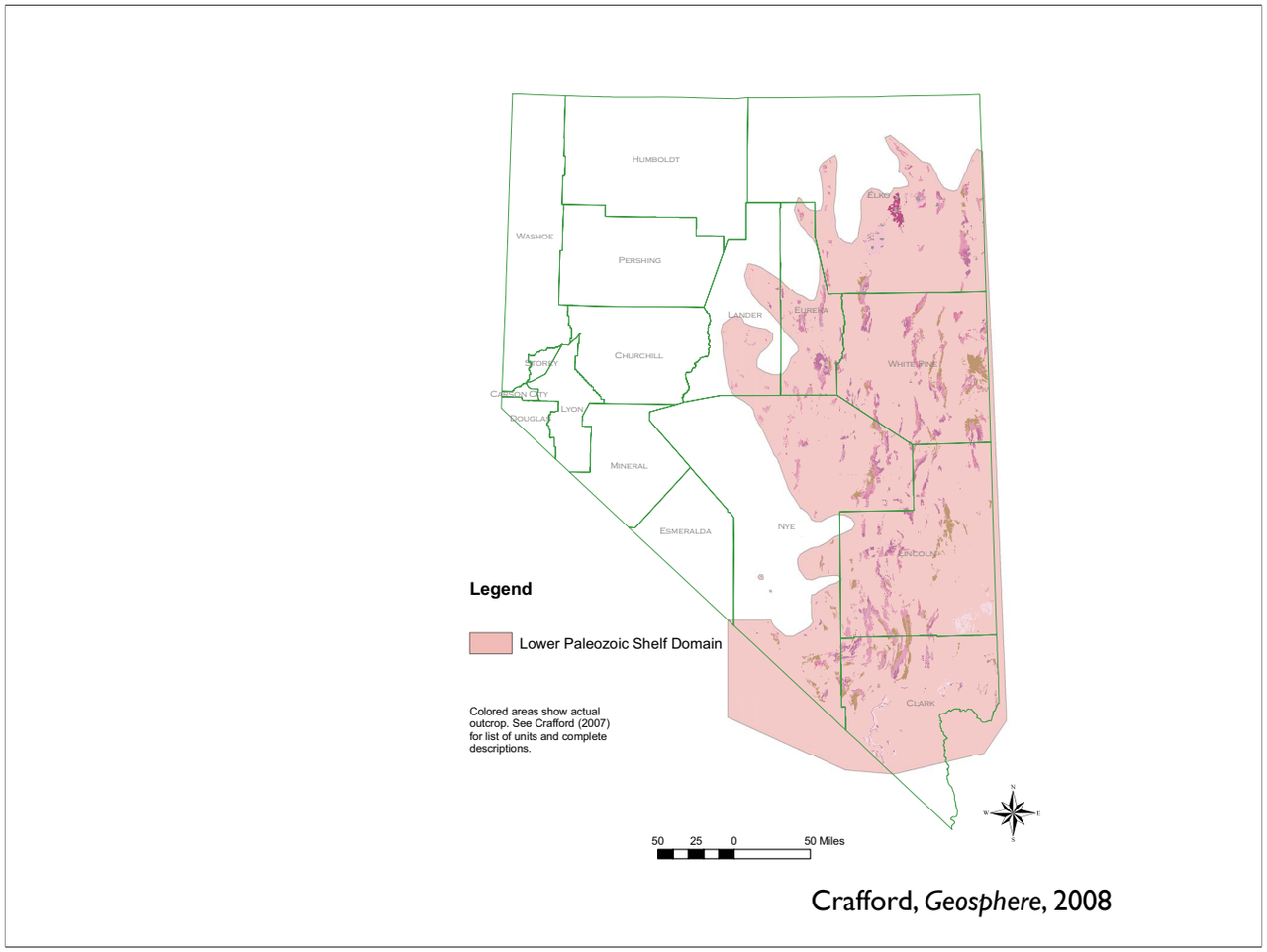
Modern boundary is a normal fault.


Diamond Peak Frm (Mississippian)

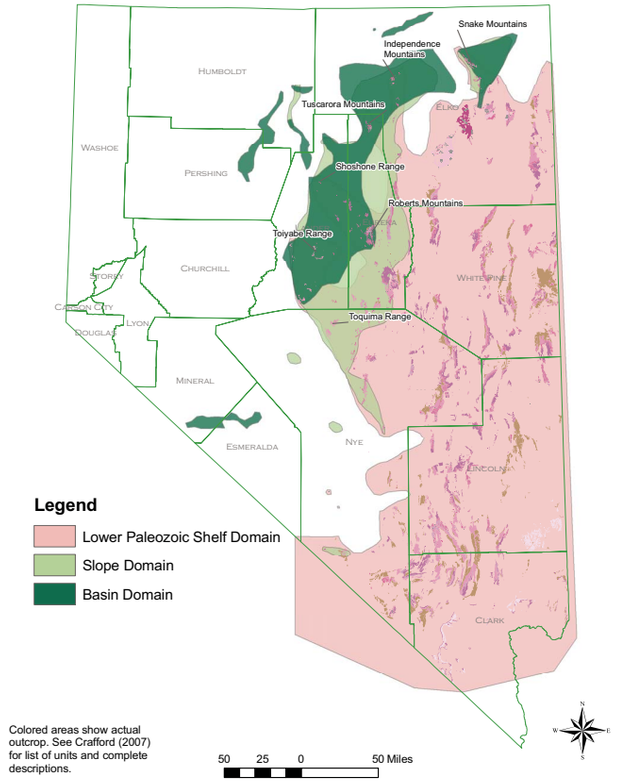
Clasts are the deep water cherts from the west, not the carbonates seen to east.



Crafford, *Geosphere*, 2008

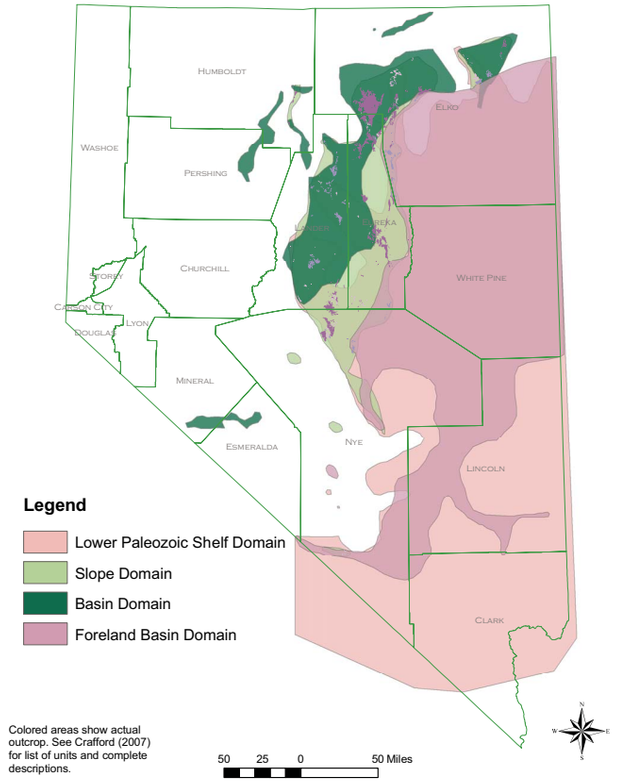
Note how far west we see shelf rocks

Overlap of shelf and basin suggests thrusting...



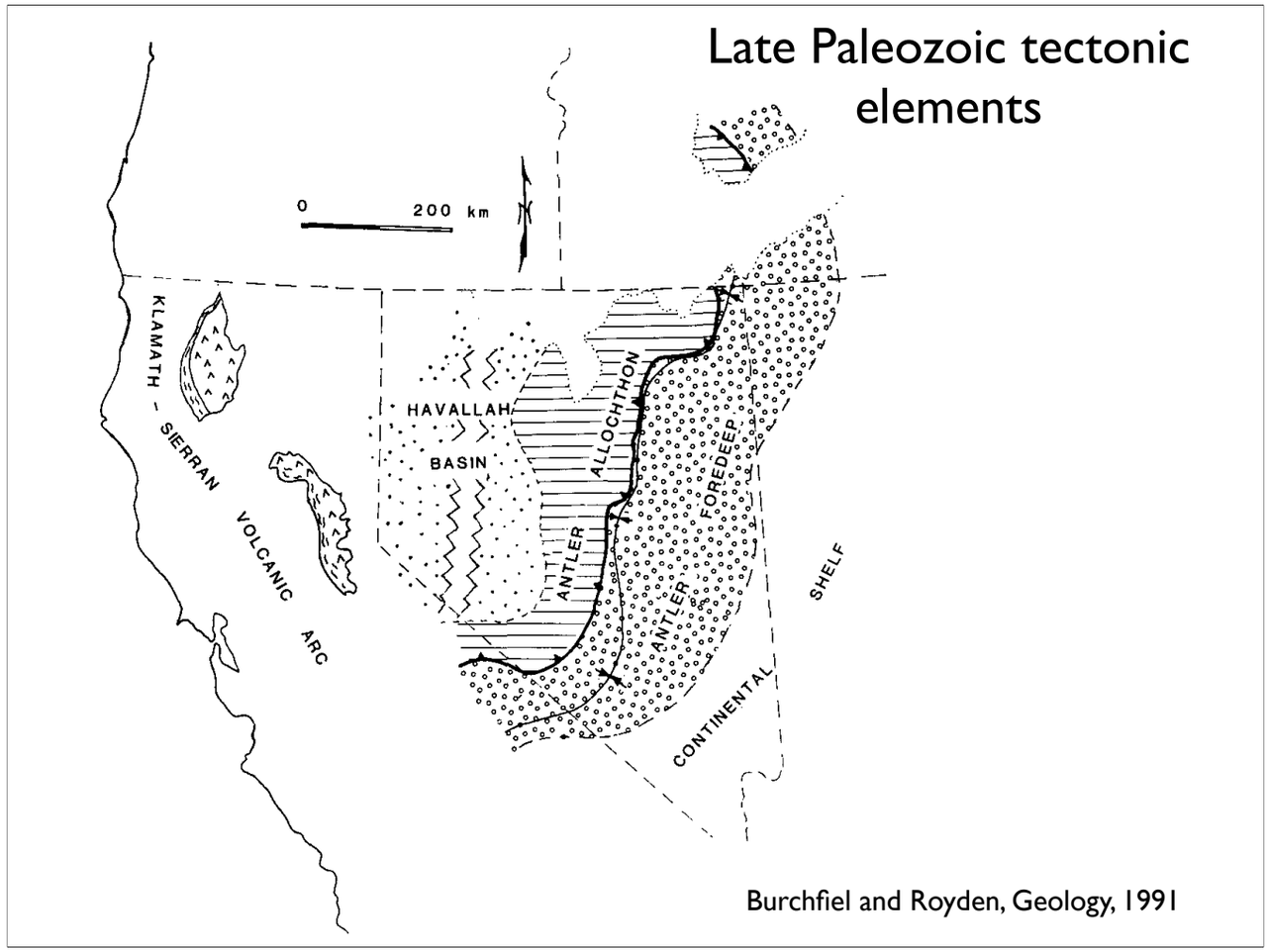
Crafford, *Geosphere*, 2008

Here we see deep water (basin domain) overlying the shelf rocks…
however, consider this quote from Cashman et al. 2011: "However, the age of folds and faults attributed to the Antler orogeny are not well constrained—the deformed rocks commonly range from Ordovician to Devonian in age, but no strata overlying these deformed rocks are older than Pennsylvanian. Based on these relationships, the deformation is permissibly much younger than the Late Devonian–Early Mississippian Antler orogeny."

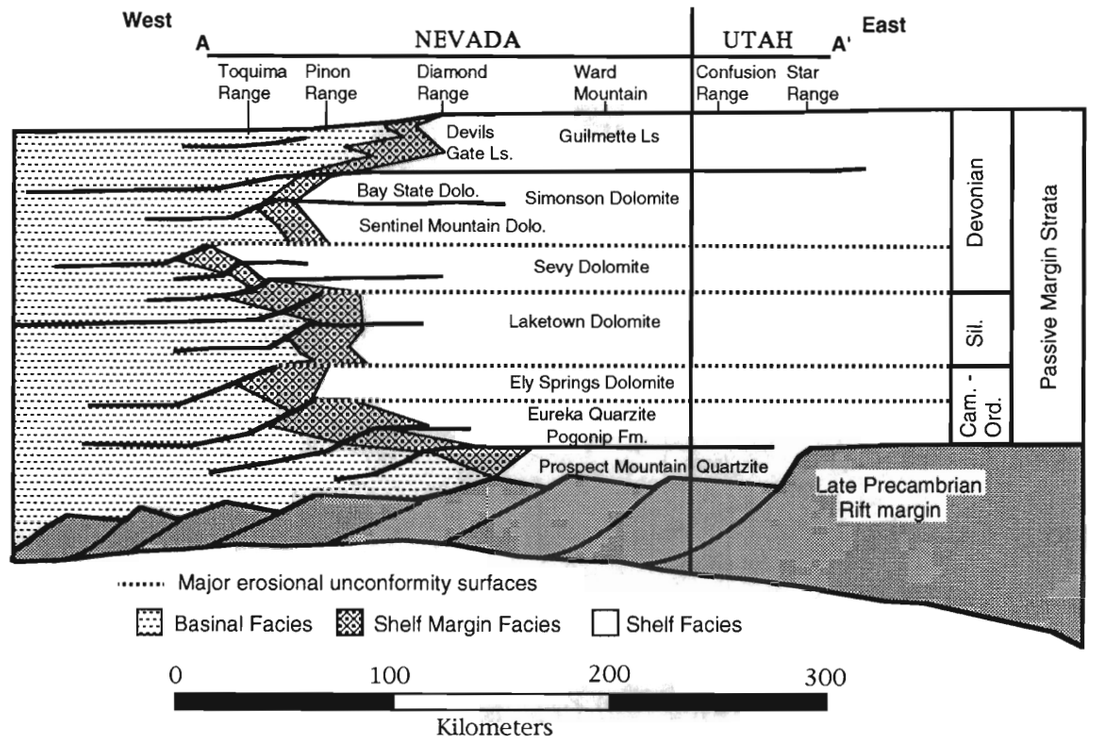


Crafford, *Geosphere*, 2008

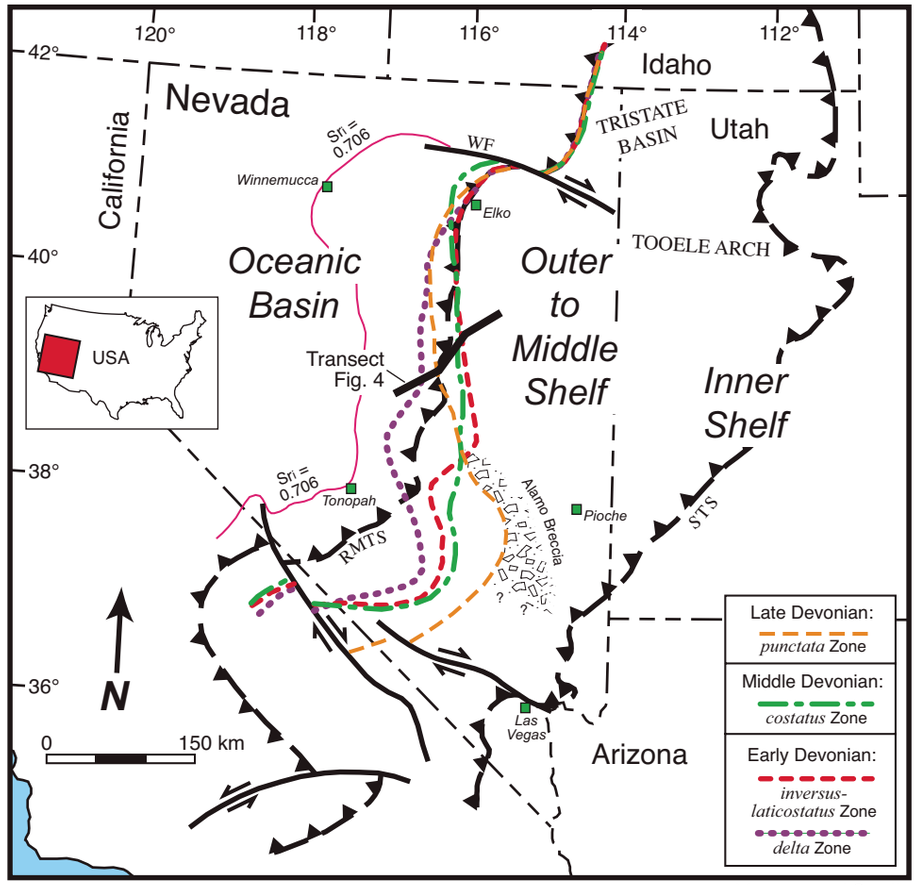
Add in Mississippian foredeep sediments and you get a picture of the Antler orogeny



