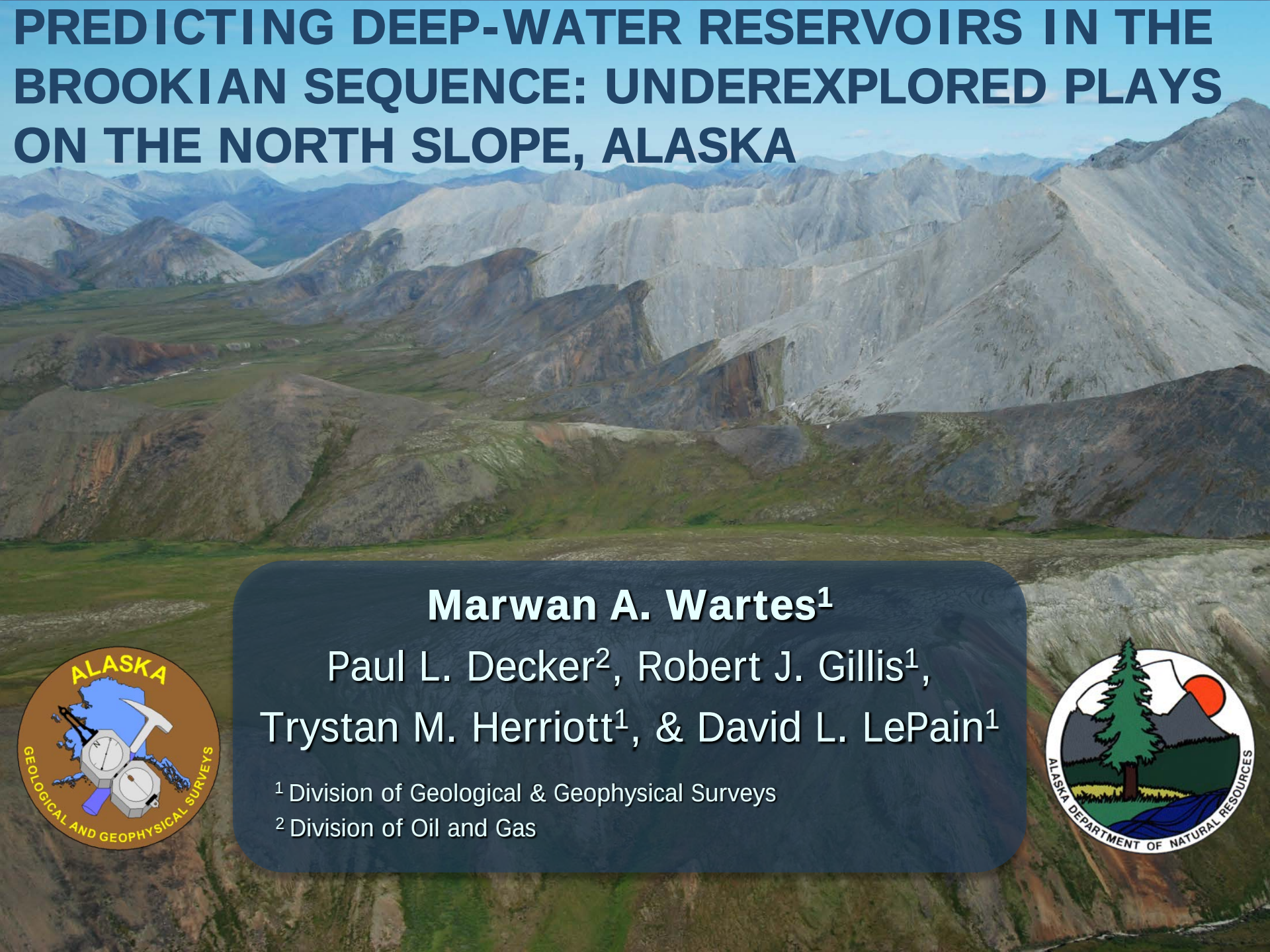
PREDICTING DEEP-WATER RESERVOIRS IN THE BROOKIAN SEQUENCE: UNDEREXPLORED PLAYS ON THE NORTH SLOPE, ALASKA



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ABSTRACT

The Brookian sequence of Alaska's North Slope remains lightly explored, despite a number of successful discoveries in the past 20 years. In order to encourage new exploration and improve our understanding of the Brookian depositional system, we've established a comprehensive sequence stratigraphic framework based on regional well log correlations, public-domain seismic data, and outcrop-based geologic mapping and stratigraphic studies. Our analysis suggests four deep-water stratigraphic intervals warrant further consideration as exploration targets:

CENOMANIAN—Cenomanian topsets of the upper Nanushuk Formation record a retrogradational stacking pattern culminating in a major transgressive flooding surface. Despite this evidence for relative sea-level rise, we have documented a significant amount of medium- to course-grained sand that was exported off the shelf. These amalgamated sediment gravity-flow deposits in the upper Torok Formation are locally oil-stained and represent a potential exploration target.

TURONIAN—The deep-water Turonian Seabee Formation locally has good reservoir quality and produces from the Bermuda interval (e.g., Tarn and Meltwater fields). These basin floor sands are encased between oil-prone tongues of the Hue Shale source rock. This vertical stratigraphic arrangement (source-reservoir-source) is widespread and the Seabee is routinely petroliferous in outcrop, indicating this play is prospective for both stratigraphic and structural traps.

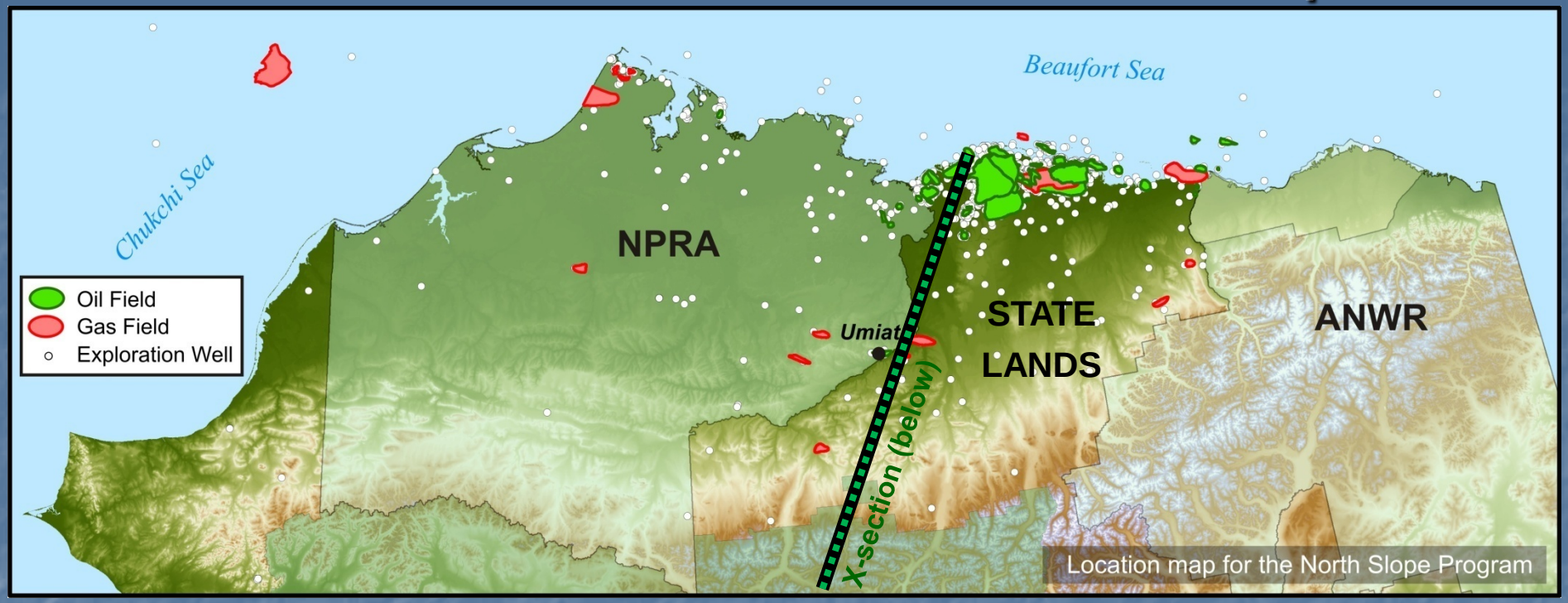
MID-CAMPANIAN—The mid-Campanian is marked by a major unconformity that truncates underlying outer-shelf topsets. Incision and relief along this sequence boundary is readily apparent in seismic data and it is overlain by valley fills and shelf-margin deltas of the middle Schrader Bluff Formation (including the reservoir at the Tabasco field). This major episode of relative sea-level fall resulted in the reworking and bypass of material into bottomsets of the Canning Formation. These potential reservoirs are overlain by a major Campanian flooding surface that may seal a lowstand wedge or related deep-water facies.

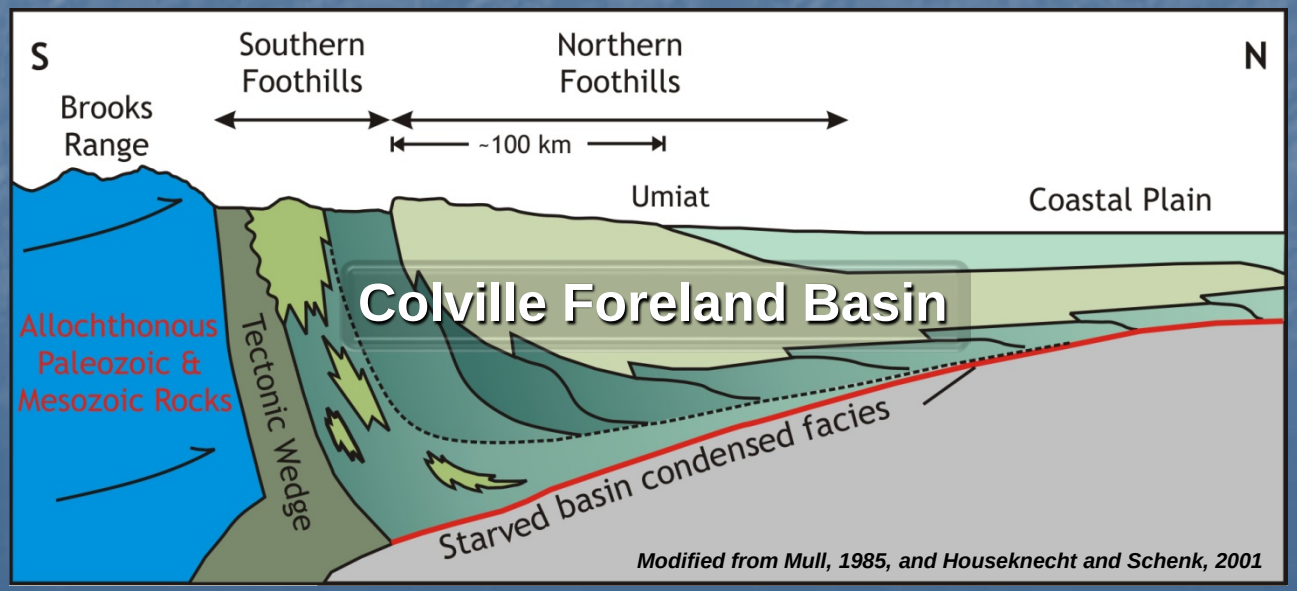
PALEOCENE—The Paleocene shelf margin was incised and deeply eroded during a major base level fall, resulting in a regional downward stepping trajectory of toplap surfaces. Seismic data indicate significant submarine scouring occurred in deep-water settings and wells typically exhibit a sharp dislocation in log motif, indicating an abrupt influx of sandstone in slope and basinal facies of the Canning Formation. Several oil-charged slope-channel and slope-apron turbidite systems have been discovered in this lowstand systems tract (e.g., Badami and Flaxman A-1 pools).

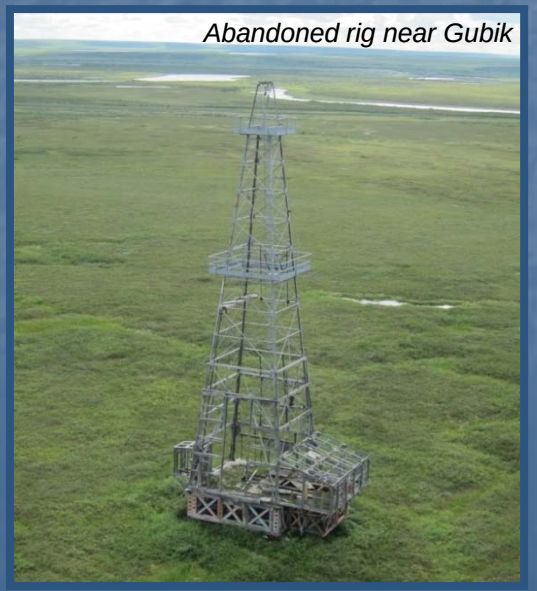
Brookian stratigraphy is complex and reservoir-scale geometries are challenging to image in available seismic data. However, our work demonstrates that potential deep-water reservoirs do exist and our analysis permits generalized predictions of when significant volumes of sand were exported off the shelf.

Authors note: A version of this material was first presented at the AAPG 3P Meeting, October 15-18, 2013 in Stavanger, Norway (speaker P. L. Decker). A slightly modified version was presented at the Alaska Geological Society Technical Conference, May 15, 2014 in Anchorage, Alaska (speaker M. A. Wartes)

Cretaceous – Cenozoic Brookian Sequence







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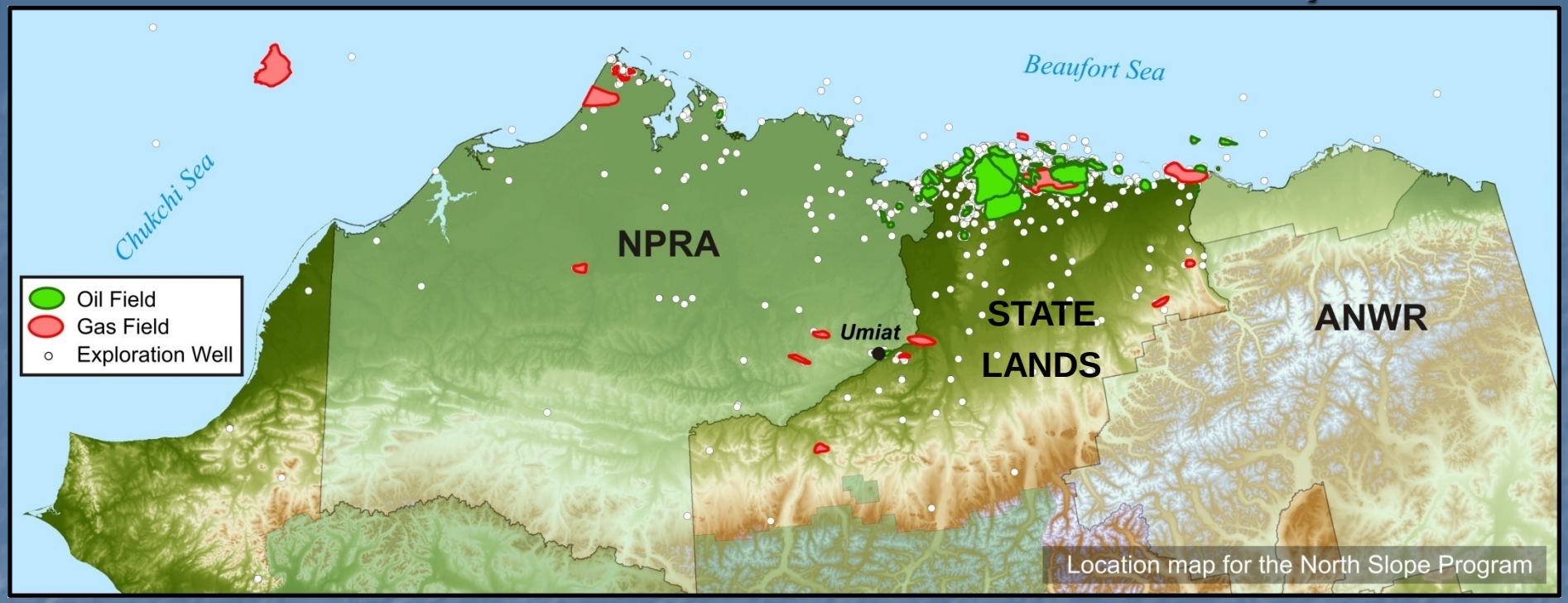

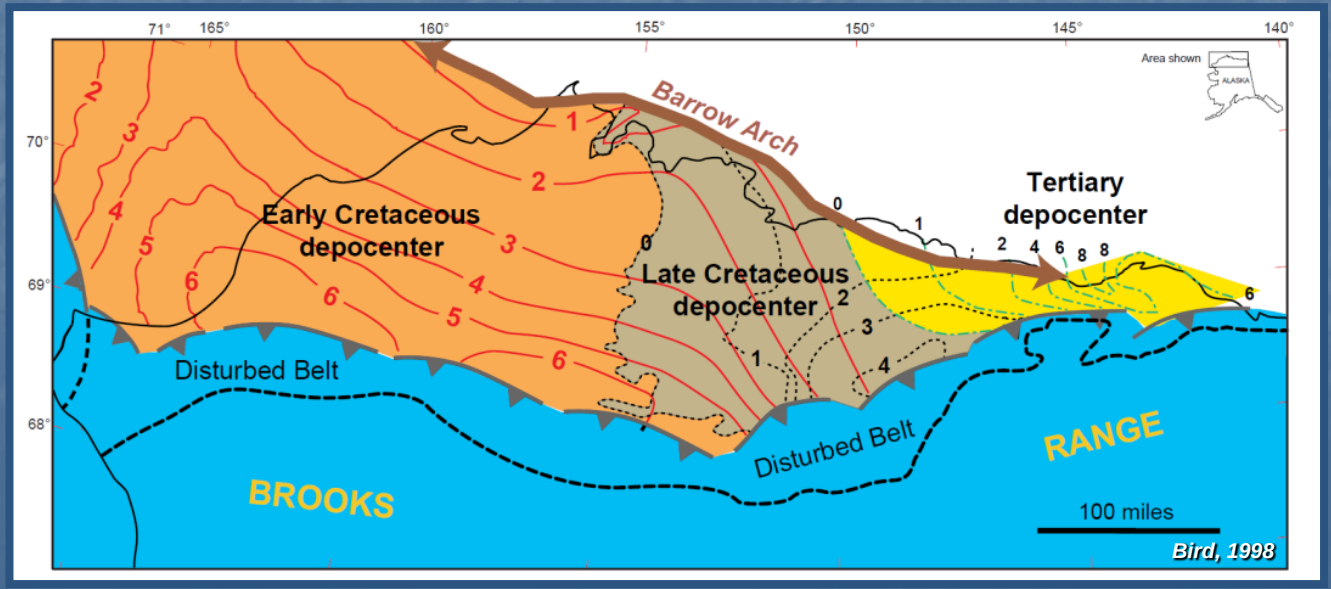

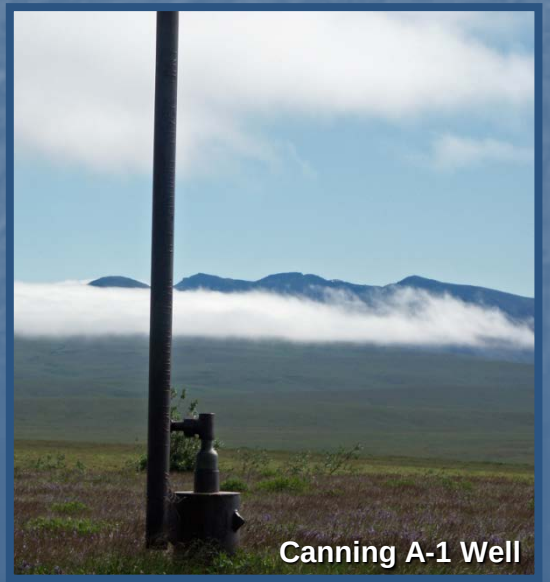

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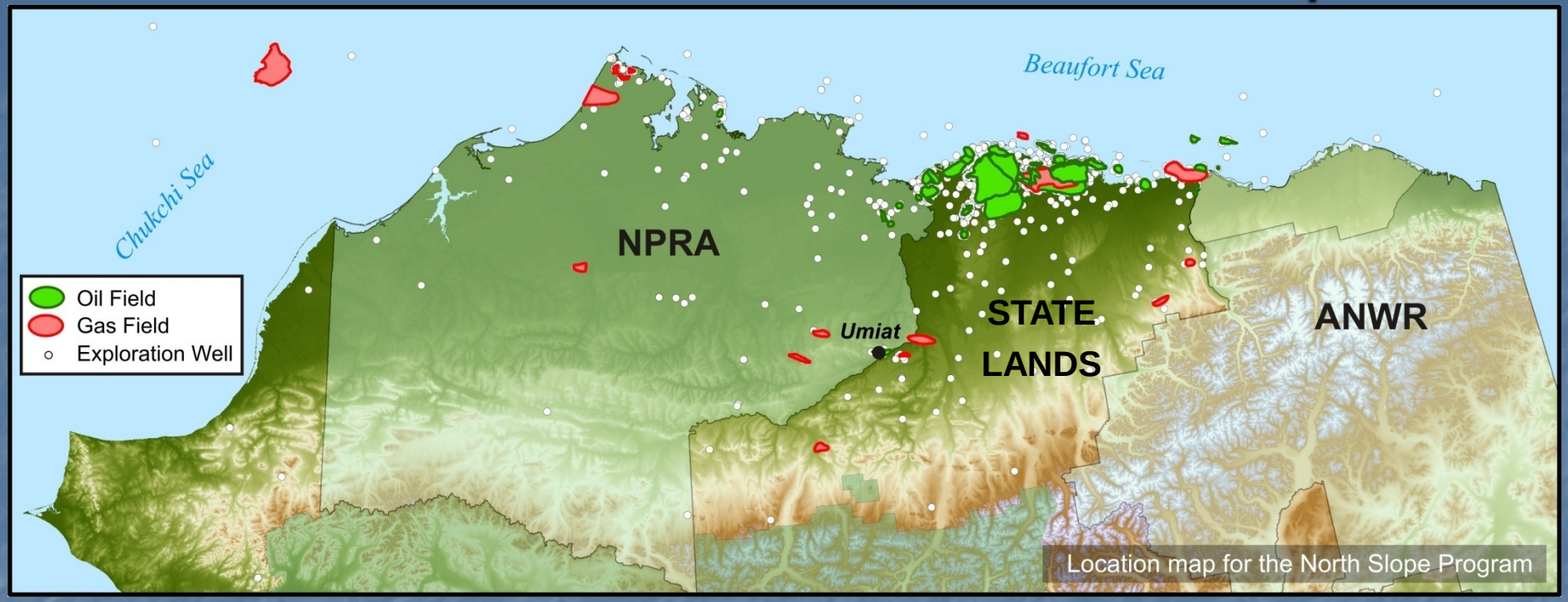
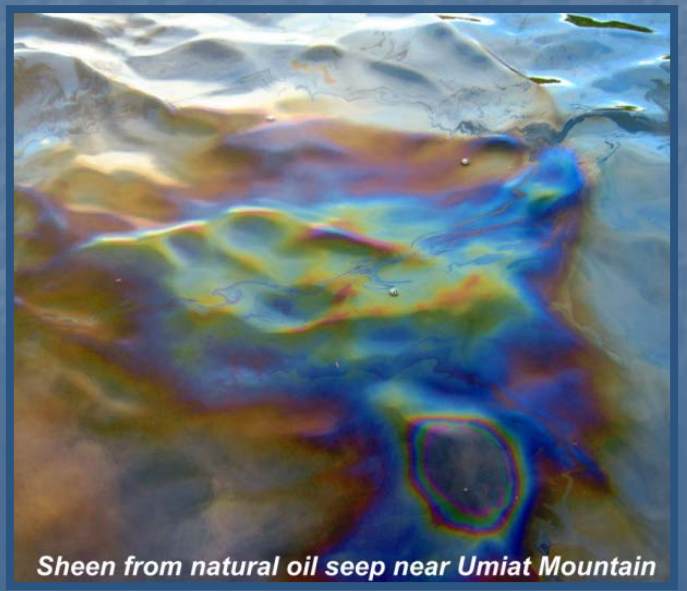


