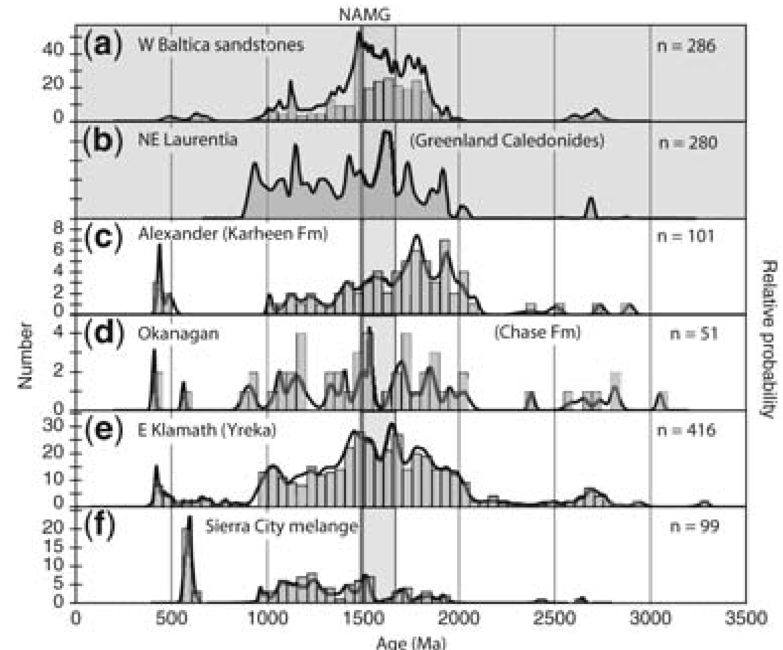
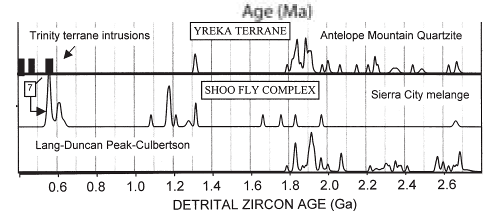
Exotic terranes

- How do we know they are "exotic"
- Where have they been?
- When and how did they arrive?

Allochthons in western NAM.

Colpron and Nelson, *Geol Soc Lond Spec Pub 318*, 2009

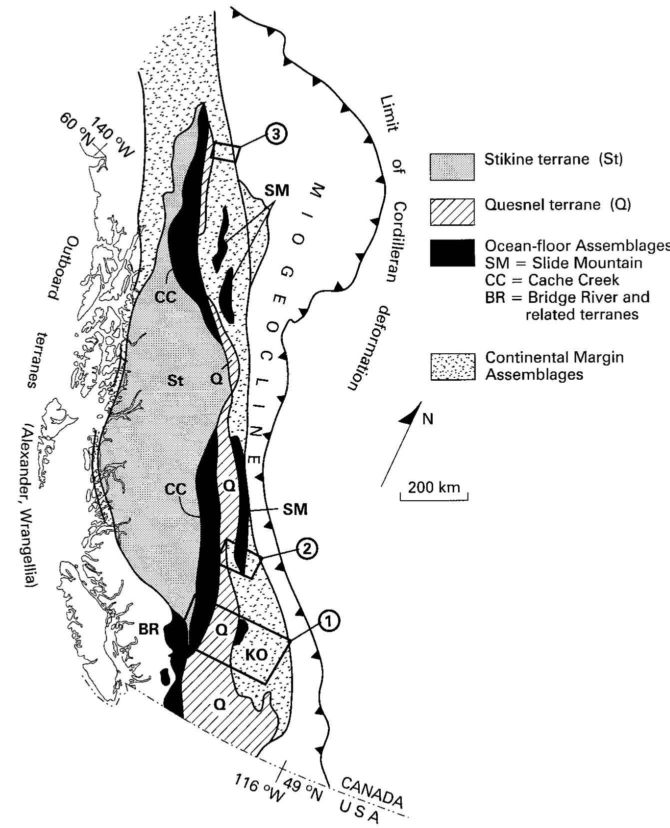




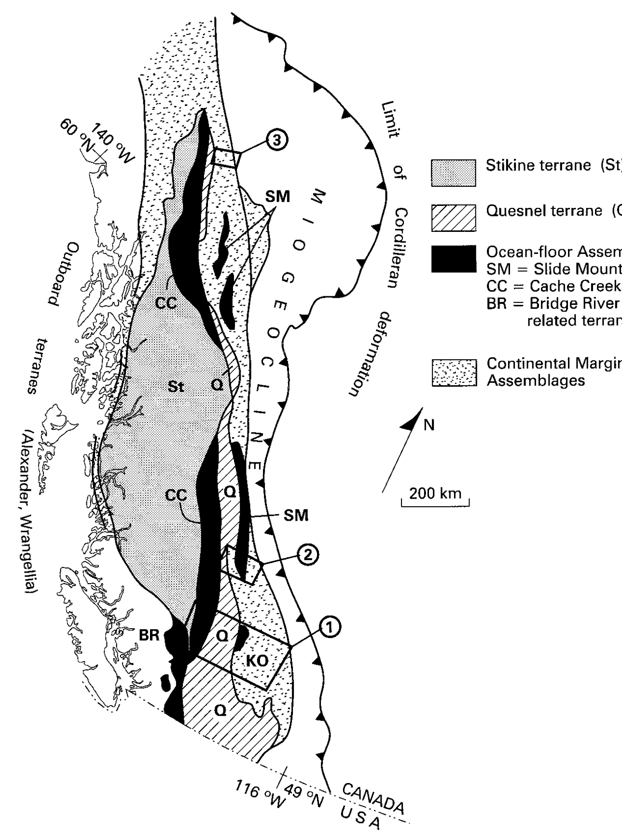
Gehrels et al., GSA SP 347, 2000

Reminder of this suggestion of a connection of the outboard terranes to Sonomia being tied to more exotic stuff. Colprin and Nelson connect allocthons in lower Shoo Fly with northern BC based on the older TIMS detrital zircon work. Here we compare with newer stuff, and maybe OK. Lang-Duncan Peak-Culbertson

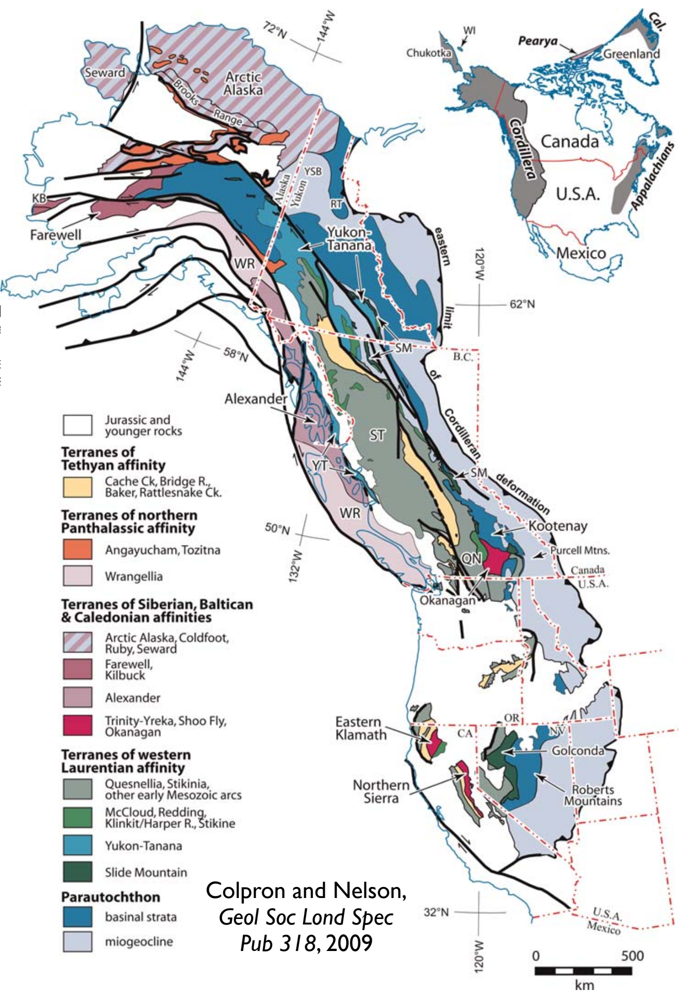
Figure 1. The Canadian Cordillera showing terranes studied here. Rectangles denote sampling regions: 1—southeastern British Columbia for Cache Creek, Quesnel, and Kootenay samples (KO = Kootenay terrane proper); 2—Wells-Barkerville region for Quesnel, Slide Mountain and Kootenay/Cassiar-equivalent samples; 3—Nisutlin assemblage at Little Salmon Lake, Yukon.



Patchett and Gehrels, J. Geol. 1998



Patchett and Gehrels, J. Geol. 1998



Colpron and Nelson, *Geol Soc Lond Spec Pub 318*, 2009

Most terrane maps focus on Canada; map at right extends this into US

Alexander Terrane

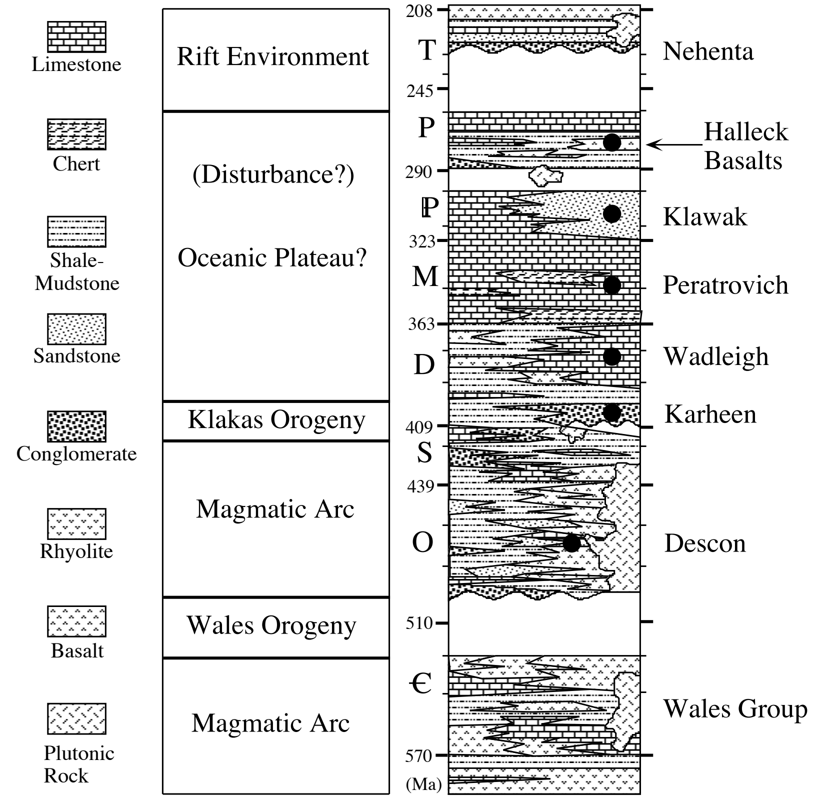
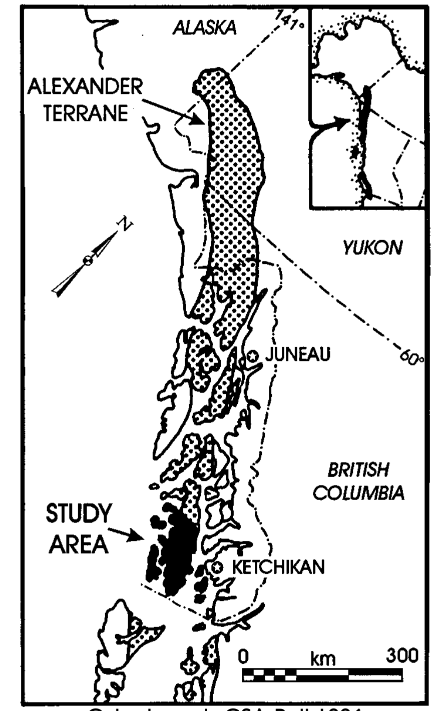


Figure 2. Stratigraphic column of the Alexander terrane in the southern part of southeast Alaska after Gehrels and Saleeby (1987). Filled circles indicate the horizons sampled for paleomagnetic study.



Gehrels et al., GSA Bull 1996

Butler et al., GSA Bull 1997

First, how do we know they are exotic? First big clue (well, maybe second) was very different geologic histories. While many terranes are relatively young, the Alexander terrane has a history going into the pC. Not a WUS history....

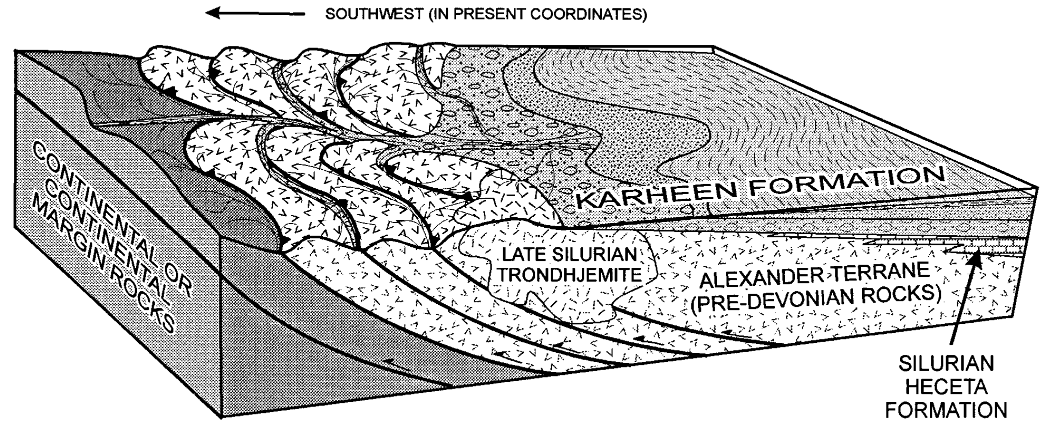
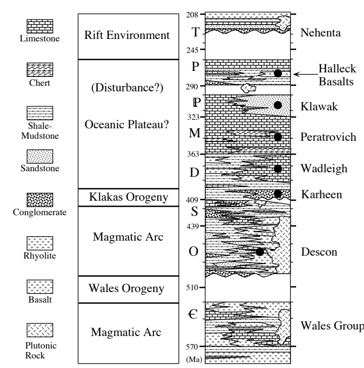


Figure 5. Schematic diagram showing the interpreted juxtaposition of the Alexander terrane with continental or continental-margin rocks during the Middle Silurian–earliest Devonian Klakas orogeny. The Karheen Formation is interpreted to be a clastic wedge shed from this orogen. The unusual geometry of clastic strata accumulating in the hinterland of the thrust system derives from the observations that Klakas-age thrusts are apparently southwest vergent, whereas Karheen strata were shed from source areas to the south or southwest.

Gehrels et al., GSA Bull 1996



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Butler et al., GSA Bull 1997

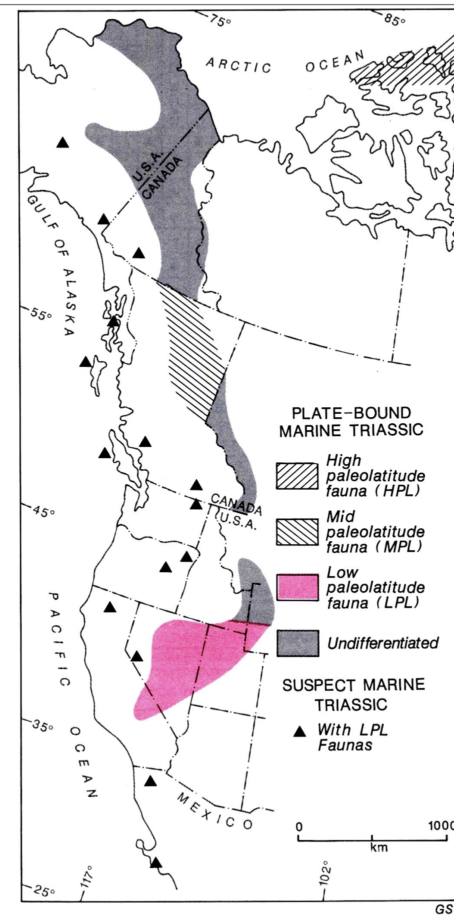
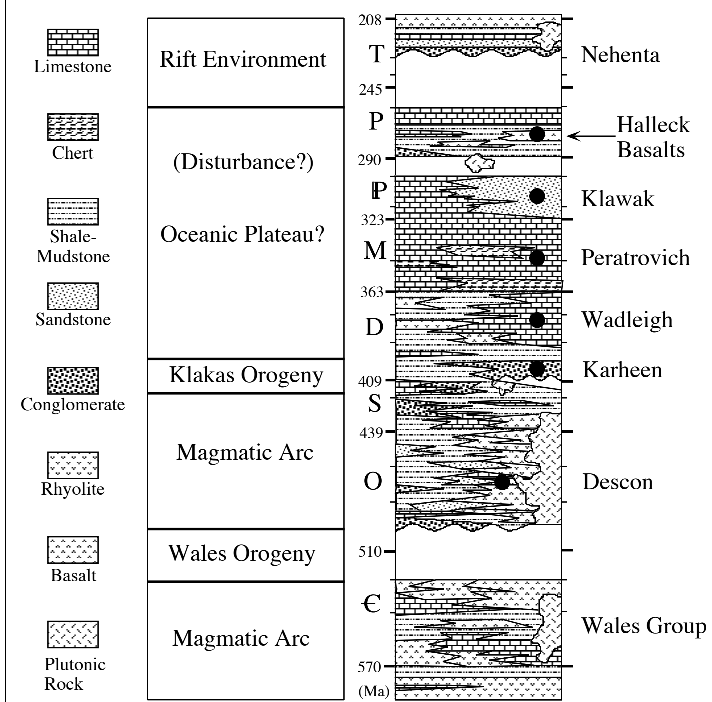


Figure 2.18. Triassic paleobiogeography of western North America (from Tozer, 1982).

Carter et al, DNAG v.G-2, 1991

Second clue fauna--lots of stuff looks wrong



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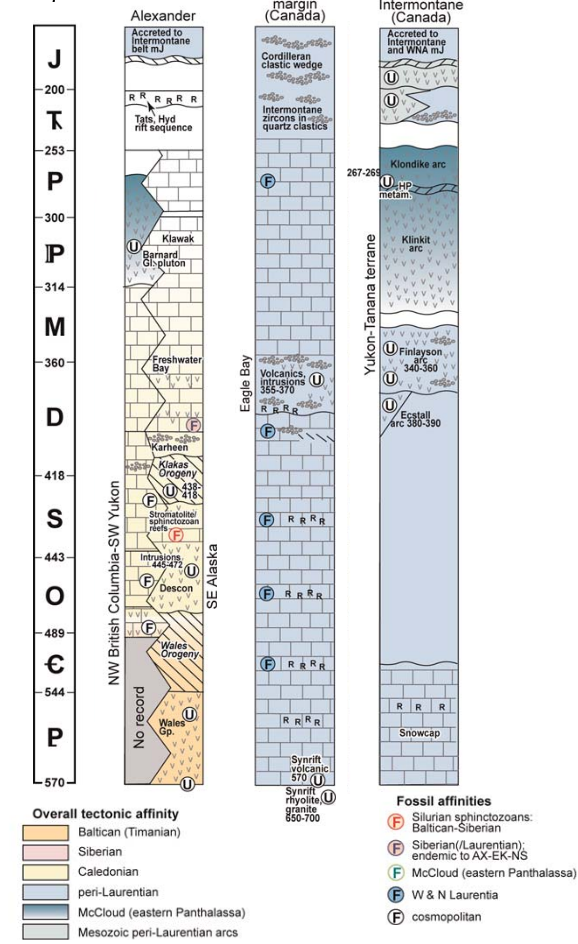
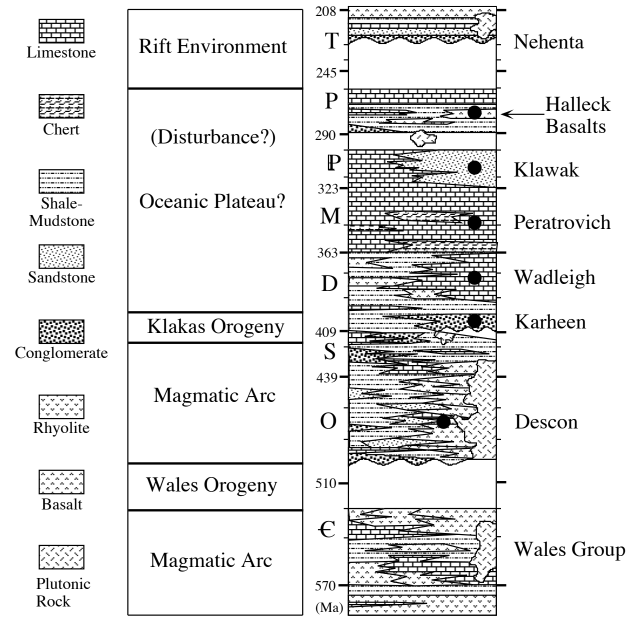
Butler et al., GSA Bull 1997

Colpron and Nelson, *Geol Soc Lond Spec Pub 318*, 2009





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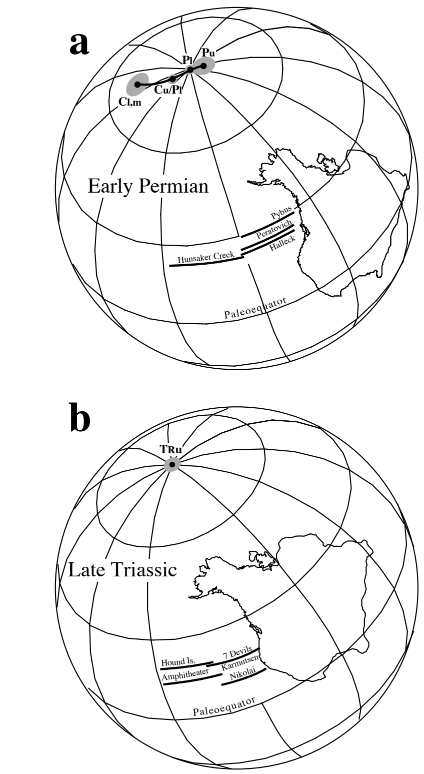
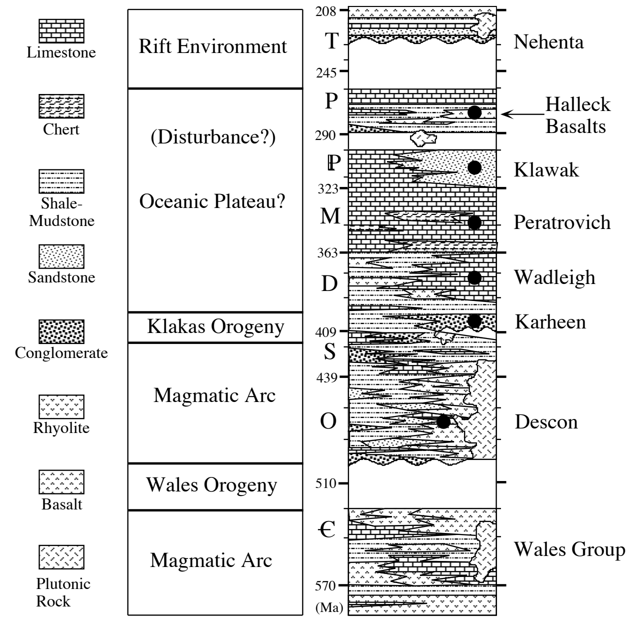


Figure 8. Paleolatitudes determined from (a) Lower Permian and (b) Upper Triassic strata of the Alexander-Wrangellia terrane. Orthographic projections use Early Permian (a) and Late Triassic (b) paleomagnetic reference poles for the axes of the paleogeographic grids (see Table 2 for details). Reference pole designations in (a): Cl, m—Early–Middle Carboniferous mean pole; Cu/Pl—Late Carboniferous–Early Permian mean pole; Pl—Early Permian mean pole; Pu—Late Permian mean pole (Van der Voo, 1993).