We're going to investigate this from the continent outward, so first the sediments on the shelf…

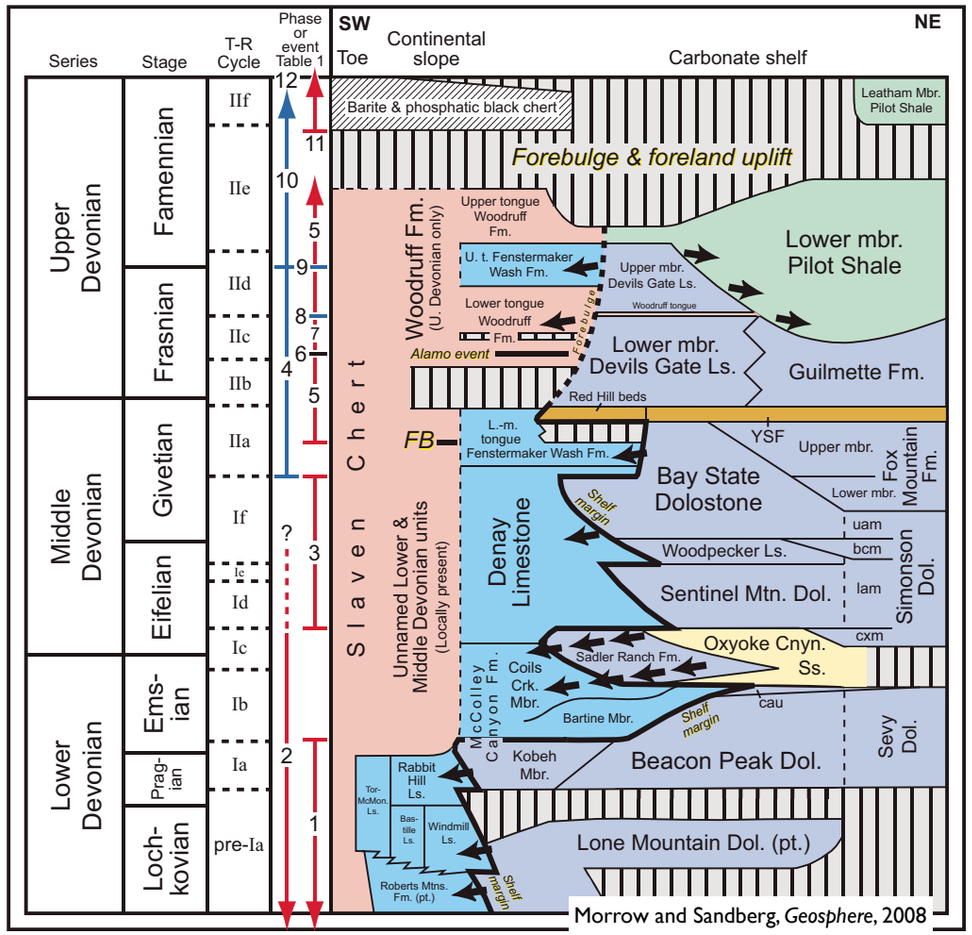


Giles & Dickinson, *SEPM SP 52*, 1995



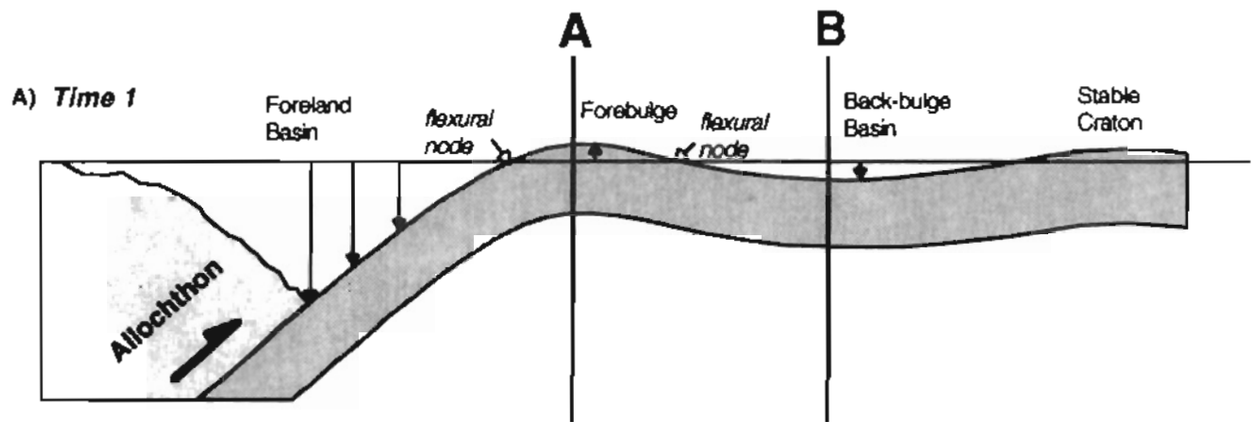
Morrow and Sandberg, *Geosphere*, 2008

Figure 3. Partly restored paleogeographic map, Nevada and western Utah, showing representative positions of the carbonate-shelf margin through the Devonian; see Figure 1 for conodont biochronology. Position of punctata Zone margin is prior to eastward shift (Fig. 6) produced by the Alamo Impact and formation of the Alamo Breccia, indicated in figure. Apparent juxtaposition of carbonate-shelf margin positions in northern Nevada is largely due to Antler orogenic compression and overthrusting. Approximate position of western edge of continental crust is indicated by Sri (87Sr/86Sr) = 0.706. Tristate basin and Tooele arch are broad, persistent Devonian structural features (Sandberg et al., 1989; Poole et al., 1992). Positions of other Devonian intrashelf basins, including depositional sites of Middle Devonian Woodpecker Limestone (Elrick, 1996) and Upper Devonian–Mississippian Pilot Shale (Sandberg et al., 1989, 2003), are omitted for simplicity. Abbreviations: RMTS—Roberts Mountains thrust system; STS—Sevier thrust system; WF—Wells fault. Major Cenozoic strike-slip faults and time-rock transect line (Fig. 4) are also shown. Data from Johnson et al. (1989) and Sandberg et al. (1989, 2002).



arrows are turbidity current directions; note reversal in Upper Devonian. FB is their interpretation of forebulge initiation…

Figure 4. Northeast to southwest, Devonian time-rock transect across central and eastern Nevada (transect line shown in Fig. 3), showing carbonate-shelf, continental slope, and toe lithostratigraphic units and relative lateral shifts in shelf margin through time. Main phases or events in shelf-margin development (Table 1) are delineated: vertical blue lines denote eustatic changes; vertical red lines denote tectonic changes. Transgressive-regressive (T-R) cycles Ia-IIf (Johnson et al., 1985, 1991; Johnson and Sandberg, 1989), main intervals of turbid- ity current and debris-flow deposition (arrows), proto-Antler forebulge initiation (FB), and timing of Alamo Impact Event are indicated. Silty dolostone and siltstone of the yellow slope-forming member (YSF), which forms the basal unit of the Guilmette Formation and Devils Gate Limestone, constitute a widespread marker lithology distributed throughout western North America (Sandberg et al., 1989, 1997, 2002). The YSF is herein correlated with fish-bearing Red Hill beds in north-central Nevada. Four members of Simonson Dolostone: cxm—coarse crystalline member; lam—lower alternating member; bcm—brown cliff member; and uam—upper alternating member. Other abbreviations: cau—cherty argillaceous unit; Cnyn.—Canyon; Crk.—Creek; Dol.—Dolostone; Fm.—Formation; L.—Lower; Ls.— Limestone; m.—middle; mbr.—member; McMon.—McMonnigal; Mtns.—Mountains; pt.—part; Ss.—Sandstone; t.—tongue; U.—Upper. Modified from Johnson and Sandberg (1977), Johnson and Murphy (1984), Johnson et al. (1996), and M.A. Murphy (14 September 2007, personal commun.), with additional data from Sandberg et al. (1989, 1997, 2002, 2003) and our personal observ.



Giles and Dickinson, 1995

Recall our differential equation for plates:

$$D\frac{d^4w}{dx^4} + P\frac{d^2w}{dx^2} + \left(\rho_a - \rho_f\right)gw = q_a(x)$$

If we drop the end load (P), then a solution by inspection is

$$w = e^{x/\alpha}\left(c_1\cos\frac{x}{\alpha} + c_2\sin\frac{x}{\alpha}\right) + e^{-x/\alpha}\left(c_3\cos\frac{x}{\alpha} + c_4\sin\frac{x}{\alpha}\right)$$

Where α is the flexural parameter:

$$\alpha = \left(\frac{4D}{g(\rho_a - \rho_w)}\right)^{1/4}$$

This sinusoidal solution lets you examine extreme cases: big lambda is isostasy, small is rigidity.

$$w = e^{x/\alpha}\left(c_1 \cos\frac{x}{\alpha} + c_2 \sin\frac{x}{\alpha}\right) + e^{-x/\alpha}\left(c_3 \cos\frac{x}{\alpha} + c_4 \sin\frac{x}{\alpha}\right)$$

Where α is the flexural parameter:

$$\alpha = \left(\frac{4D}{g(\rho_a - \rho_w)}\right)^{1/4}$$

By inspection, for x>0, c_1 and c_2 must be zero.

With the load V_0 at x=0, slope should be zero, so $c_3 = c_4$

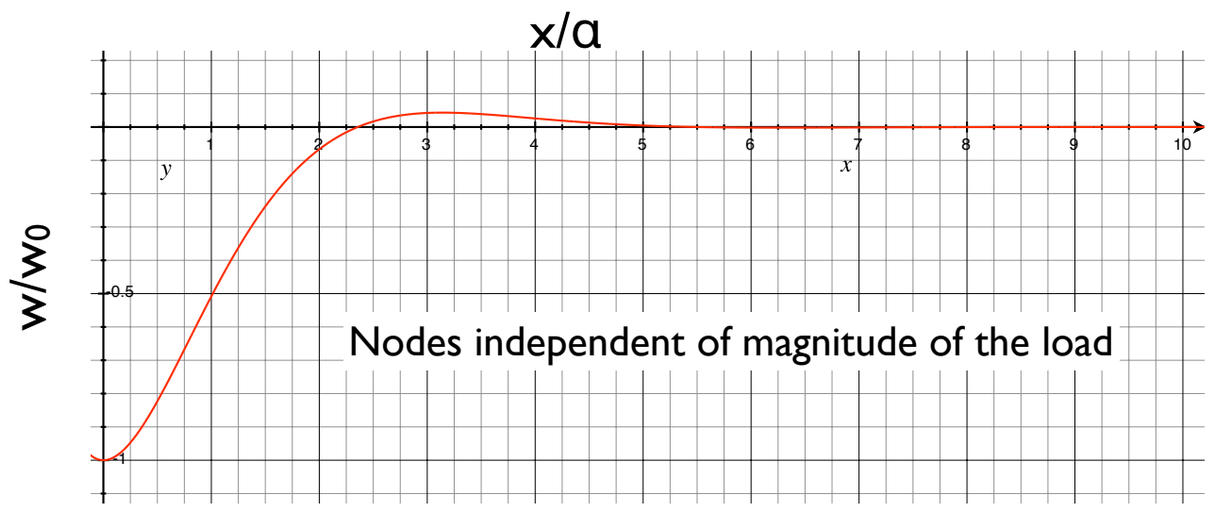
$$w = w_0 e^{-x/\alpha}\left(\cos\frac{x}{\alpha} + \sin\frac{x}{\alpha}\right) \quad \text{where} \quad w_0 = \frac{V_0 \alpha^3}{8D}$$

This sinusoidal solution lets you examine extreme cases: big lambda is isostasy, small is rigidity.

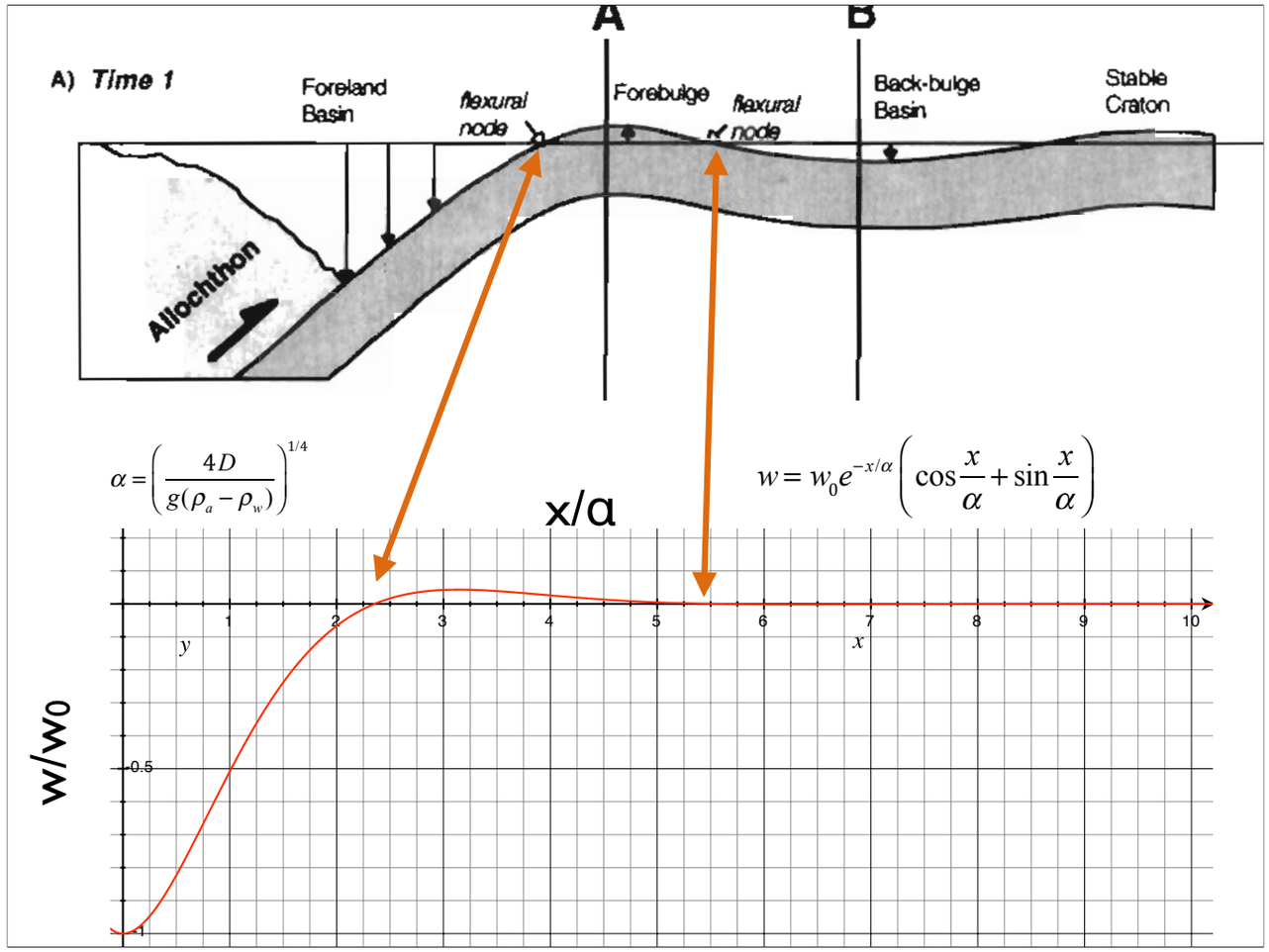
$$\alpha = \left(\frac{4D}{g(\rho_a - \rho_w)} \right)^{1/4}$$

$$w = w_0 e^{-x/\alpha} \left(\cos\frac{x}{\alpha} + \sin\frac{x}{\alpha} \right)$$

