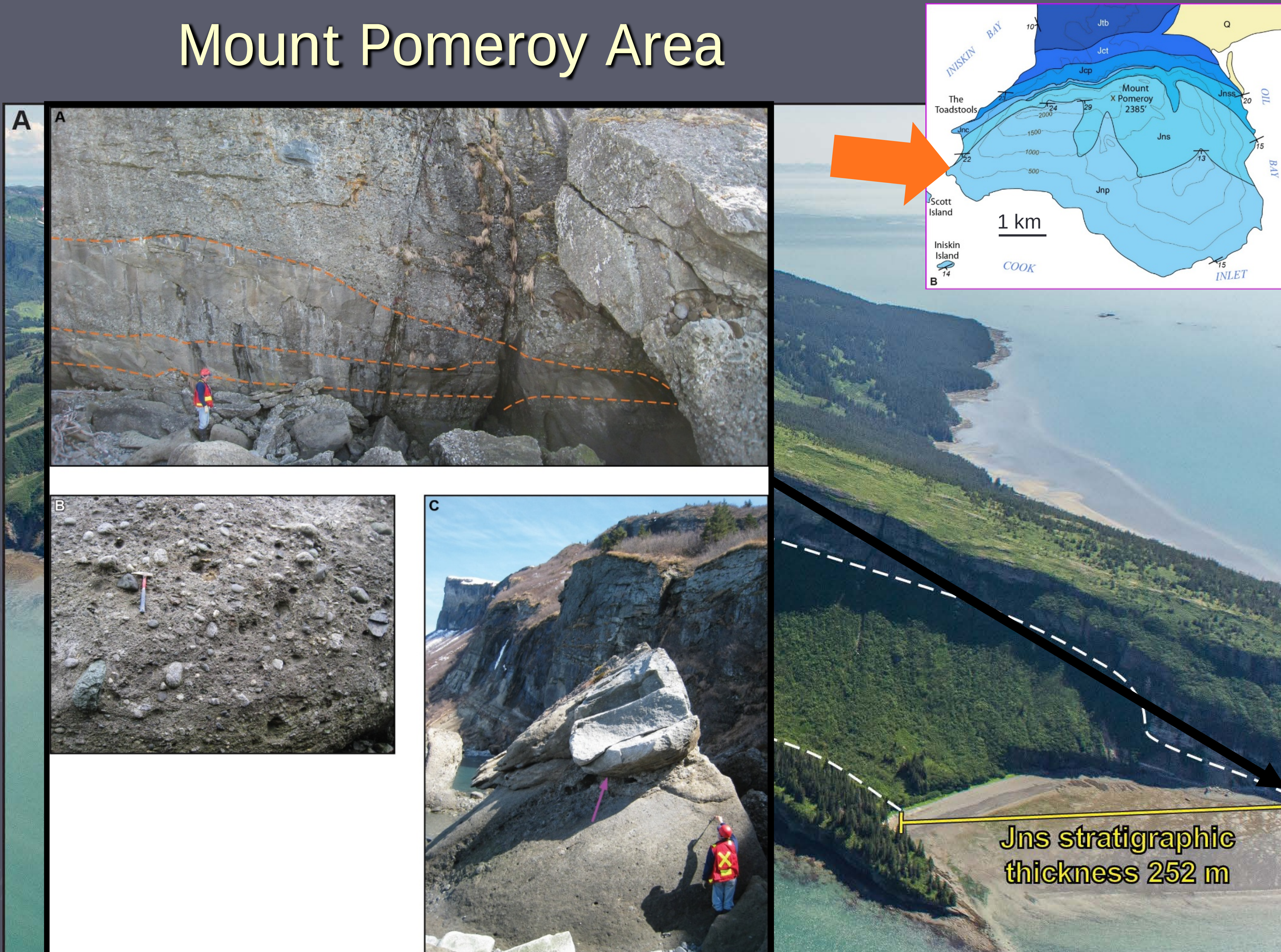


Mount Pomeroy Area



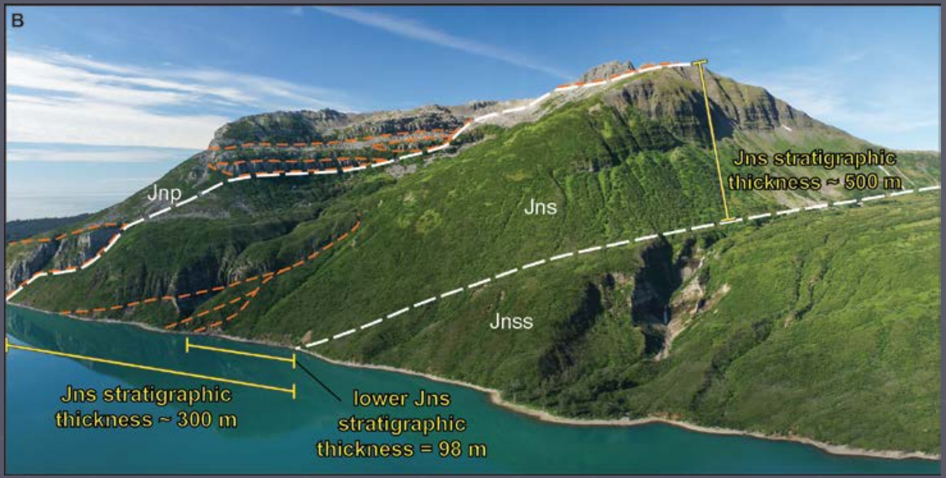
- ~175 m of litho-stratigraphic relief at Jns–Jnp contact
- Minimum "container" width of ~4 km
- Jnp conglomeratic at Iniskin Bay

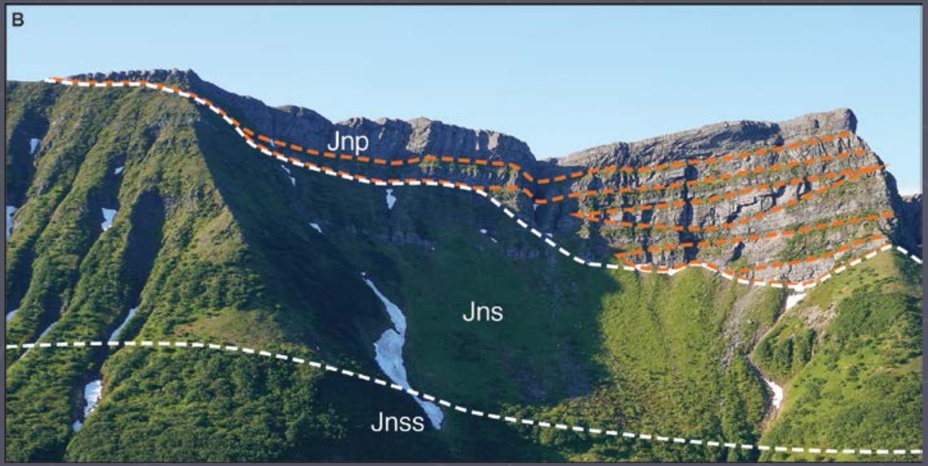
Mount Pomeroy Area



Hickerson Lake & Mount Pomeroy "Containers":

- Seismic-scale features exhibit 100s of m of relief and extend laterally for many km
  - Host: tabular-bedded Jns strata
    - Anomalously thick approaching "container" rims
  - Fill: channelized, tabular, and lobate(?) strata of dominantly Jnp (locally Jns)
    - Onlaps host strata
    - Locally conglomeratic
  - Erosional signature at margins/floors

