

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



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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 Reieux, Erik Bachmann, Amy Tuzzolino, Colby Wright, Abraham Emond, Gina Graham, Laurel Burns
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- And many others...

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Alaska Division of Geological & Geophysical Surveys (DGGGS)



...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)

Palladium (Pd)

Rhodium (Rh)

Iridium (Ir)

Osmium (Os)

Ruthenium (Ru)

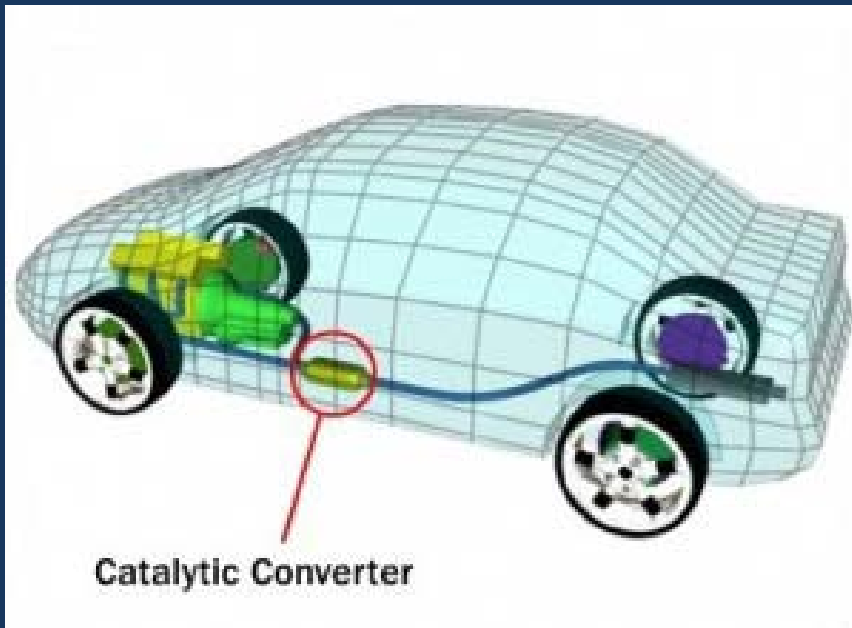
1 H Hydrogen 1.00794		Atomic # Symbol Name Atomic Mass		[C] Solid		Metals										Nonmetals				2 He Helium 4.002602																	
3 Li Lithium 6.941		4 Be Beryllium 9.012182		[Hg] Liquid		[H] Gas		[Rf] Unknown		Alkal earth metals		Lanthanoids		Transition metals		Poor metals		Other nonmetals		Noble gases		5 B Boron 10.811		6 C Carbon 12.0107		7 N Nitrogen 14.0067		8 O Oxygen 15.9994		9 F Fluorine 18.9984032		10 Ne Neon 20.1797					
11 Na Sodium 22.98976928		12 Mg Magnesium 24.3050																				13 Al Aluminium 26.9815386		14 Si Silicon 28.0855		15 P Phosphorus 30.973762		16 S Sulfur 32.065		17 Cl Chlorine 35.453		18 Ar Argon 39.948					
19 K Potassium 39.0983		20 Ca Calcium 40.078		21 Sc Scandium 44.955912		22 Ti Titanium 47.887		23 V Vanadium 50.9415		24 Cr Chromium 51.9961		25 Mn Manganese 54.938045		26 Fe Iron 55.845		27 Co Cobalt 58.933195		28 Ni Nickel 58.6934		29 Cu Copper 63.546		30 Zn Zinc 65.38		31 Ga Gallium 69.723		32 Ge Germanium 72.64		33 As Arsenic 74.9216		34 Se Selenium 78.96		35 Br Bromine 79.904		36 Kr Krypton 83.798			
37 Rb Rubidium 85.4678		38 Sr Strontium 87.62		39 Y Yttrium 88.90585		40 Zr Zirconium 91.224		41 Nb Niobium 92.90638		42 Mo Molybdenum 95.96		43 Tc Technetium (97.9072)		44 Ru Ruthenium 101.07		45 Rh Rhodium 102.90550		46 Pd Palladium 106.42		47 Ag Silver 107.8682		48 Cd Cadmium 112.411		49 In Indium 114.818		50 Sn Tin 118.710		51 Sb Antimony 121.760		52 Te Tellurium 127.60		53 I Iodine 126.90447		54 Xe Xenon 131.293			
55 Cs Cesium 132.9054519		56 Ba Barium 137.327		57-71		72 Hf Hafnium 178.49		73 Ta Tantalum 180.94788		74 W Tungsten 183.84		75 Re Rhenium 186.207		76 Os Osmium 190.23		77 Ir Iridium 192.225		78 Pt Platinum 195.084		79 Au Gold 196.966569		80 Hg Mercury 200.59		81 Tl Thallium 204.3833		82 Pb Lead 207.2		83 Bi Bismuth 208.98040		84 Po Polonium (209.9824)		85 At Astatine (209.9871)		86 Rn Radon (222.0176)			
87 Fr Francium (223)		88 Ra Radium (226)		89-103		104 Rf Rutherfordium (261)		105 Db Dubnium (262)		106 Sg Seaborgium (266)		107 Bh Bohrium (264)		108 Hs Hassium (277)		109 Mt Meitnerium (268)		110 Ds Darmstadtium (271)		111 Rg Roentgenium (272)		112 Uub Ununbium (285)		113 Uut Ununtrium (284)		114 Uuq Ununquadium (289)		115 Uup Ununpentium (288)		116 Uuh Ununhexium (292)		117 Uus Ununseptium (294)		118 Uuo Ununoctium (294)			
For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.																																					
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57 La Lanthanum 138.90547		58 Ce Cerium 140.116		59 Pr Praseodymium 140.90768		60 Nd Neodymium 144.242		61 Pm Promethium (145)		62 Sm Samarium 150.36		63 Eu Europium 151.964		64 Gd Gadolinium 157.25		65 Tb Terbium 158.92535		66 Dy Dysprosium 162.500		67 Ho Holmium 164.93032		68 Er Erbium 167.259		69 Tm Thulium 168.93421		70 Yb Ytterbium 173.054		71 Lu Lutetium 174.9668									
89 Ac Actinium (227)		90 Th Thorium 232.03806		91 Pa Protactinium 231.03588		92 U Uranium 238.02891		93 Np Neptunium (237)		94 Pu Plutonium (244)		95 Am Americium (243)		96 Cm Curium (247)		97 Bk Berkelium (247)		98 Cf Californium (251)		99 Es Einsteinium (252)		100 Fm Fermium (257)		101 Md Mendelevium (258)		102 No Nobelium (259)		103 Lr Lawrencium (262)									

Ptable.com

The PGEs are critically important to modern life:

Catalysts

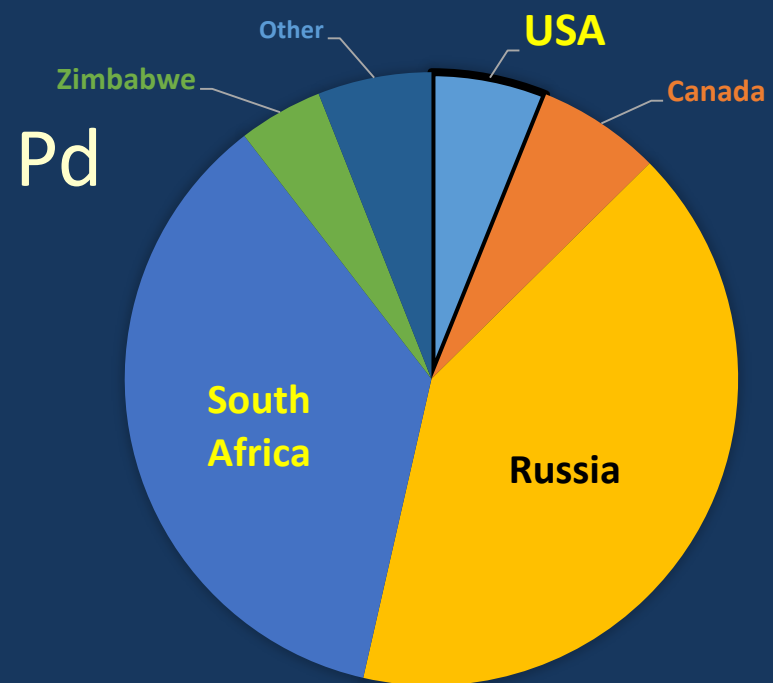
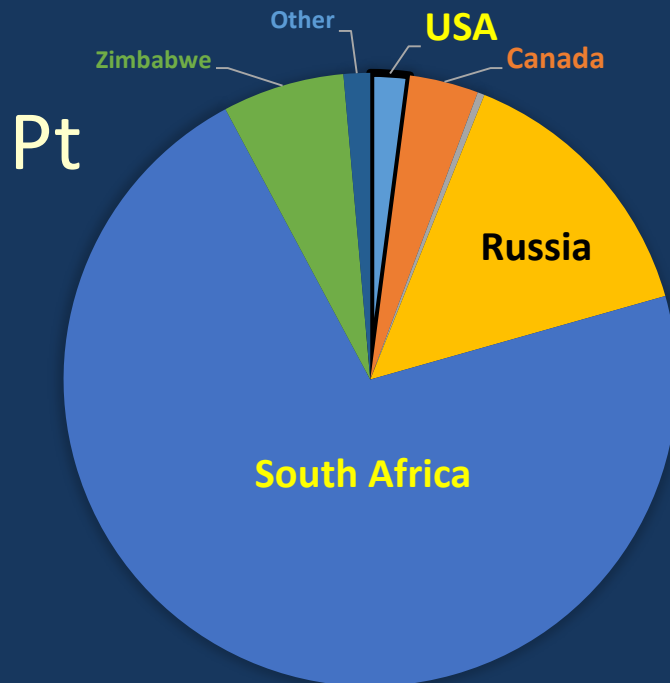
- Chemical refining
- EPA Wood stoves
- Low-emissions vehicles



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

Meanwhile, in the Yukon...

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

Measured and Indicated Resource:

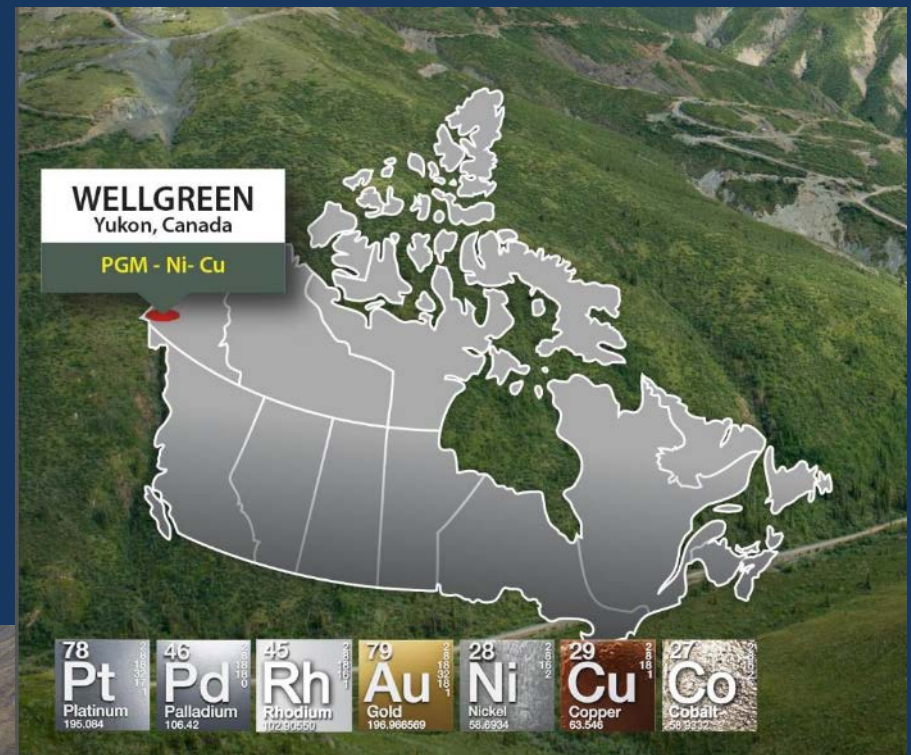
5.1 million ounces Pt + Pd

1.9 billion pounds Ni

Additional Inferred Resource:

12.5 million ounces Pt + Pd

4.4 billion pounds Ni



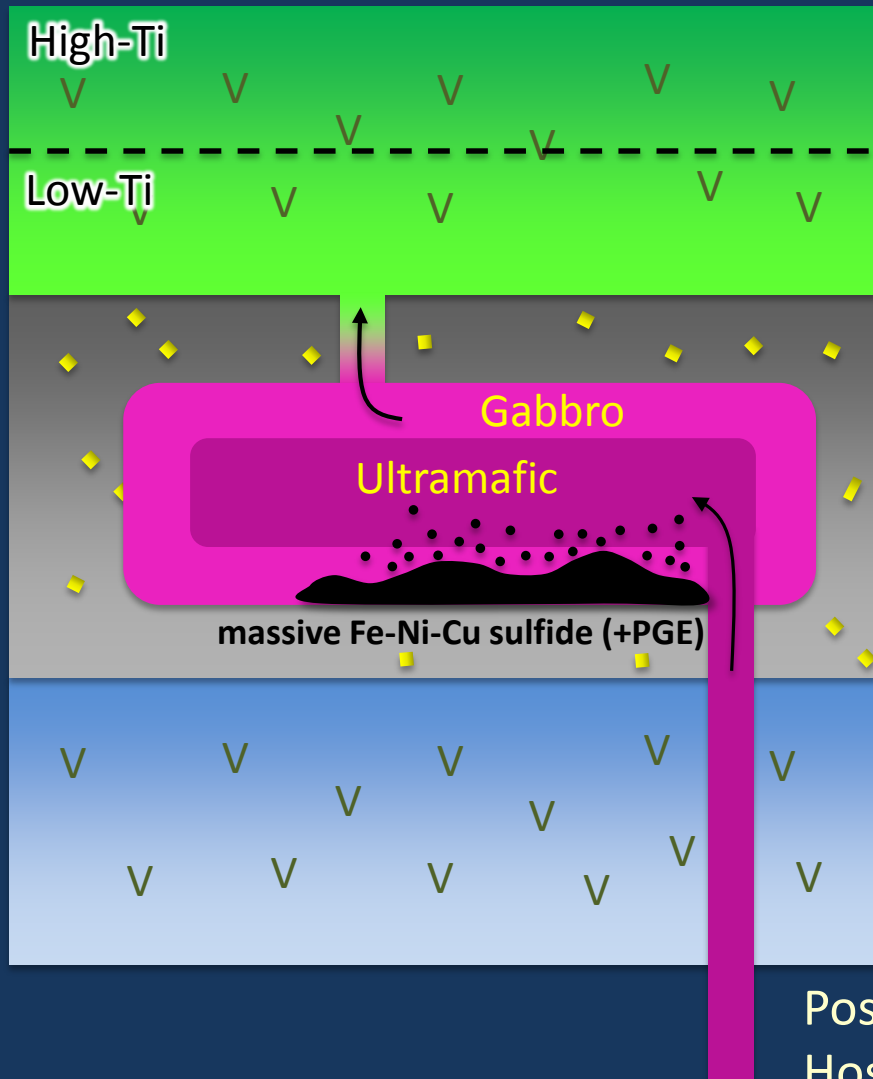
Wellgreen Deposit 2015

Preliminary Economic Assessment:

- Net present value: ~ \$1 billion
- 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

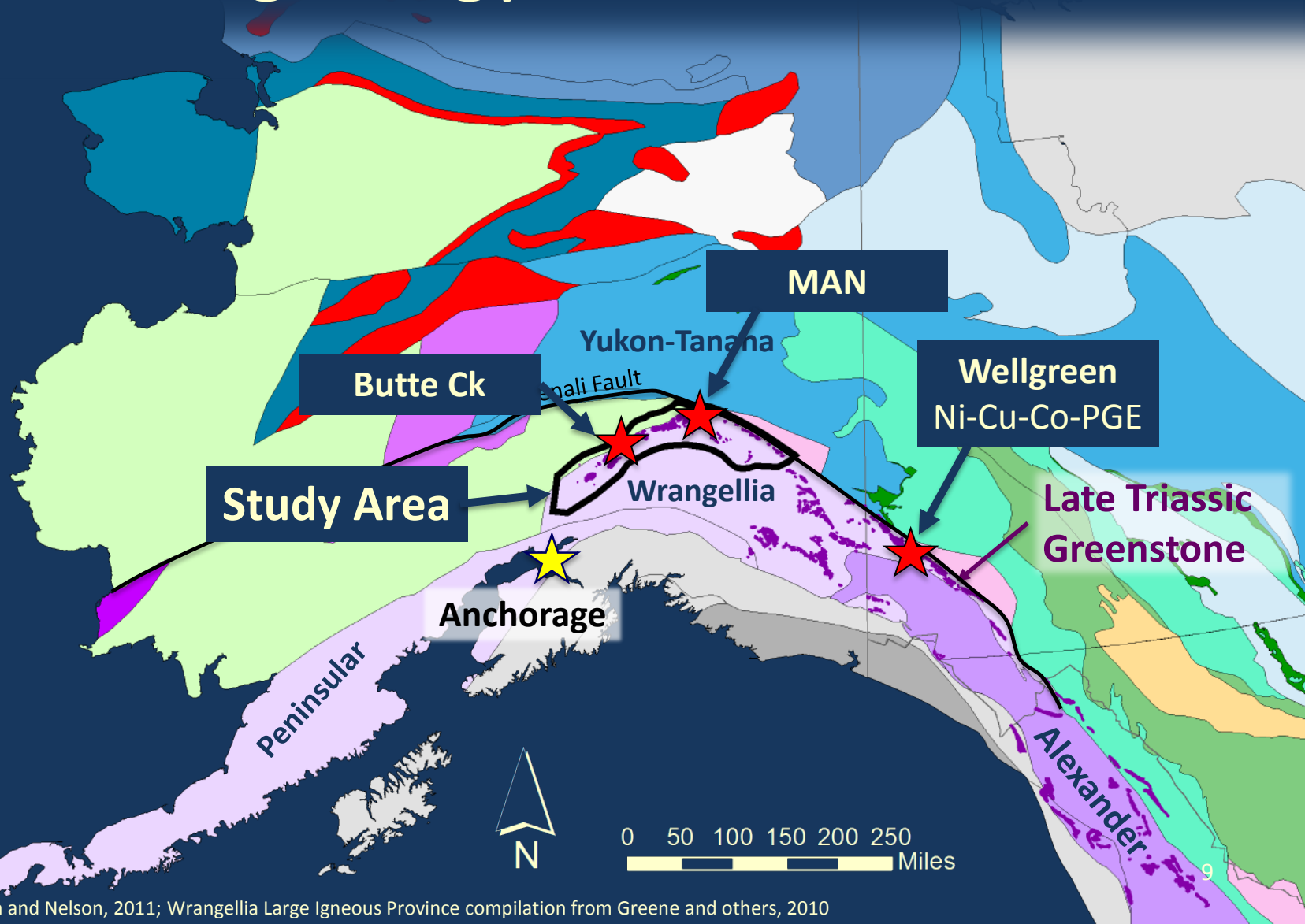
- Hasen Creek (Wrangells, Yukon)
- Slana Spur, Eagle Creek (AK Range)

Pennsylvanian-Permian volcanic rocks

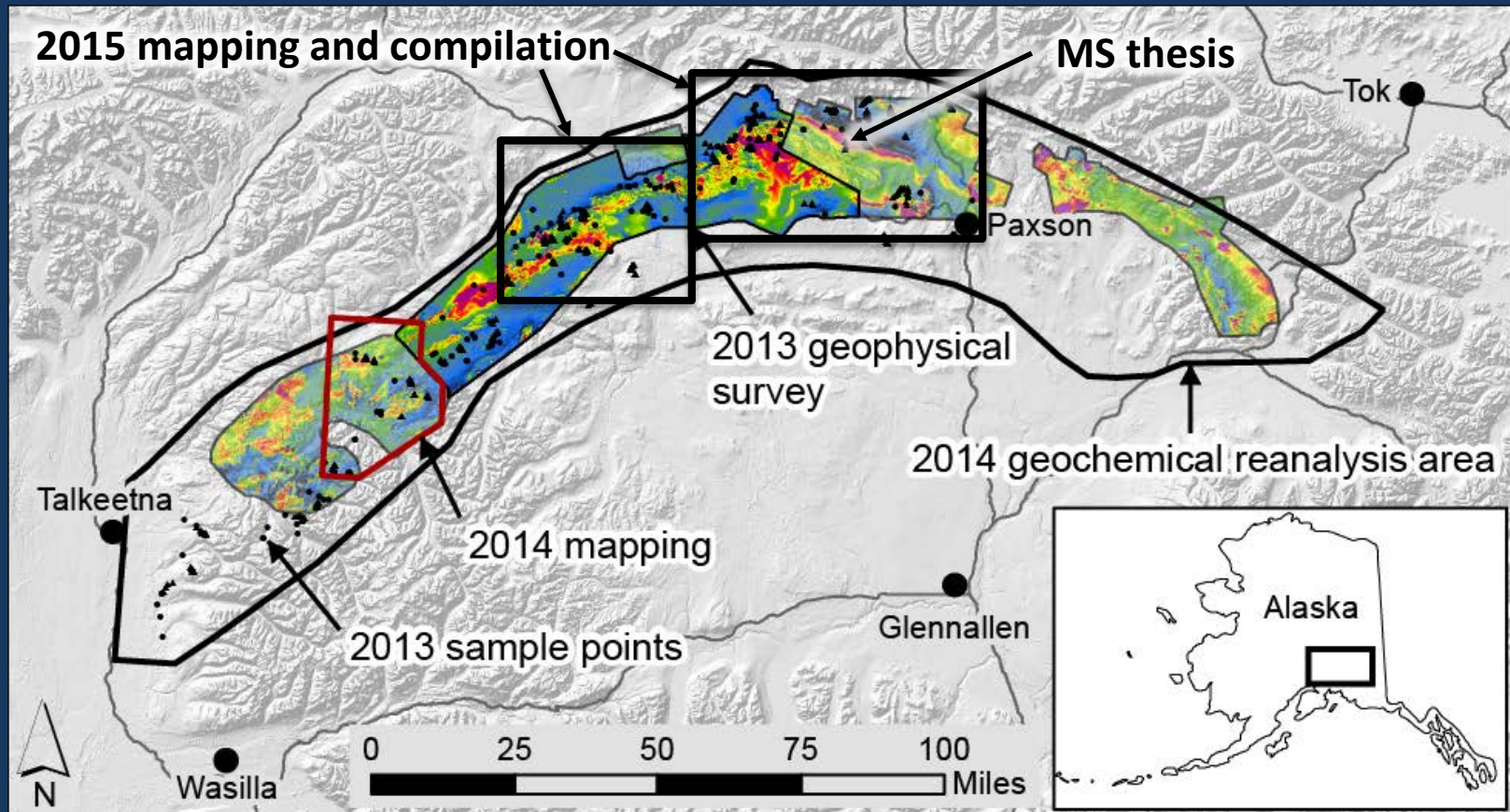
- Skolai Arc oceanic island arc
- Station Creek, Tetelna volcanics