Butler et al., GSA Bull 1997

Third clue paleomag--often messed up relative to NAM



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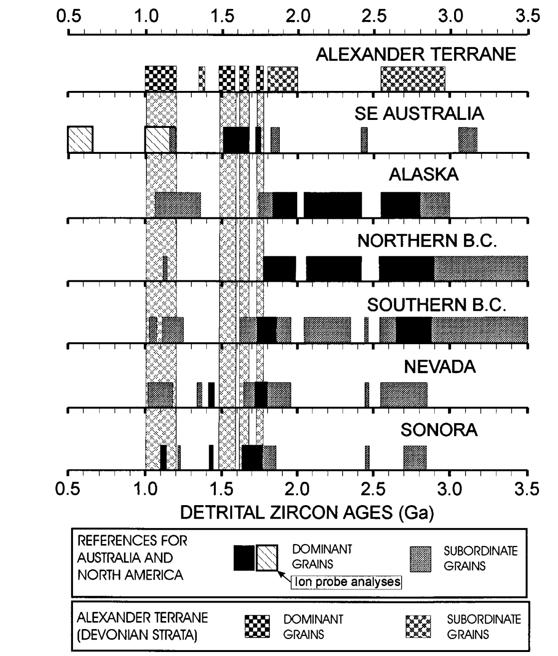
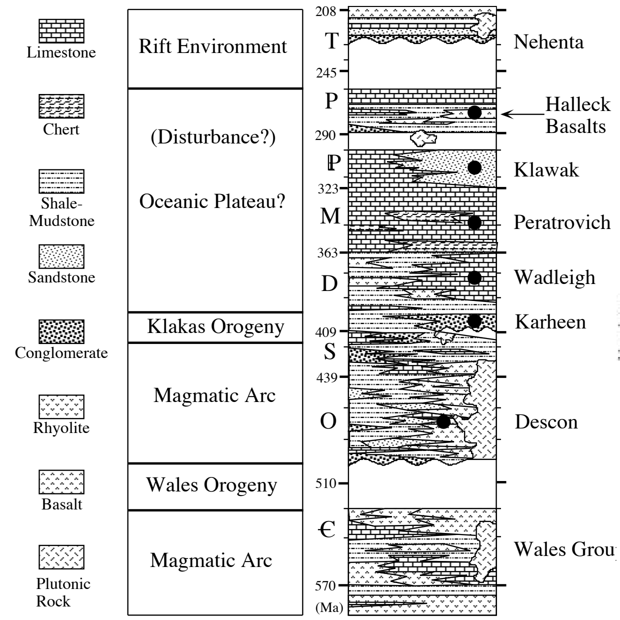


Figure 8. Comparison of Precambrian detrital zircons in the Alexander terrane, miogeoclinal strata of western North America, and eastern Australia. The miogeoclinal reference for western North America is from Gehrels et al. (1995). The Australian age ranges include isotope dilution analyses (from Table 3) and ion probe analyses (from Ireland, 1992; Ireland et al., 1994).

Butler et al., GSA Bull 1997

Gehrels et al., GSA Bull 1996

A more recent approach is our old friend detrital zircons. Here we see a lousy fit to NAM, and not great to Australia (other areas in Aus better)



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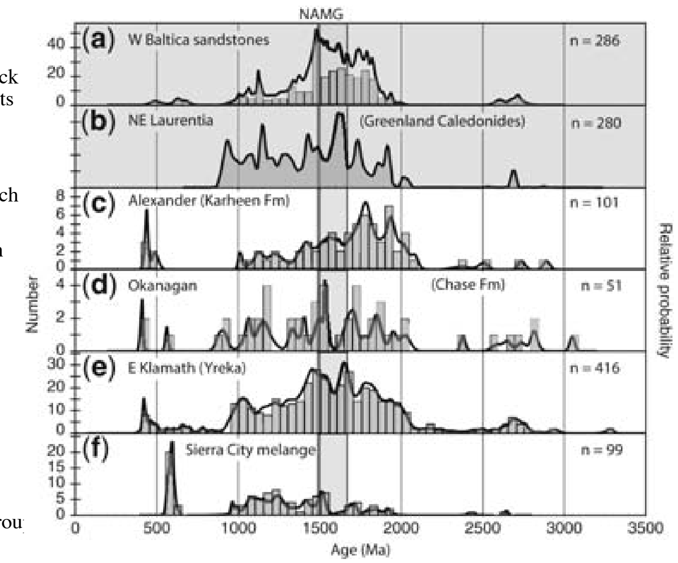
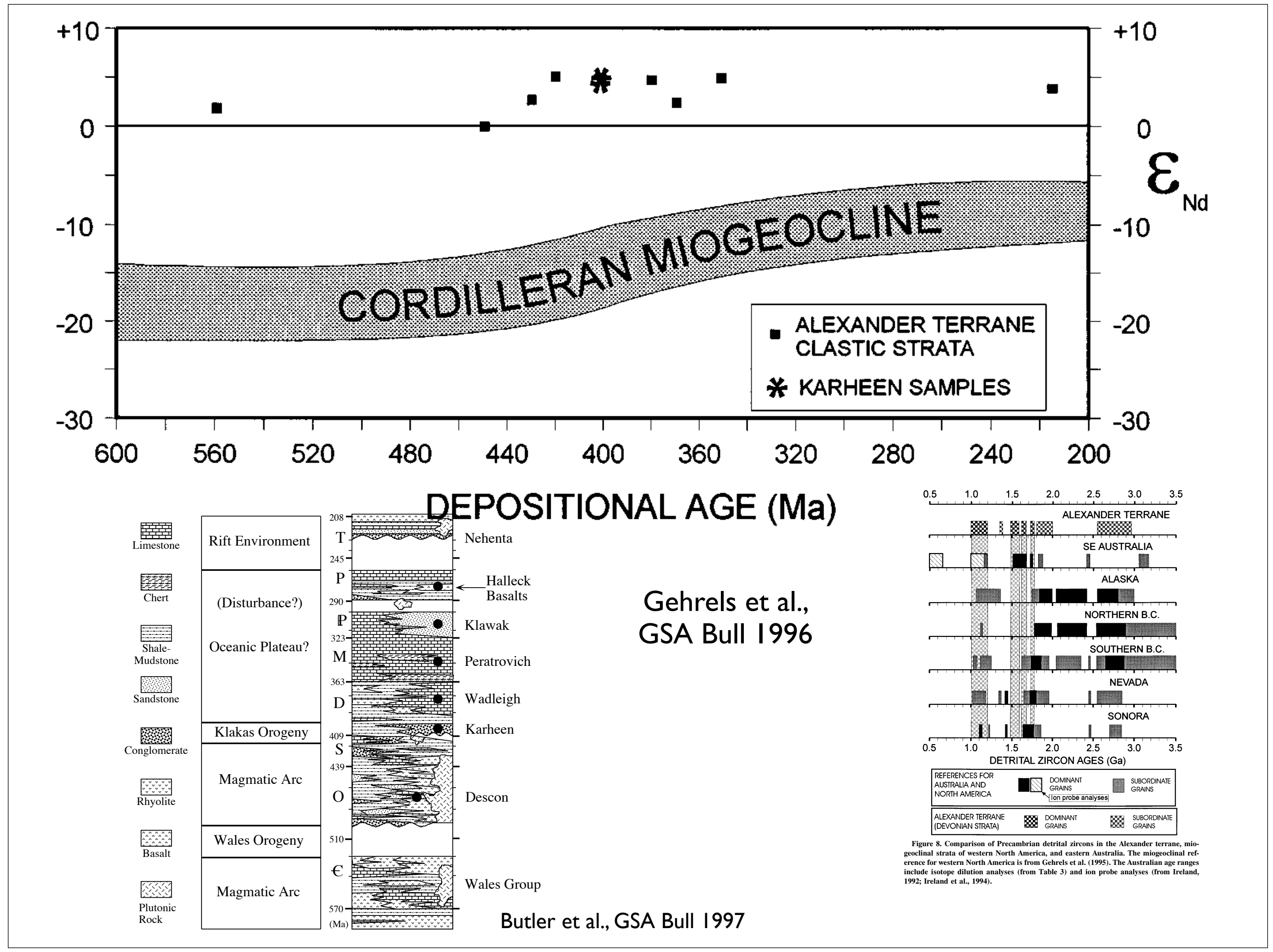


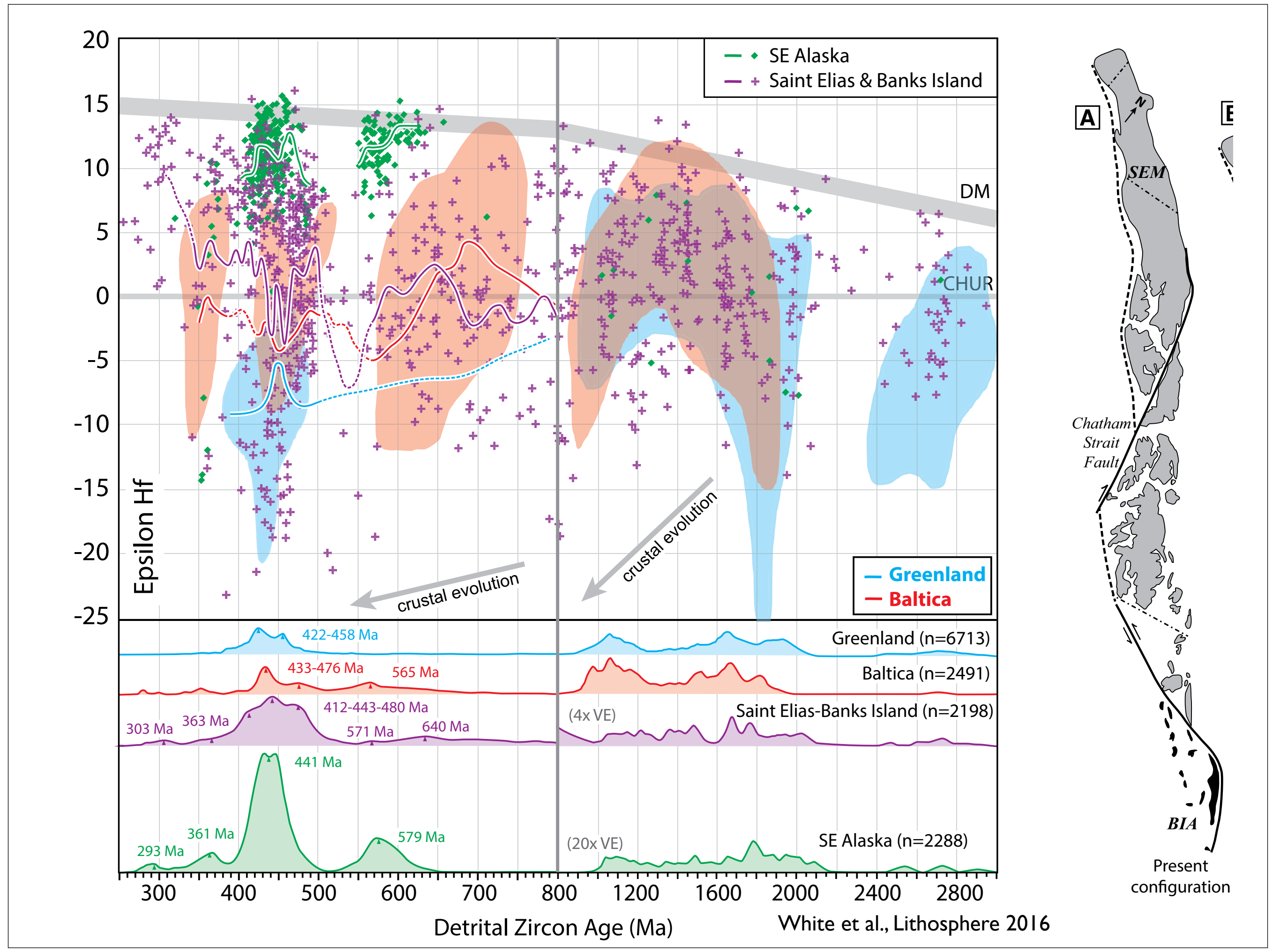
Colpron and Nelson, *Geol Soc Lond Spec Pub 318*, 2009

Butler et al., GSA Bull 1997

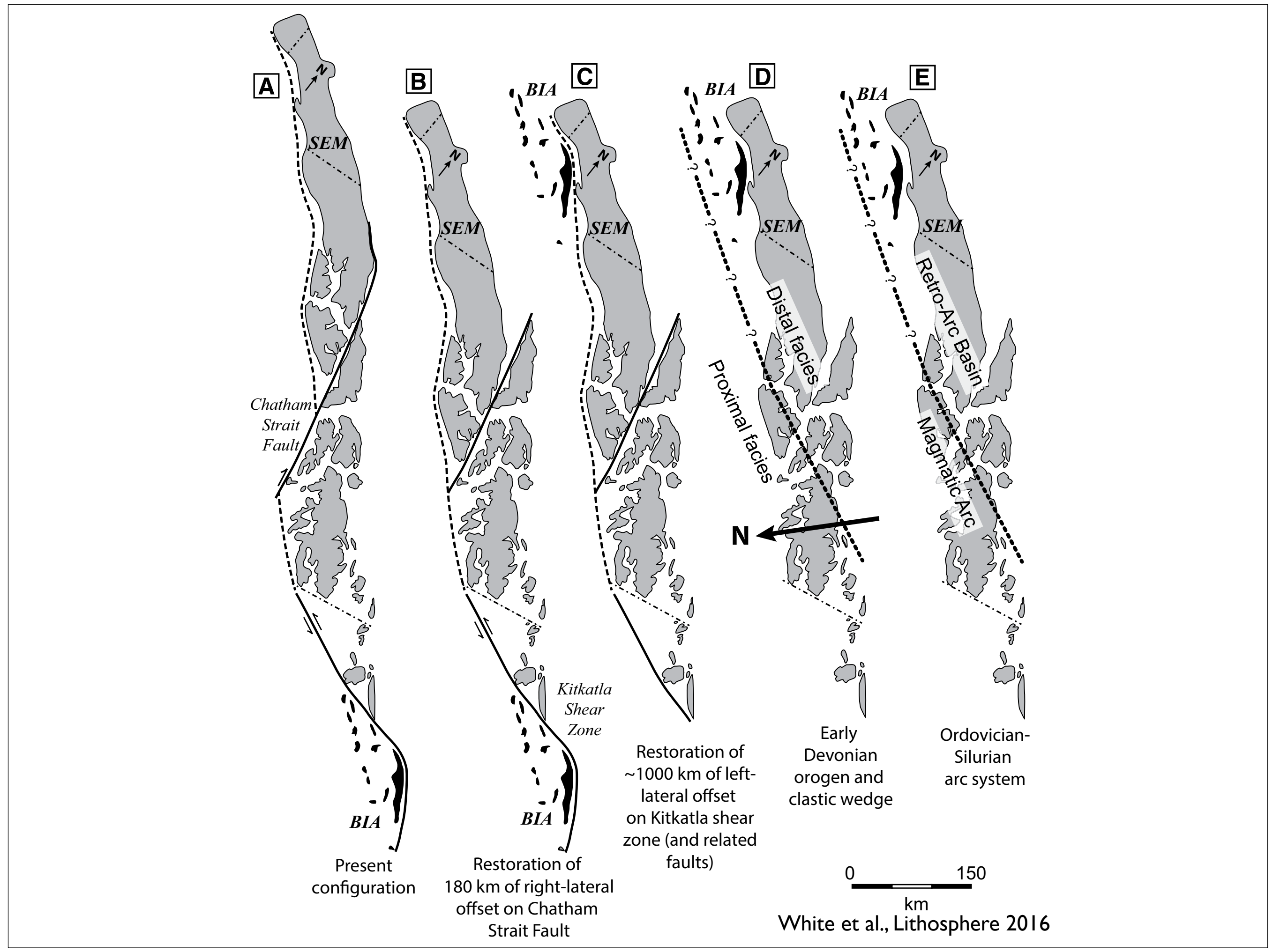
Newer work has focused on Baltica and the northern Calidonides.

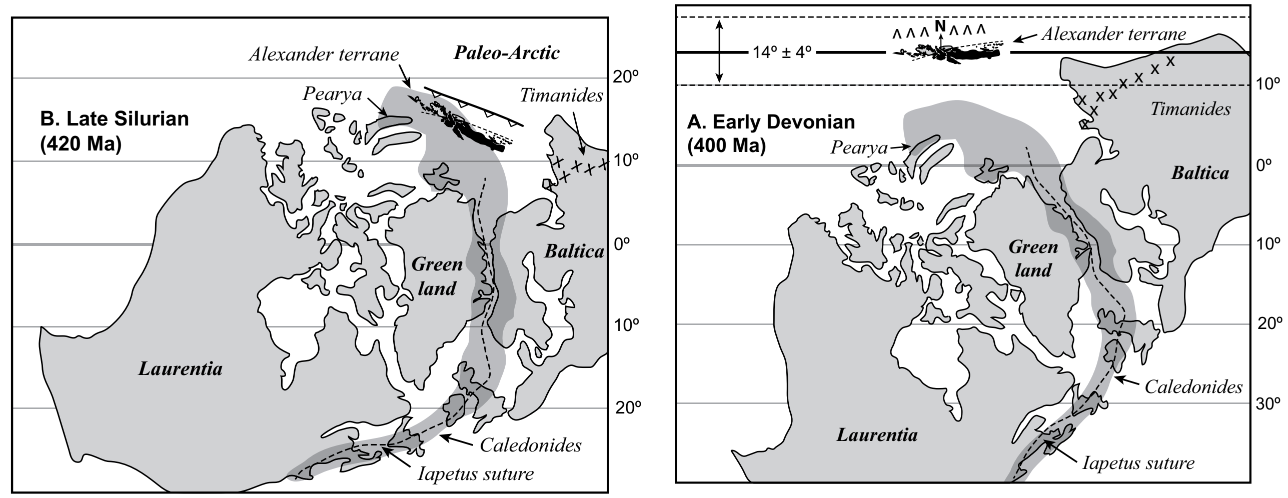


We can also look at other isotopic systems. So here measurements on detrital zircons of E-Nd show that stuff in the Karheen allocthon still don’t look North American [which is actually an interesting problem beyond our scope]



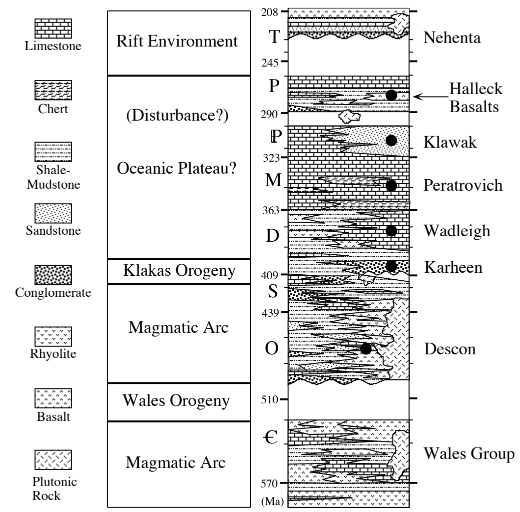
Actually quite a range in Alexander Terrane—some very immature stuff in SE Alaska


A
B
C
D
E
BIA
SEM
N
Chatham
Strait
Fault
Kitkatla
Shear
Zone
Distal facies
Proximal facies
Retro-Arc Basin
Magmatic Arc
Present
configuration
Restoration of
180 km of right-lateral
offset on Chatham
Strait Fault
Restoration of
~1000 km of left-
lateral offset
on Kitkatla shear
zone (and related
faults)
Early
Devonian
orogen and
clastic wedge
Ordovician-
Silurian
arc system
0
150
km
White et al., Lithosphere 2016



White et al., Lithosphere 2016

So early part of history of Alexander Terrane seems to be coming into focus…



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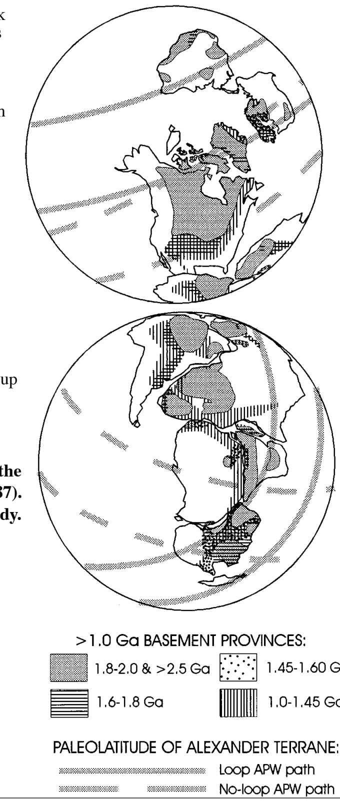
Butler et al., GSA Bull 1997



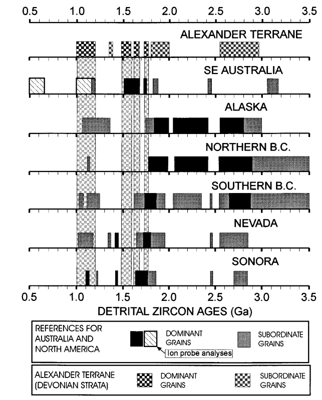


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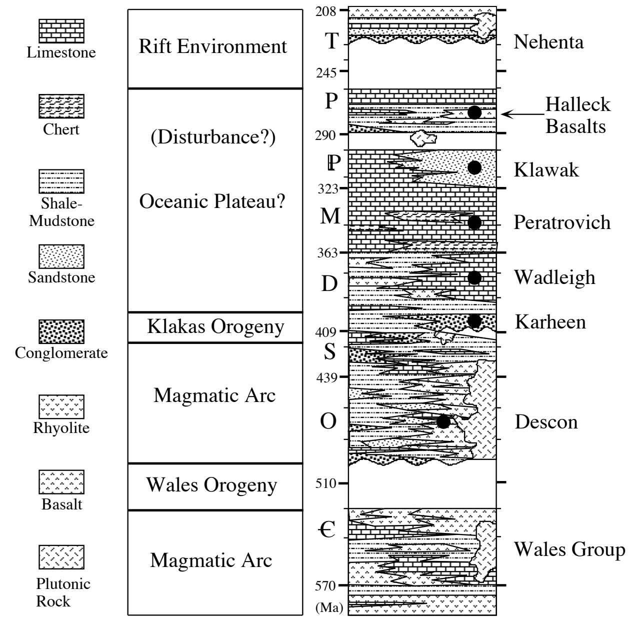
Figure 7. Paleogeographic map showing the distribution of continents during Early Devonian time. Gray bands on the map are the 14° ± 5° paleolatitudes determined from the Karheen Formation (Bazard et al., 1995), assuming both loop-present and no-loop apparent polar wander (APW) paths for North America and Gondwana (Van der Voo, 1990, 1993). Precambrian rocks are shown in the age groupings represented by detrital zircons in the Karheen Formation (compiled from Hoffman, 1989; Goodwin, 1991).