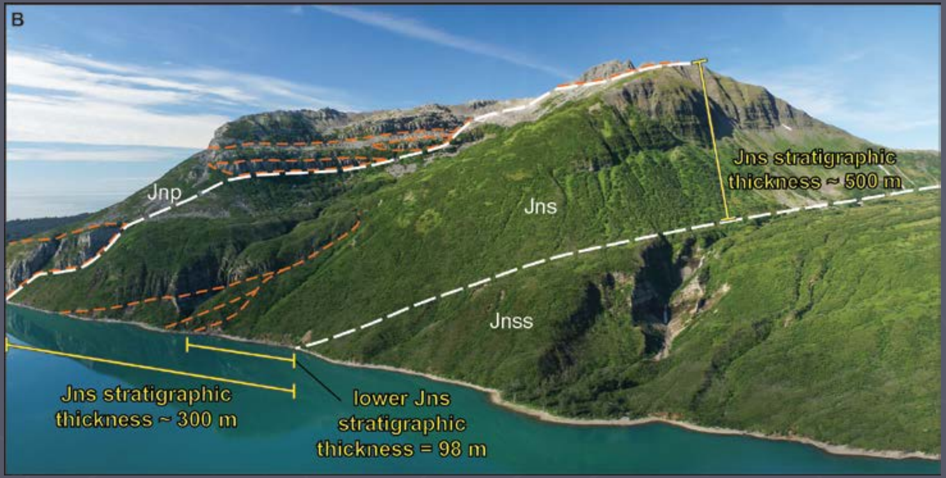




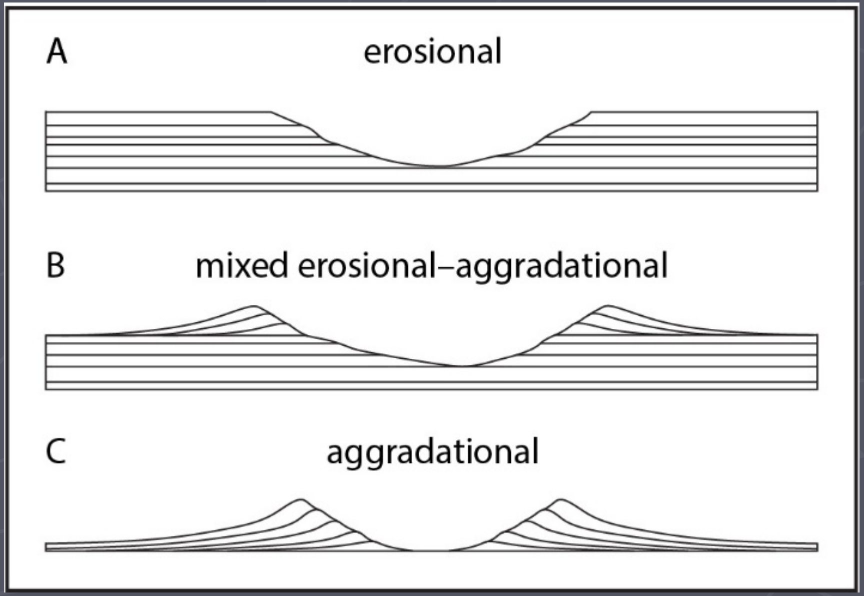
Hickerson Lake & Mount Pomeroy "Containers": Deep-Water Canyons

- Definition: wide (km-scale), deep (100s of m), erosive-based, slope-associated, long-lived (~m.y.-scale) conduits for transport of mud, sand, and gravel in deep marine environments

Reading and Richards, 1994; Galloway and Hobday, 1996; Richards et al., 1998; Posamentier and Allen, 1999; Prather, 2003; Sprague et al., 2005; Weimer and Slatt, 2006; Di Celma, 2011; Jobe et al., 2011; Williams and Graham, 2013; Hubbard et al., 2014



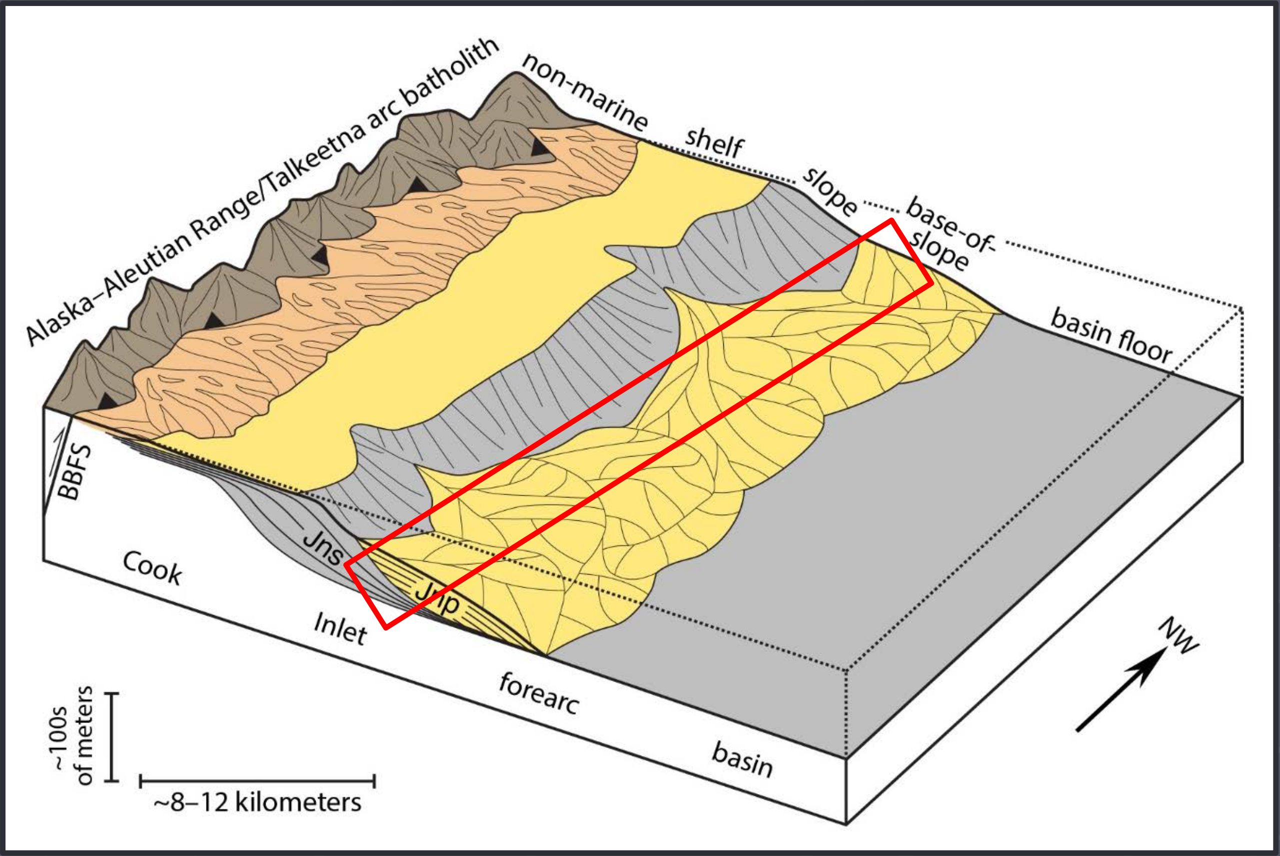
- Transport pathways for bypass of coarse-grained arkosic sediment that fed Jnp
- Canyons were ultimately backfilled by depositional elements of lower Pomeroy that backstepped and onlapped the inherited Snug Harbor slope depositional profile
- Canyon confinement: erosional (inception) to aggradational (later-in-life)
  - Erosional floors/margins
  - Jns thicknesses
  - Deep-water channel systems (e.g., Fildani et al., 2013)



modified from Clark and Pickering, 1996

Snug Harbor–Pomeroy: A Depositional Model

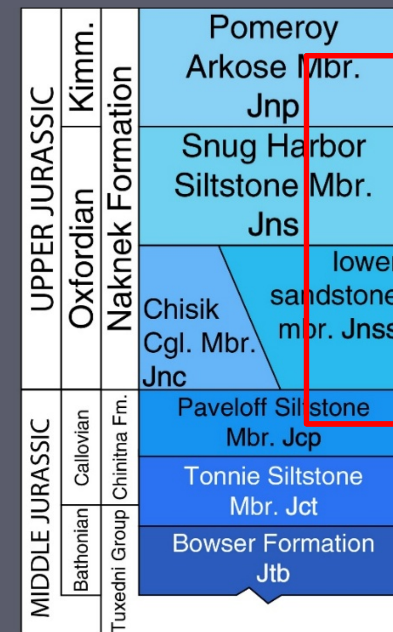
- Base-of-slope (Jnp) on slope (Jns) stacking predicts bypass: deep-water canyons (e.g., Miall, 1990; Hubbard et al., 2012)
- Deep-water erosion is a gravity driven process that varies as a function of seafloor gradient
- Depositional environment stacking and canyon erosion strongly suggest shelf–slope–basin floor depositional profile during Jns sedimentation

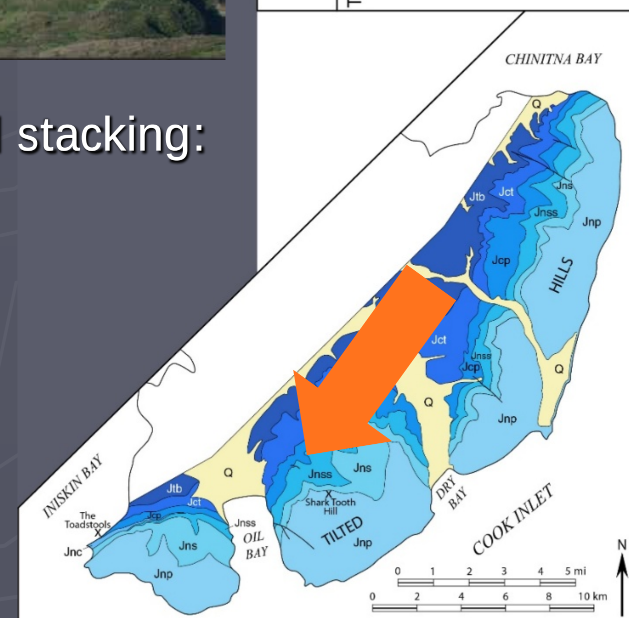


modified after Reading and Richards, 1994

- Gradient transitions along deep-water depositional profiles delineate regions prone to erosion and bypass vs. sedimentation
  - Incision: slope
  - Sediment accumulation: base-of-slope and beyond
- Changes through time and space: equilibrium grade
  - Erosion vs. aggradation

