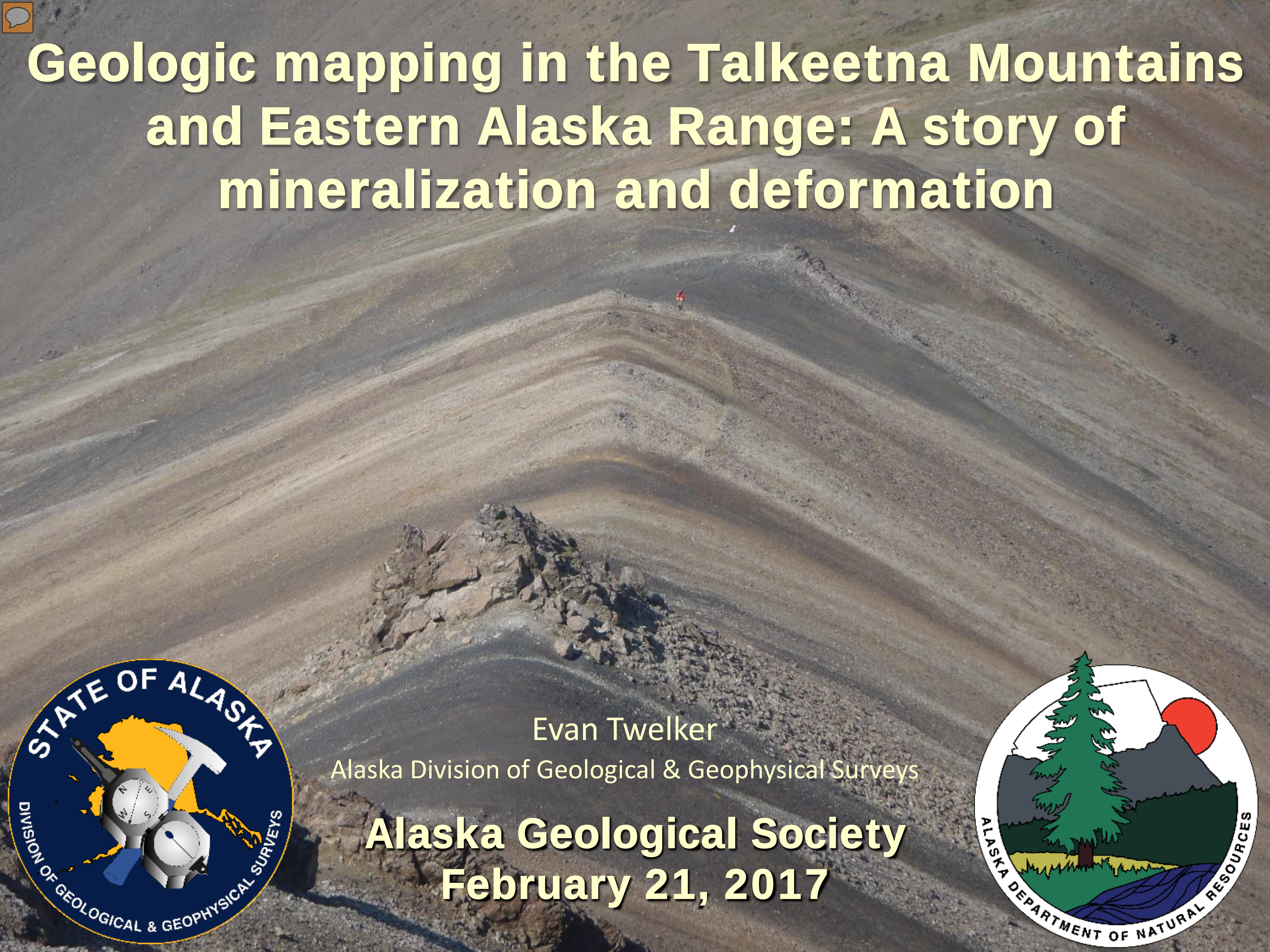
Geologic mapping in the Talkeetna Mountains and Eastern Alaska Range: A story of mineralization and deformation



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Alaska Division of Geological & Geophysical Surveys

Alaska Geological Society
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Thanks to the many people who have contributed to this project:

- Lauren Lande, Rainer Newberry, Alicja Wypych, Karri Sicard
- Larry Freeman, Melanie Werdon, David Reioux, Erik Bachmann, Amy Tuzzolino, Colby Wright, Abraham Emond, Gina Graham, Laurel Burns
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- CIRI and Cook Inlet Region Working Group villages for 2014 land access
- And many others…

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Alaska Division of Geological & Geophysical Surveys (DGGS)

…shall conduct geological and geophysical surveys to determine the potential of Alaskan land for production of metals, minerals, fuels … (AS 41.08.020)

→ 'future state revenues'

How?

- Build the 'geological framework' that explains where metals/oil/gas are found
- Geological mapping, stratigraphy, and relevant research (e.g. petrology, geochronology, etc.)
- Good old fashioned prospecting

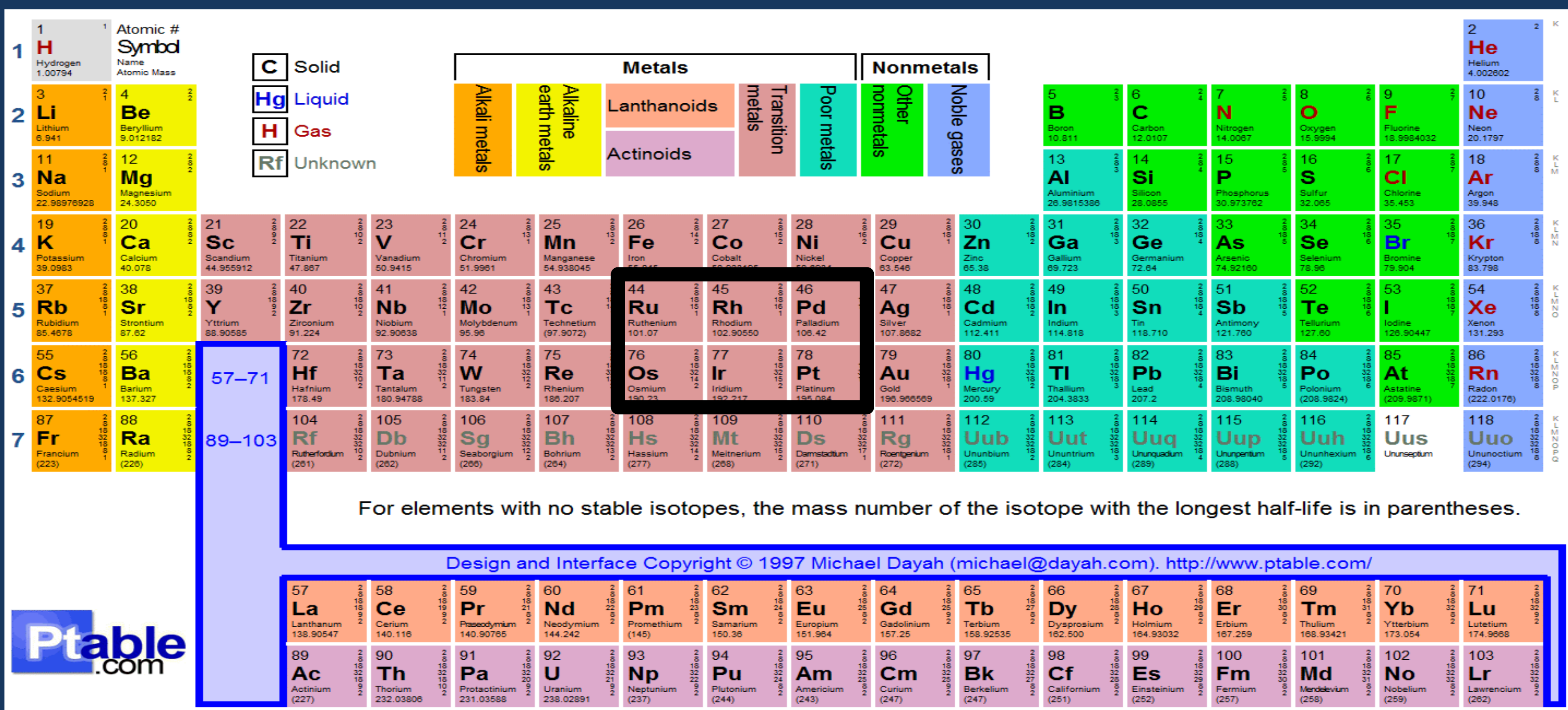
DGGS Strategic & Critical Minerals (SCM) assessment

Platinum-group elements:

Platinum (Pt) Iridium (Ir)

Palladium (Pd) Osmium (Os)

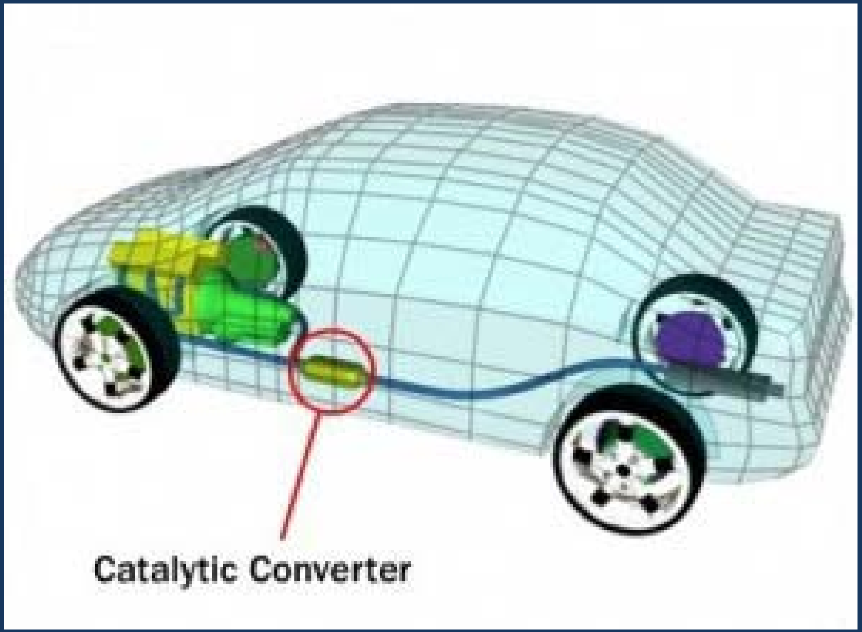
Rhodium (Rh) Ruthenium (Ru)



The PGEs are critically important to modern life:

Catalysts

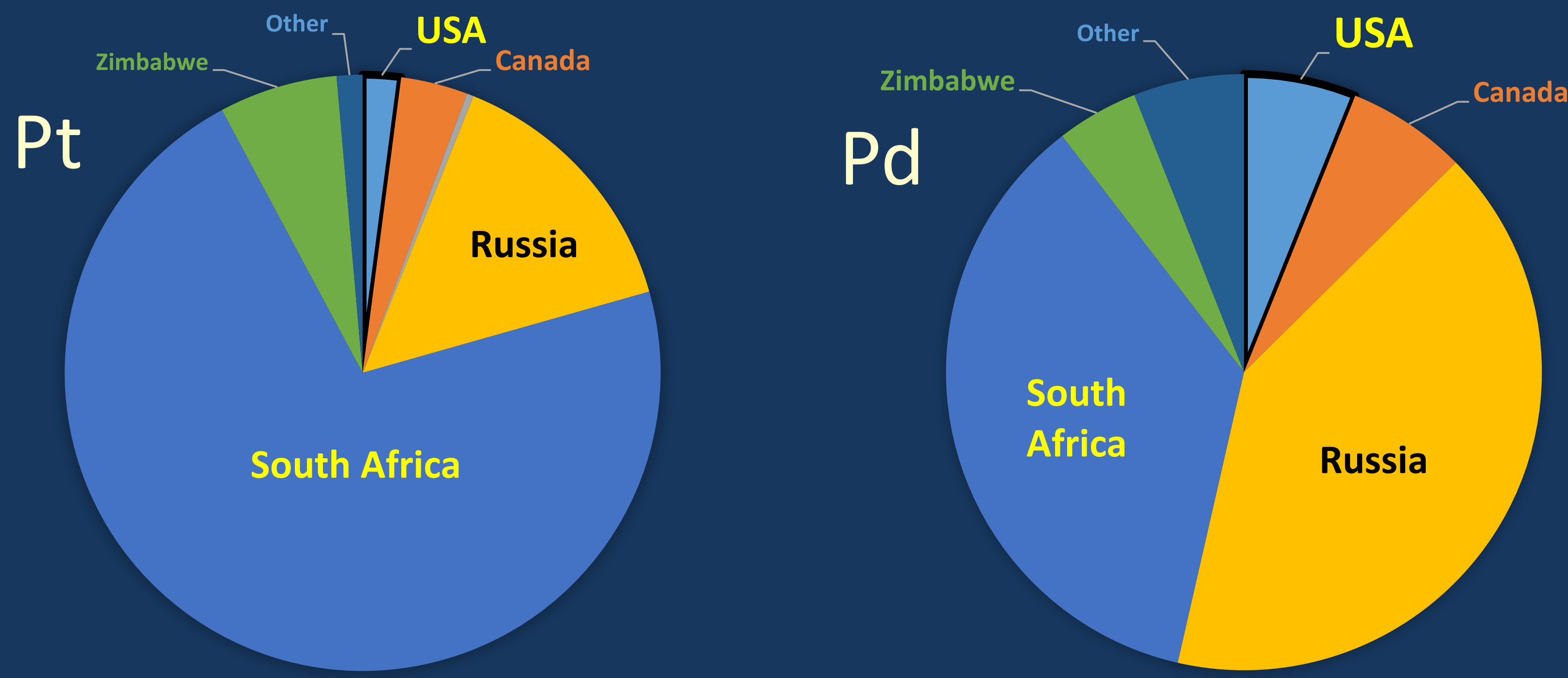
- Chemical refining
- EPA Wood stoves
- Low-emissions vehicles



Supply Challenged

US Net import reliance: Pt: **91%**, Pd: **56%**

Share of world mine production (2012):



Critical/military importance + supply challenge

= **Strategic and Critical Minerals**

Source: USGS 2013 Commodity summary for Platinum-Group Metals

Meanwhile, in the Yukon…

“One of the world’s largest undeveloped nickel-PGM projects”

Measured and Indicated Resource:

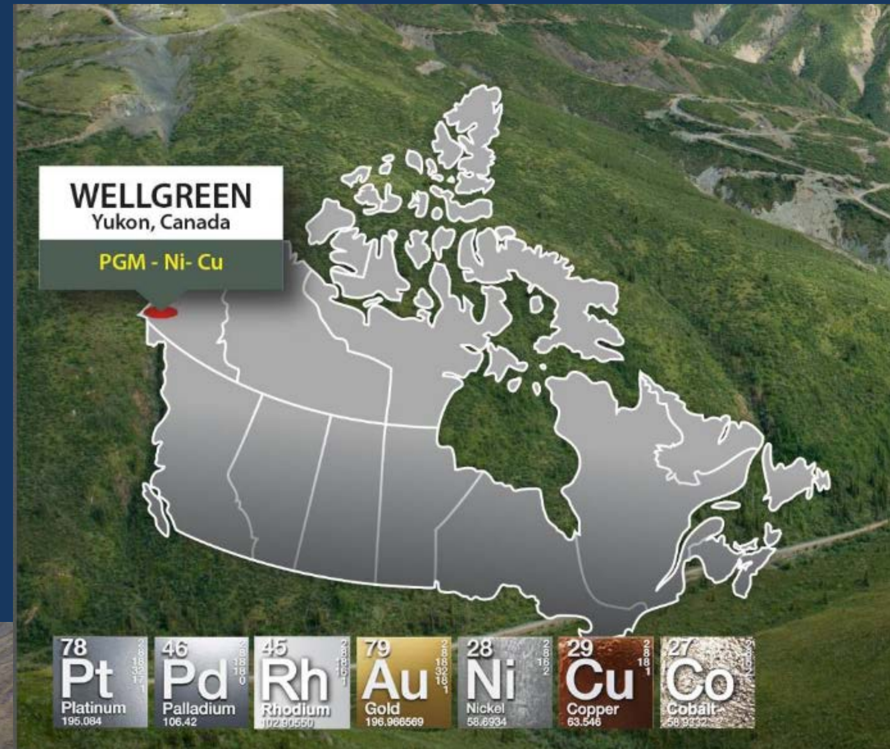
5.1 million ounces Pt + Pd

1.9 billion pounds Ni

Additional Inferred Resource:

12.5 million ounces Pt + Pd

4.4 billion pounds Ni



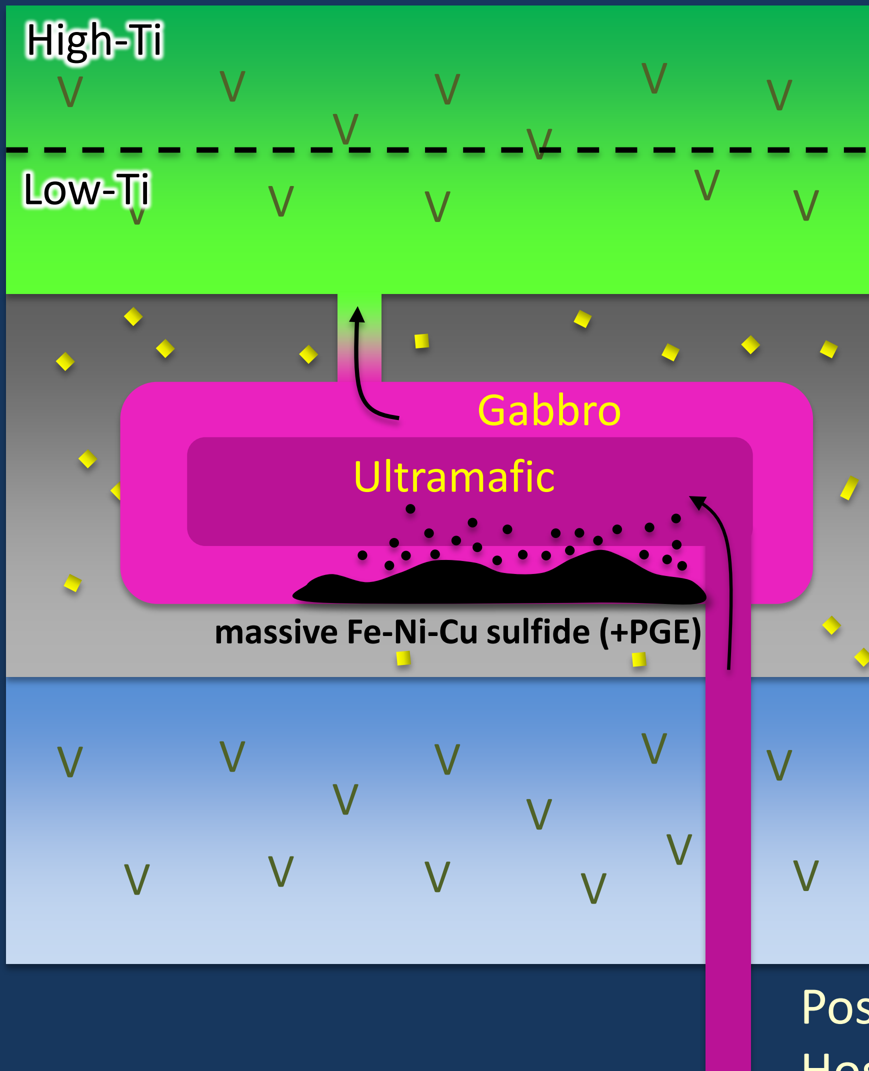
Wellgreen Deposit 2015

Preliminary Economic Assessment:

- Net present value: ~ $1 billon
- 3-year payback
- Mine life 25 years+

Source: Wellgreen Platinum Corporate presentation Feb 2016

Basic Wellgreen Geologic Model
Wrangellia stratigraphy



Nikolai Greenstone:

- Late Triassic flood basalts: "Large Igneous Province"

Mafic to Ultramafic sills:

- Feeders to Nikolai Greenstone
- Gabbroic margins, dunite center
- Sulfur saturation reached; **sulfide accumulates**

Permian to Triassic sedimentary ± volcanic rocks

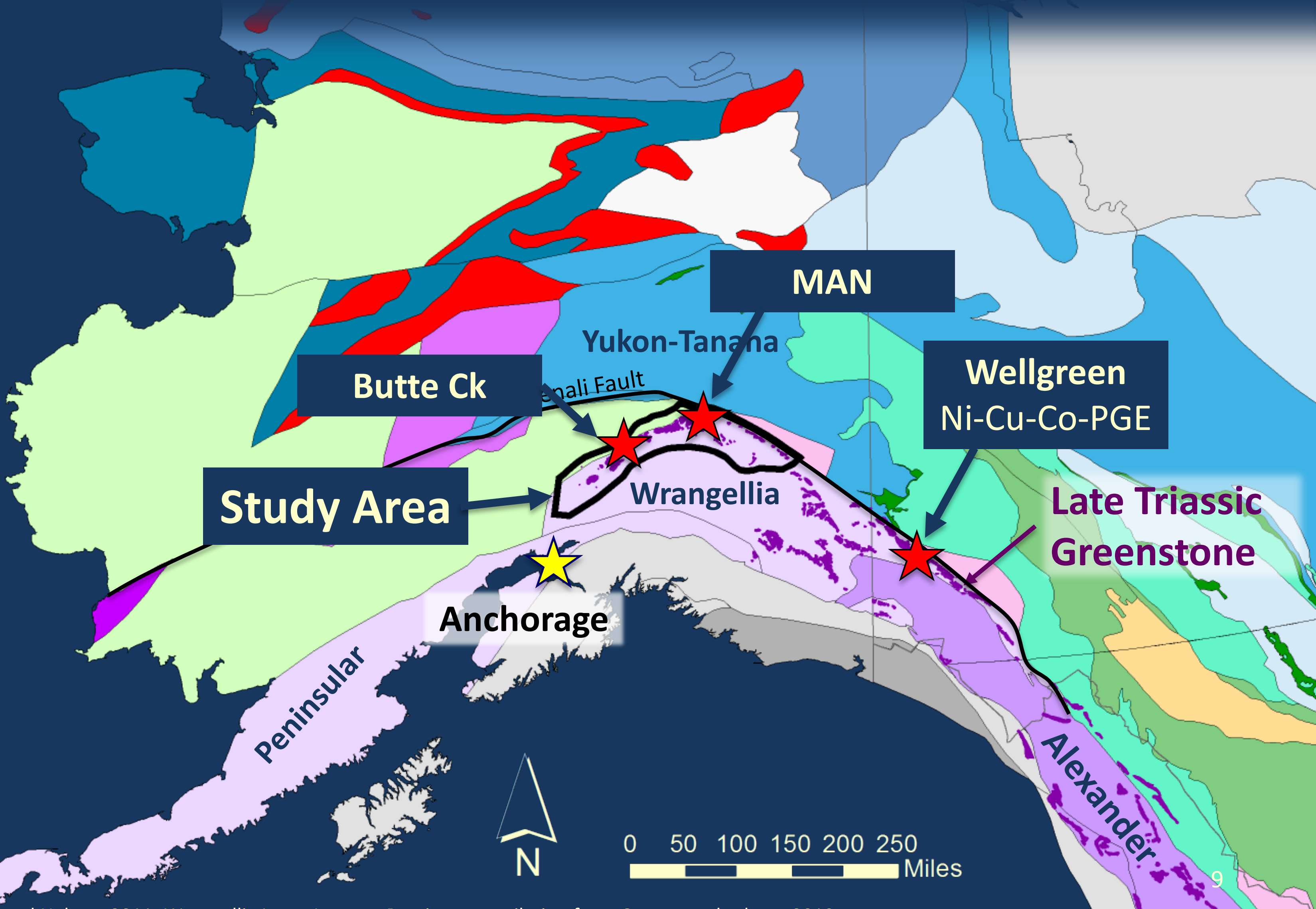
- Hasen Creek (Wrangells, Yukon)
- Slana Spur, Eagle Creek (AK Range)