Gehrels et al., GSA Bull 1996

Does this all agree with the paleomag (which we will talk more about next time)?



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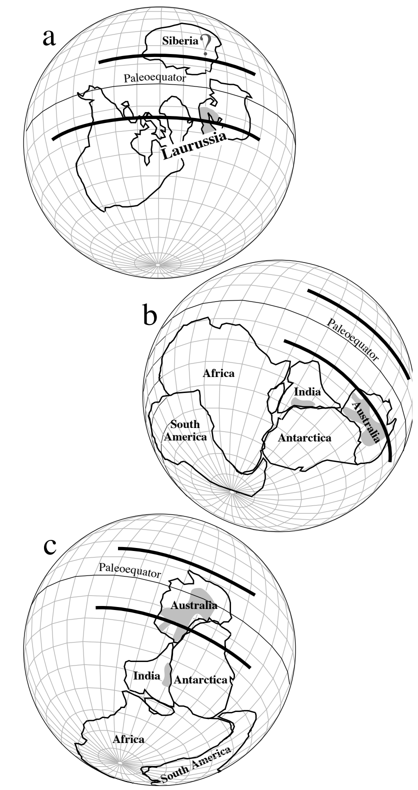
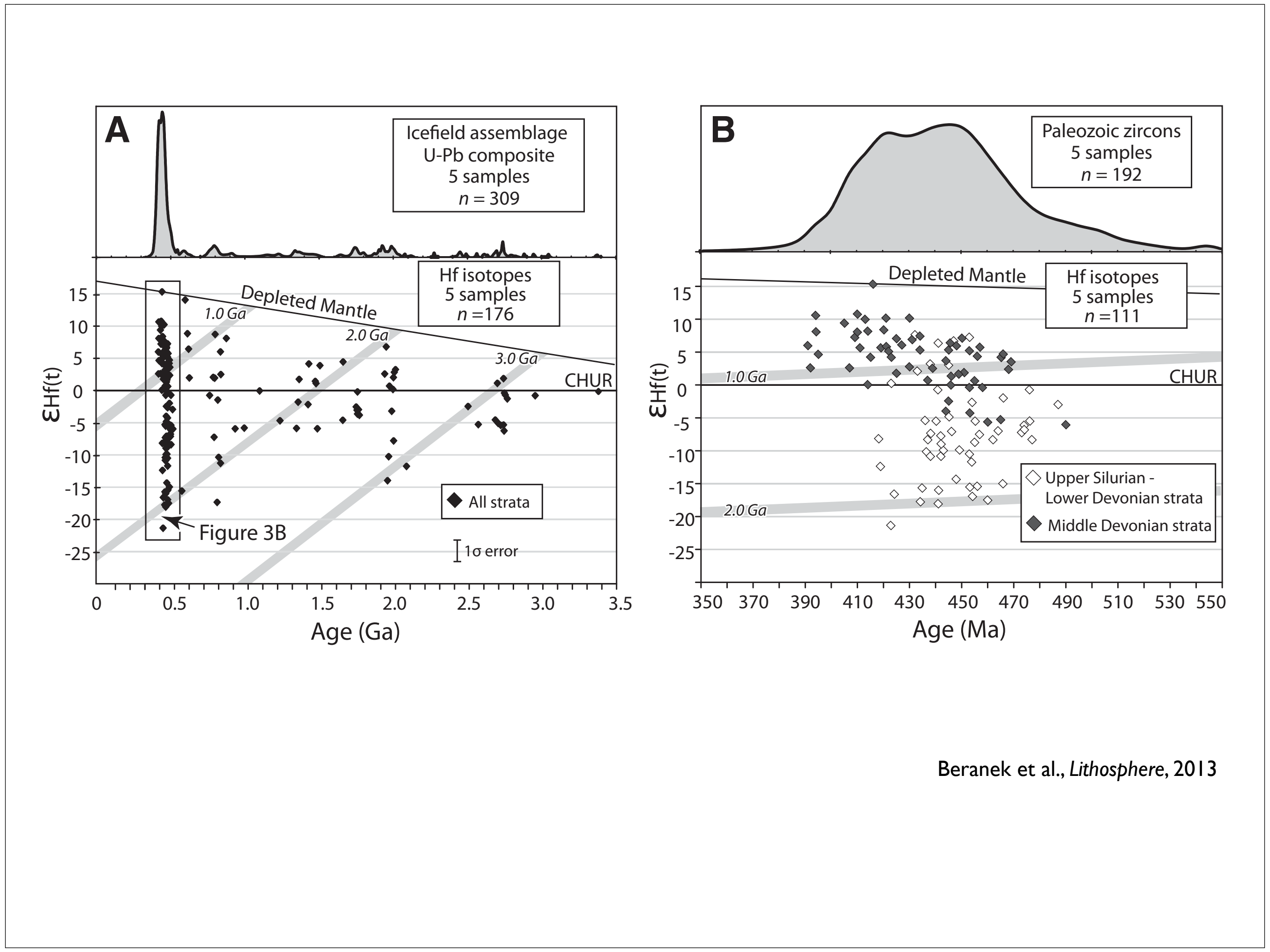


Figure 9. Late Silurian–Early Devonian world paleogeographies. (a) Paleogeography of the northern continents using Late Silurian–Early Devonian mean paleomagnetic pole for North America as axis of paleogeographic grid. (b) Paleogeography for Gondwana in Late Silurian–Early Devonian time using paleomagnetic pole from the Aïr complex as axis of paleogeographic grid. (c) Alternative Late Silurian–Early Devonian paleogeography for Gondwana using an interpolated Late Silurian–Early Devonian pole as axis of paleogeographic grid. Dark bands show 14° paleolatitudes determined for the Karheen Formation. Dark stippled areas are parts of cratons containing rocks within age windows of 1.6–1.8 Ga and 1.45–1.6 Ga. Question mark is placed in Siberia because of uncertain paleogeographic location in Late Silurian–Early Devonian time. See text for discussion.

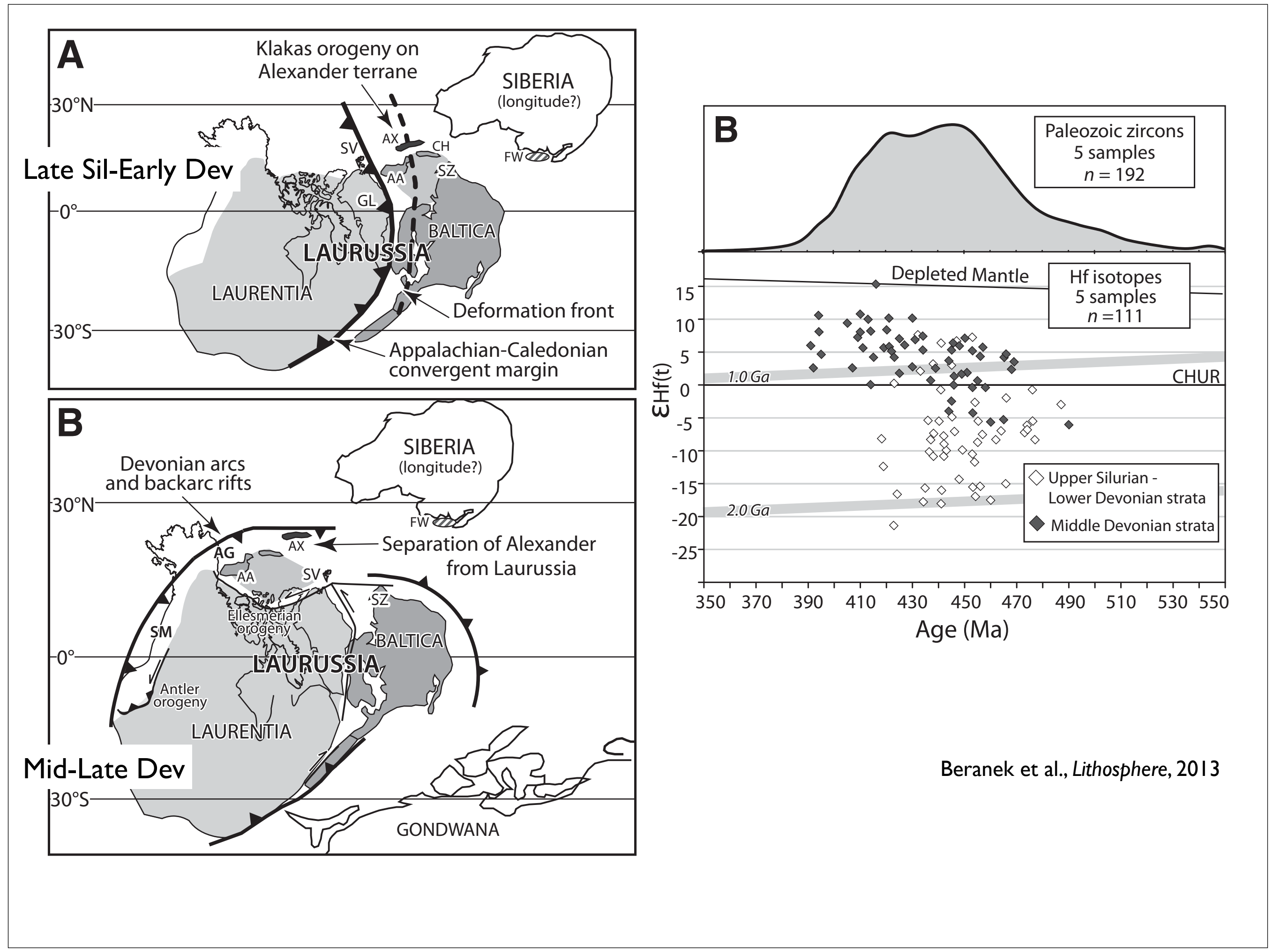
Butler et al., GSA Bull 1997

Yes, it does.



Beranek et al., *Lithosphere*, 2013

Can start to see when departed. Argue that the big change in epsilon Hf from lower Dev to Mid Dev is departure from scandinavian margin and creation of arc--think this agrees well with Scandinavia [unfortunately this pub lacks a good comparison figure]. Ice field is in St. Elias area.



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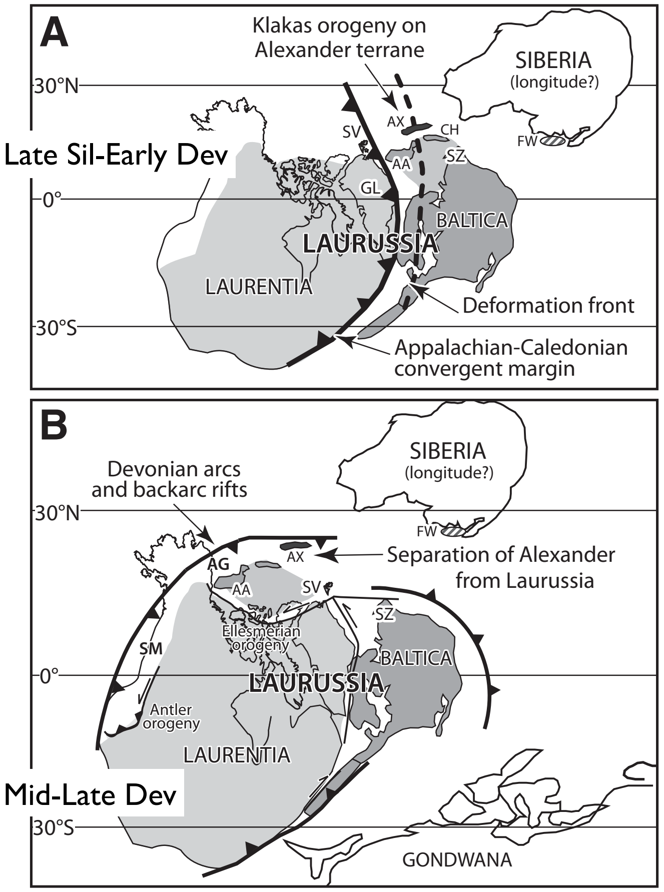
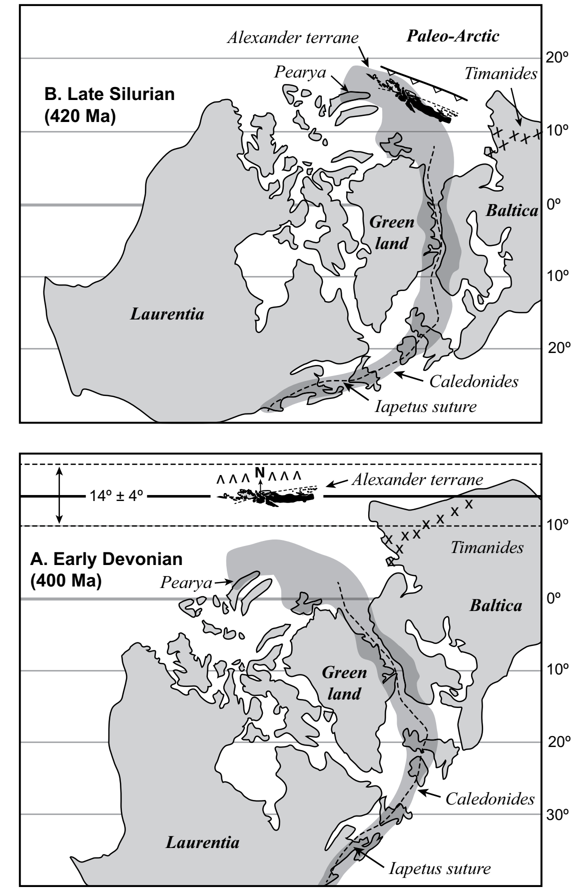


Beranek et al., *Lithosphere*, 2013



White et al., Lithosphere 2016

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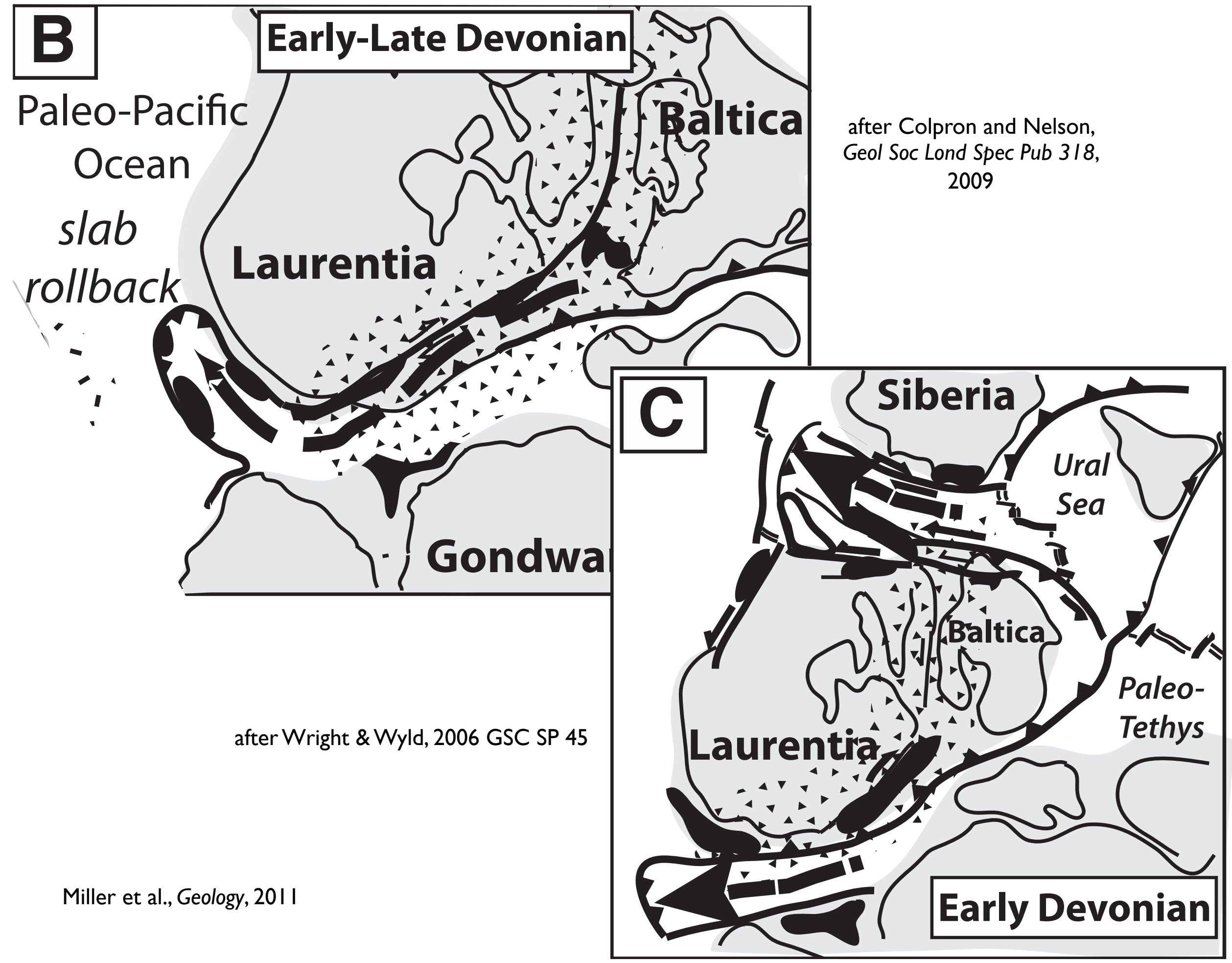
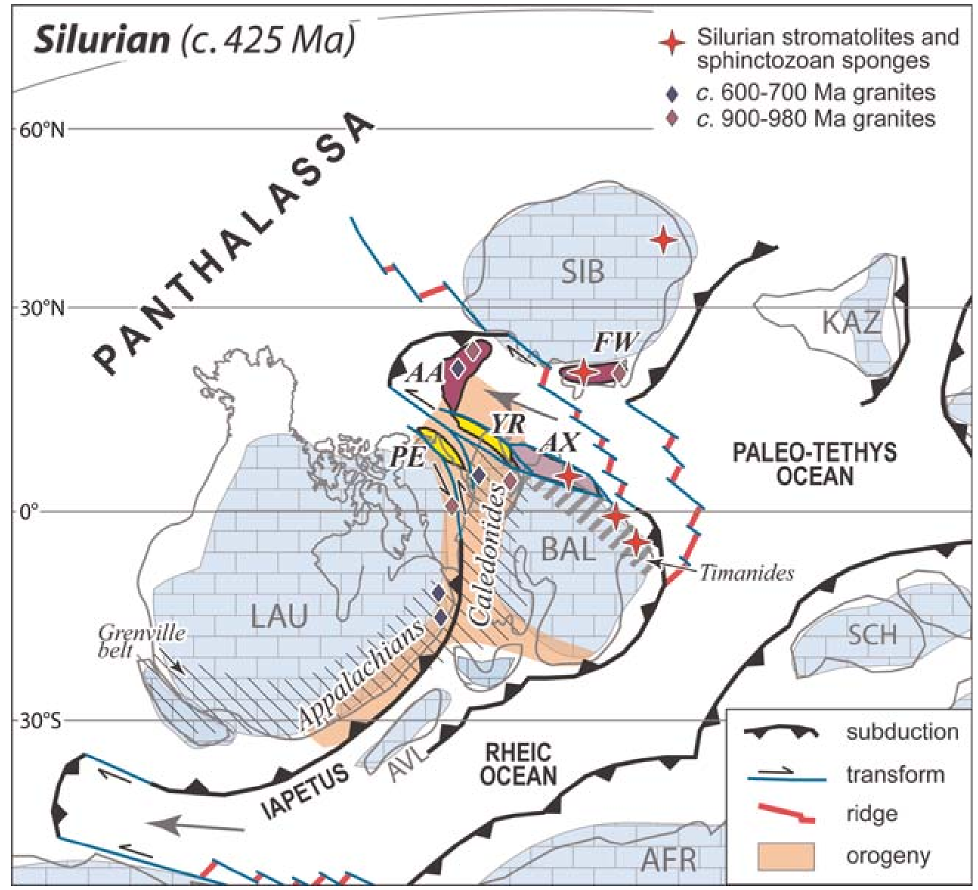