Sequence Stratigraphic Framework of the Naknek Formation

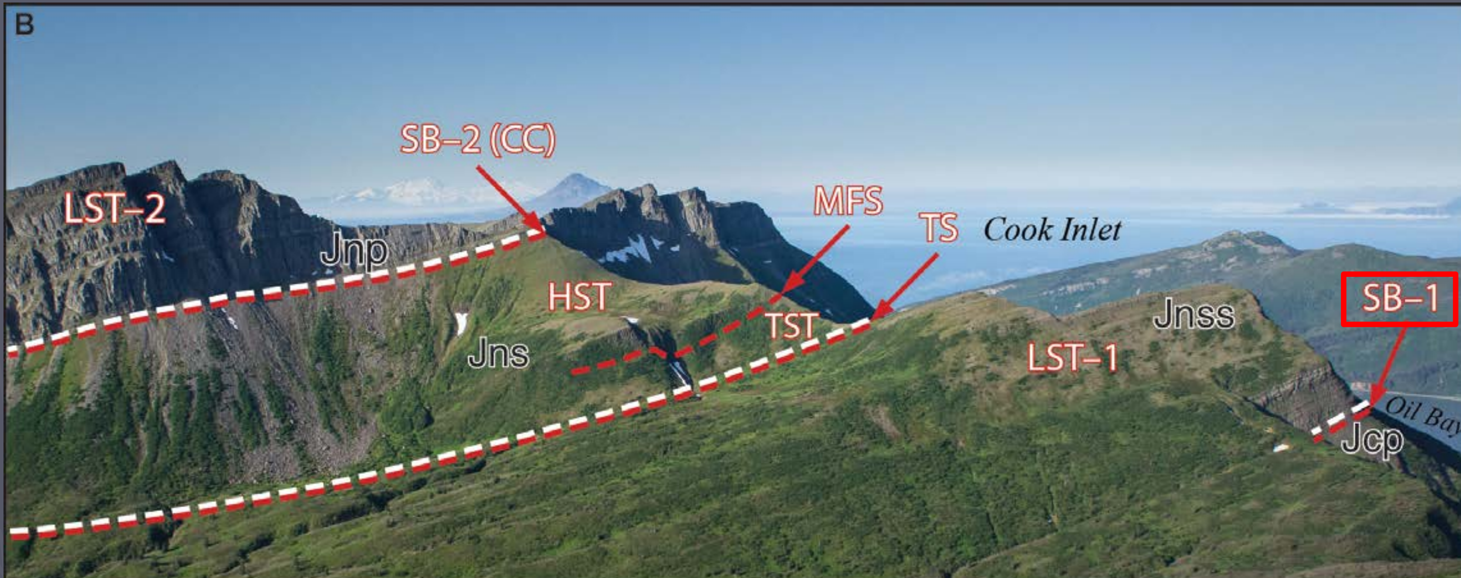


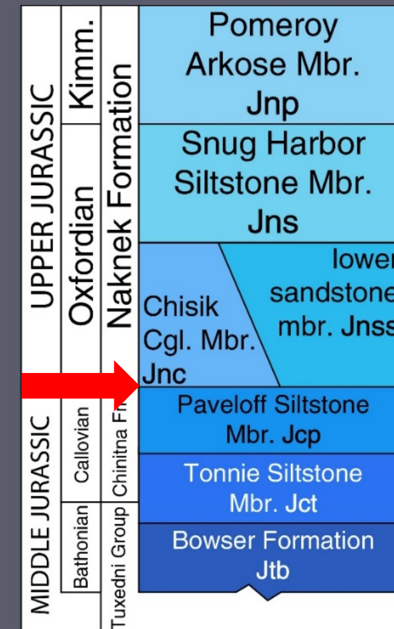


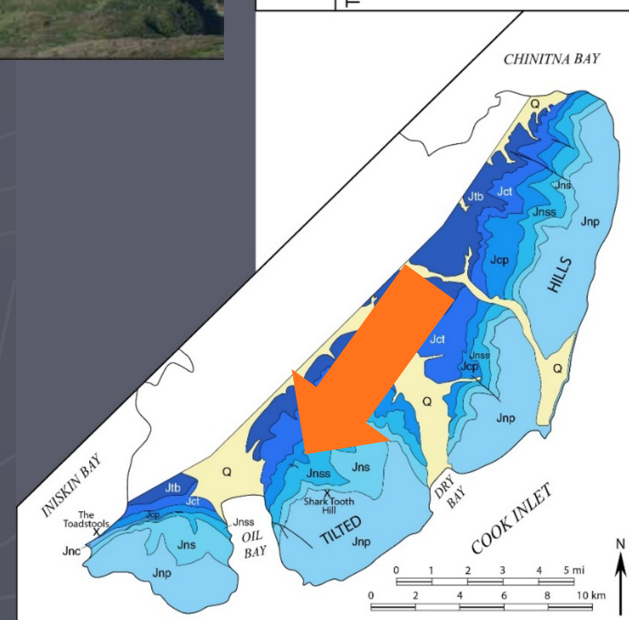
Lithostratigraphy, depositional environments, and stratal stacking:

- Sequence stratigraphic surfaces
- Systems tracts
- Stratigraphic sequences
- Methods:
  - Neal and Abreu (2009)
  - Deep-water SBs and CCs after Posamentier and Allen (1999)
  - Catuneanu et al. (2009)