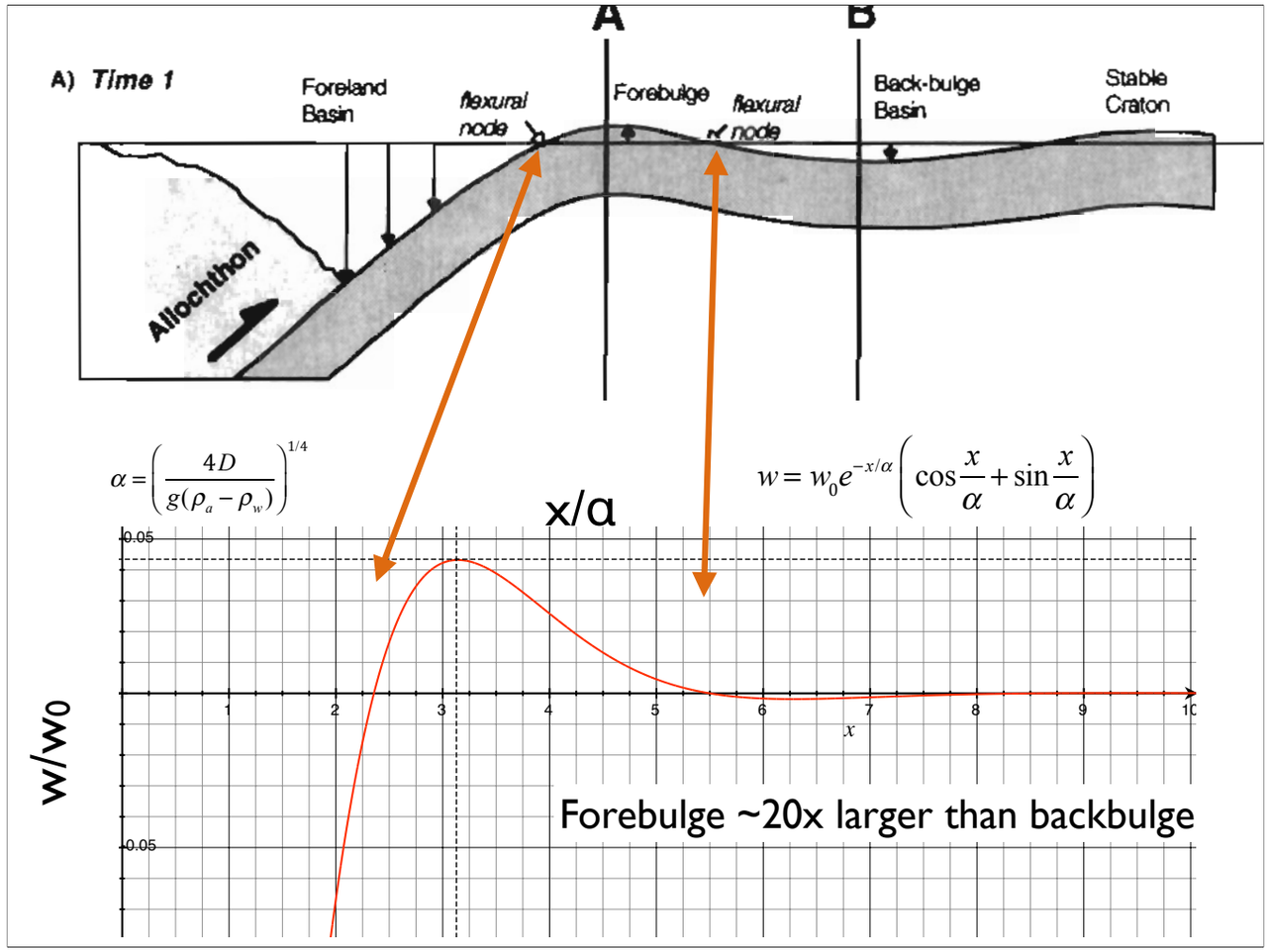
Consider places where w = 0; these are termed nodes.
They are where cos(x/α)=-sin(x/α), or x=α(3π/4 +nπ)



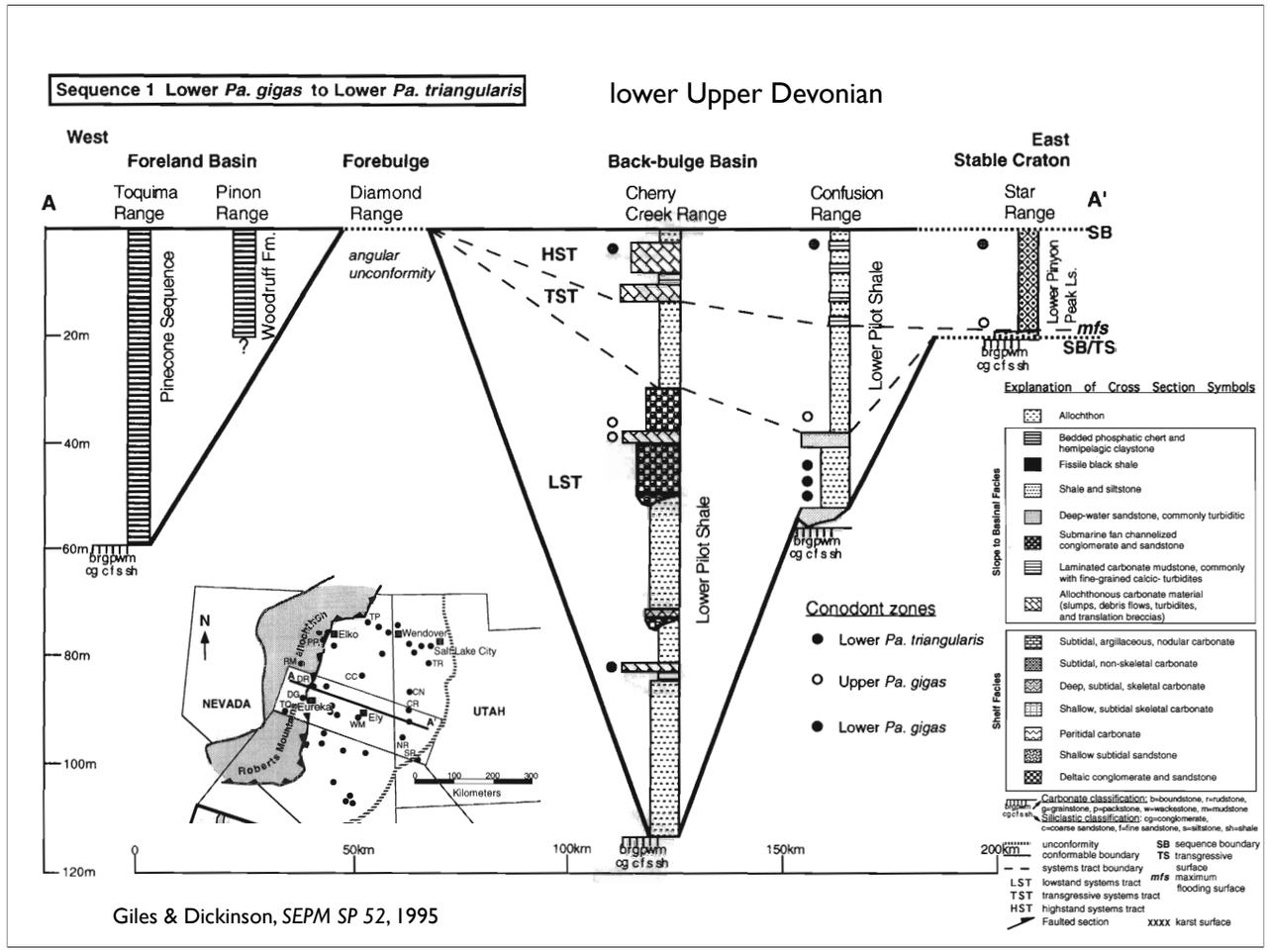
This sinusoidal solution lets you examine extreme cases: big lambda is isostasy, small is rigidity.



This sinusoidal solution lets you examine extreme cases: big lambda is isostasy, small is rigidity.



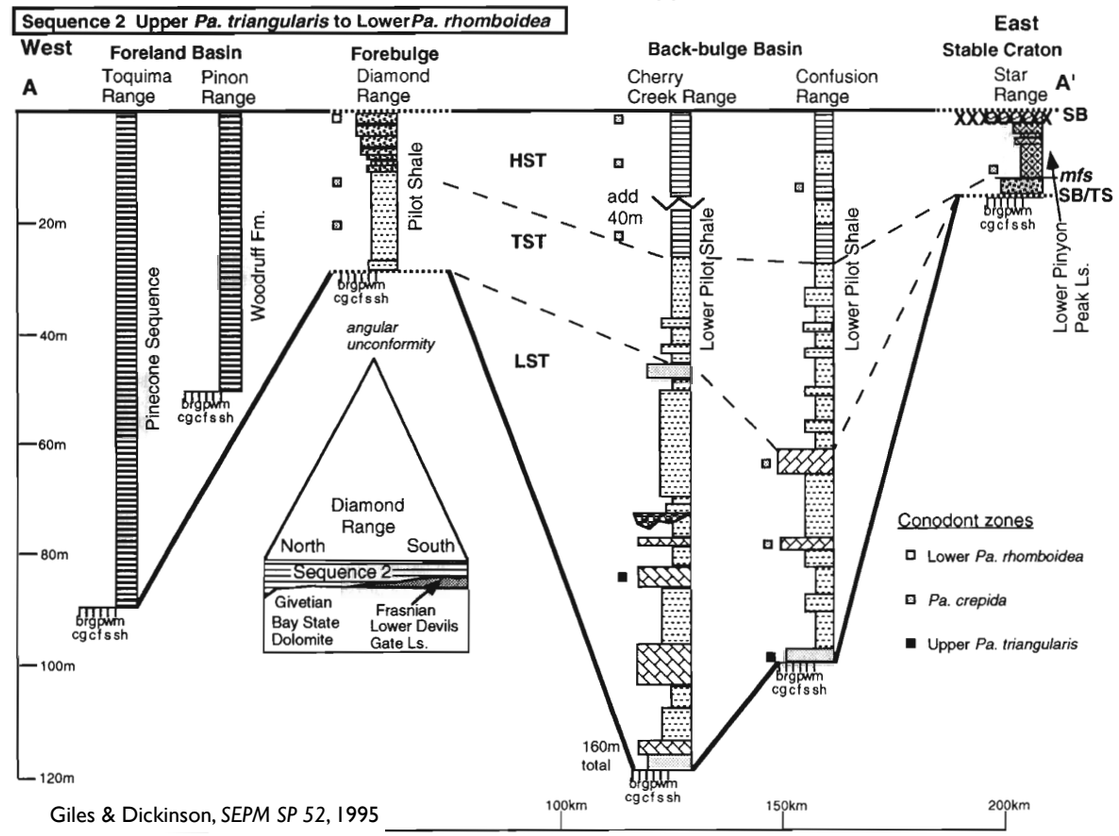
This sinusoidal solution lets you examine extreme cases: big lambda is isostasy, small is rigidity.



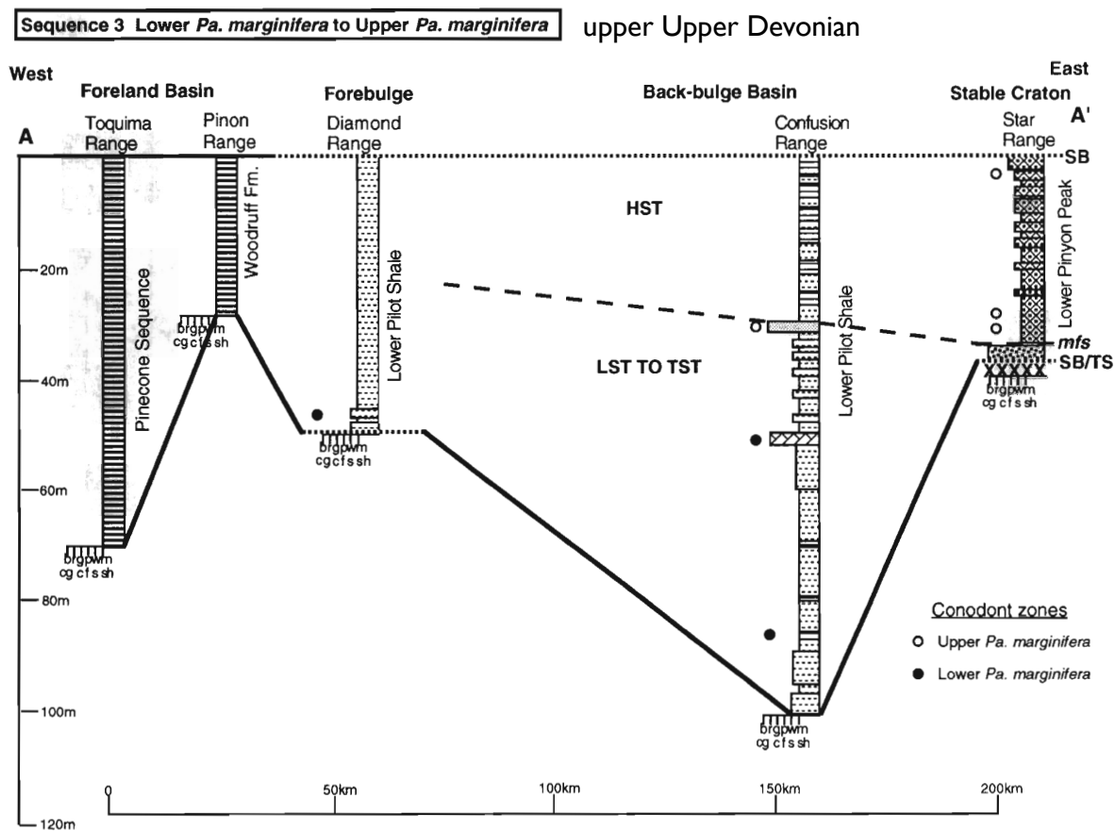
Giles & Dickinson, *SEPM SP 52*, 1995

Note carbonate type/clast size scale below each section

middle Upper Devonian



Giles & Dickinson, *SEPM SP 52*, 1995



Giles & Dickinson, *SEPM SP 52*, 1995

upper Upper Devonian

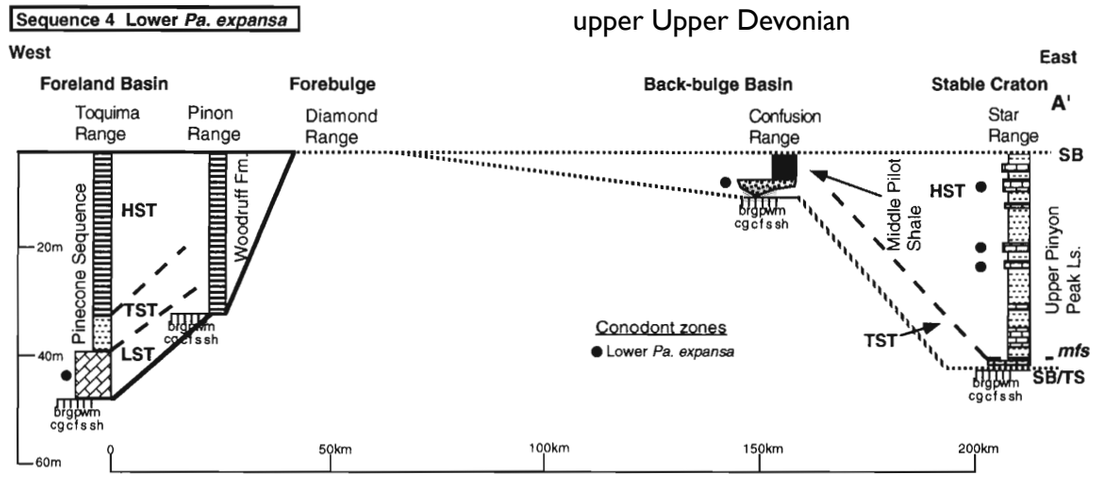
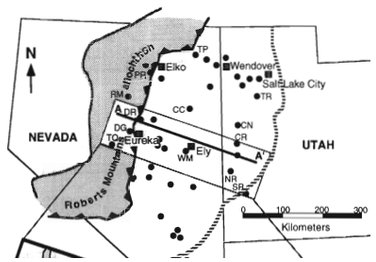


FIG. 8.—Cross section A to A′ displaying Sequence 3 (Lower *Pa. marginifera* to Upper *Pa. marginifera* conodont zone) foreland strata.