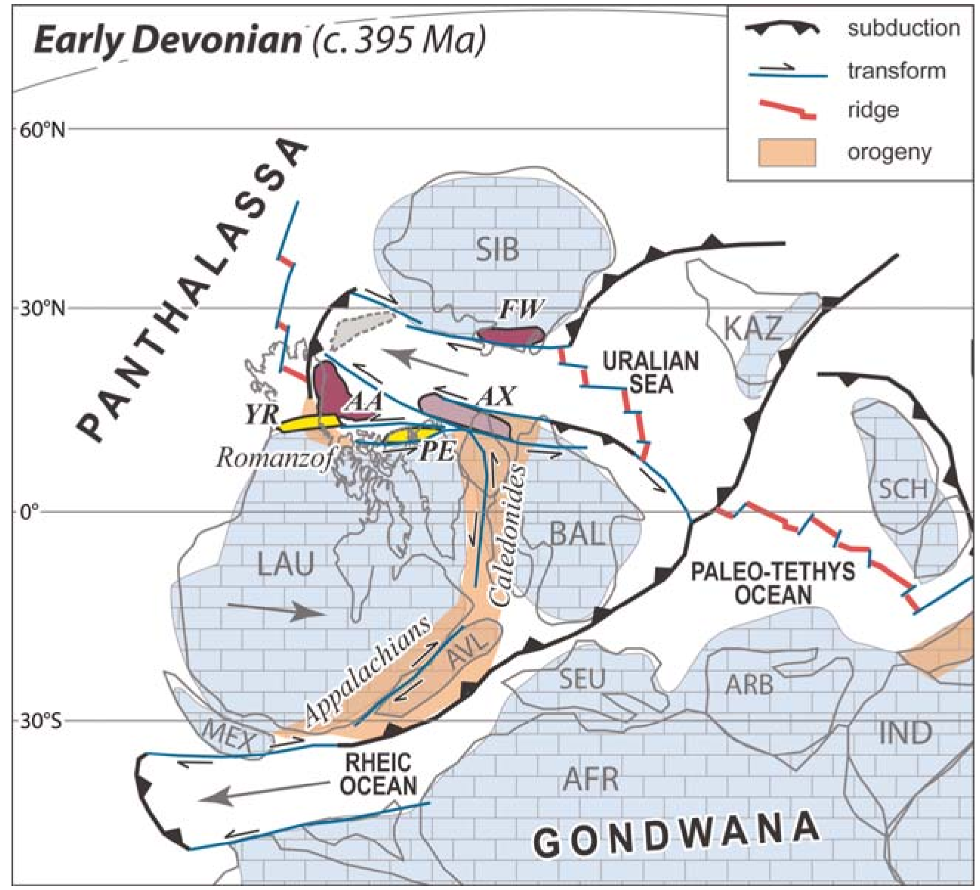
after Colpron and Nelson, *Geol Soc Lond Spec Pub 318*, 2009

after Wright & Wyld, 2006 GSC SP 45

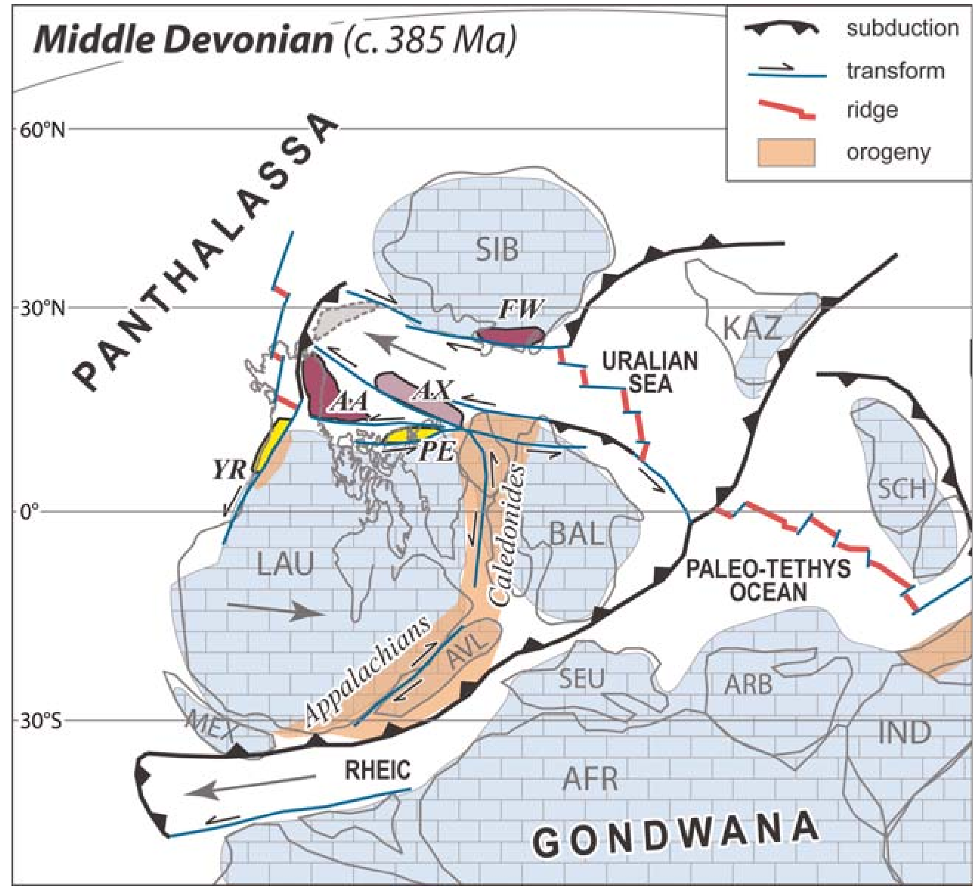
Miller et al., *Geology*, 2011



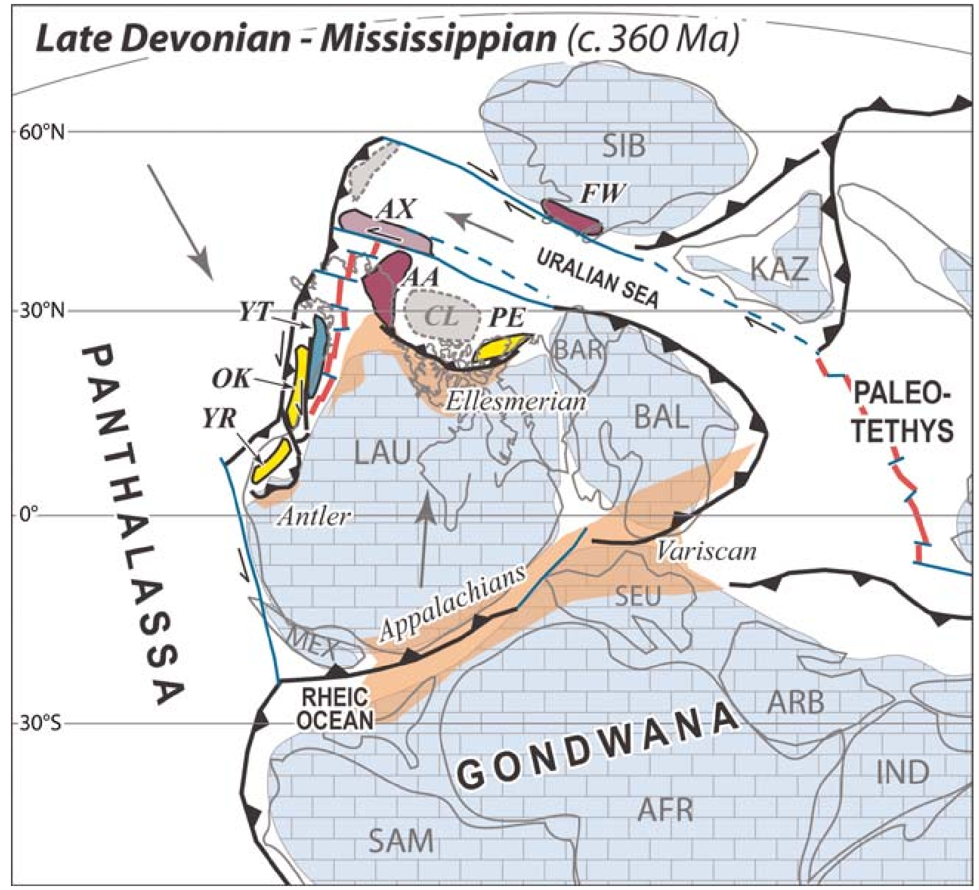
Colpron and Nelson, *Geol Soc Lond Spec Pub 318*, 2009



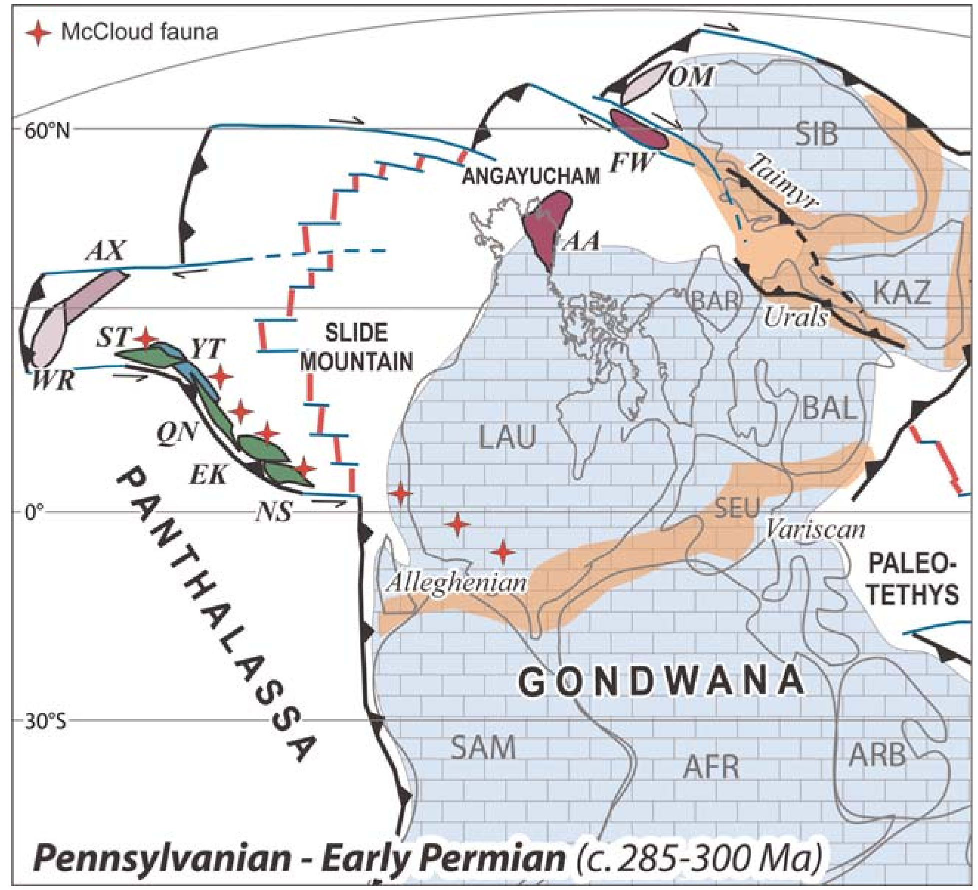
Colpron and Nelson, *Geol Soc Lond Spec Pub 318*, 2009



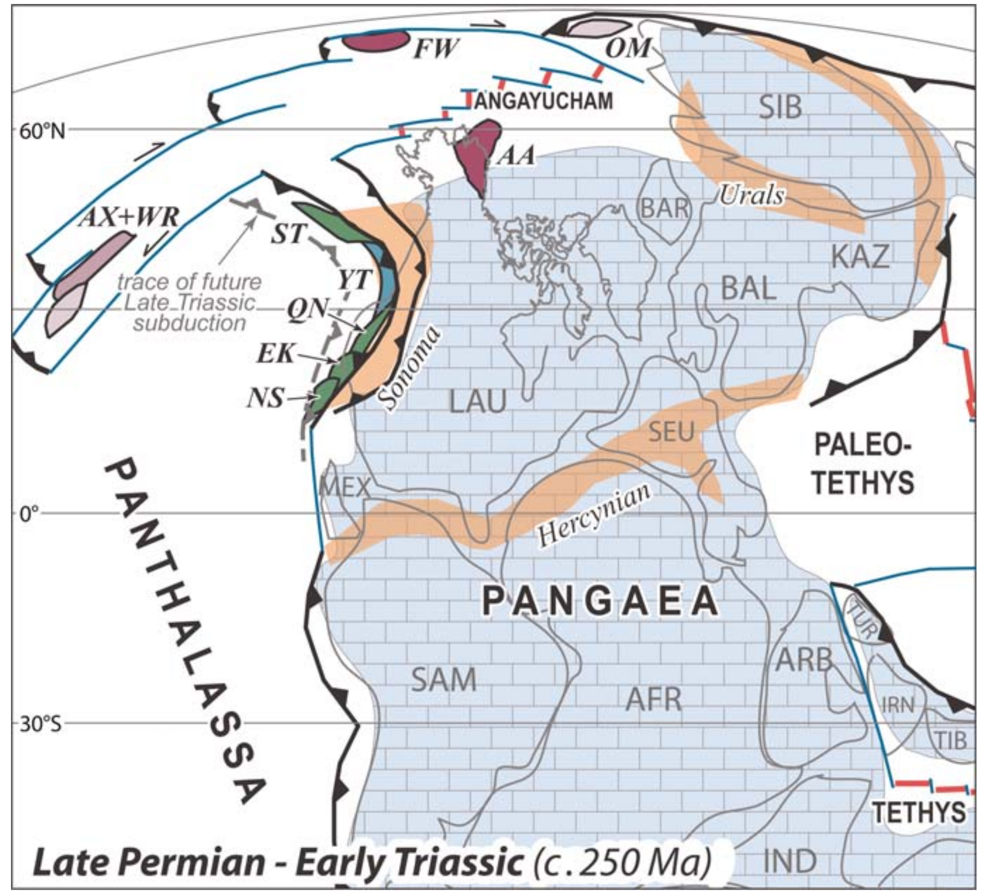
Colpron and Nelson, *Geol Soc Lond Spec Pub 318*, 2009



Colpron and Nelson, *Geol Soc Lond Spec Pub 318*, 2009



Colpron and Nelson, *Geol Soc Lond Spec Pub 318*, 2009



Colpron and Nelson, *Geol Soc Lond Spec Pub 318*, 2009

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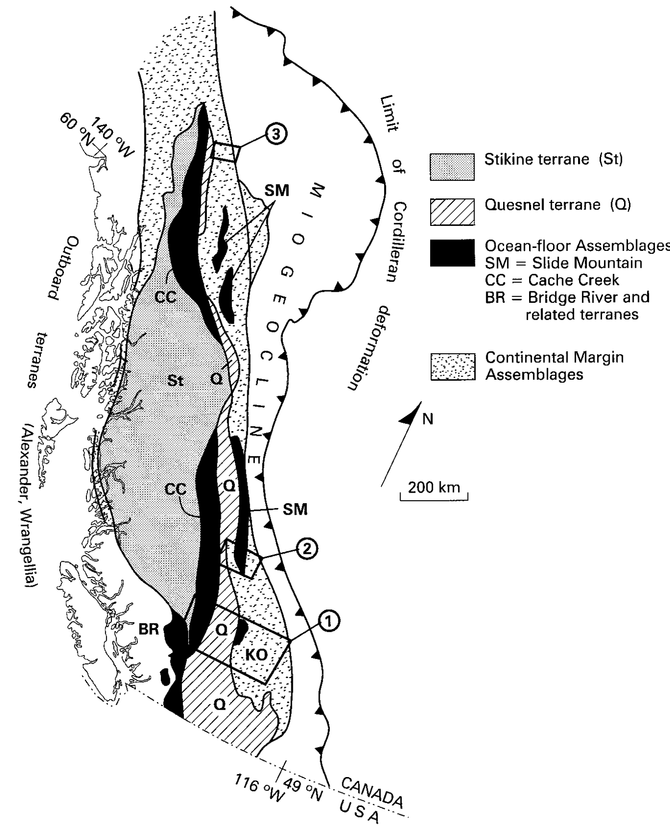


Patchett and Gehrels, J. Geol. 1998

OK< now where were things?

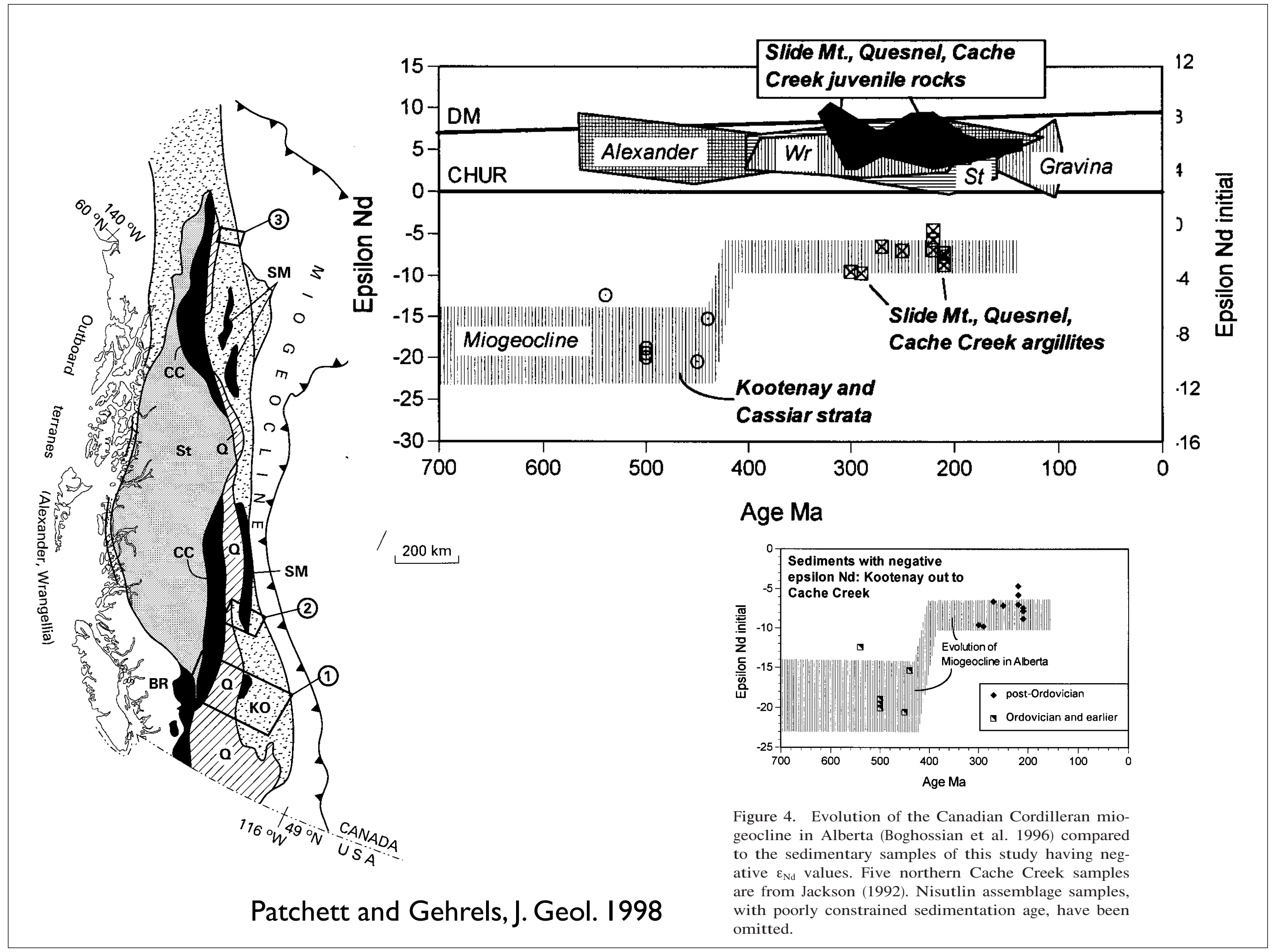
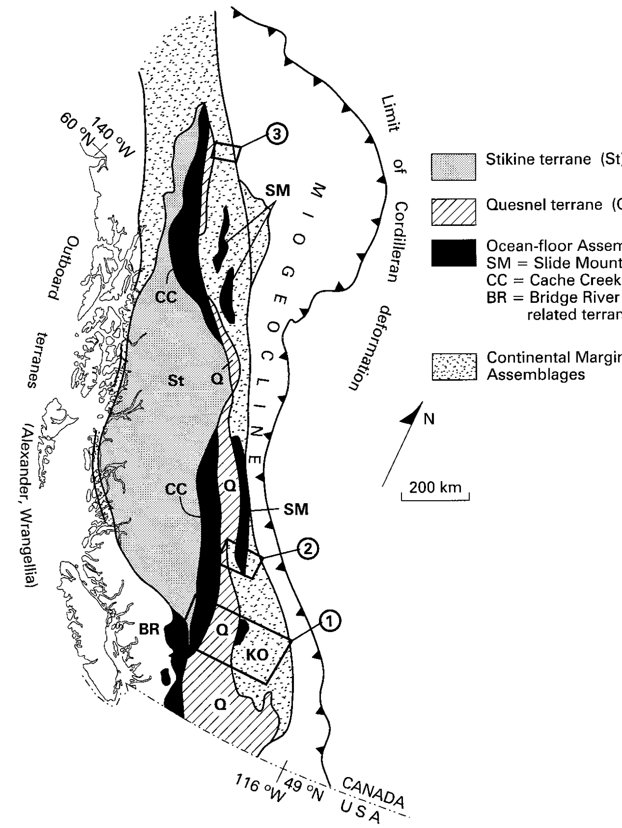
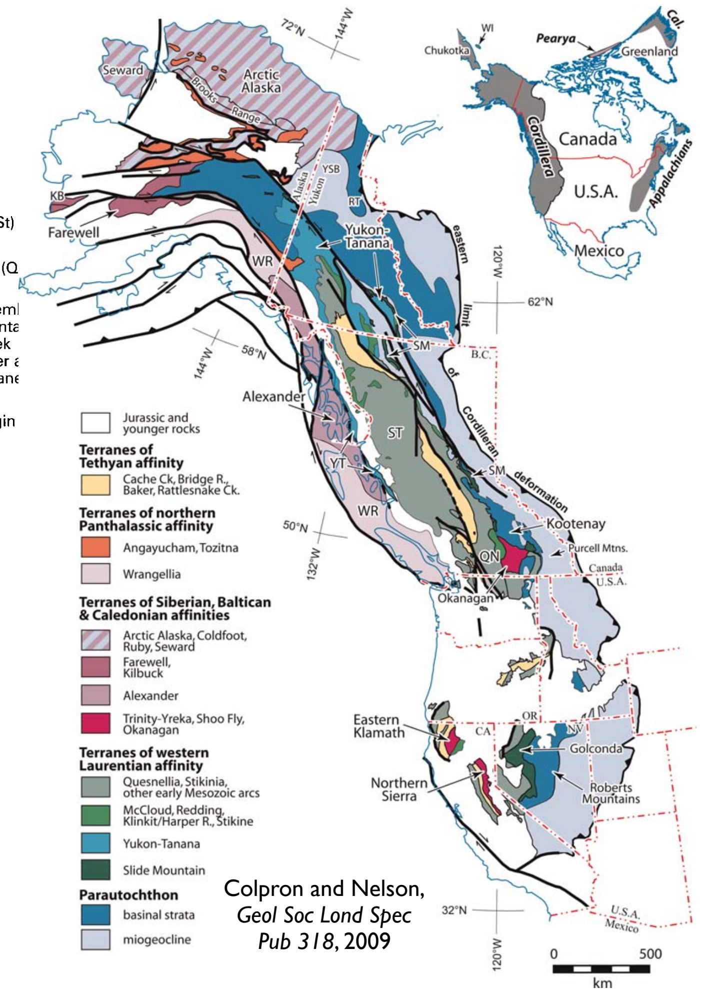