Sequence Stratigraphic Framework of the Naknek Formation



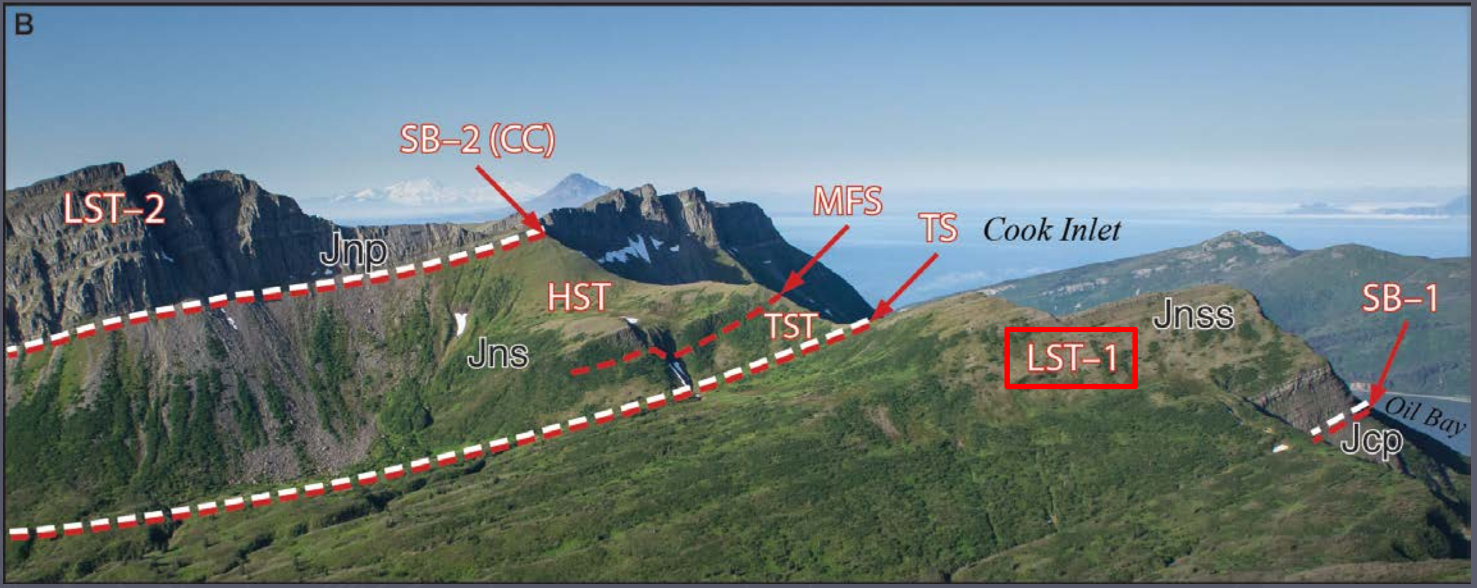


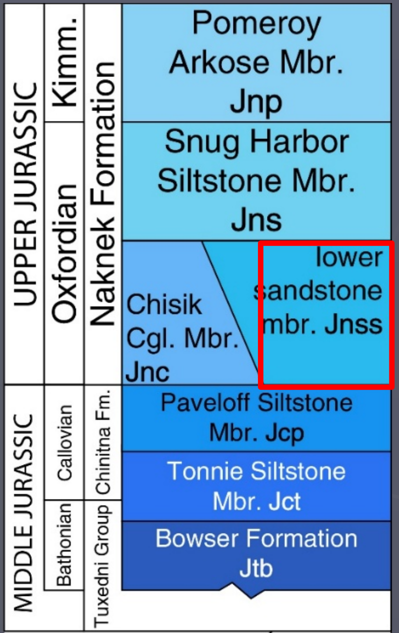


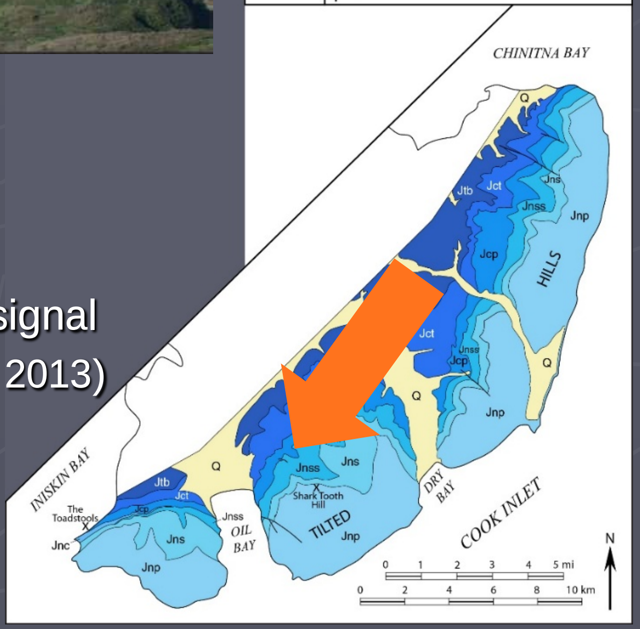
SURFACES AND SYSTEMS TRACTS

- SB–1: Sequence Boundary–1
  - Shallow marine on unconformity stacking
    - Locally erosional
    - <1 m.y. hiatus at end of Callovian (Detterman and Hartsock, 1966; Imlay, 1975)
  - Shoreline trajectory: basinward

Sequence Stratigraphic Framework of the Naknek Formation



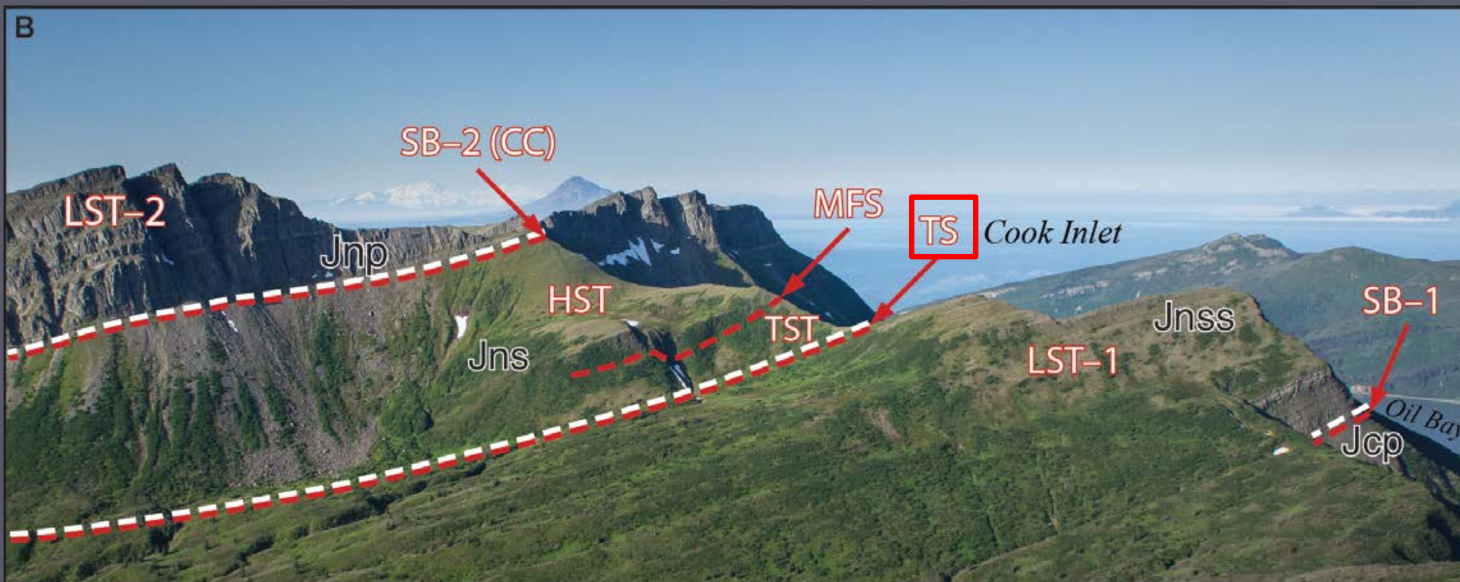


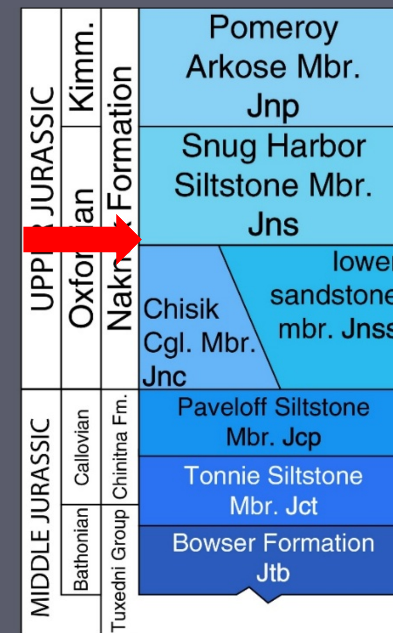


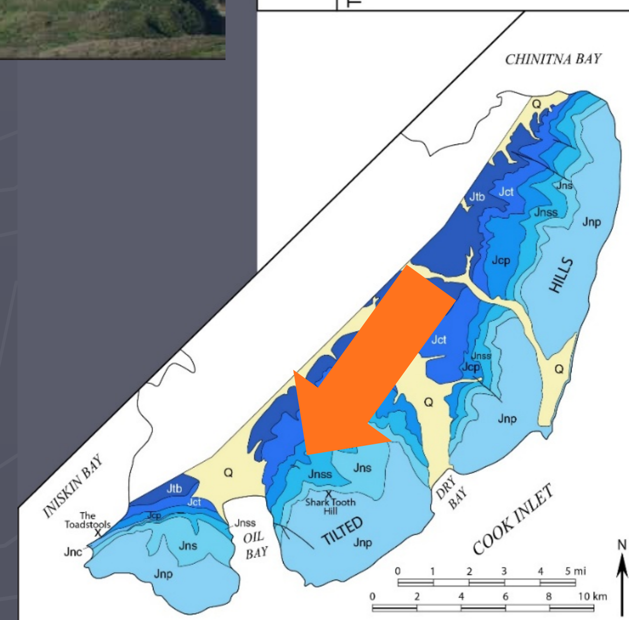
SURFACES AND SYSTEMS TRACTS

- LST–1: Lowstand Systems Tract–1
  - lower sandstone and Chisik
  - Strong, convergent margin-scale arkosic sediment supply signal
    - Tectonics: onset of pluton exhumation (see LePain et al., 2013)
      - Alaska Peninsula: e.g., Detterman et al., 1996
      - Cook Inlet: Detterman and Hartsock, 1966; Wartes et al., 2013
      - Talkeetna Mountains: Trop et al., 2005
  - Subordinate increase of accommodation