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

Alaska's side of the border: ± Same geology



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



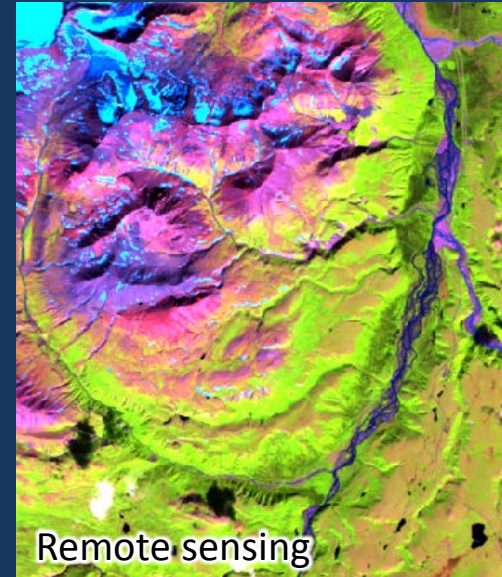
DGGS mapping: Low tech / high tech

Magnetic susceptibility



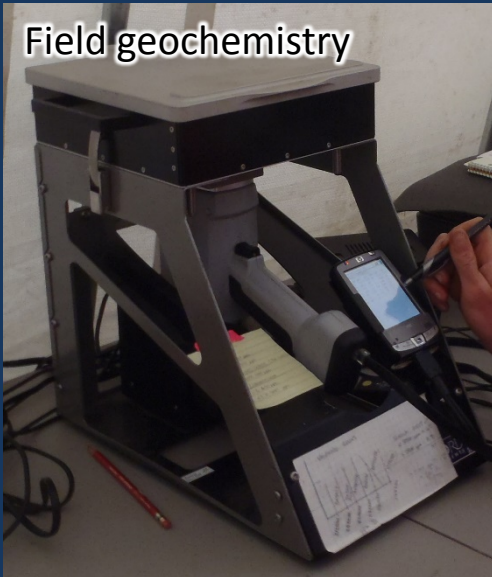
Digital data collection

Geophysical surveys



Remote sensing

Field geochemistry



Lab geochemistry



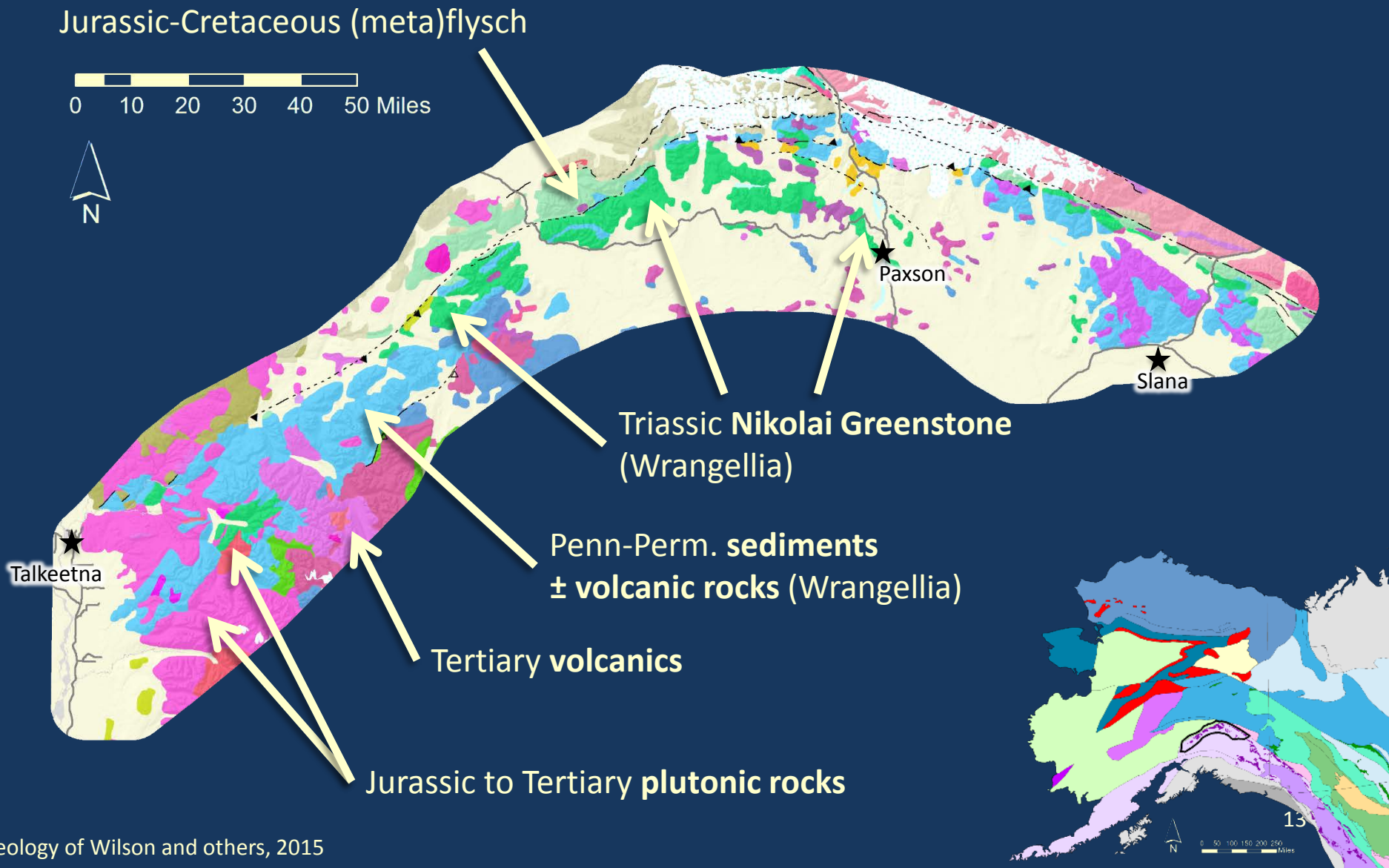
Geochronology



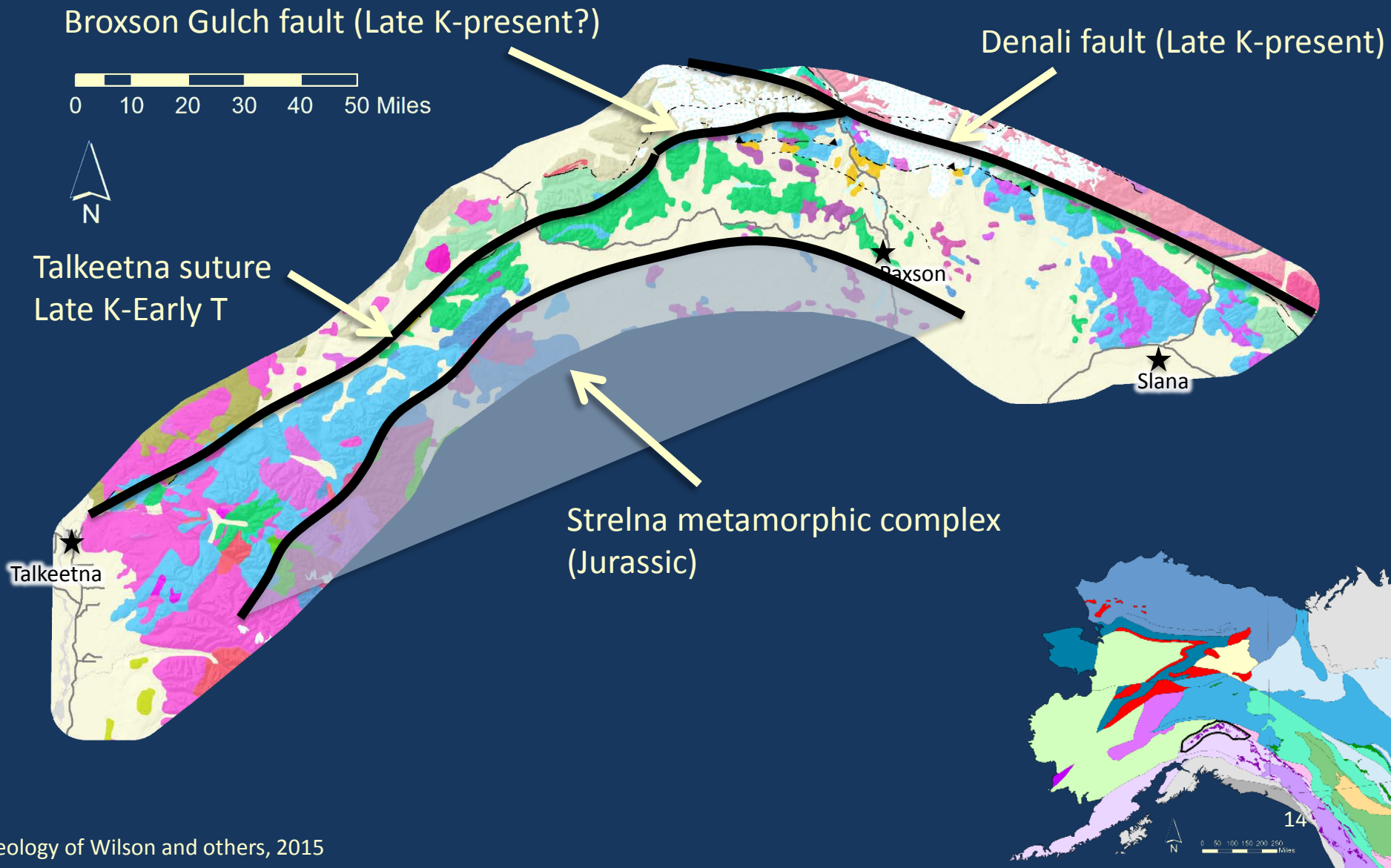
Archived samples to GMC



Geology of the project area

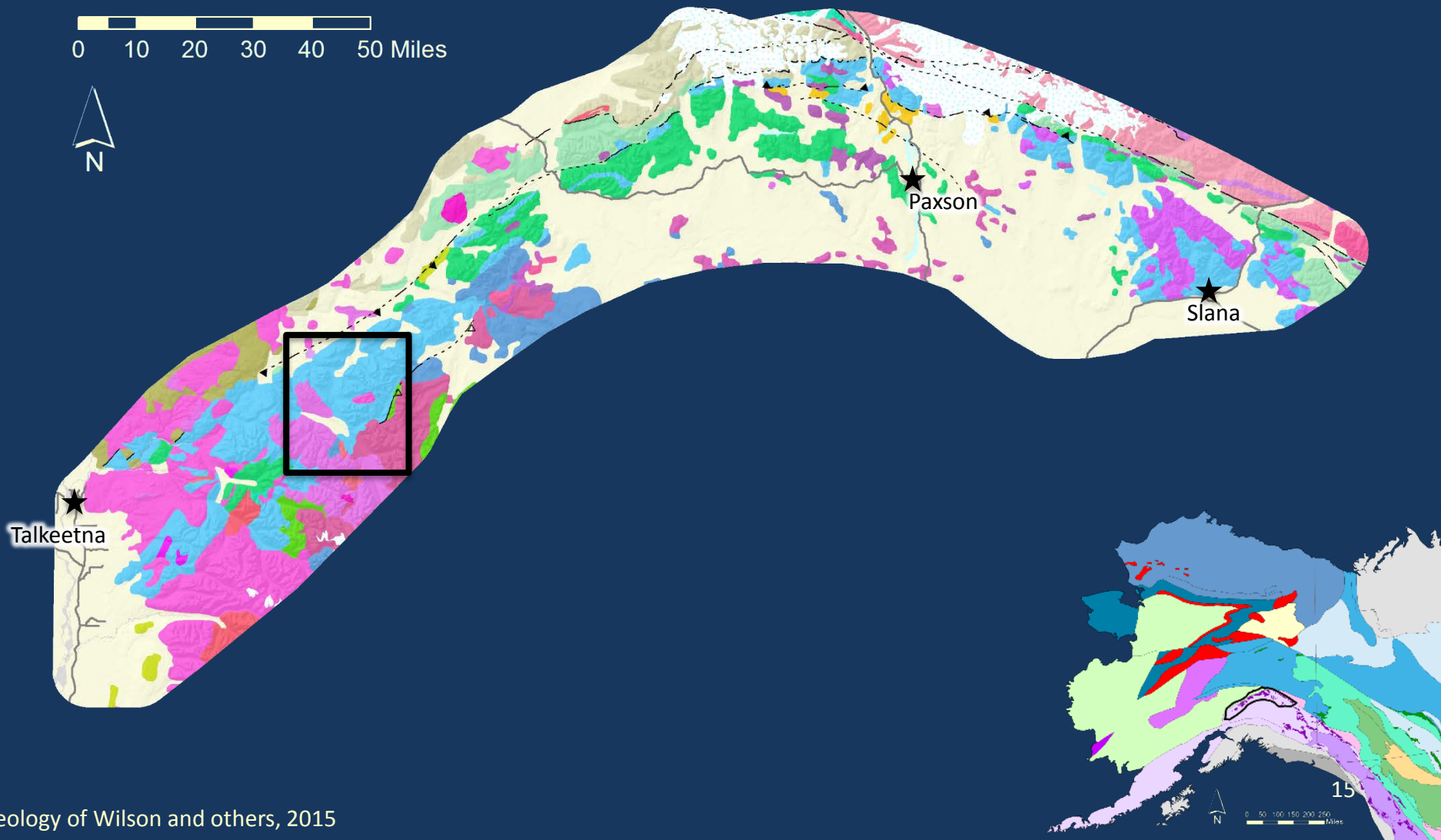


Geology of the project area



Part 1: Central Talkeetna Mountains

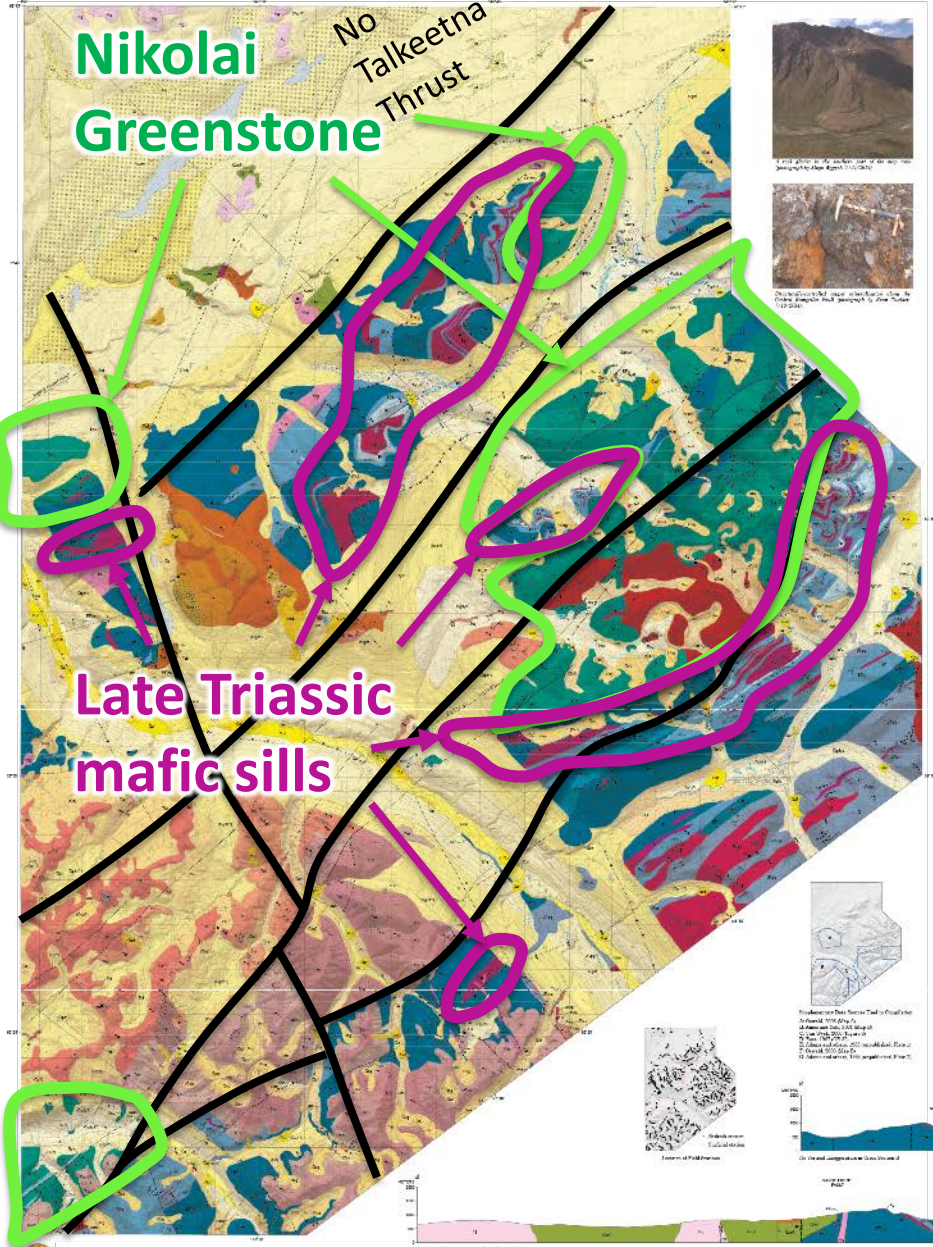
Terrane accretion and translation



→ No Late Triassic mapped

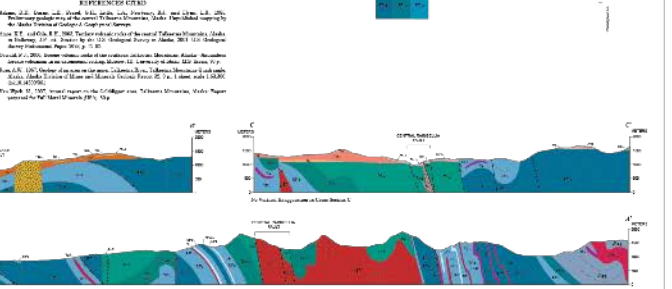
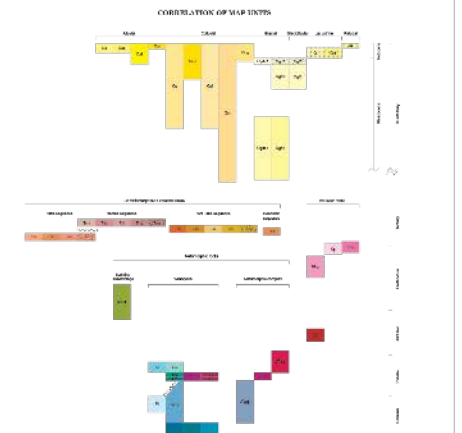
2015 STATEMAP