Figure 4. Evolution of the Canadian Cordilleran miogeocline in Alberta (Boghossian et al. 1996) compared to the sedimentary samples of this study having negative ε_{Nd} values. Five northern Cache Creek samples are from Jackson (1992). Nisutlin assemblage samples, with poorly constrained sedimentation age, have been omitted.

One clue is stuff separating the really exotic from the not-so-exotic. Black terranes are juvenile oceanic terranes. In contrast, stuff to east shows signs of looking like NAM



Patchett and Gehrels, J. Geol. 1998



Colpron and Nelson, *Geol Soc Lond Spec Pub 318*, 2009

Most terrane maps focus on Canada; map at right extends this into US

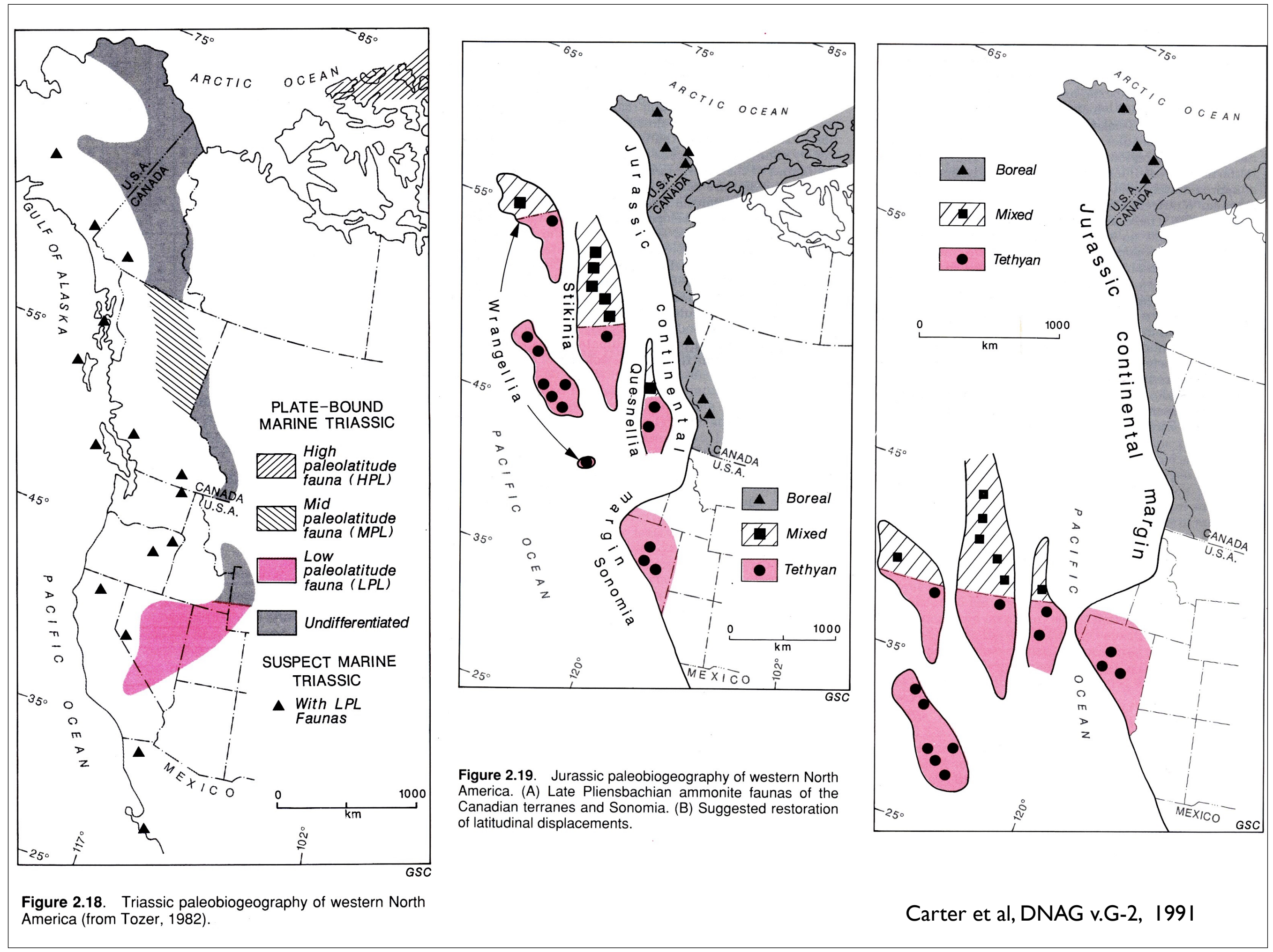
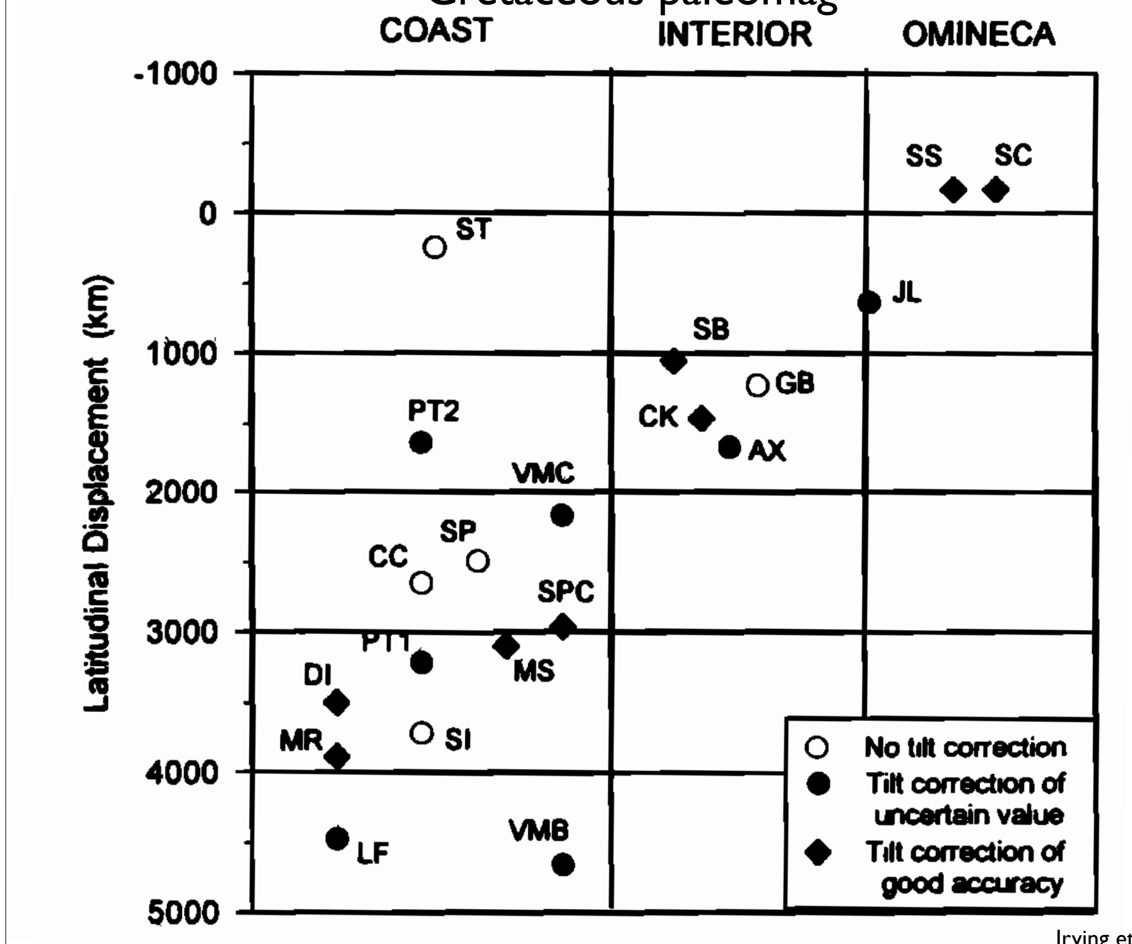


Figure 2.18. Triassic paleobiogeography of western North America (from Tozer, 1982).

Figure 2.19. Jurassic paleobiogeography of western North America. (A) Late Pliensbachian ammonite faunas of the Canadian terranes and Sonomia. (B) Suggested restoration of latitudinal displacements.

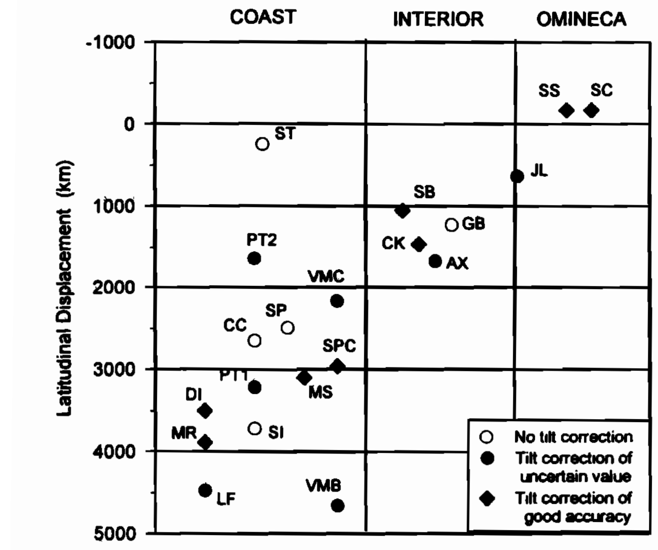
Fauna work here too...

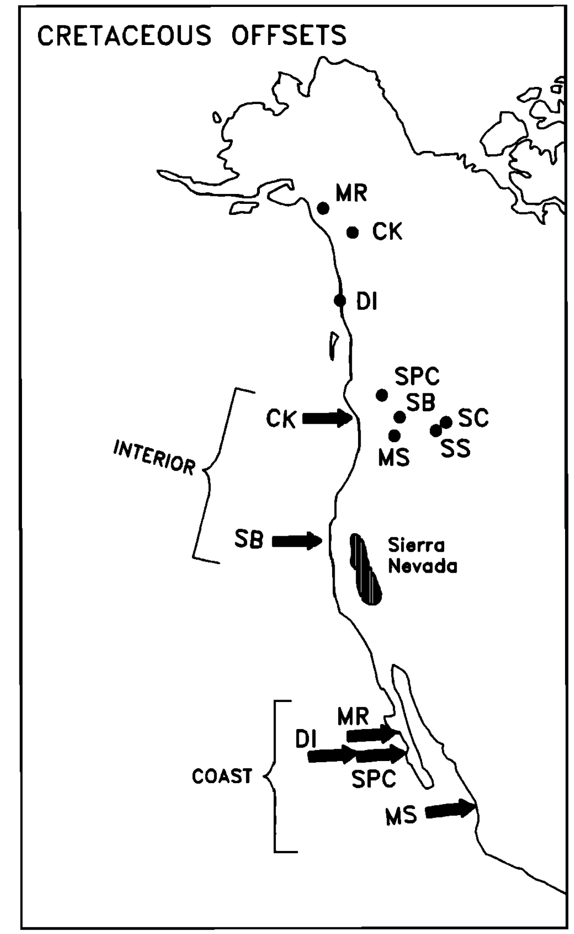
Cretaceous paleomag



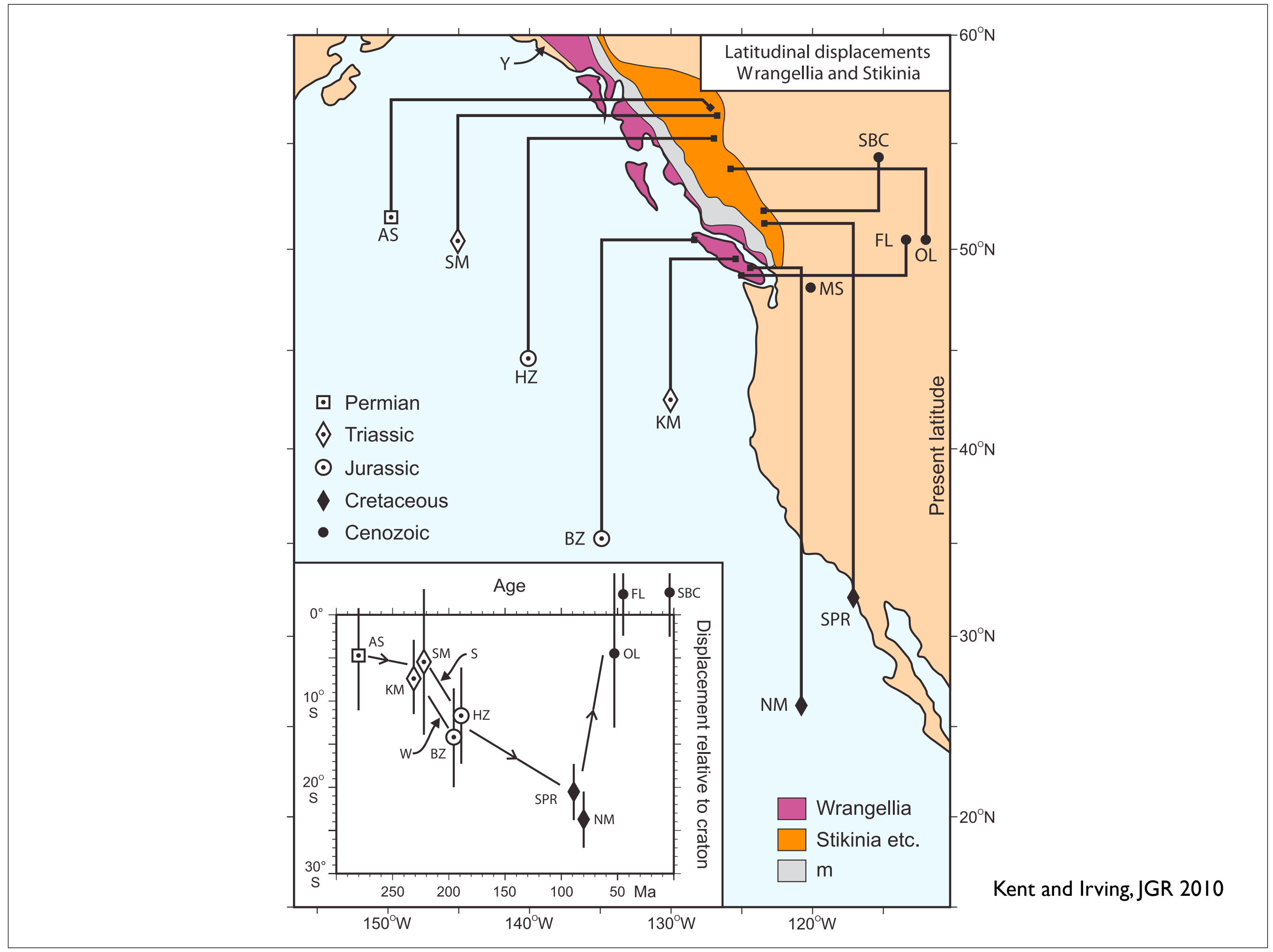
Irving et al., JGR, 1996

Paleomag often used. Here is K from a compilation a few years back

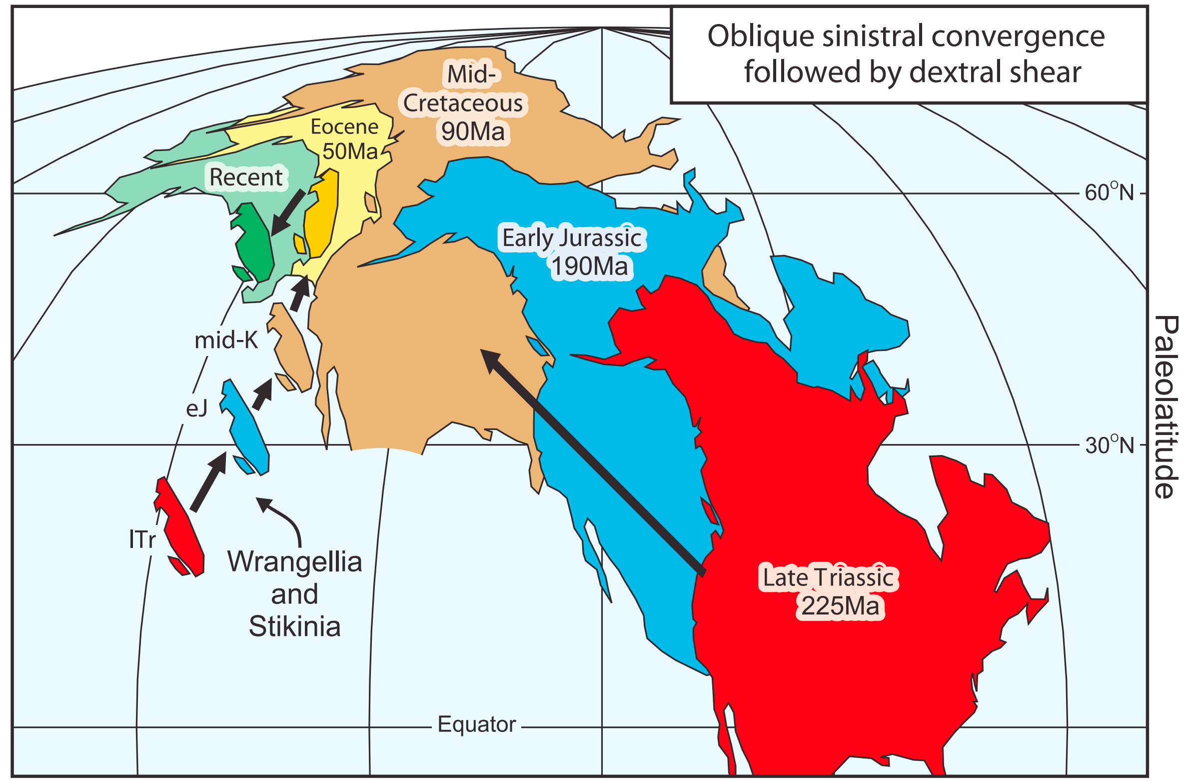




Irving et al., JGR, 1996

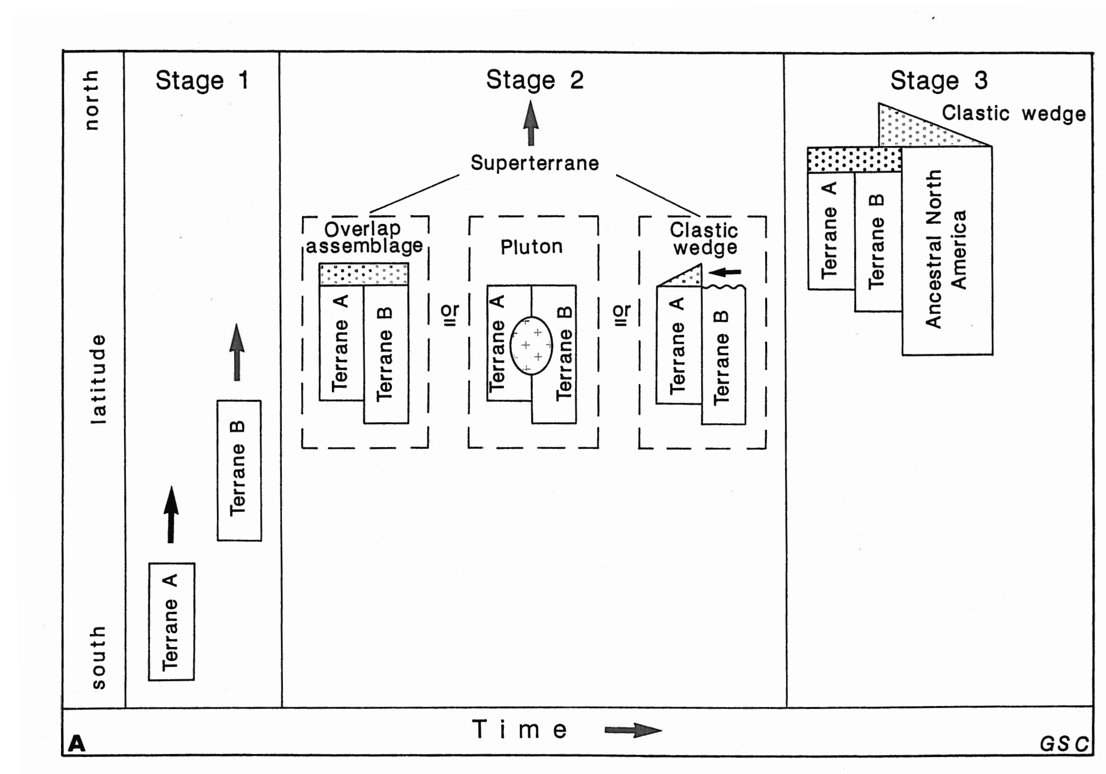


We can in theory combine pmag and compare with NAM to see N-S motions….(this is based on a strongly revised NAM paleolatitude analysis)