Sequence Stratigraphic Framework of the Naknek Formation



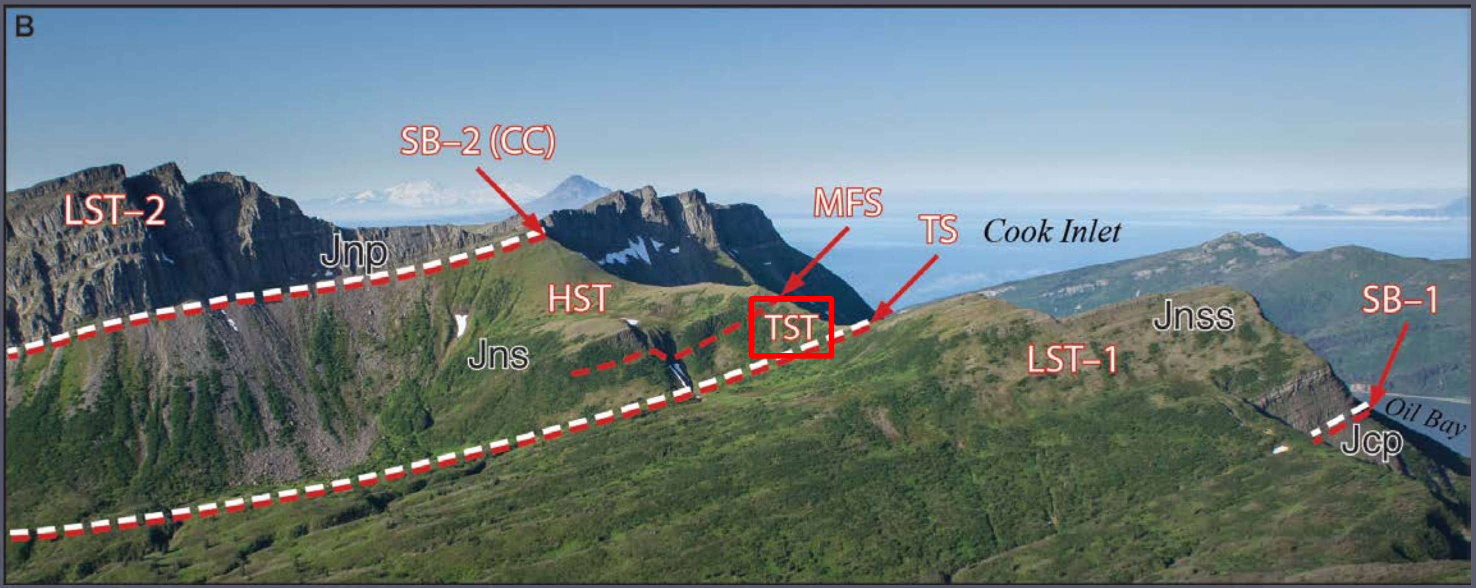


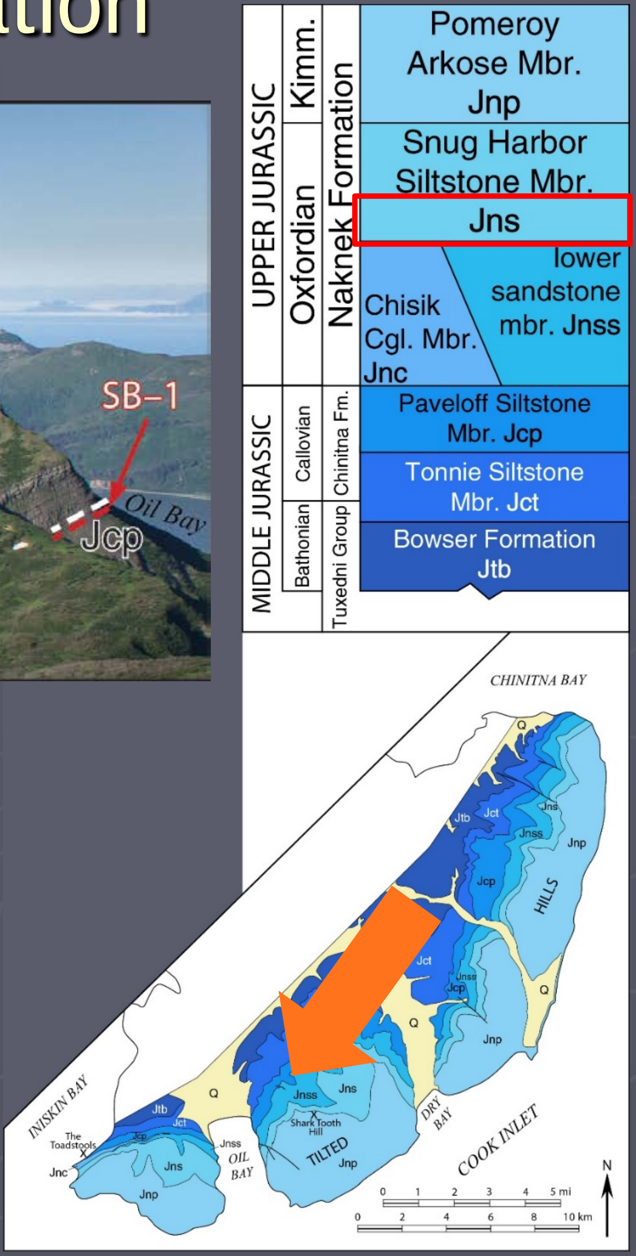


SURFACES AND SYSTEMS TRACTS

- TS: Transgressive Surface
  - Outer shelf on shelf stacking
  - Recessive weathering profile
  - New shoreline trajectory: landward

Sequence Stratigraphic Framework of the Naknek Formation

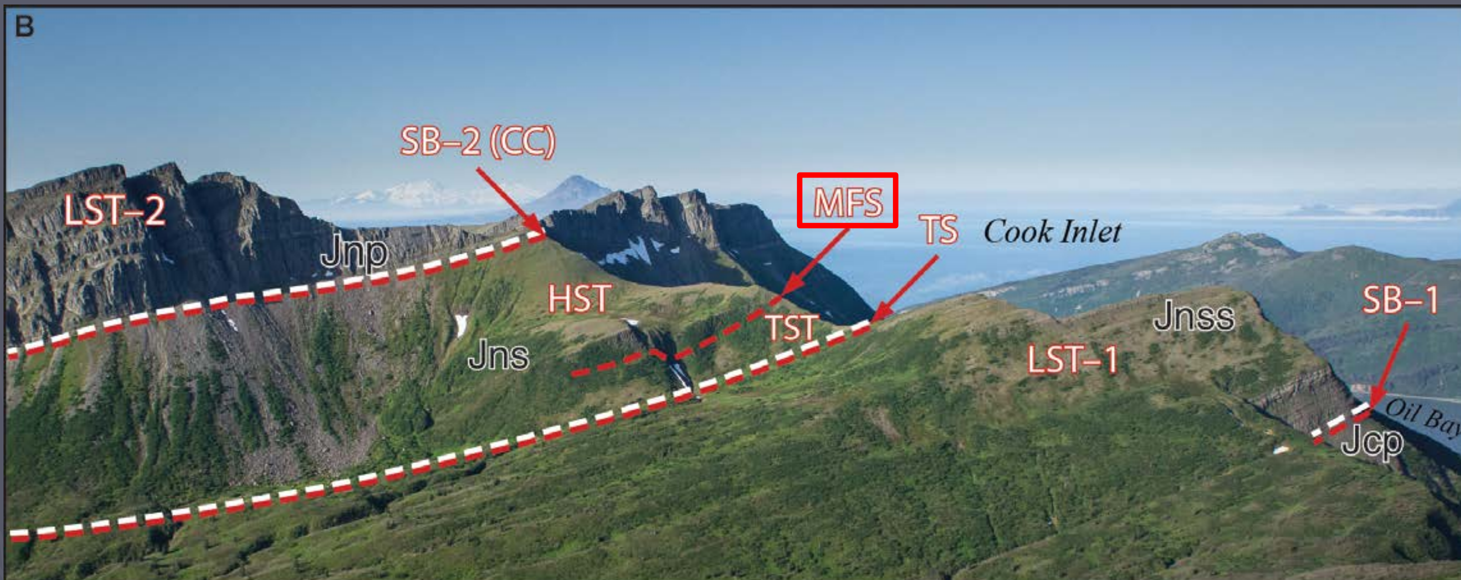


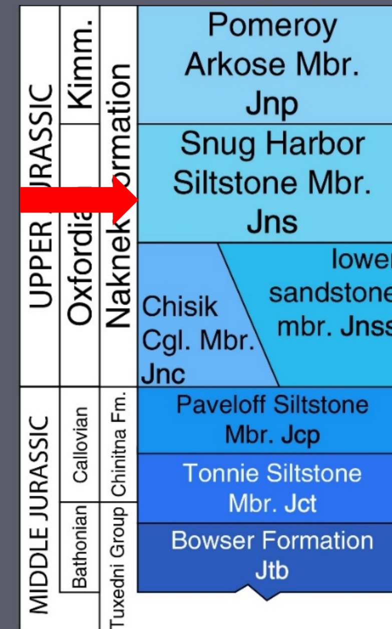


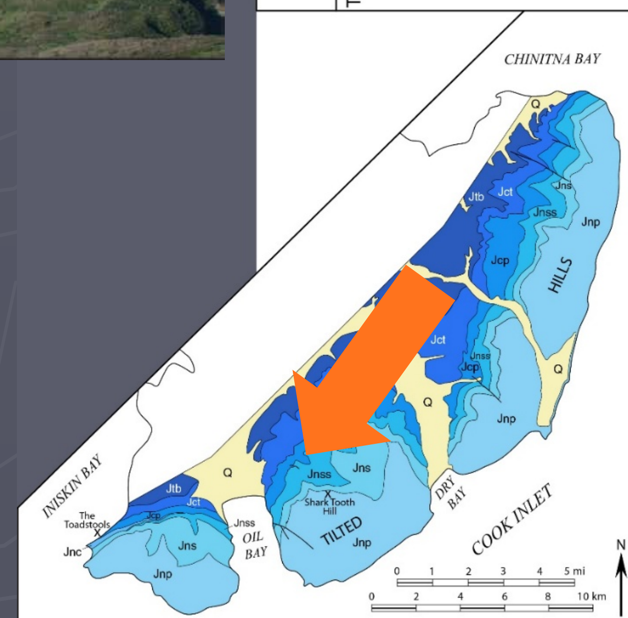
SURFACES AND SYSTEMS TRACTS

- TST: Transgressive Systems Tract
  - lower part of Snug Harbor Siltstone
  - Accommodation > sediment supply