- The Brookian sequence remains lightly explored, despite numerous successful discoveries
- Although petroleum system is recognized, Brookian stratigraphy is challenging to work in detail


Sheen from natural oil seep near Umiat Mountain

- PROJECT GOALS:
  - Create a comprehensive sequence stratigraphic framework
  - Improve our understanding of the depositional system
  - Predict *when* significant sand was exported off the shelf into deep-water
  - Encourage exploration
- DATA SOURCES:
  - Regional well log correlations
  - Public-domain seismic data
  - Outcrop-based geologic mapping & stratigraphic studies

Curious Cubs. . .

Regional Brookian X-sections

Beaufort Sea Areawide Sale

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18

Toolik Fed 3

Lake 79 Fed 1

W Staines St 18-09-23

seismic traverse ARCO 80-07 & 80-06

NPRA

1002 Area

ANWR

Decker, 2007

Decker & others, in press

Trans-Alaska Pipeline System

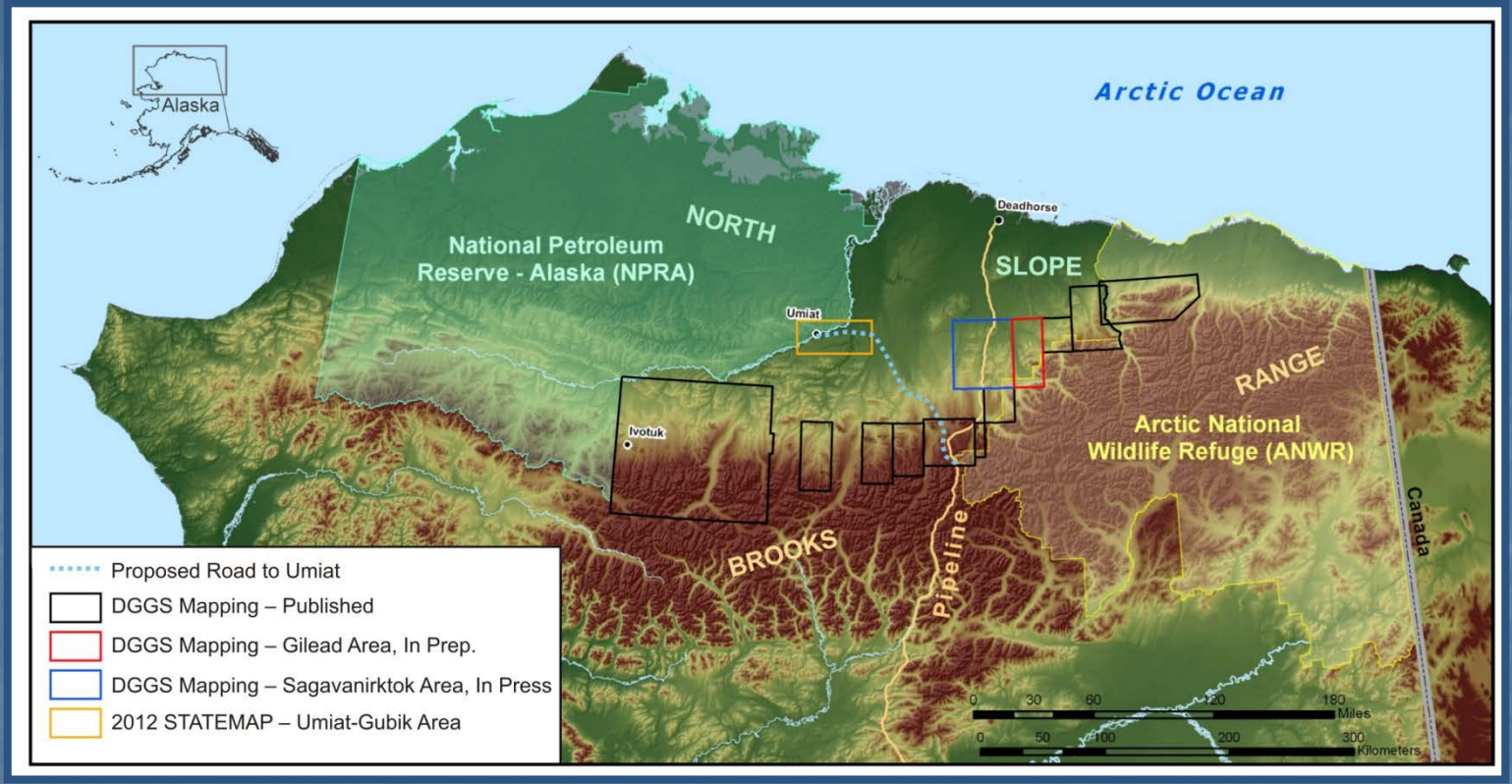
North Slope Areawide Sale

Foothills Areawide Sale

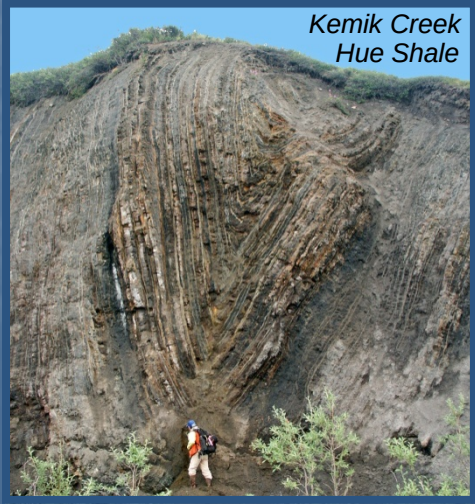
10 km

10 mi

Field-based Mapping & Stratigraphy



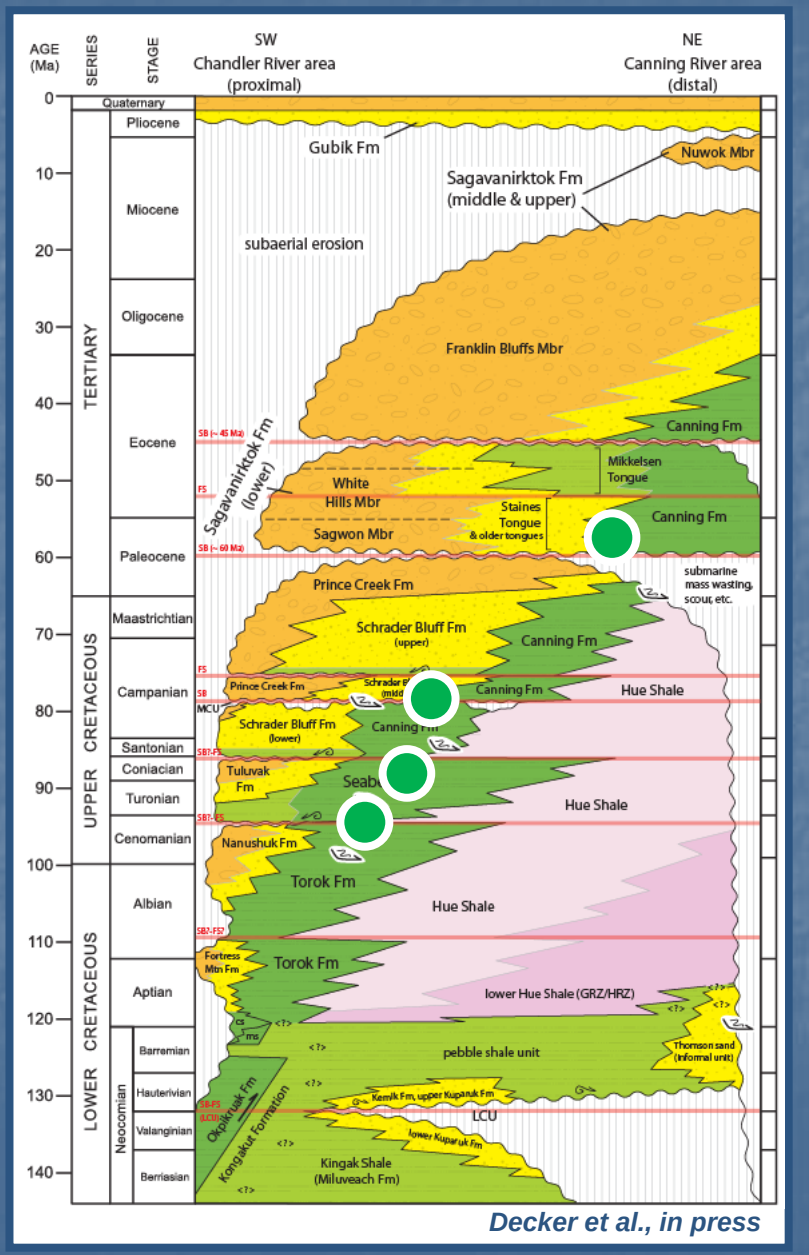

Colville River
Seabee Fm.


Kemik Creek
Hue Shale


Tuktu Bluff (Nanushuk Fm.)

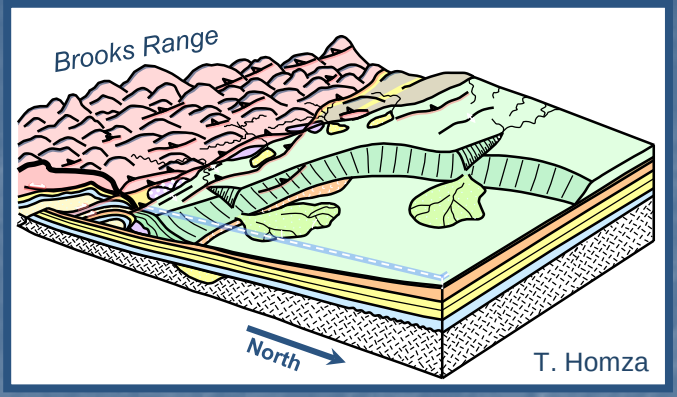
Key Findings

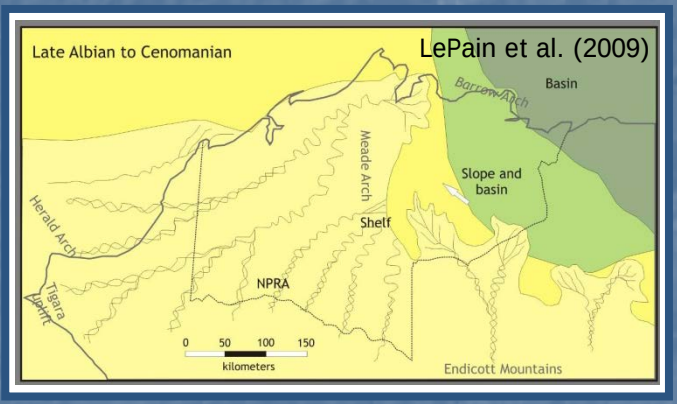
- Semi-regional surfaces of fundamental sequence-stratigraphic significance
  - Lowstand sequence boundaries
  - Transgressive flooding surfaces
  - Surfaces of composite origin
- Primary genetic units comprise time-equivalent topset, foreset, and bottomset facies
  - Some genetic units encompass all or parts of one or more formations as defined by lithostratigraphic criteria
- **Sandstone is exported into deep-water settings, creating exploration targets during:**
  1. **Cenomanian**
  2. **Turonian**
  3. **mid-Campanian**
  4. **Paleocene**