1:50,000 scale



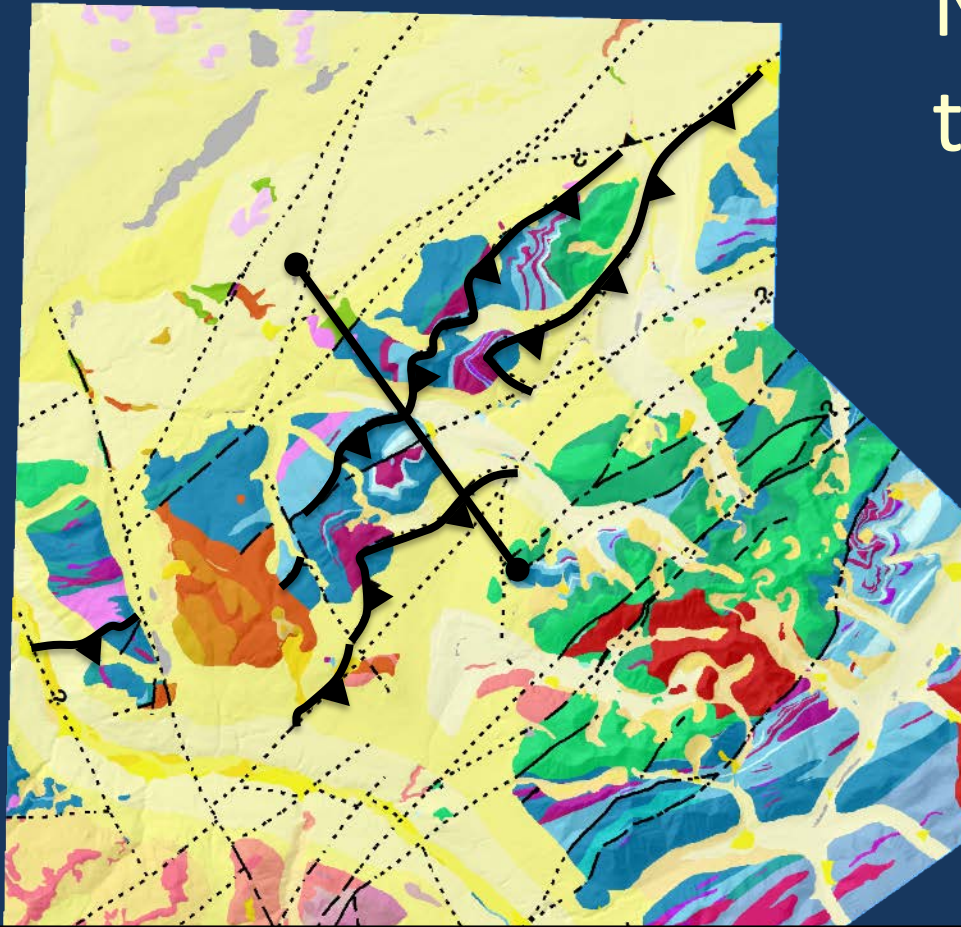
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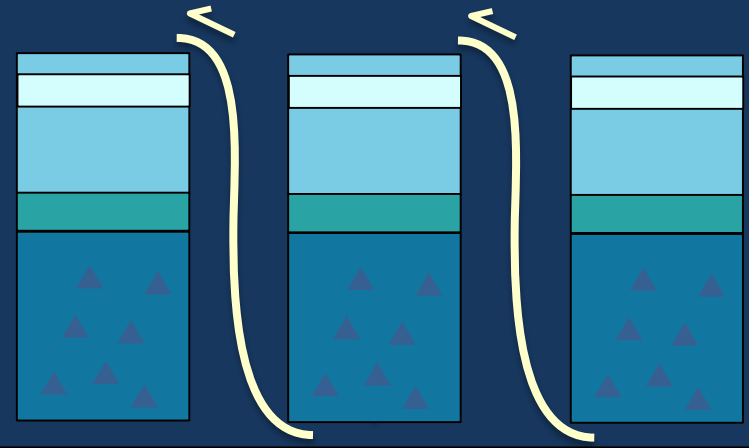


NW-vergent thrust faulting

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

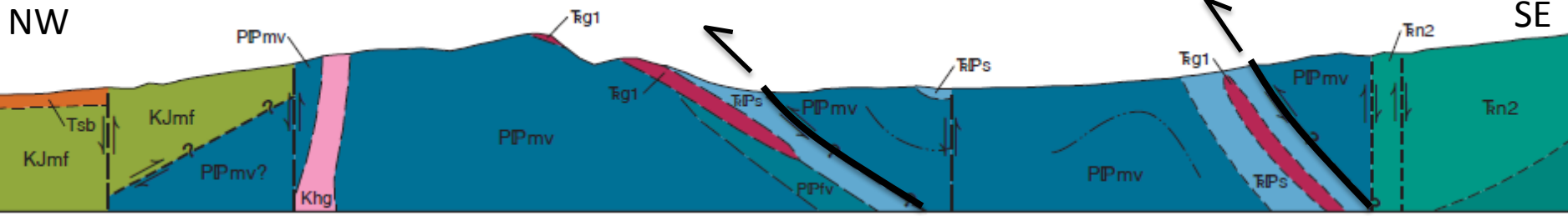


Slana Spur | Eagle Ck



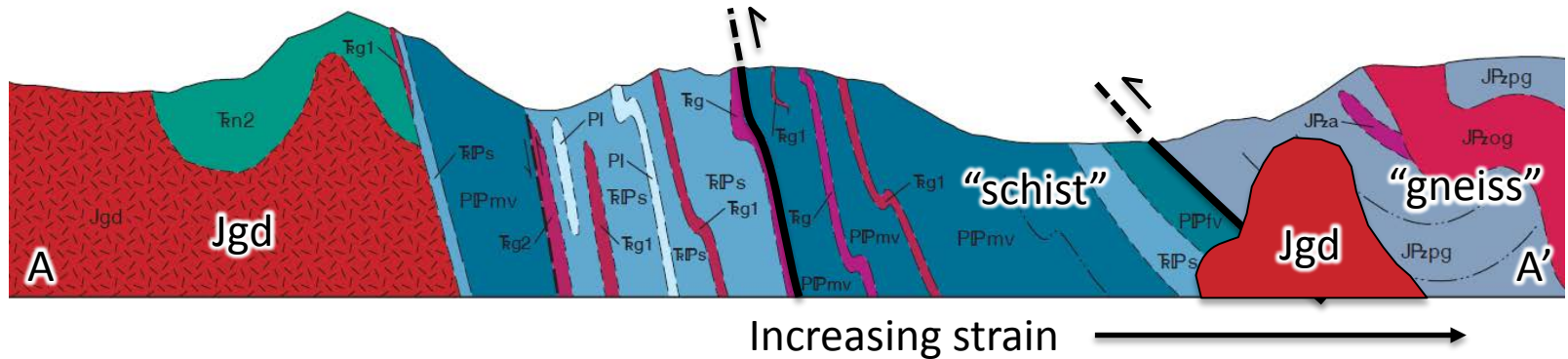
NW

SE



0 2 4 6 8 Miles

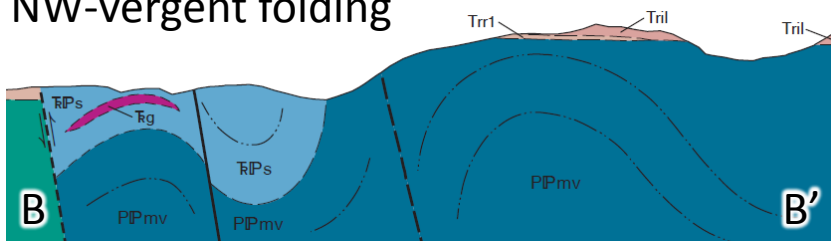
Stratigraphic repetition, high grade over low grade



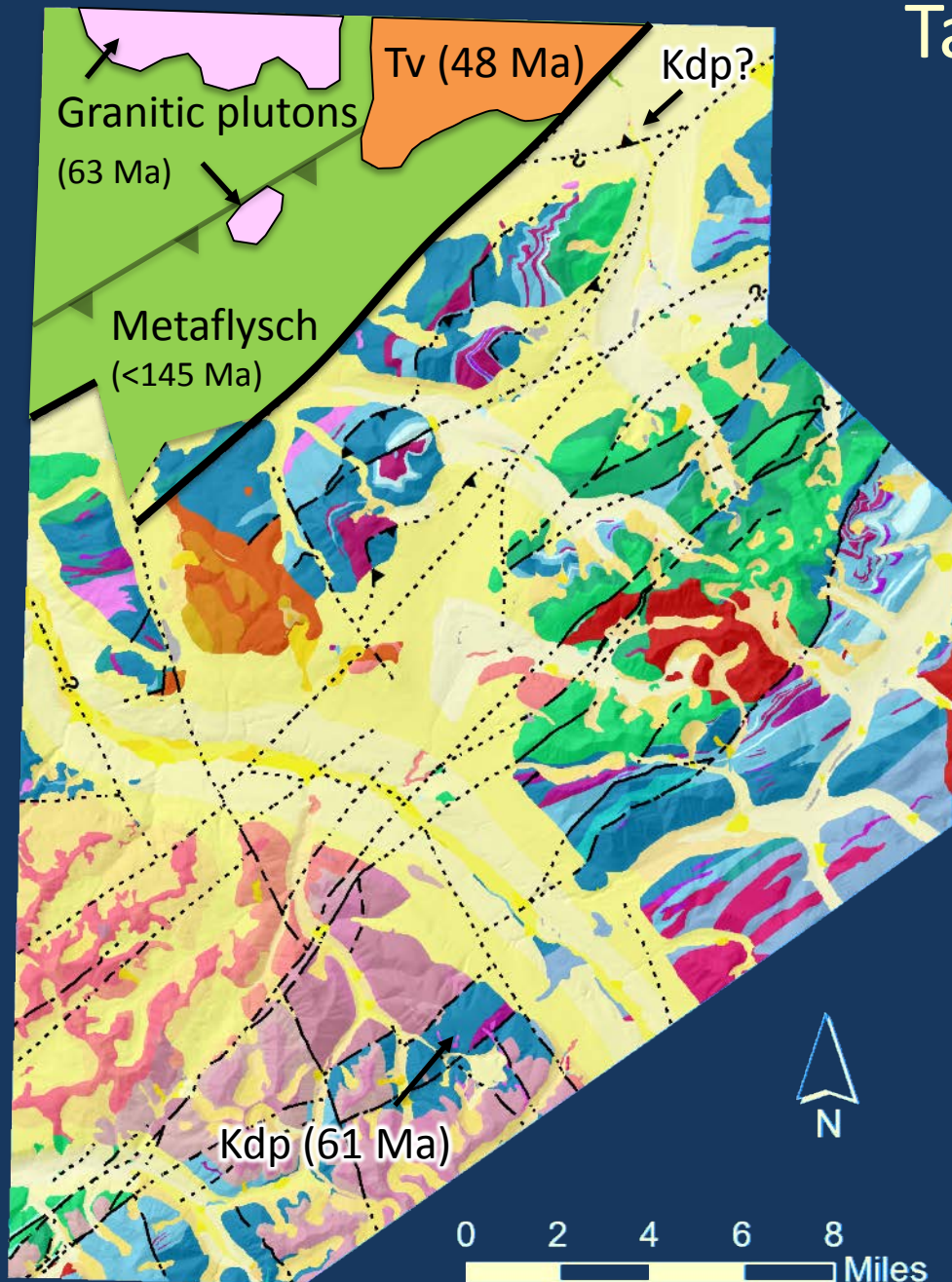
Metamorphic cooling:
186 Ma (musc.) 195 Ma (hbd)

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

NW-vergent folding



Shortening,
amalgamation of
Wrangellia and
Peninsular Terranes



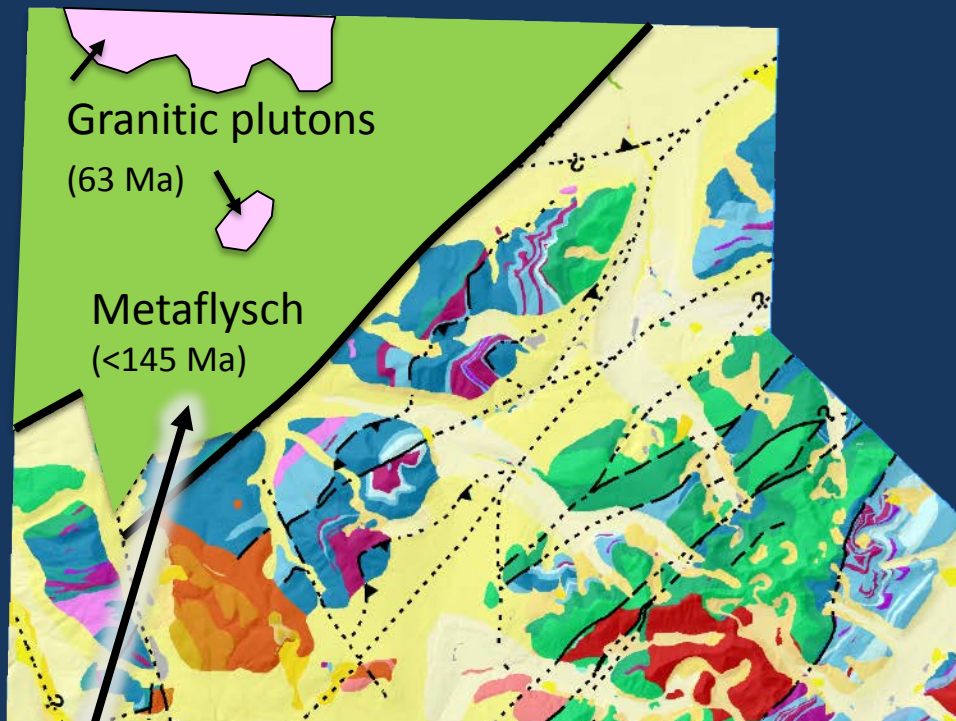
Talkeetna Suture Zone

- Metamorphosed flysch reaches amphibolite grade
 - biotite, hornblende; fabric
- Plutonic rocks to NW (63 Ma¹)
- Porphyry dikes (Kdp) of similar composition & age intrude Wrangellia to the SE (61 Ma²)
- Volcanic rocks unconformably overlie metaflysch (48 Ma³)
- Tertiary faulting likely hides some earlier complexity

¹ Benowitz and others (2015)

² Todd and others (2017)

³ Schmidt and others (2002)

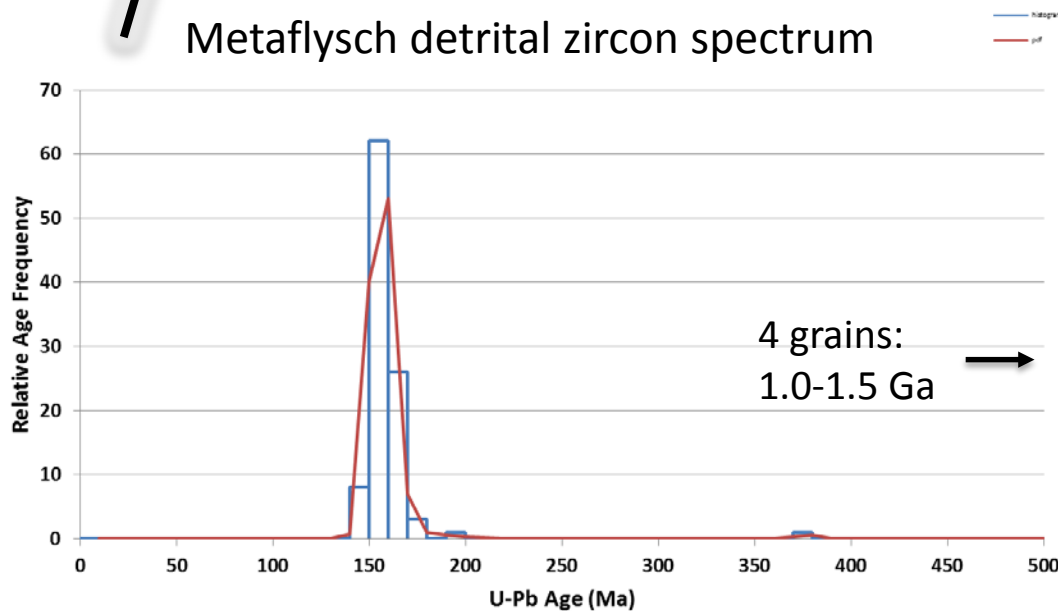


Metaflysch provenance:

Detrital zircons:

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

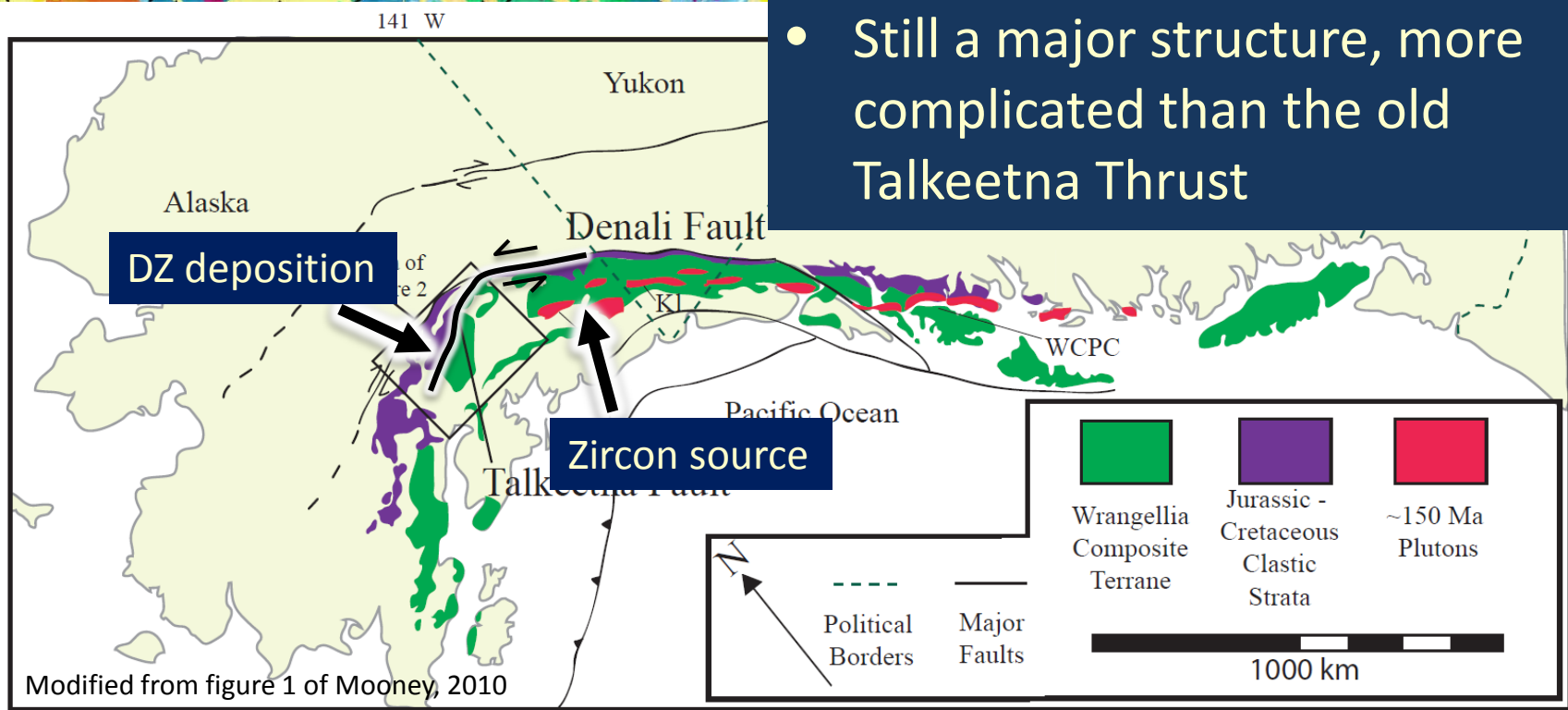
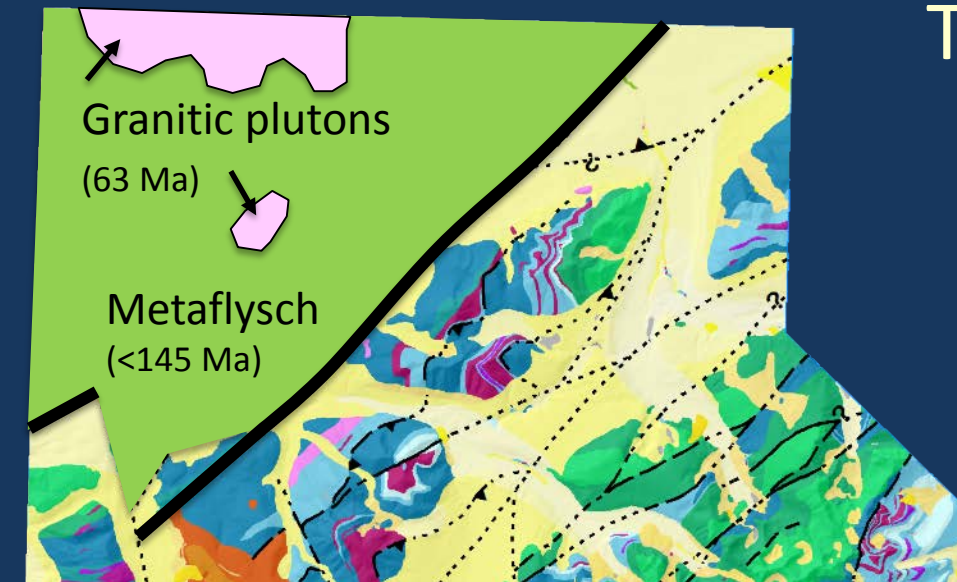
Metaflysch detrital zircon spectrum