Sequence Stratigraphic Framework of the Naknek Formation



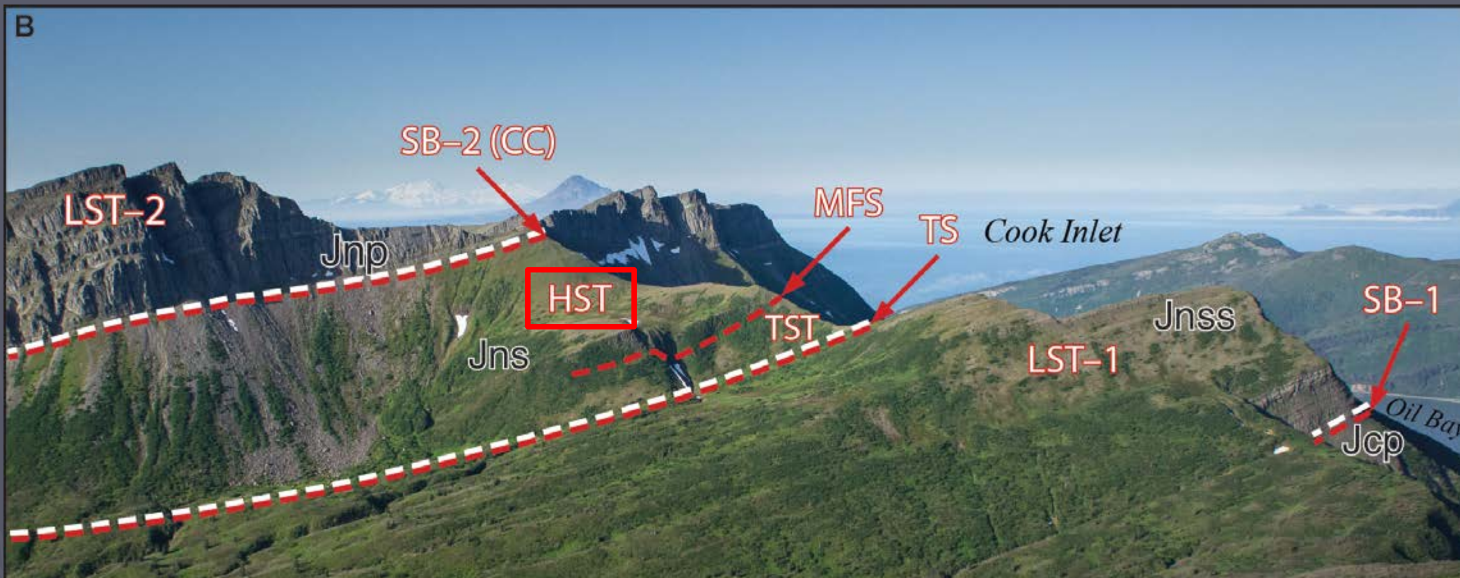


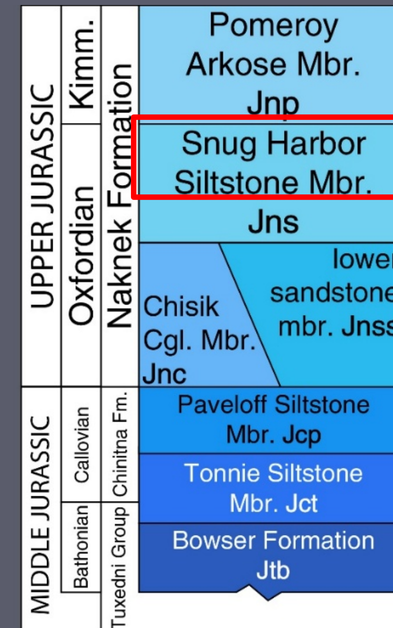


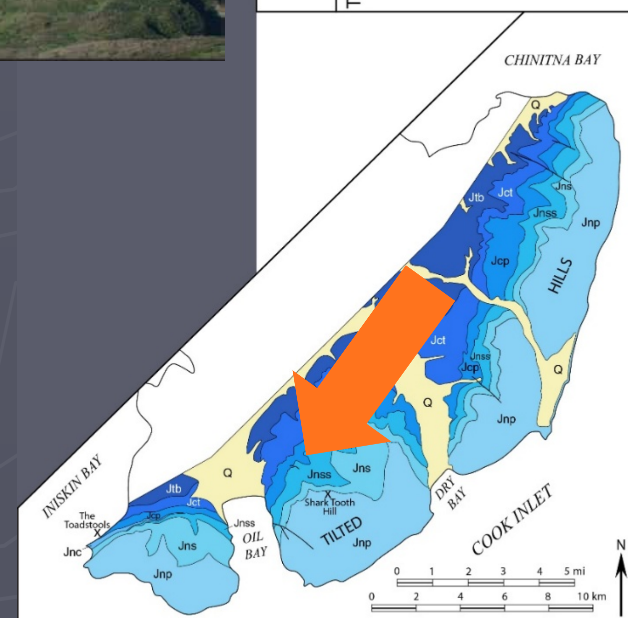
SURFACES AND SYSTEMS TRACTS

- MFS: Maximum Flooding Surface
  - Slope on outer shelf stacking
  - Weathering profile changes
  - Stacking motif changes
  - New shoreline trajectory: basinward

Sequence Stratigraphic Framework of the Naknek Formation



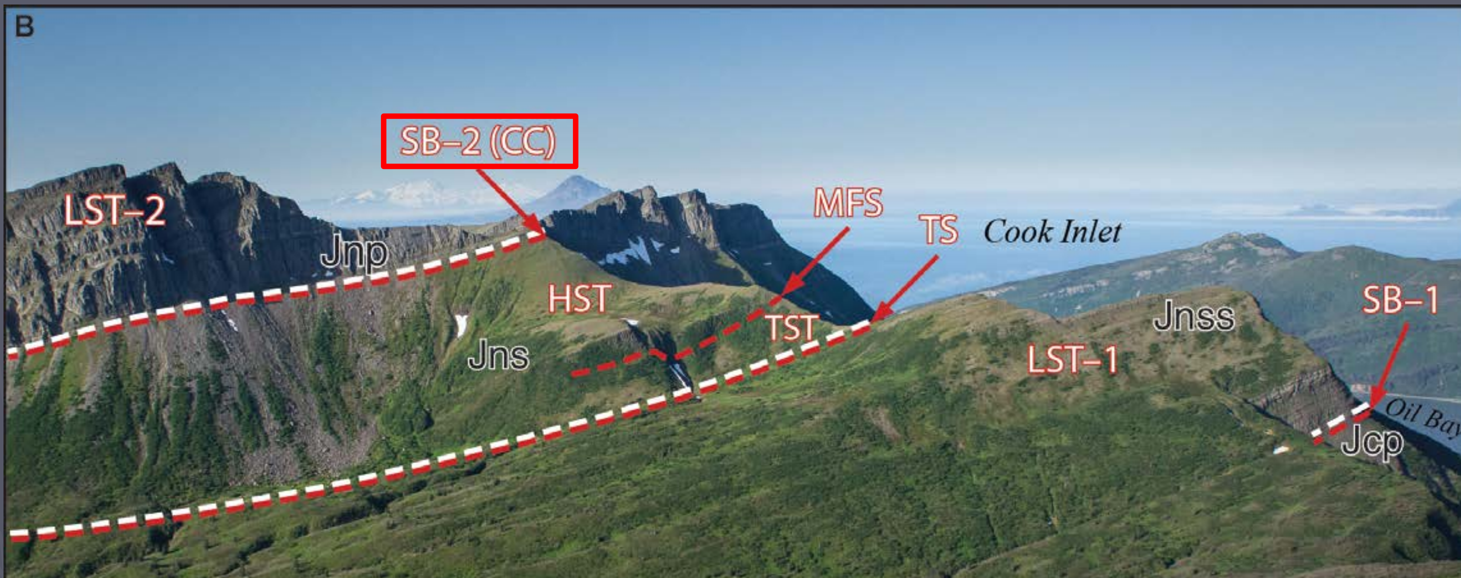


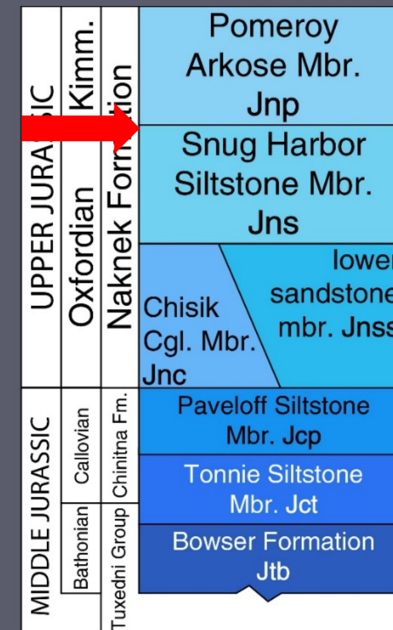


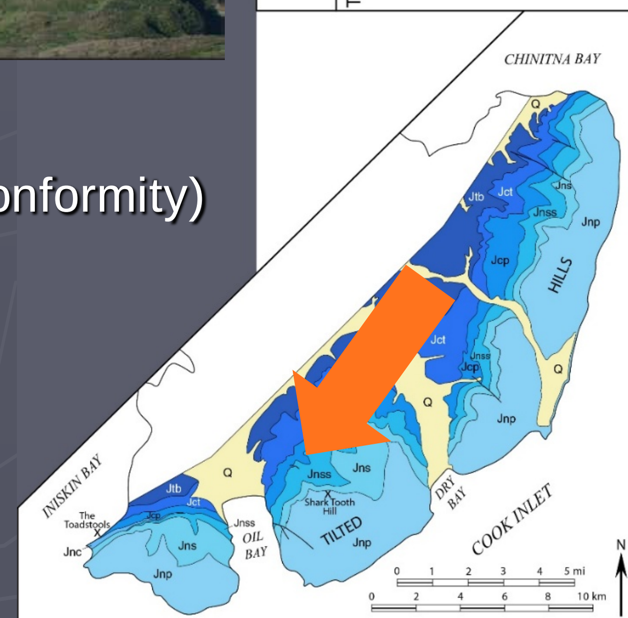
SURFACES AND SYSTEMS TRACTS

- HST: Highstand Systems Tract
  - upper part of Snug Harbor Siltstone
  - Sediment supply > accommodation
  - Progradation of clinoforms
    - Depositional profile setting the stage for:
      - Erosion of canyons
      - Accumulation and onlap of lower Pomeroy onto inherited Jns slope