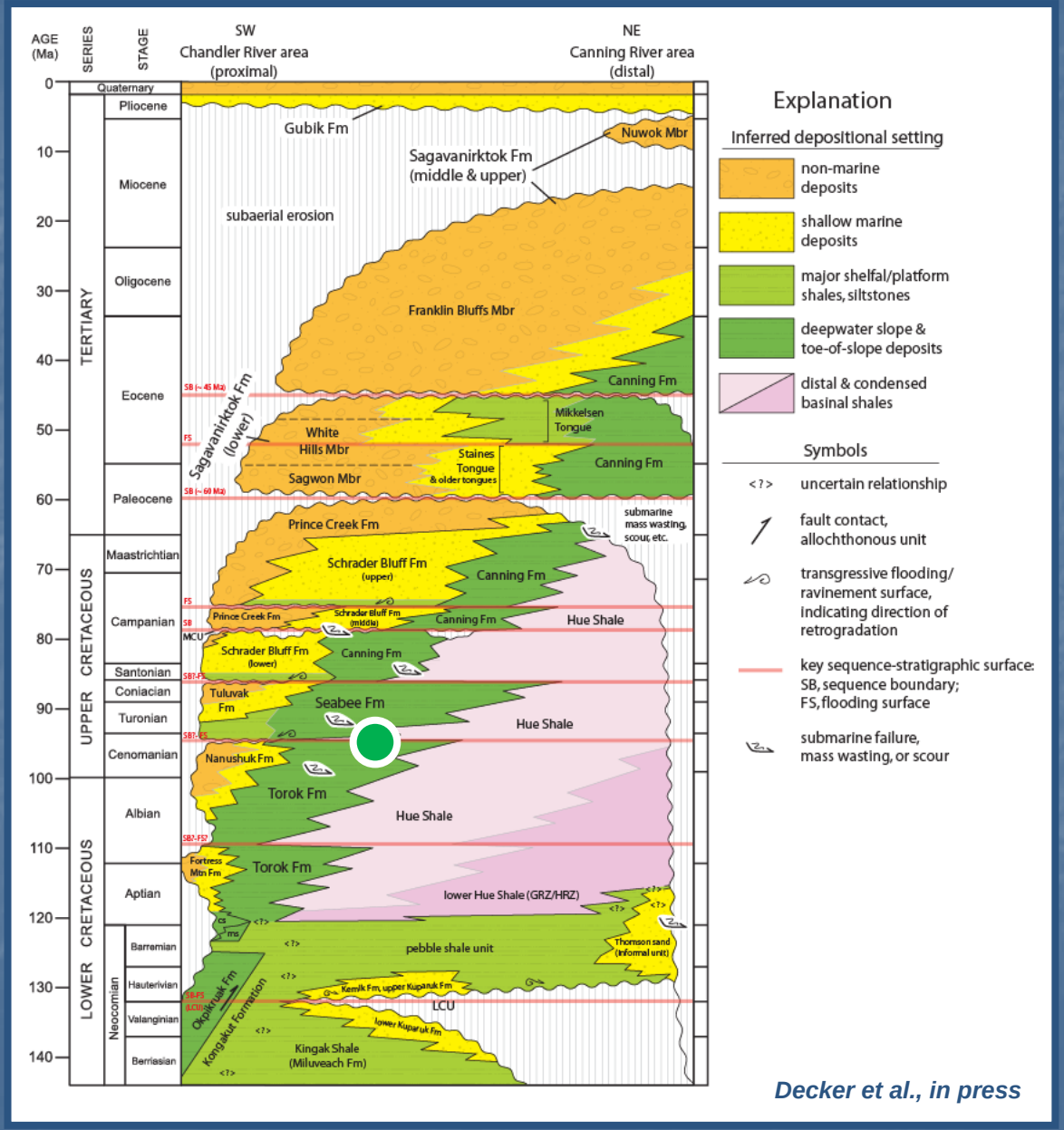


Decker et al., in press

1) Cenomanian – Upper Torok Formation

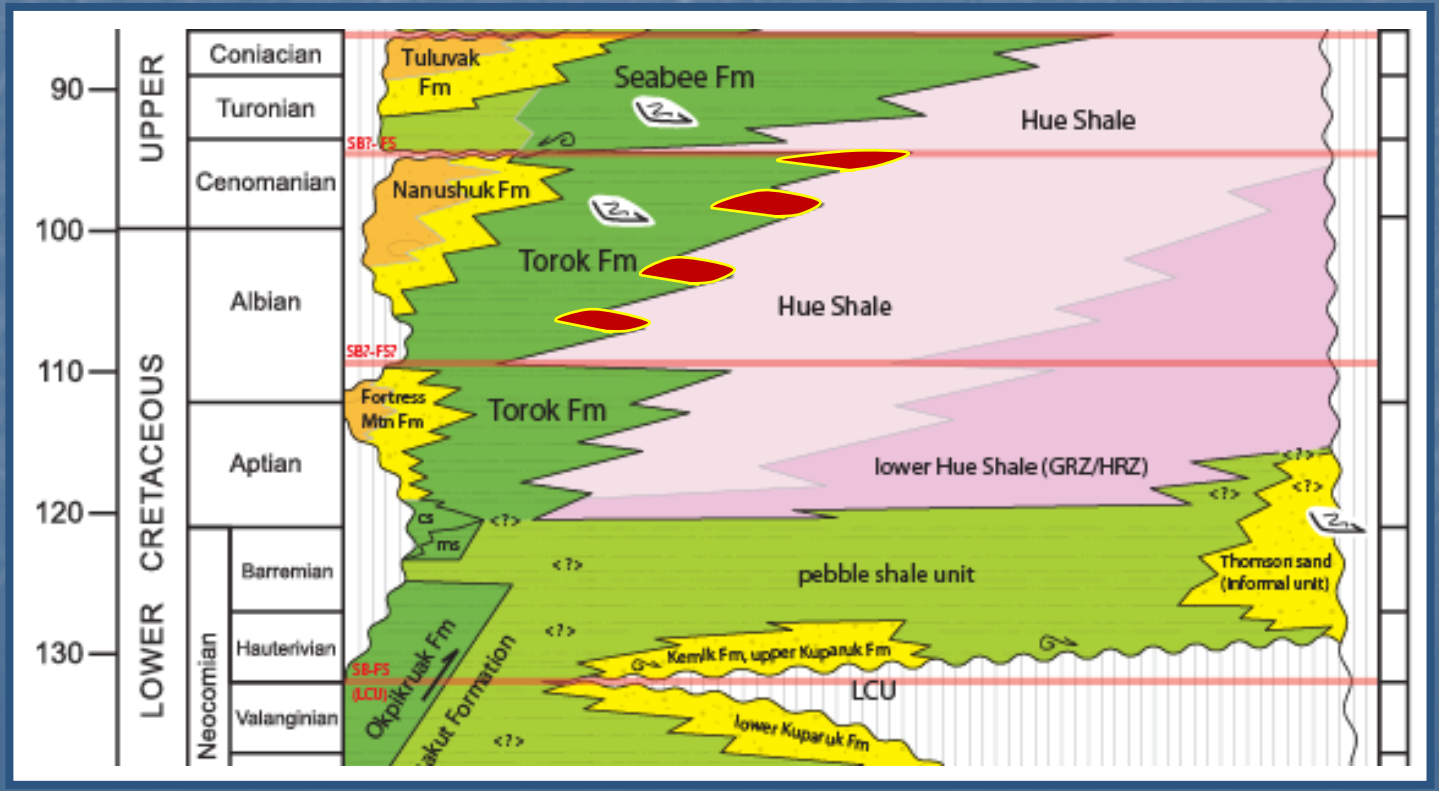




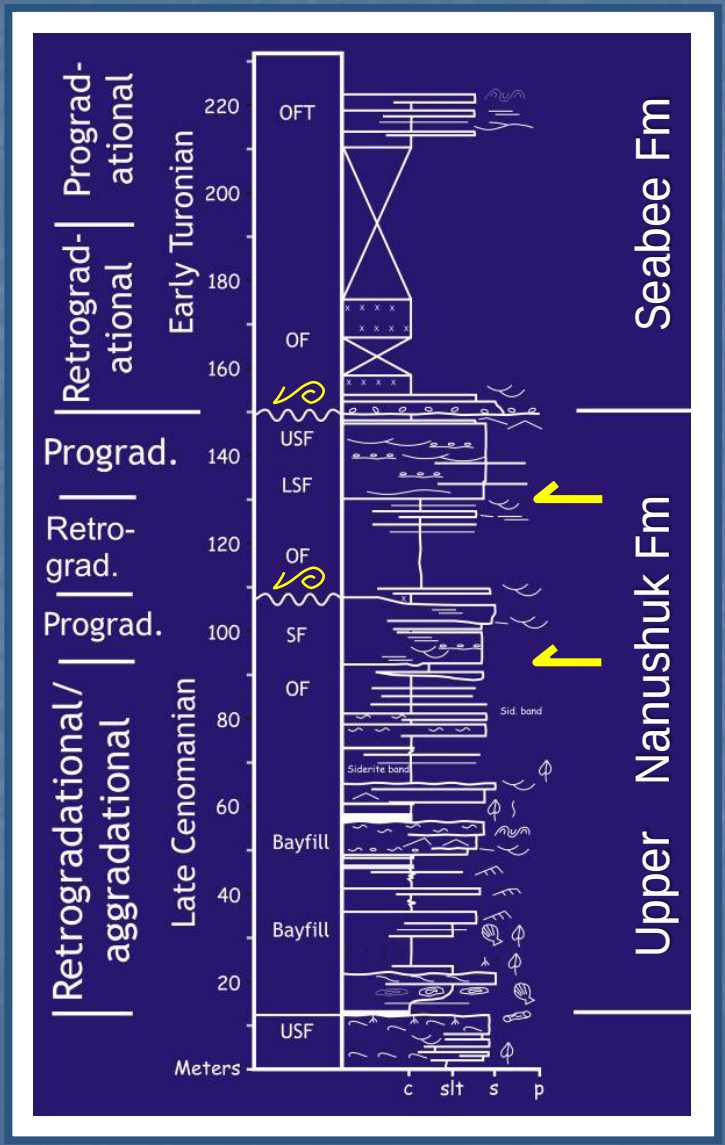


Cenomanian – Upper Torok Formation

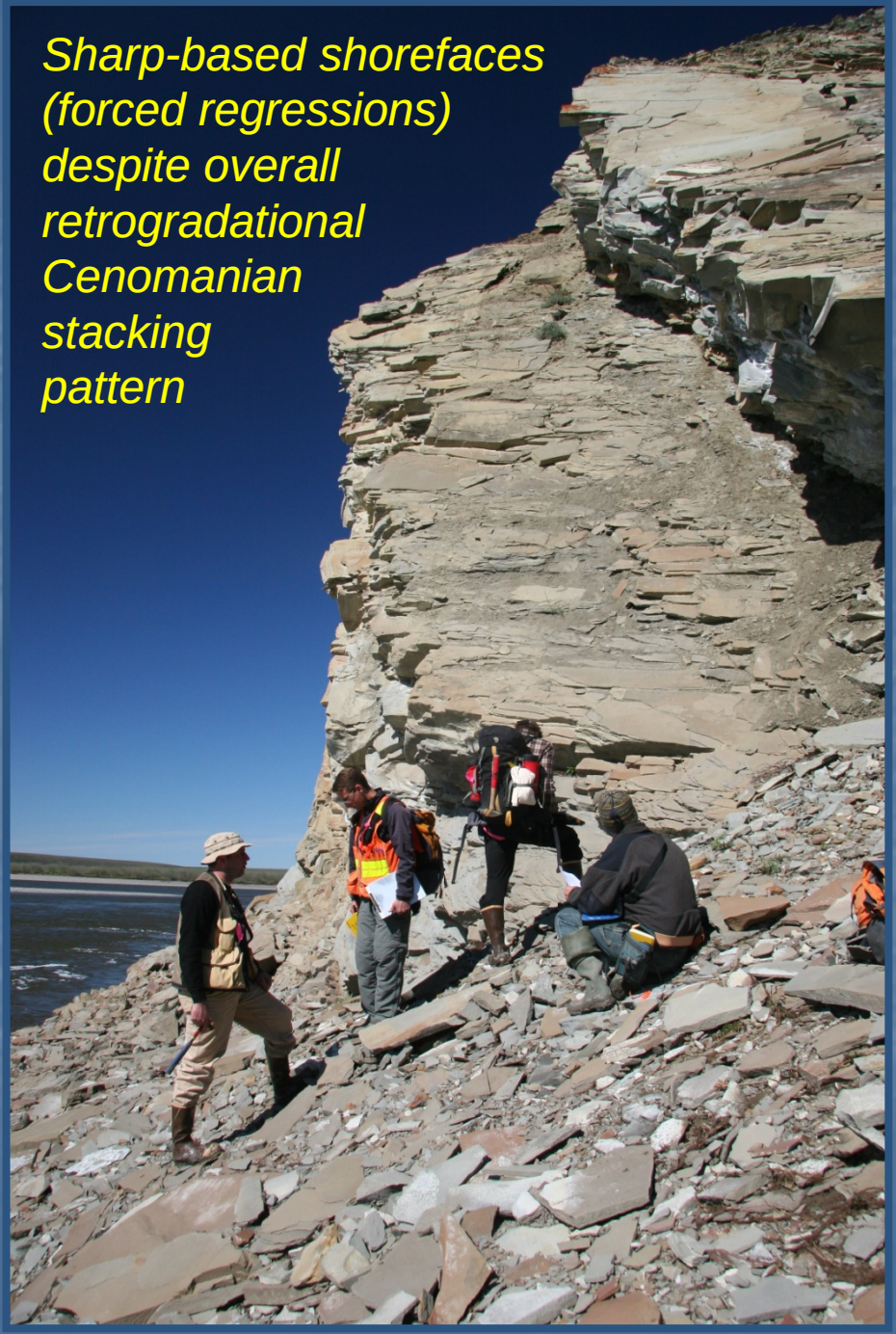
- Part of very large prograding clinoform system
- Upper Nanushuk retrogradational topsets record several erosional sequence boundaries nested within an overall transgressive assemblage
- In outcrop, the age-equivalent upper Torok include coarse-grained, amalgamated sediment gravity flow deposits that are occasionally oil-stained



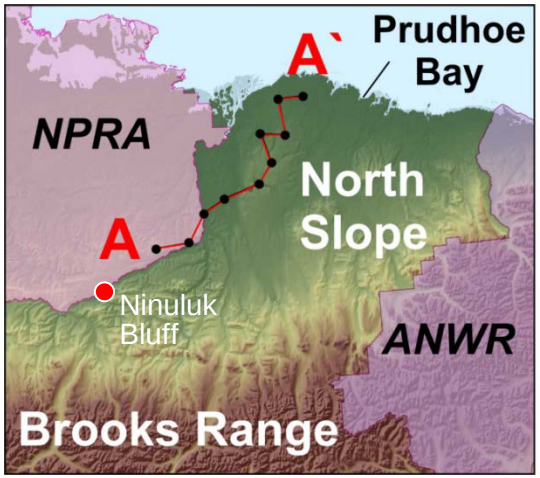
Cenomanian Topsets, uppermost Nanushuk Fm



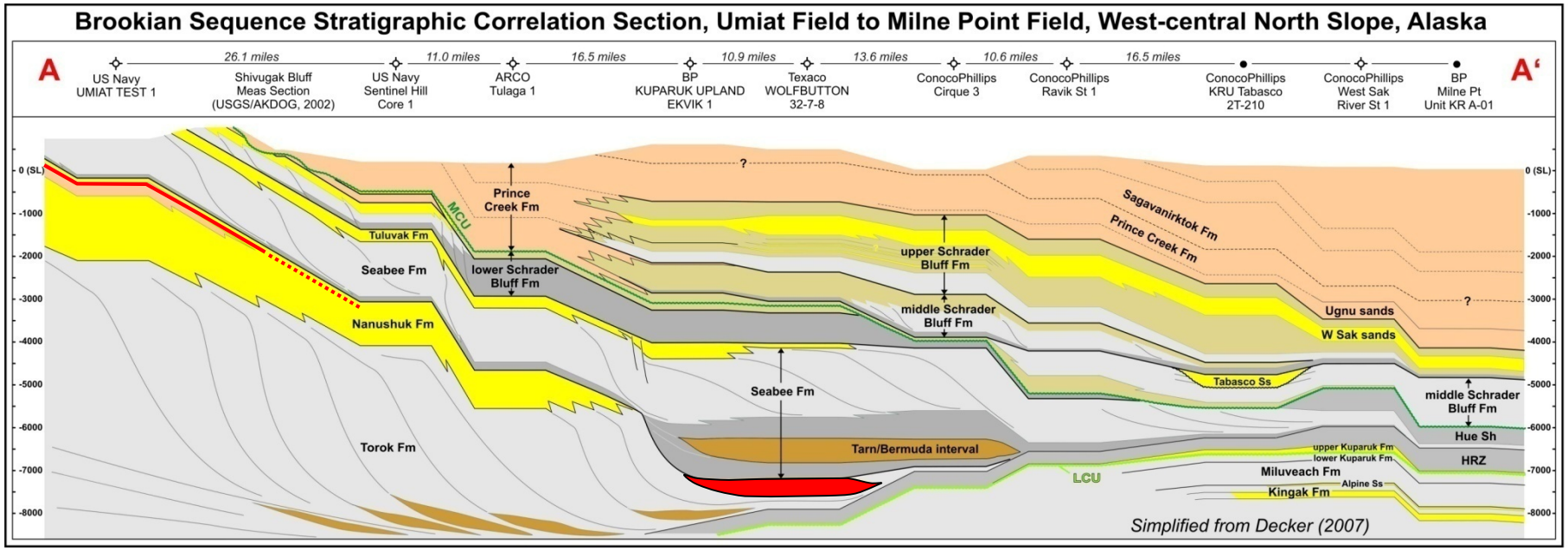
Ninuluk Bluff, Colville River -- LePain et al., 2009



Cenomanian bypass of sandstone into deep-water

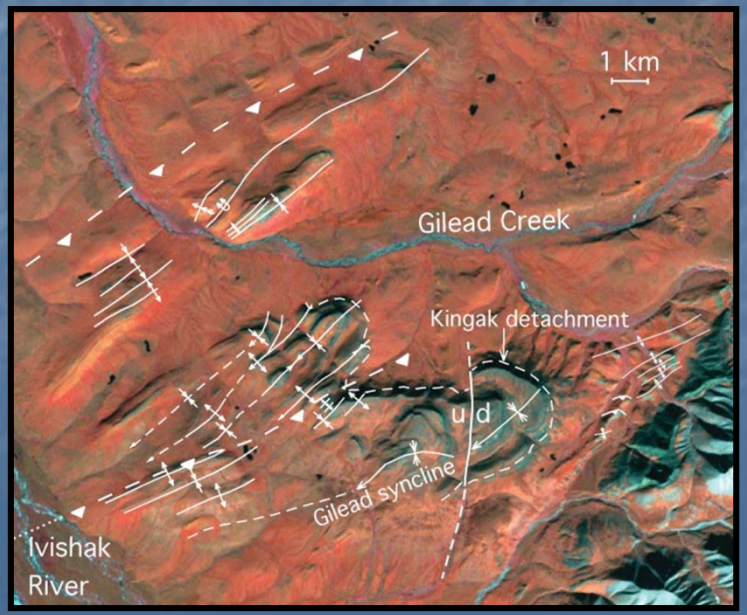


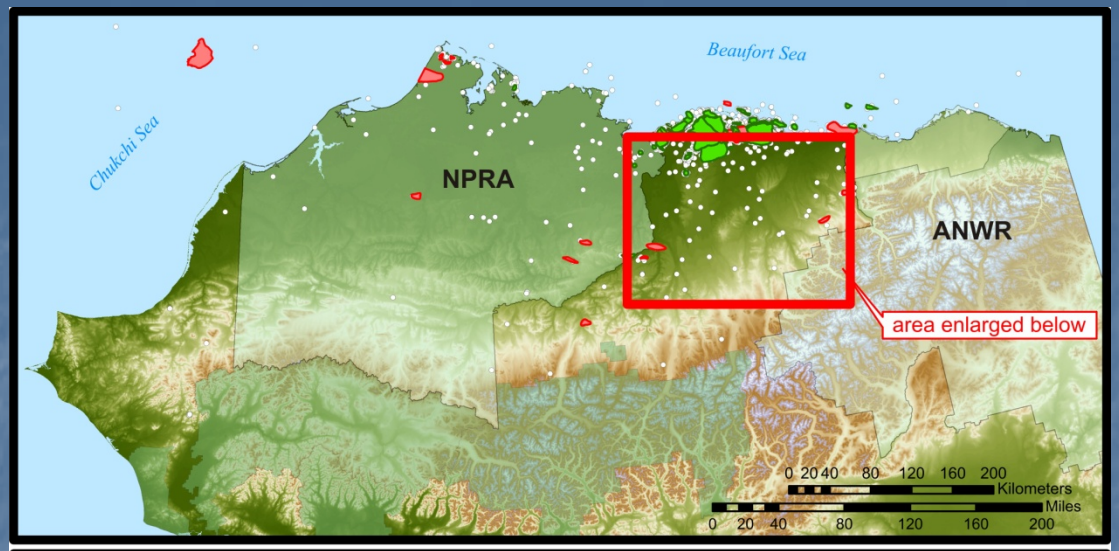
- nonmarine undifferentiated
- shallow marine to proximal shelf ss.
- distal shelf ss. to sltst.
- toe-of-slope turbidites (sand-prone)
- shelf to slope mudst. to sltst.
- condensed or bentonitic sh.

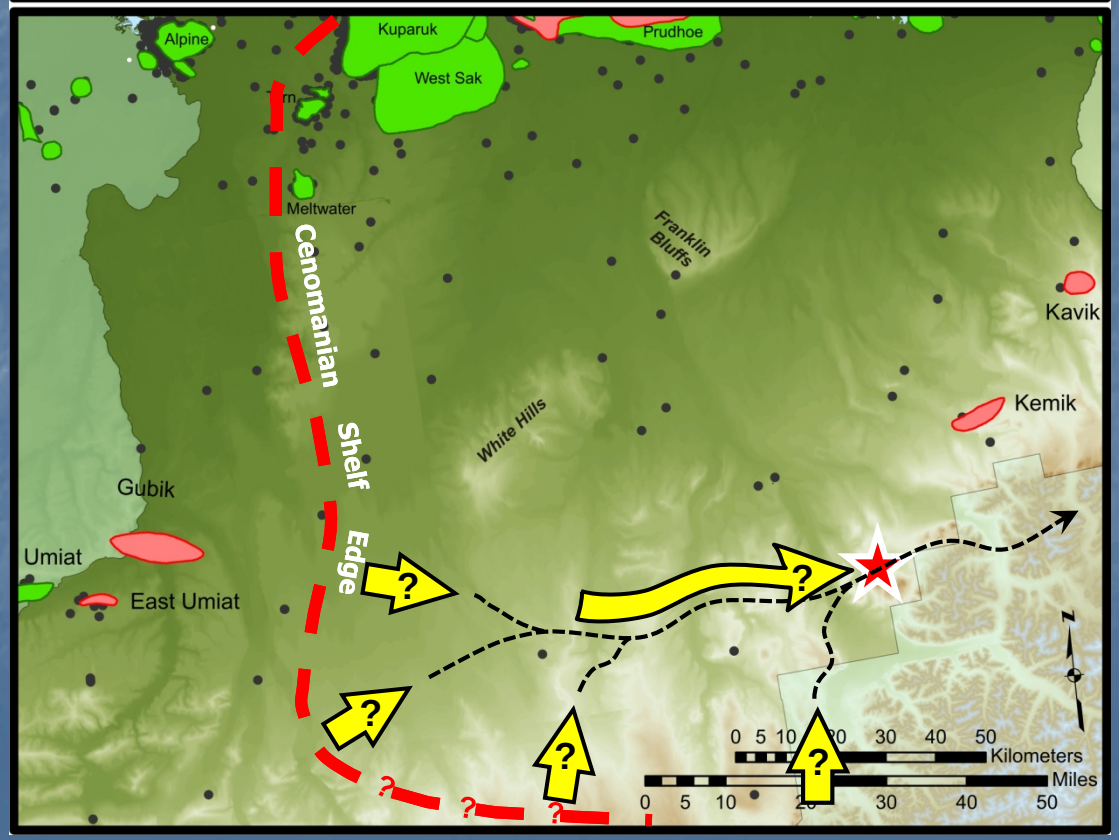


Cenomanian Upper Gilead Ss

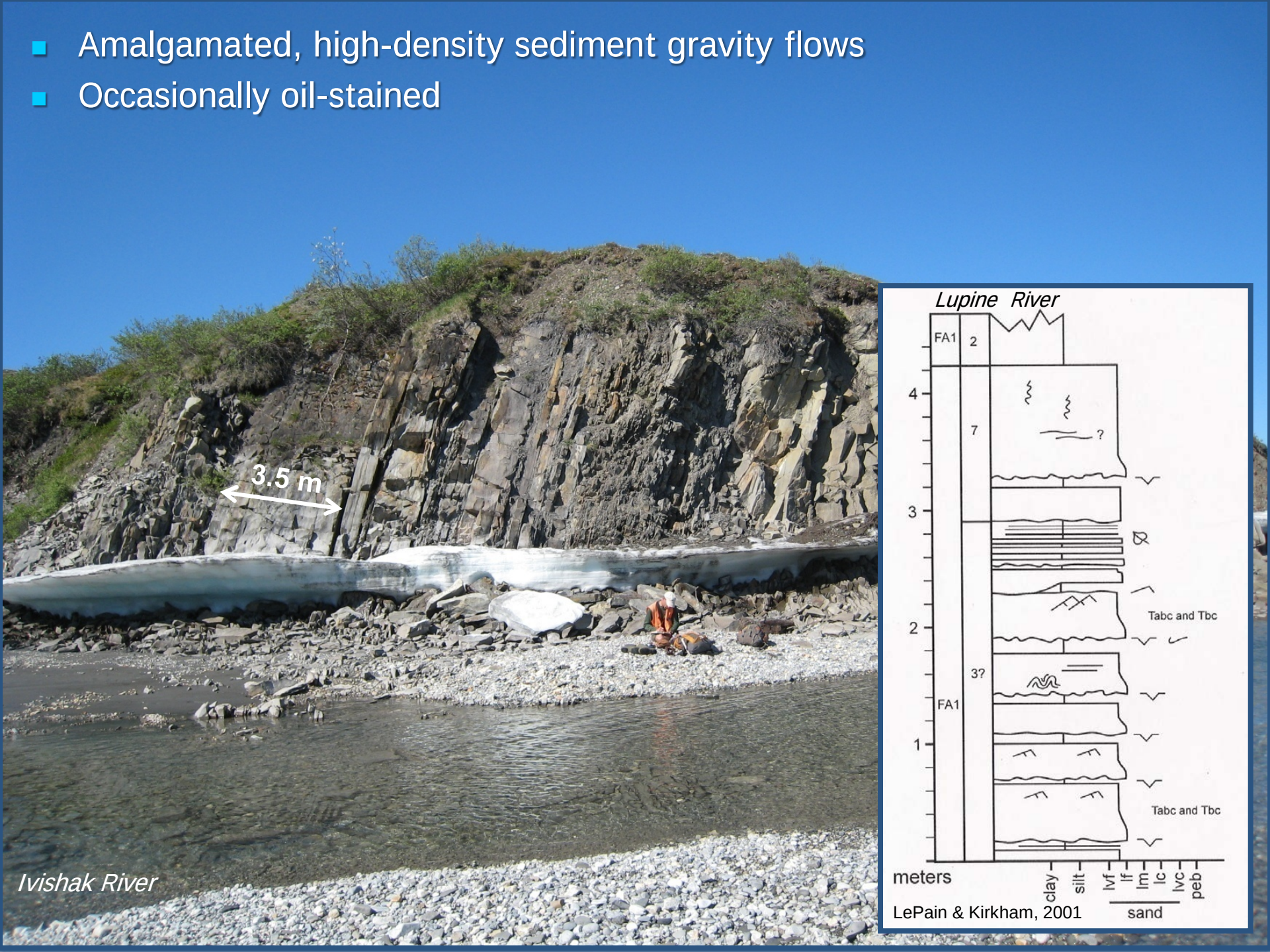
- Equivalent to the upper Torok
- Thick, bench-forming, amalgamated sandstone units
- Sourced out of the south or southwest → ENE axial flow(?)
- Location of southern shelf edge uncertain