Giles & Dickinson, *SEPM SP 52*, 1995

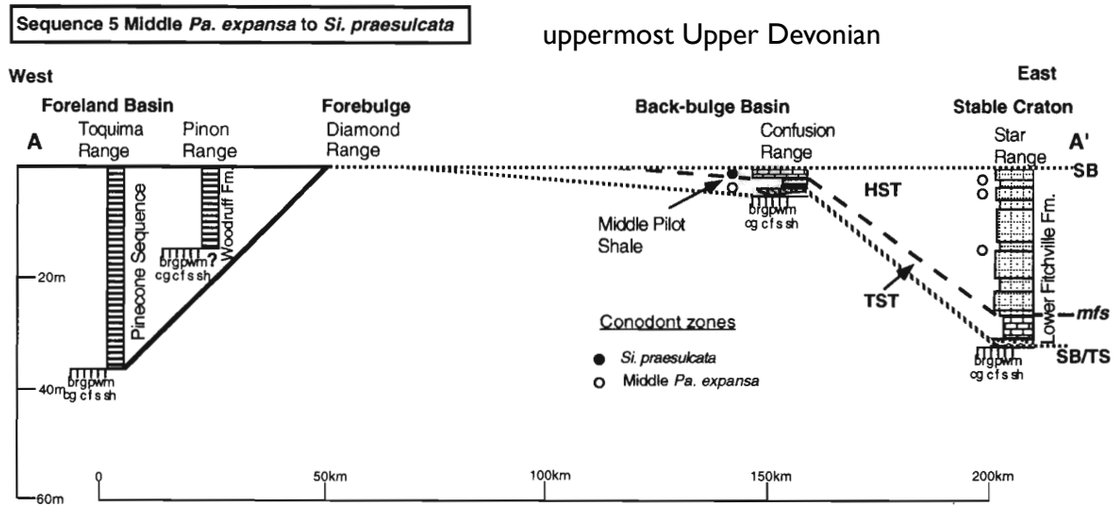
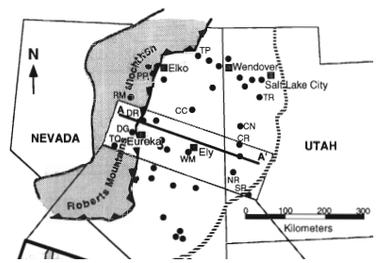
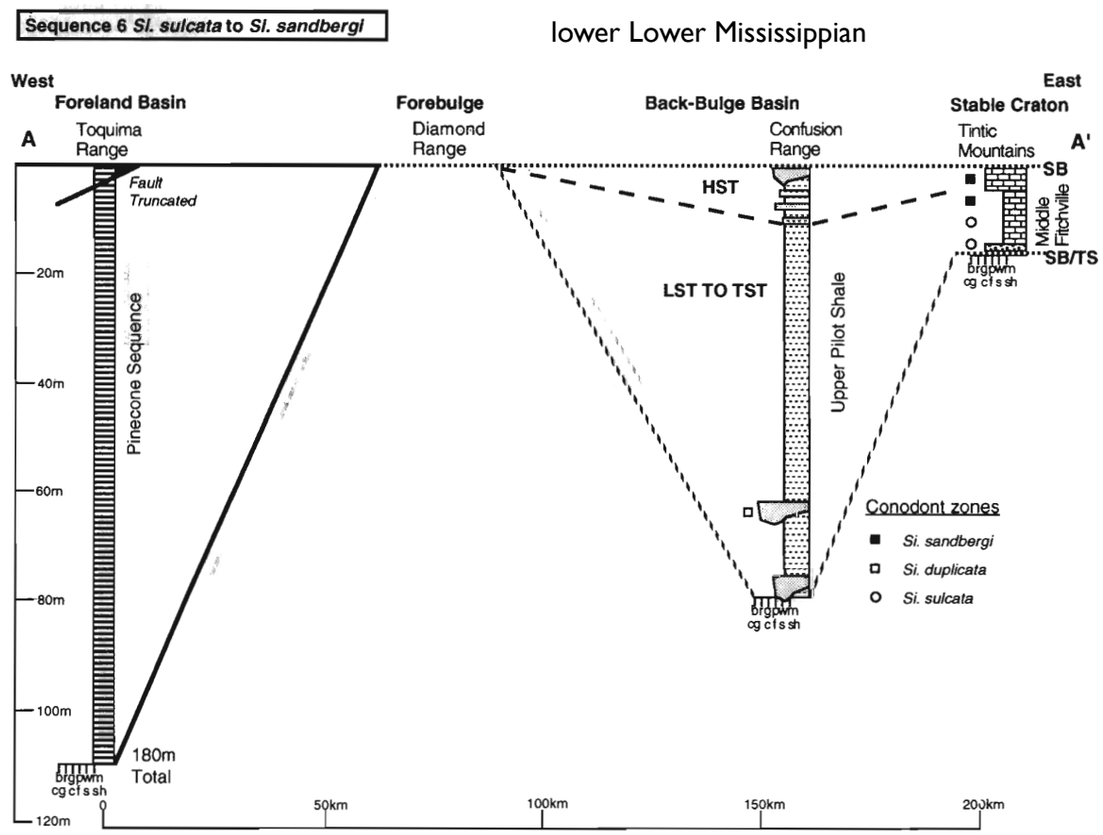


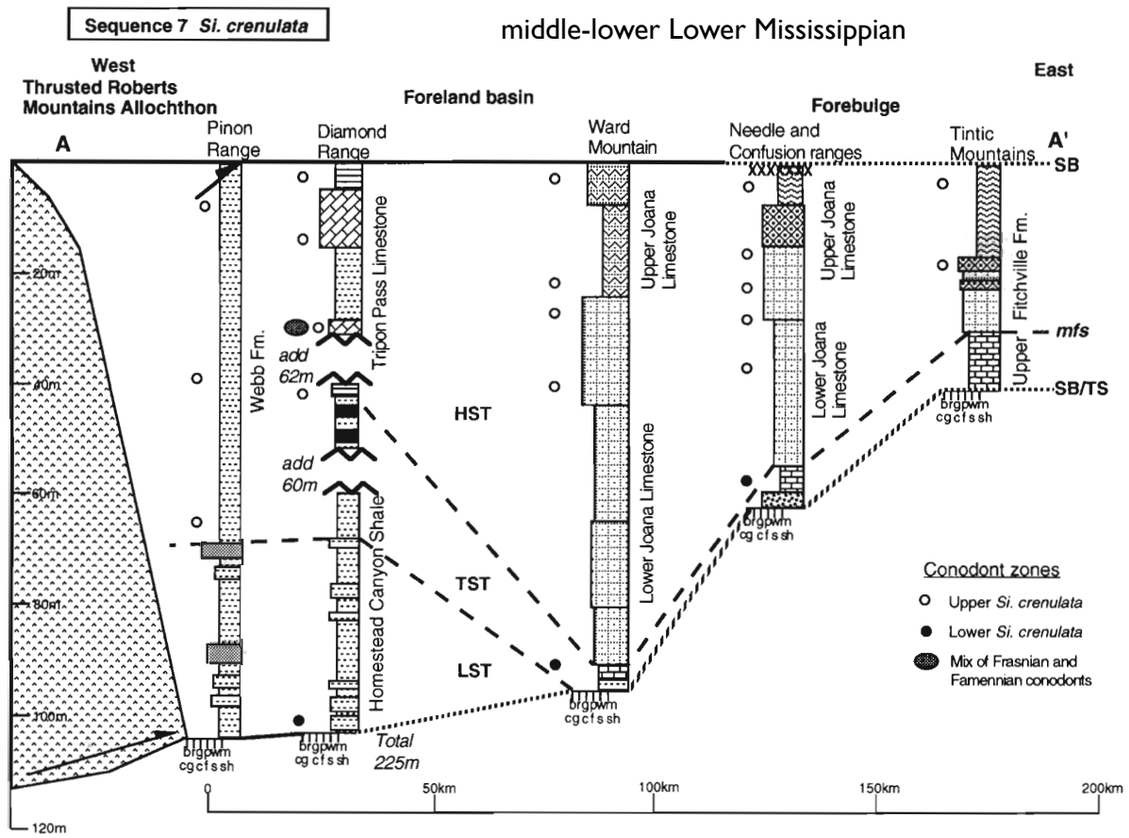
FIG. 9.—Cross section A to A′ displaying Sequence 4 (Lower *Pa. expansa* conodont zone) foreland strata.