Sequence Stratigraphic Framework of the Naknek Formation



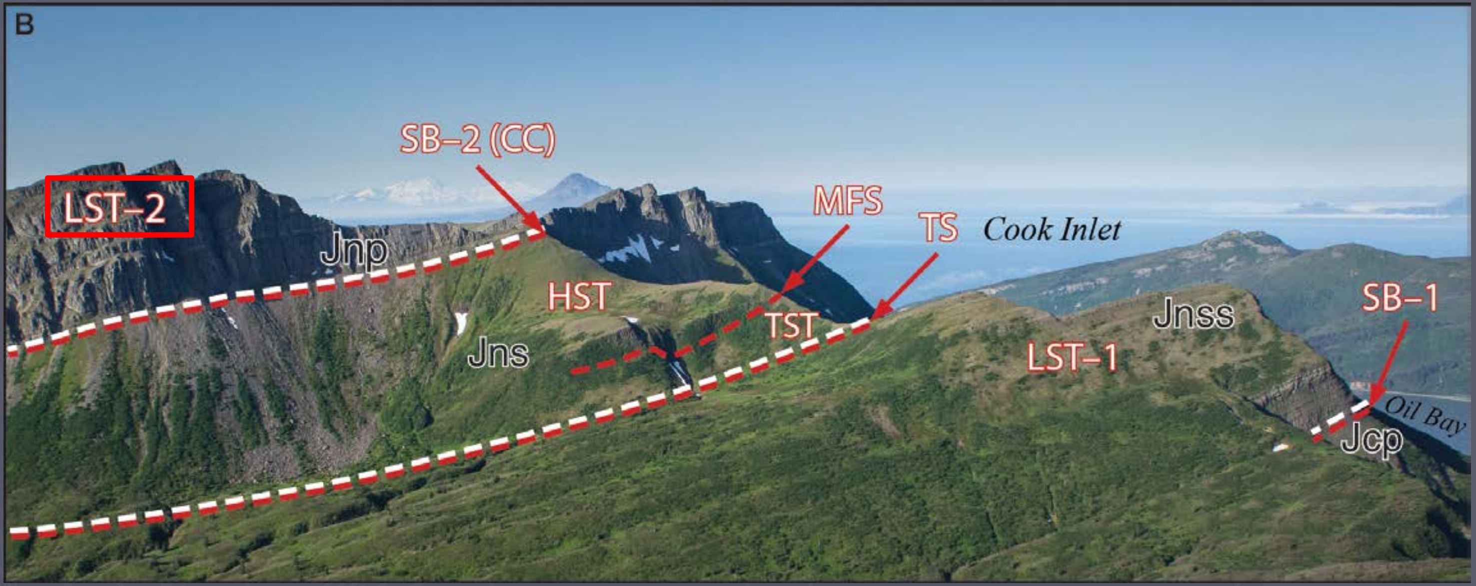


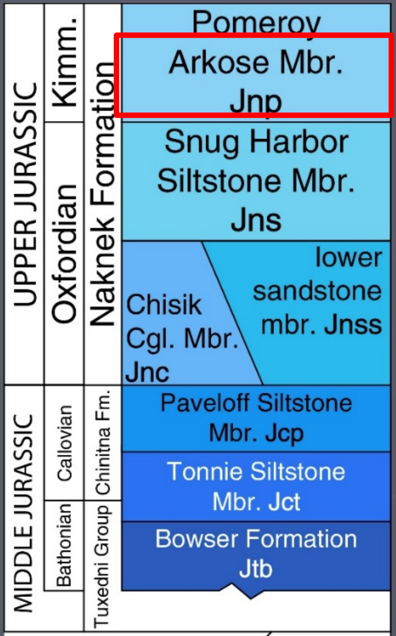


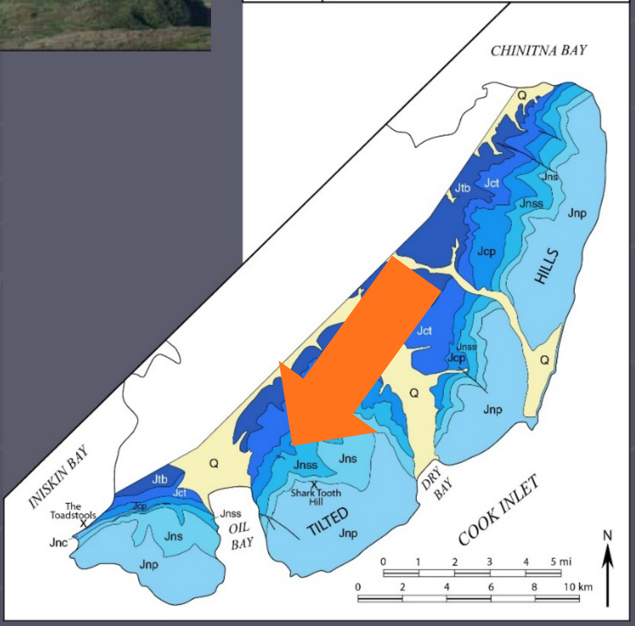
SURFACES AND SYSTEMS TRACTS

- SB–2 (CC): Sequence Boundary–2 (Correlative Conformity)
  - Base-of-slope on slope stacking
  - Deep-water canyons-associated SB
  - Shoreline trajectory: basinward