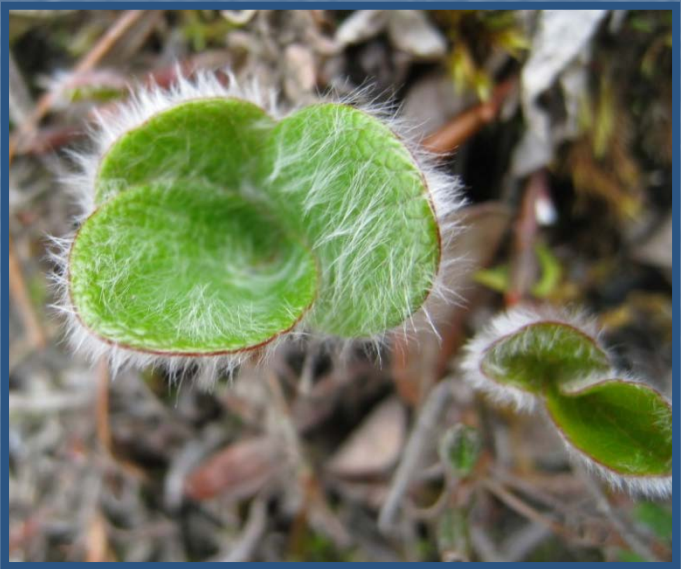


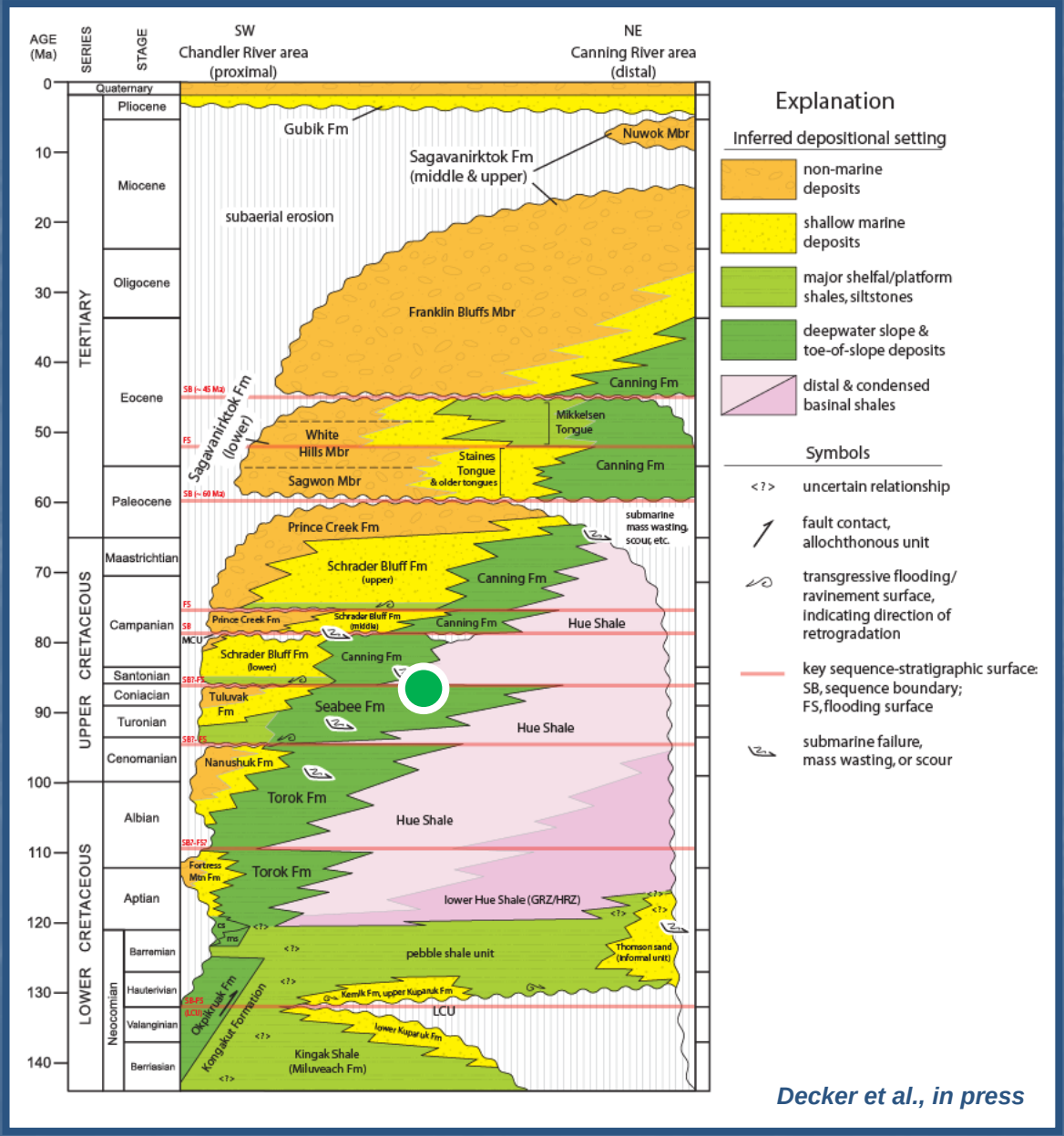
- Amalgamated, high-density sediment gravity flows
- Occasionally oil-stained



- Coarsest facies observed in Torok-equivalent strata
- Overlain by bentonitic, organic-rich condensed section

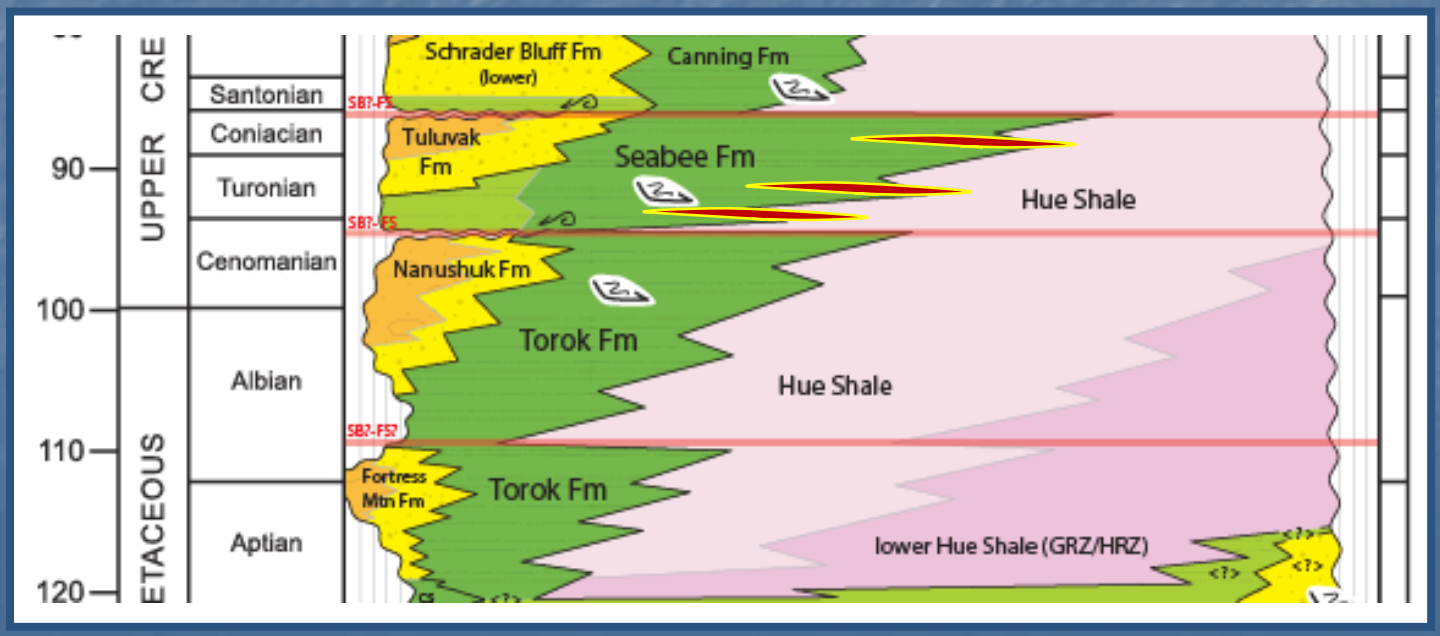
2) Turonian – Seabee Formation

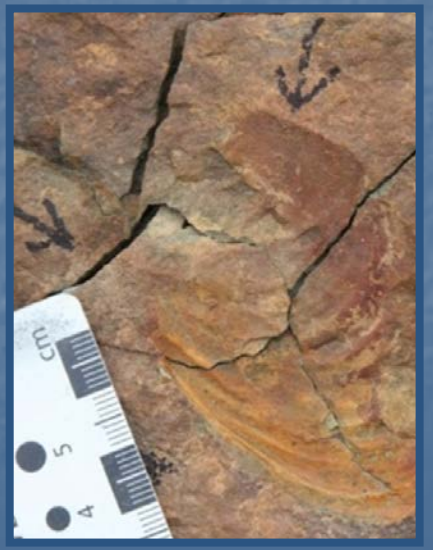




Turonian – Seabee Formation

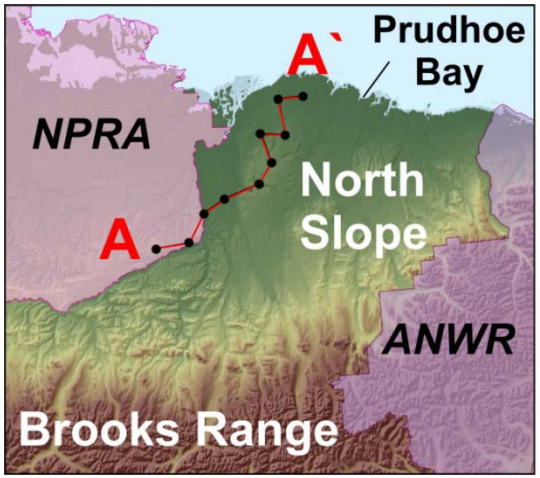
- Tuluvak – Seabee clinothem onlaps inherited mid-Cretaceous bathymetry
- Tuluvak topsets locally exhibit excellent reservoir quality
- Lowstand Seabee wedge (e.g. Tarn and Meltwater)
- Deep-water Seabee is encased and intertongues with Hue Shale source rocks





Mytiloides labiatus (Turonian)

Turonian bypass of sandstone into deep-water



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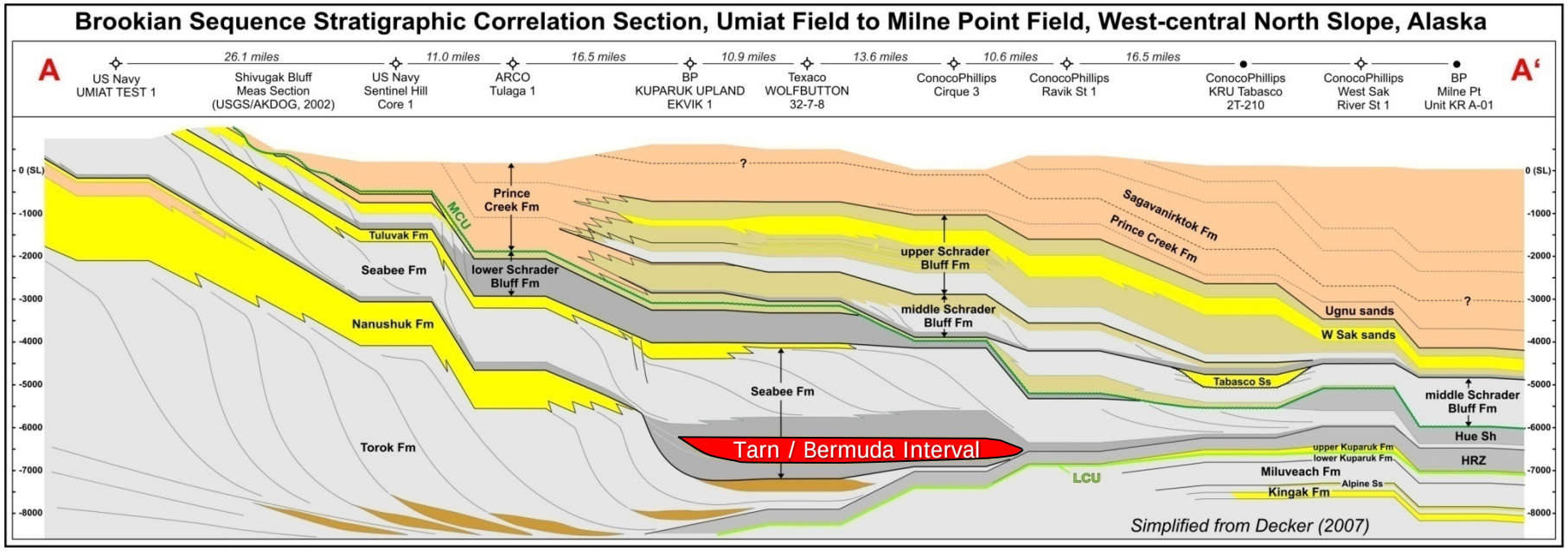
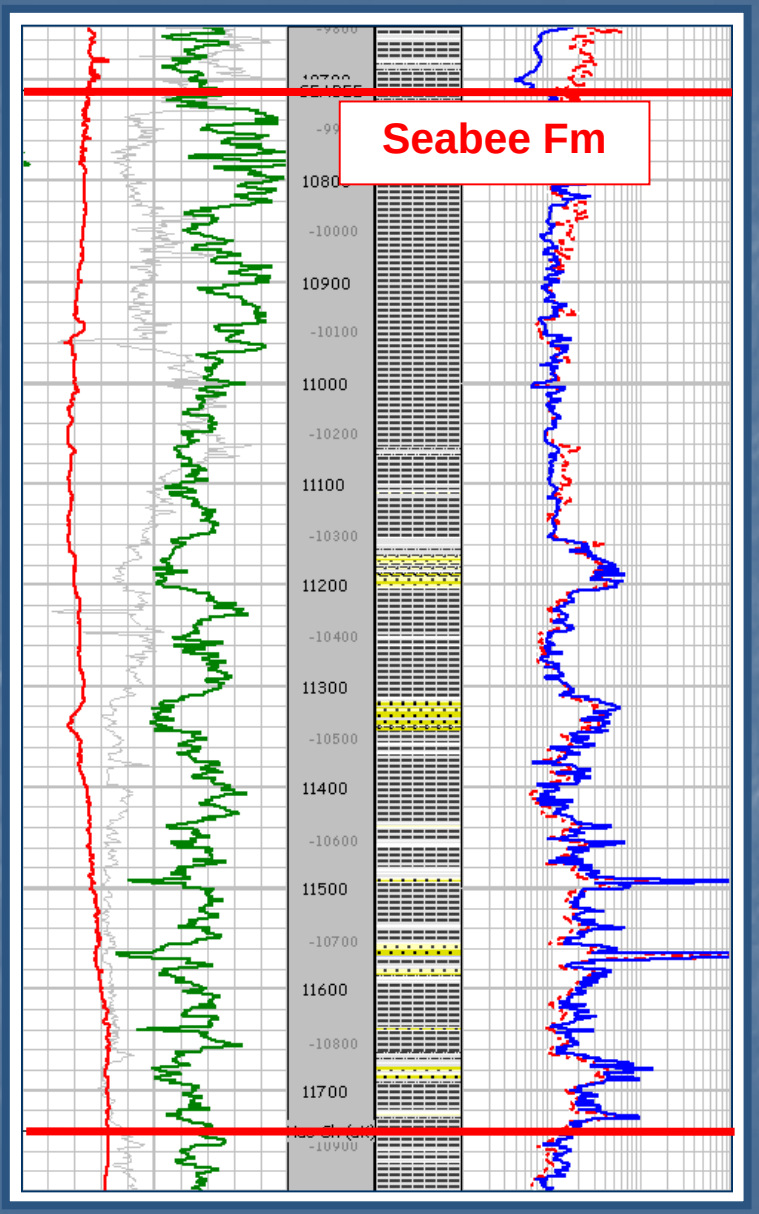
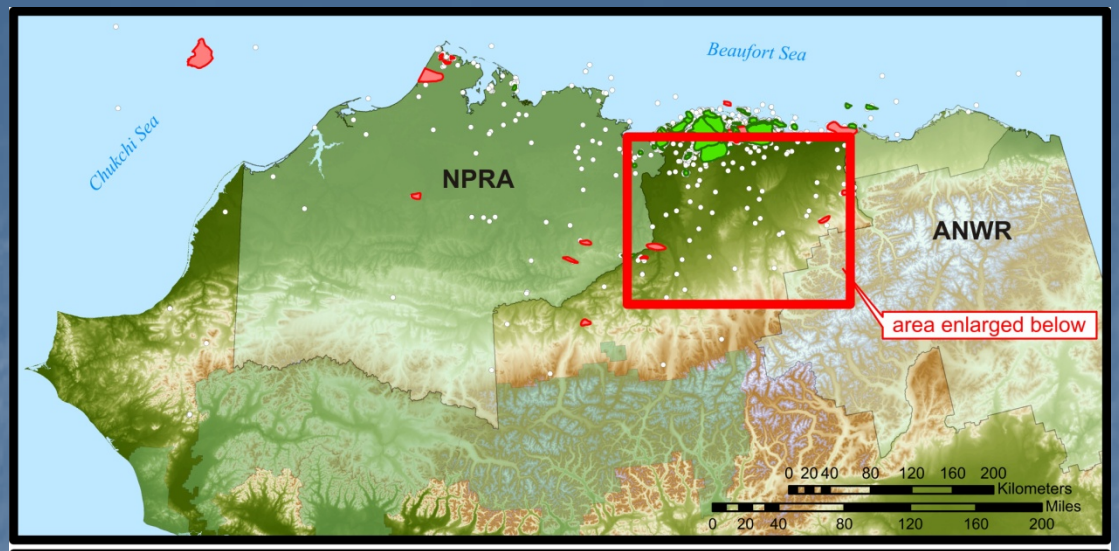
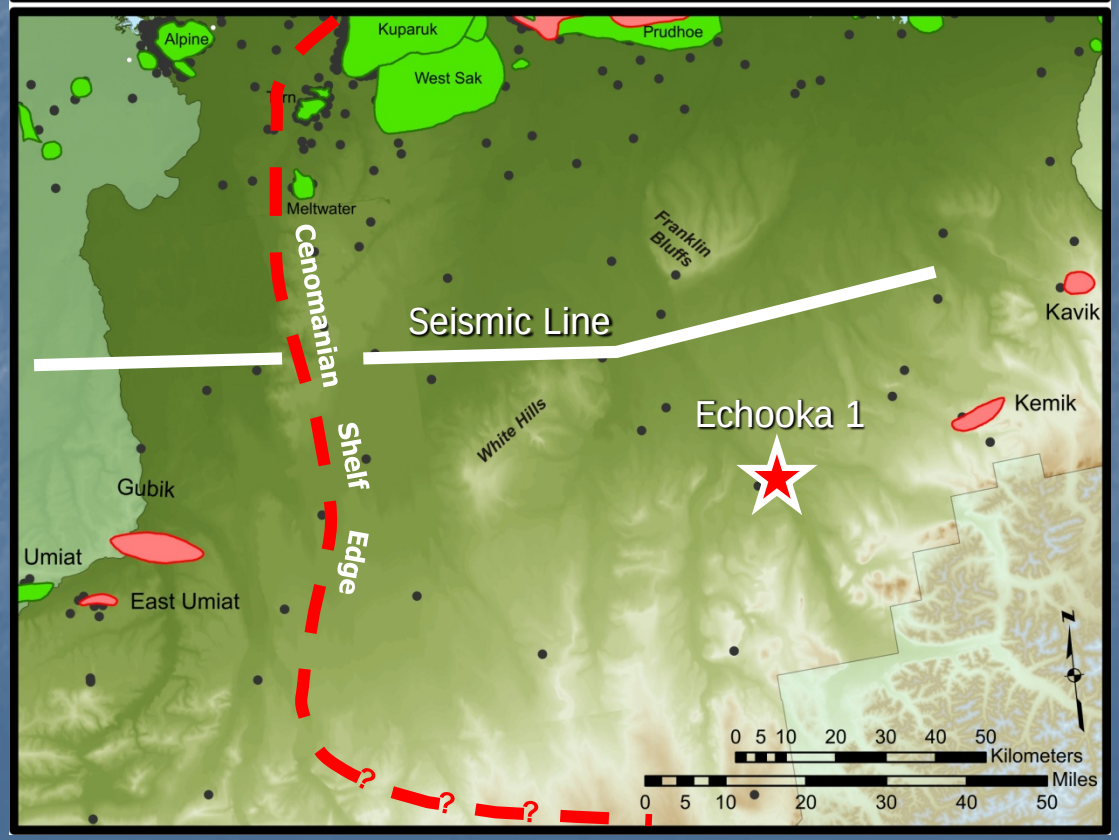