Pennsylvanian-Permian volcanic rocks

- Skolai Arc oceanic island arc
- Station Creek, Tetelna volcanics

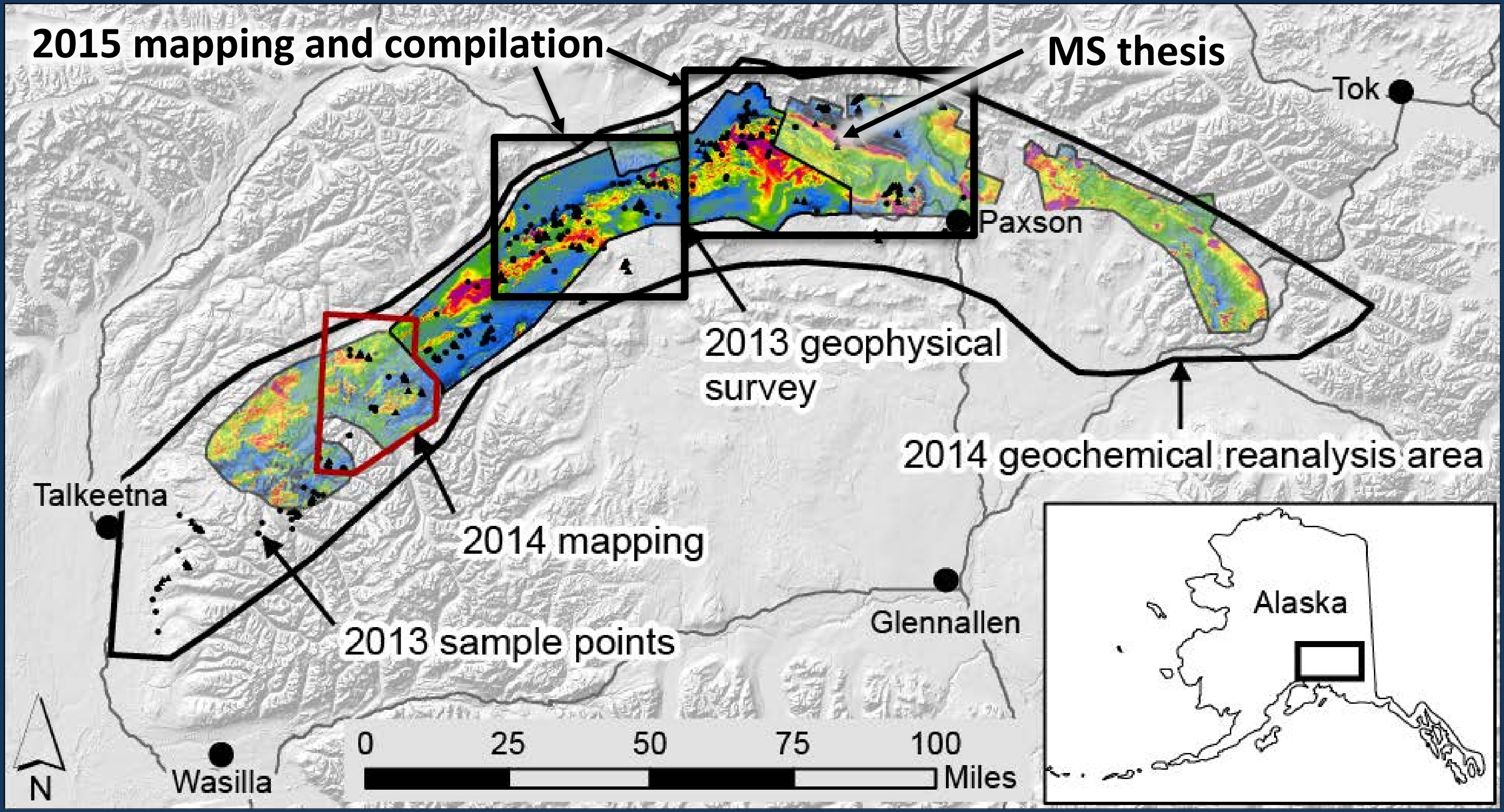
Possible global analog: Norilsk/Talnakh
Hosted in feeders to Siberian Traps

Alaska's side of the border:
± Same geology



Terrane Map of Colpron and Nelson, 2011; Wrangellia Large Igneous Province compilation from Greene and others, 2010

DGGS Wrangellia project 2013-2015



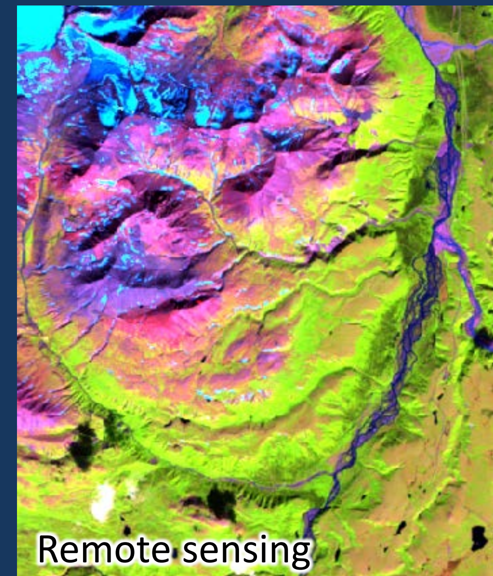
- New airborne magnetic and electromagnetic survey
- Geochemistry and geochronology raw data releases
- Targeted geologic mapping and research
- Compilation and interpretation

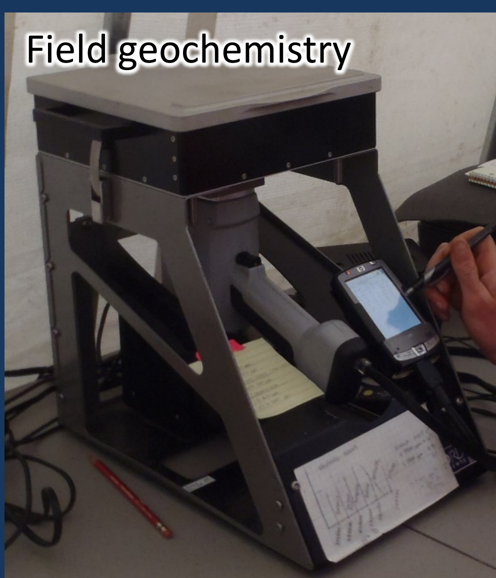
DGGS mapping: Low tech / high tech





DGGS mapping: Low tech / high tech



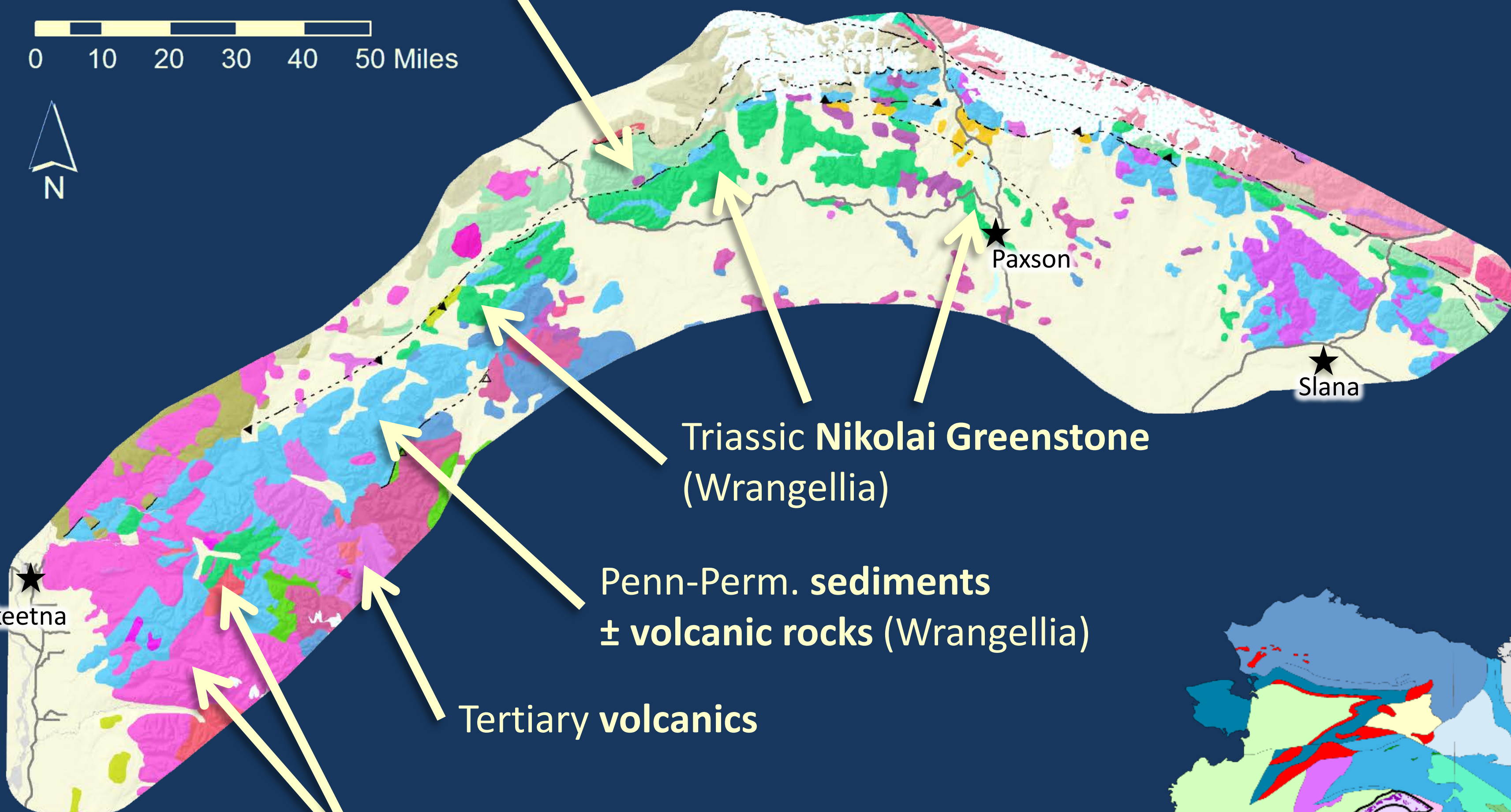


Geochronology

USGS science for a changing world UAF

Geology of the project area

Jurassic-Cretaceous (meta)flysch

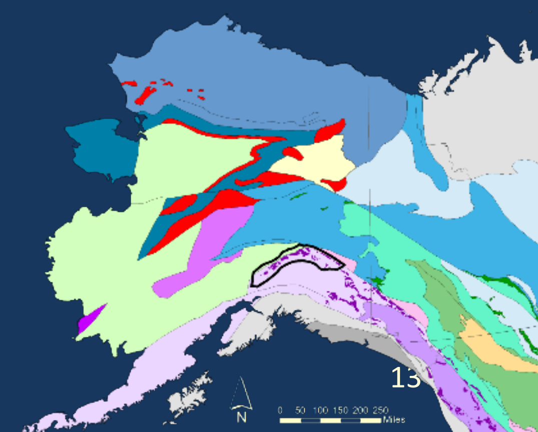


Triassic **Nikolai Greenstone** (Wrangellia)

Penn-Perm. **sediments** ± **volcanic rocks** (Wrangellia)