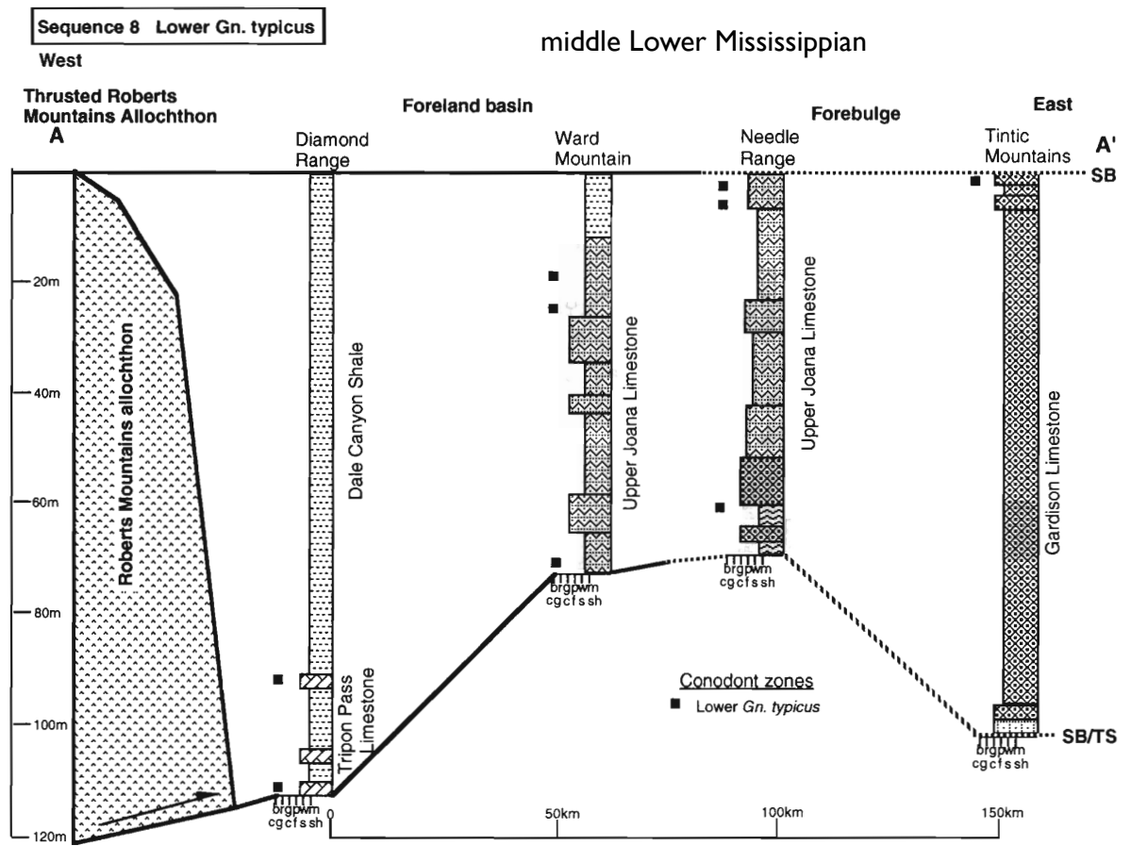
Giles & Dickinson, *SEPM SP 52*, 1995



Giles & Dickinson, *SEPM SP 52*, 1995

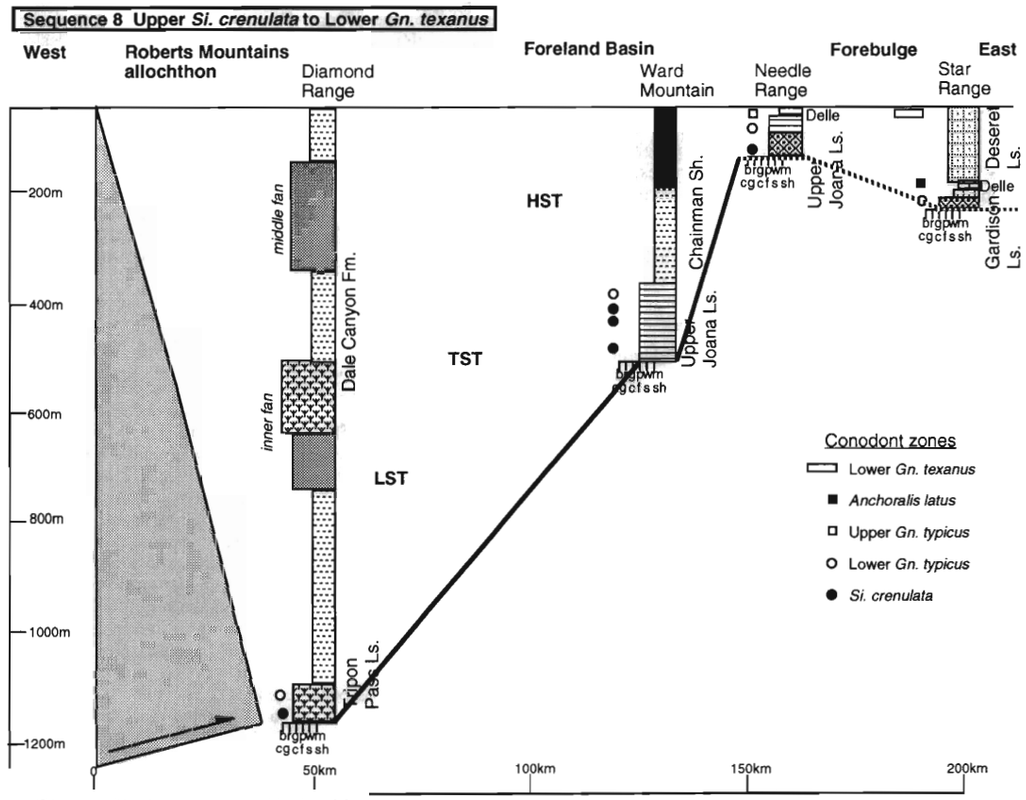


Giles & Dickinson, *SEPM SP 52*, 1995

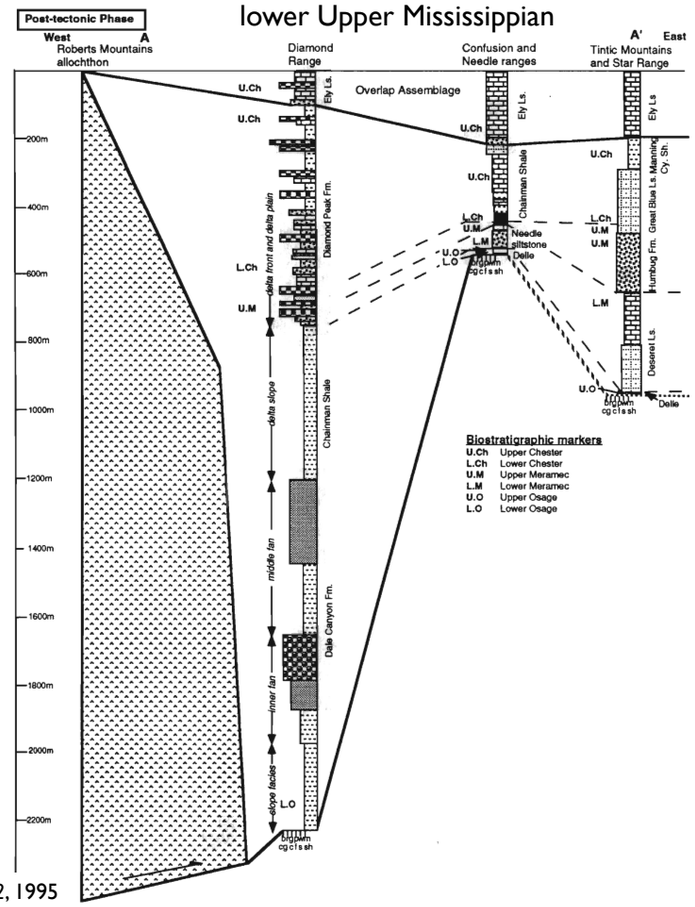


Giles & Dickinson, *SEPM SP 52*, 1995

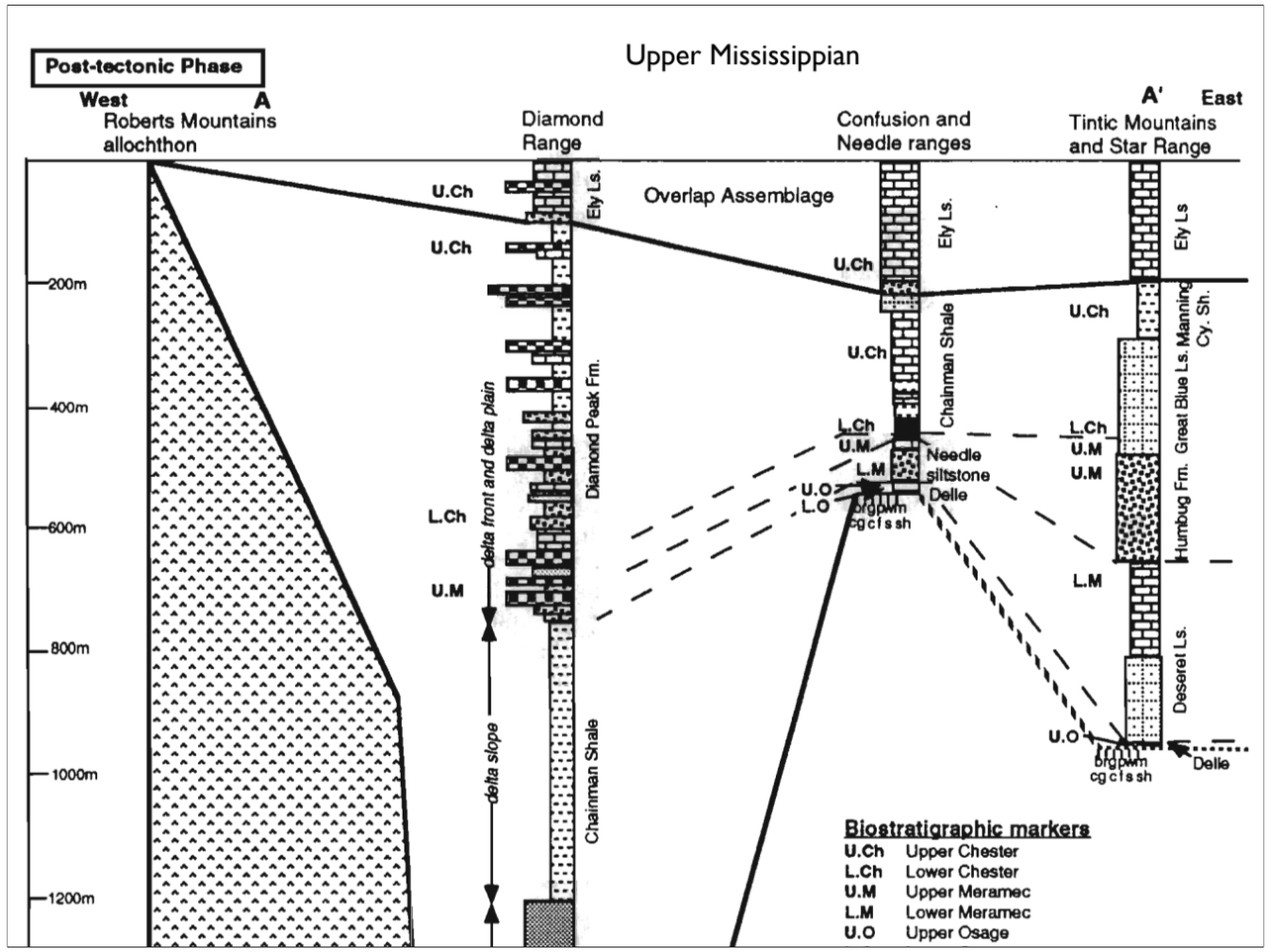
upper Lower Mississippian

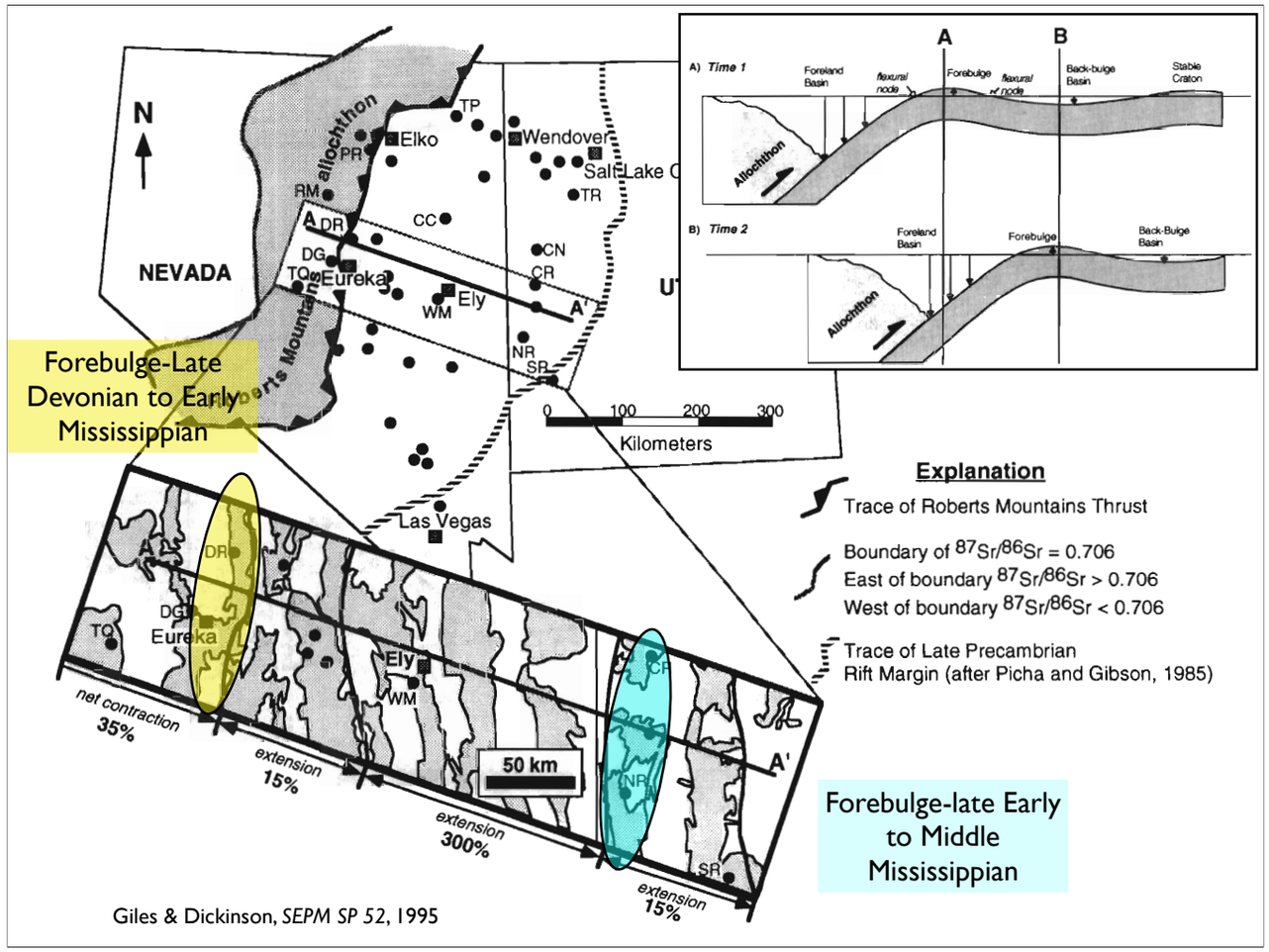


Giles & Dickinson, *SEPM SP 52*, 1995



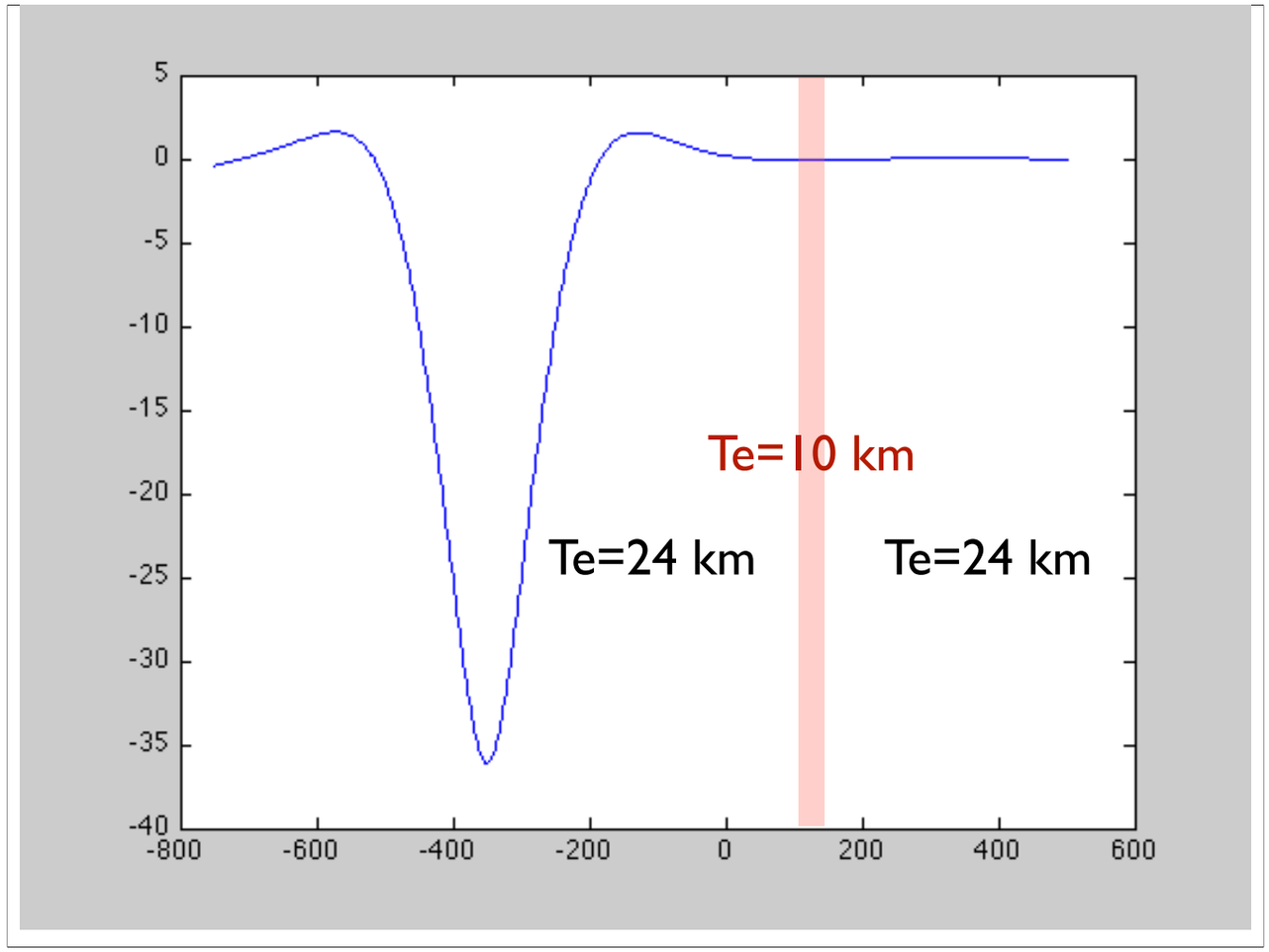
Giles & Dickinson, *SEPM SP 52*, 1995


Post-tectonic Phase
Upper Mississippian
West
A
Roberts Mountains allochthon
Diamond Range
Confusion and Needle ranges
A'
East
Tintic Mountains and Star Range
Overlap Assemblage
Ely Ls.
Diamond Peak Fm.
Chainman Shale
delta front and delta plain
delta slope
Needle siltstone
Delle
Ely Ls
Manning Cy. Sh.
Great Blue Ls.
Humbug Fm.
Deseret Ls.
U.Ch
L.Ch
U.M
L.M
U.O
L.O
200m
400m
600m
800m
1000m
1200m
Biostratigraphic markers
U.Ch Upper Chester
L.Ch Lower Chester
U.M Upper Meramec
L.M Lower Meramec
U.O Upper Osage