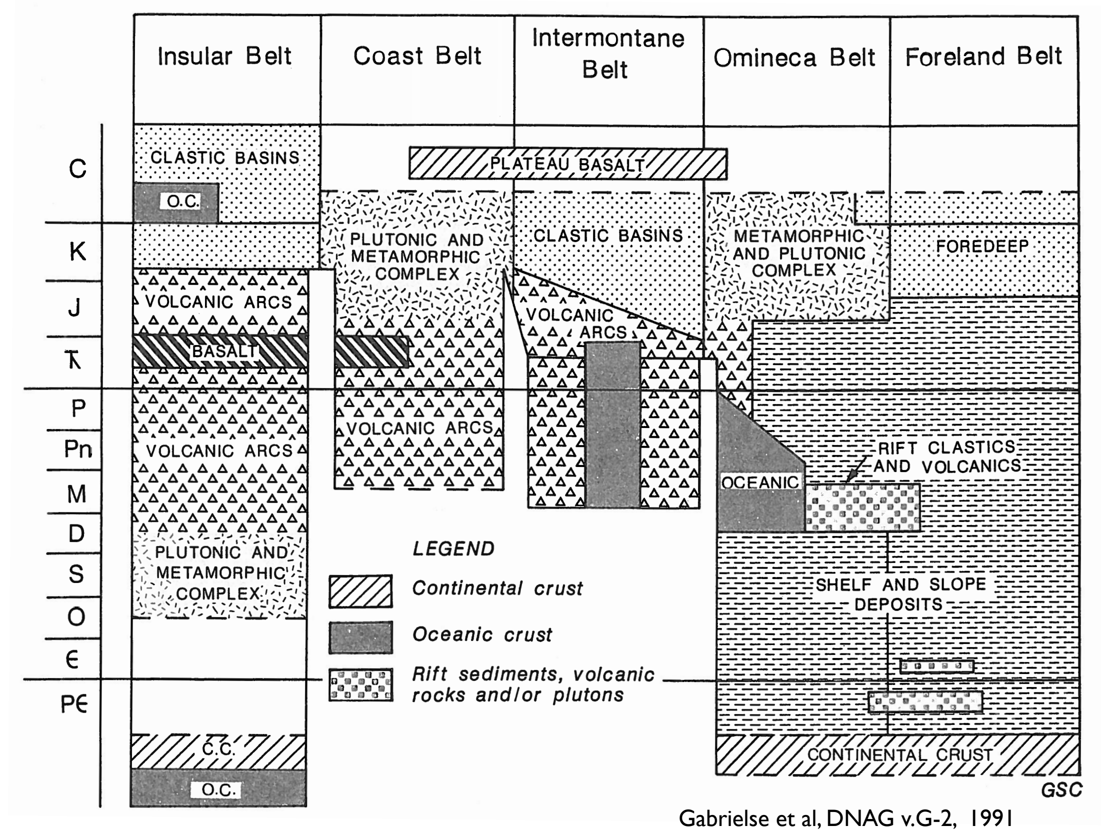
Kent and Irving, JGR 2010

Of course longitude is unclear...

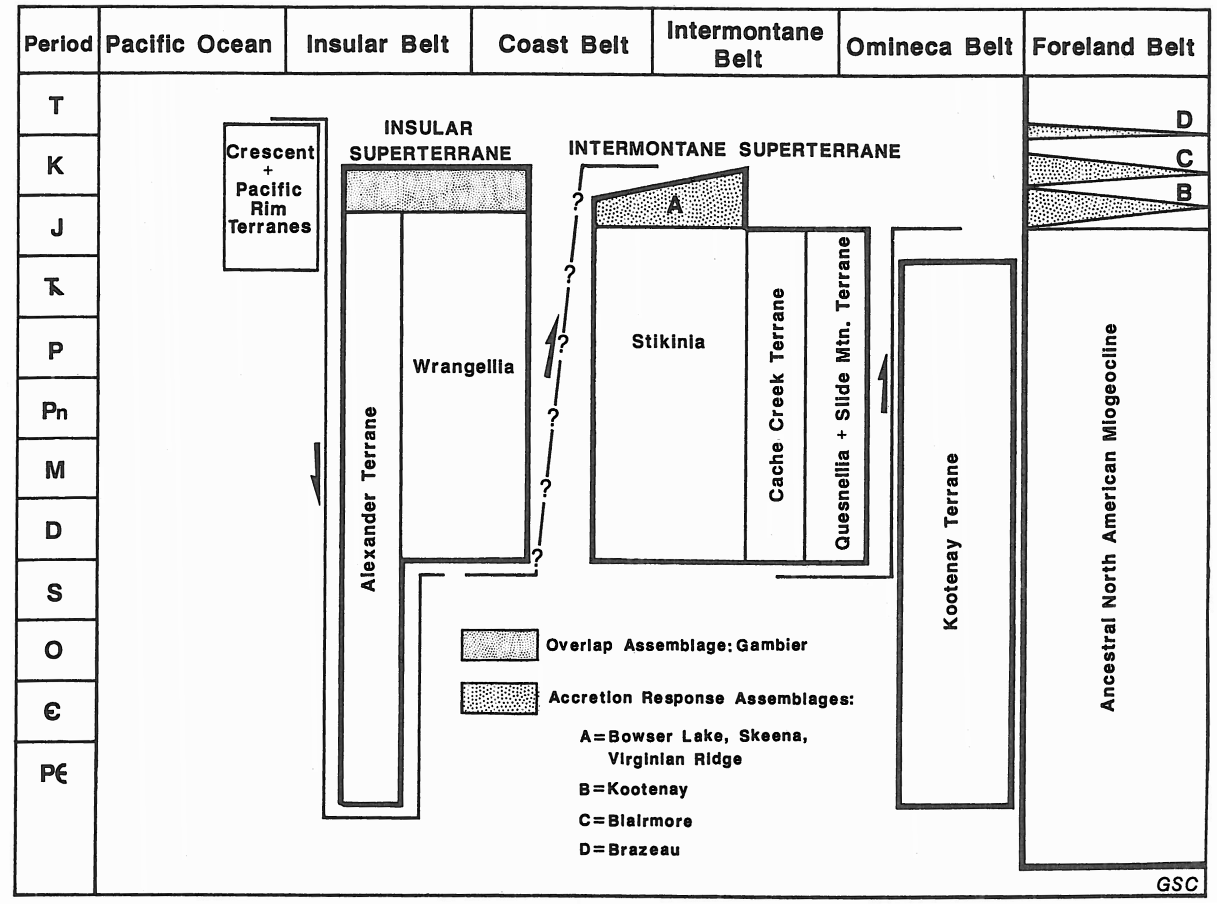


Gabrielse et al, DNAG v.G-2, 1991

OK, when did stuff arrive? Here is where controversy arises. Overlap or stitching plutons usually what is used...

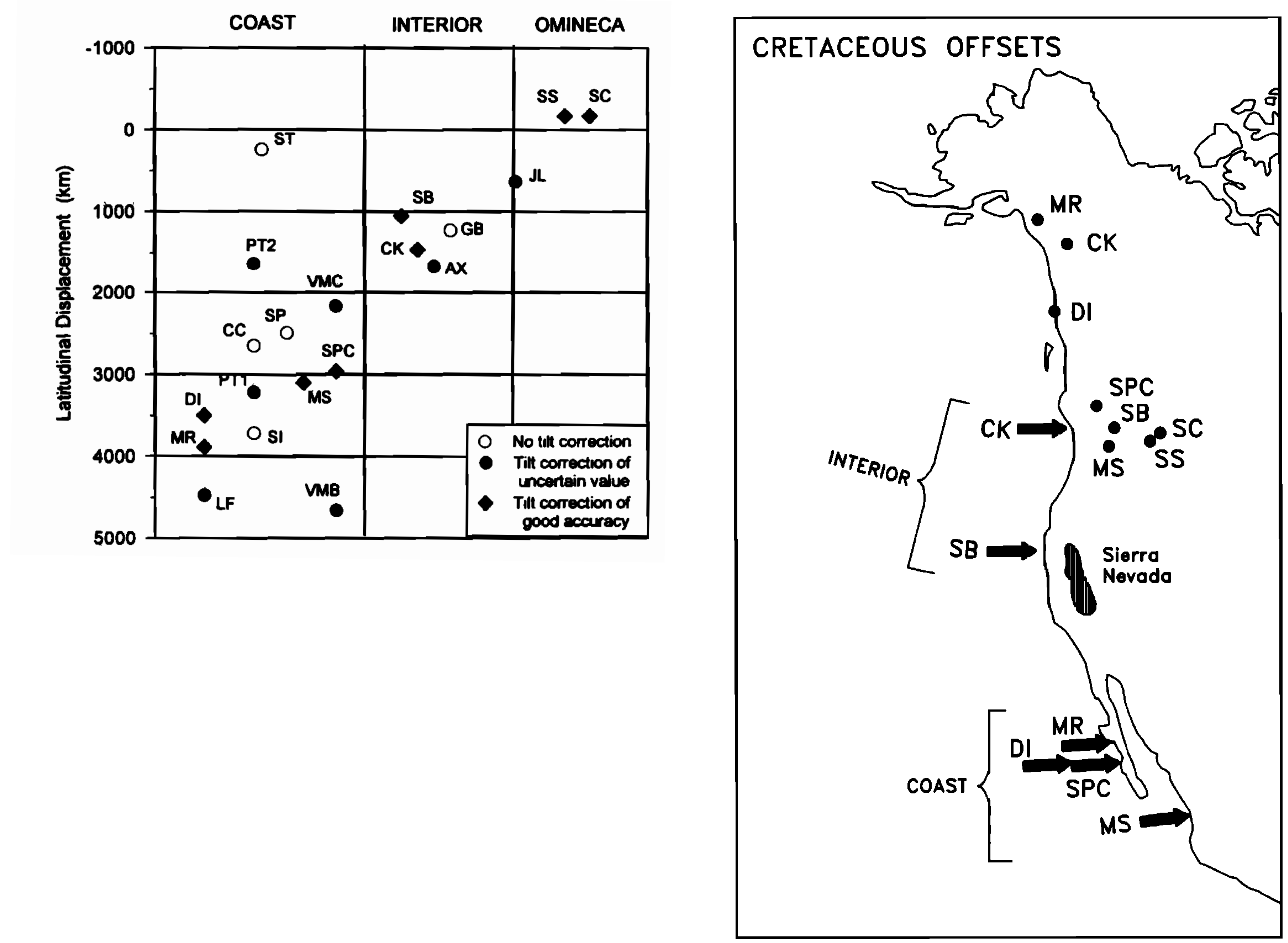


By geologic measures, might think Intermontane terrane docked in J and Insular (Alex + Wrang) in early K.



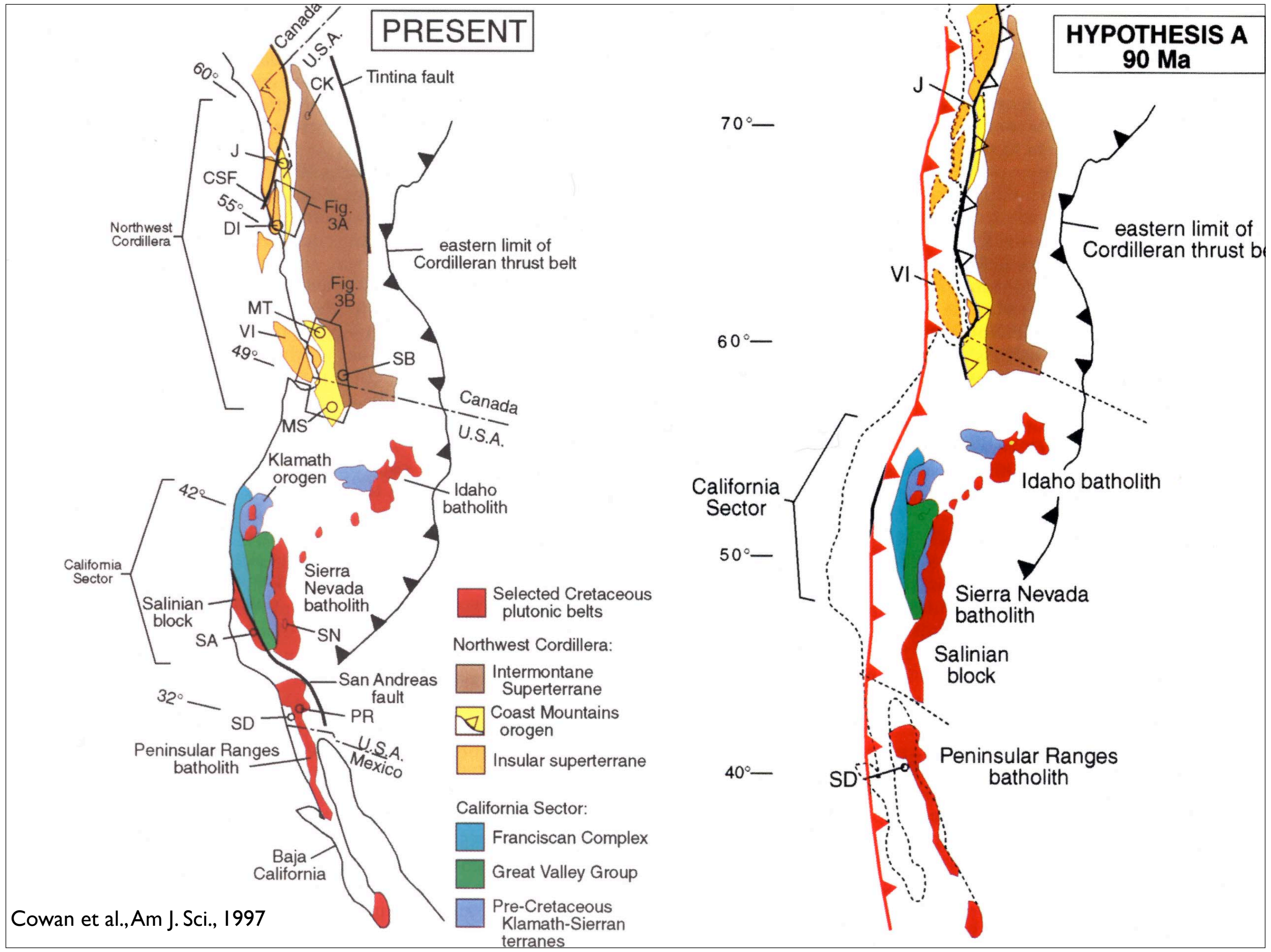
Gabrielse et al, DNAG v.G-2, 1991

...and this is the cartoon interpretation.

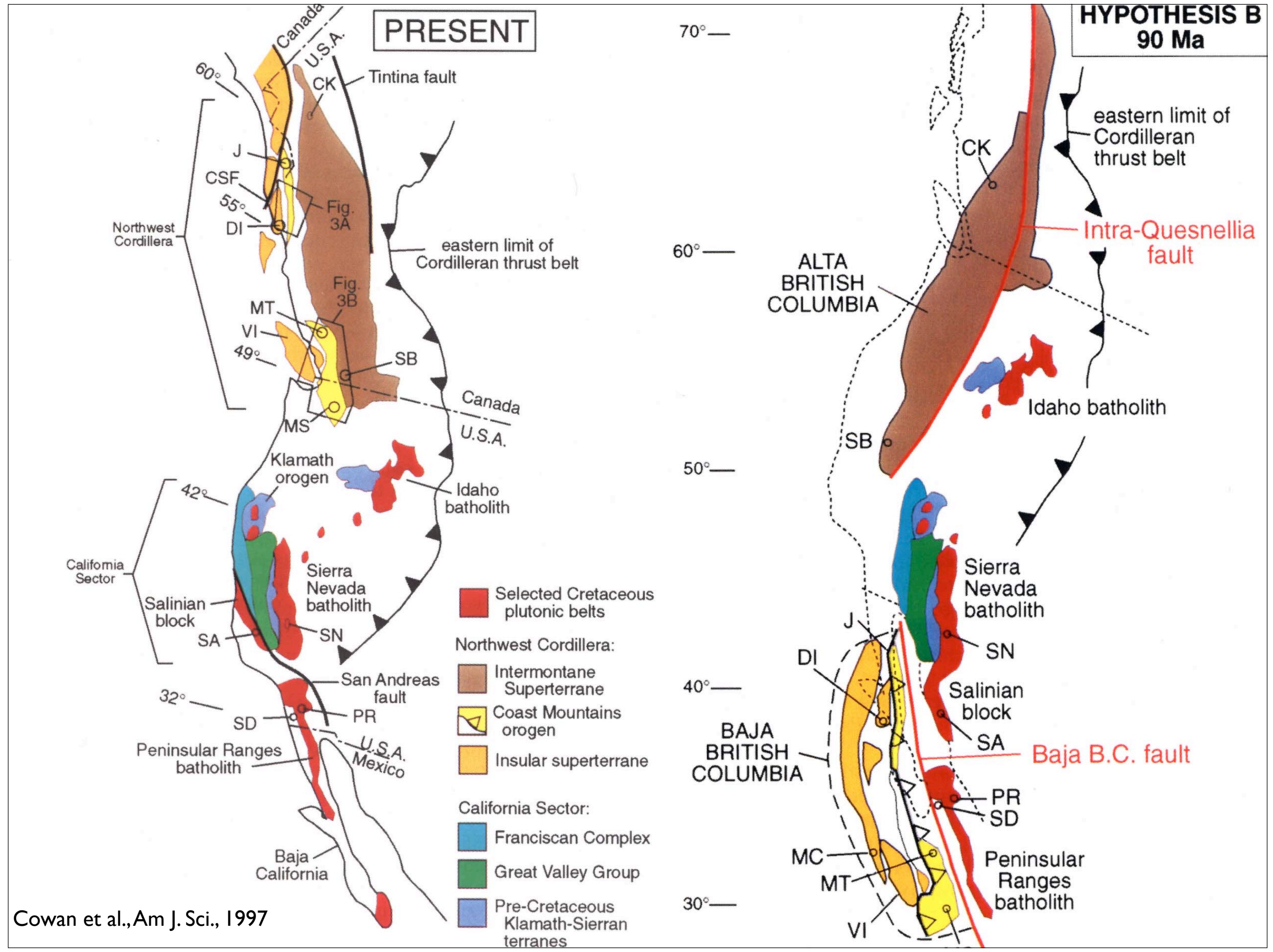


Irving et al., JGR, 1996

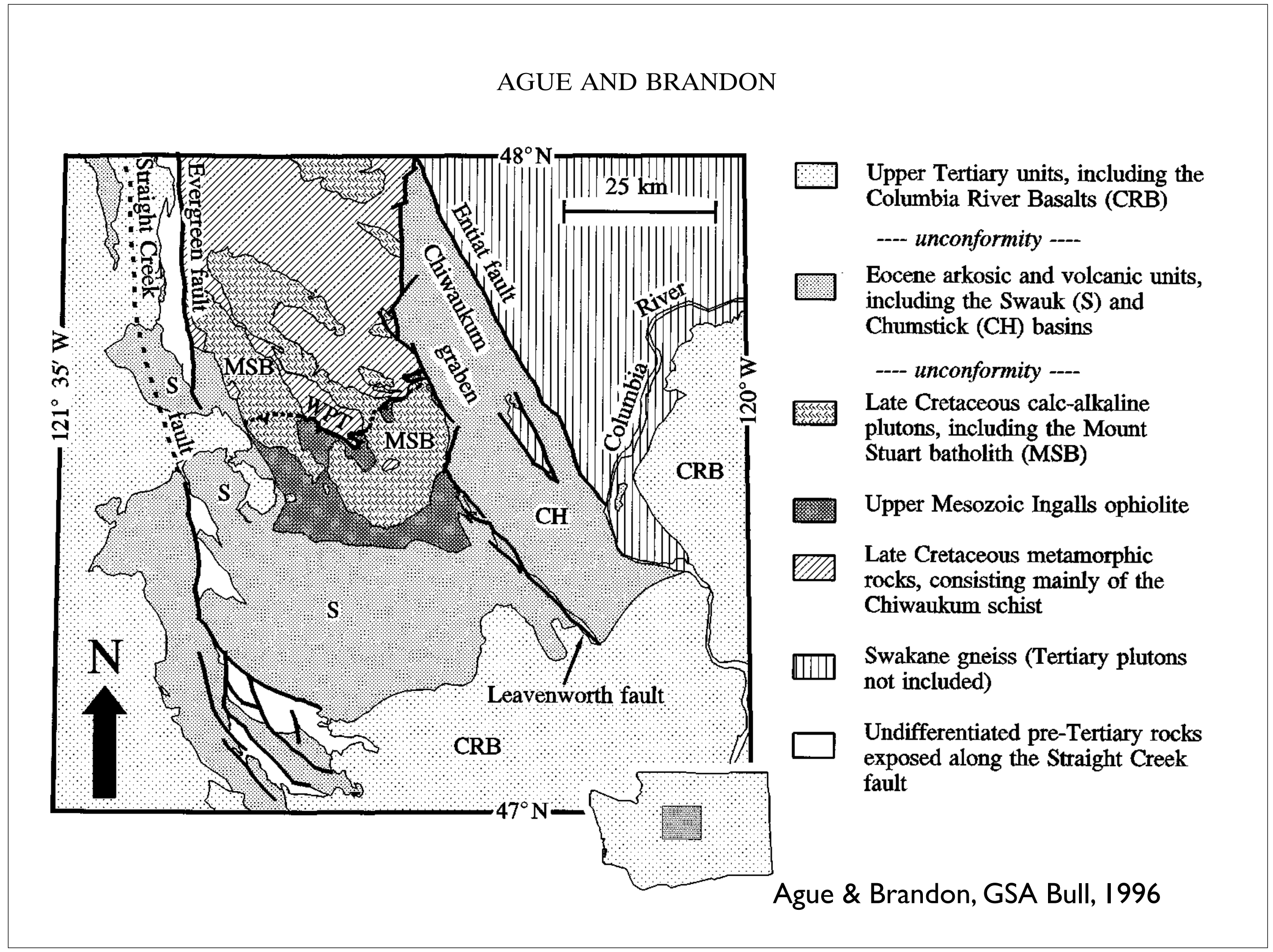
but recall this pmag. Suggests not docked in early K. This is heart of trouble...