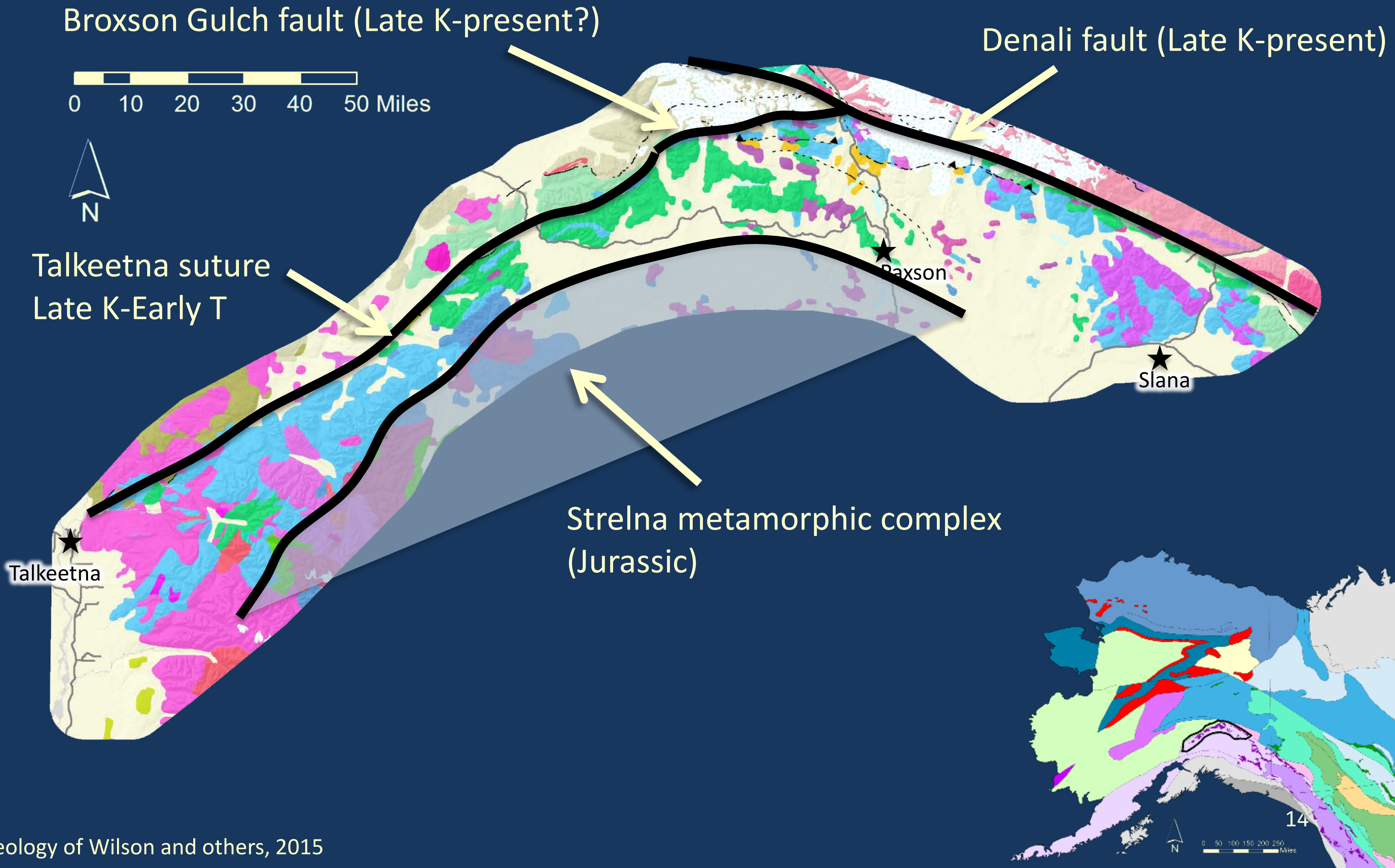
Tertiary **volcanics**

Jurassic to Tertiary **plutonic rocks**



Geology of Wilson and others, 2015

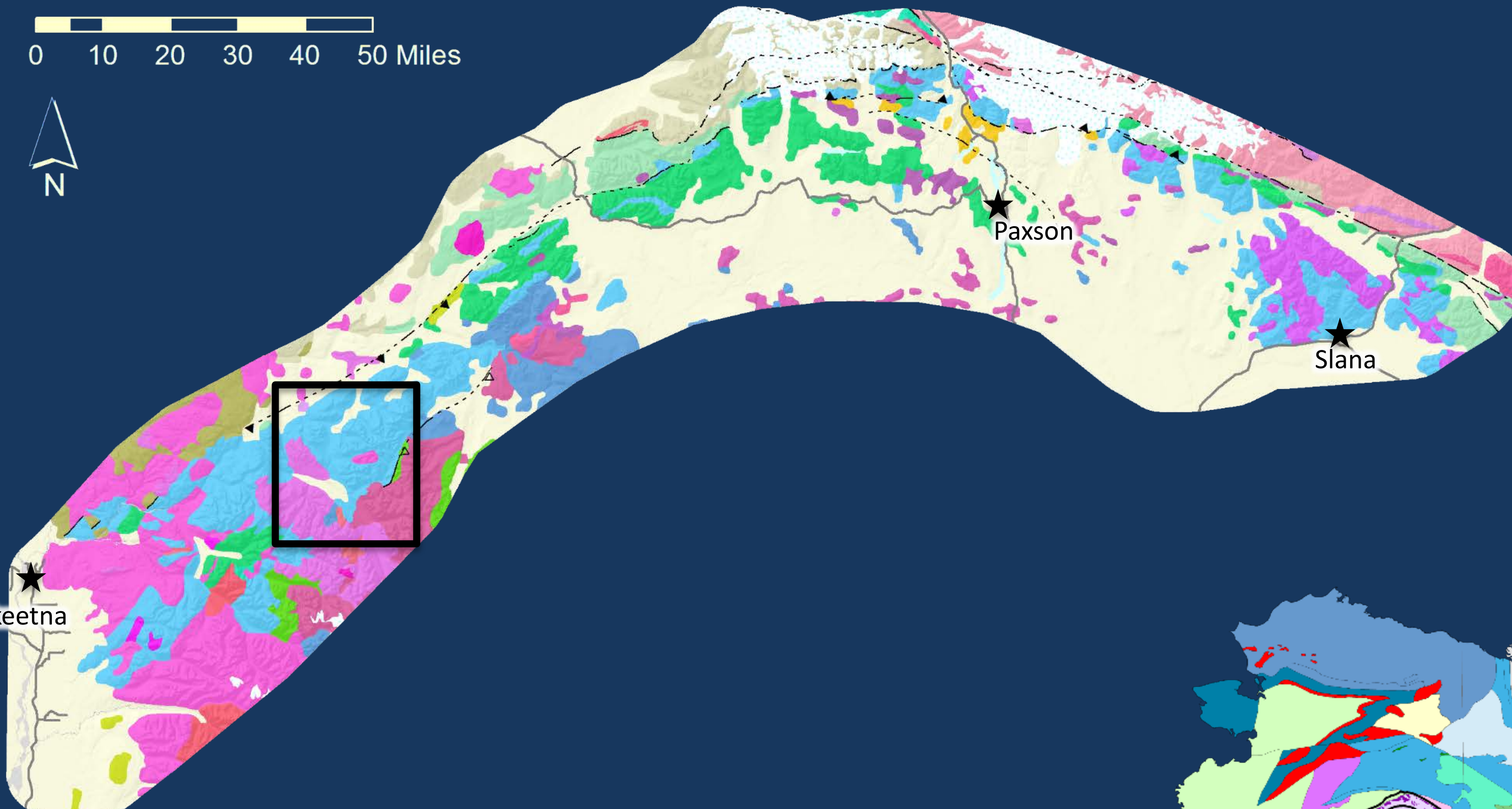
Geology of the project area

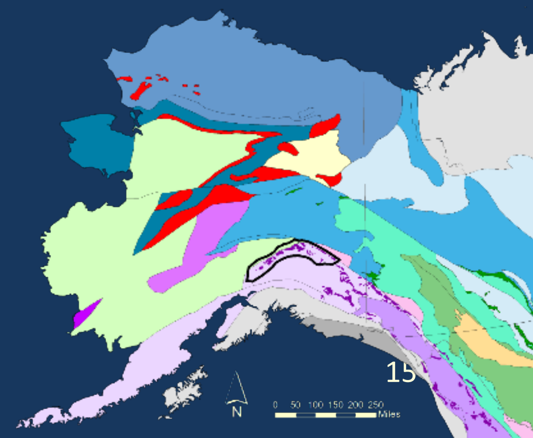


Geology of Wilson and others, 2015

Part 1: Central Talkeetna Mountains

Terrane accretion and translation

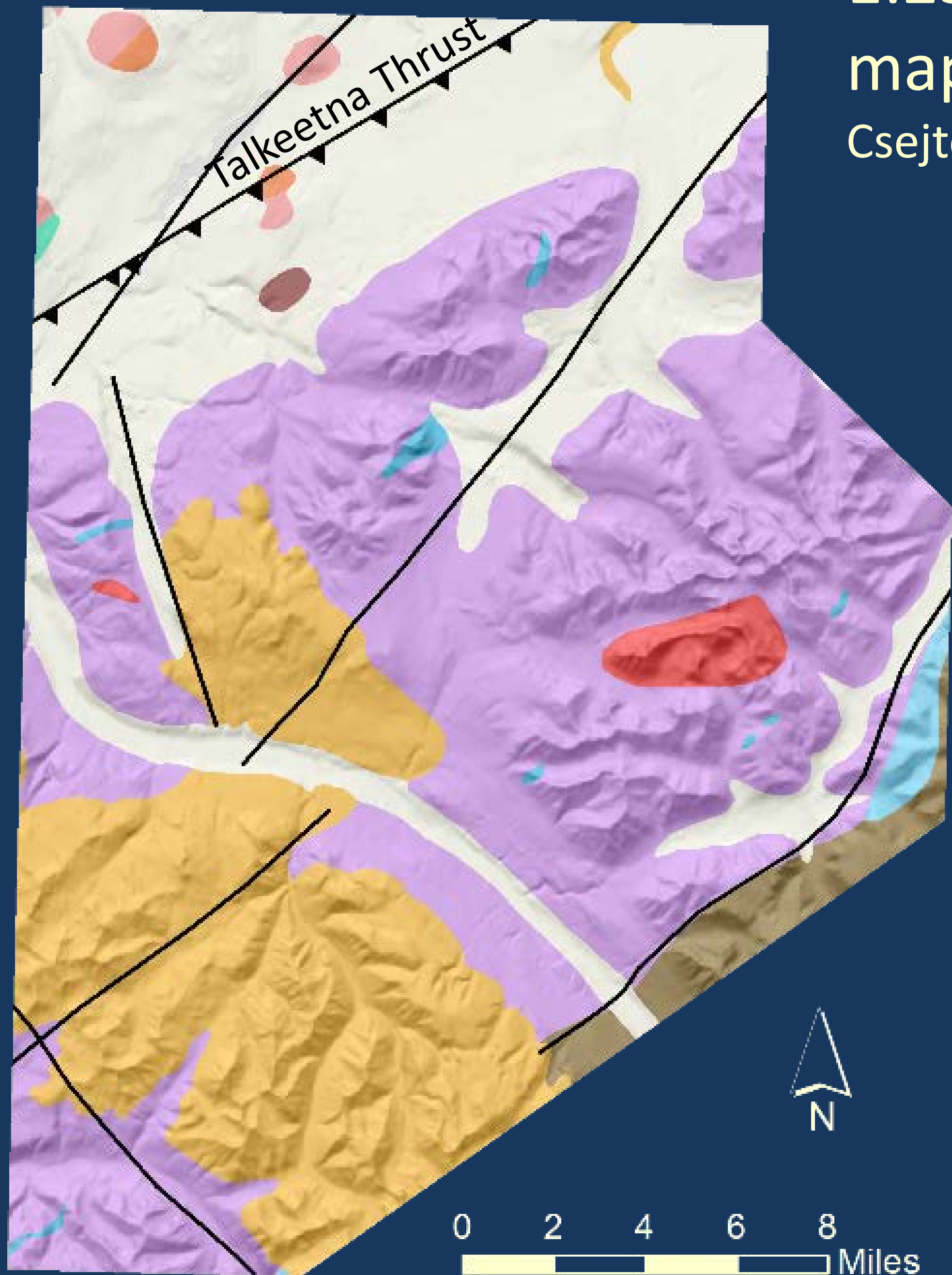




Geology of Wilson and others, 2015

1:250,000 Reconnaissance-scale mapping

Csejtey et al., 1978



Geology after Wilson and others, 2015

Tertiary Volcanics

- Basalt
- Undifferentiated volcanics

Cretaceous-Tertiary Plutons

- T granodiorite
- T-K quartz monzonite
- T-K granodiorite
- Jurassic gneiss

Kahiltna Assemblage

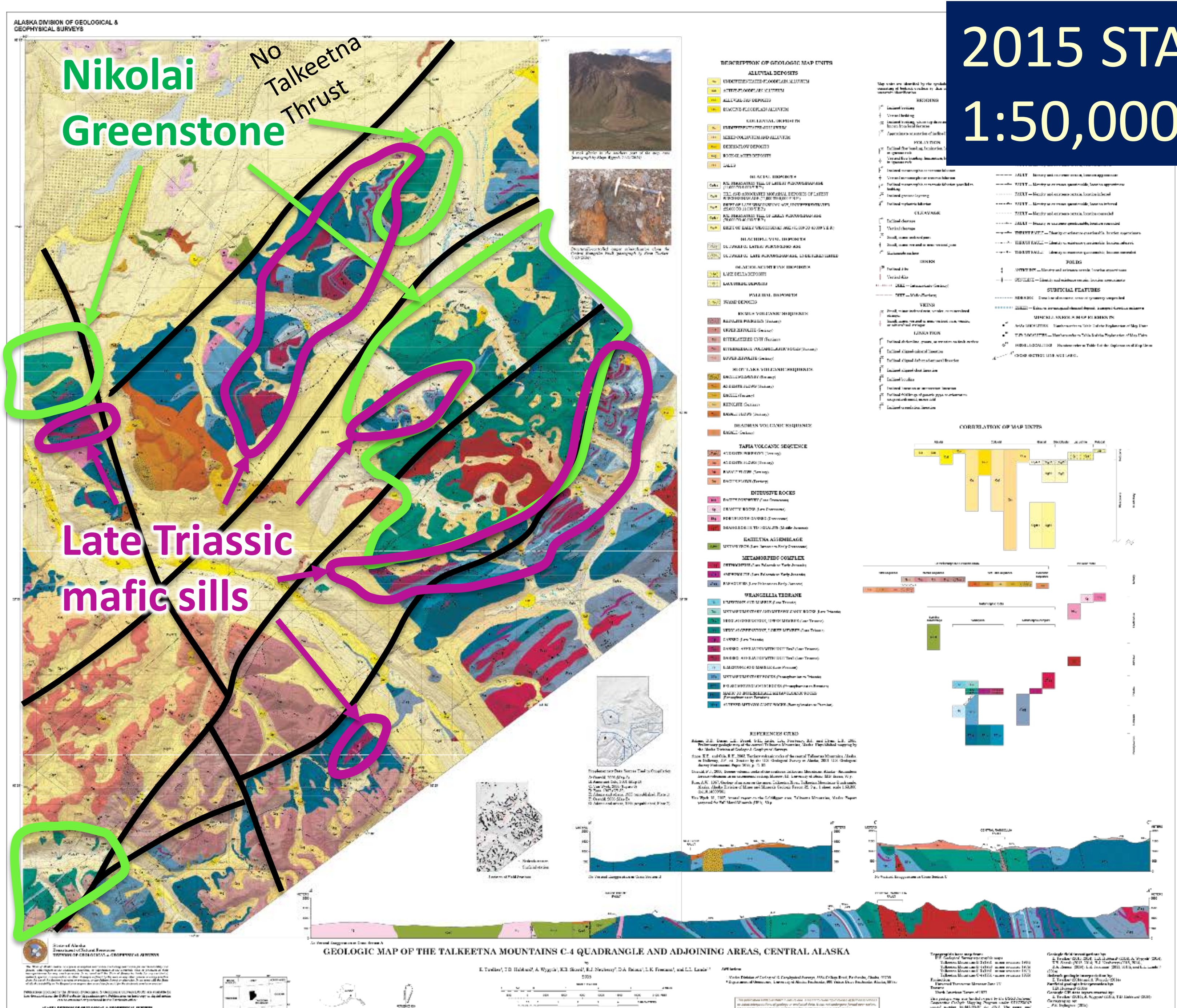
- Flysch

Wrangellia Terrane

- Permian limestone
- Volcanics

→ No Late Triassic mapped

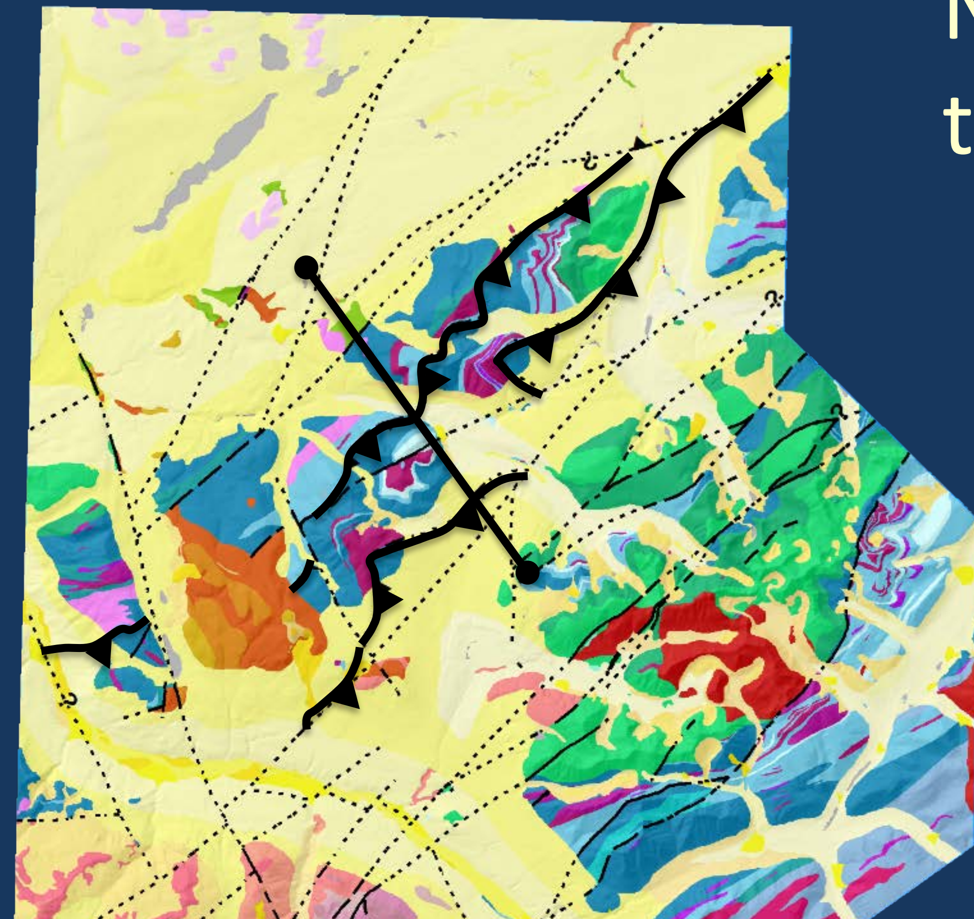
2015 STATEMAP
1:50,000 scale

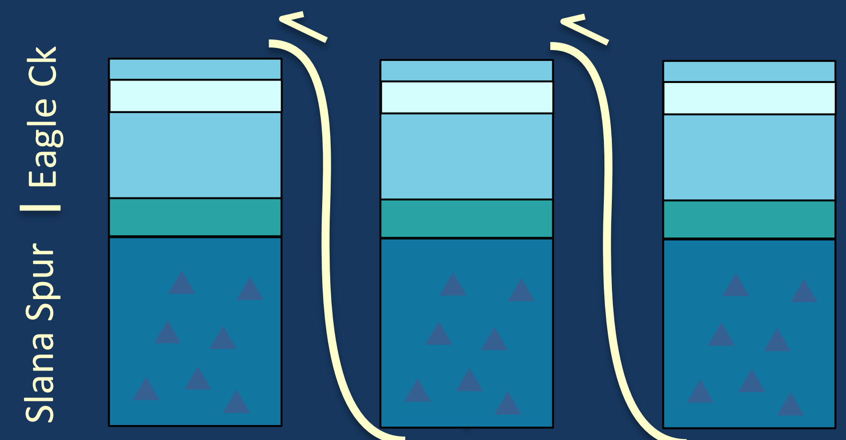


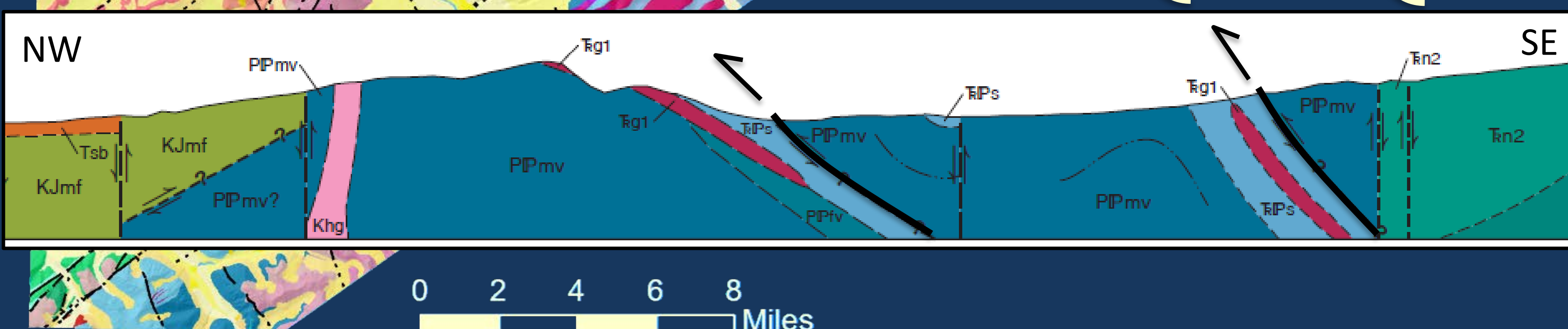
Map: PIR 2015-6 (Twelker and others, 2015)

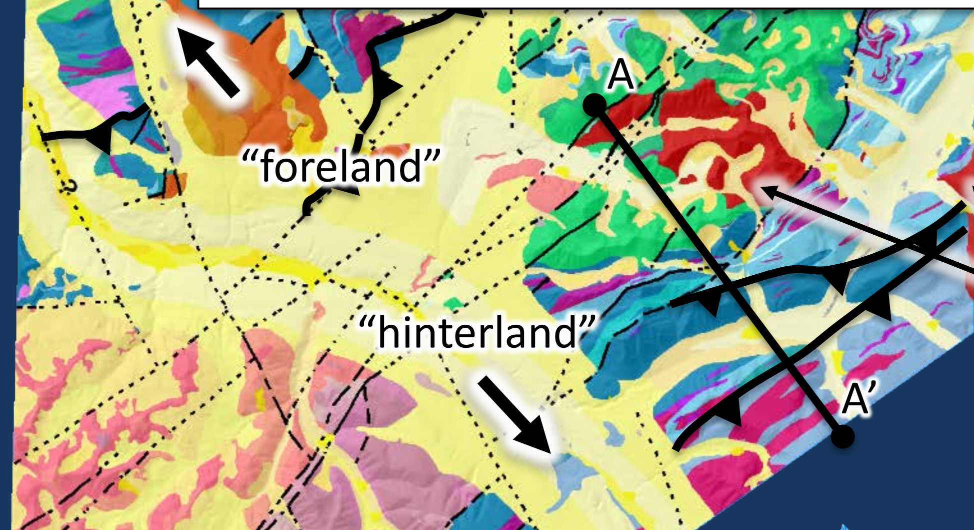
NW-vergent thrust faulting

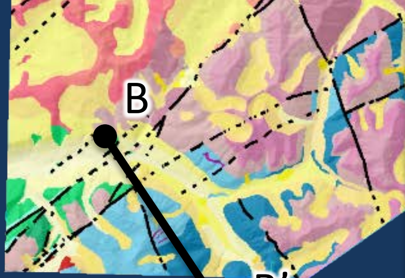
- Paleozoic section is too thick
  - > 5 km as mapped
- Stratigraphic repetition

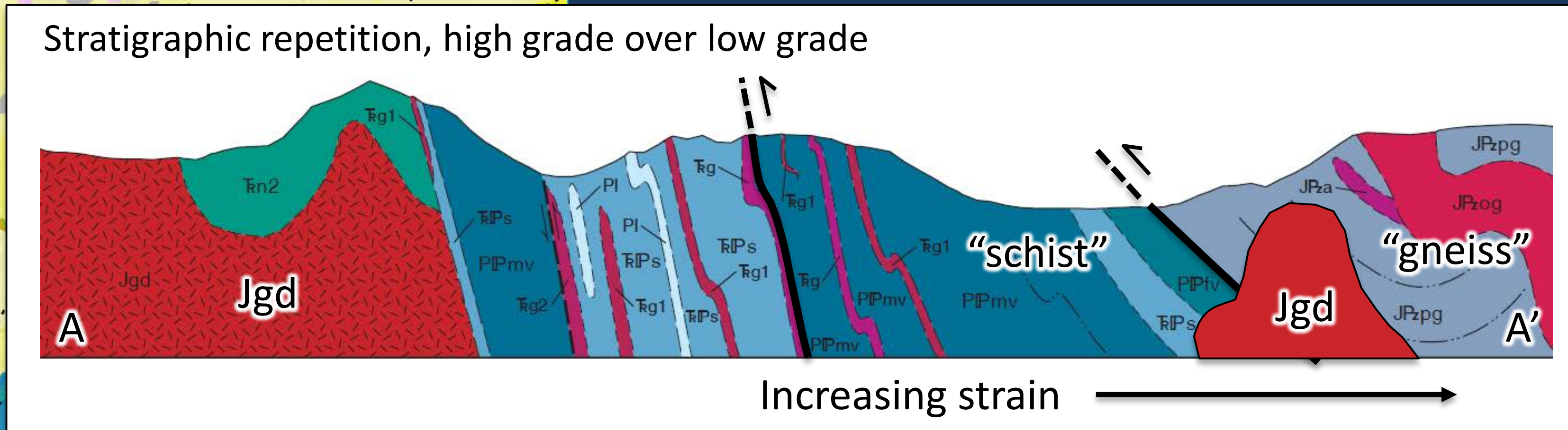






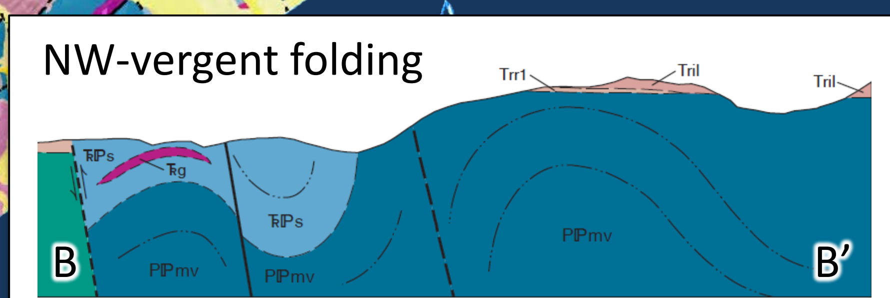






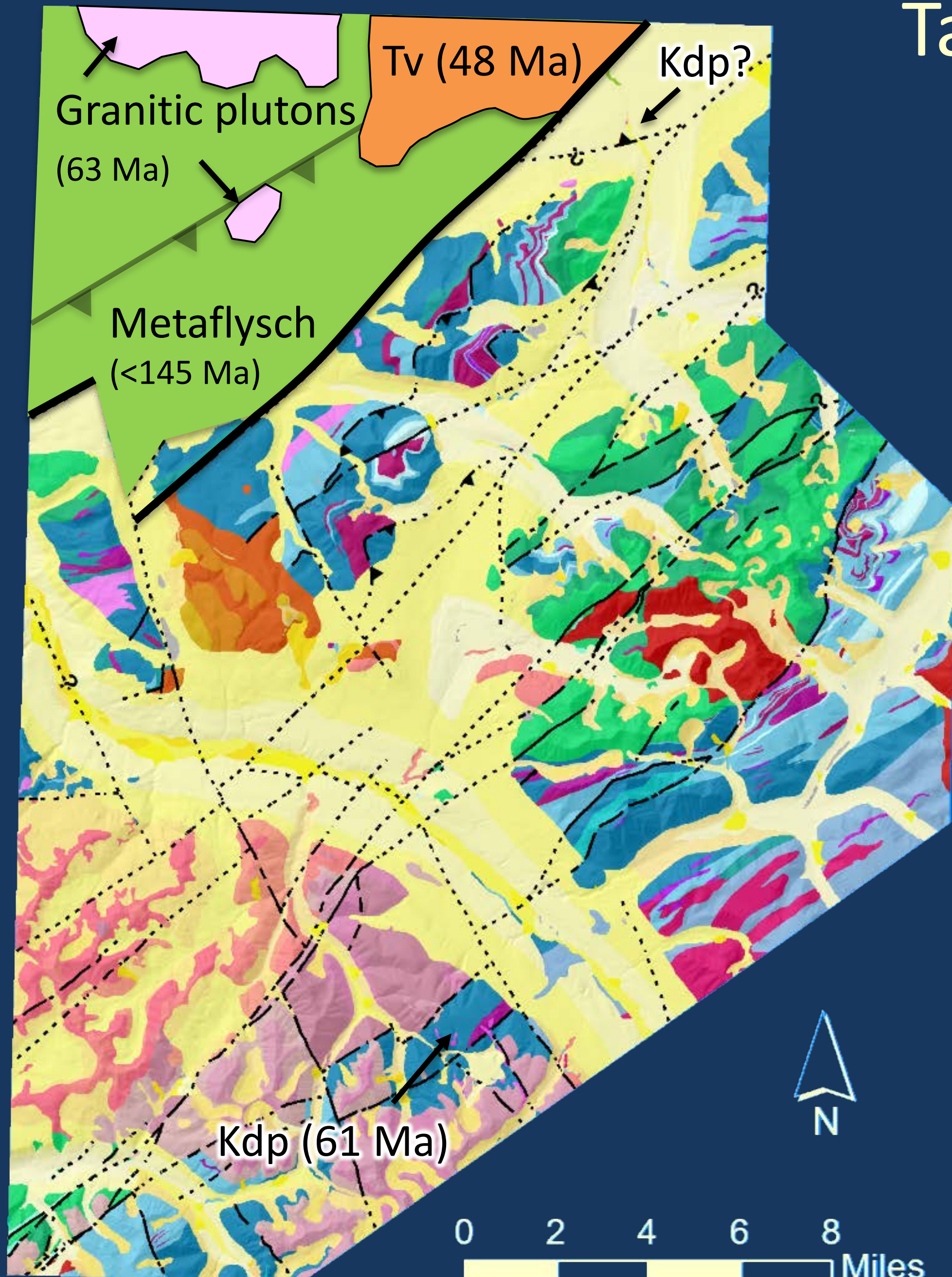
Metamorphic cooling:
186 Ma (musc.) 195 Ma (hbd)

165 Ma post-metamorphic plutons (Jgd) seal contact
similar emplacement depths



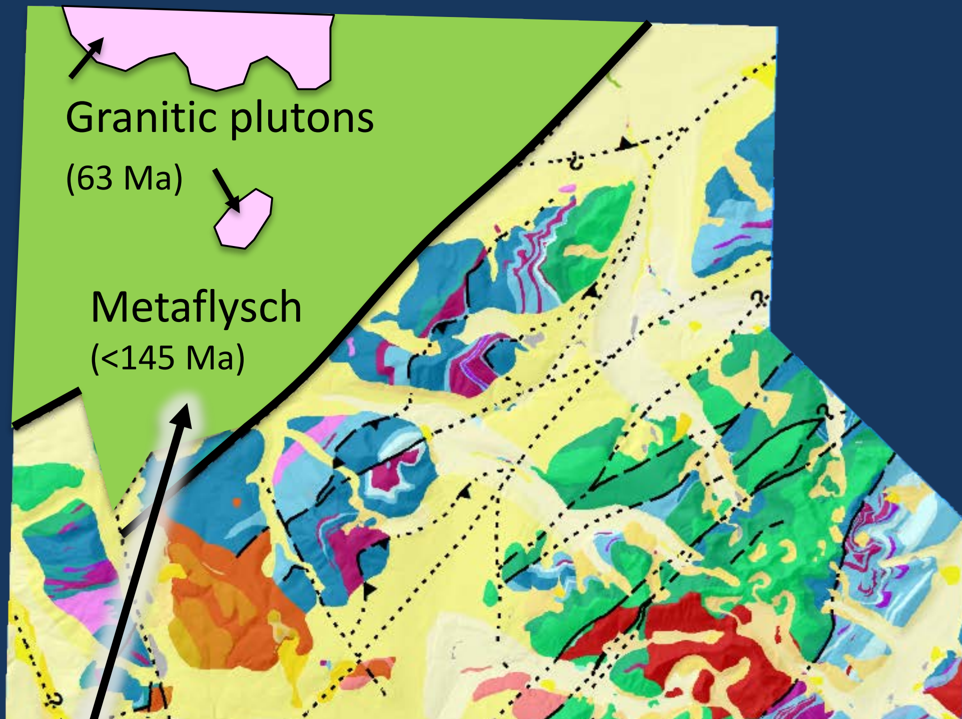
Shortening, amalgamation of Wrangellia and Peninsular Terranes

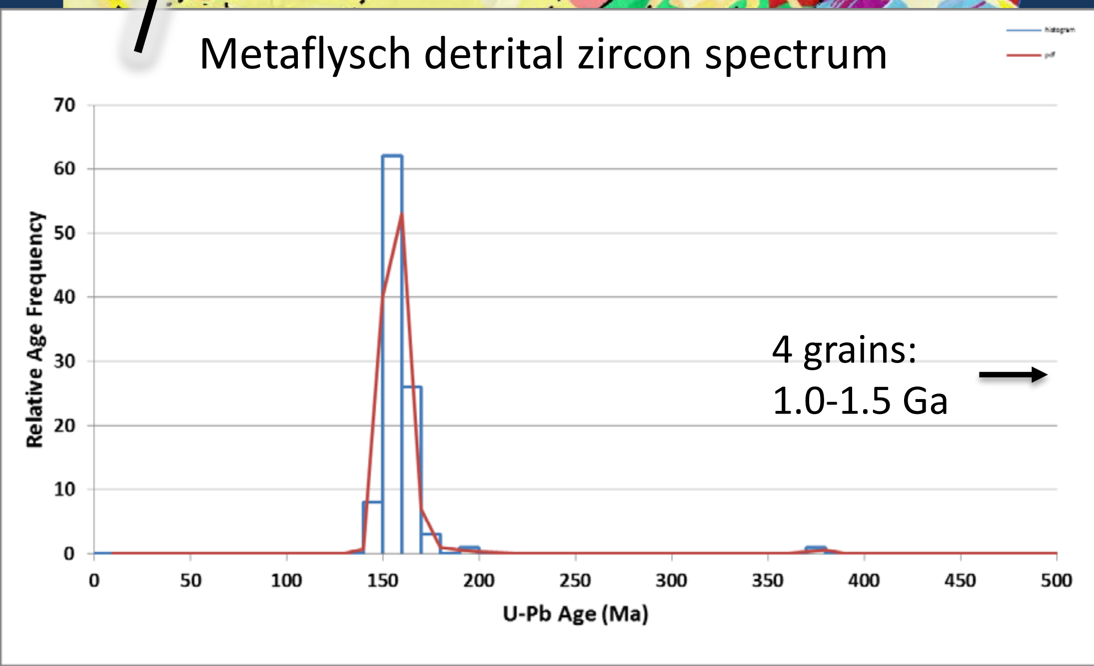
Talkeetna Suture Zone



- Metamorphosed flysch reaches amphibolite grade
  - biotite, hornblende; fabric
- Plutonic rocks to NW (63 Ma[1])
- Porphyry dikes (Kdp) of similar composition & age intrude Wrangellia to the SE (61 Ma[2])
- Volcanic rocks unconformably overlie metaflysch (48 Ma[3])
- Tertiary faulting likely hides some earlier complexity

[1] Benowitz and others (2015)
[2] Todd and others (2017)
[3] Schmidt and others (2002)





Metaflysch provenance:

Detrital zircons:

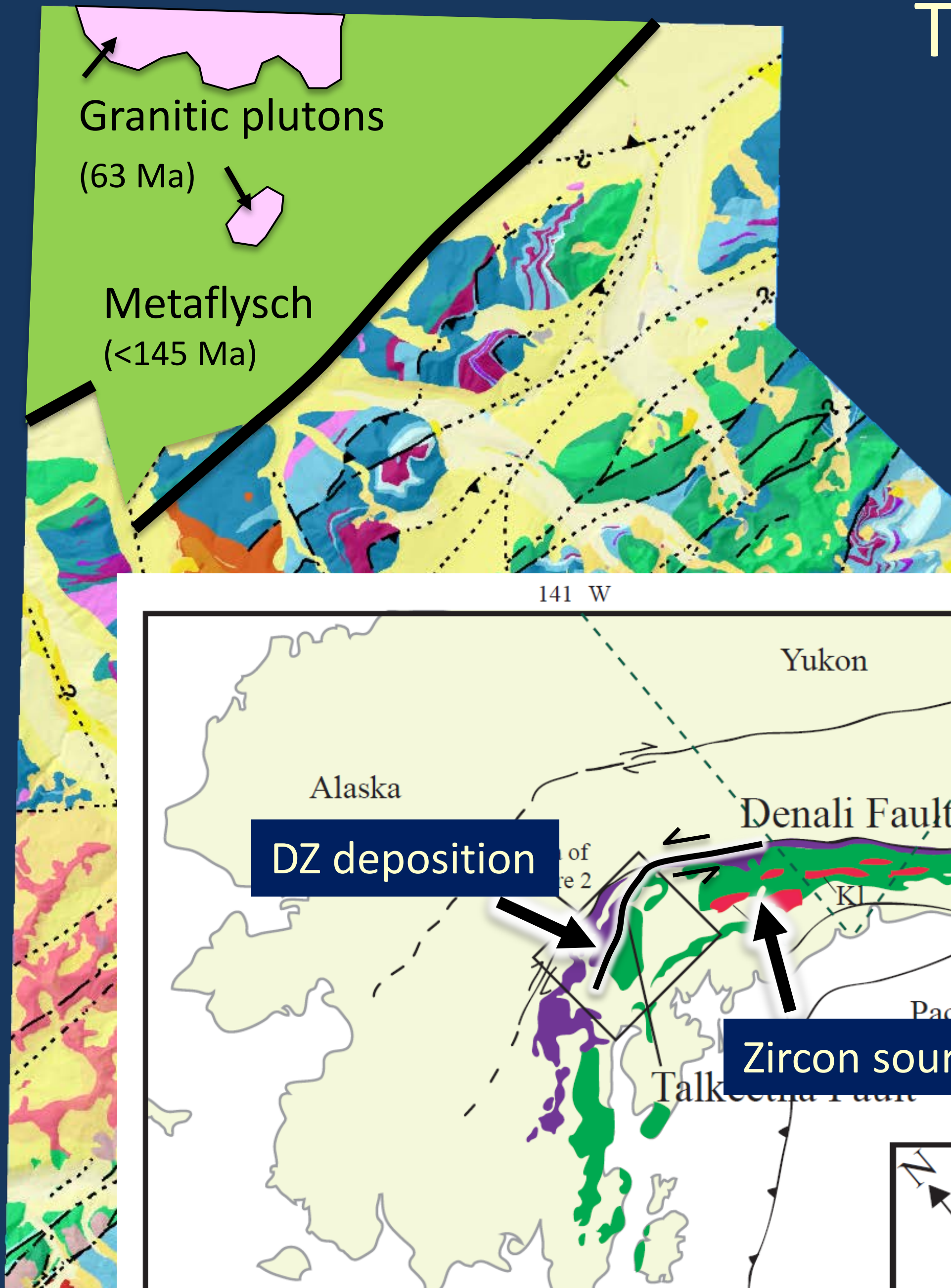
- Major population 165-145 Ma
  - Chitina Arc
- *Lacks* main Talkeetna Arc ages (200-178 Ma)
- Scattered Pz, Proterozoic
  - YTT source

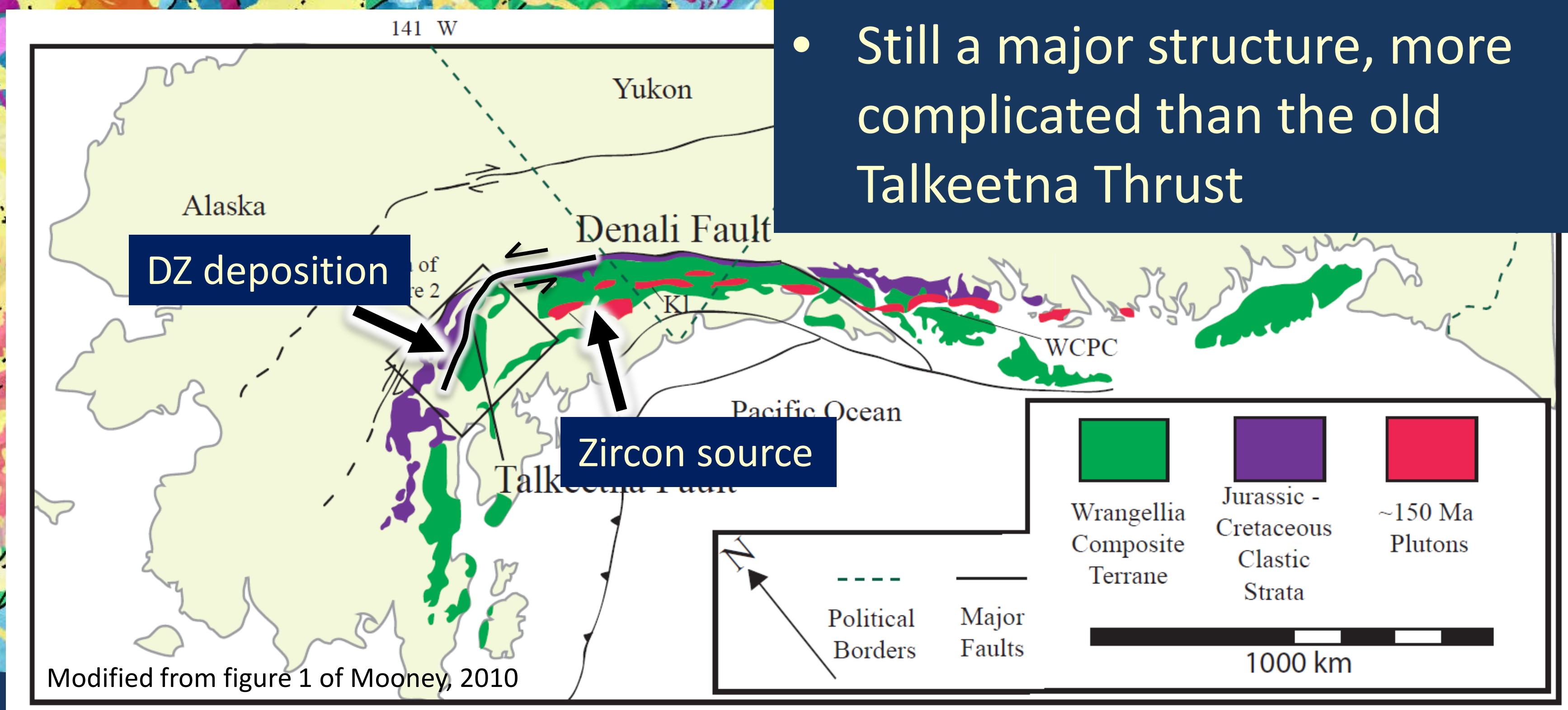
Close match to Nutzotin Mountains Sequence
(e.g. Hults and others, 2013)

Data by Paul O'Sullivan, courtesy Jamey Jones

Talkeetna Suture Zone

- Exhumation from mid-crustal conditions to surface between Late Cretaceous and 45 Ma
- Significant left-lateral translation suggested to link metaflysch to Chitina Arc
- Still a major structure, more complicated than the old Talkeetna Thrust

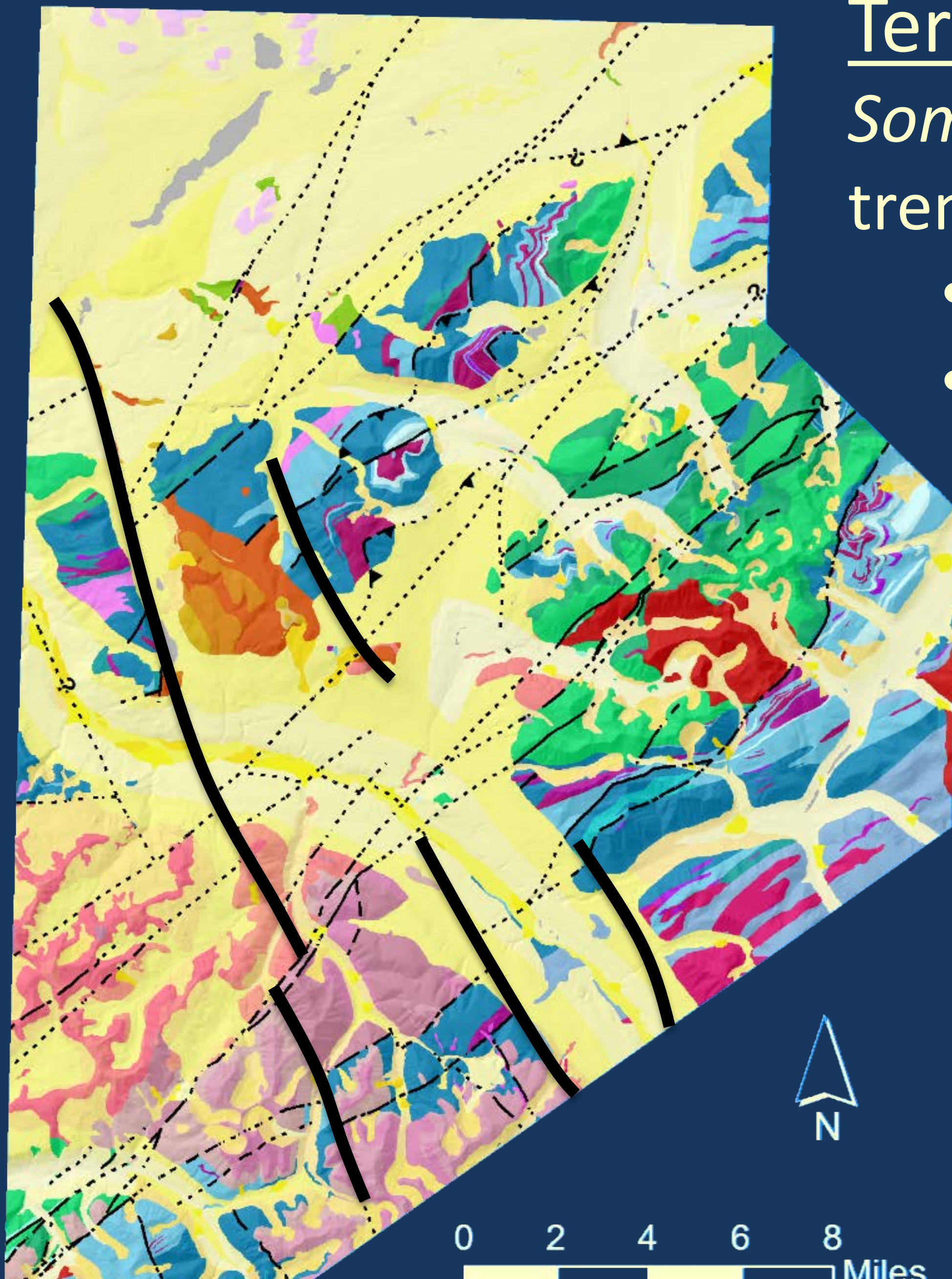


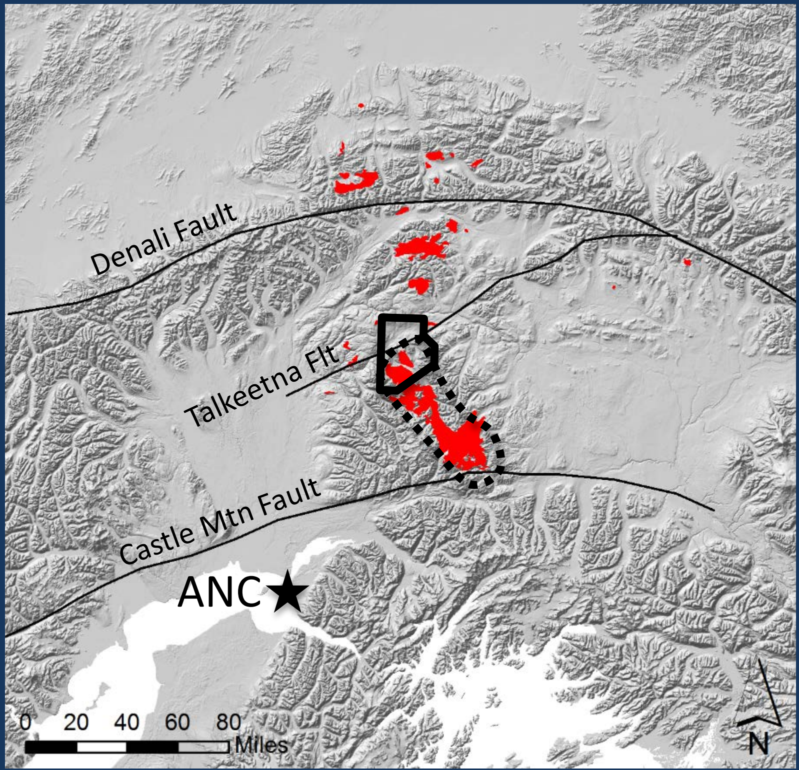


Tertiary faulting & volcanism

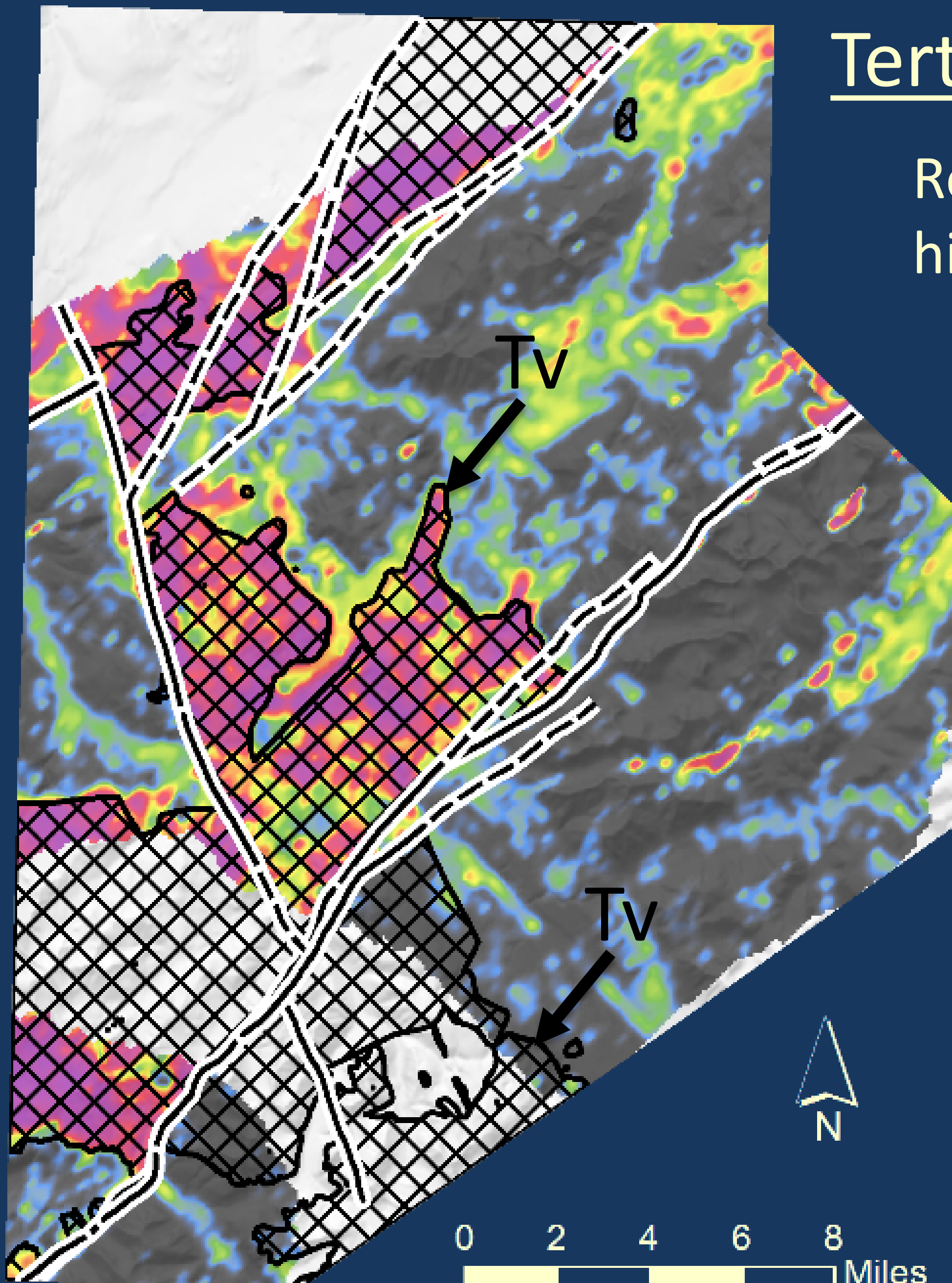
Some faults parallel regional trend of Tertiary volcanics

- Rift / NE-SW extension?
- It's not that simple





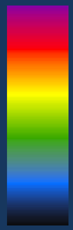
Tertiary faulting & volcanism



Resistivity map (900Hz; DGGS data) highlights major lineaments

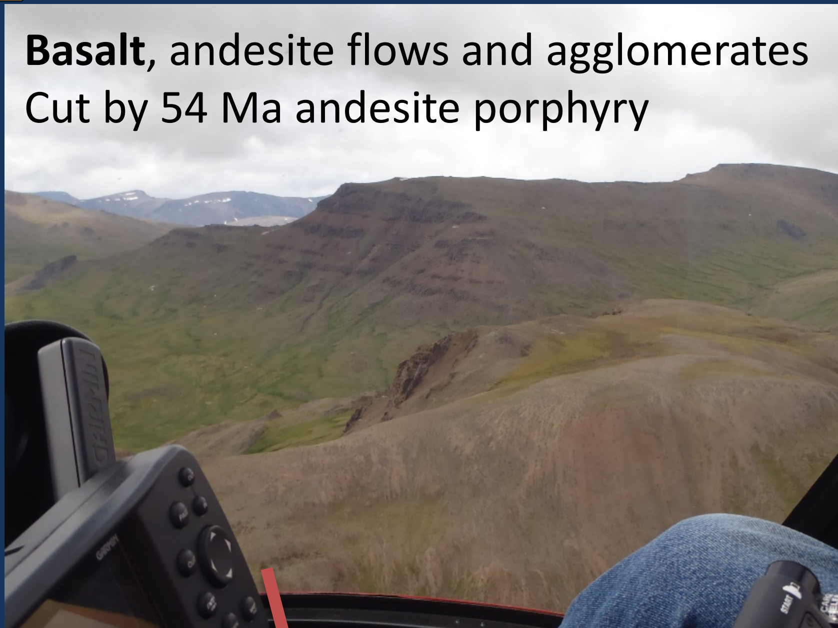
Major breaks are faults

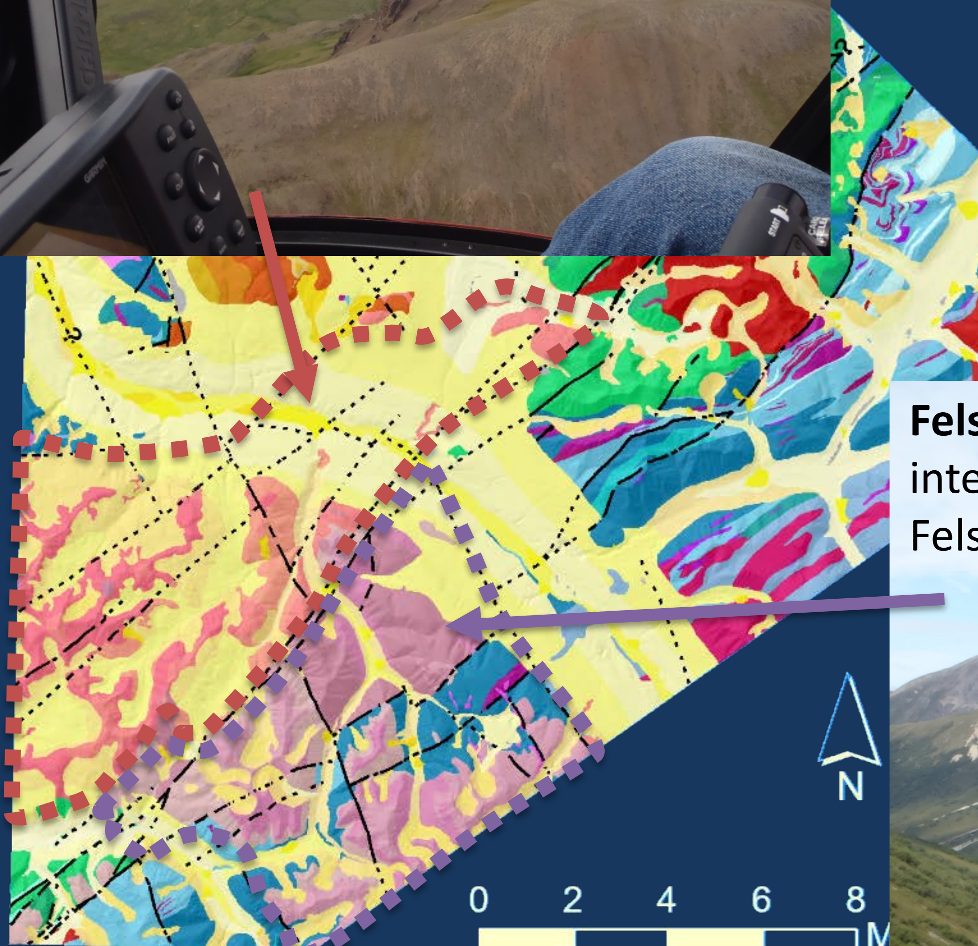
Low resistivity maps *some* of the Tertiary volcanics (volcanic rocks not inherently conductive, but depositional environment may include conductive sediments)

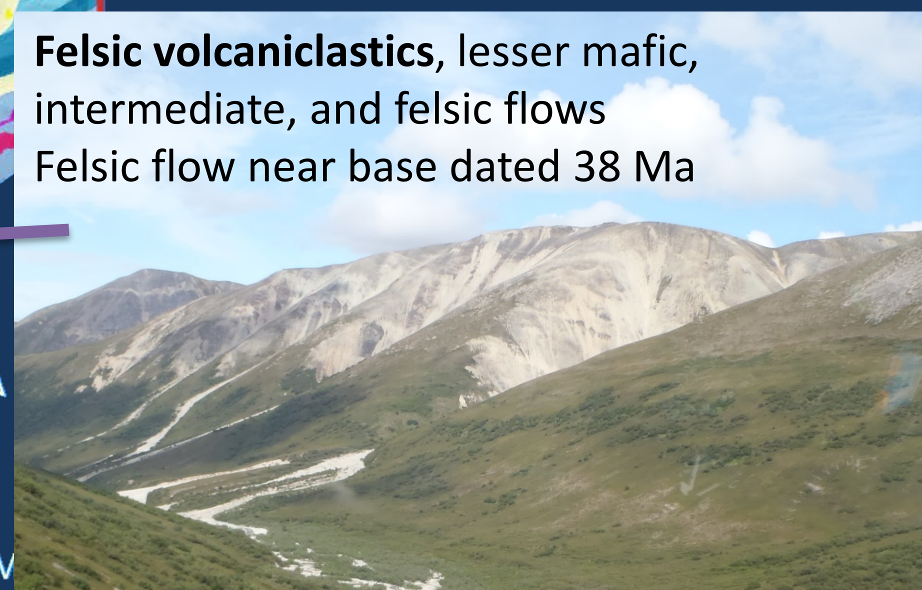


Geophysical data: Burns and others (2014)