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

Talkeetna Suture Zone

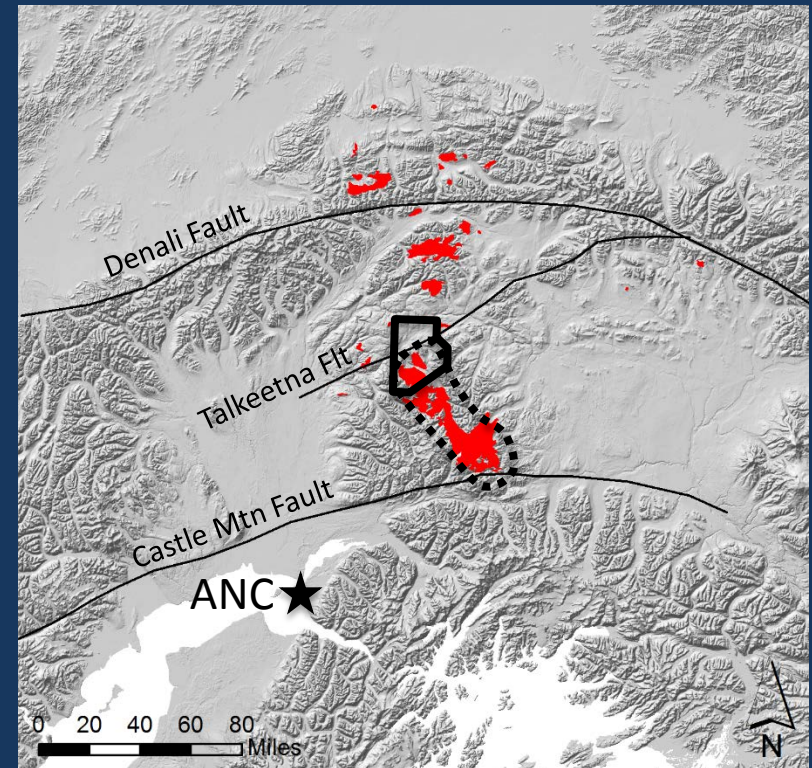
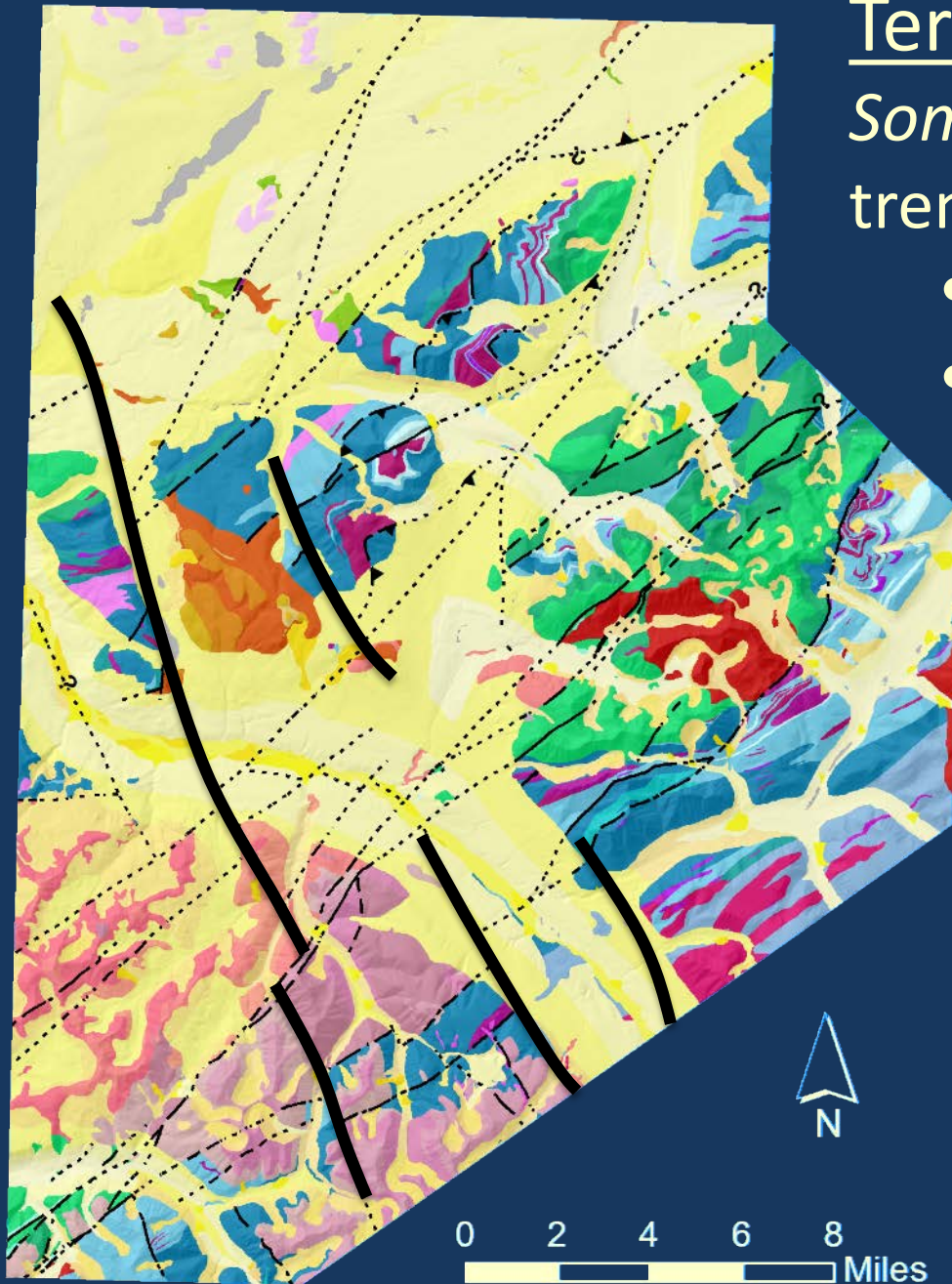
- Exhumation from mid-crustal conditions to surface between Late Cretaceous and 45 Ma
- Significant left-lateral translation suggested to link metaflysch to Chitina Arc
- Still a major structure, more complicated than the old Talkeetna Thrust



Tertiary faulting & volcanism

Some faults parallel regional trend of Tertiary volcanics

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

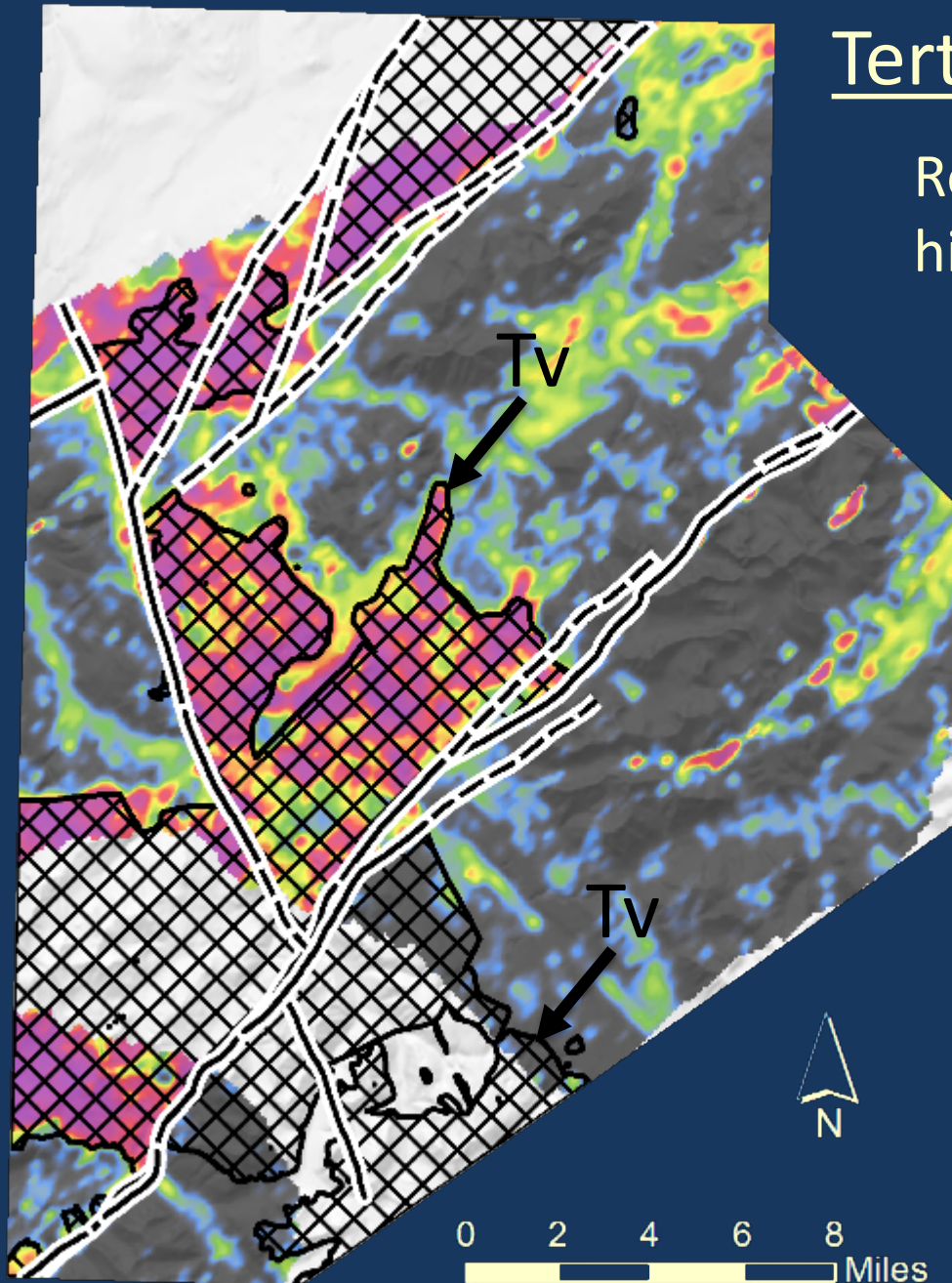


Tertiary faulting & volcanism

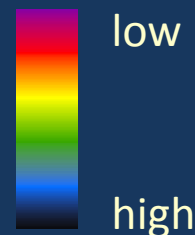
Resistivity map (900Hz; DGGS data) highlights major lineaments

Major breaks are faults

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



900 Hz Resistivity

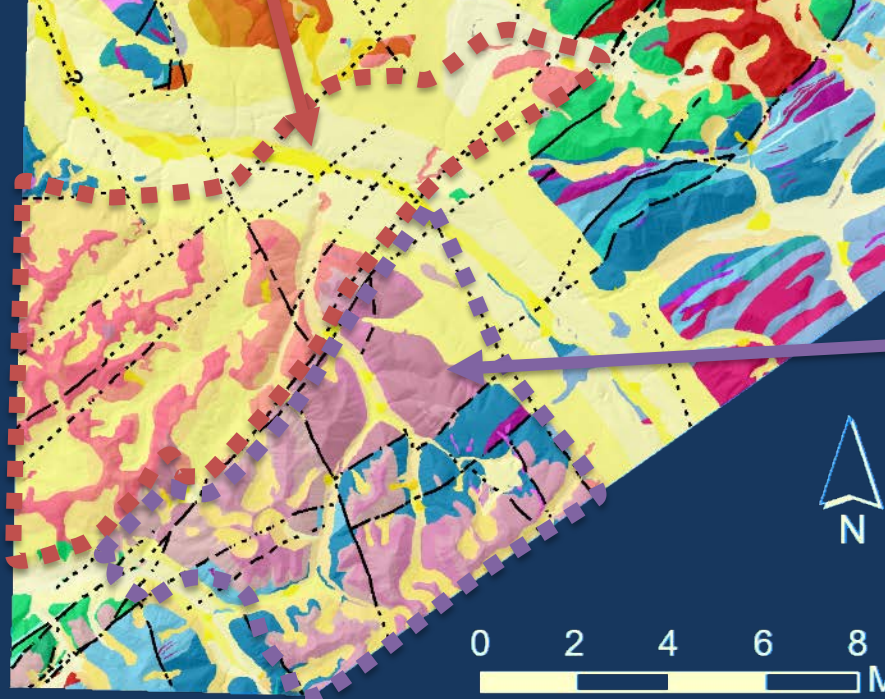


Geophysical data: Burns and others (2014)

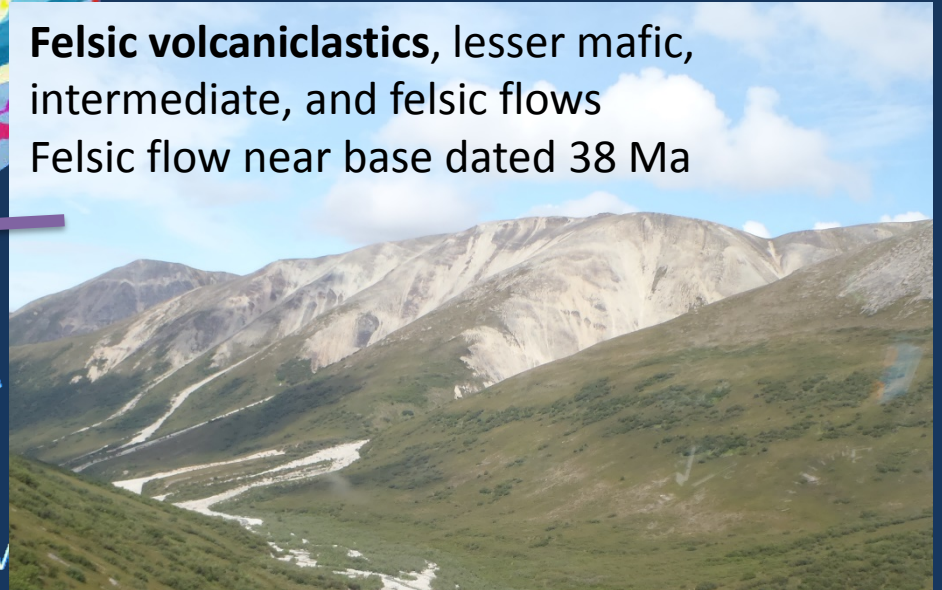
Basalt, andesite flows and agglomerates
Cut by 54 Ma andesite porphyry



Crosscutting relationships
with volcanics help date
relative fault motions



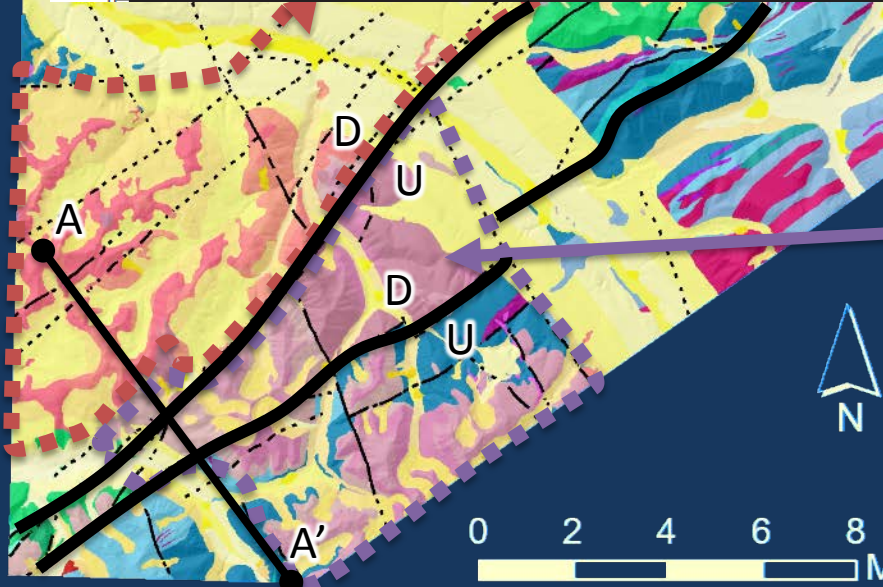
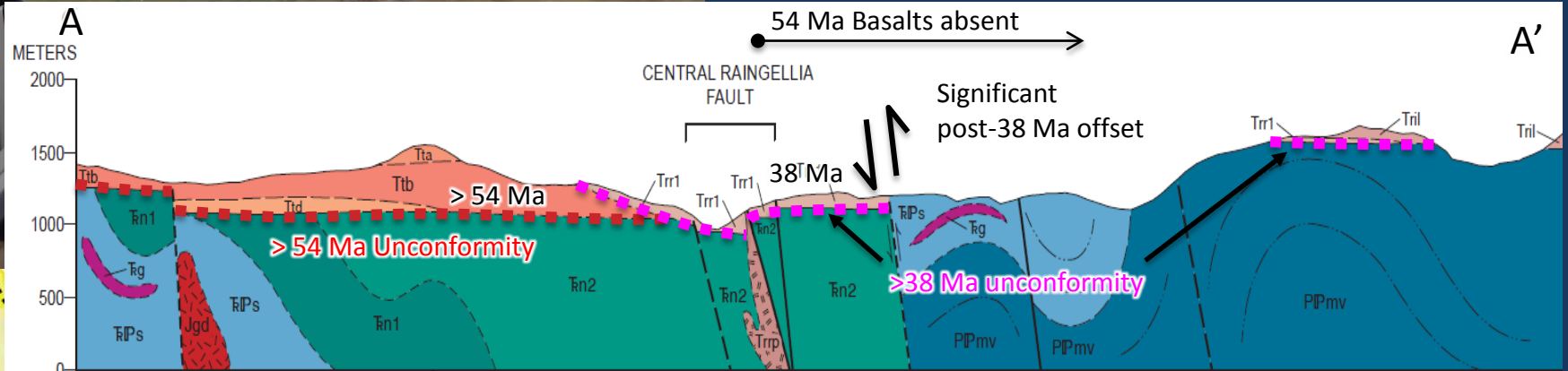
Felsic volcaniclastics, lesser mafic,
intermediate, and felsic flows
Felsic flow near base dated 38 Ma



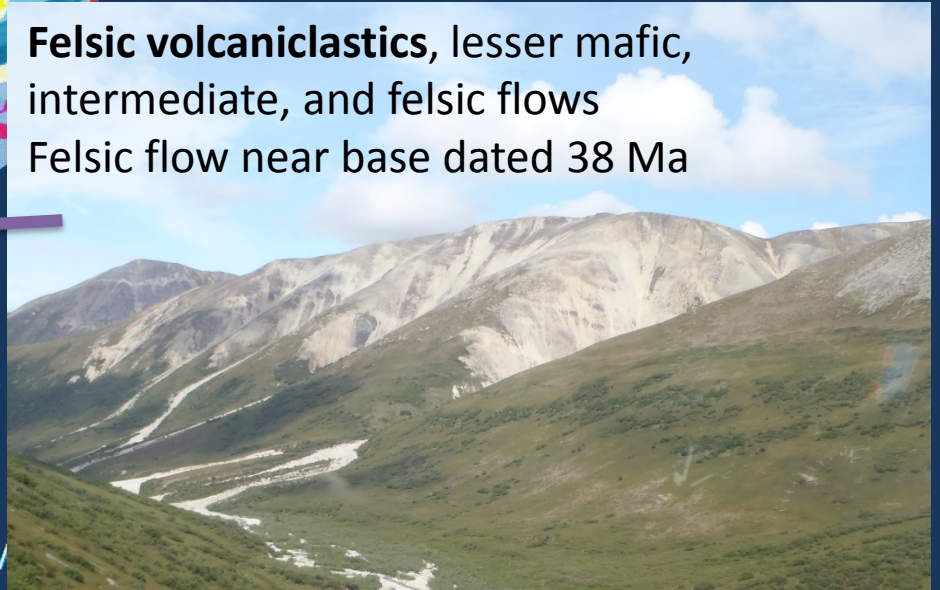
Basalt, andesite flows and agglomerates
Cut by 54 Ma andesite porphyry



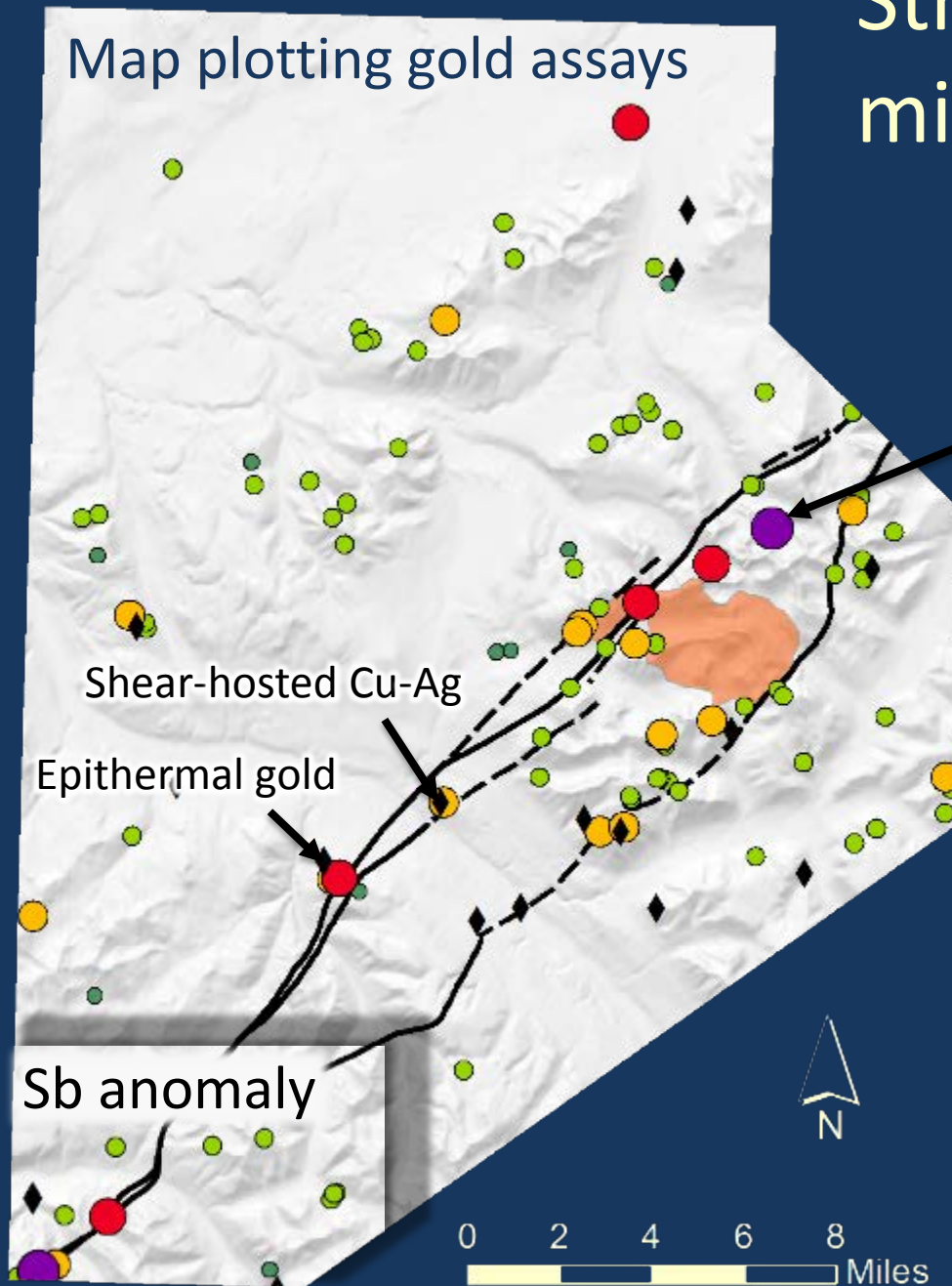
Crosscutting relationships with volcanics help time fault motions