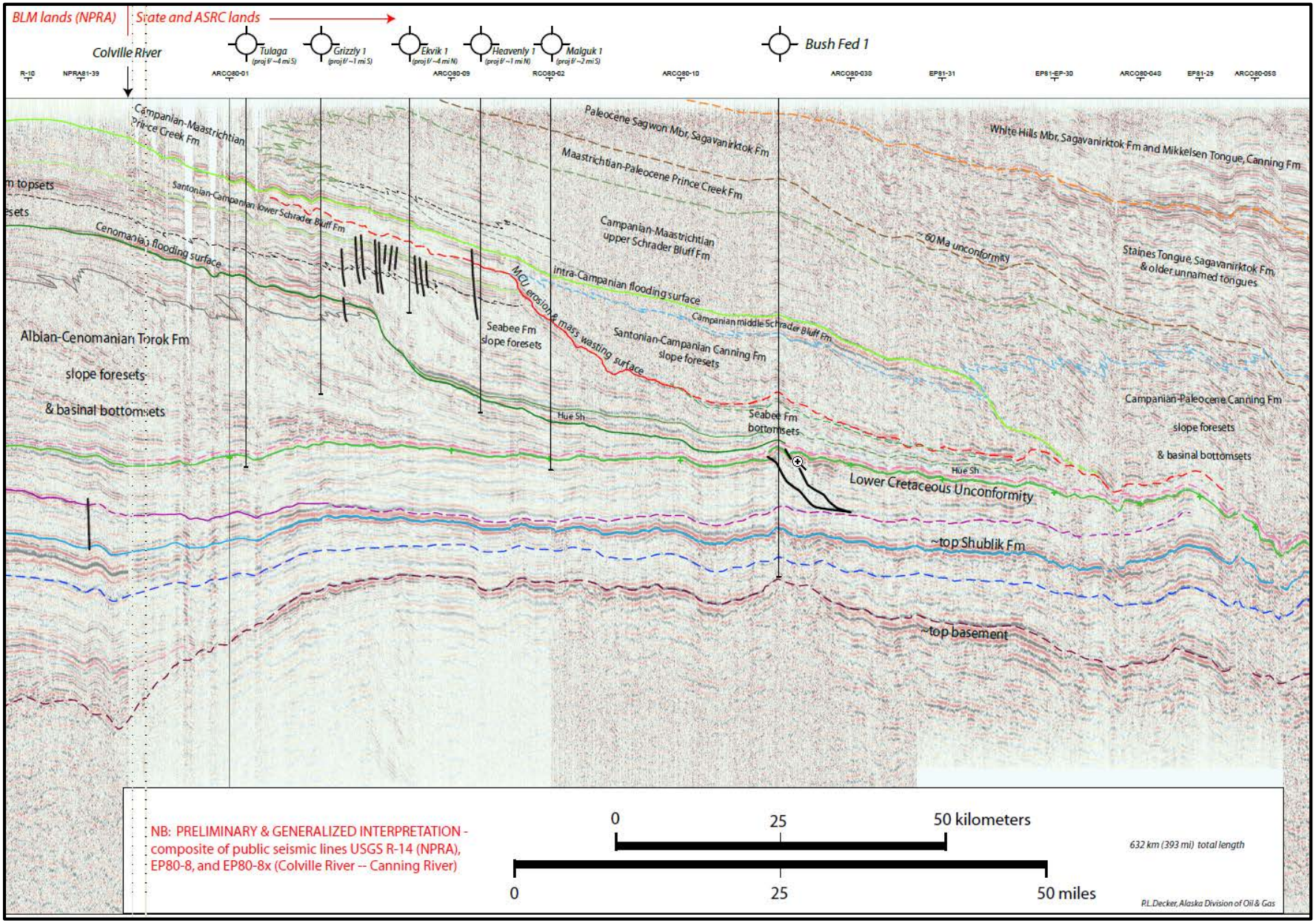
Echooka 1 well







Turonian – Seabee Formation



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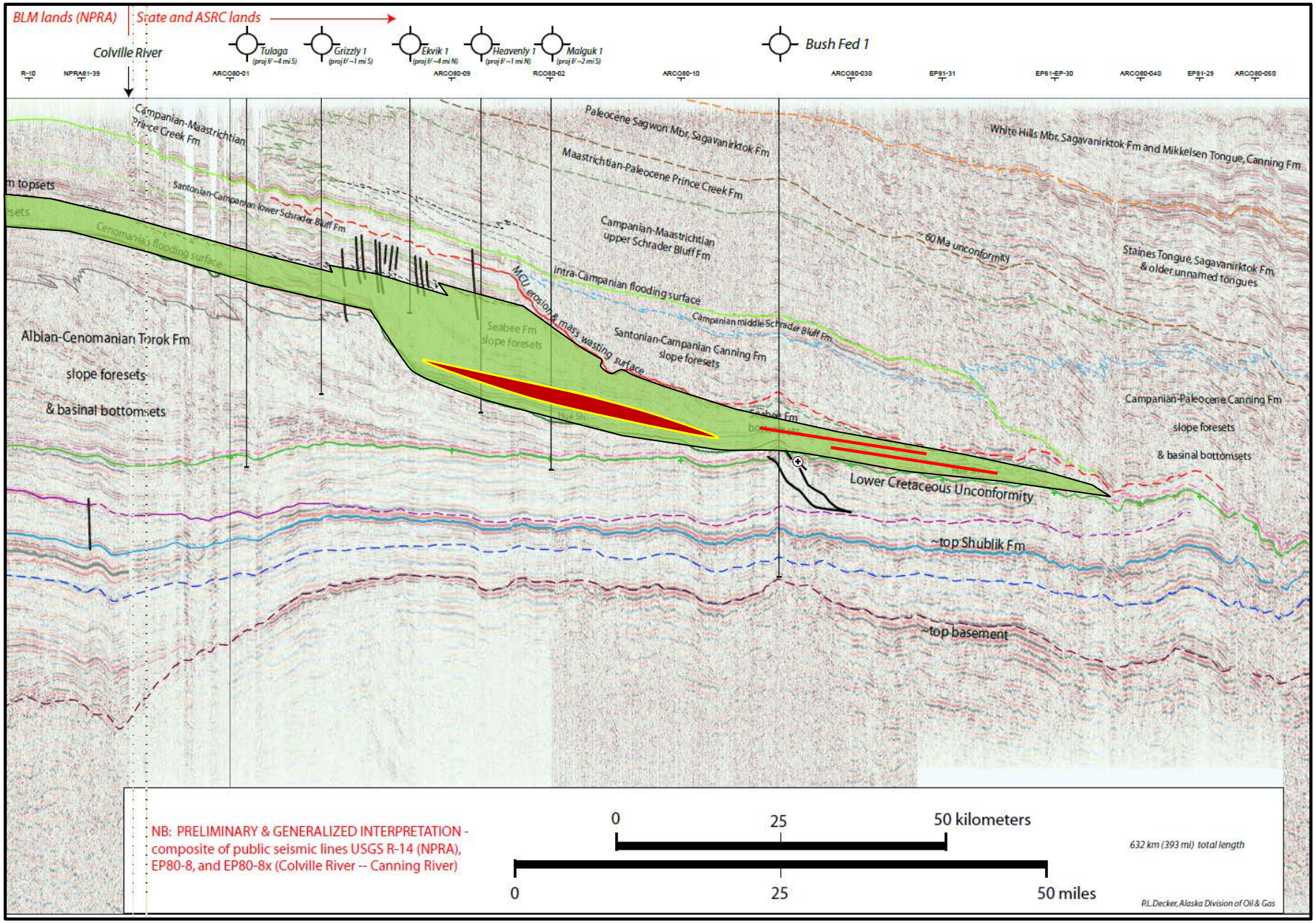
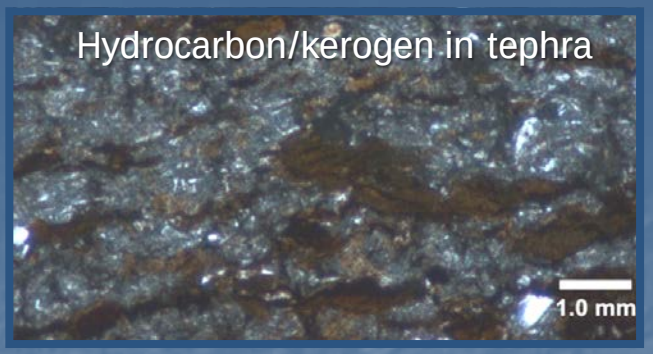
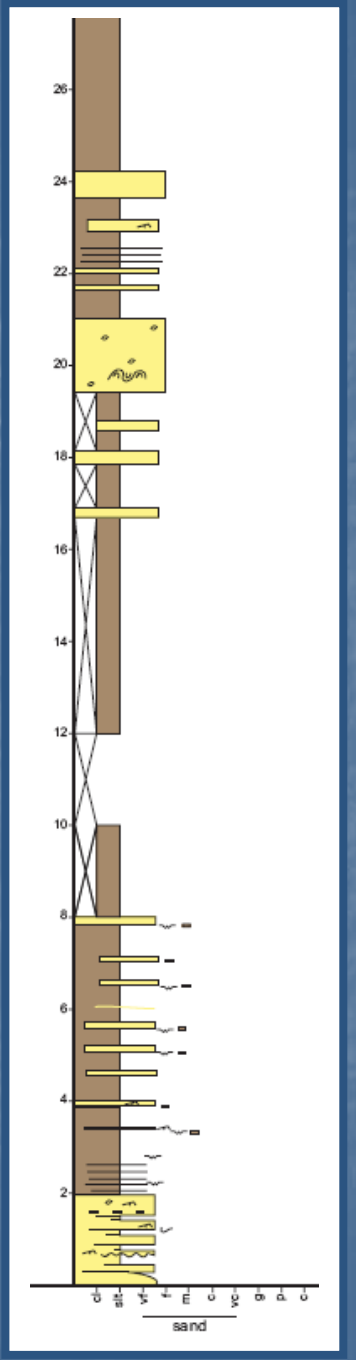


Distal Seabee in outcrop

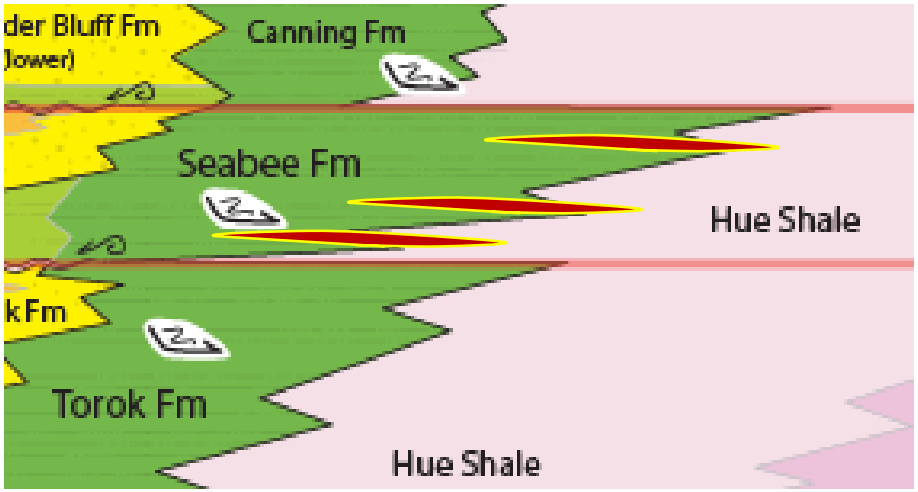
- Amalgamated to heterolithic sediment-gravity flow facies
- Commonly petroliferous

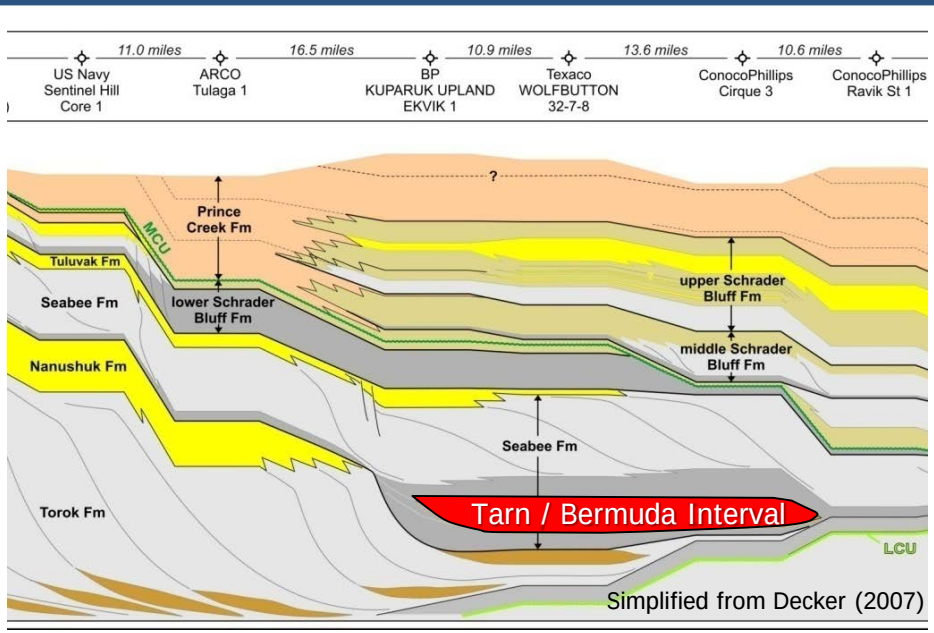




LePain et al., 2009

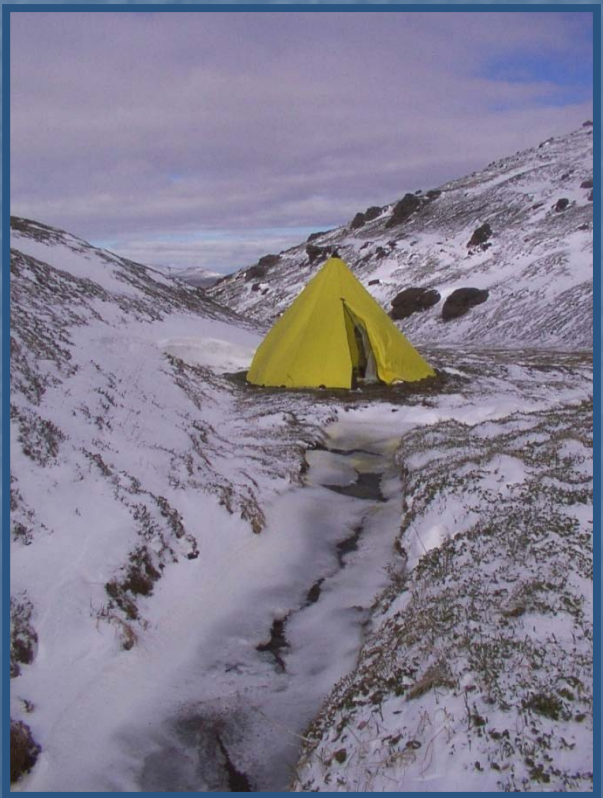
The “Hue Sandwich”

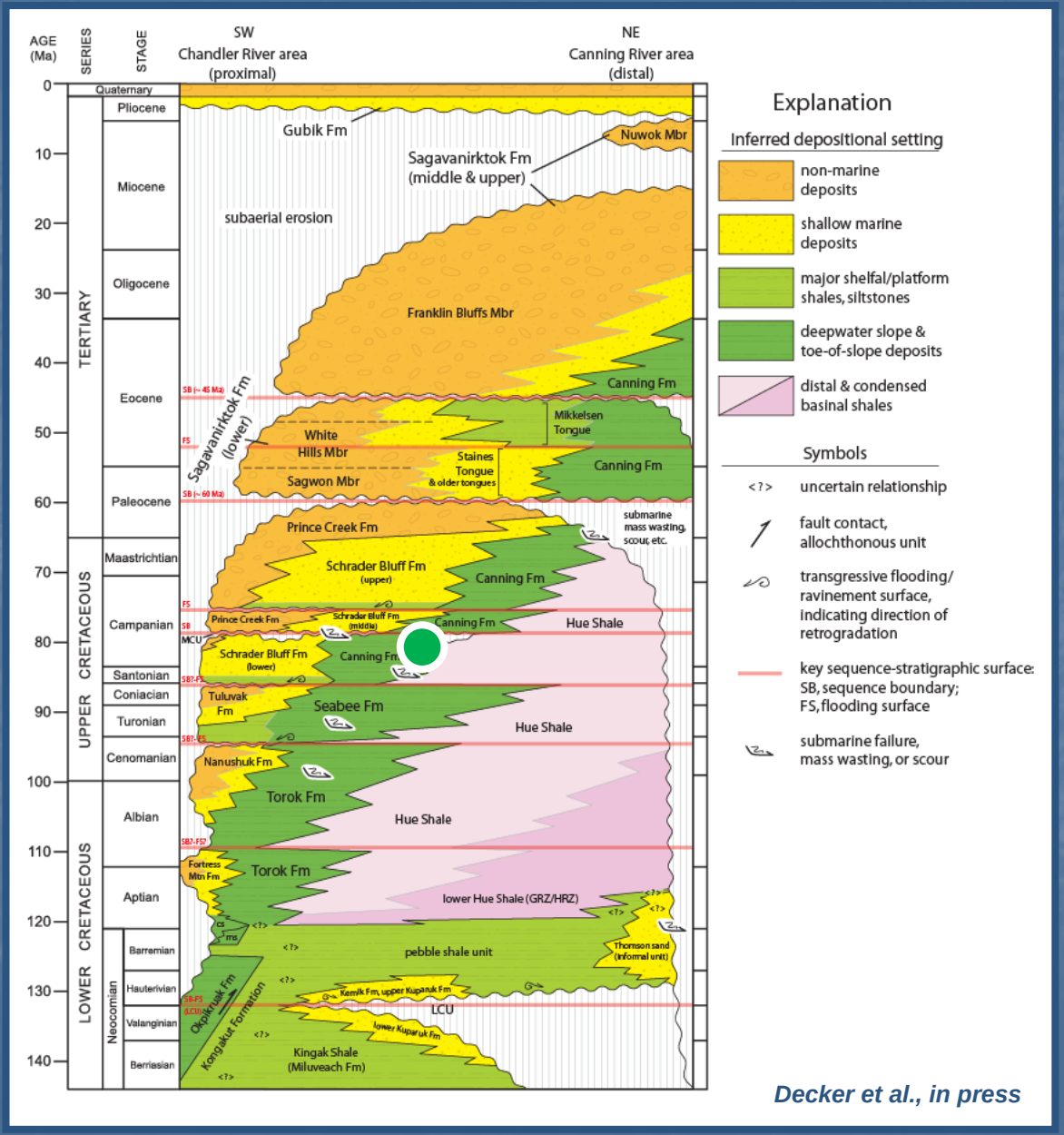




Simplified from Decker (2007)