Crosscutting relationships with volcanics help date relative fault motions

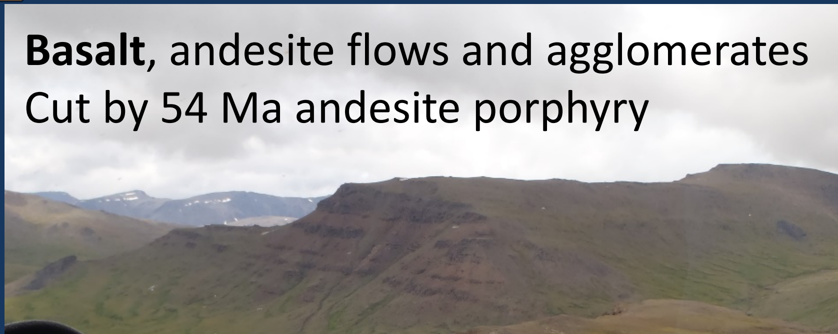


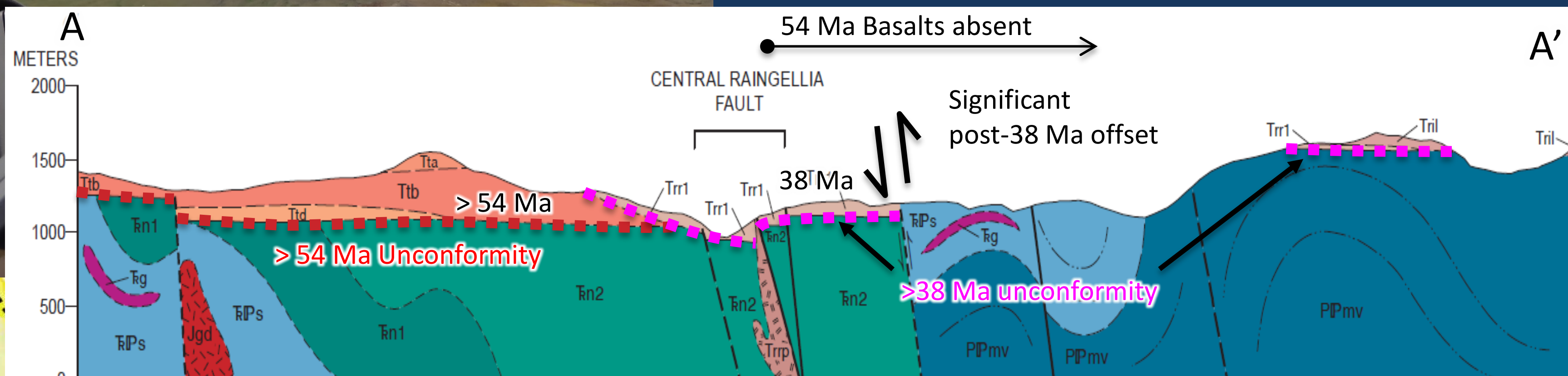


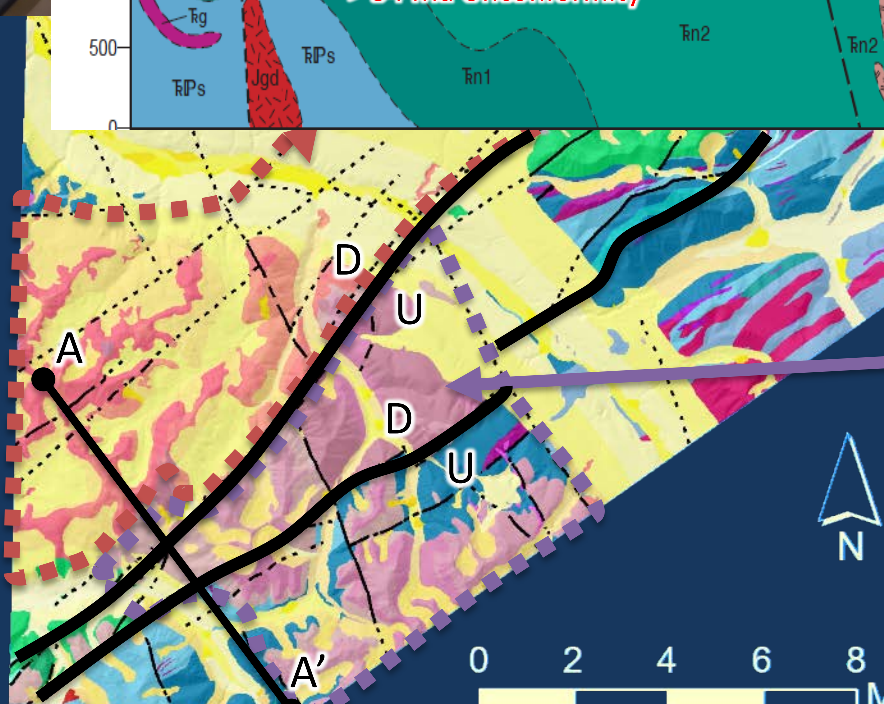


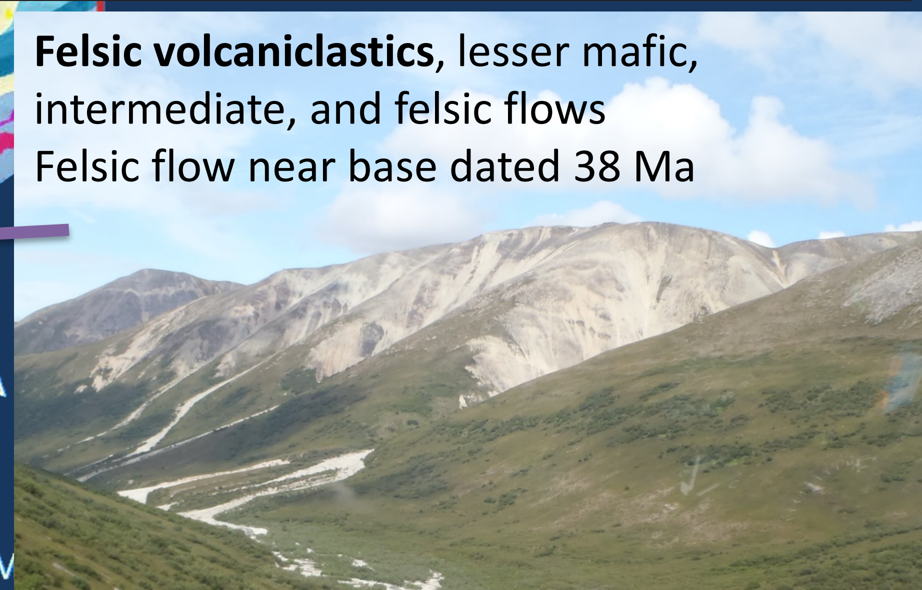
Age data: Benowitz et al (2015)

Crosscutting relationships with volcanics help time fault motions



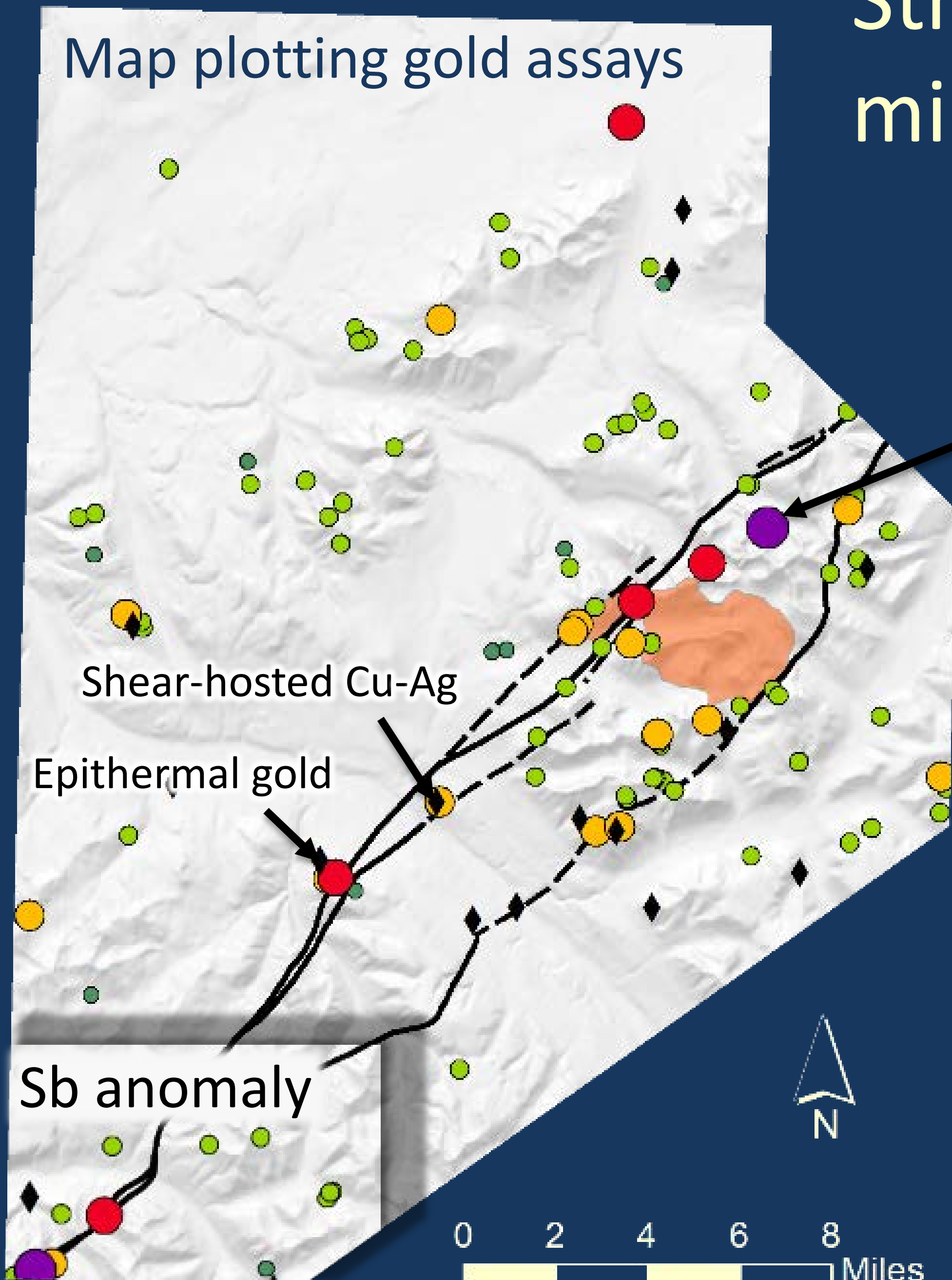






Age data: Benowitz et al (2015)

Structurally controlled mineralization

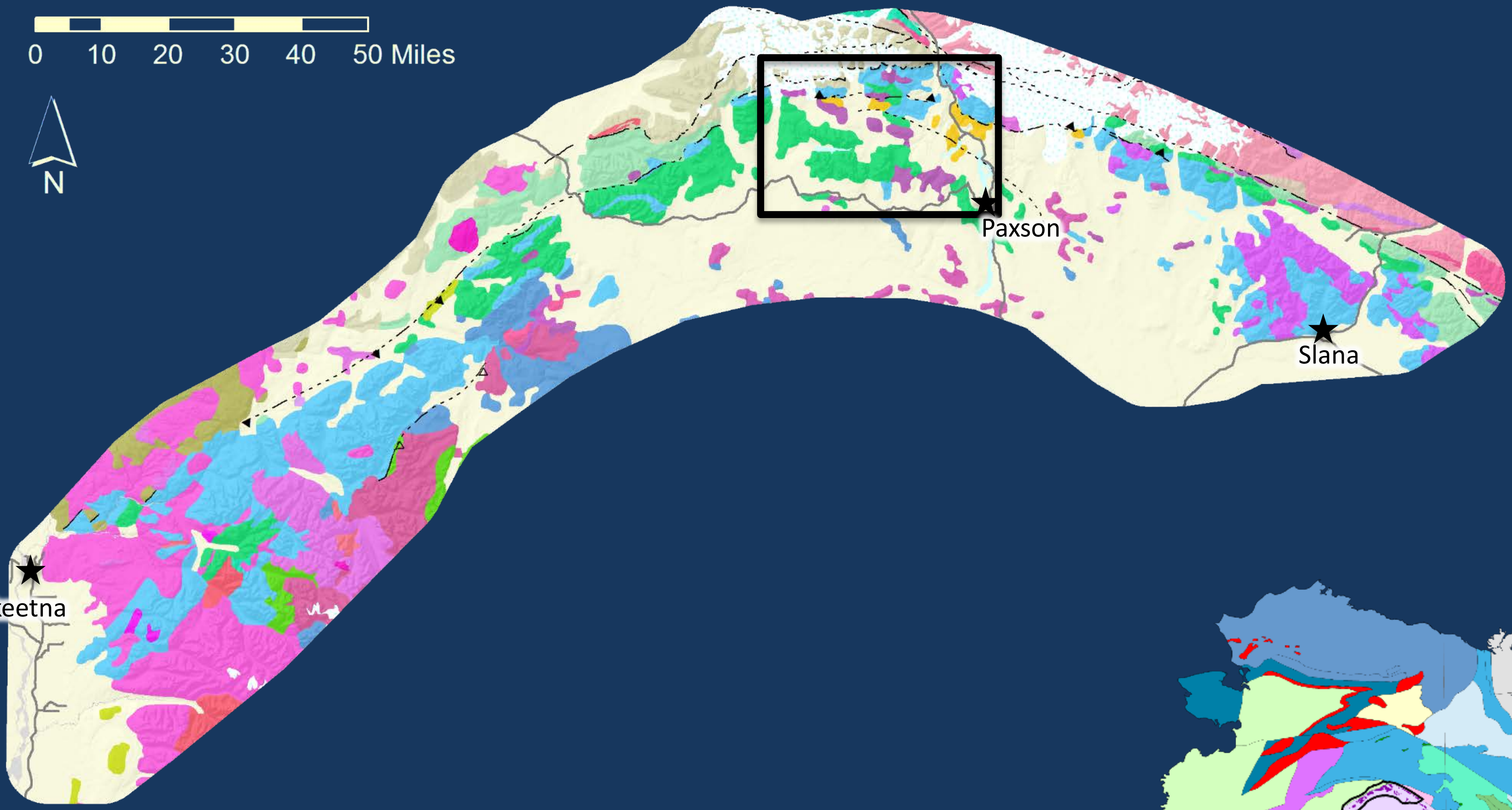


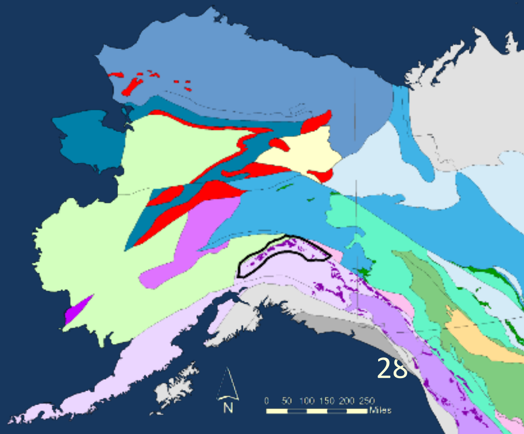
Z-score
(log-transformed)
- < -3
- -3 to -2
- -2 to -1
- -1 to 1
- 1 to 2
- 2 to 3
- > 3

Selected geology
- Fault
- Granodiorite

Data from RDF 2014-22 (Wypych and others, 2014)

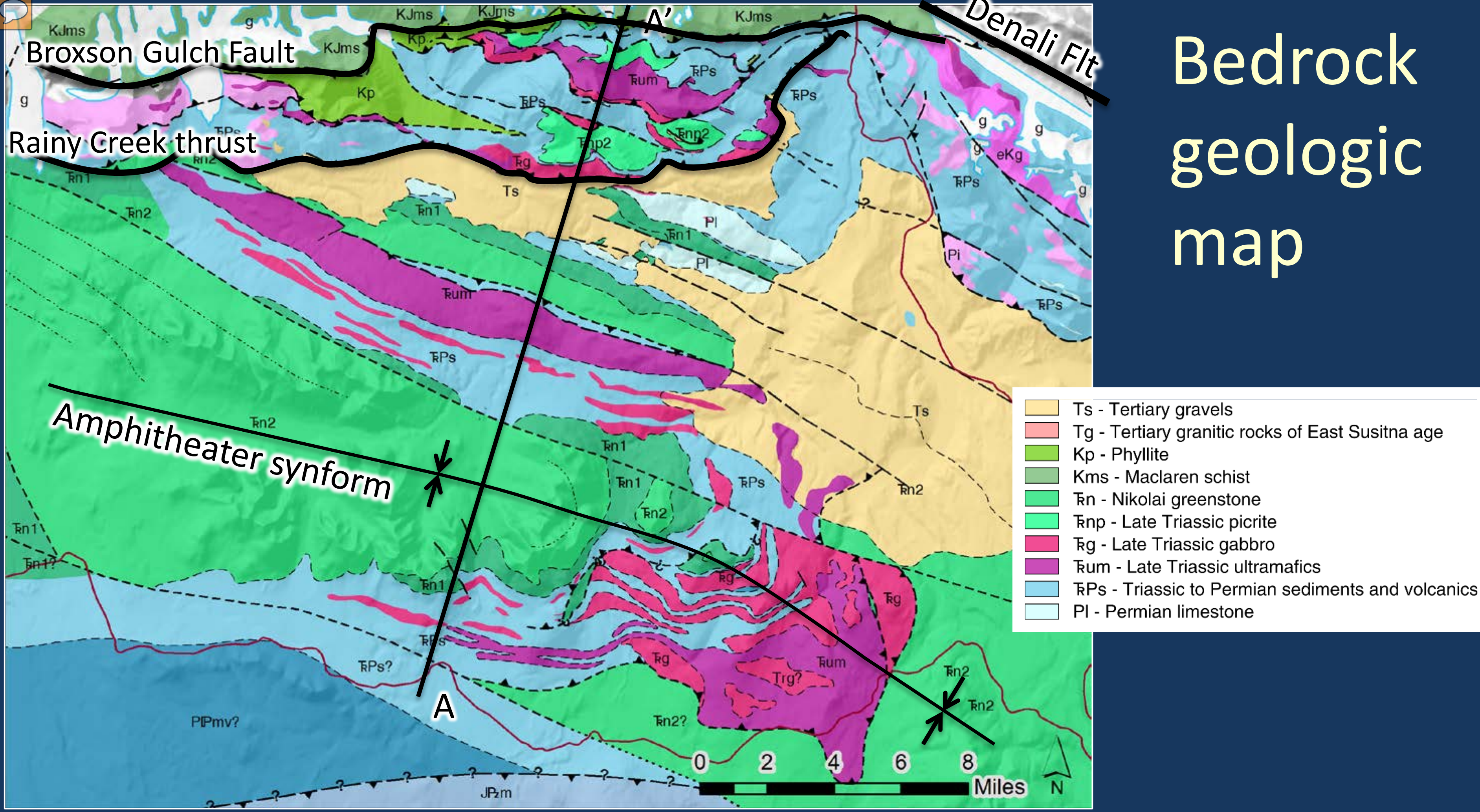
Part 2: Eastern Alaska Range Ultramafics & young deformation

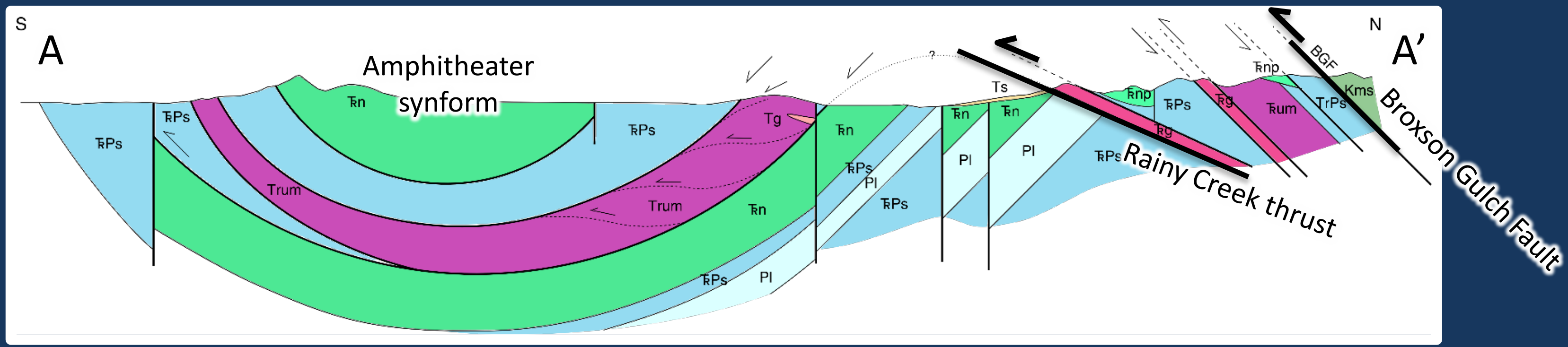


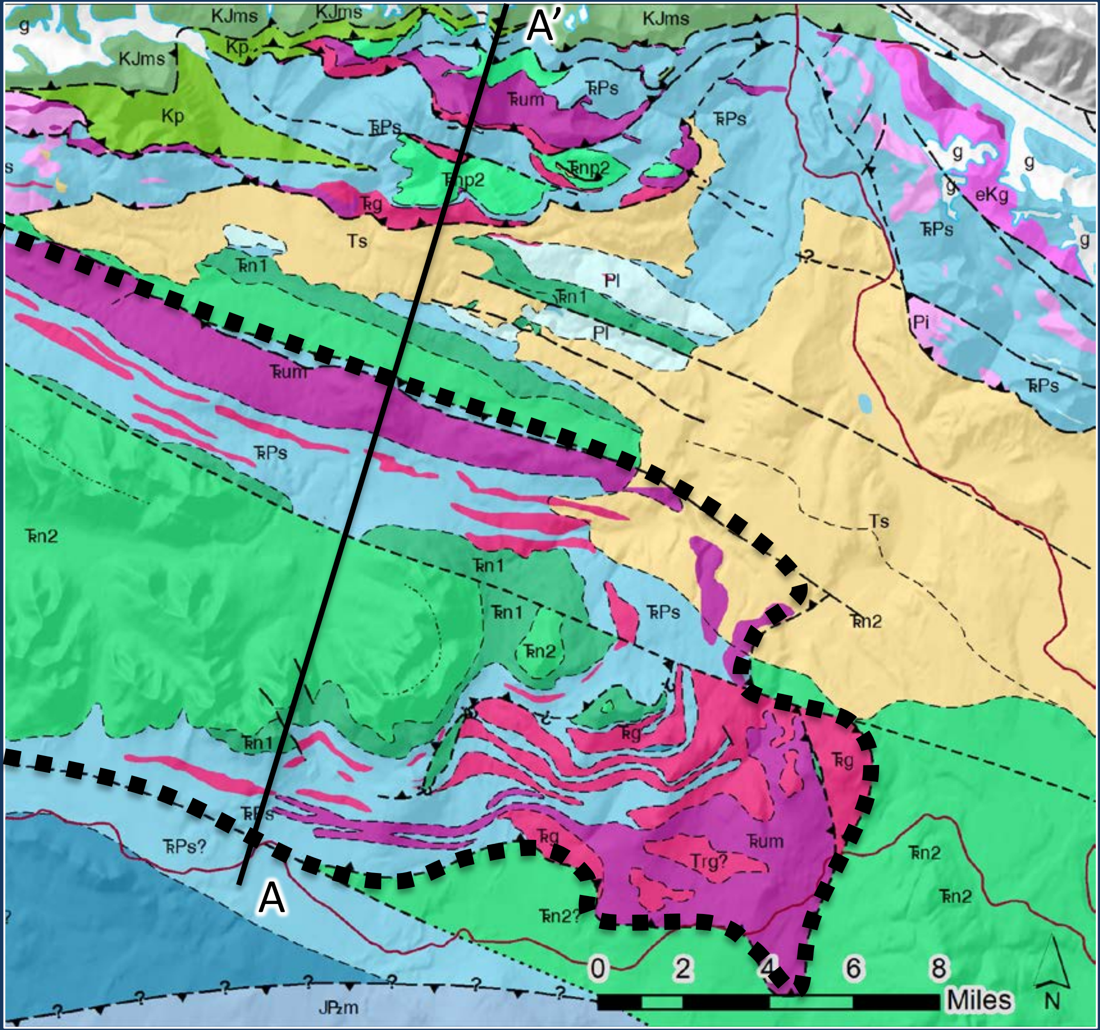


Geology of Wilson and others, 2015

Bedrock geologic map





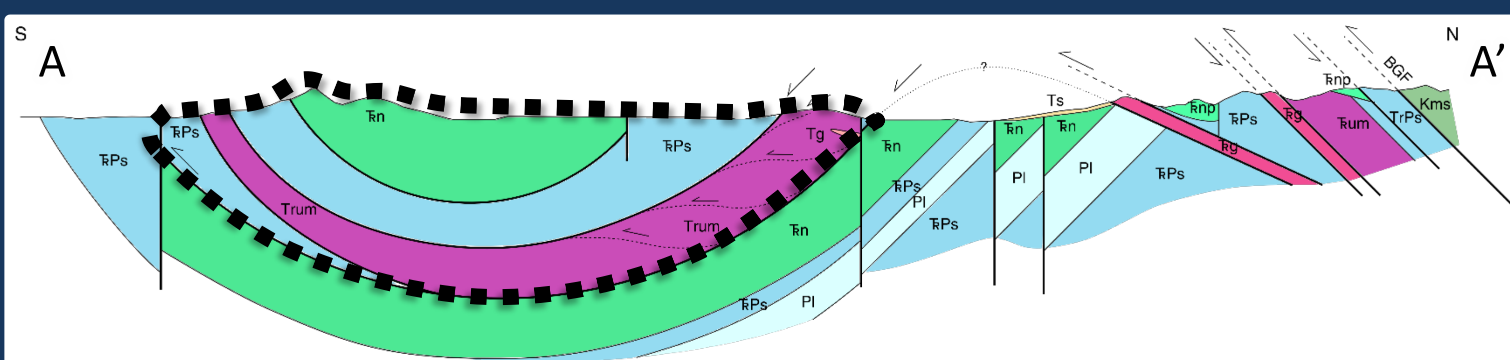


Three lithologic subdivisions

1: Amphitheater group:

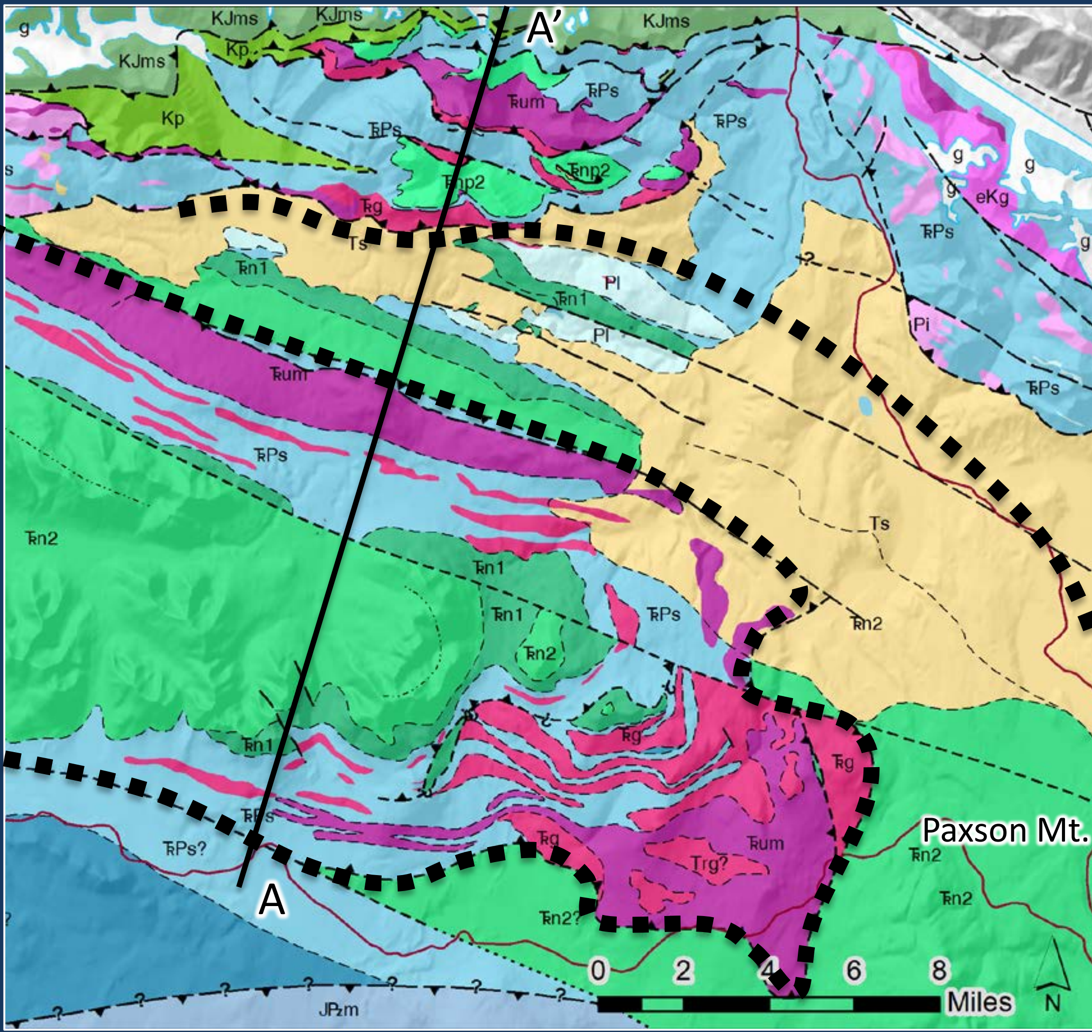
- Nikolai Greenstone (thick)
- Tr-P sediments (lacking limestone)
- Ultramafics, including Alpha/Fish Lake complex

- Ts - Tertiary gravels
- Tg - Tertiary granitic rocks of East Susitna age
- Kp - Phyllite
- Kms - Maclaren schist
- TRn - Nikolai greenstone
- TRnp - Late Triassic picrite
- TRg - Late Triassic gabbro
- TRum - Late Triassic ultramafics
- TRPs - Triassic to Permian sediments and volcanics
- Pl - Permian limestone



2. Paxson Mountain group:

- Nikolai Greenstone (thick)
- Permian limestone (Eagle Creek Formation)
- Lacking gabbro and ultramafics



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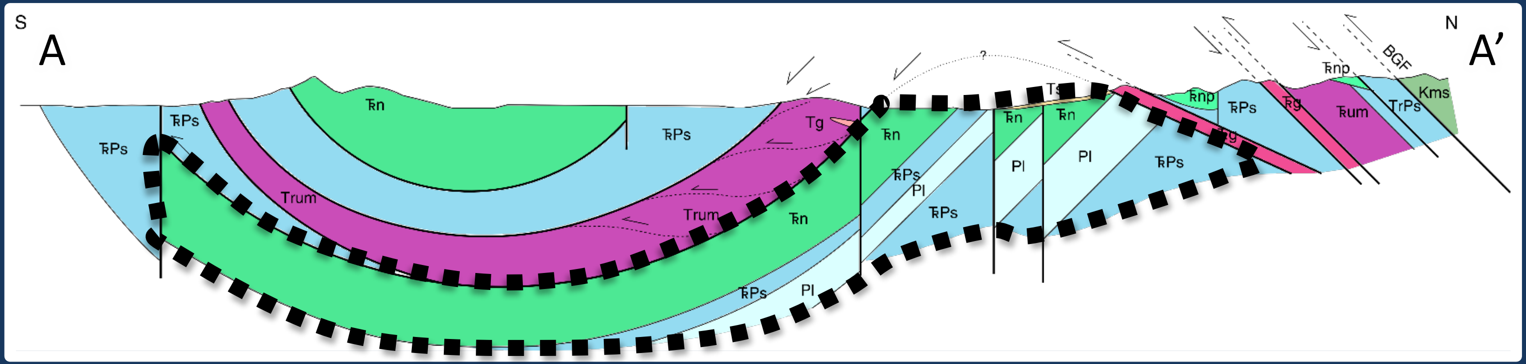
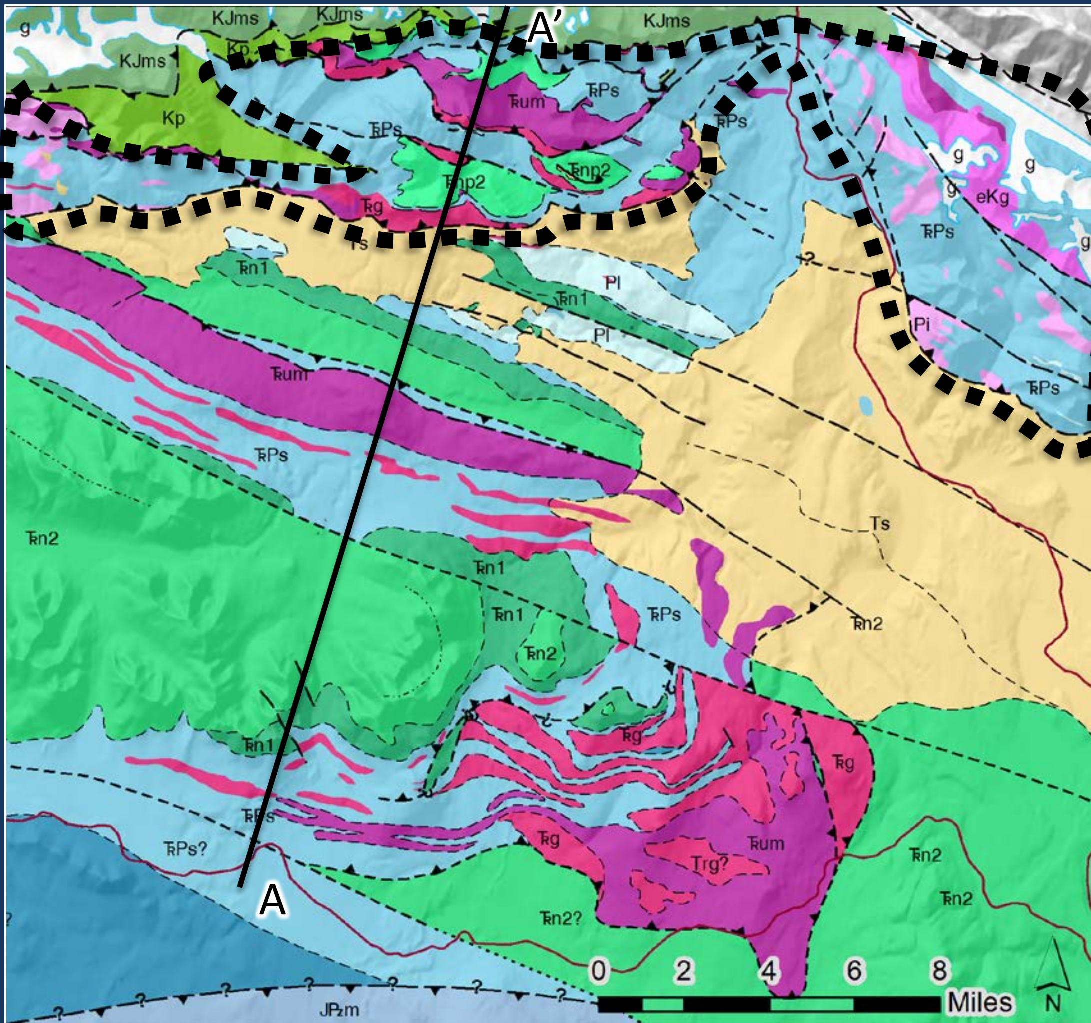


3. Rainy Creek group:

- Late Triassic picrite volcanics (very primitive basalt)
- Lacks ‘normal’ Nikolai
- Ultramafic bodies
- Permian-Triassic sediments, volcanics, *limited* limestone



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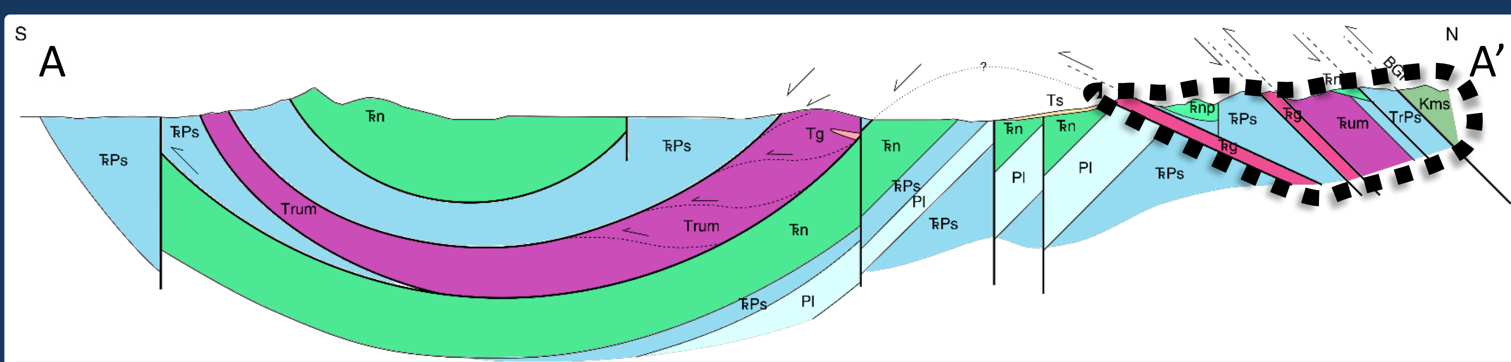
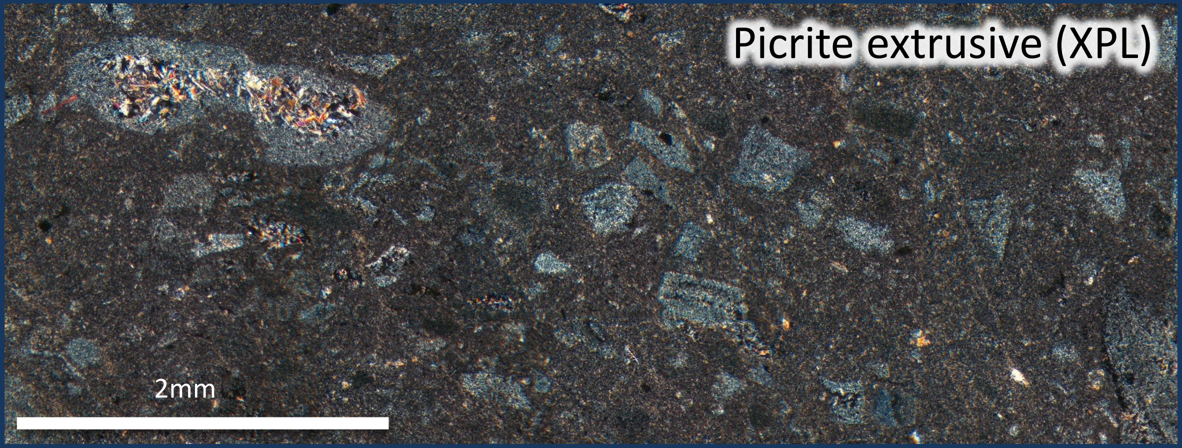
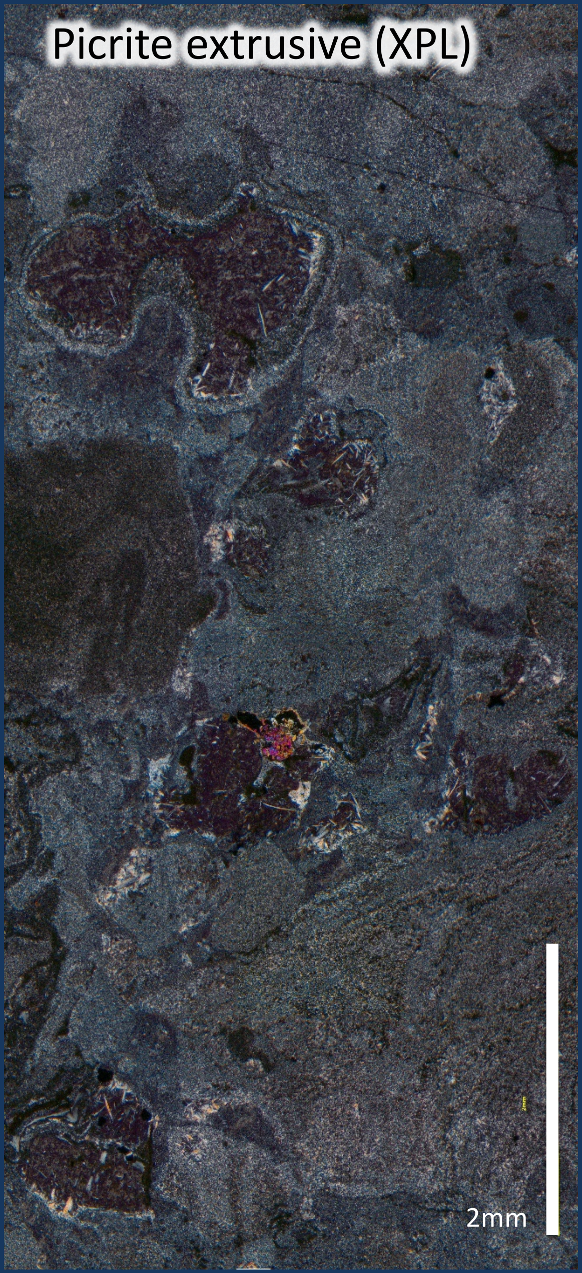


Rainy Creek Picrite

- Very fine grained volcanic breccia
- Fine-grained dikes
- Geochemically primitive:
  - High MgO, Ni, Cr
  - Low Al_2O_3, Zr
  - Primitive olivine, clinopyroxene
- Late Triassic: 225.7 ± 2 Ma (hbd)
  (Bittenbender and others, 2007)

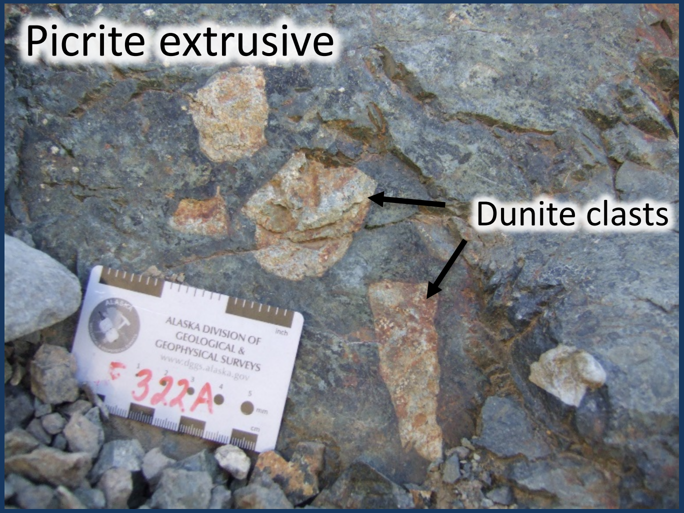


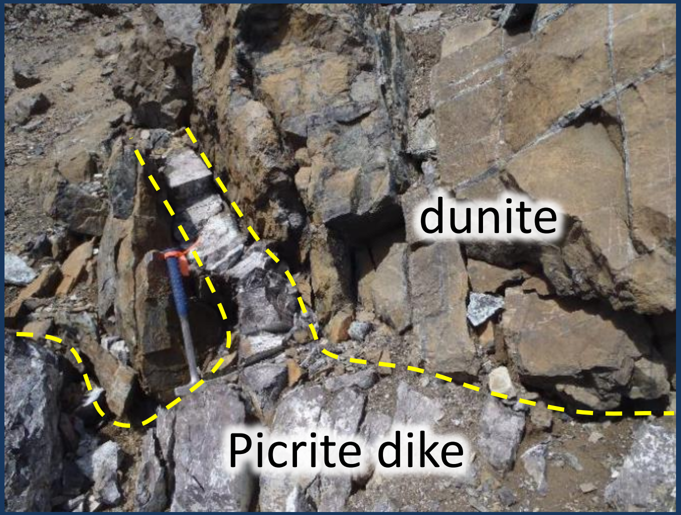
Very fine grained, fragmental, high-Mg lower greenschist minerals: actinolite + chlorite; lacks cumulate olivine

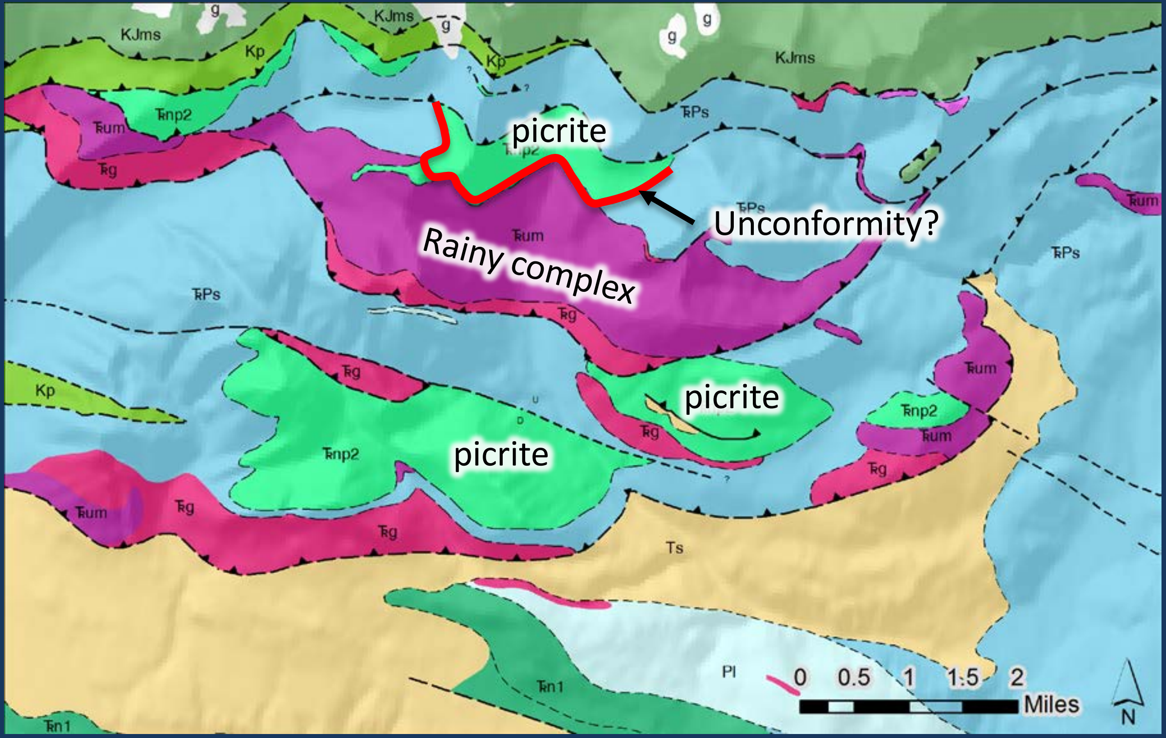


Volcanic environment

- Rainy ultramafic complex linked to low-Ti, early phase of Nikolai Greenstone
  - Olivine more primitive, low-Ti
- Intruded by high-Ti series dikes
- Clasts in high-Ti volcanic rocks (lithified)
- Uplift, unconformity *during* Late Tr event?
  - In contrast: magma mixing at Alpha complex