Felsic volcanoclastics, lesser mafic,
intermediate, and felsic flows
Felsic flow near base dated 38 Ma



Structurally controlled mineralization



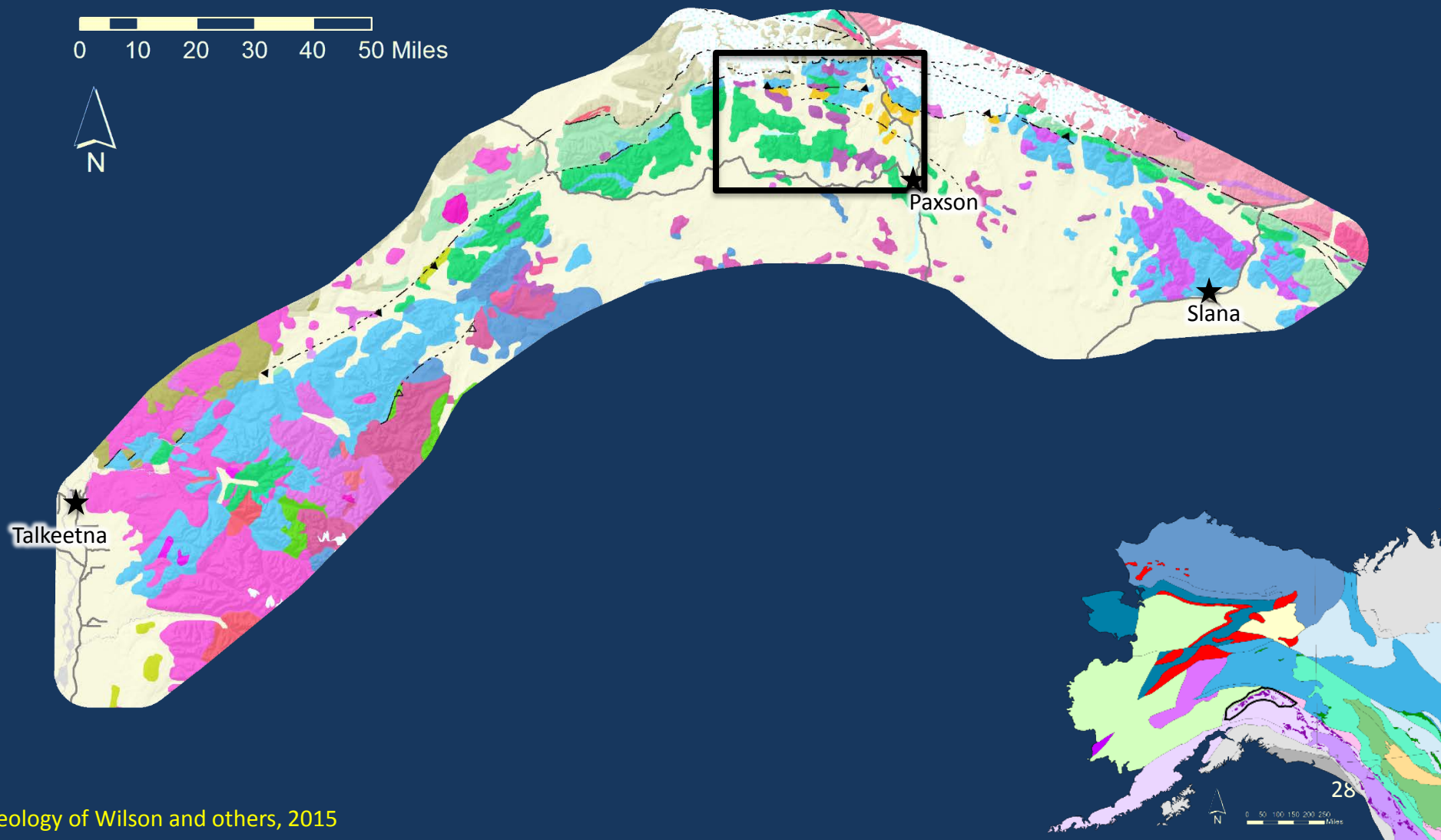
Z-score
(log-transformed)

- < -3
- -3 to -2
- -2 to -1
- -1 to 1
- 1 to 2
- 2 to 3
- > 3

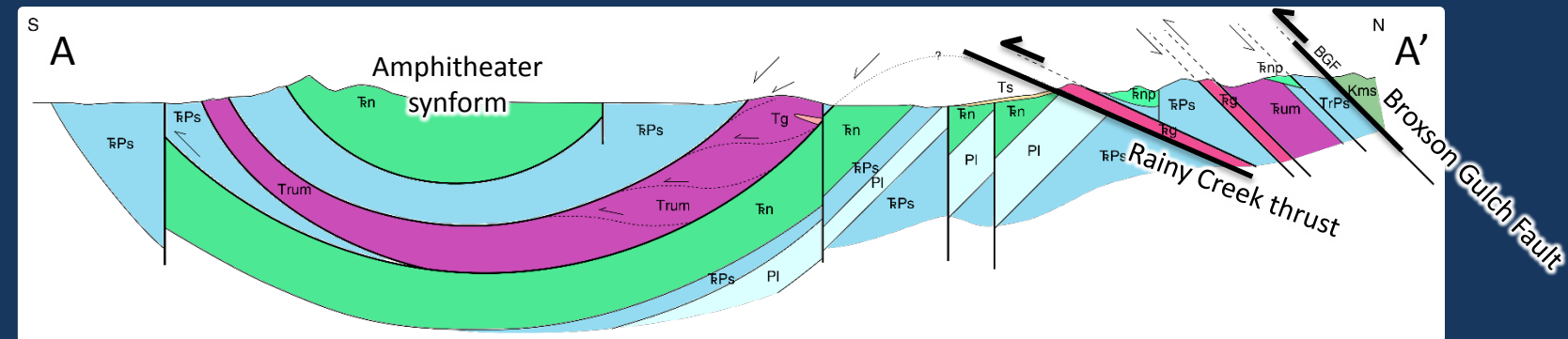
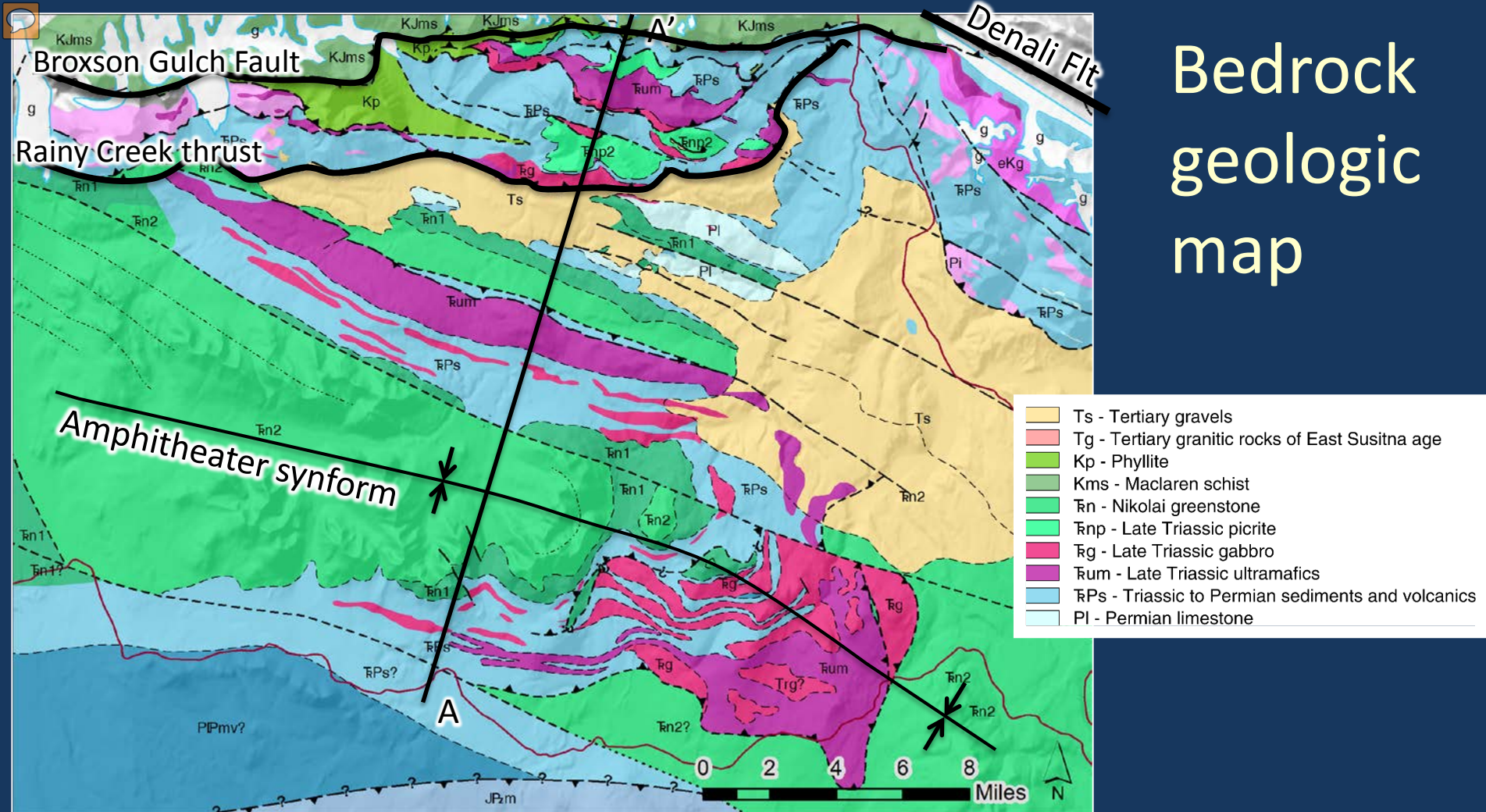
Selected geology

- Fault
- Granodiorite

Part 2: Eastern Alaska Range Ultramafics & young deformation



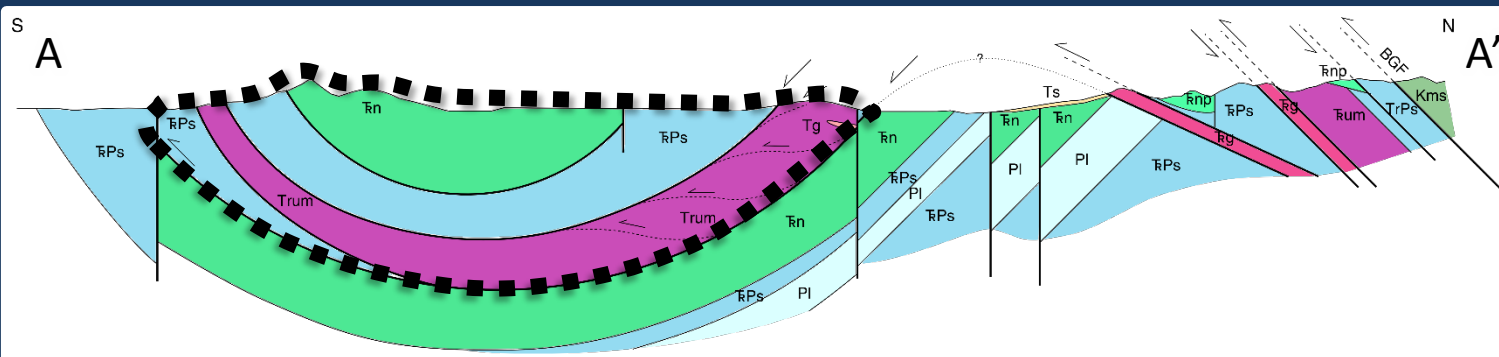
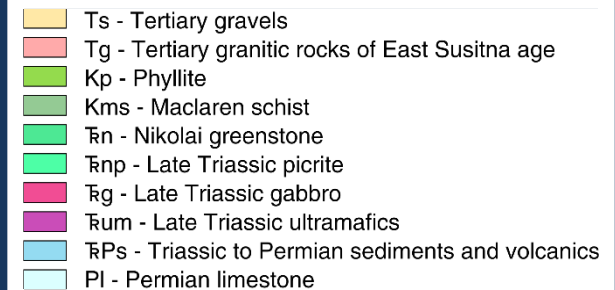
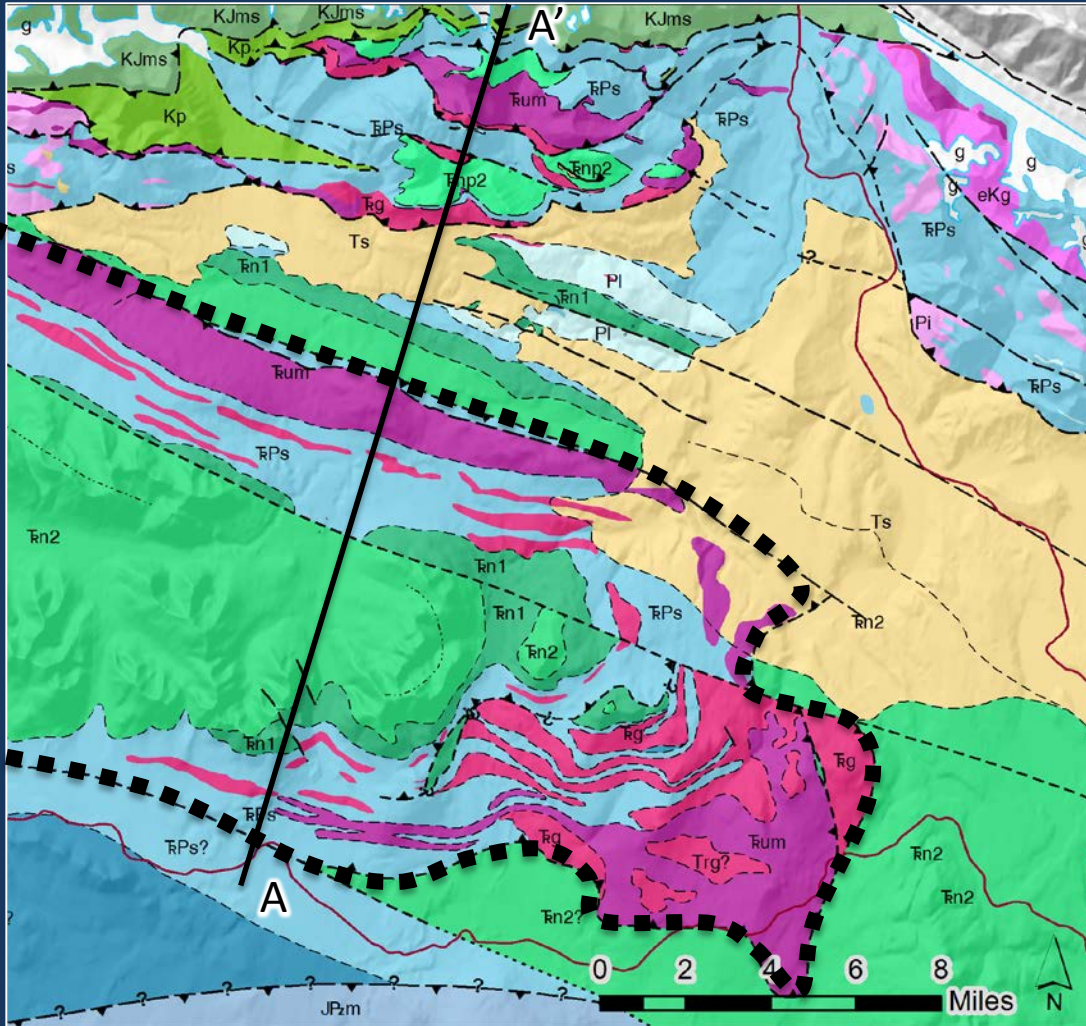
Bedrock geologic map



Three lithologic subdivisions

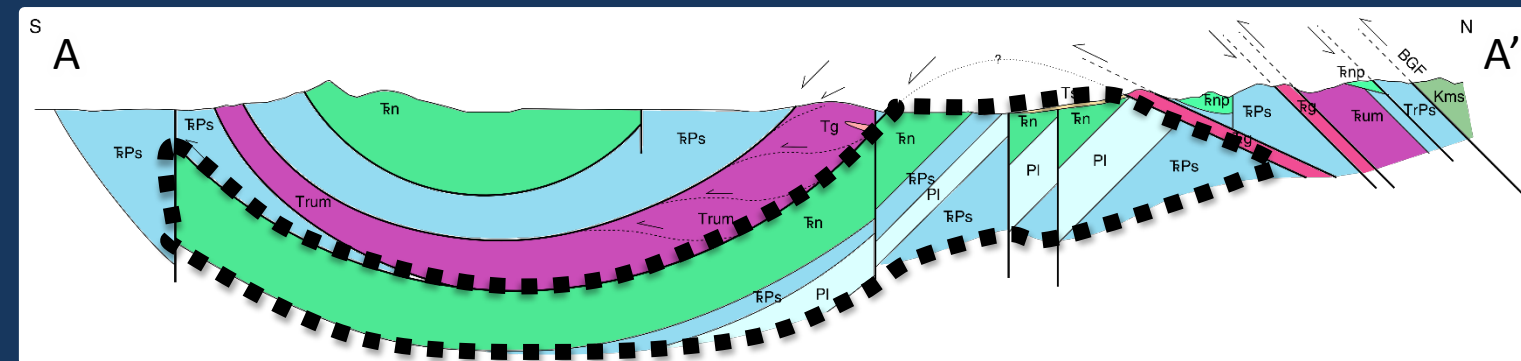
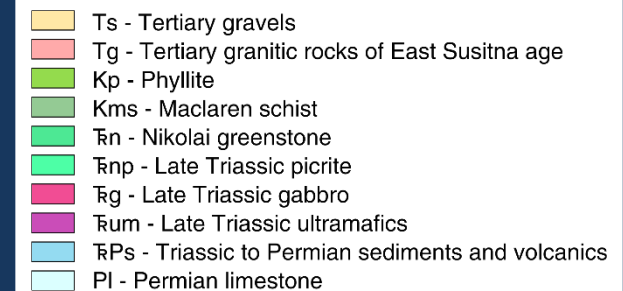
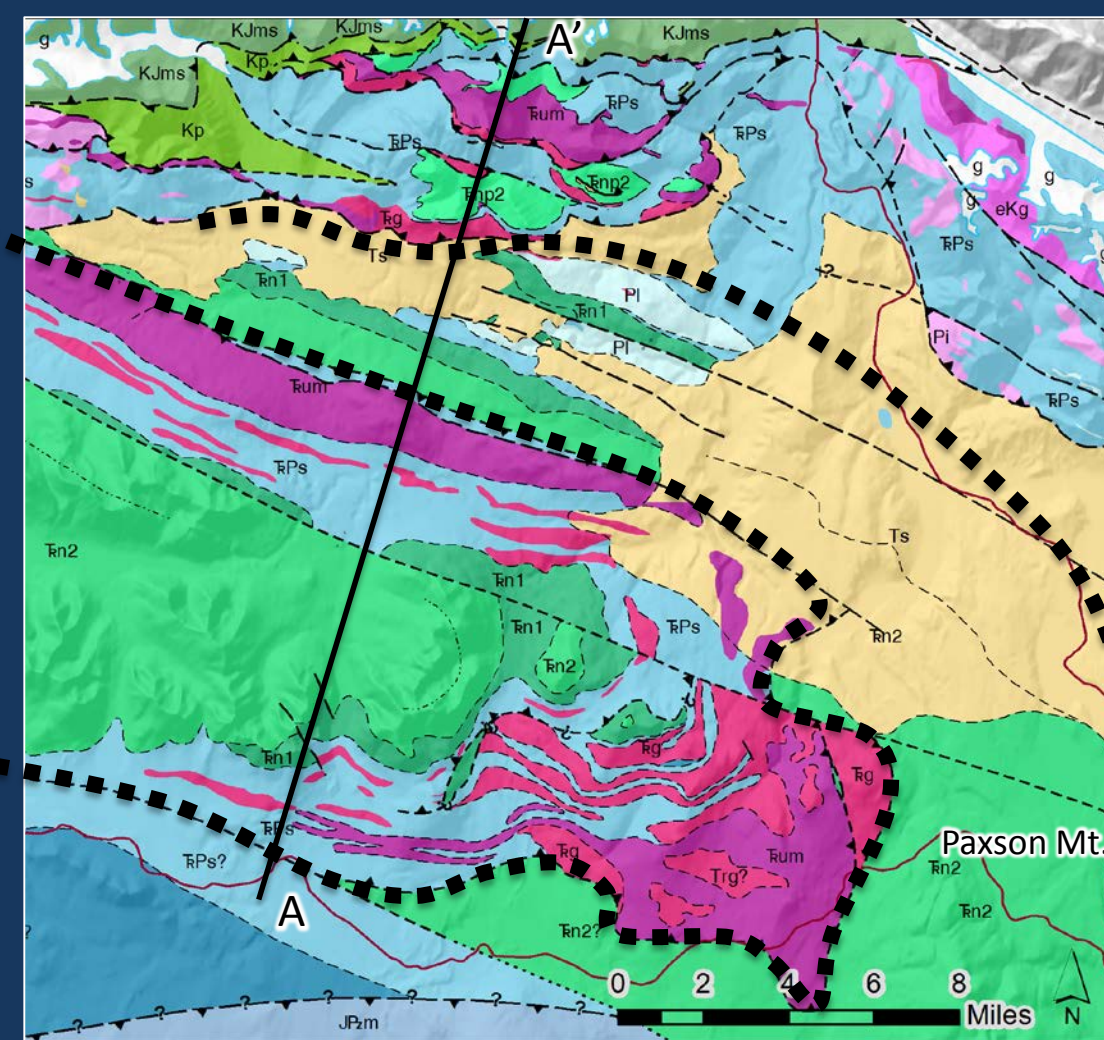
1: Amphitheater group:

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



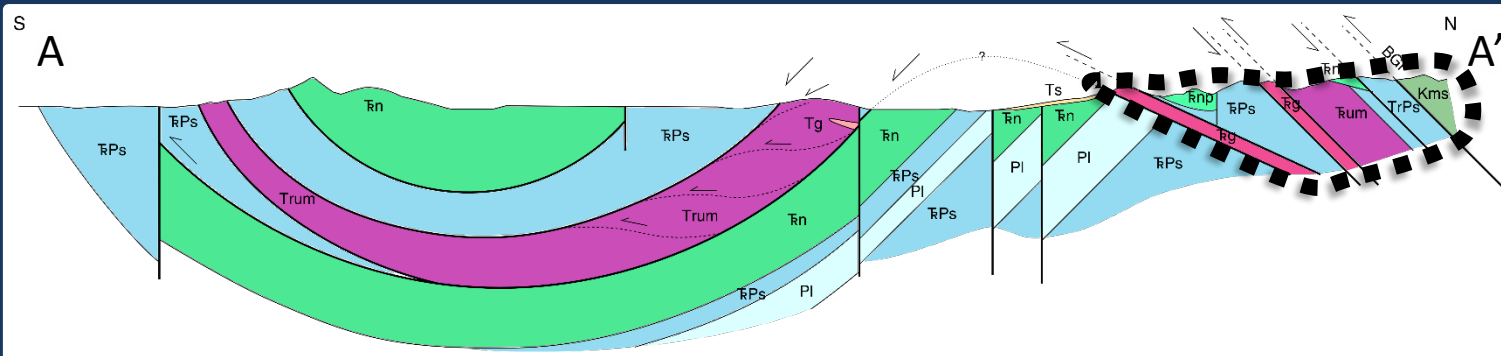
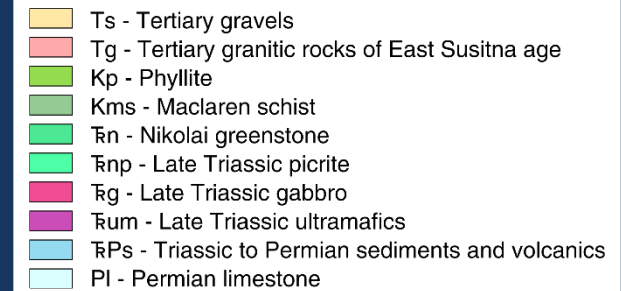
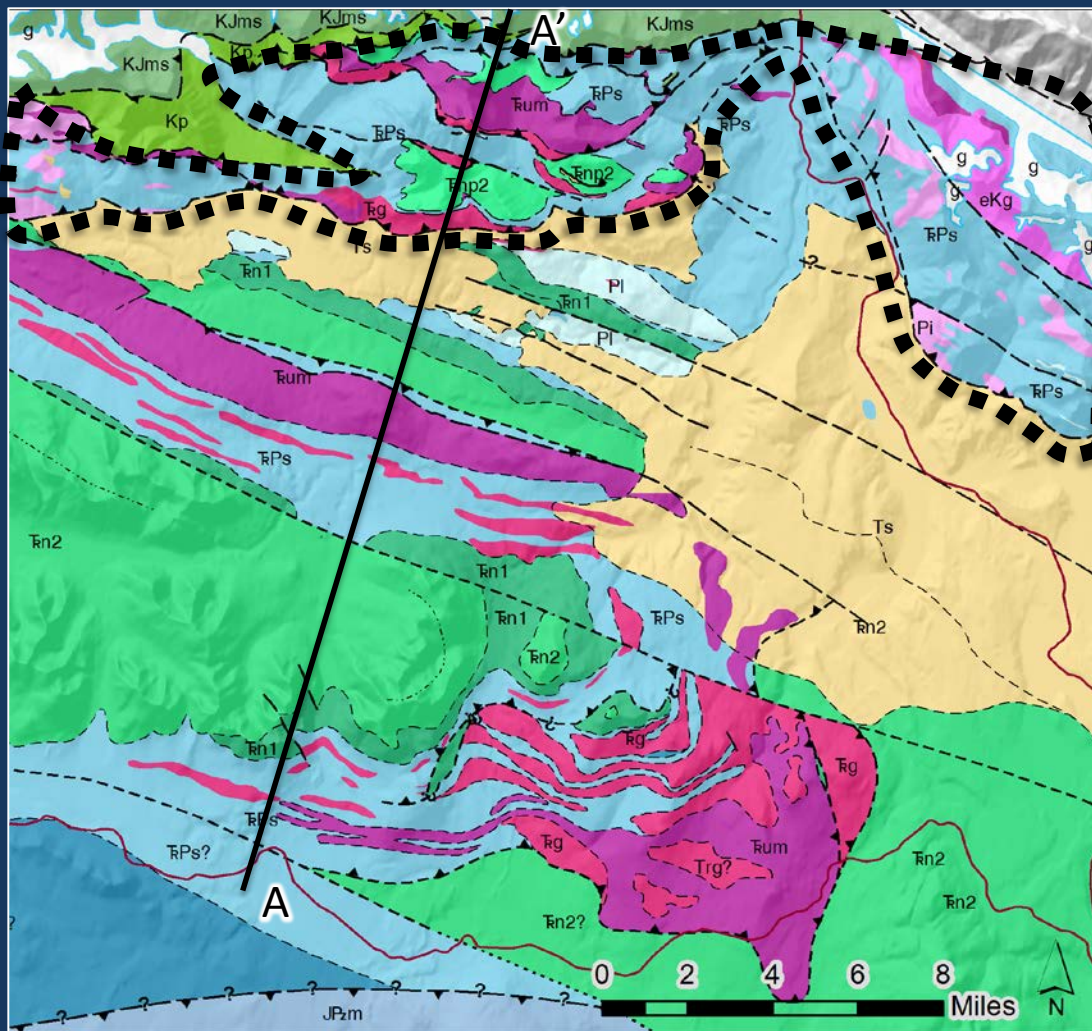
2. Paxson Mountain group:

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



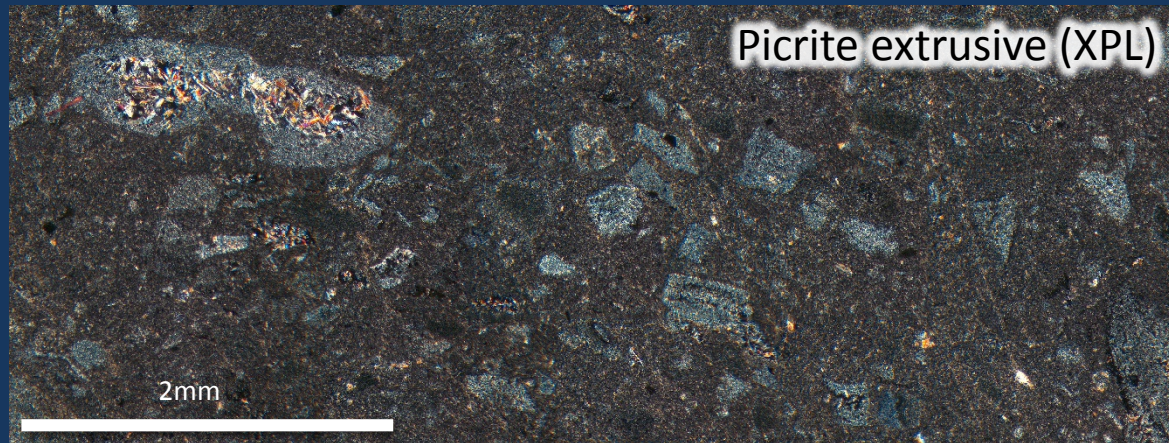
3. Rainy Creek group:

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

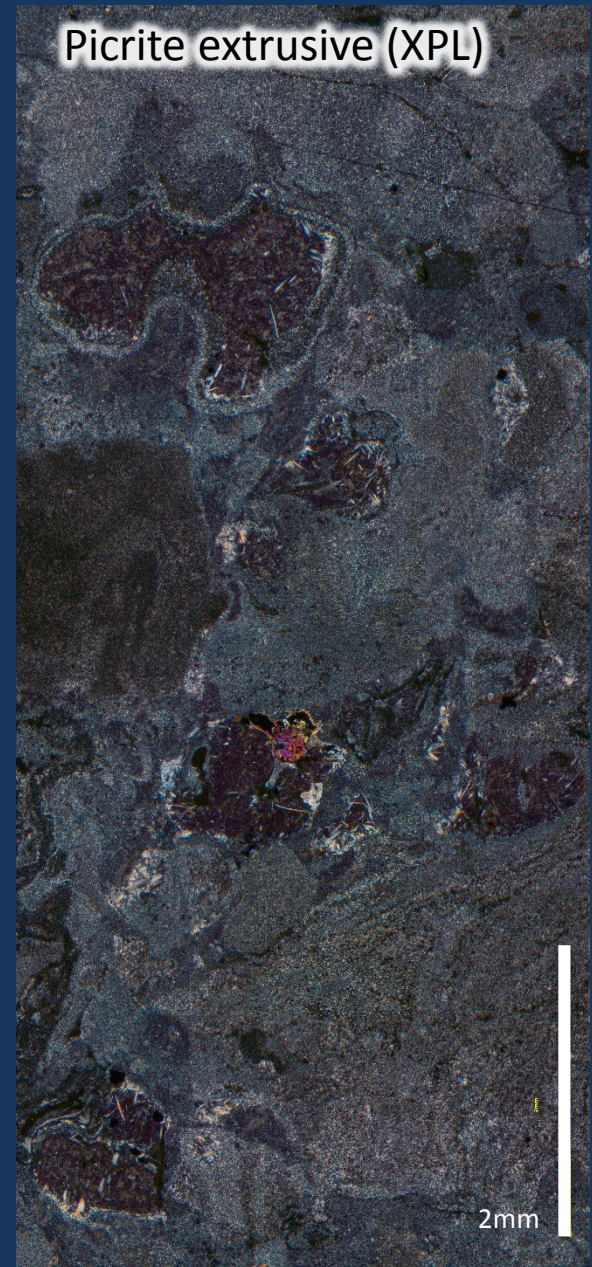


Rainy Creek Picrite

- 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)

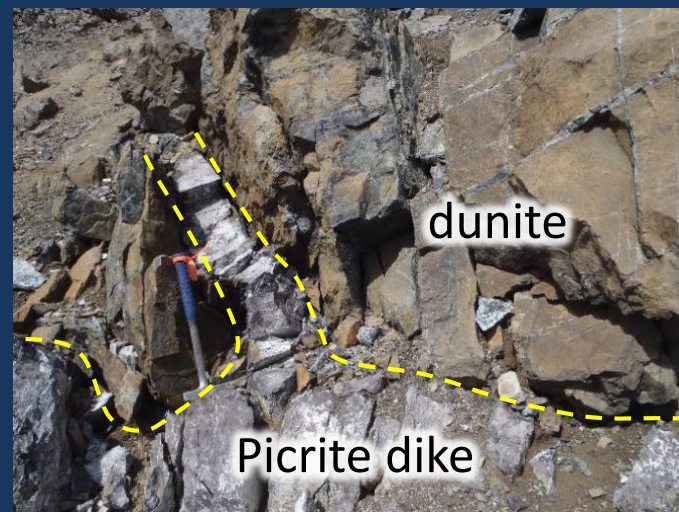
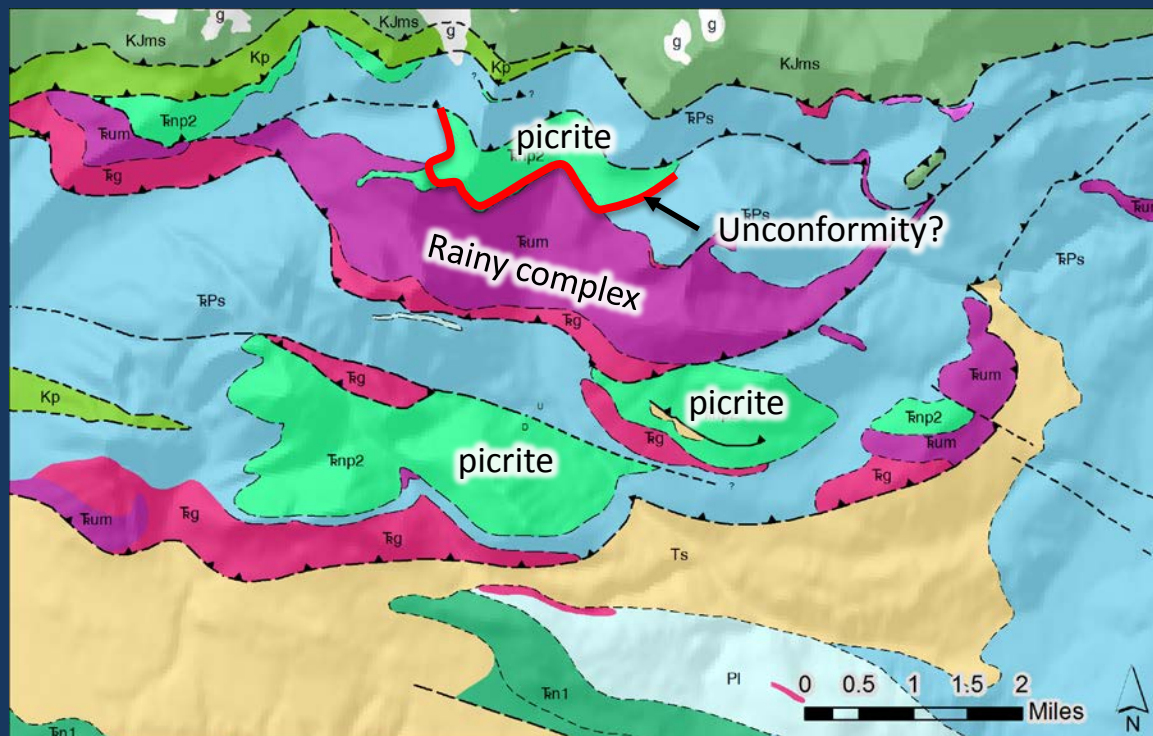


Very fine grained, fragmental, high-Mg lower greenschist minerals: actinolite + chlorite; lacks cumulate olivine



Volcanic environment

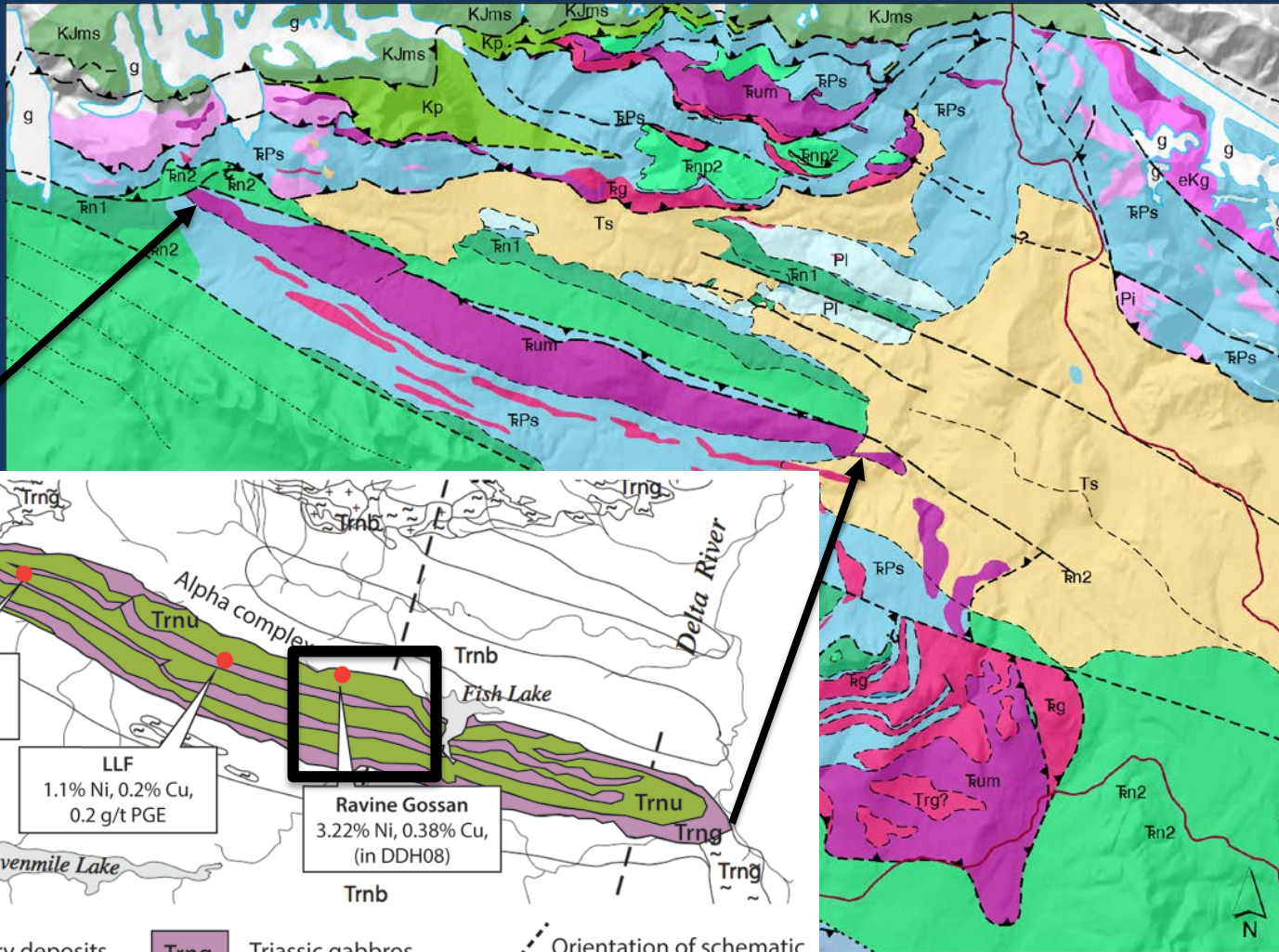
- Rainy ultramafic complex linked to low-Ti, early phase of Nikolai Greenstone
 - Olivine more primitive, low-Ti
- Intruded by high-Ti series dikes
- Clasts in high-Ti volcanic rocks (lithified)
- Uplift, unconformity *during* Late Tr event?
 - In contrast: magma mixing at Alpha complex



Ts	Tertiary gravels
Tg	Tertiary granitic rocks of East Susitna age
Kp	Phyllite
Kms	Maclaren schist
Tn	Nikolai greenstone
Tnp2	Late Triassic picrite
Tg	Late Triassic gabbro
Tum	Late Triassic ultramafics
Tps	Triassic to Permian sediments and volcanics
PI	Permian limestone