Sequence Stratigraphic Framework of the Naknek Formation





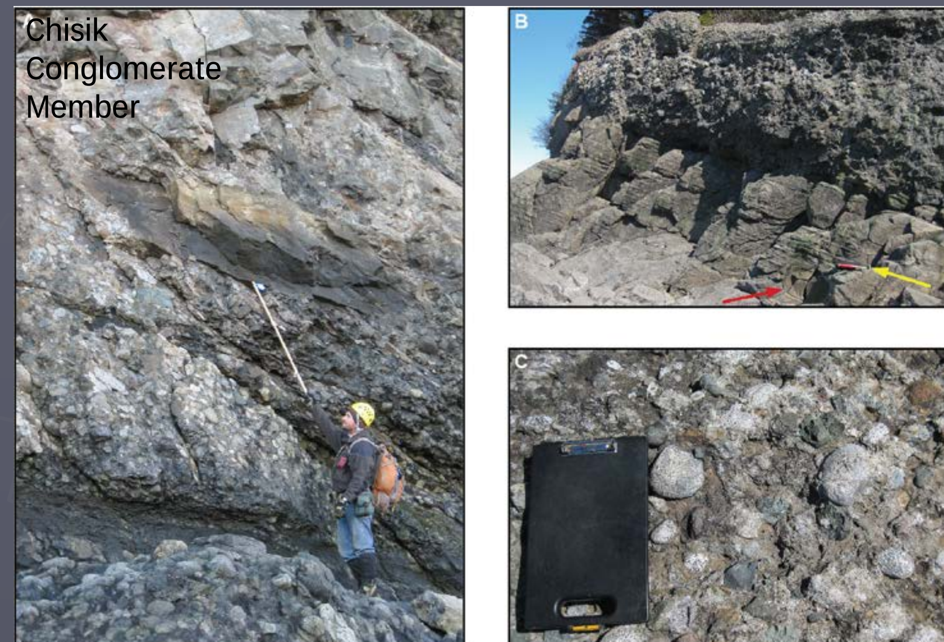


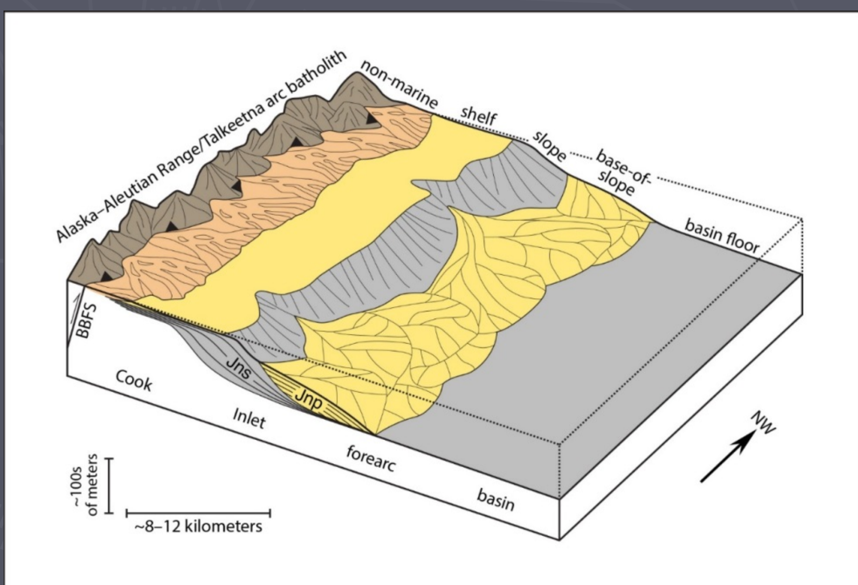
SURFACES AND SYSTEMS TRACTS

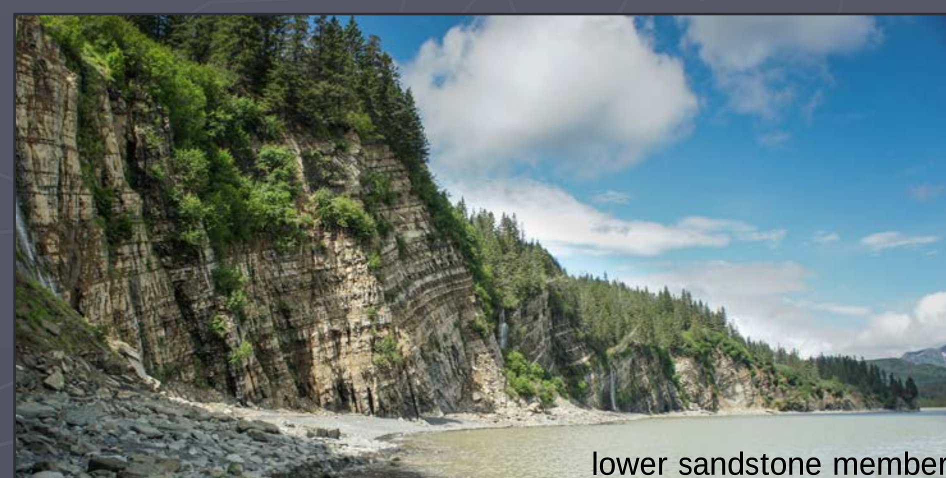
- LST–2: Lowstand Systems Tract–2
  - Lower part of Pomeroy Arkose
    - Locally: canyon fill (including Jns)
  - Strong sediment supply signal
    - Deep-water accommodation not a limiting factor

Hydrocarbon Reservoir Implications: LSTs

- LST–1 sand-prone settings:
  - Shelfal in outcrop
  - Distal extents not well defined
    - Deep-water sands(?)
- LST–2 sand-prone settings:
  - Shelf (inferred)
  - Canyon axis
  - Master levee(?)
  - Base-of-slope and basin floor







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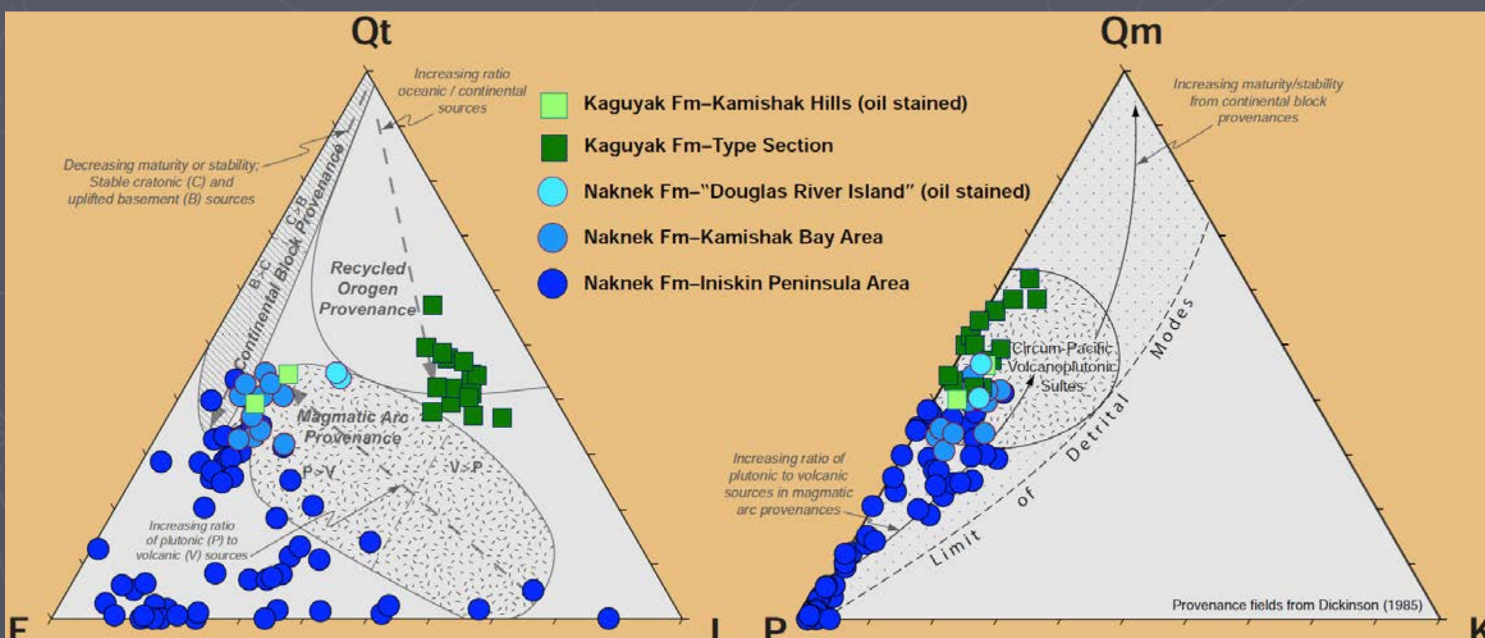
- What about reservoir quality?
  - Helmold et al., 2013: poor RQ parameters for Naknek sandstones in Iniskin–Tuxedni region
  - Better plutonic provenance elsewhere? Maybe.



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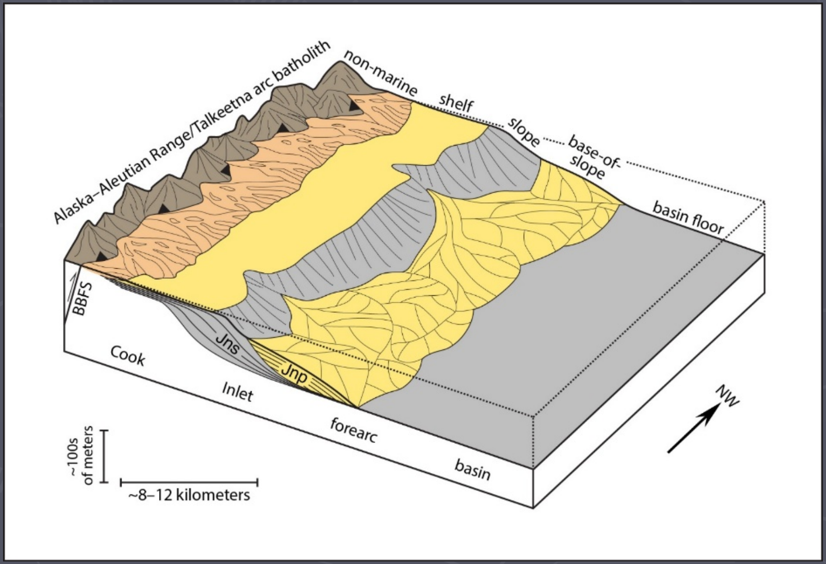
- What about reservoir quality?
  - Helmold et al., 2013: poor RQ parameters for Naknek sandstones in Iniskin–Tuxedni region
  - Better plutonic provenance elsewhere? Maybe.
  - If so, sediment routing is key

- Unconventional, fractured reservoirs



from Gillis et al., 2013

Conclusions

- Newly recognized seismic-scale stratigraphic containers are deep-water canyons
  - Globally, similar features are observed in seismic data, but are uncommon in outcrop
- Shelf–slope–basin floor depositional profile established during Snug Harbor time
- Lithostratigraphic relations, depositional environments, and stacking patterns permit sequence stratigraphic interpretation of the Naknek Formation of Cook Inlet
  - Surfaces, systems tracts, and stratigraphic sequences
- Identification of base-level cycles, shoreline trajectories, and accommodation/ sediment supply balance through time answers many questions and poses more
- Framework for predicting coarse-grained Naknek sedimentation in time and space
  - Implications for hydrocarbon reservoirs
- Basin fill record: regional tectonic evolution

DEEP WATER CANYONS AND SEQUENCE STRATIGRAPHIC FRAMEWORK OF THE UPPER JURASSIC NAKNEK FORMATION, COOK INLET FOREARC BASIN, SOUTH-CENTRAL ALASKA

Trystan M. Herriott[1], Marwan A. Wartes[1], and Paul L. Decker[2]

Insert footnote near here

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Thank You