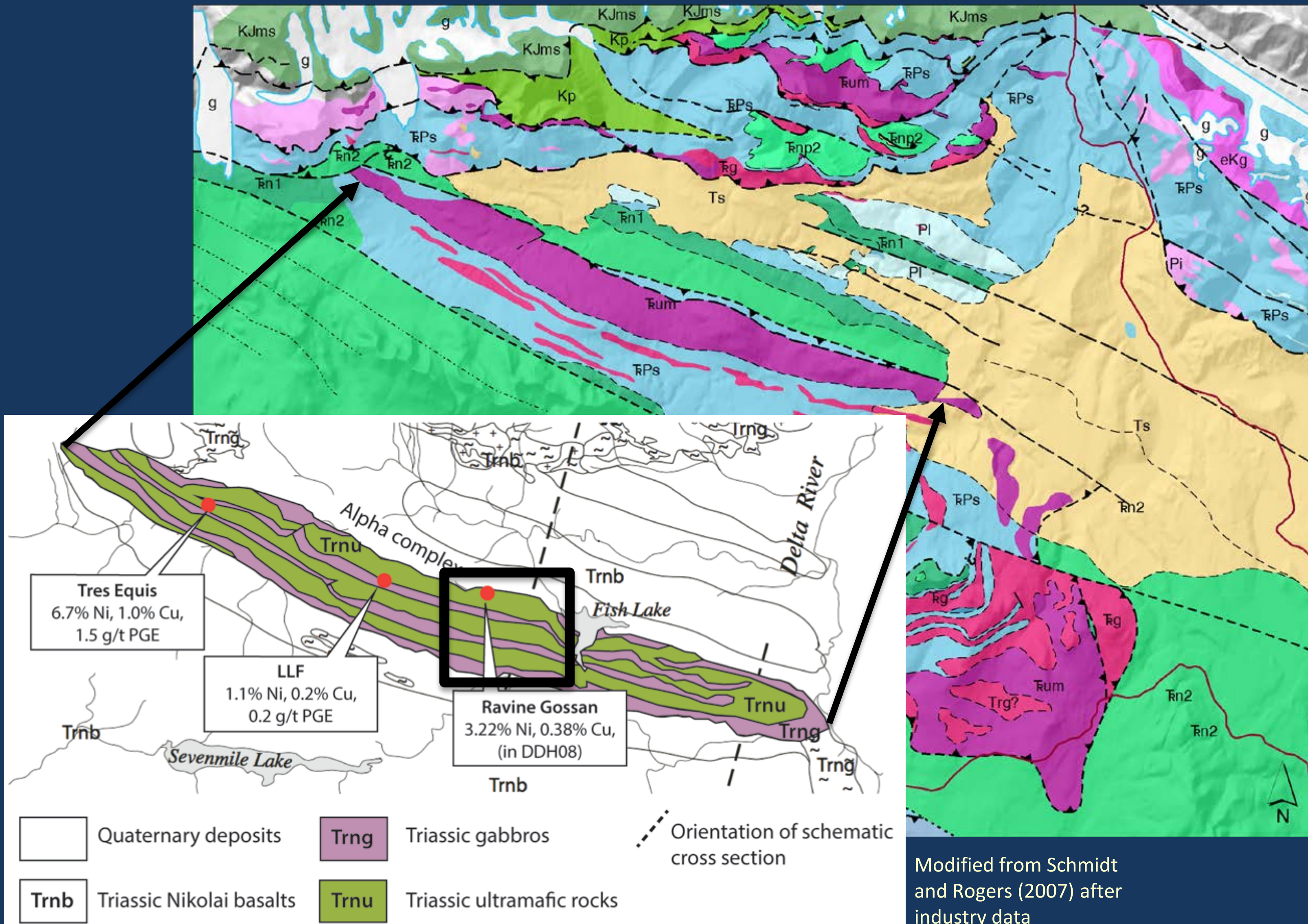




- Ts - Tertiary gravels
- Tg - Tertiary granitic rocks of East Susitna age
- Kp - Phyllite
- Kms - Maclaren schist
- Ꞧn - Nikolai greenstone
- Ꞧnp - Late Triassic picrite
- Ꞧg - Late Triassic gabbro
- Ꞧum - Late Triassic ultramafics
- ꞦPs - Triassic to Permian sediments and volcanics
- Pl - Permian limestone

Ultramafic complex architecture

Major implications for PGE deposit type and exploration strategy

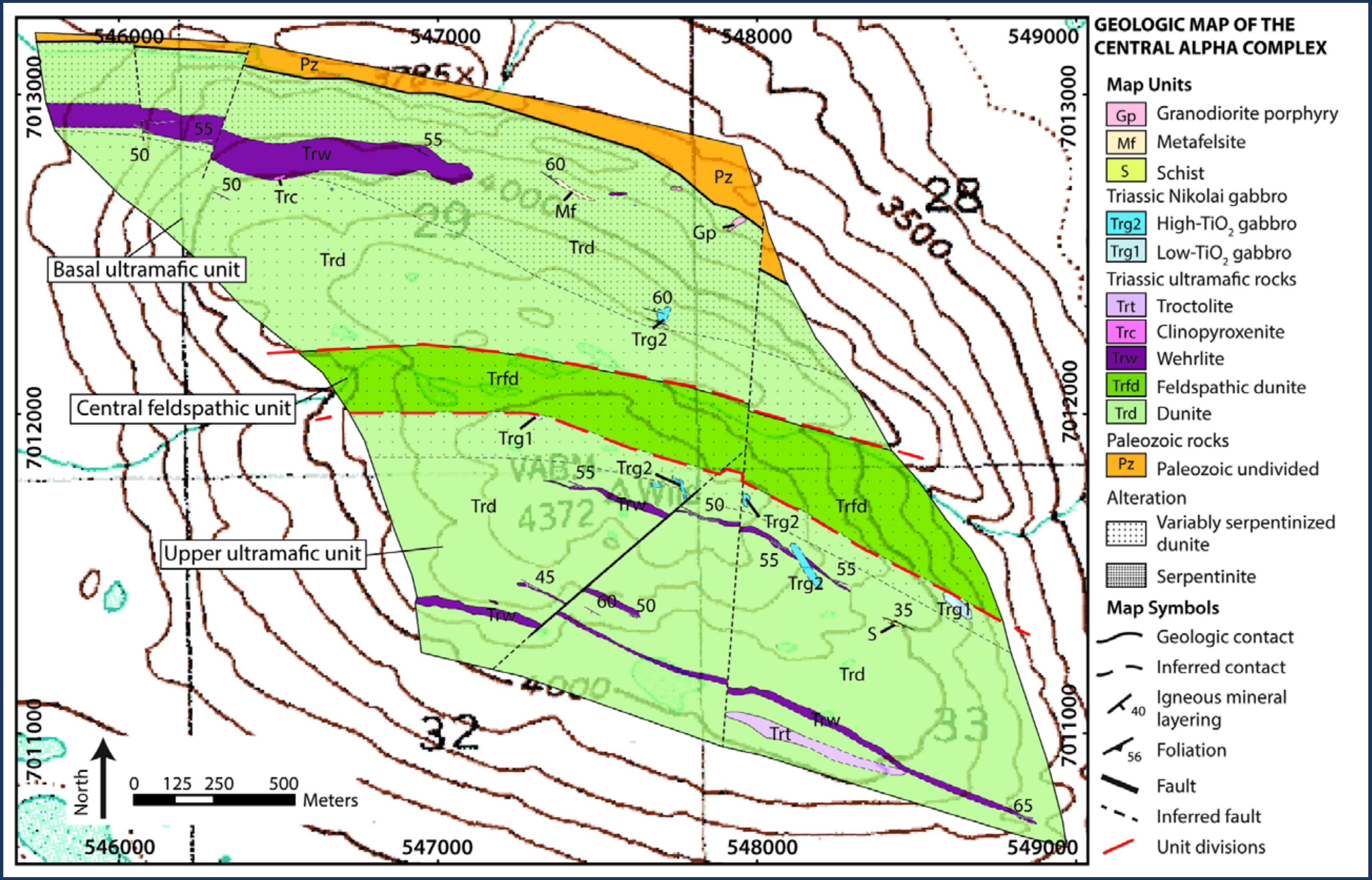


Modified from Schmidt and Rogers (2007) after industry data

Previous interpretation: *cyclical* ultramafic to gabbro layered complex

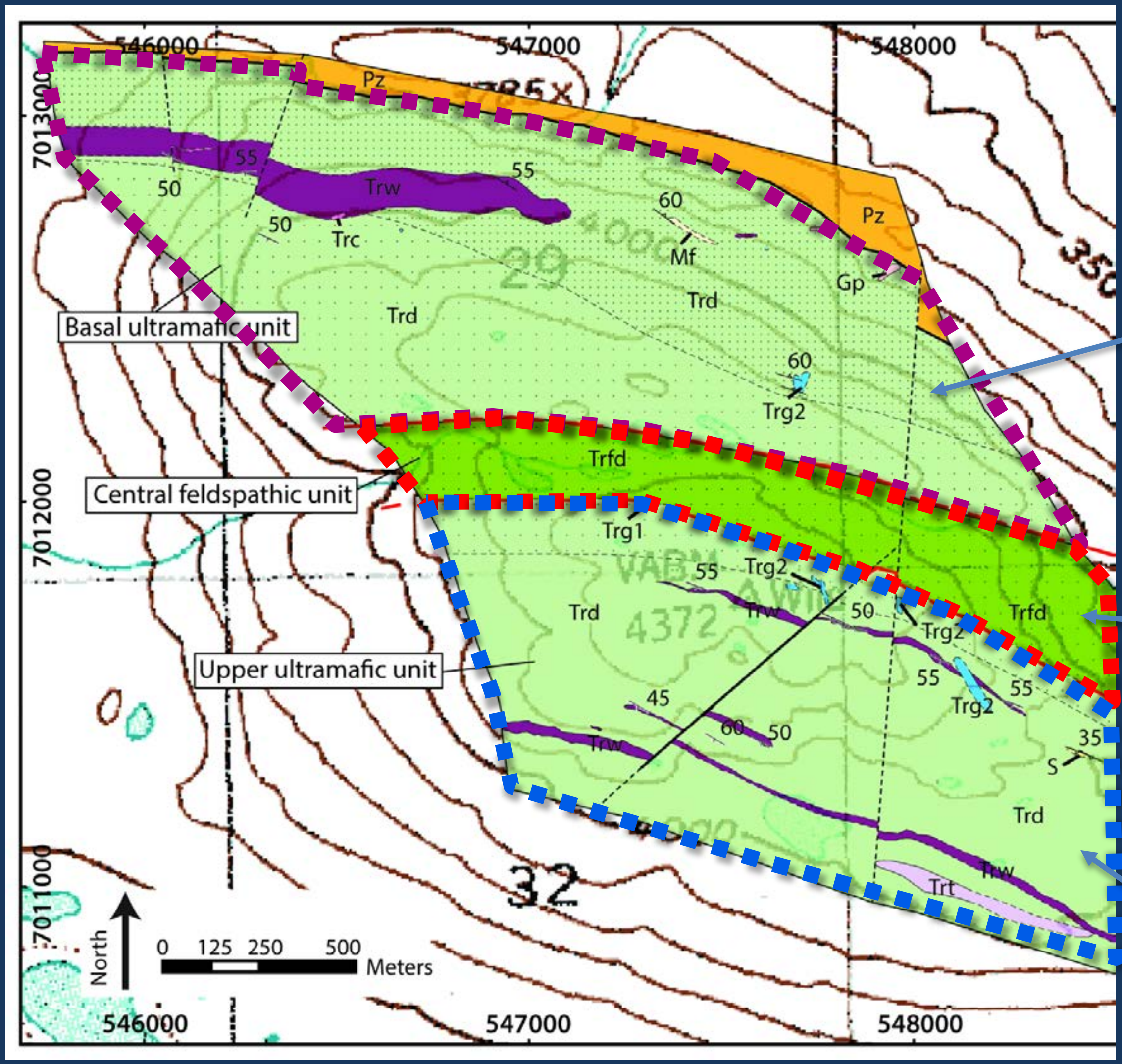
Detailed mapping of Alpha complex

Completed by Lauren Lande through DGGS-UAF MS Research Internship



Gabbro is shown in blue: traceable as thin crosscutting dikes

A multiphase sill complex

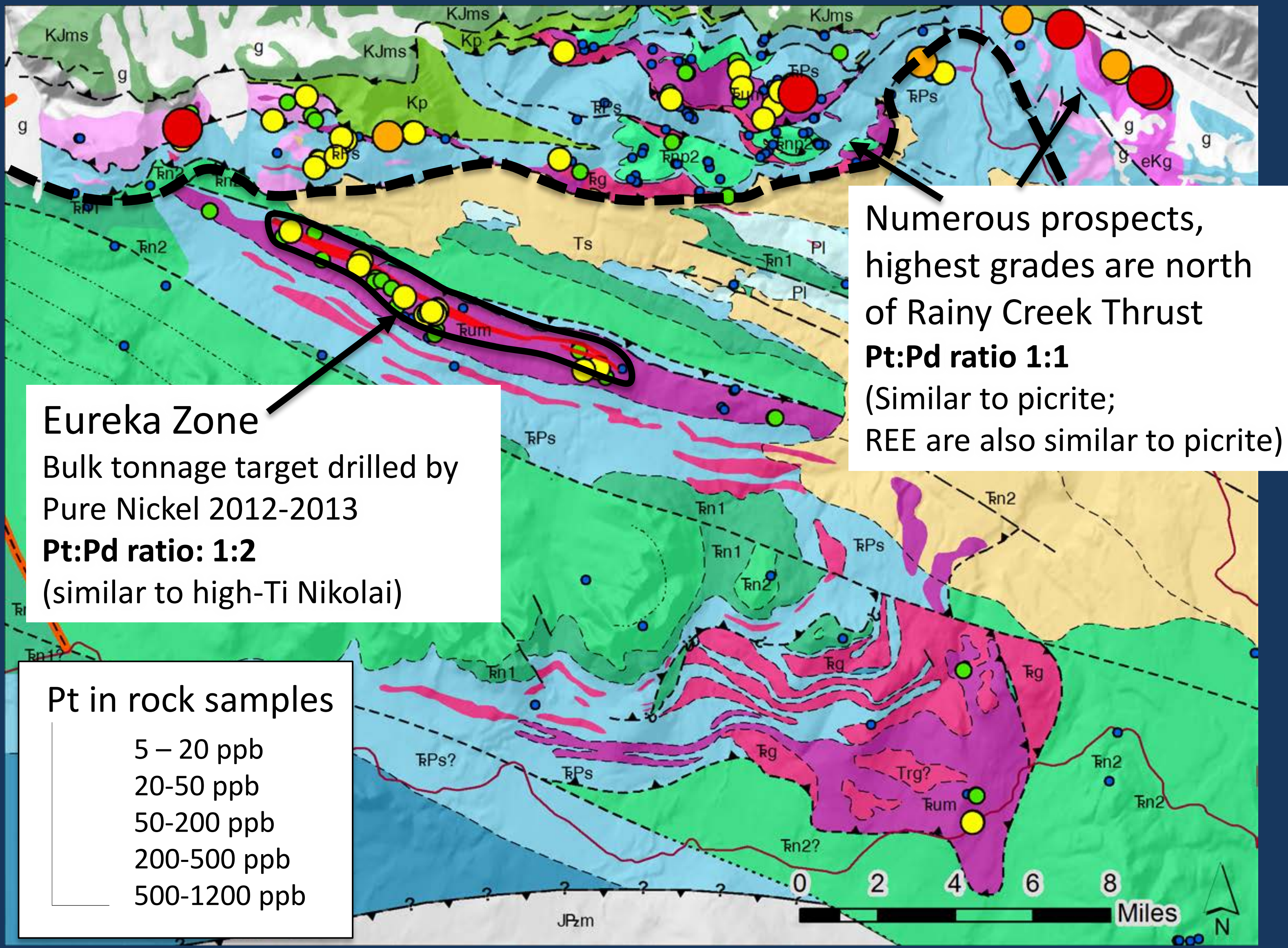


Basal ultramafic unit:
Intermediate Ti clinopyroxene;
Disequilibrium textures:
magma mixing?

Central feldspathic unit:
High Ti clinopyroxene:
Crystallized from high Ti magma (Upper Nikolai)
=Eureka PGE mineralized zone

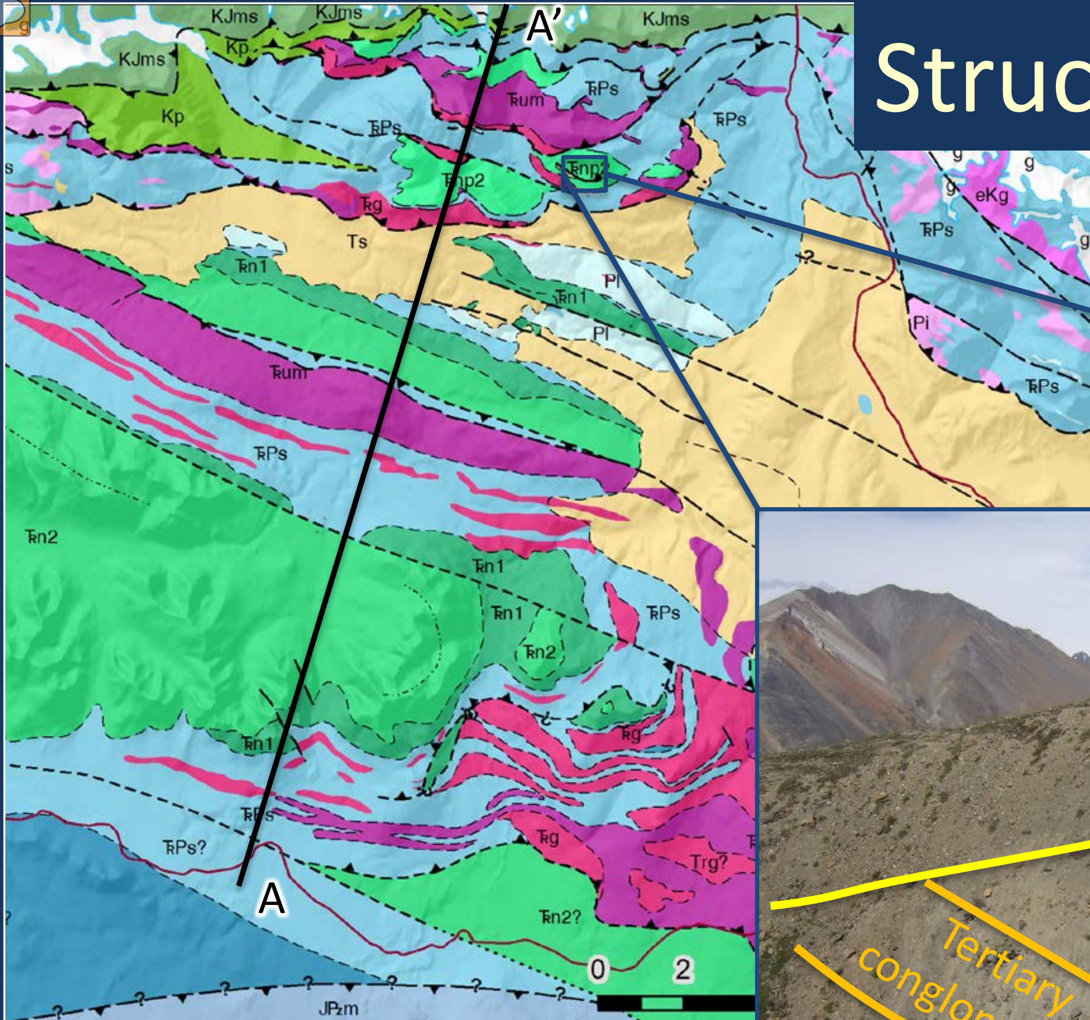
Upper ultramafic unit:
Low Ti clinopyroxene:
Crystallized from low Ti magma (Lower Nikolai)

PGE mineralization

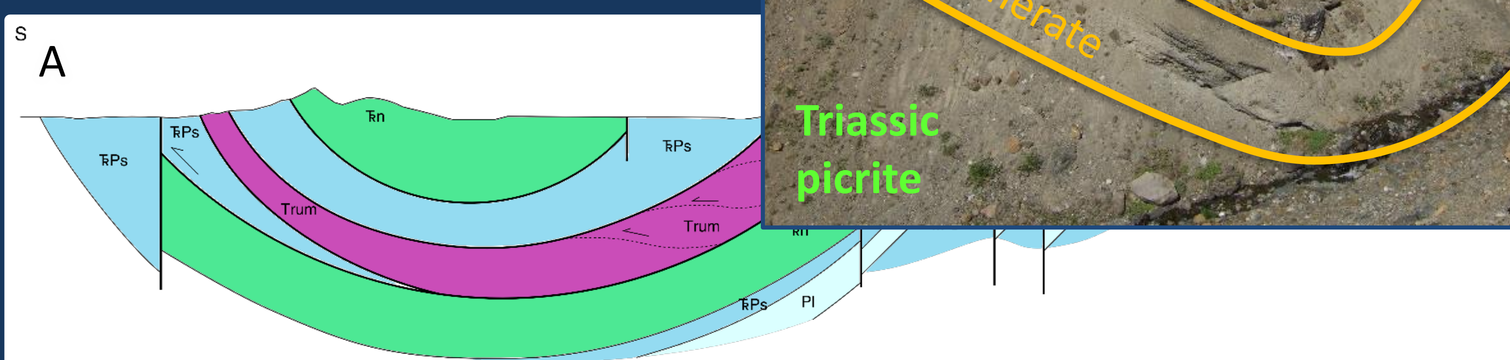


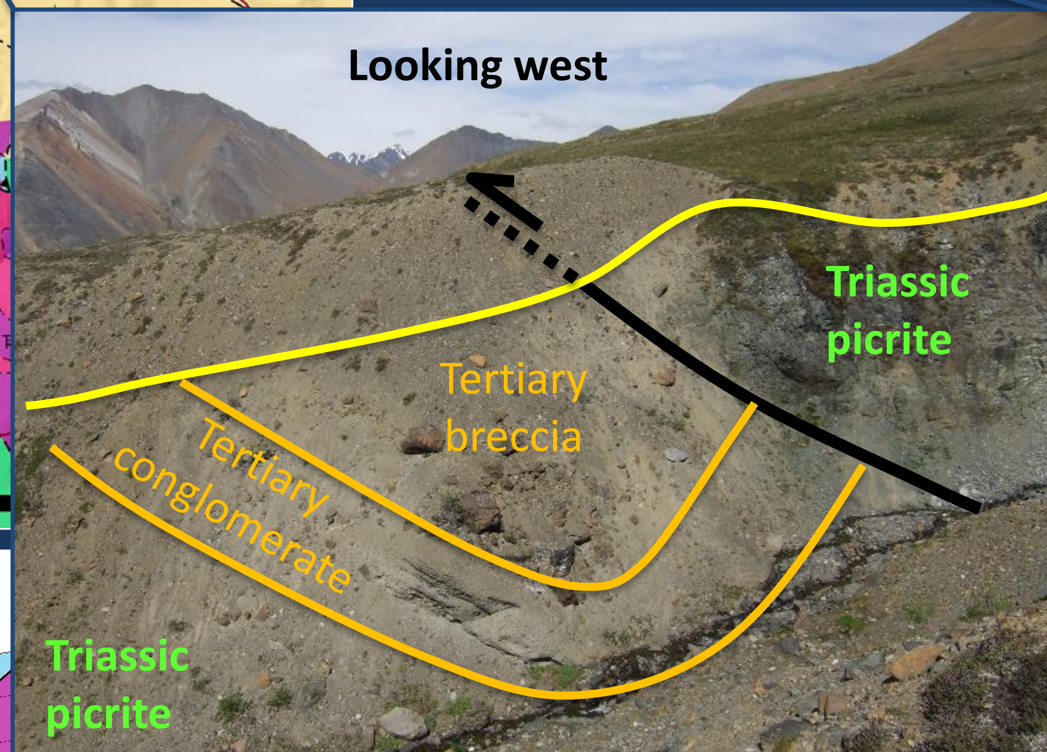
Data from DGGS (Twelker and others, 2014, Wypych and others, 2015), BLM (Bittenbender and others, 2007), and Pure Nickel Inc.