Ultramafic complex architecture

Major implications for PGE deposit type and exploration strategy

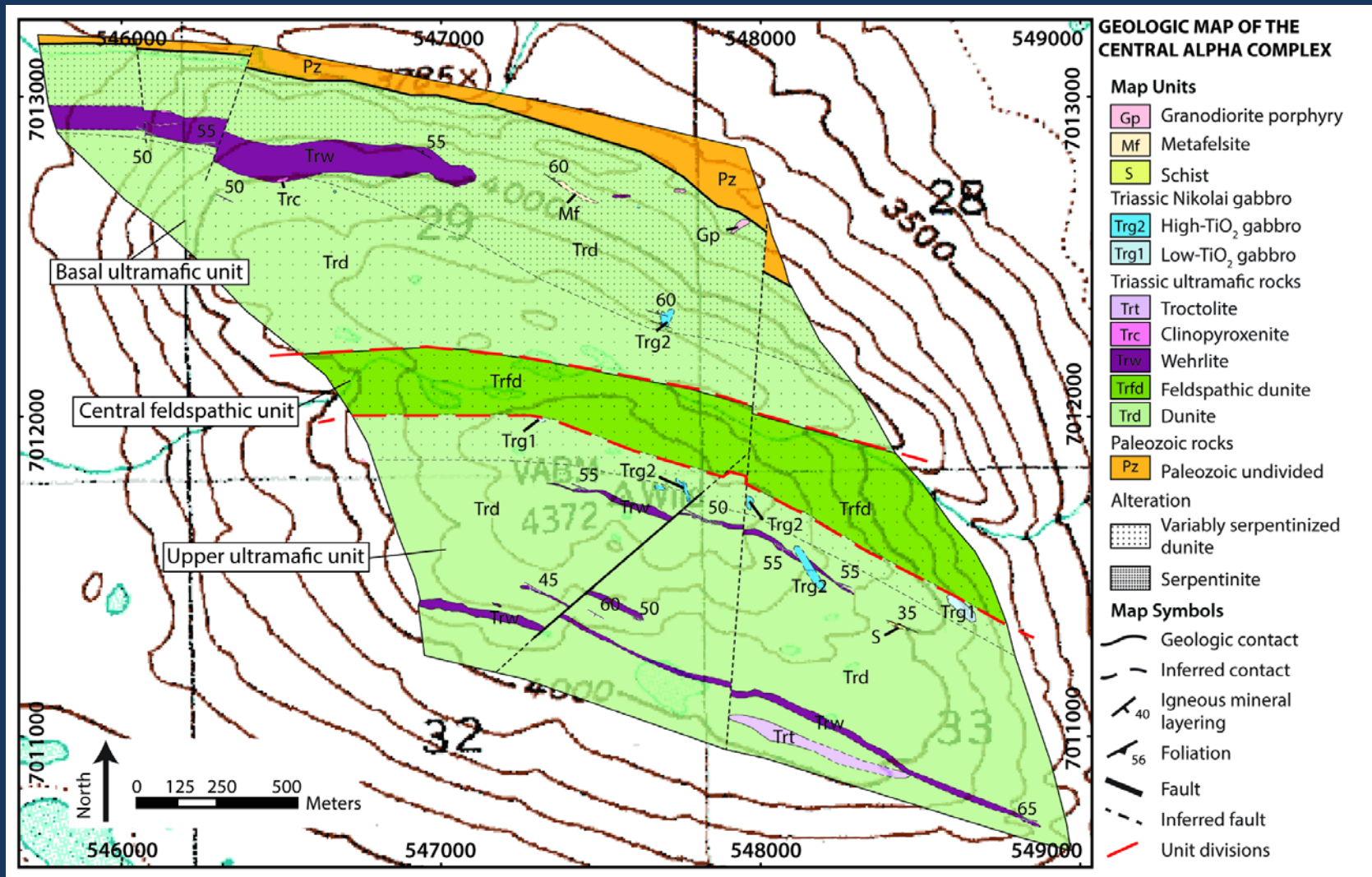


Modified from Schmidt and Rogers (2007) after industry data

Previous interpretation: *cyclical* ultramafic to gabbro layered complex

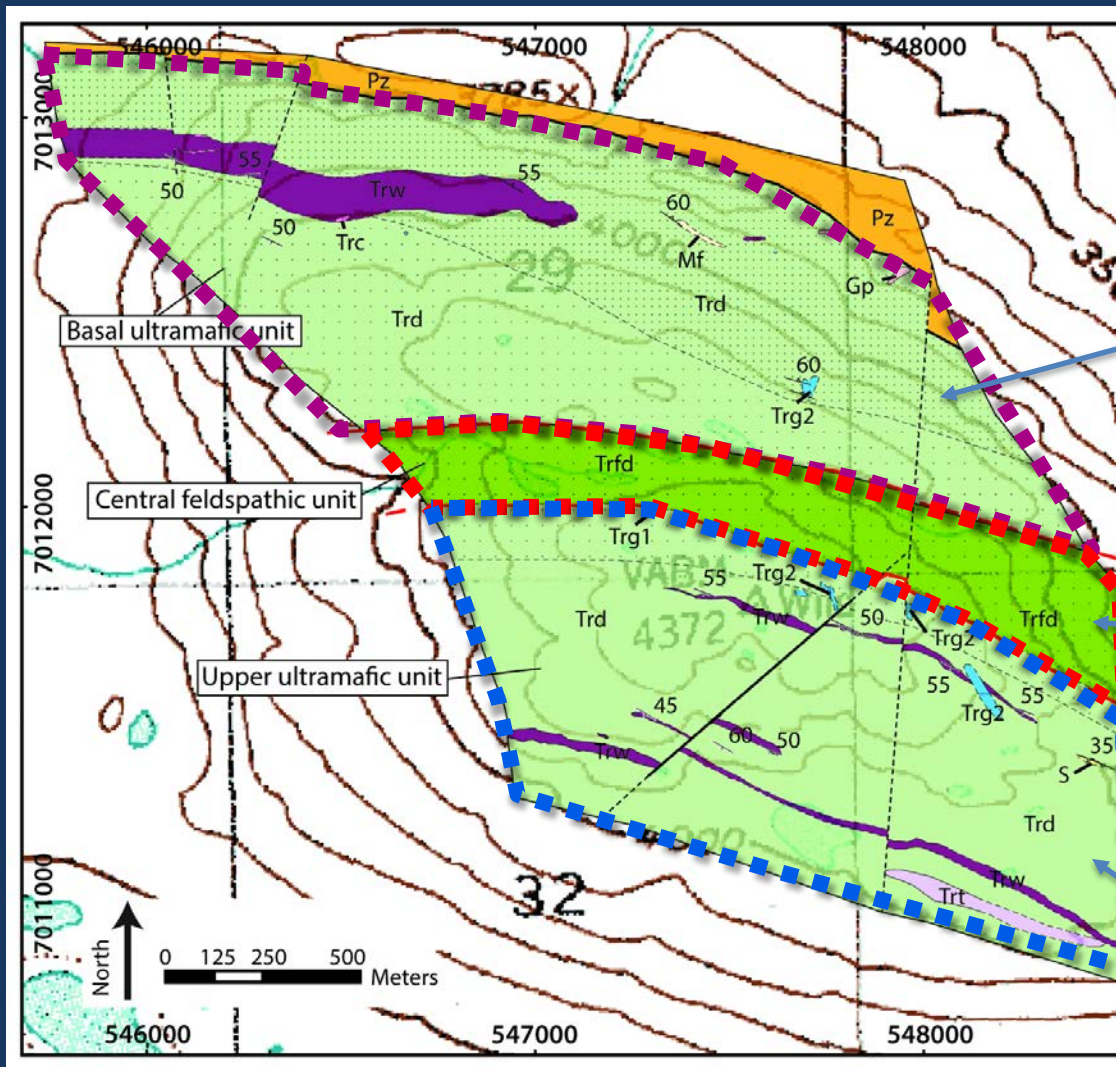
Detailed mapping of Alpha complex

Completed by Lauren Lande through DGGS-UAF MS Research Internship



Gabbro is shown in blue: traceable as thin crosscutting dikes

A multiphase sill complex

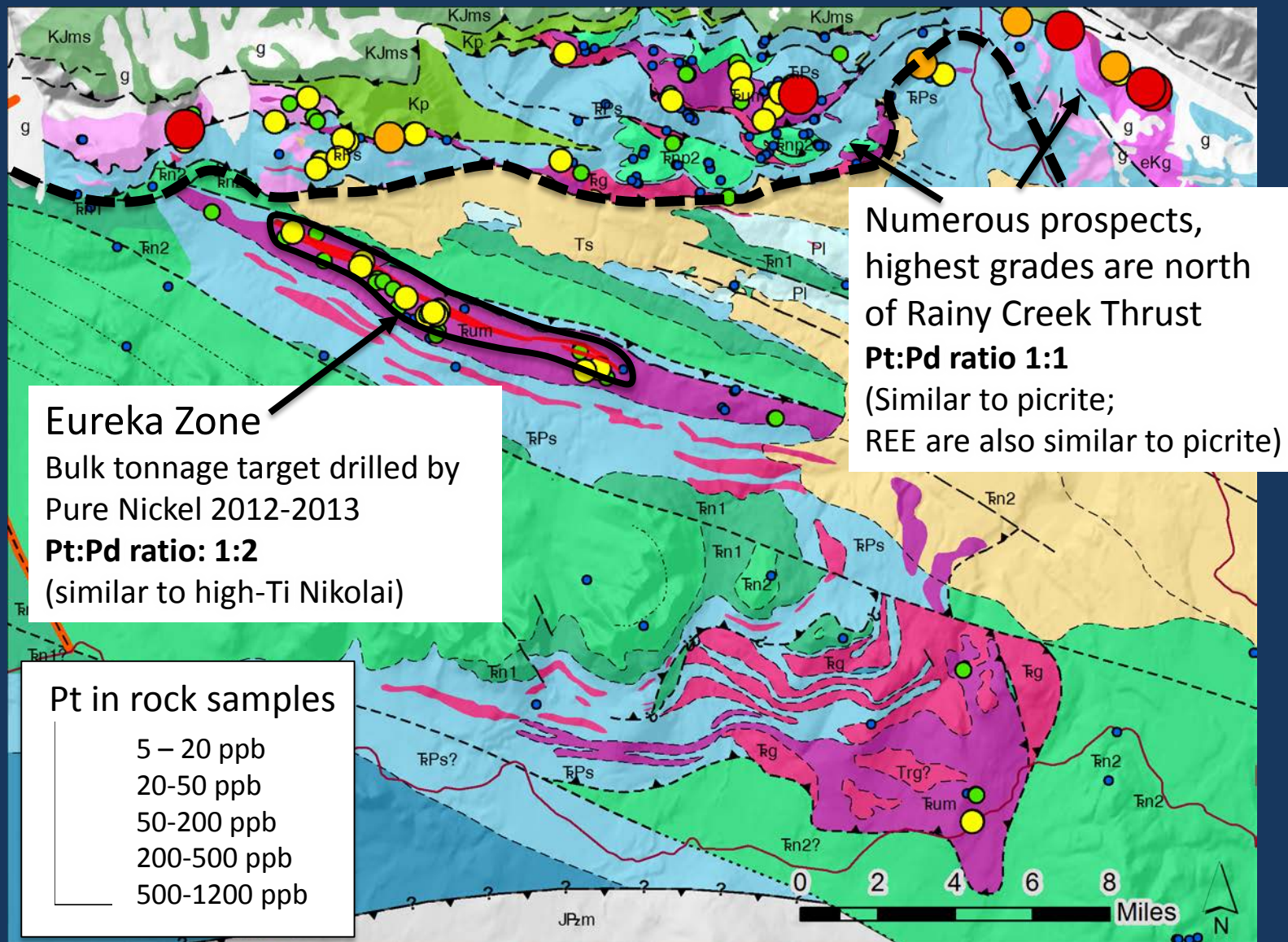


Basal ultramafic unit:
Intermediate Ti clinopyroxene;
Disequilibrium textures:
magma mixing?

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

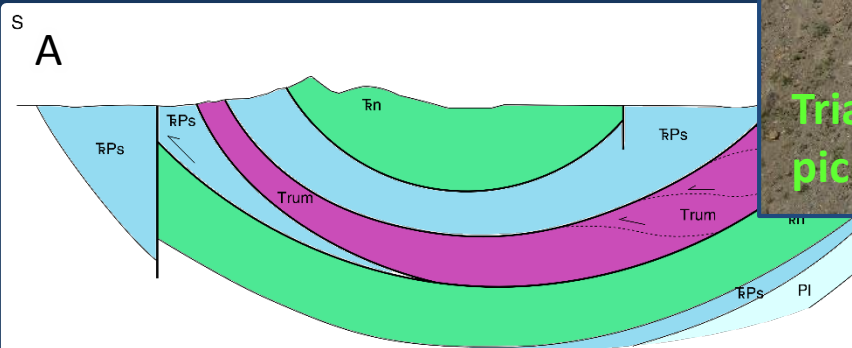
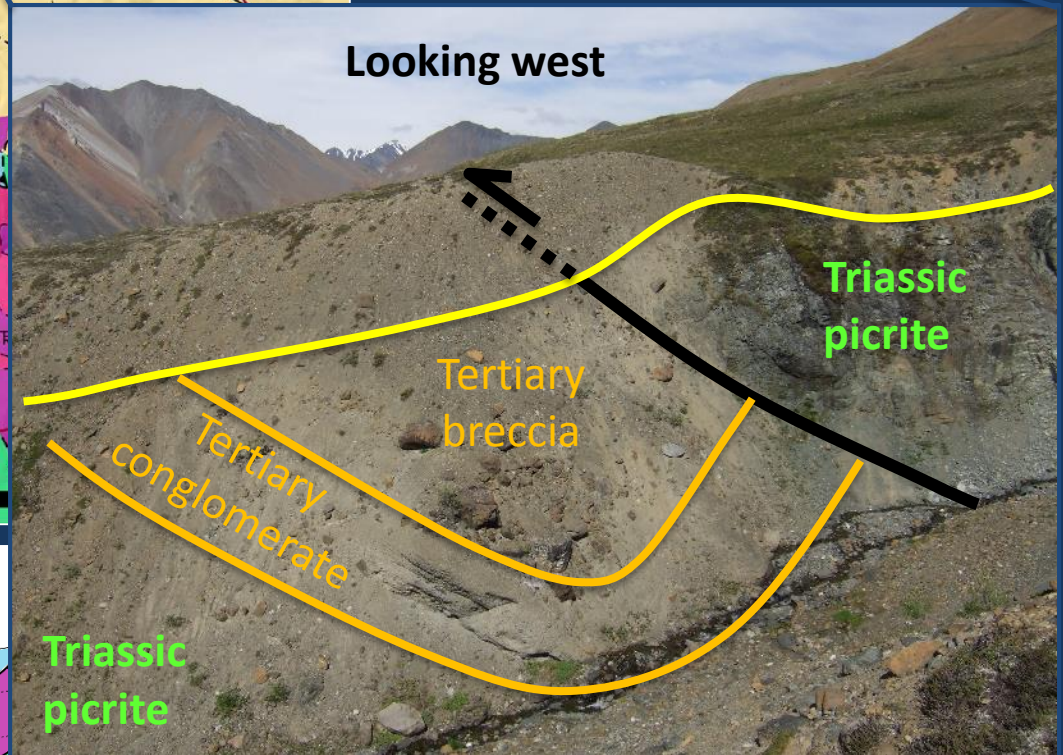
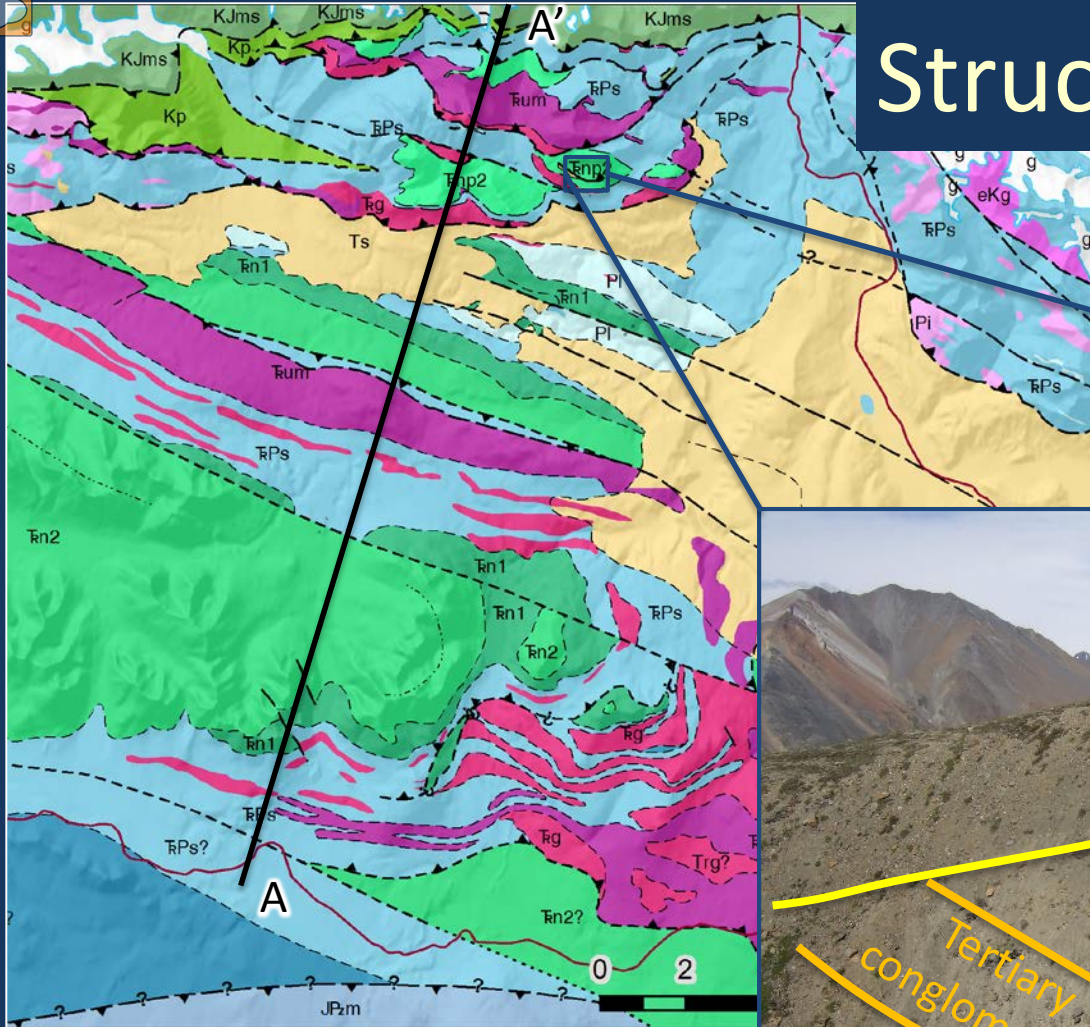
Upper ultramafic unit:
Low Ti clinopyroxene:
Crystallized from **low Ti**
magma (Lower Nikolai)

PGE mineralization



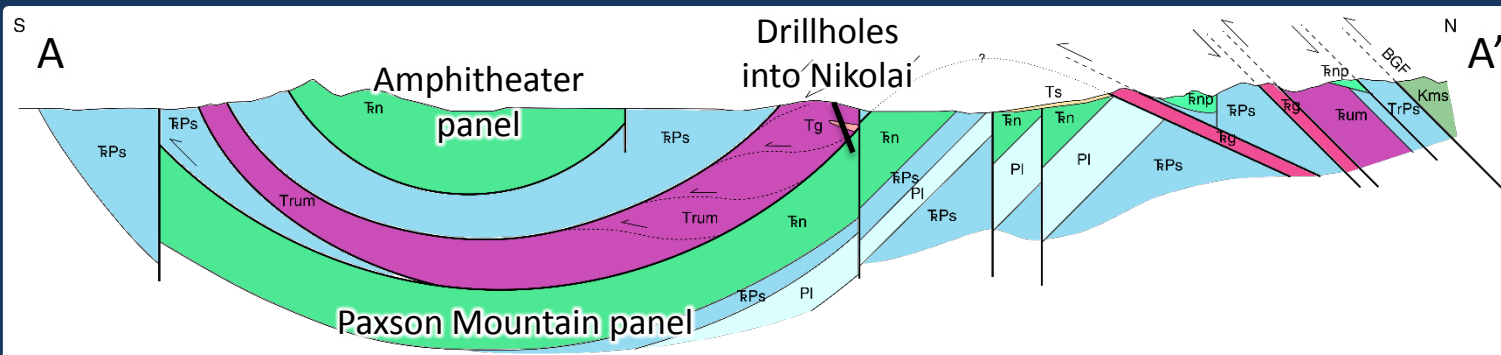
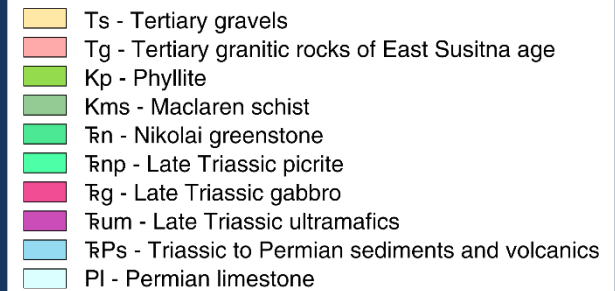
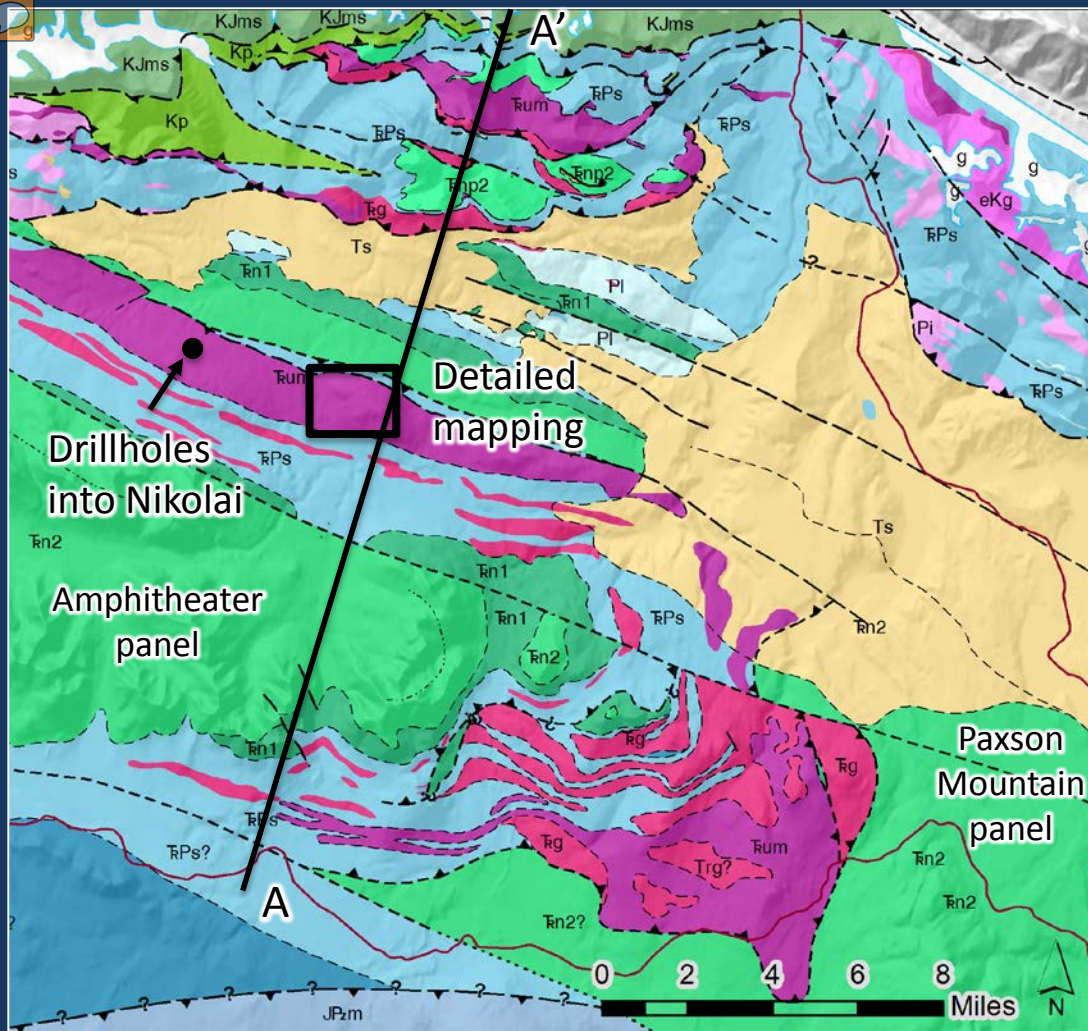
Structural disruption:

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



More shortening:

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





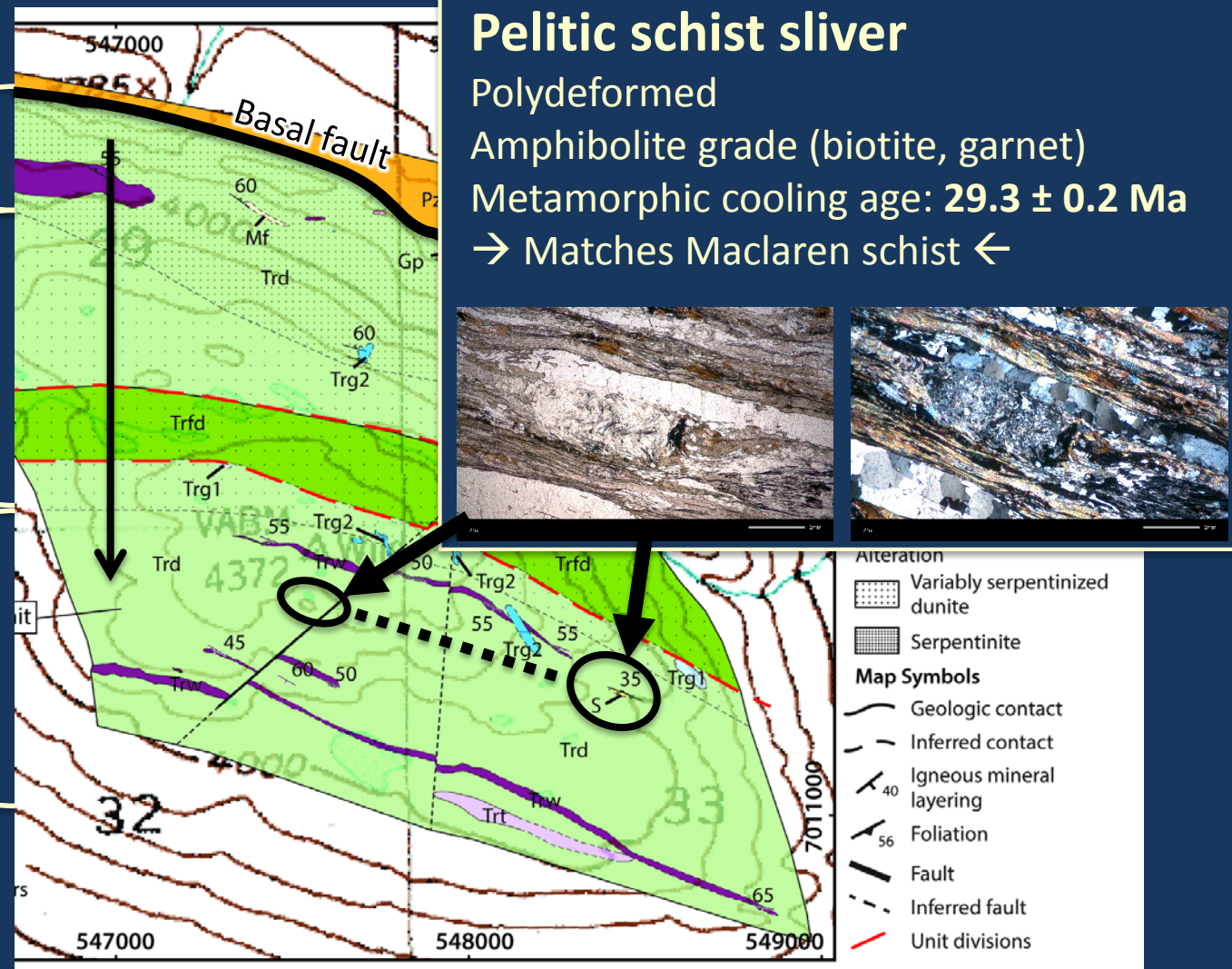
Fault at base of ultramafics

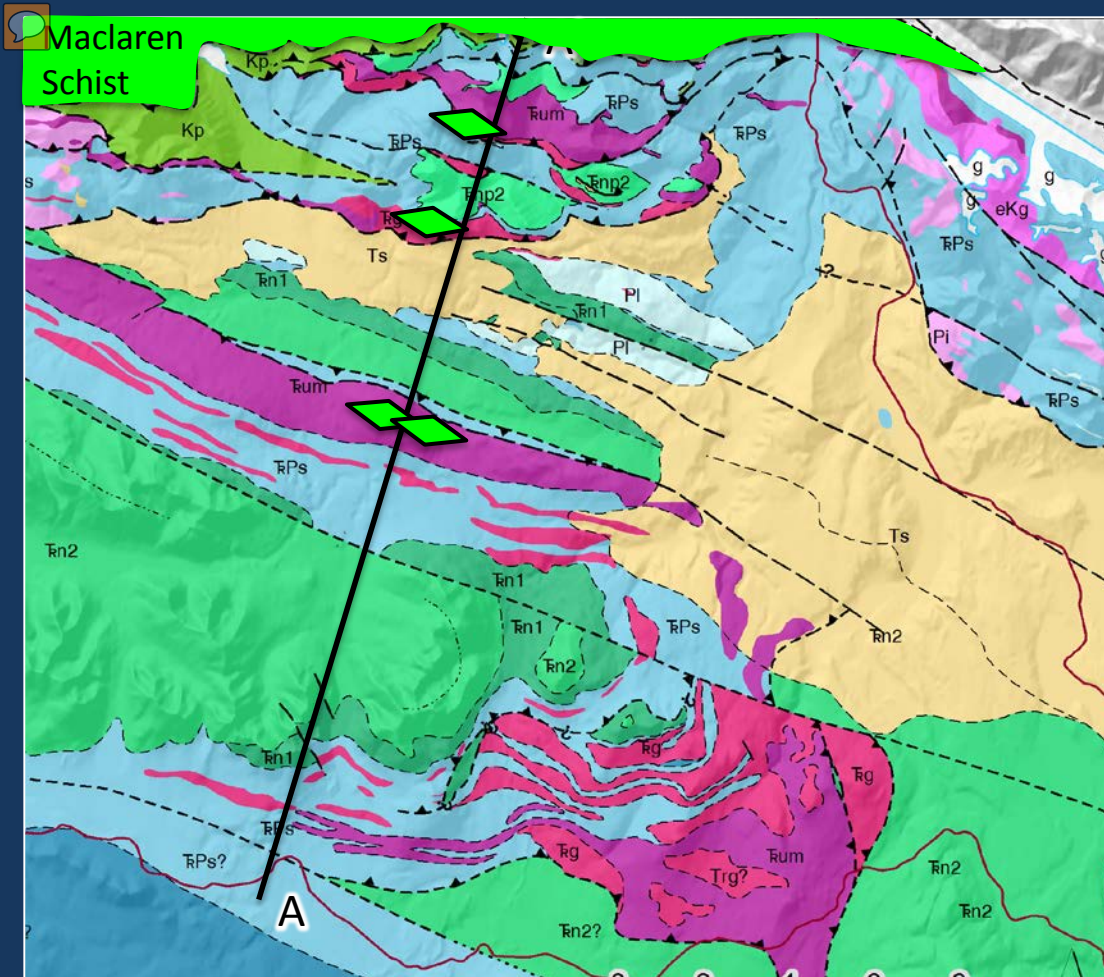
Serpentinization increases from base of complex upward:

Near-pervasive serpentinization

Partial serpentinization

Little serpentinization

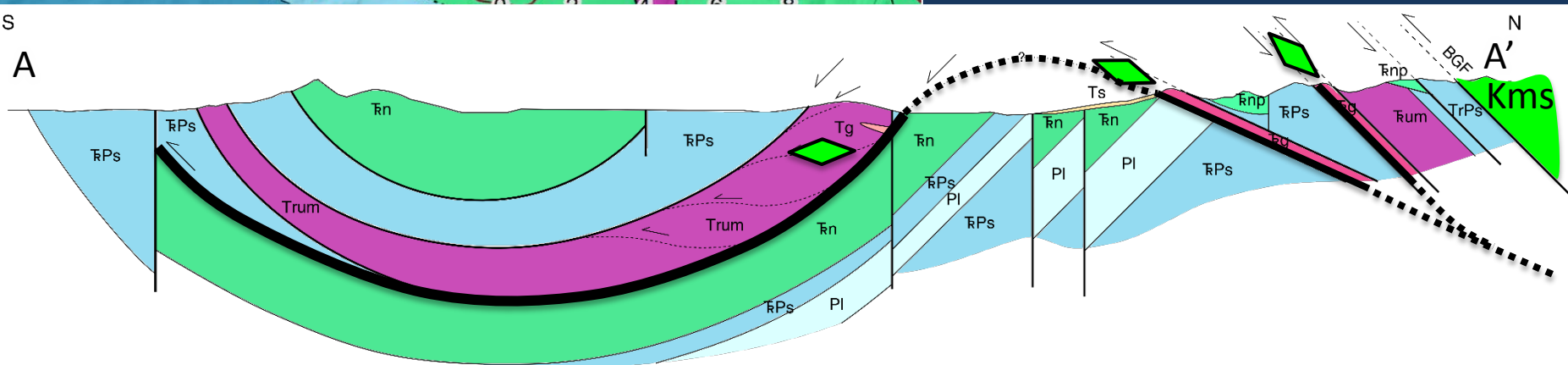
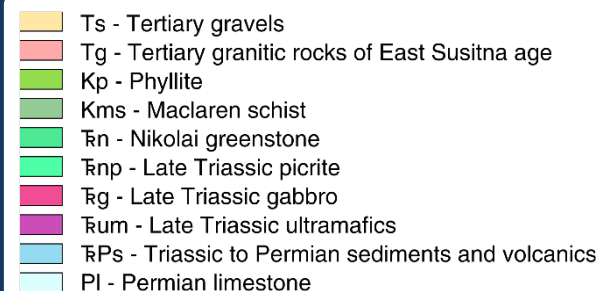




Schist slivers were also found in/near other thrust faults:

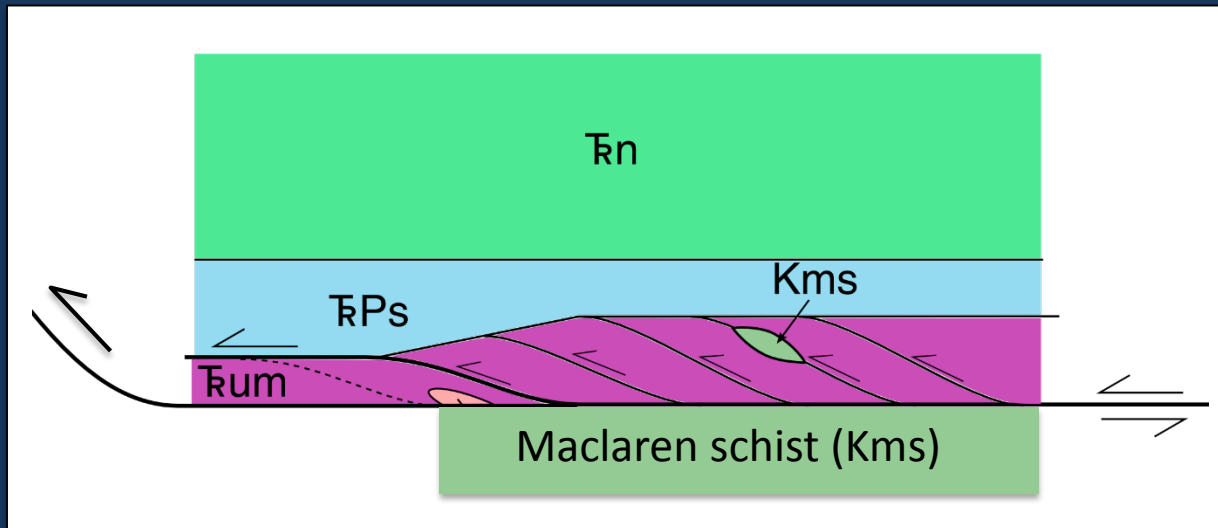
- Motion young (<30 Ma)
- Displacement significant

 Schist slivers



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

Duplexing of slippery, \pm serpentized 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



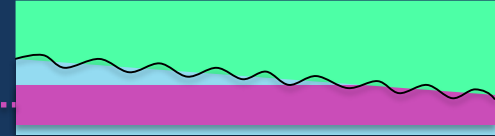
Amphitheater Mountains:

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



Rainy Creek:

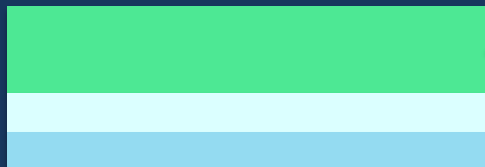
Most primitive magmas
Possible Late Tr erosion
Numerous PGE prospects



Schematic paleogeography in the Late Triassic

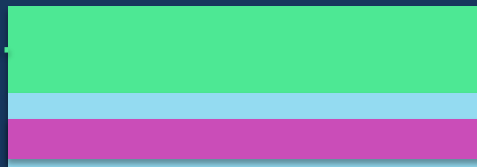
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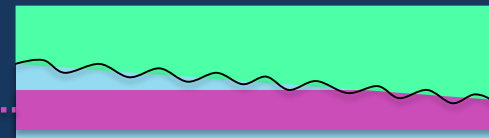
Amphitheater Mountains:

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

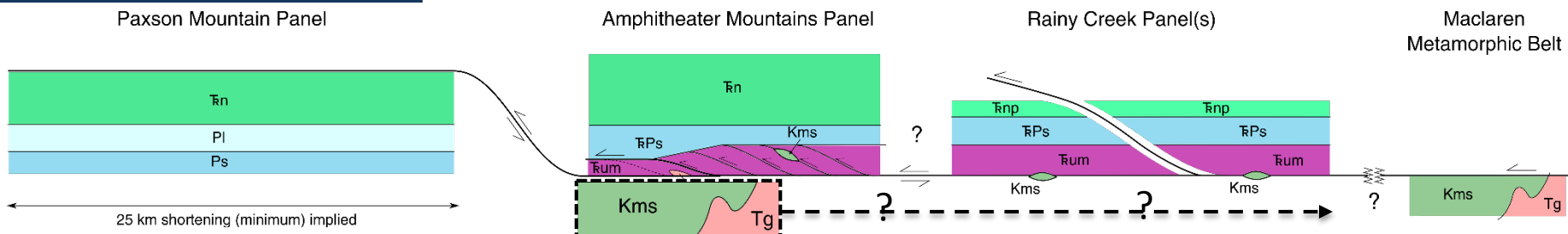


Rainy Creek:

Most primitive magmas
Possible Late Tr erosion
Numerous PGE prospects



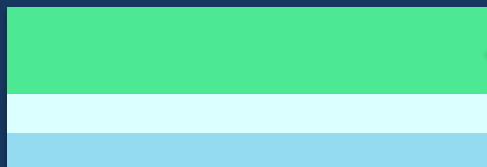
Pre-shortening schematic



Schematic paleogeography in the Late Triassic

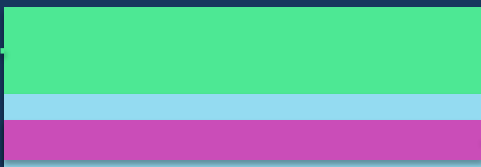
Paxson Mountain:

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



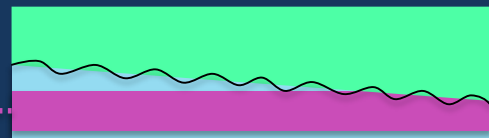
Amphitheater Mountains:

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

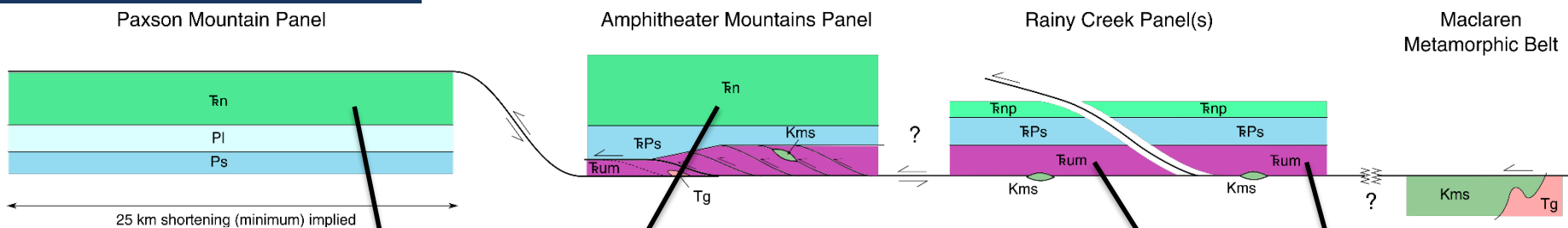


Rainy Creek:

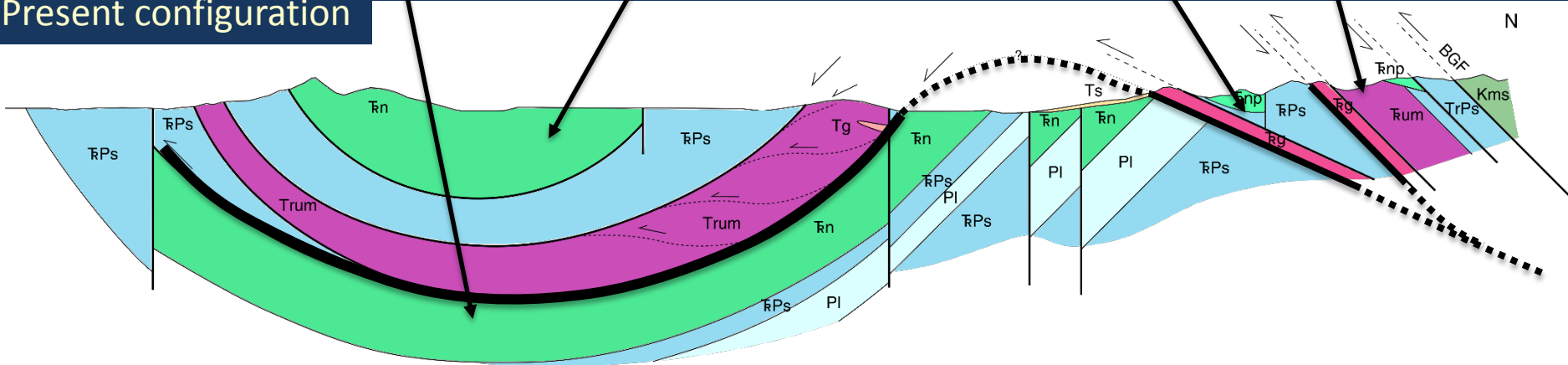
Most primitive magmas
Possible Late Tr erosion
Numerous PGE prospects



Pre-shortening schematic



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 (\pm 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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