Cowan et al., Am J. Sci., 1997



Cowan et al., Am J. Sci., 1997



Attention focused on one pluton for what could be wrong in pmag...

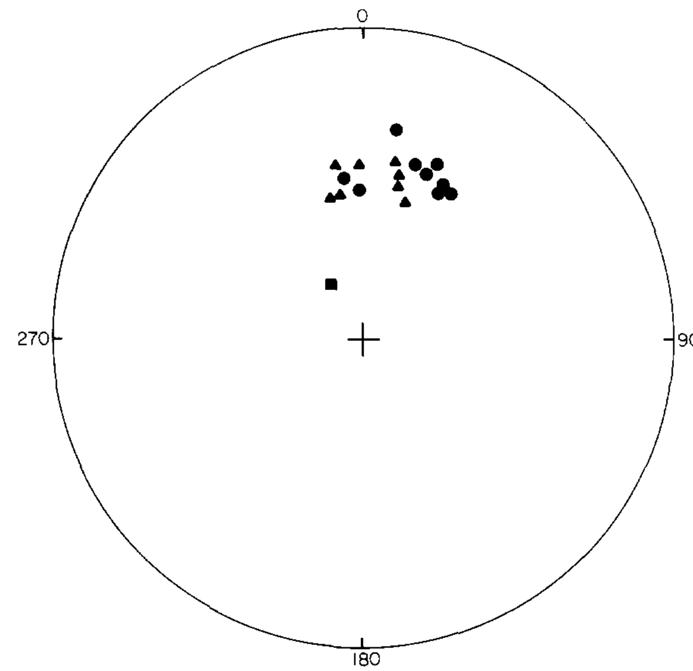


Fig. 3. Equal-area projection on the lower hemisphere, showing site-mean directions of magnetism for the Mt. Stuart batholith. Symbols are keyed to Fig. 4; eastern sites are shown by triangles, western sites by circles. The solid square represents the Cretaceous expected direction at the present latitude and longitude of the Mt. Stuart rocks, calculated from Mankinen [19].

Beck et al., EPSL, 1981

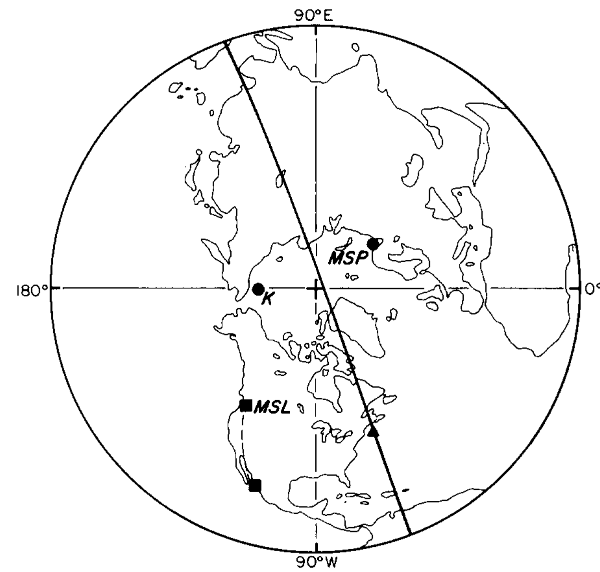


Fig. 5. A tectonic-transport ("microplate") solution. *MSL* = location of Mt. Stuart Batholith; *MSP* = Mt. Stuart paleomagnetic pole; *K* = Cretaceous reference pole for North America. The heavy curve bisects the distance between *K* and *MSP* and therefore is the locus of all possible Euler poles about which *K* can be displaced to *MSP* by a single finite rotation. The triangle shows the unique rotation pole that results from assuming that the Mt. Stuart Batholith originated on the edge of North America. *MSL* is shown rotated back to western Mexico about this pole.

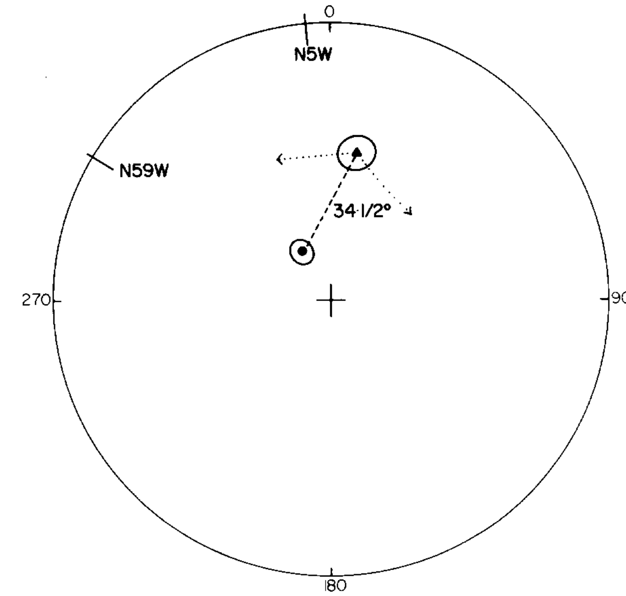
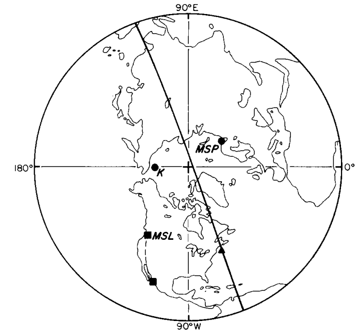


Fig. 6. A tilt solution. Circle is the Cretaceous expected direction, with circle of confidence; triangle is the observed direction for the Mt. Stuart Batholith, also with circle of confidence. A rotation of 34.5° about a fold-axis trending N59W will bring the two into coincidence. Tilt to the southeast or west does not reduce the discordance.

Beck et al., EPSL, 1981

could translate or tilt....



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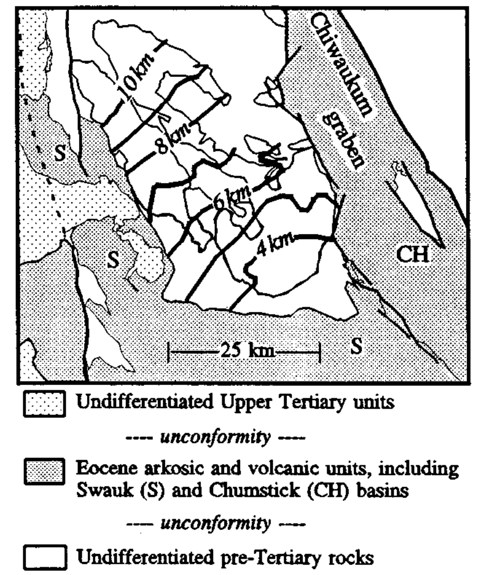
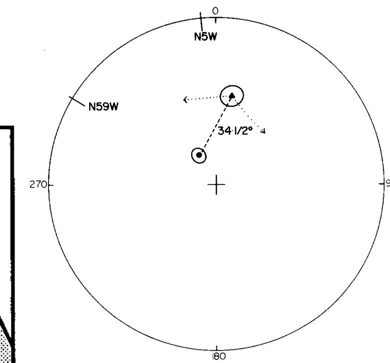


Figure 10. Depth contours computed from the best-fit paleo-surface by determining the intersection of the present topography with surfaces of constant crystallization depth (cf. text and Fig. 2A).



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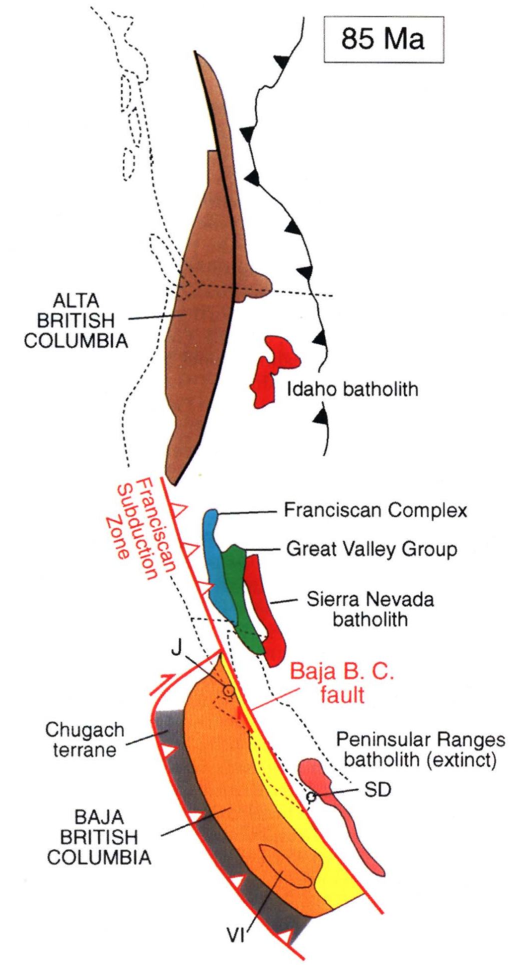
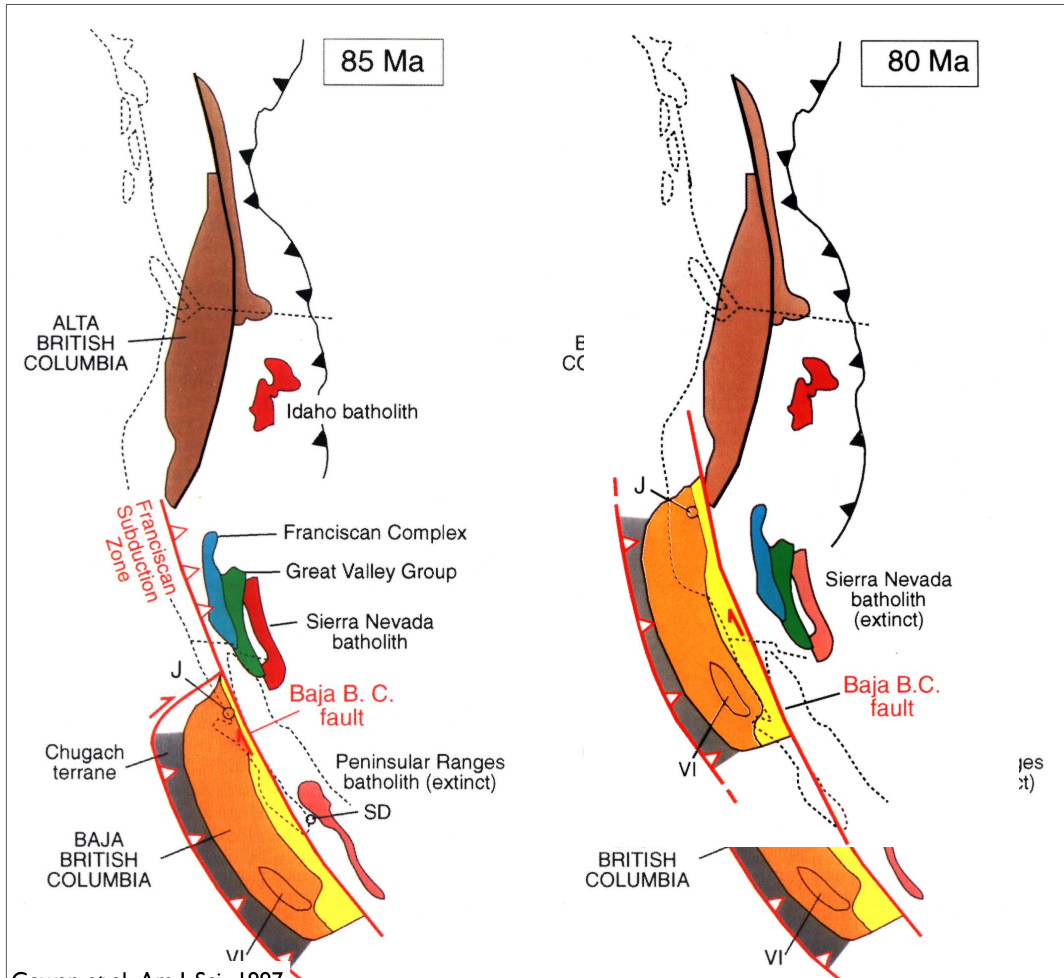
Beck et al., EPSL, 1981