Structural disruption:



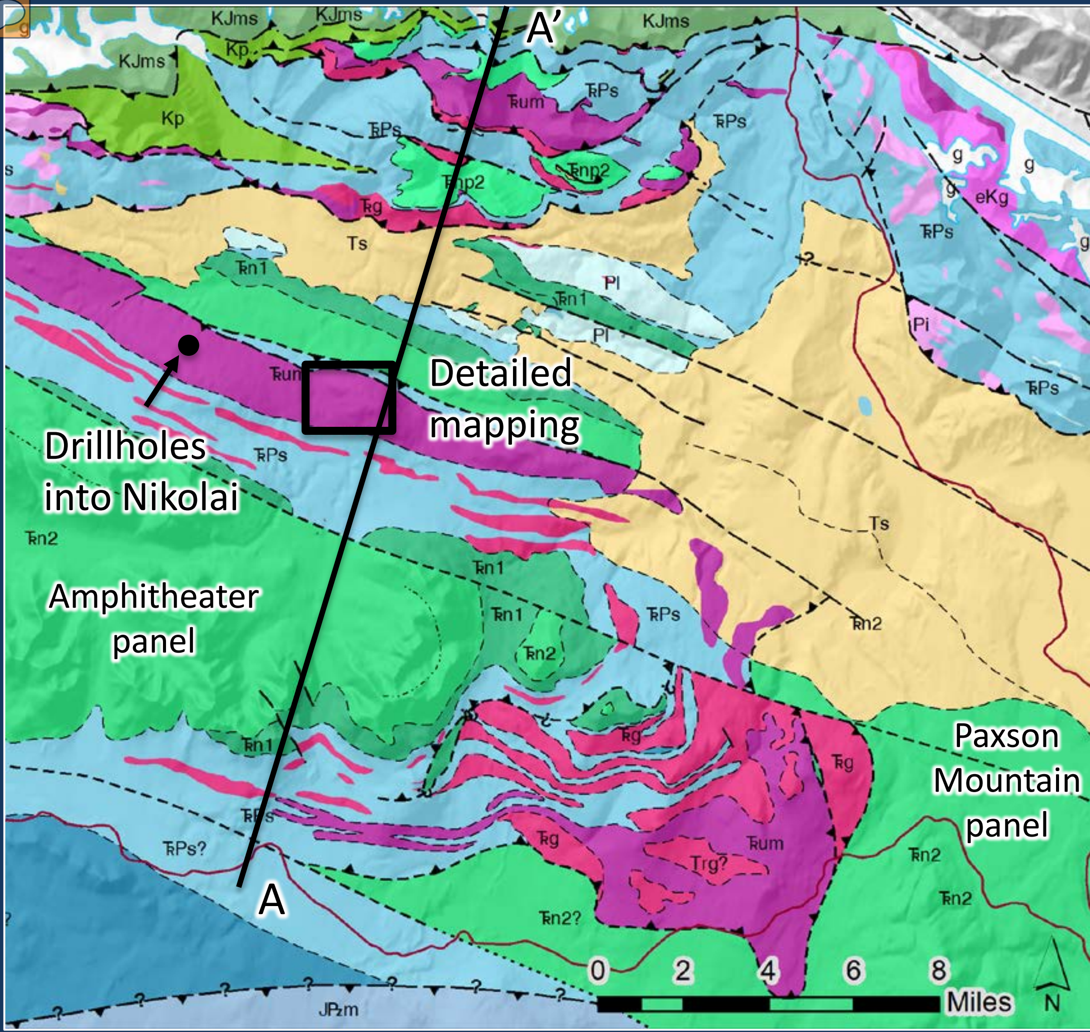
S-vergent thrust faulting builds the Alaska Range
Root into Denali Fault
Exhumation ± 20 Ma-present





More shortening:

- Amphitheater panel rocks emplaced over Paxson Mountain panel
- Approx. 25 km (min.) shortening implied



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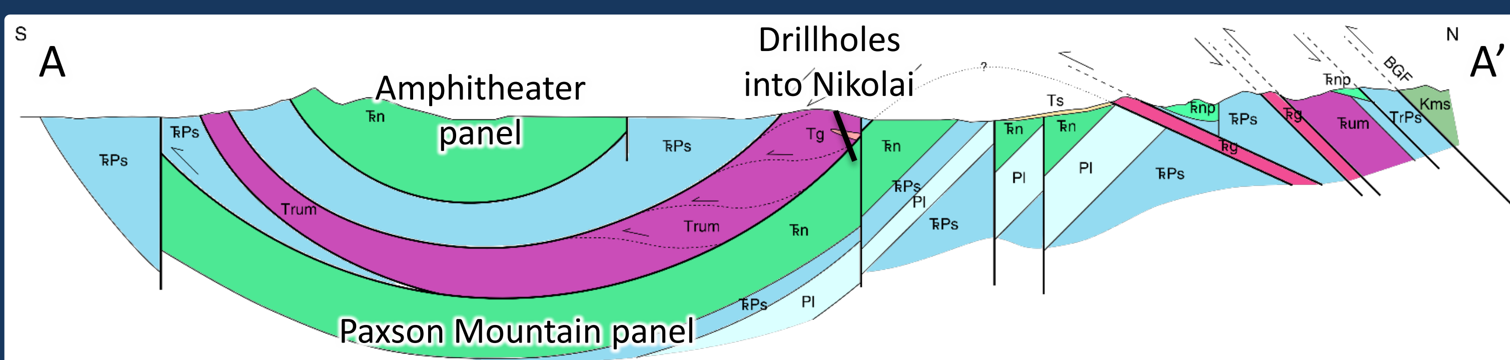


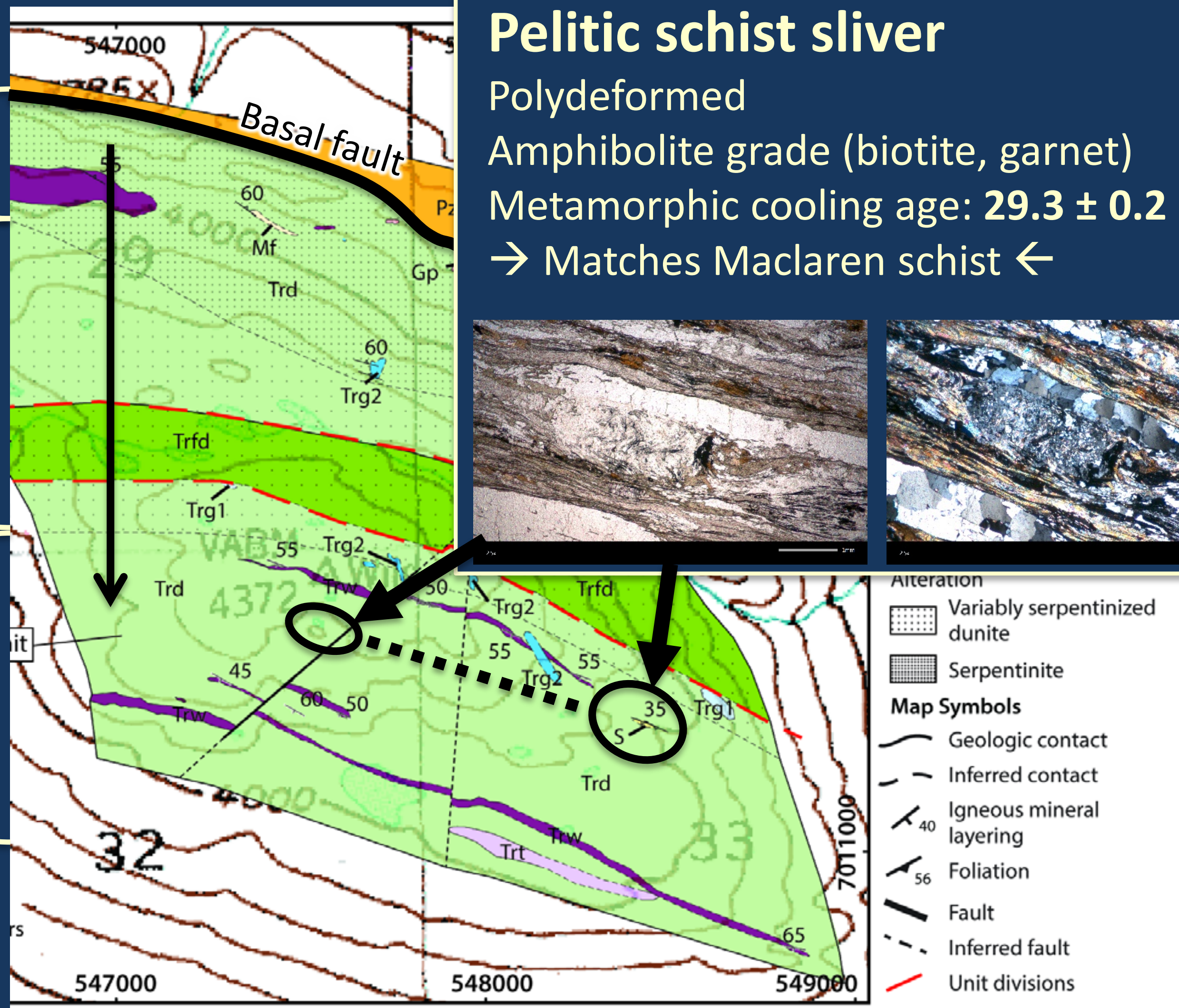
Fault at base of ultramafics

Serpentinization increases from base of complex upward:

Near-pervasive serpentinization

Partial serpentinization

Little serpentinization



Pelitic schist sliver

Polydeformed

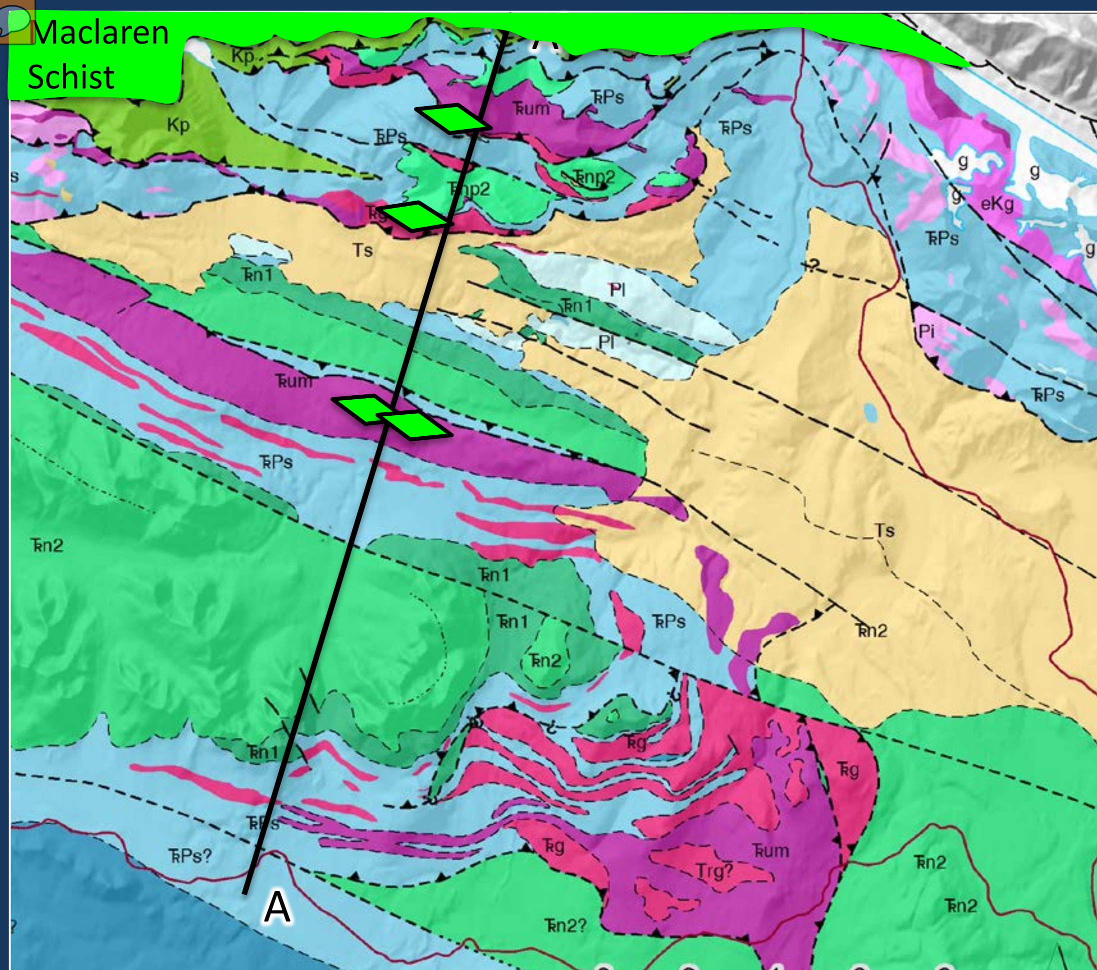
Amphibolite grade (biotite, garnet)

Metamorphic cooling age: **29.3 ± 0.2 Ma**

→ Matches Maclaren schist ←

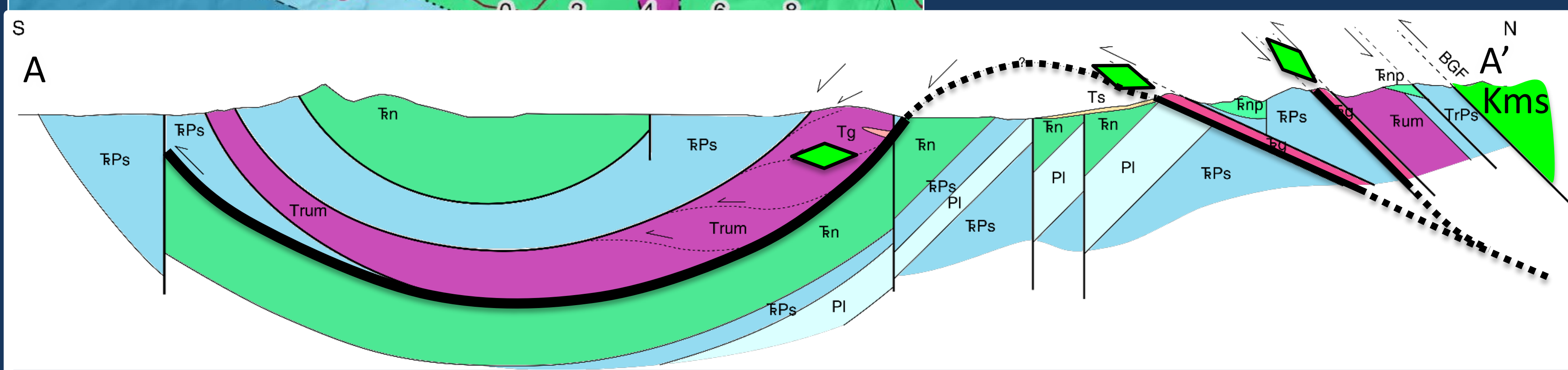
Mapping of Lande, 2016

Age data: Benowitz and others (2017)



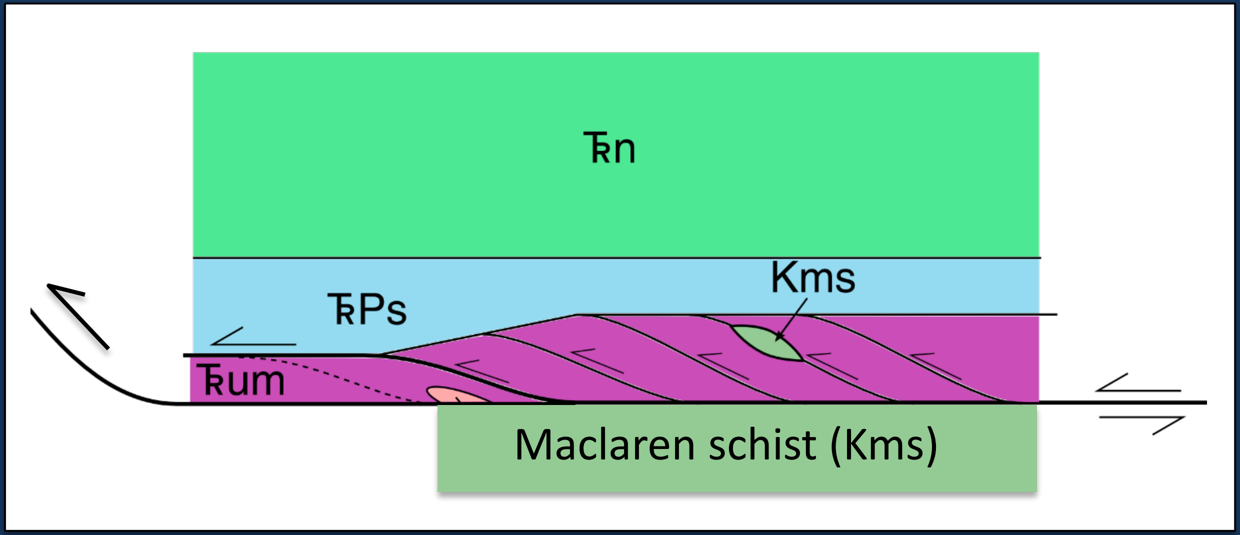
Schist slivers were also found in/near other thrust faults:

- Motion young (<30 Ma)
- Displacement significant



Fault at the base of ultramafic… schist slivers in the middle?

Duplexing of slippery, ± serpentinized ultramafic rocks could explain



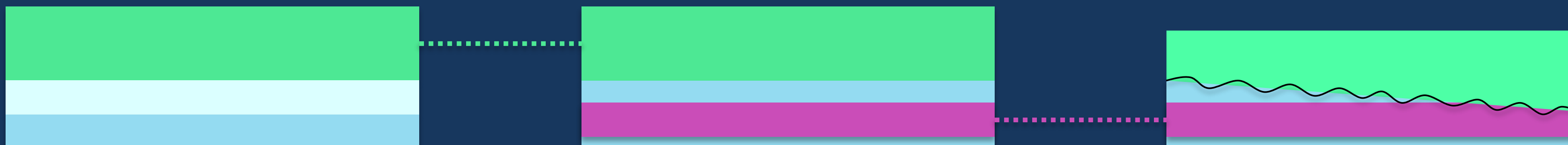
The implication would be that Wrangellia ultramafic slid over Maclaren schist prior to being thrust back over Wrangellia

Schematic paleogeography in the Late Triassic

Paxson Mountain:
Thick, 'normal' Nikolai greenstone
Significant Permian carbonates
Lacking gabbros, PGE prospects

Amphitheater Mountains:
Thick, 'normal' Nikolai greenstone
Thick ultramafic complex
Bulk tonnage Ni-Cu-PGE target

Rainy Creek:
Most primitive magmas
Possible Late Tr erosion
Numerous PGE prospects



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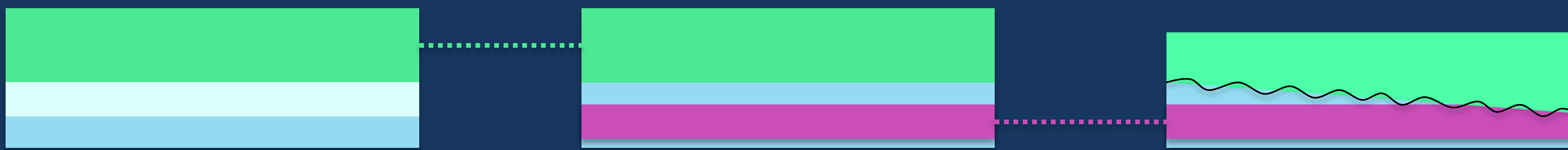
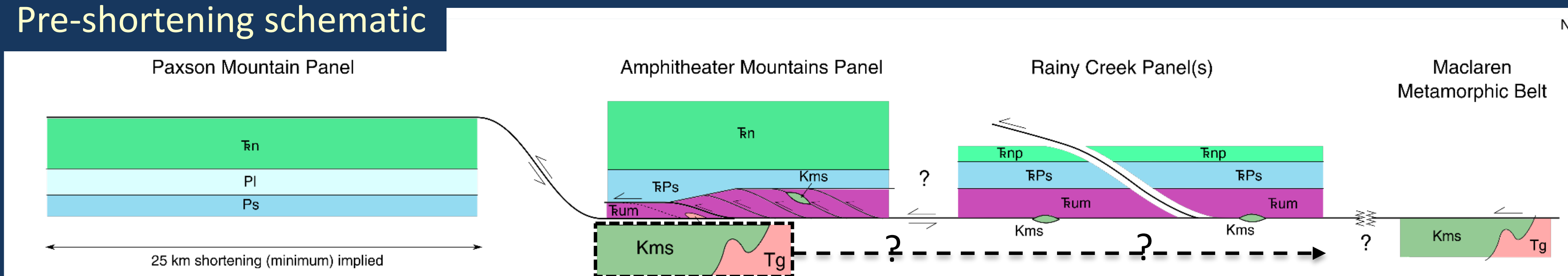


Pre-shortening schematic



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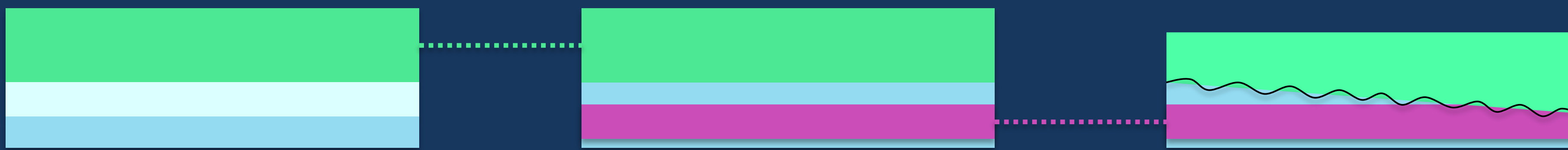

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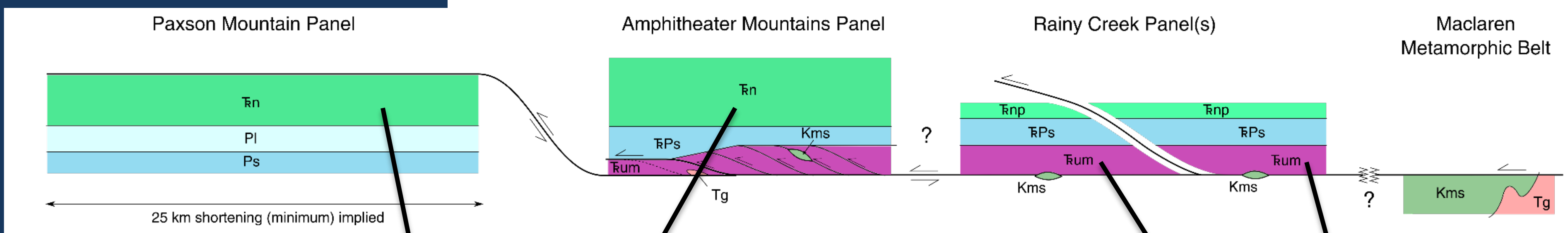
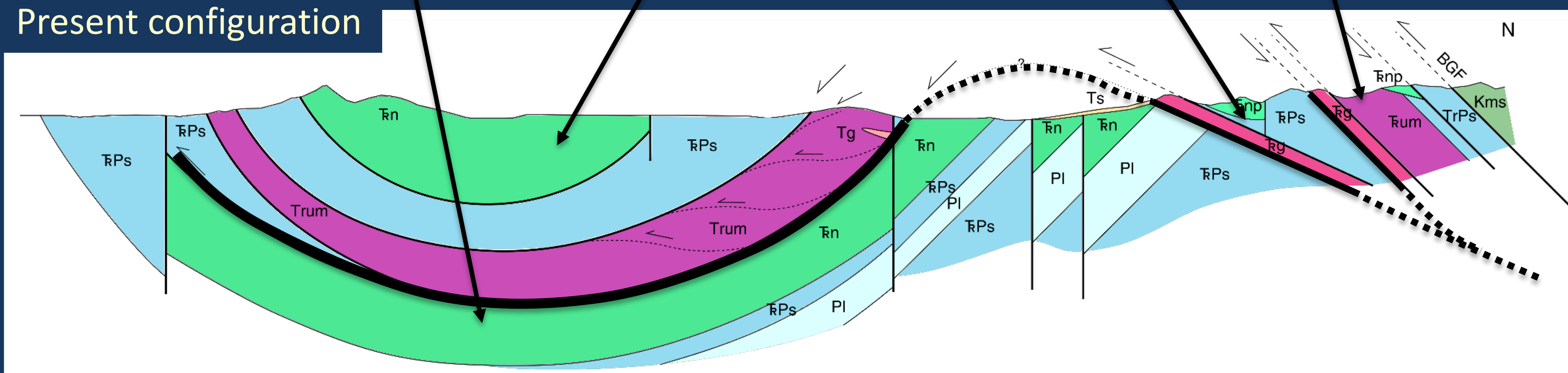


Present configuration



Conclusions

- Wrangellia in central Alaska has undergone multiple significant deformational events (Jurassic to present)
  - Jurassic NW-directed shortening: Wrangellia-Talkeetna Arc
  - Late K exhumation, translation of J-K metaflysch
  - Eocene northeasterly normal (± strike slip) faults
  - Oligocene-present Alaska Range shortening, exhumation
- Understanding these structures helps reconstruct the magmatic environments related to the Ni-Cu-PGE mineralizing system
- Many parts of Alaska are still not adequately mapped
  - DGGS is working on it (but it's still a > 100 year job)
  - We must continue to find ways to use technology to assist

Thanks!

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