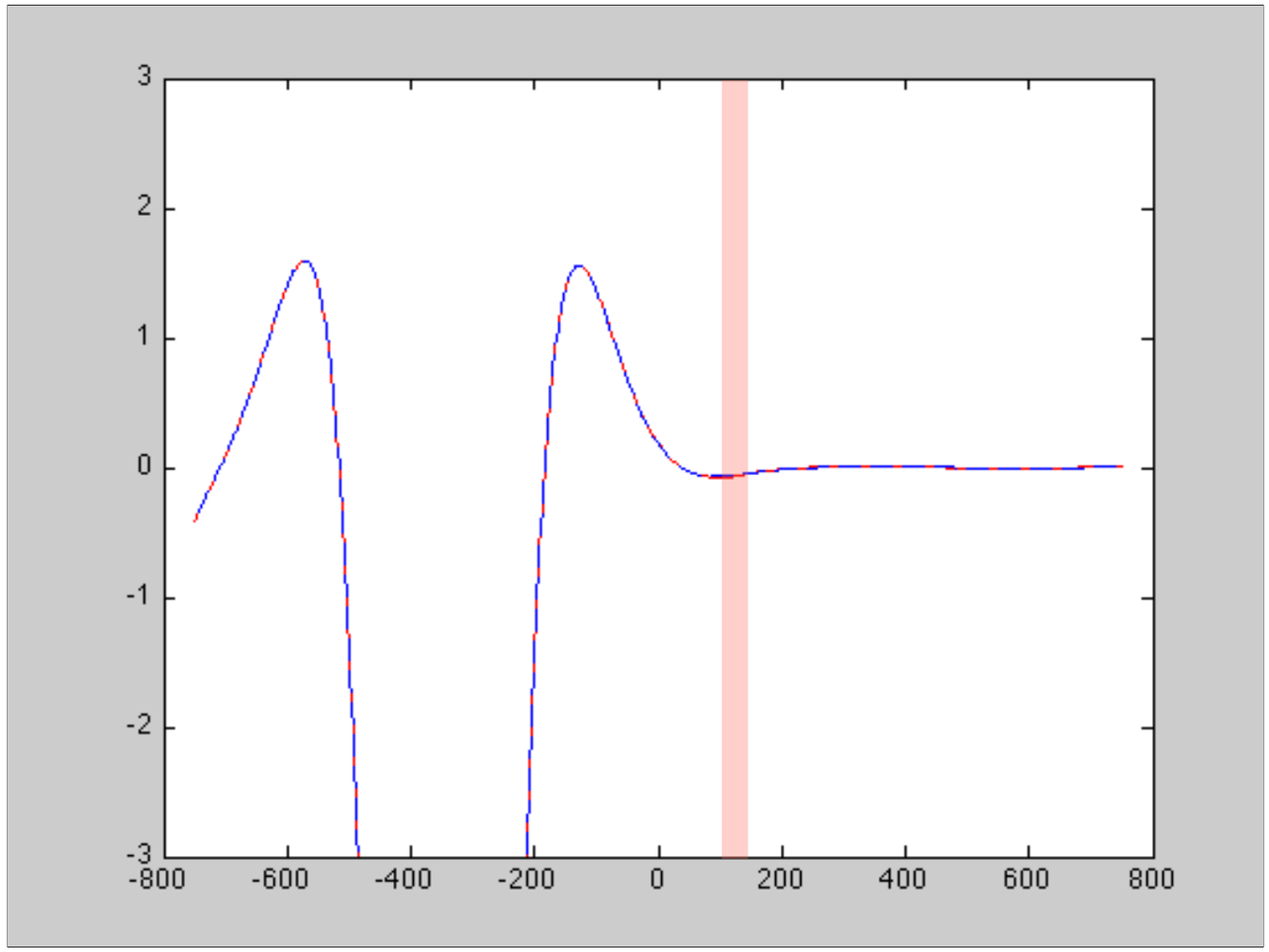


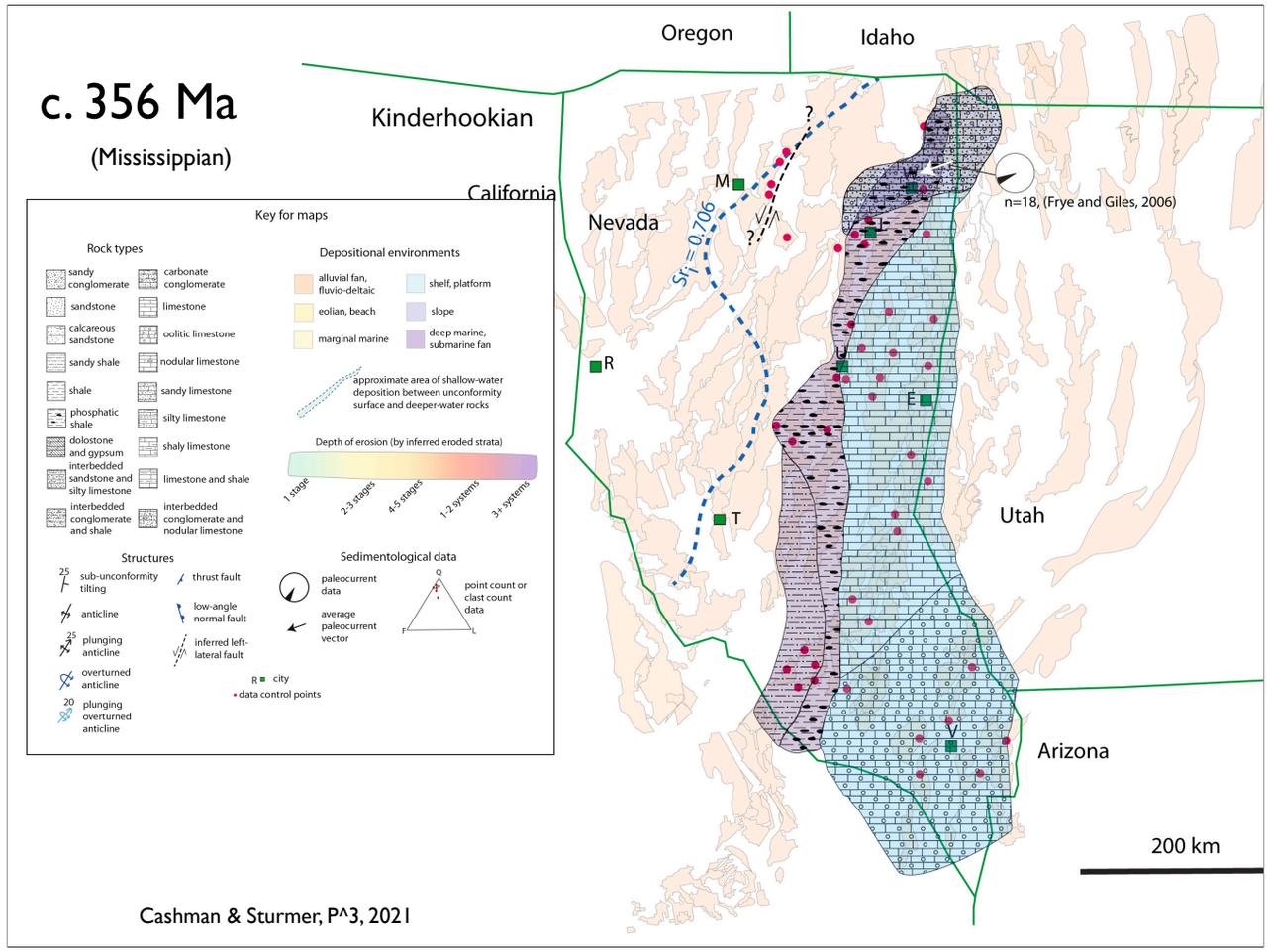
Giles & Dickinson, *SEPM SP 52*, 1995

Seems odd to have forebulge jump so dramatically--how does this happen? Is the flexural interpretation wrong? [Yeah, probably…the earlier forebulge quite plausibly is poor stratigraphy]. Even if older Diamond Range forebulge an artifact, why might the eastern one get stuck? Load not advancing?

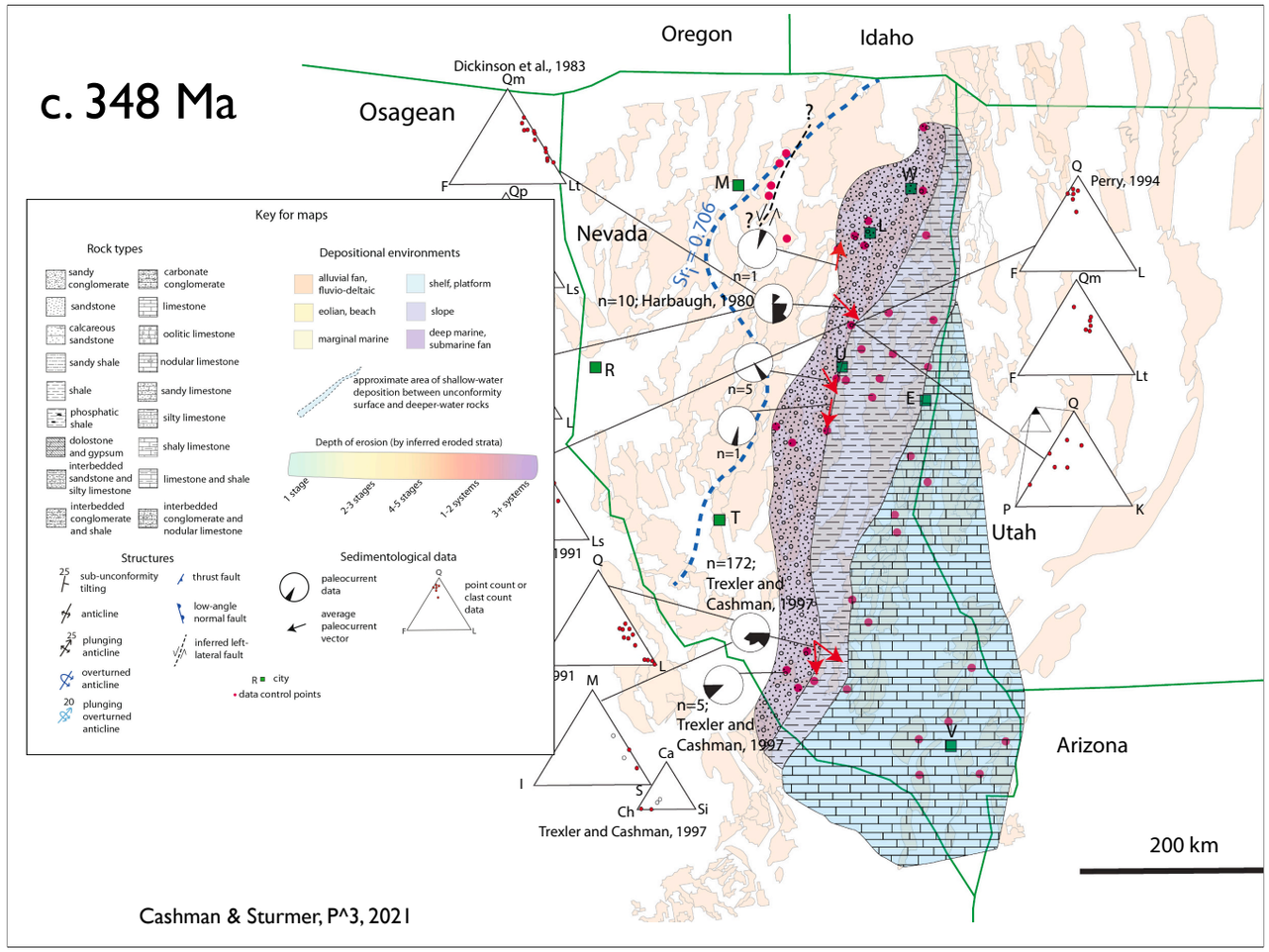


Seems that the forebulge isn't moving smoothly east, right?