3) Mid-Campanian – Canning Formation

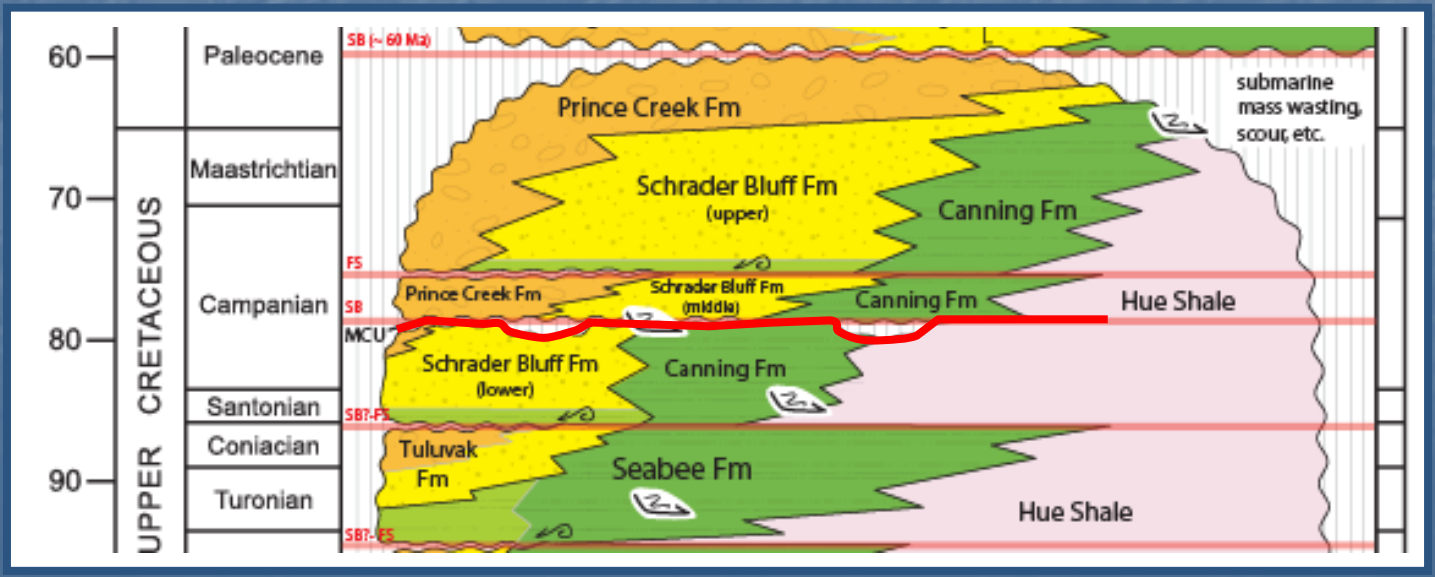




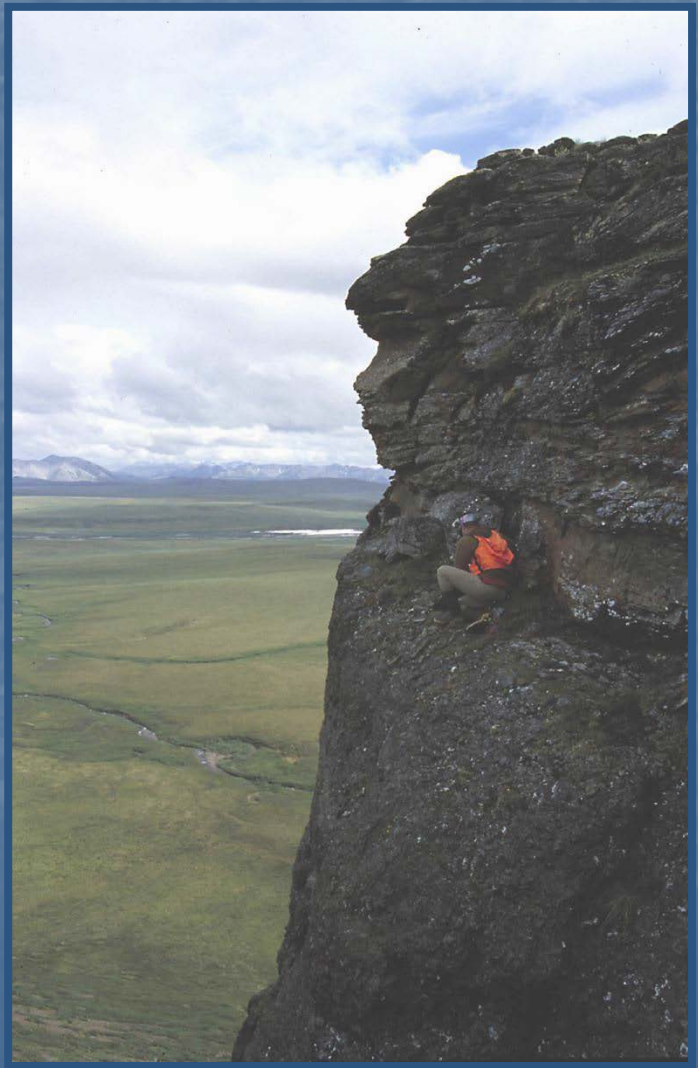
Decker et al., in press

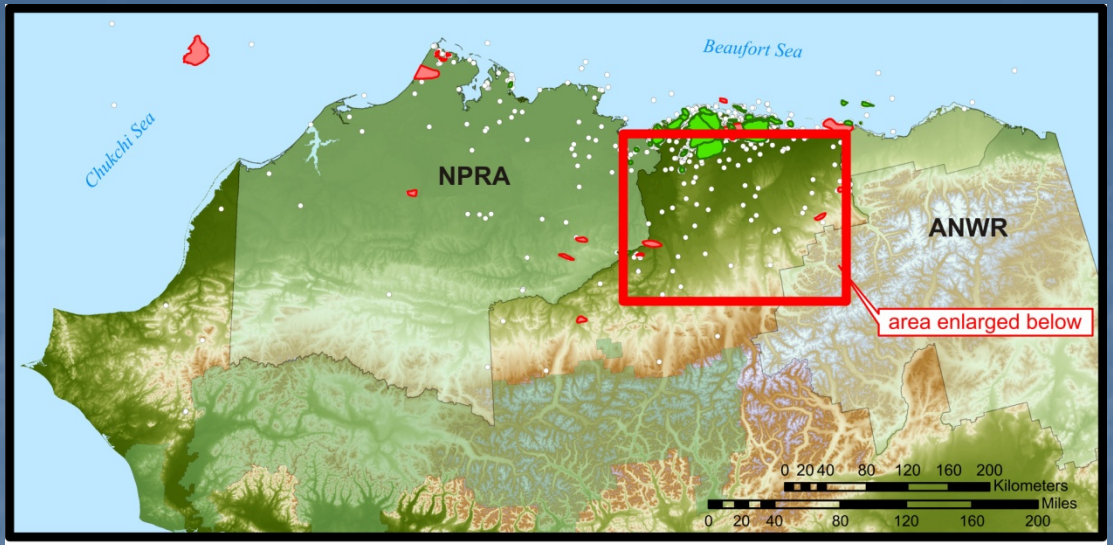
Mid-Campanian – Canning Formation

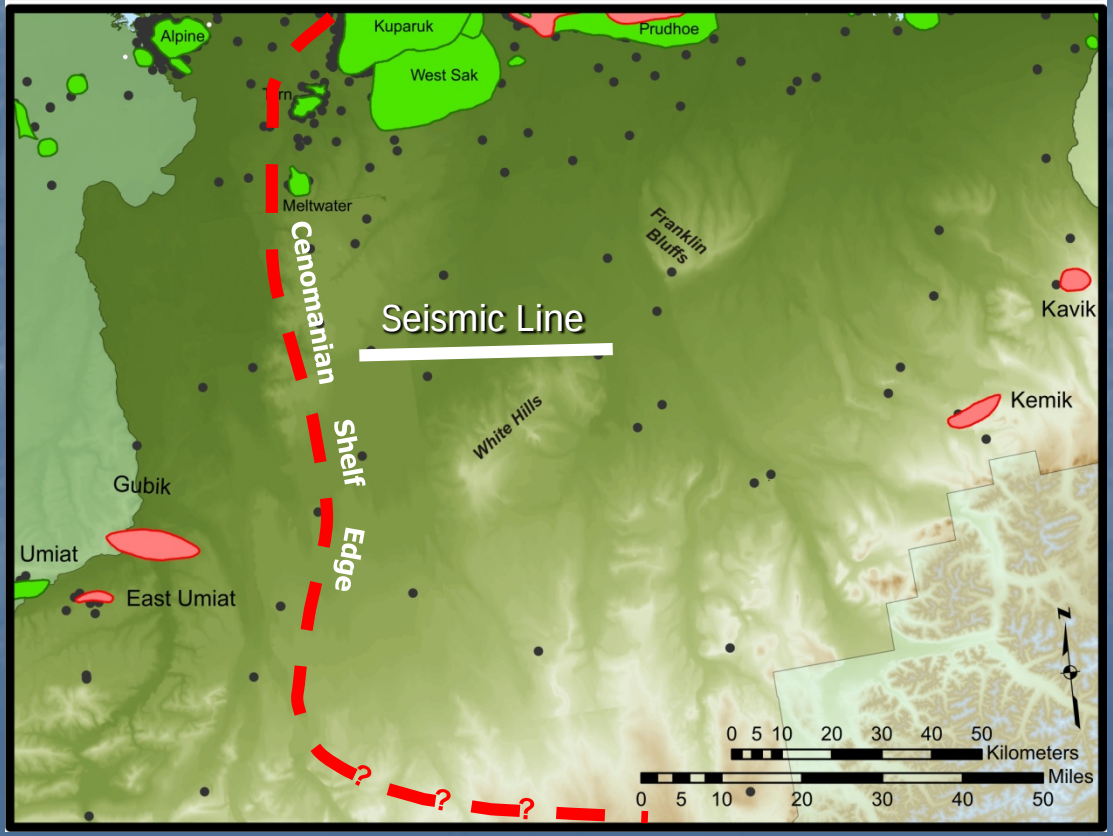
- Major mid-Campanian sequence boundary (MCU)
  - Incised valleys, shelf-margin incision and upper slope truncations
  - Basinal scours and erosional remnants
- Erosional relief created accomodation for bypassed sandstone
  - Valley fills
  - Shelf-margin deltas (Tabasco field)
  - Toe-of-slope lowstand wedge
  - Ponded sediment-gravity flows



MCU
Seismic Expression

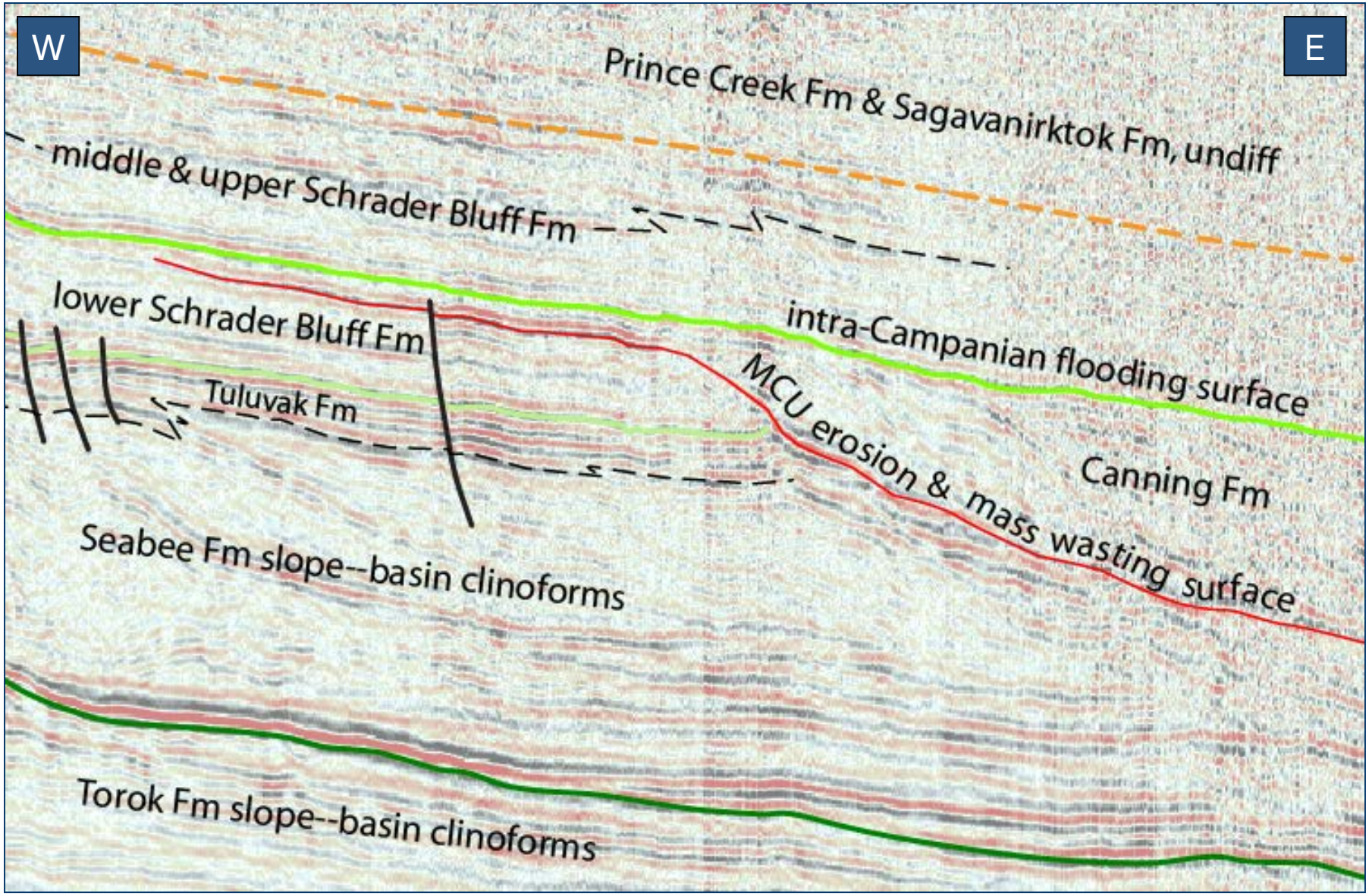






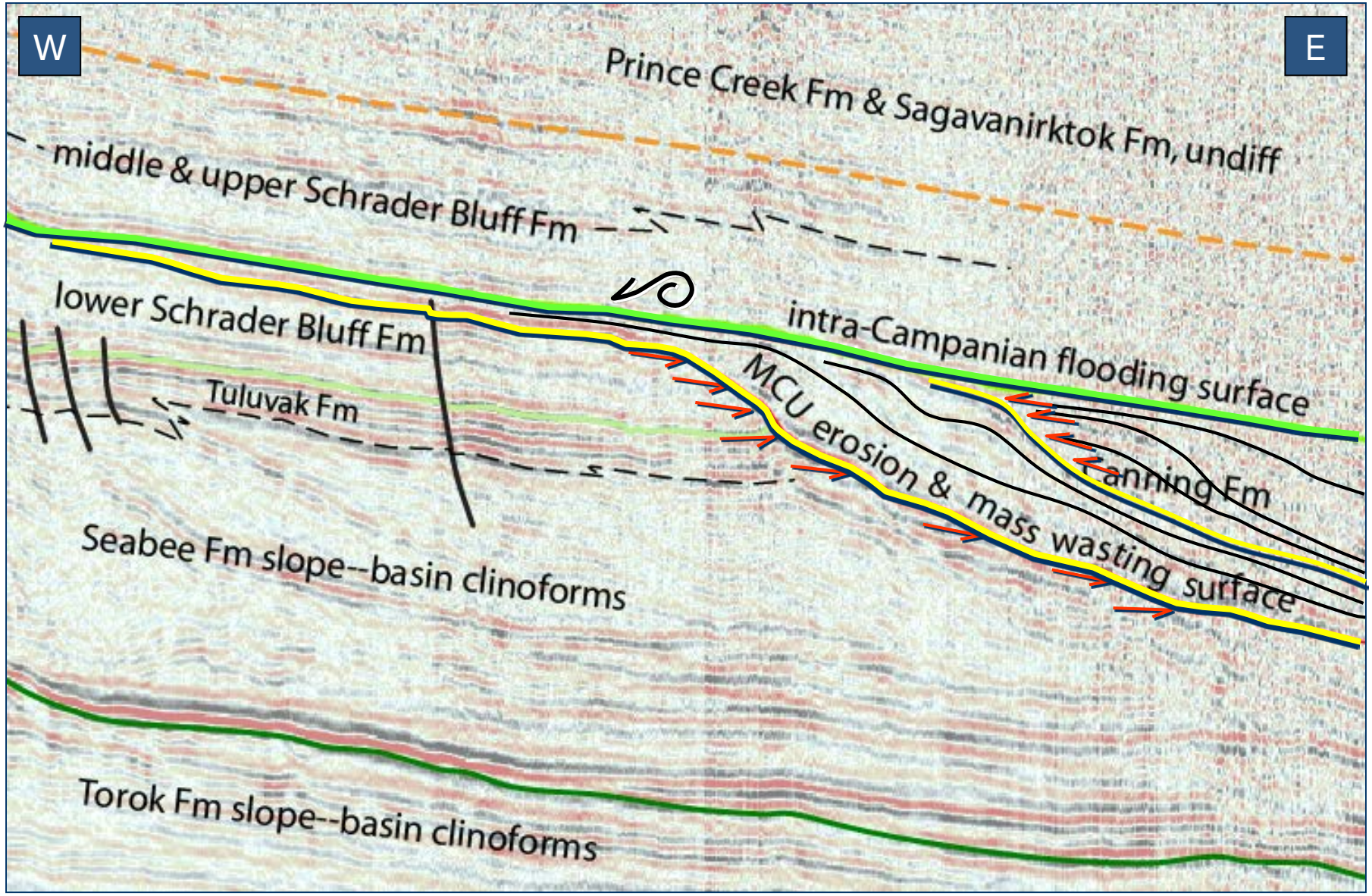
Mid-Campanian Unconformity

and other key sequence stratigraphic surfaces



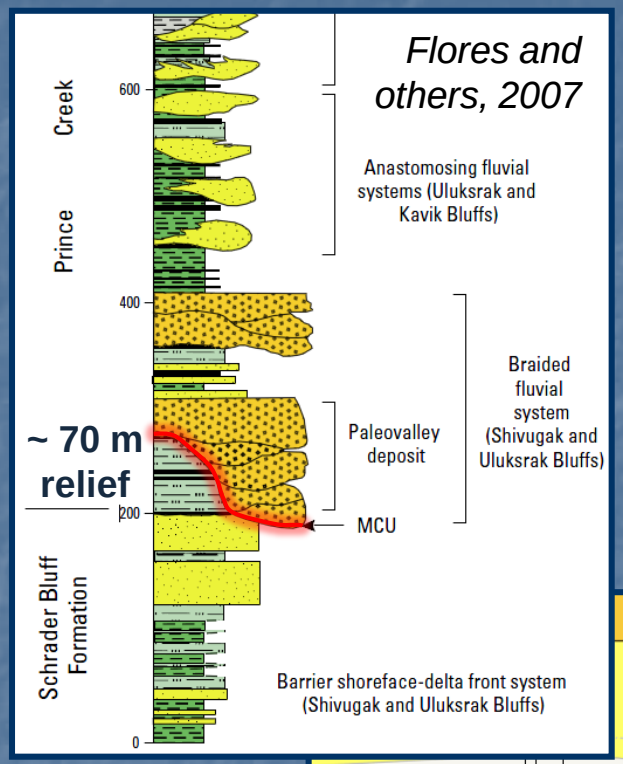
Mid-Campanian Unconformity

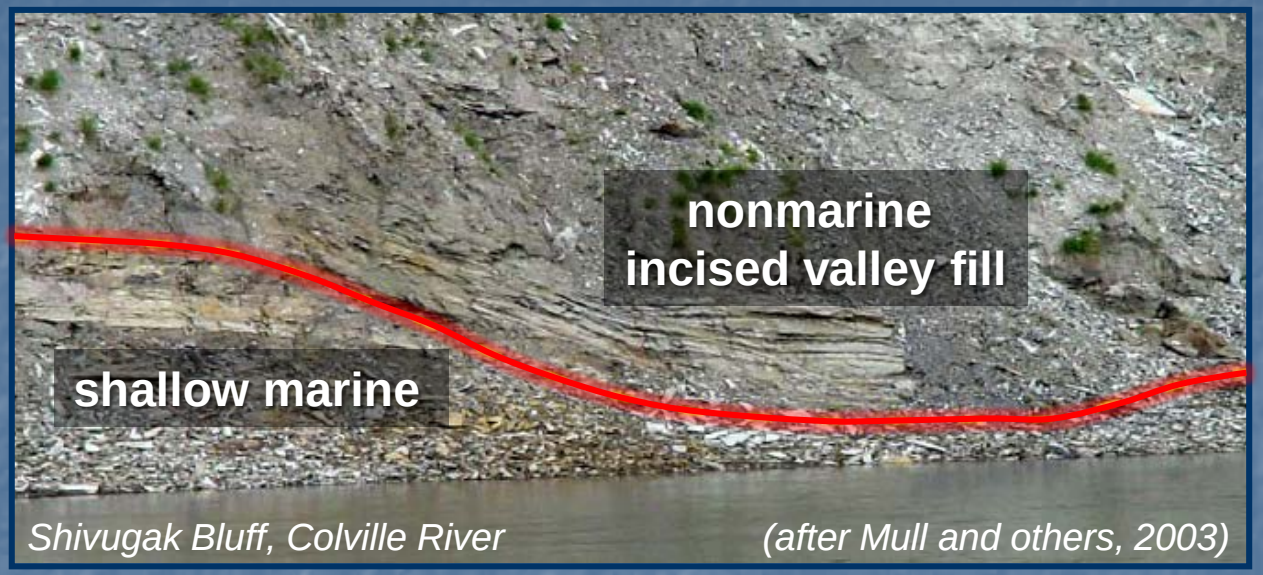
and other key sequence stratigraphic surfaces

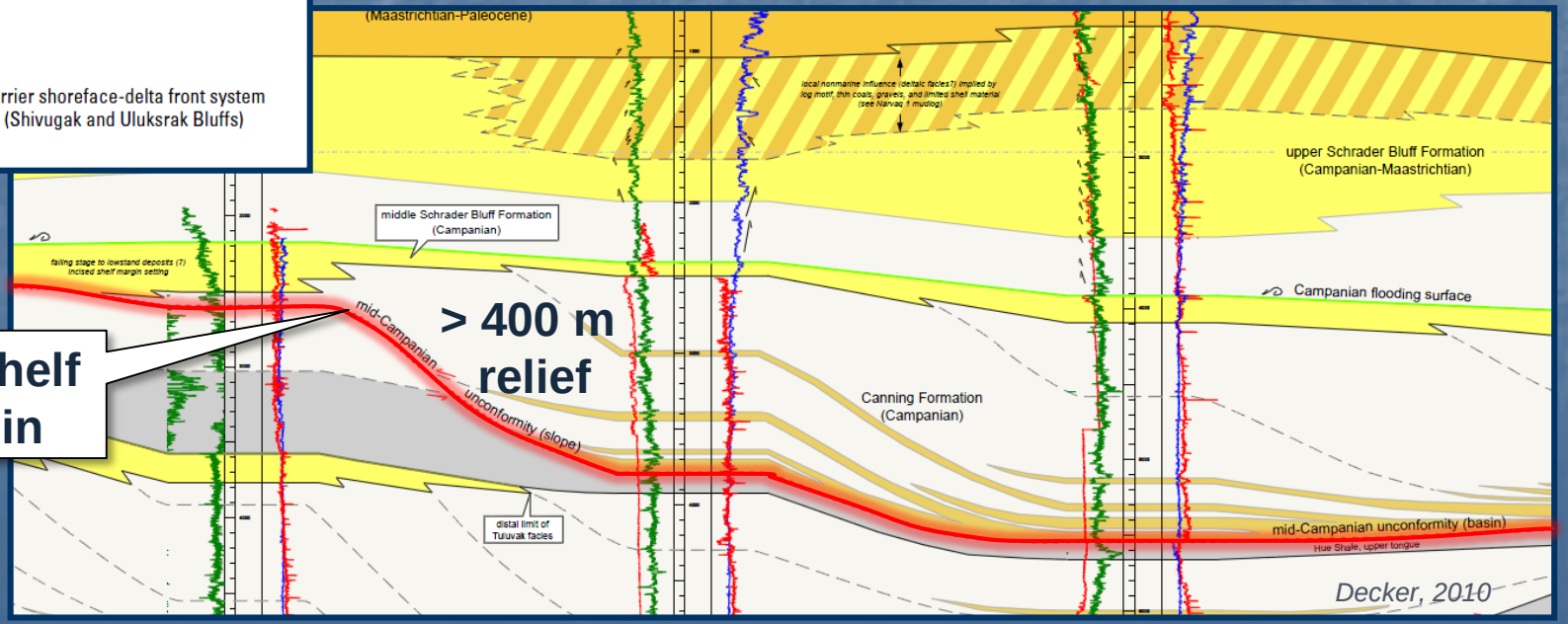


Mid-Campanian Unconformity

Subaerial unconformity (outcrop) and deepwater sequence boundary (wells)