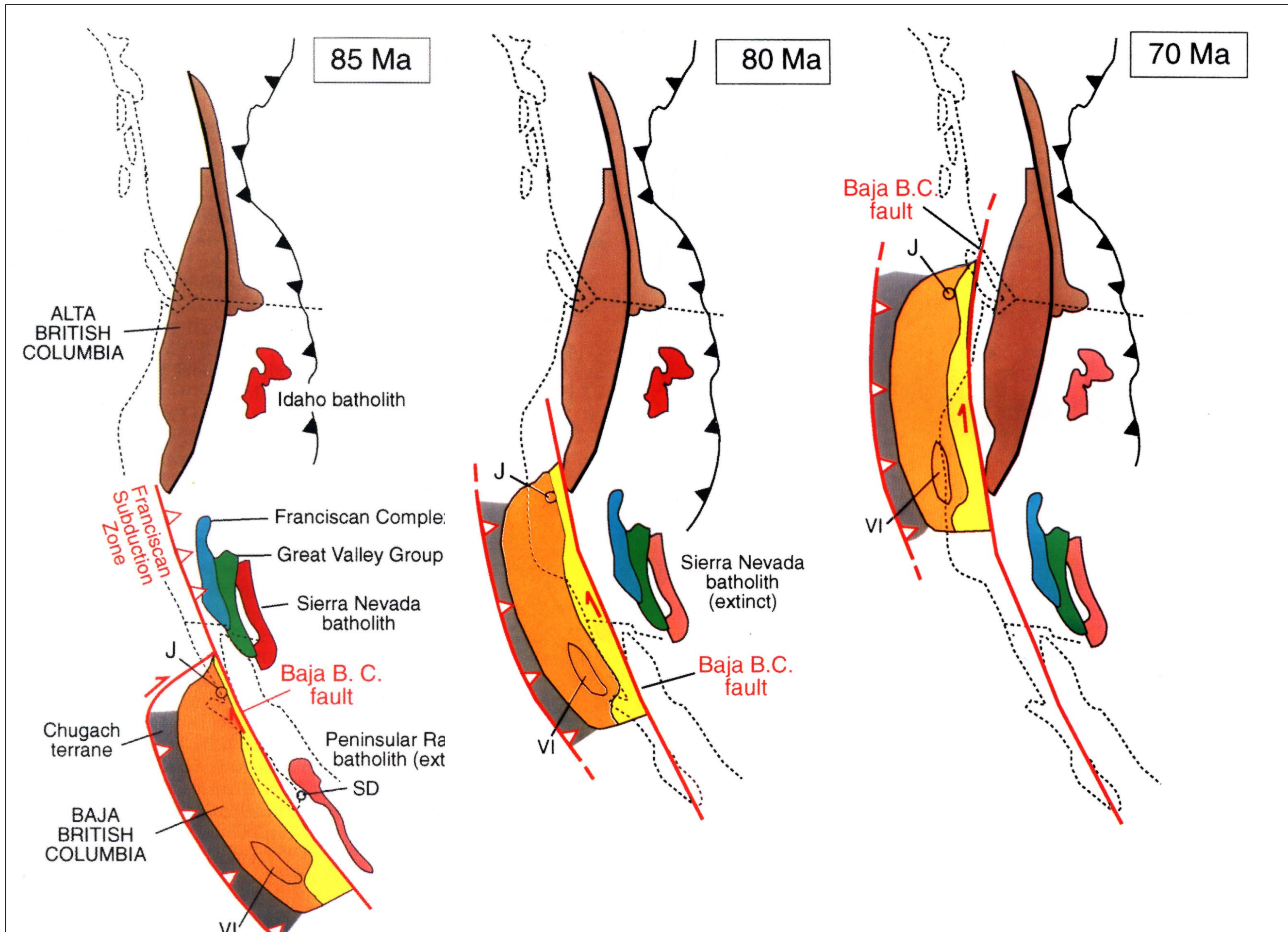
Ague & Brandon, GSA Bull, 1996



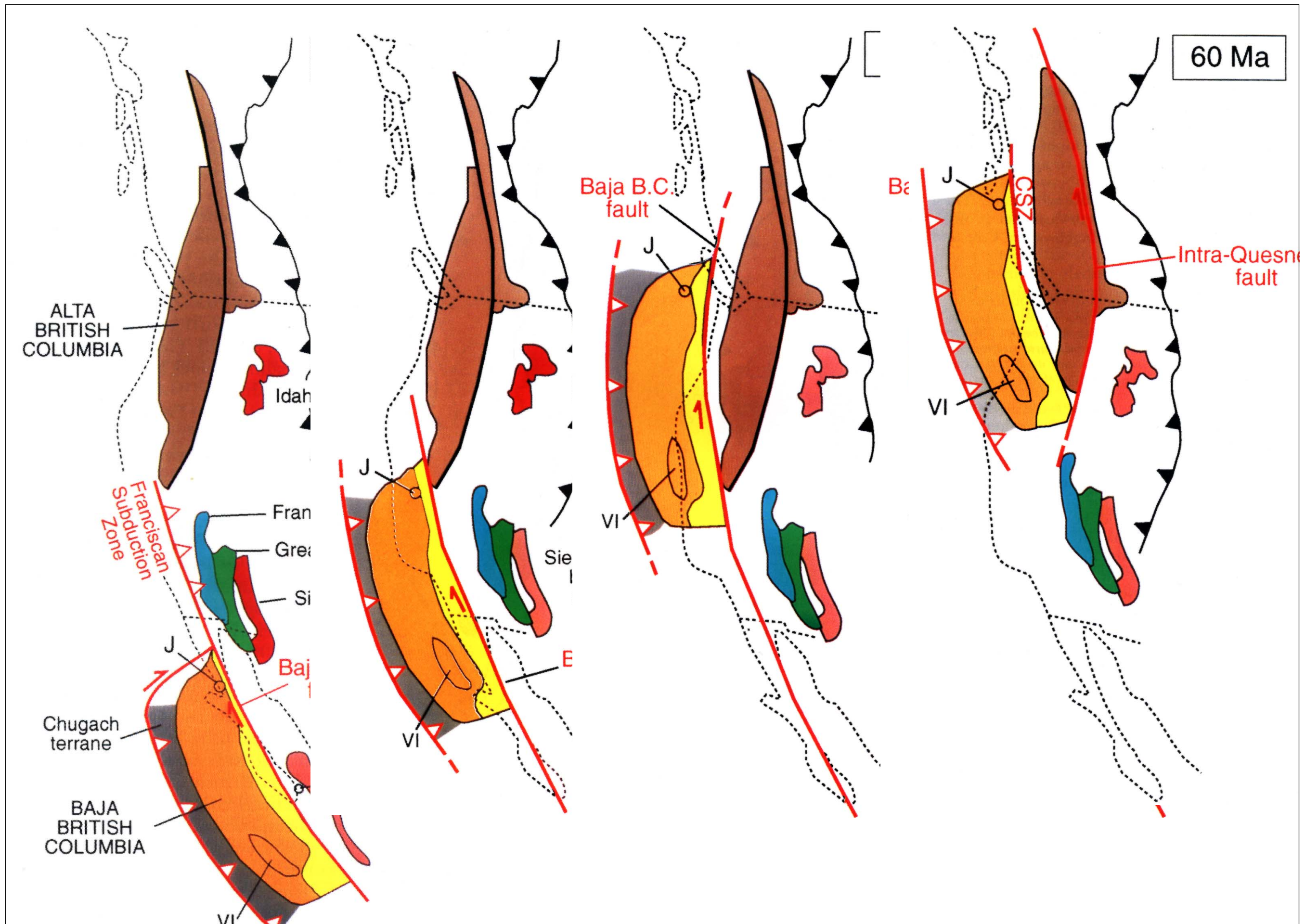
Cowan et al., Am J. Sci., 1997



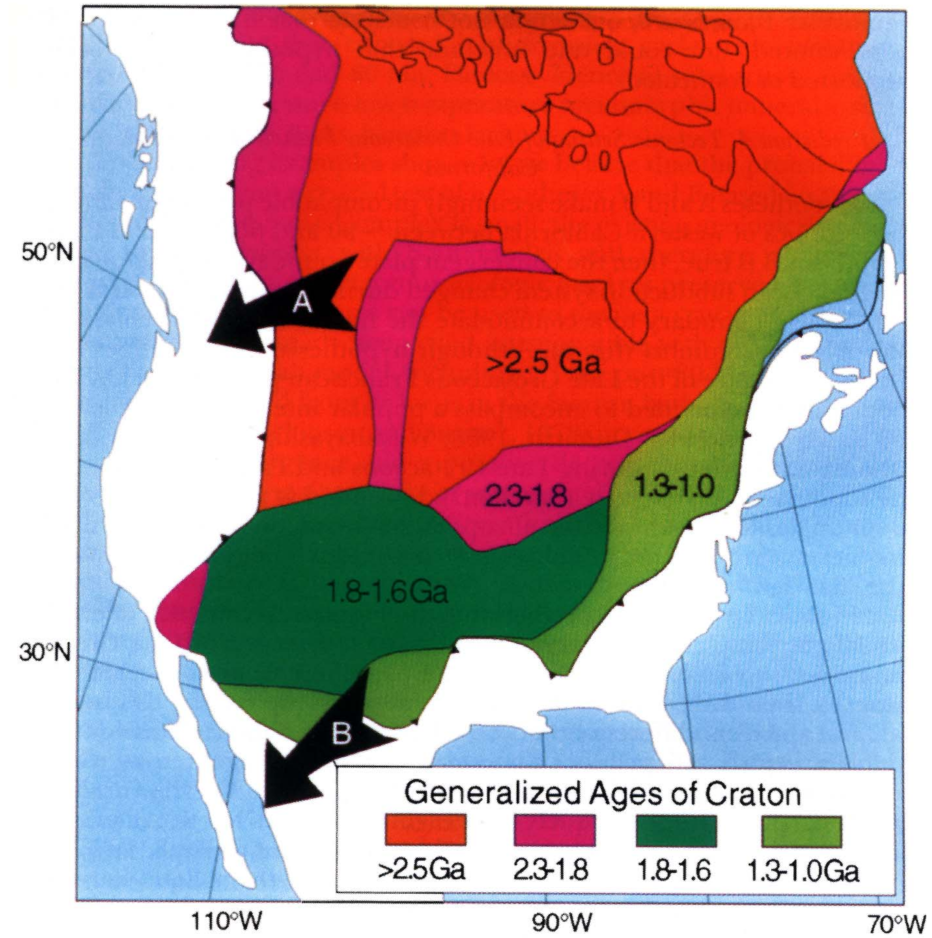
Cowan et al., Am J. Sci., 1997



Cowan et al., Am J. Sci., 1997

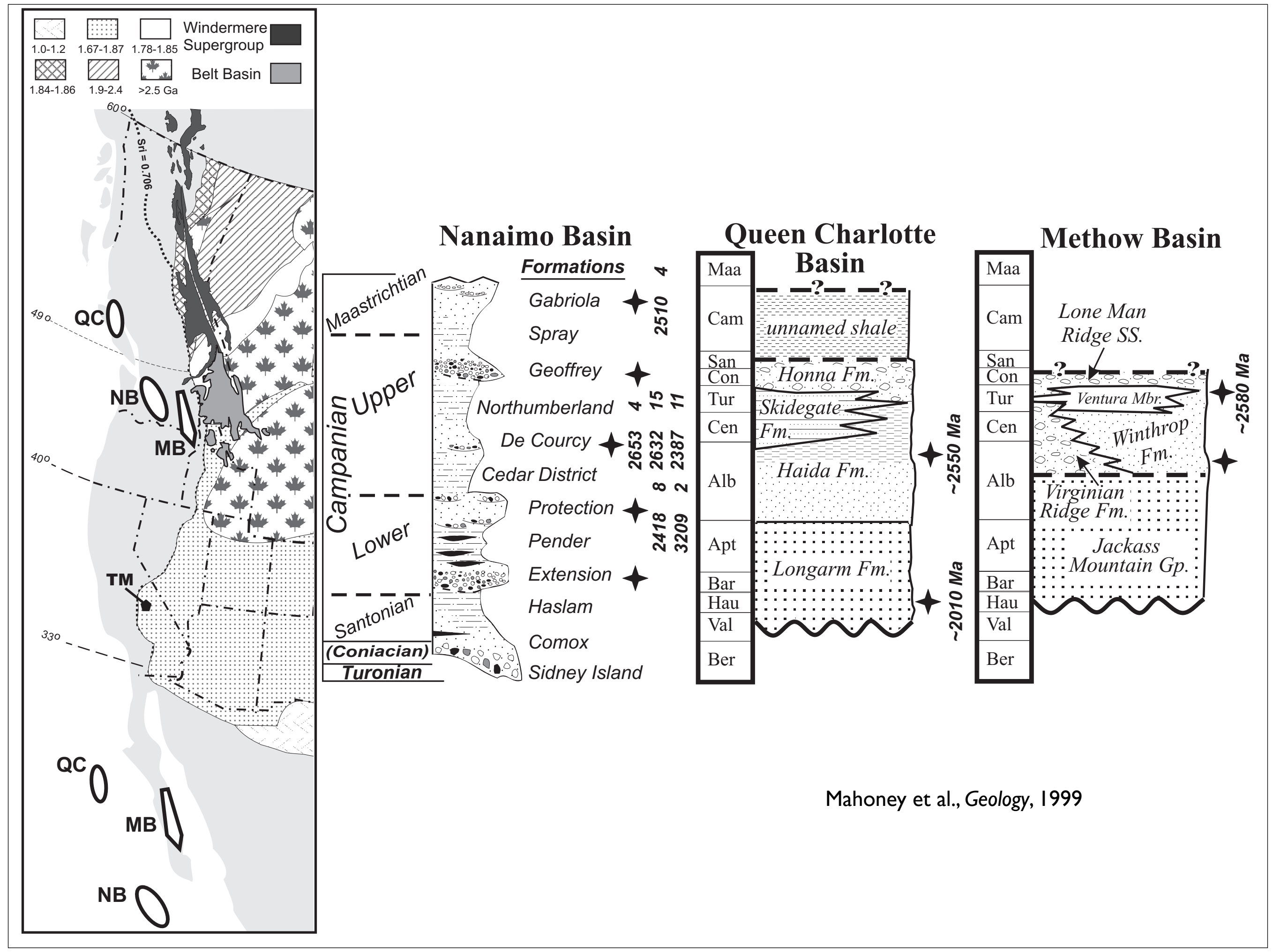


Cowan et al., Am J. Sci., 1997



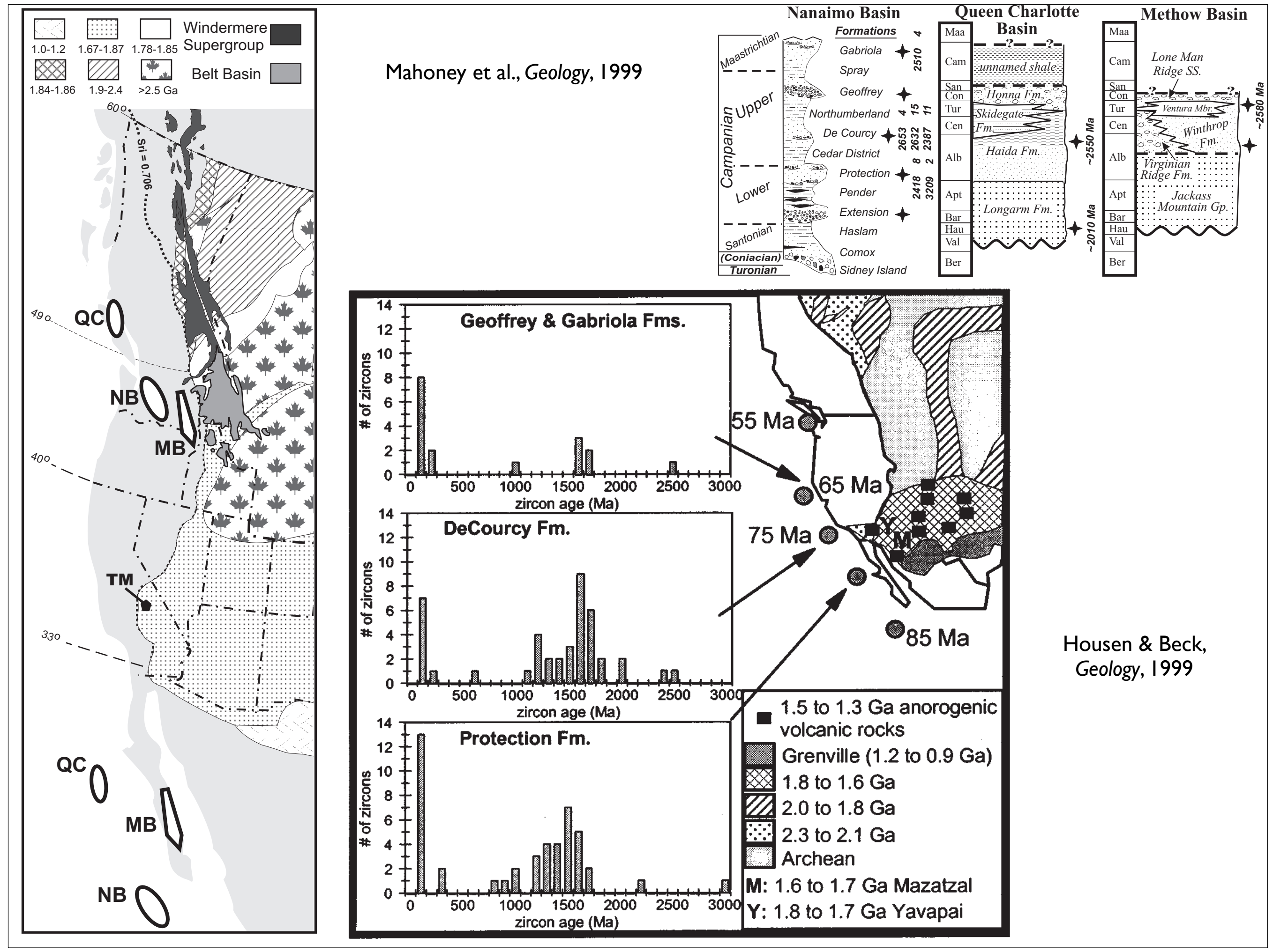
Cowan et al., Am J. Sci., 1997

So suggestion that detrital zircons should be the answer....

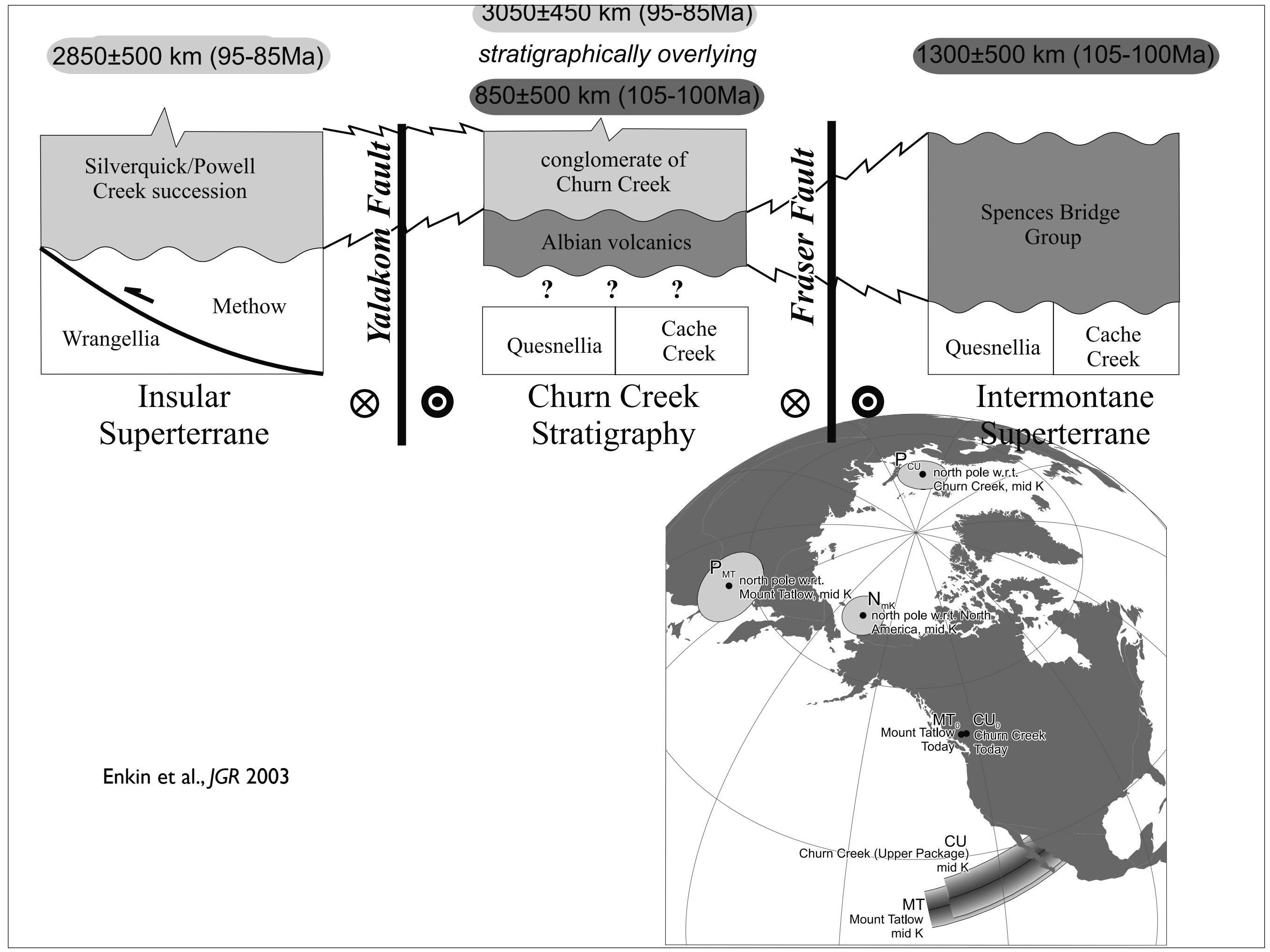


Mahoney et al., *Geology*, 1999

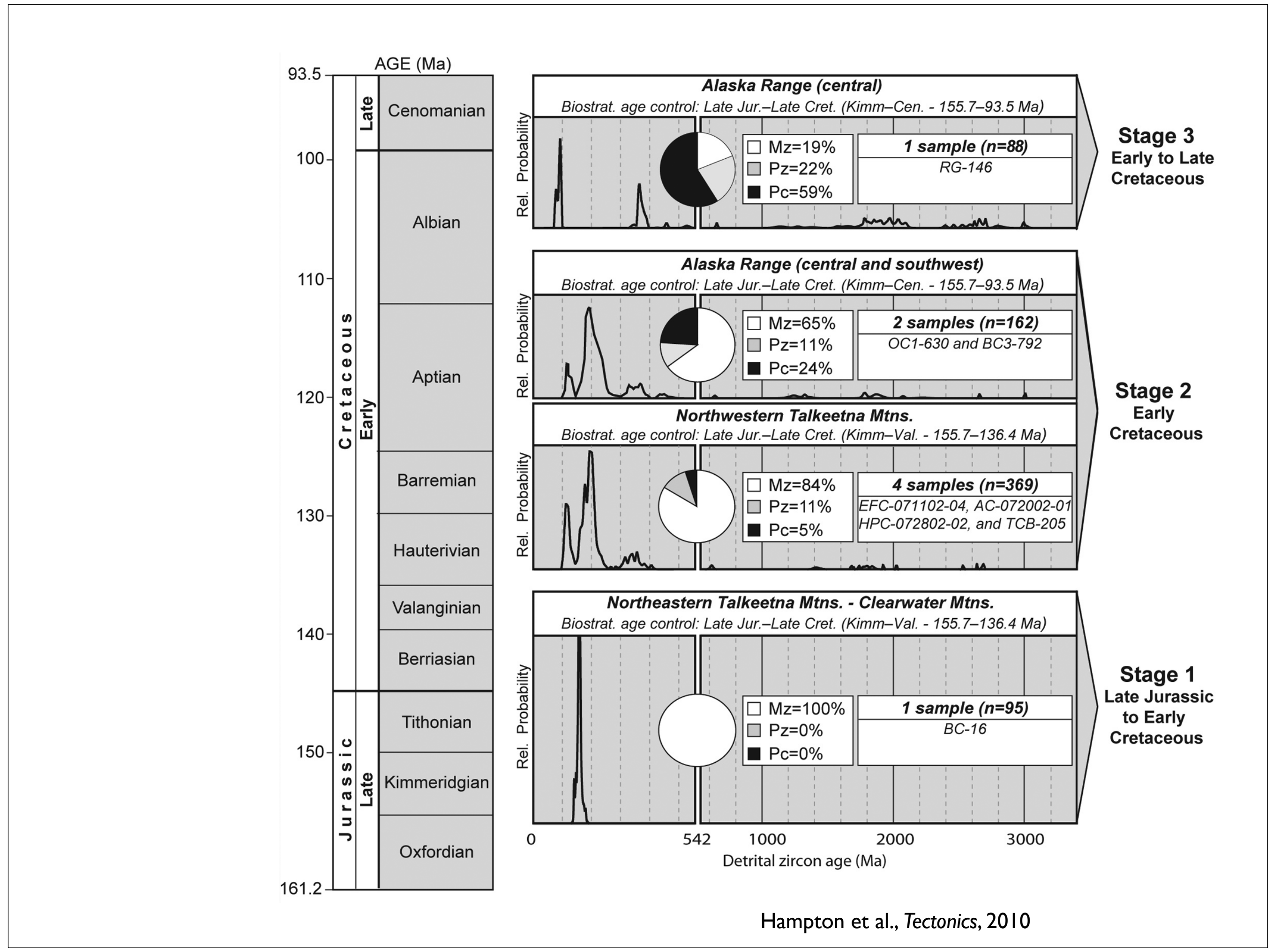
Note small numbers of zircons in this analysis



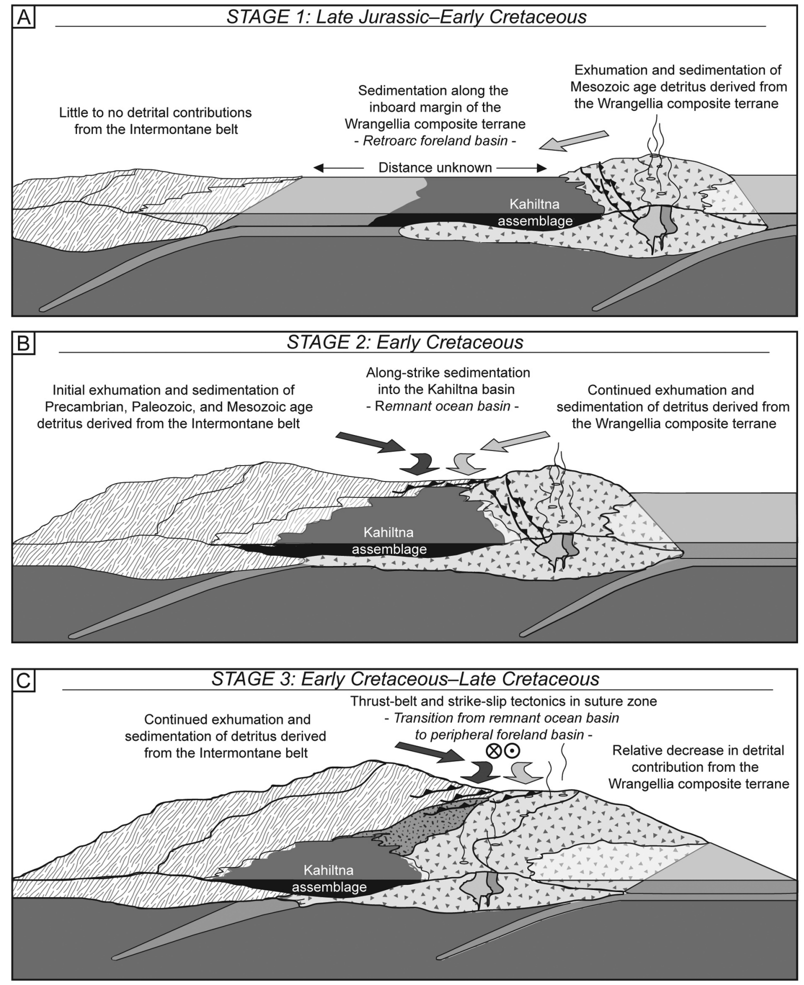
not so fast say Housen and Beck--look at all these 1.2-1.7 Ga zircons… [but remember where the magmatic gap was? Do these look Baltica?]



Even more extreme is the “yo-yo” model where Baja BC is close and then moves way south and then north again...



These are from Wrangellia-affinity rocks (Kahiltna assemblage). they don't exactly land on either side but do argue this records suturing of Wrangellia to Intermontane terrane


A
STAGE 1: Late Jurassic–Early Cretaceous
Little to no detrital contributions from the Intermontane belt
Sedimentation along the inboard margin of the Wrangellia composite terrane
- Retroarc foreland basin -
Exhumation and sedimentation of Mesozoic age detritus derived from the Wrangellia composite terrane
Distance unknown
Kahiltna assemblage
B
STAGE 2: Early Cretaceous
Initial exhumation and sedimentation of Precambrian, Paleozoic, and Mesozoic age detritus derived from the Intermontane belt
Along-strike sedimentation into the Kahiltna basin
- Remnant ocean basin -
Continued exhumation and sedimentation of detritus derived from the Wrangellia composite terrane
Kahiltna assemblage
C
STAGE 3: Early Cretaceous–Late Cretaceous
Continued exhumation and sedimentation of detritus derived from the Intermontane belt
Thrust-belt and strike-slip tectonics in suture zone
- Transition from remnant ocean basin to peripheral foreland basin -
Relative decrease in detrital contribution from the Wrangellia composite terrane
Kahiltna assemblage