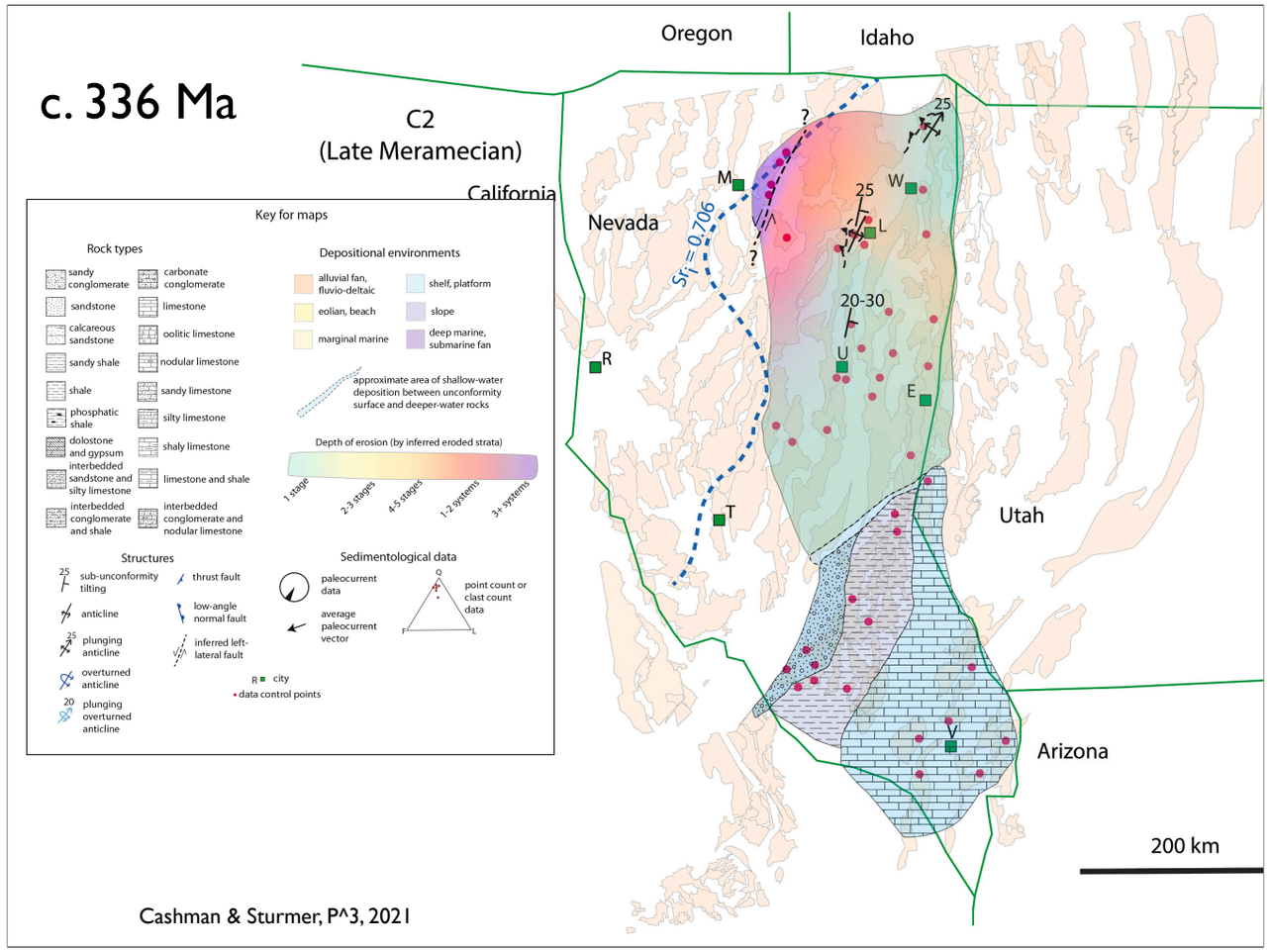

3
2
1
0
-1
-2
-3
-800
-600
-400
-200
0
200
400
600
800



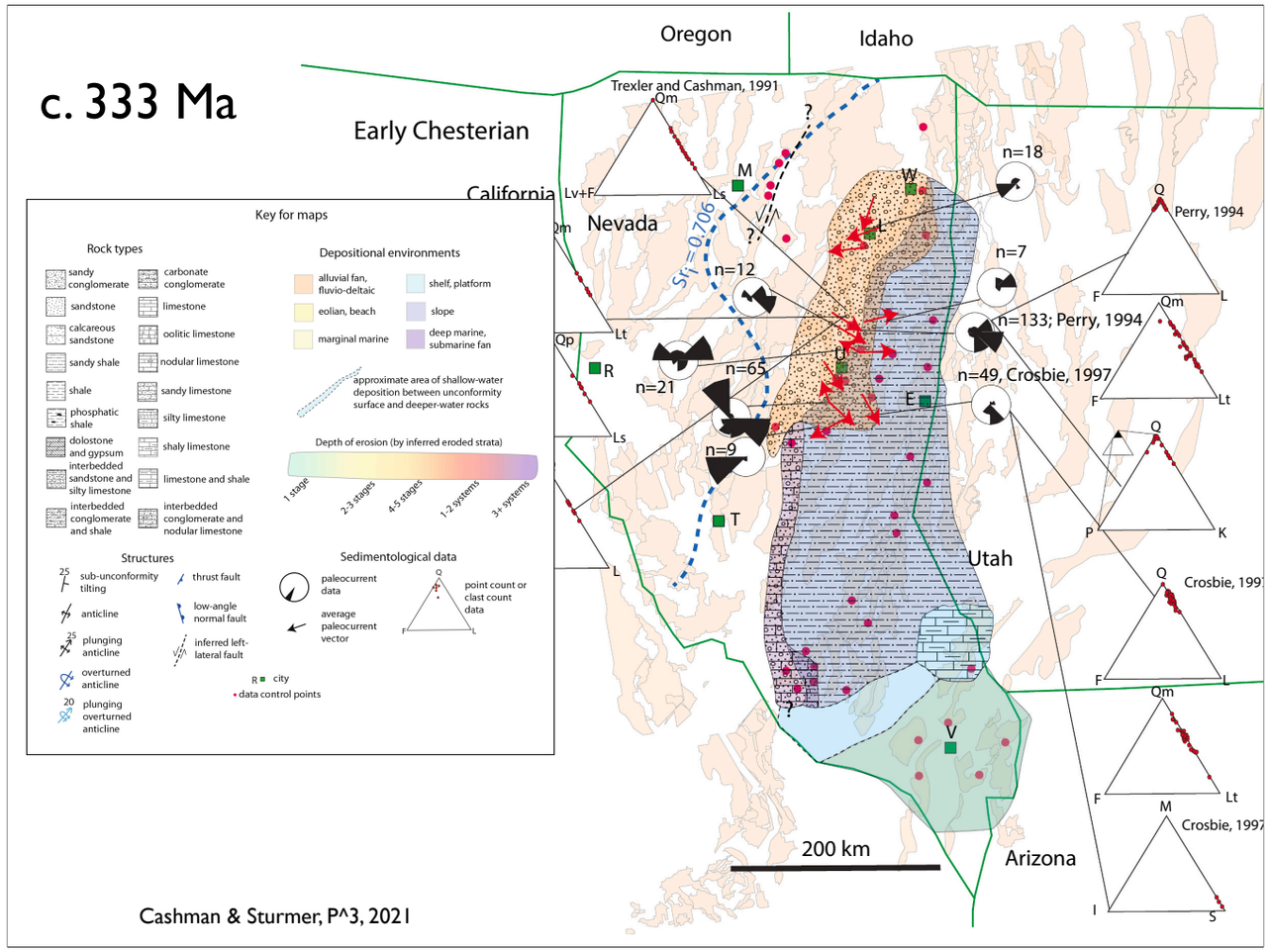
Cashman & Sturmer, P^3, 2021



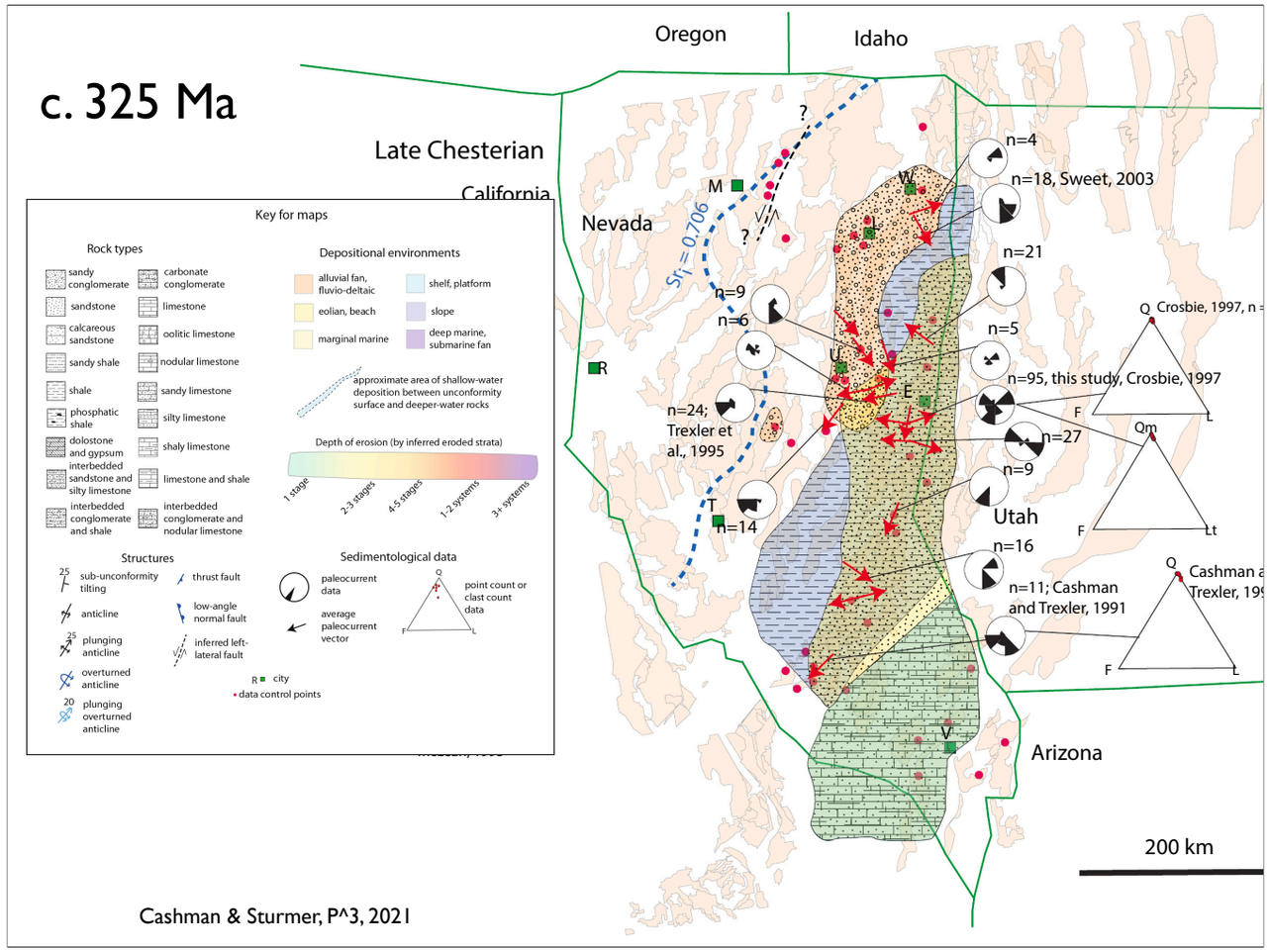
This is the first appearance of sediment (according to these authors) from the Antler allocthon.