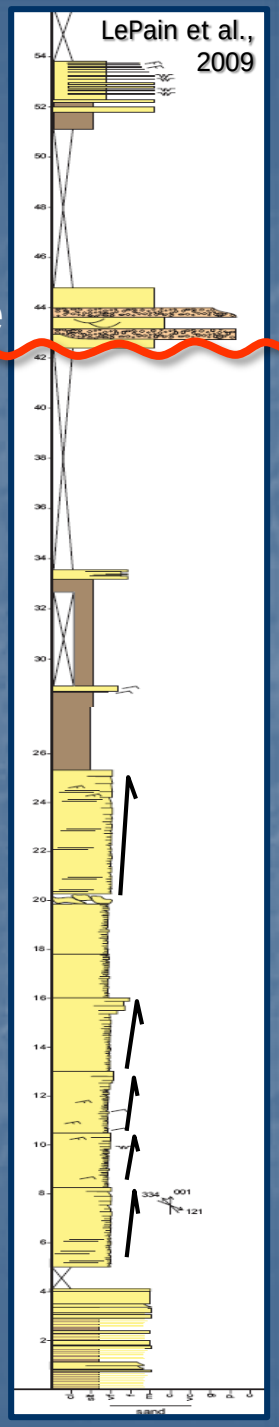
MCU shelf margin

Deepwater slump failure deposit in lower Canning – analogous to MCU mass wasting event

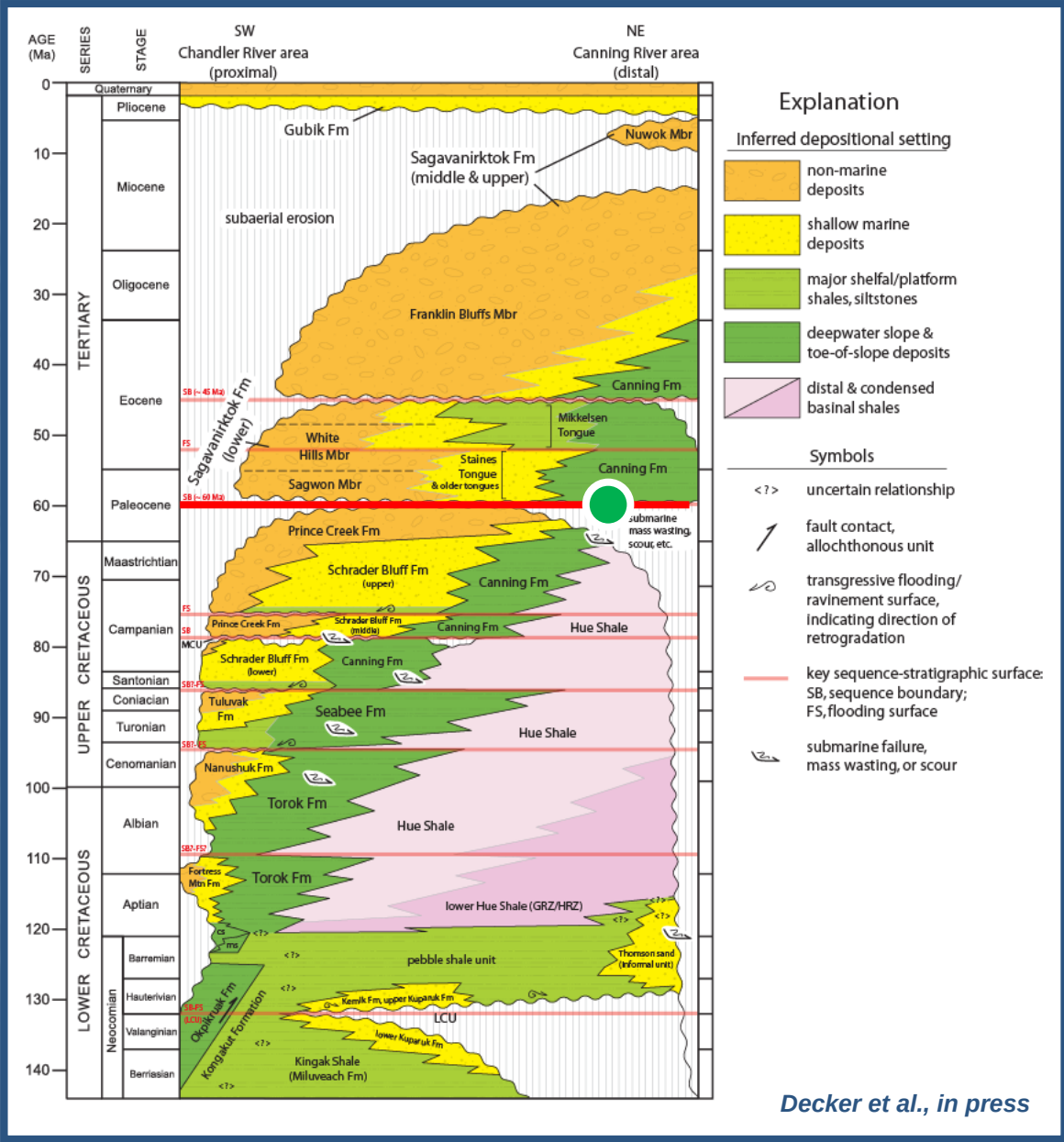
Mid-Campanian thin-bedded to amalgamated turbidites and channelized(?) pebble-cobble conglomeratic sediment-gravity flows

Lowstand channel/lobe

Gullied lower slope?



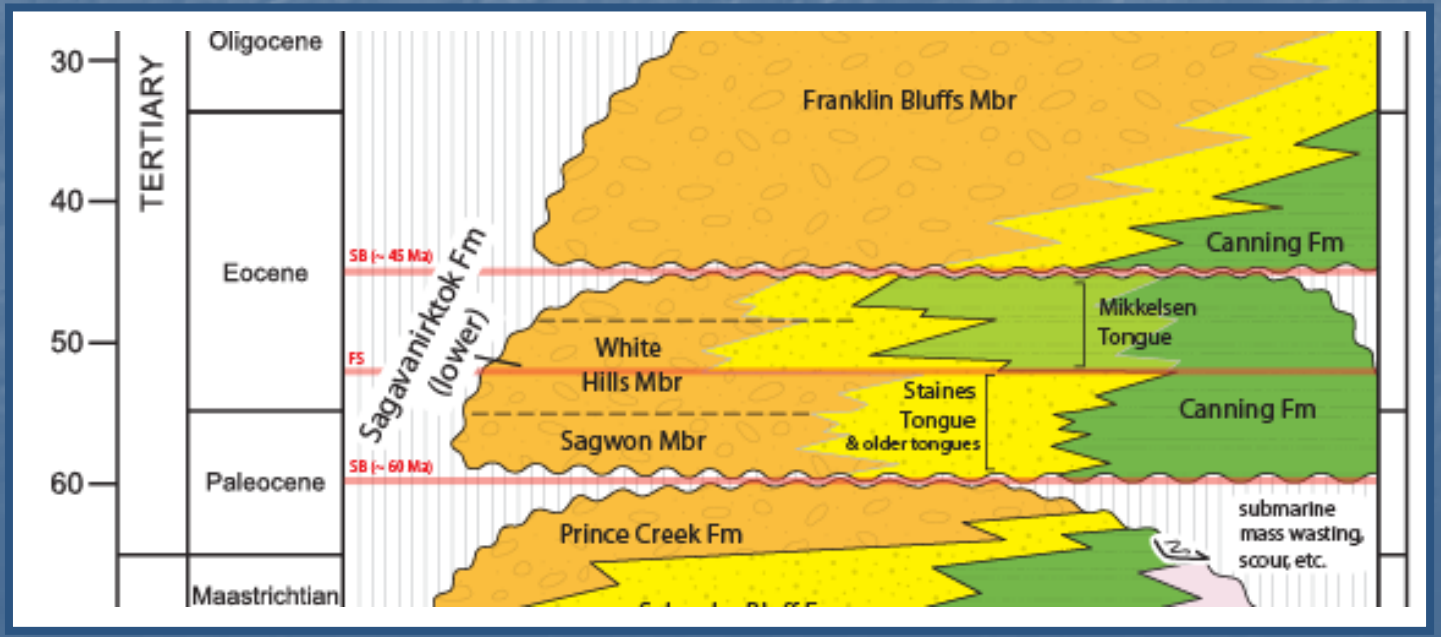
4) Paleocene – Canning Formation



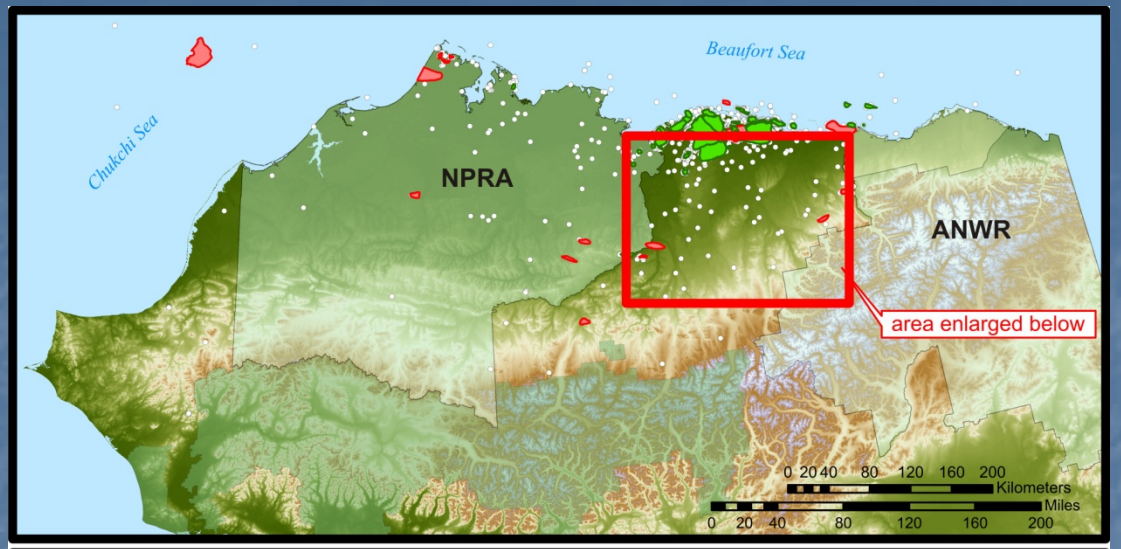
Decker et al., in press

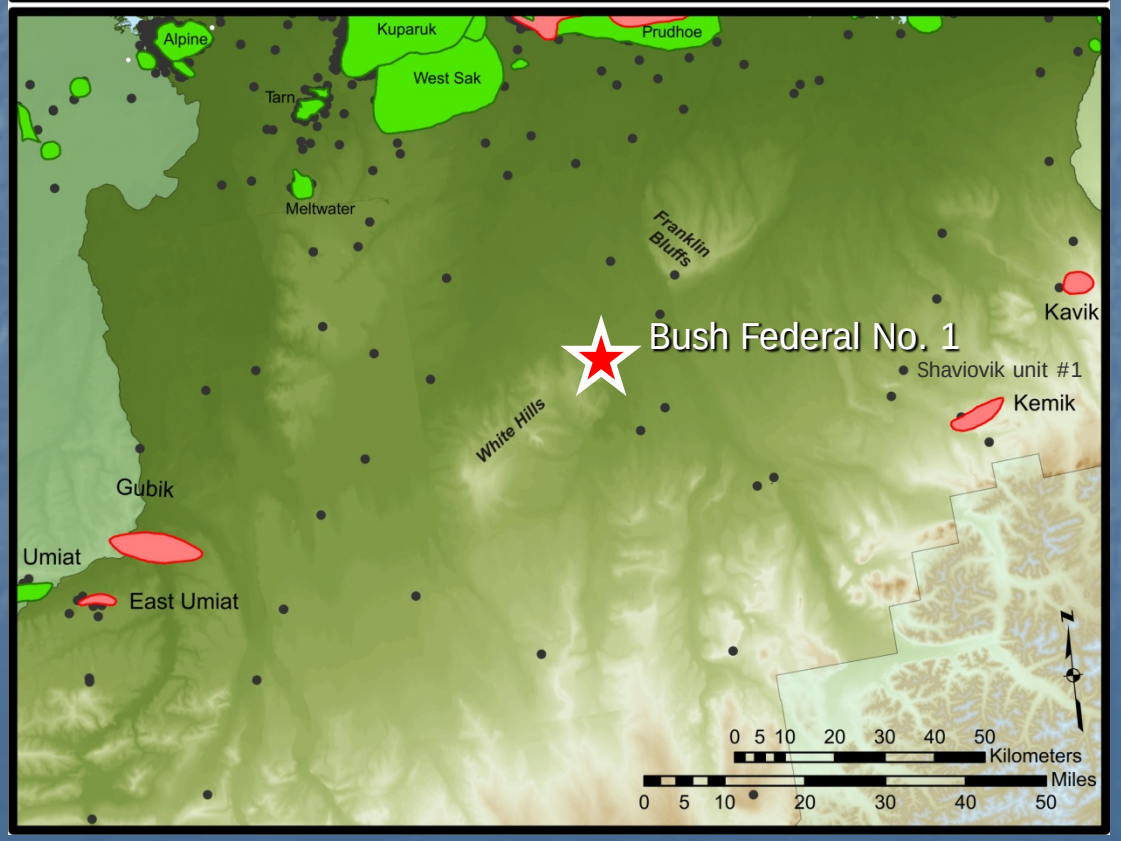
Paleocene – Canning Formation

- Paleocene orogenesis in Brooks Range reorganized the Colville foreland basin
- Major sequence bounding unconformity recognized in topset, shelf margin, and basinal settings
- Resultant bypass of unroofed material accumulated in the eastern sector of the basin, including sand-prone reservoir facies



Topset Sequence Boundary

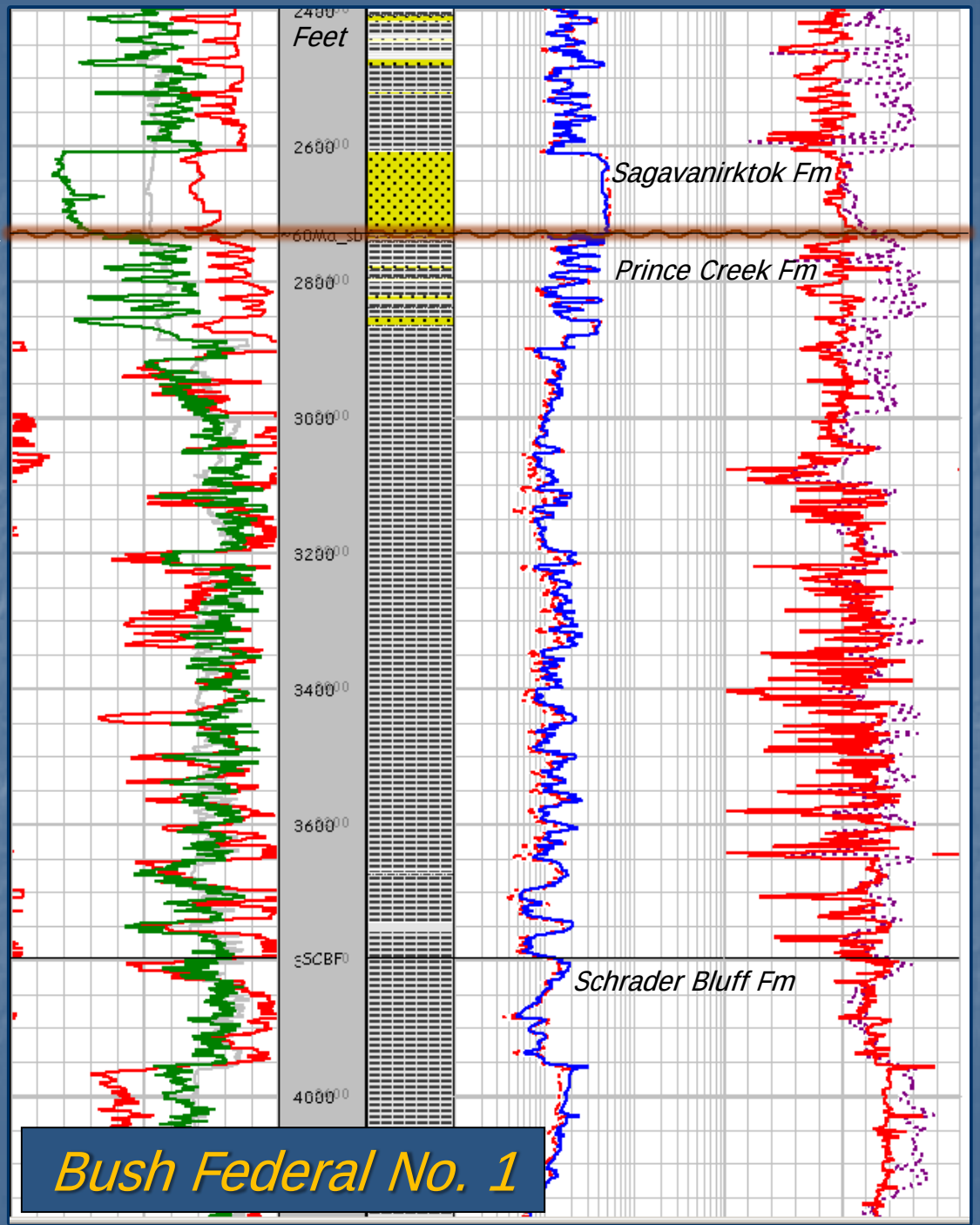




Topset Sequence Boundary

Bush Federal No. 1

- Subaerial unconformity at basal gravelly sands in Sagavanirktok Fm.
- Sandy upper Prince Creek Fm.

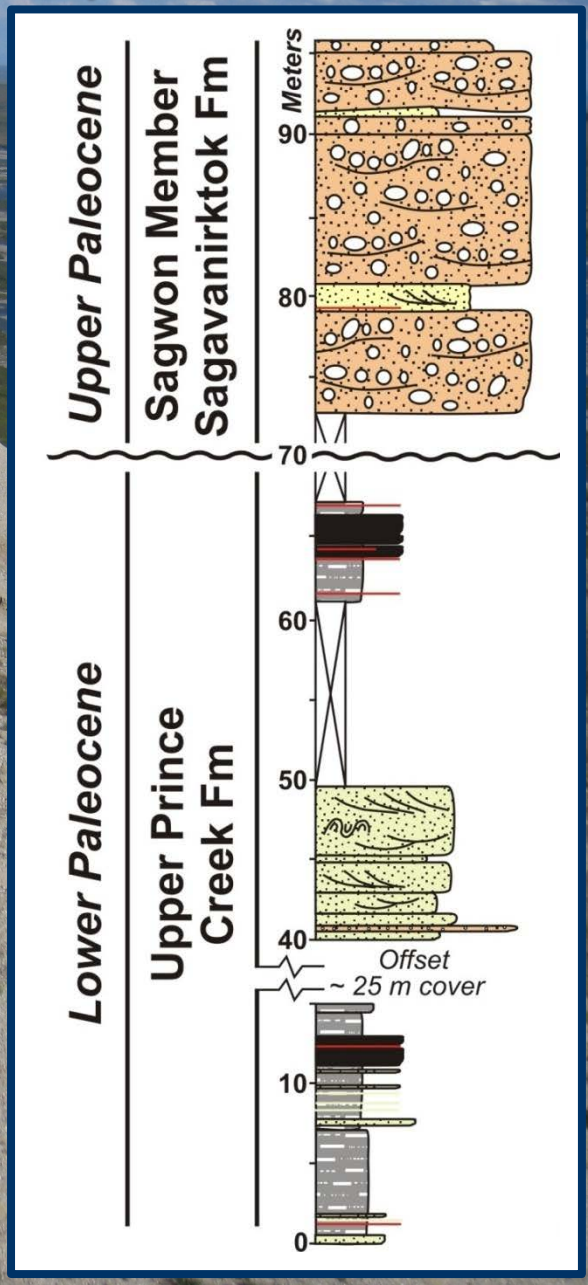


Paleocene sequence boundary in outcrop (Sagwon Bluffs)

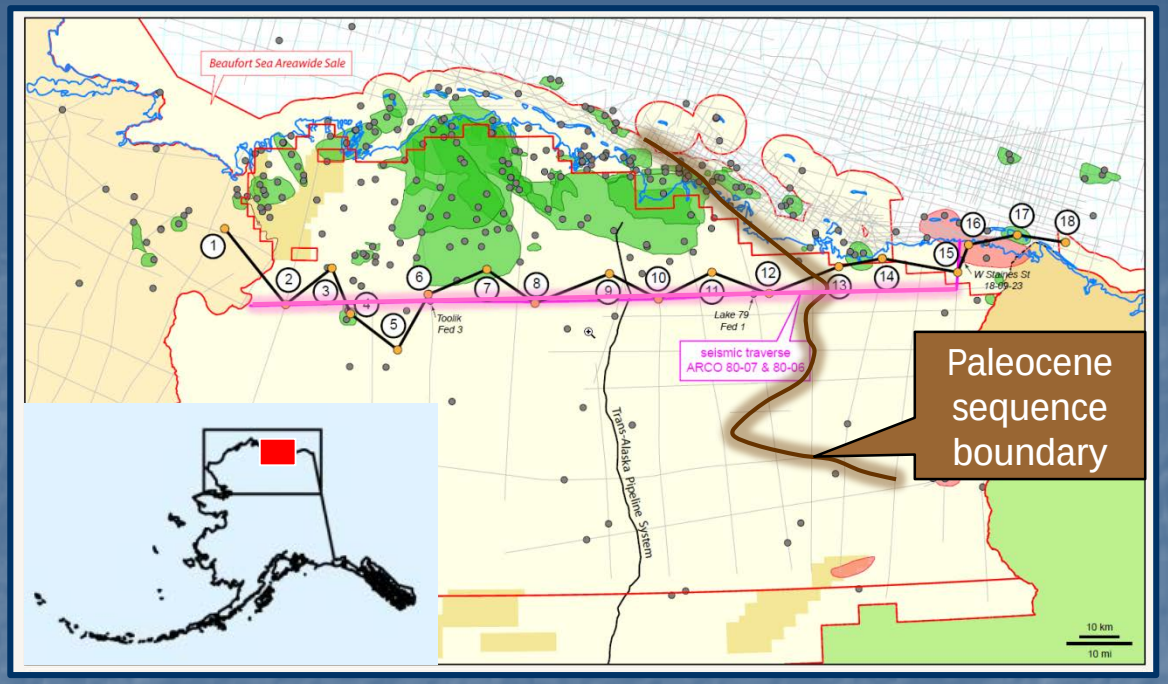
Paleocene sequence boundary in outcrop (Sagwon Bluffs)

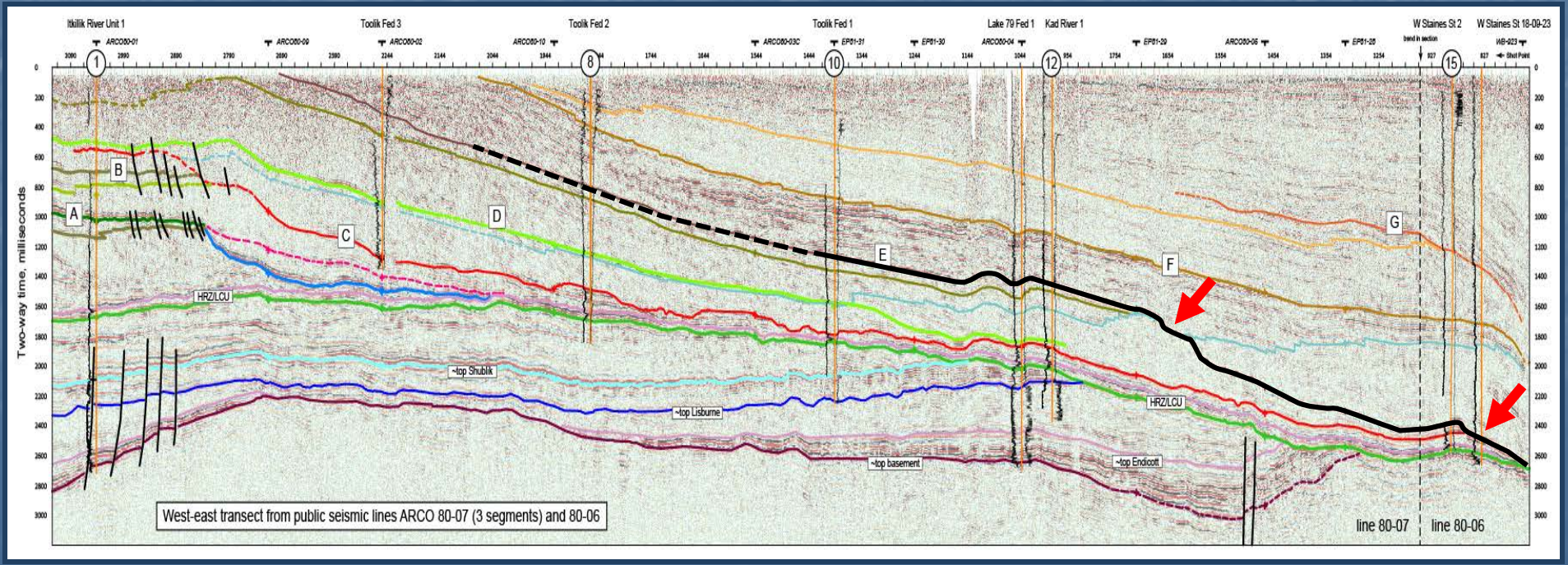
Changes in nonmarine topsets across unconformity

- Abrupt increase in grain size
- Fluvial style
- Sandstone composition
- Clast composition

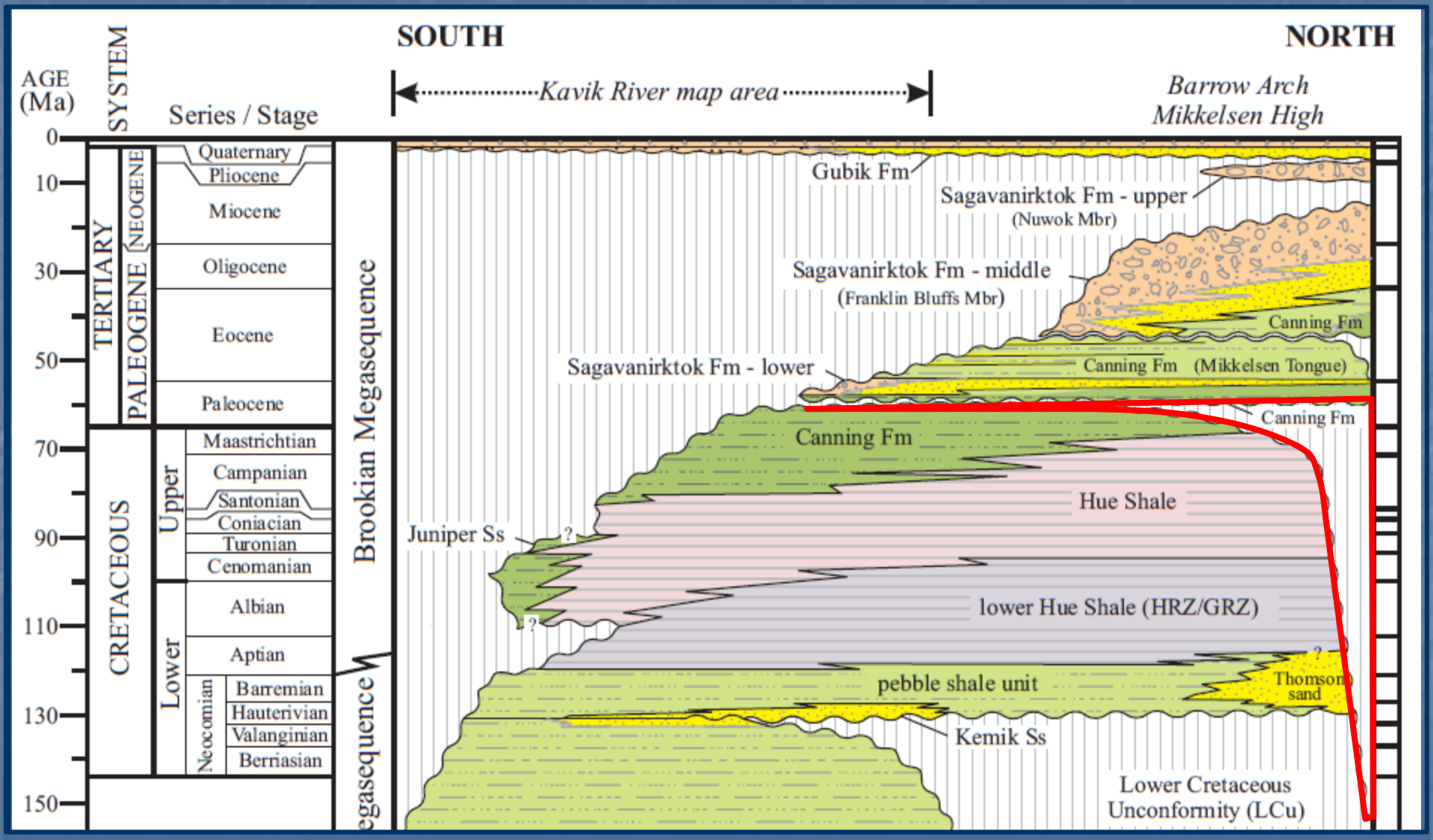


- Shelf margin incision
- Downward stepping trajectory of toplap surfaces
- Submarine scouring and slumping
- Significant erosional relief, even in distal deepwater settings



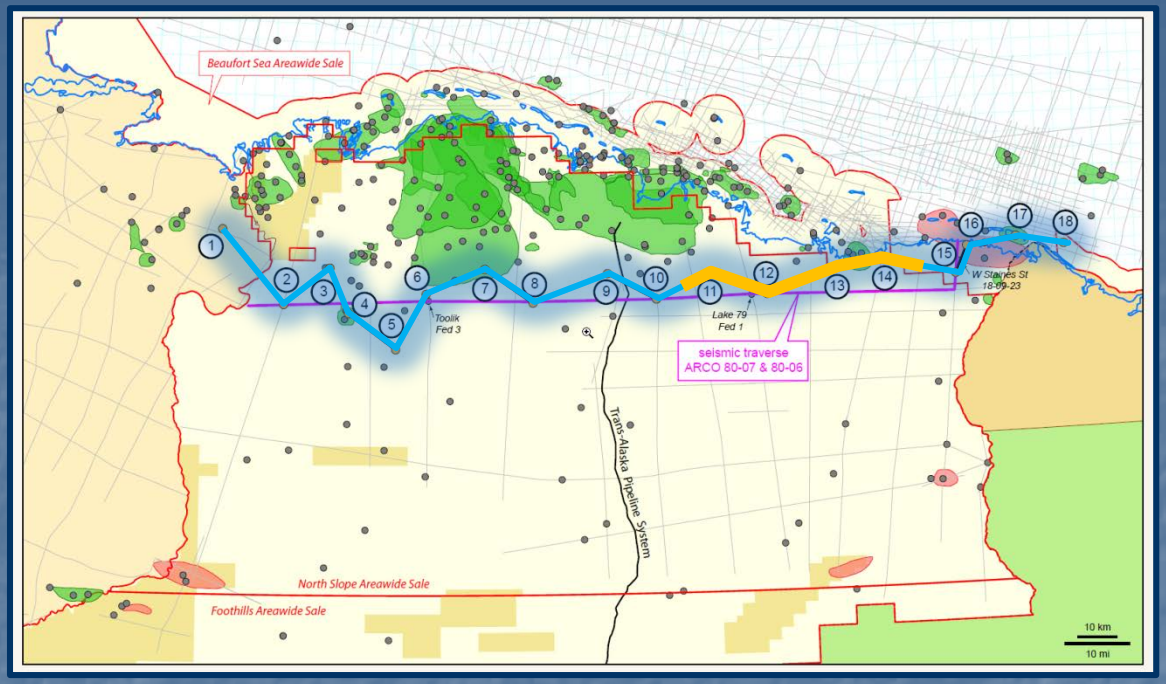


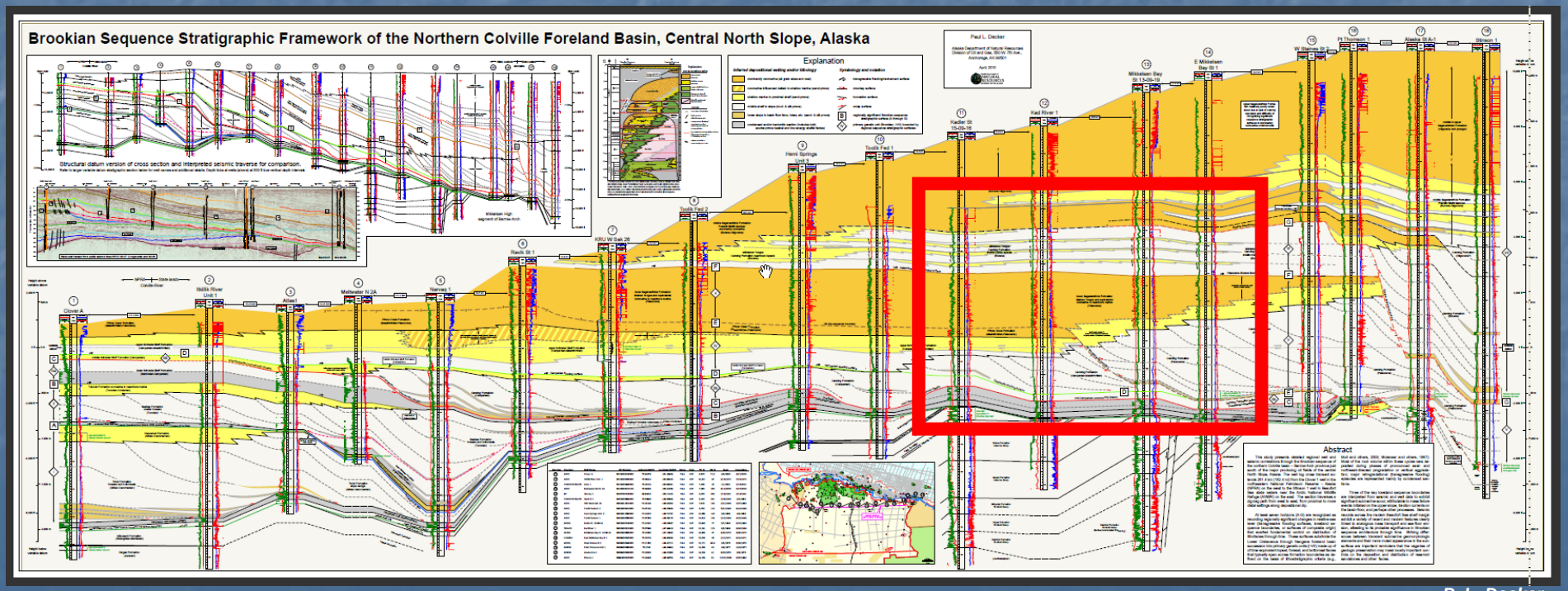
- Paleocene unconformity underlain by Maastrichtian – pre-Mississippian units



Wartes et al., 2011

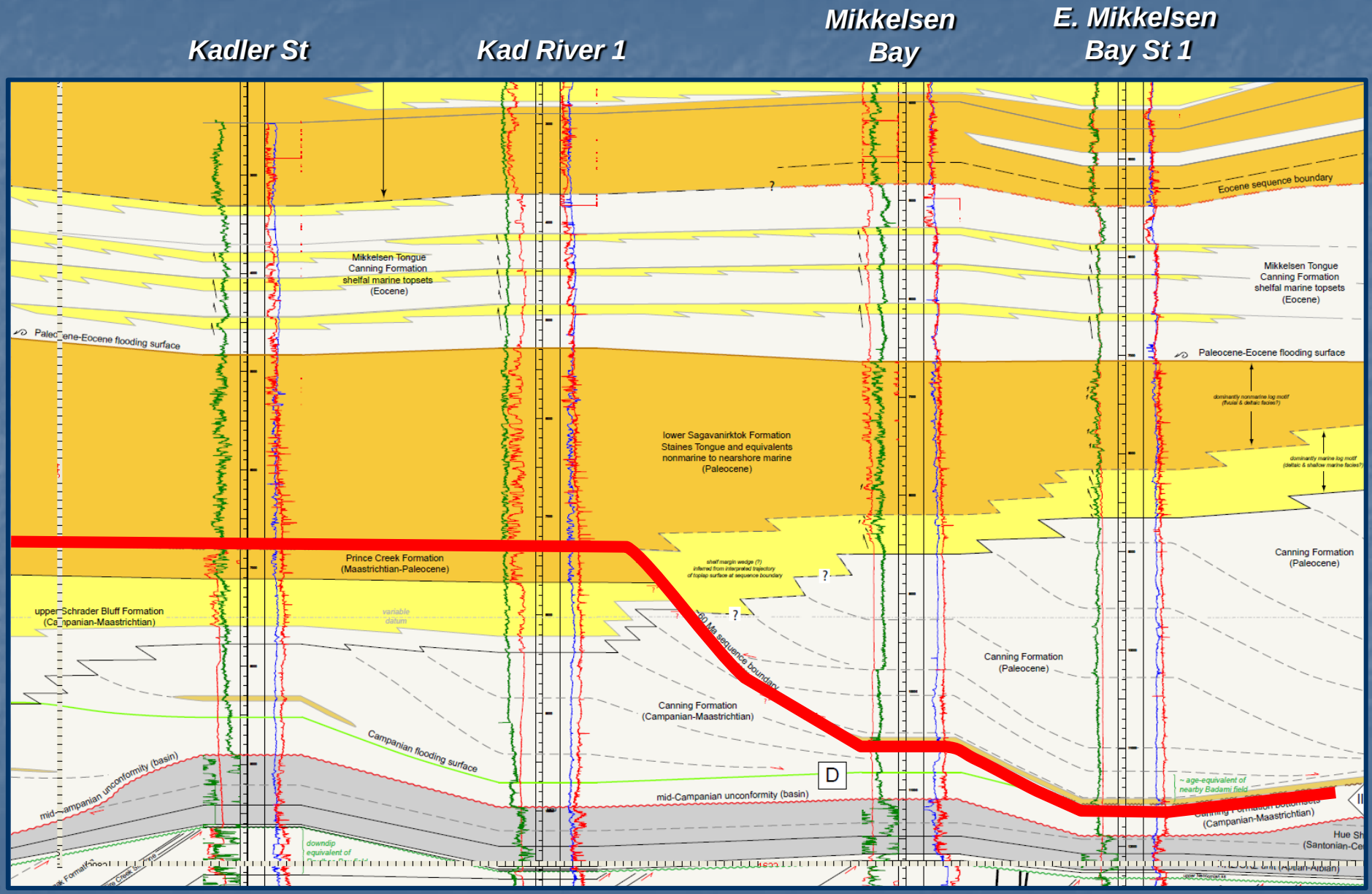
- Sequence boundary marked by sharp dislocation in log motif
- Abrupt influx of sandstone in slope and basinal position





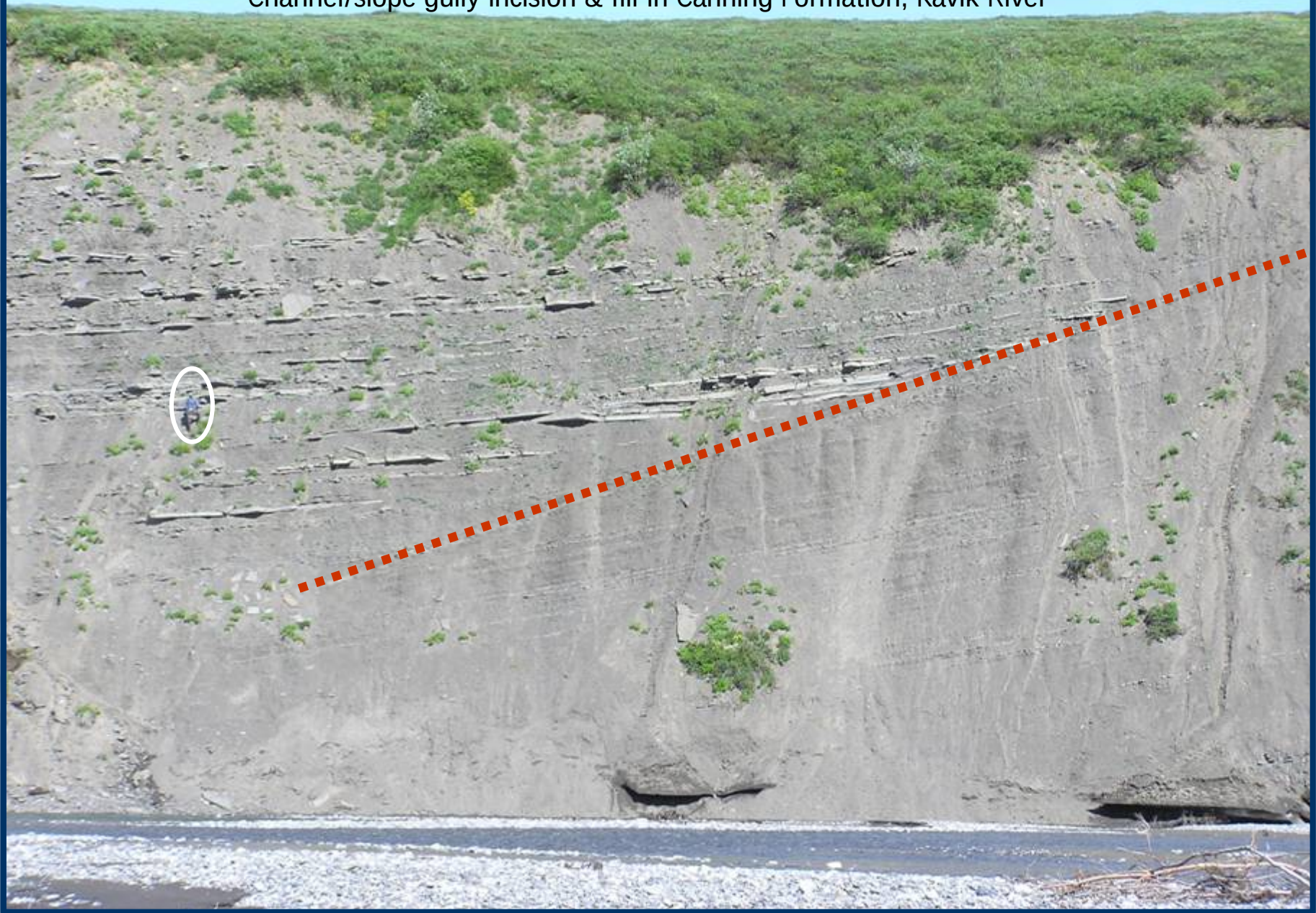
P. L. Decker

Deepwater sandstone reservoirs deposited on and near scoured Paleocene sequence boundary, perhaps during shelfal bypass: *Badami, Flaxman A-1 pools*



Possible outcrop analogue

Channel/slope gully incision & fill in Canning Formation, Kavik River



Summary

- The Colville Basin of Alaska's North Slope represents one of the most promising onshore exploration frontiers in North America
- Integration of surface and subsurface data within a sequence stratigraphic framework can help predict when significant sand was likely exported into deep-water settings
- Despite complex stratigraphy, and challenges associated with imaging reservoir-scale elements, the underexplored Brookian includes several stratigraphic intervals that warrant further consideration as exploration targets

Acknowledgments

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  - ***AK Div. of Geological & Geophysical Surveys***
  - ***AK Div. of Oil & Gas***
  - ***DNR Industry Sponsors Group***

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Questions. . .