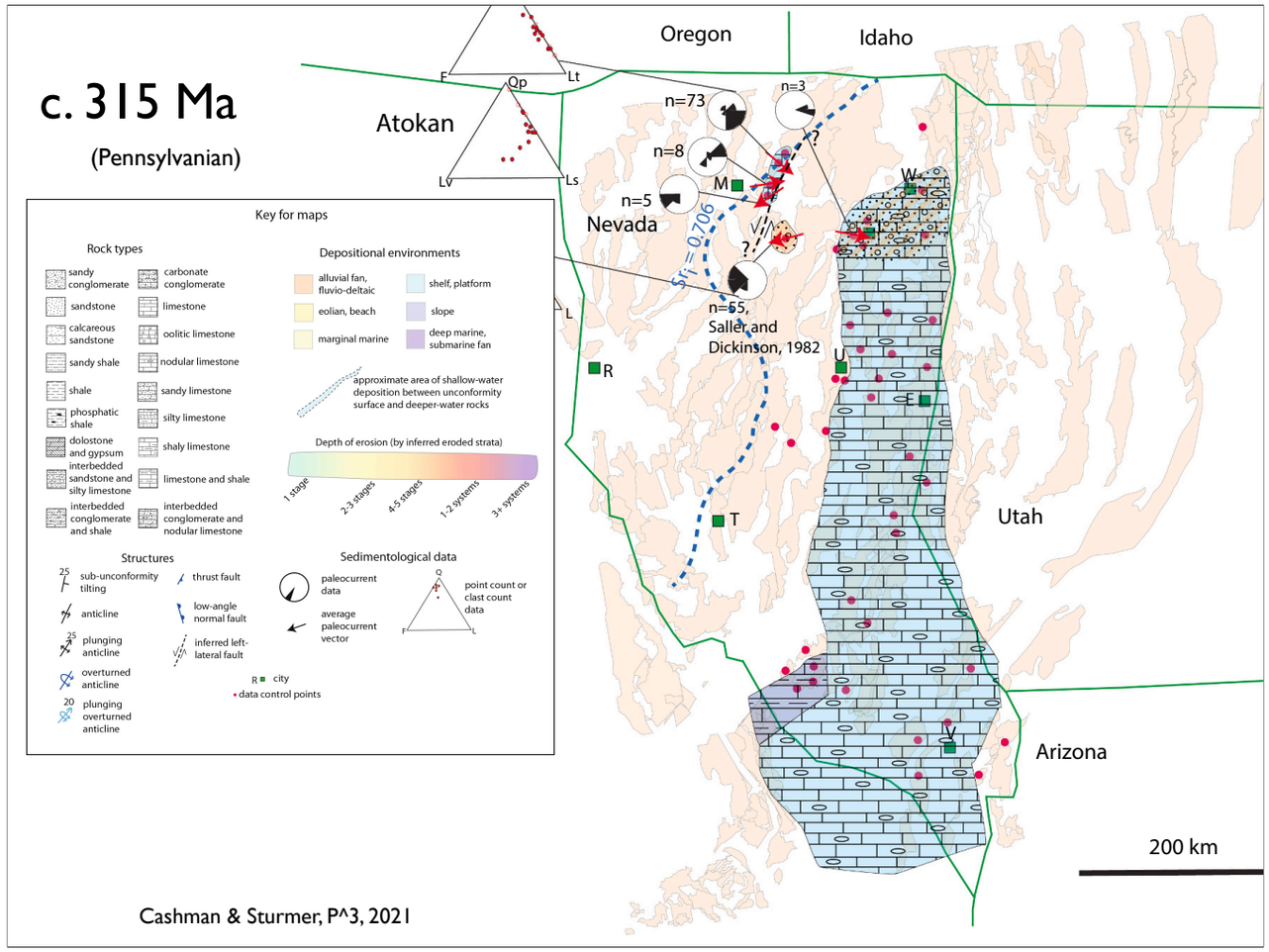
Cashman & Sturmer, P^3, 2021



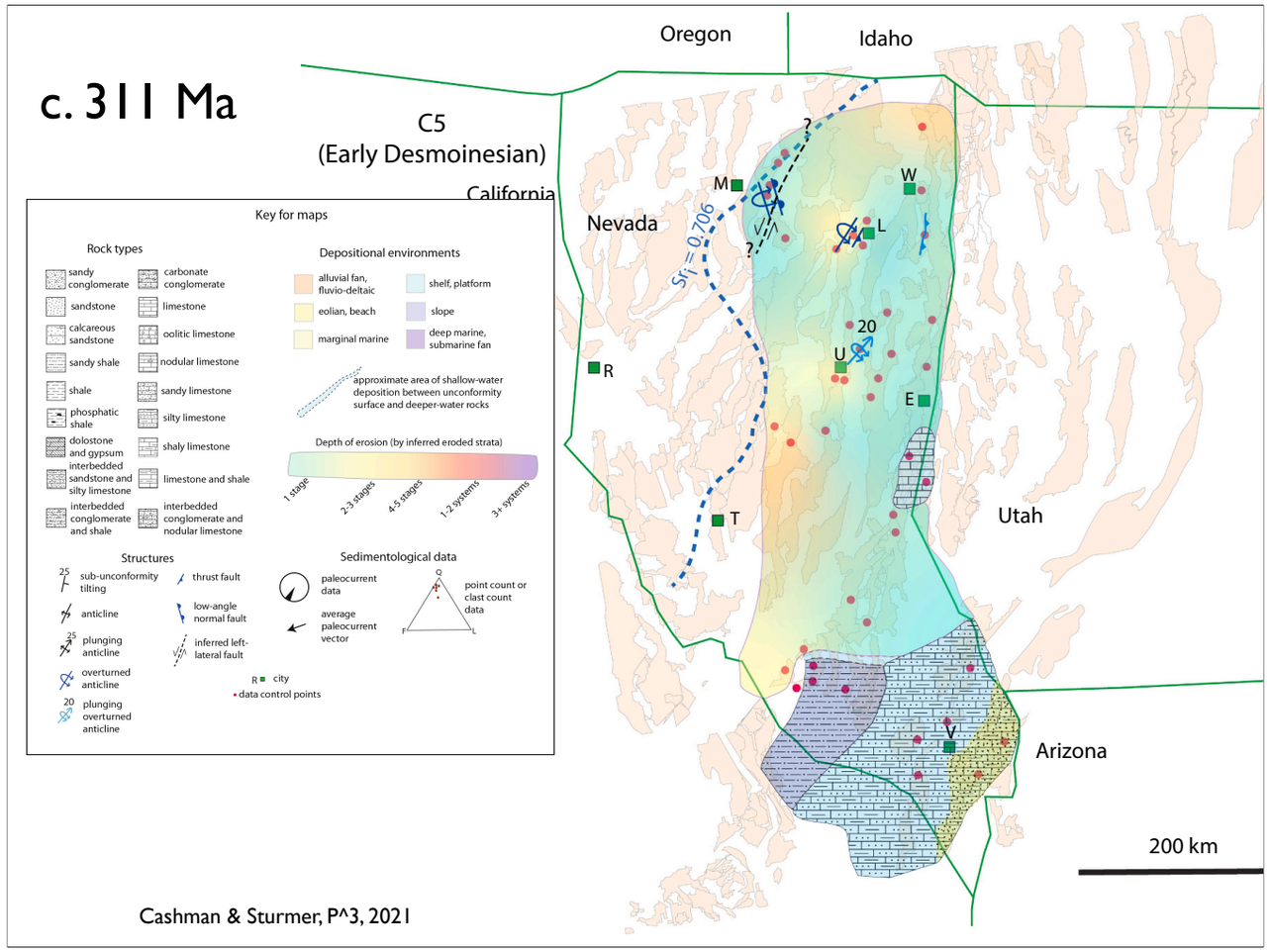
Cashman & Sturmer, P^3, 2021



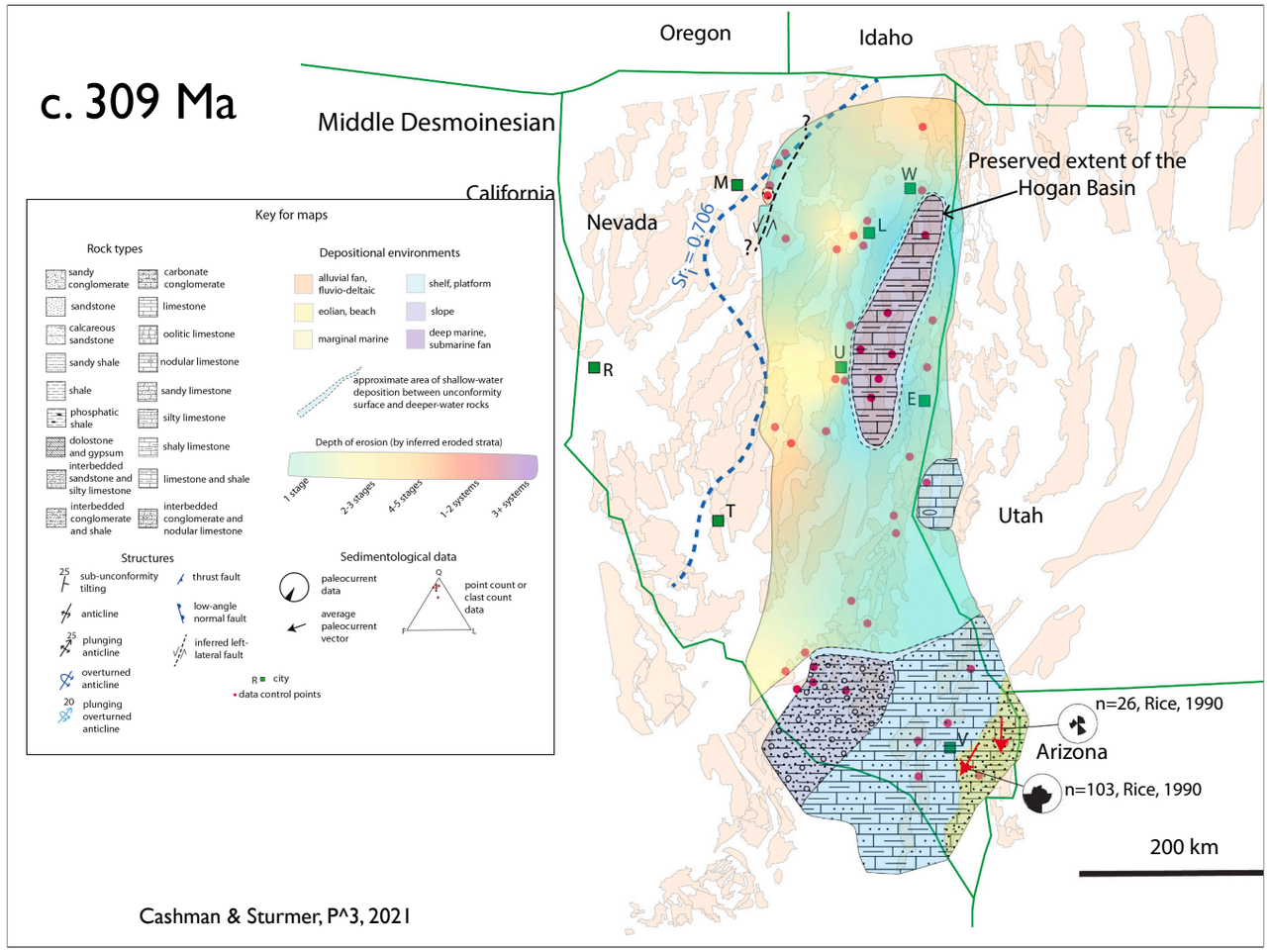
Cashman & Sturmer, P^3, 2021



Cashman & Sturmer, P^3, 2021



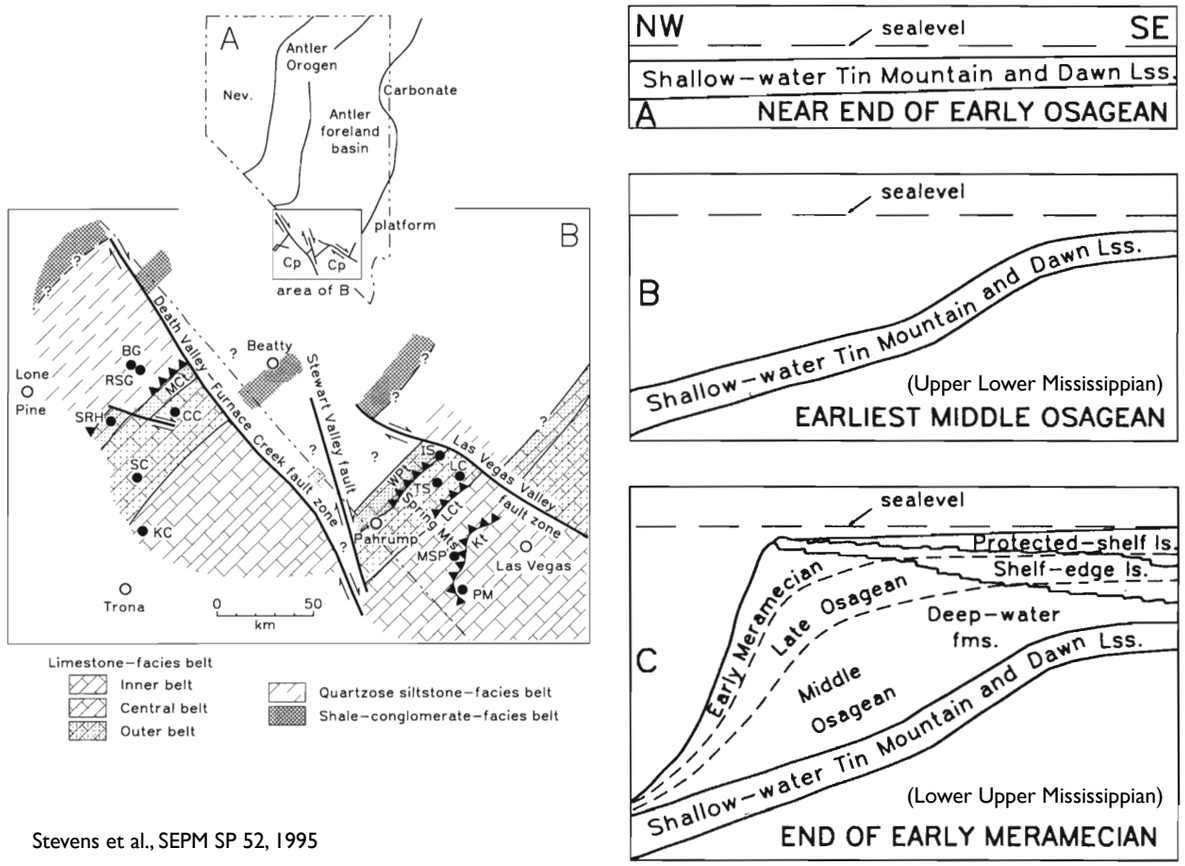
Cashman & Sturmer, P^3, 2021



Cashman & Sturmer, P^3, 2021

This is about the height of the Ancestral Rockies.

Subsidence of Mississippian platform from final Antler?



Stevens et al., SEPM SP 52, 1995

Other evidence of what happened? Mississippian shelf in SE CA subsided rapidly and stablized (kind of like what we saw in Ancestral Rockies). This incidentally suggests there was Antler material to the west…also would make a geo history diagram than would be quite abbreviated.

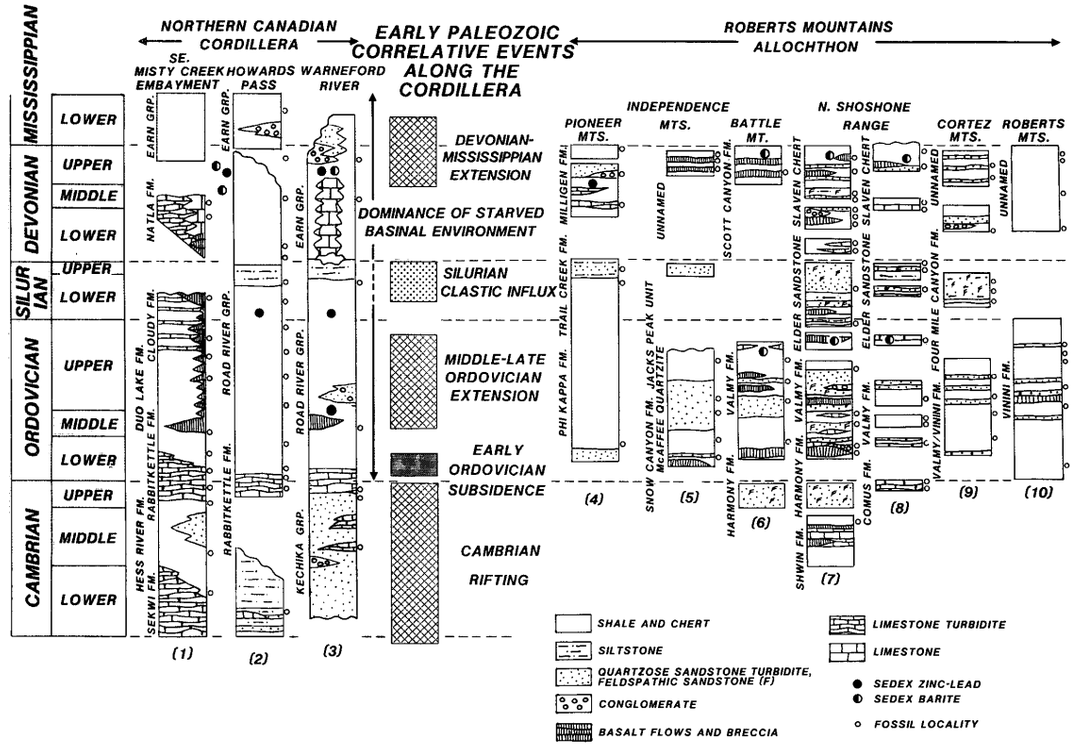


Figure 2. Comparison of stratigraphy of outer continental margin basinal strata of selected areas in northern Canadian Cordillera with strata of Roberts Mountains allochthon. Sources of data for numbered stratigraphic sections: 1—Cecile (1982); 2—Gordey (1981a); 3—Gordey et al (1987); MacIntyre (1983); Fritz (1979); 4—Dover (1981); Turner and Otto (1988); 5—Churkin and Kay (1967); 6, 7, and 9—Madrid (1987); 8—C. T. Wrucke (unpub. data); 10—Murphy et al. (1984); Minnick (1975). Symbols for sedex deposits between stratigraphic columns 1 and 2 represent deposits of Macmillan Pass area, Yukon.

Turner et al., Geology, 1989

Now look at the upper plate…So how extensive is this event (or events?). Some similarities to stuff in Canada, though note that Canadian allocthon is attenuated continental crust while no evidence of such material in Nevada

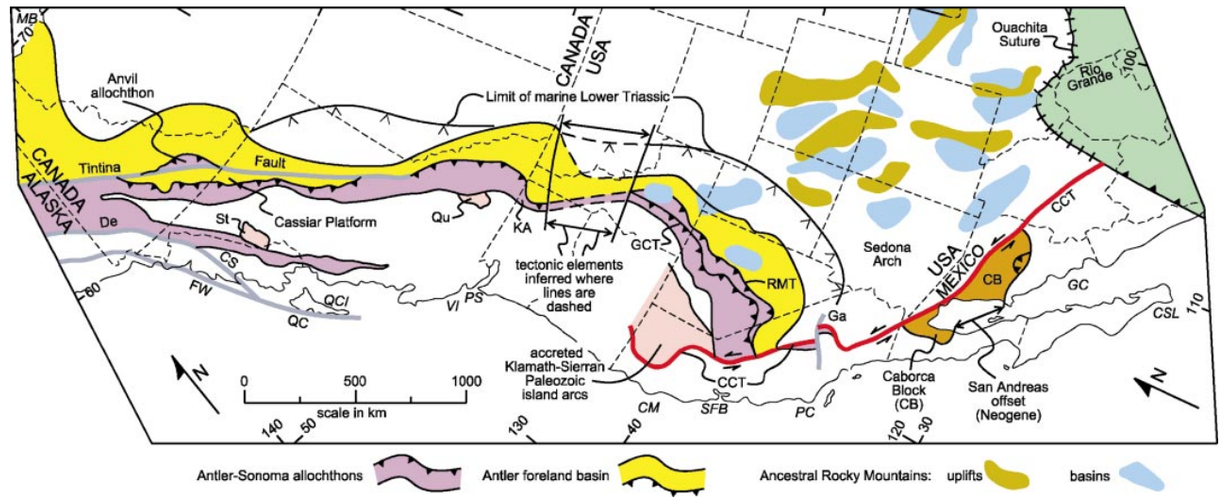
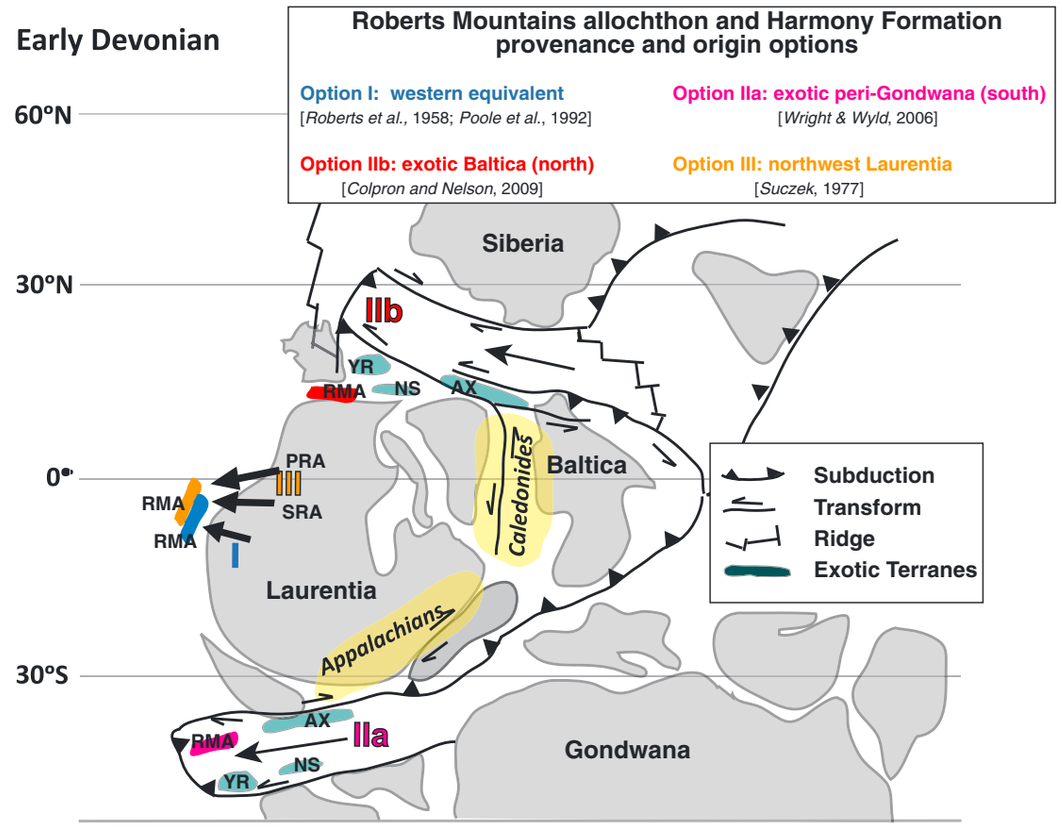


Figure 6 Geotectonic features of the Antler orogen (Late Devonian–Early Mississippian), the Ancestral Rocky Mountains province (Pennsylvanian–Early Permian), and the Sonoma orogen (Late Permian–Early Triassic) of the North American Cordillera (allochthons of Antler and Sonoma age are combined, but note the uncertain continuity of tectonic trends along the trans-Idaho discontinuity of Figure 5). See text for discussion of Kootenay structural arc (KA) and remnants of Paleozoic arc assemblages in Quesnellia (Qu) and Stikinia (St). Key active faults: RMT, Devonian-Mississippian Roberts Mountains thrust; GCT, Permian-Triassic Golconda thrust; CCT, Permian-Triassic California-Coahuila transform. Gondwanan Mexico restored (after Dickinson & Lawton 2001a) to position before mid-Mesozoic opening of the Gulf of Mexico. Tintina and De-CS-FW-QC fault systems are Cenozoic structures. See Figure 5 for geographic legend.

Dickinson, Earth Plan Sci Rev., 2004

OK, so what is this event?



Linde et al., *Tectonics*, 2017

Where might the allocation have come from?

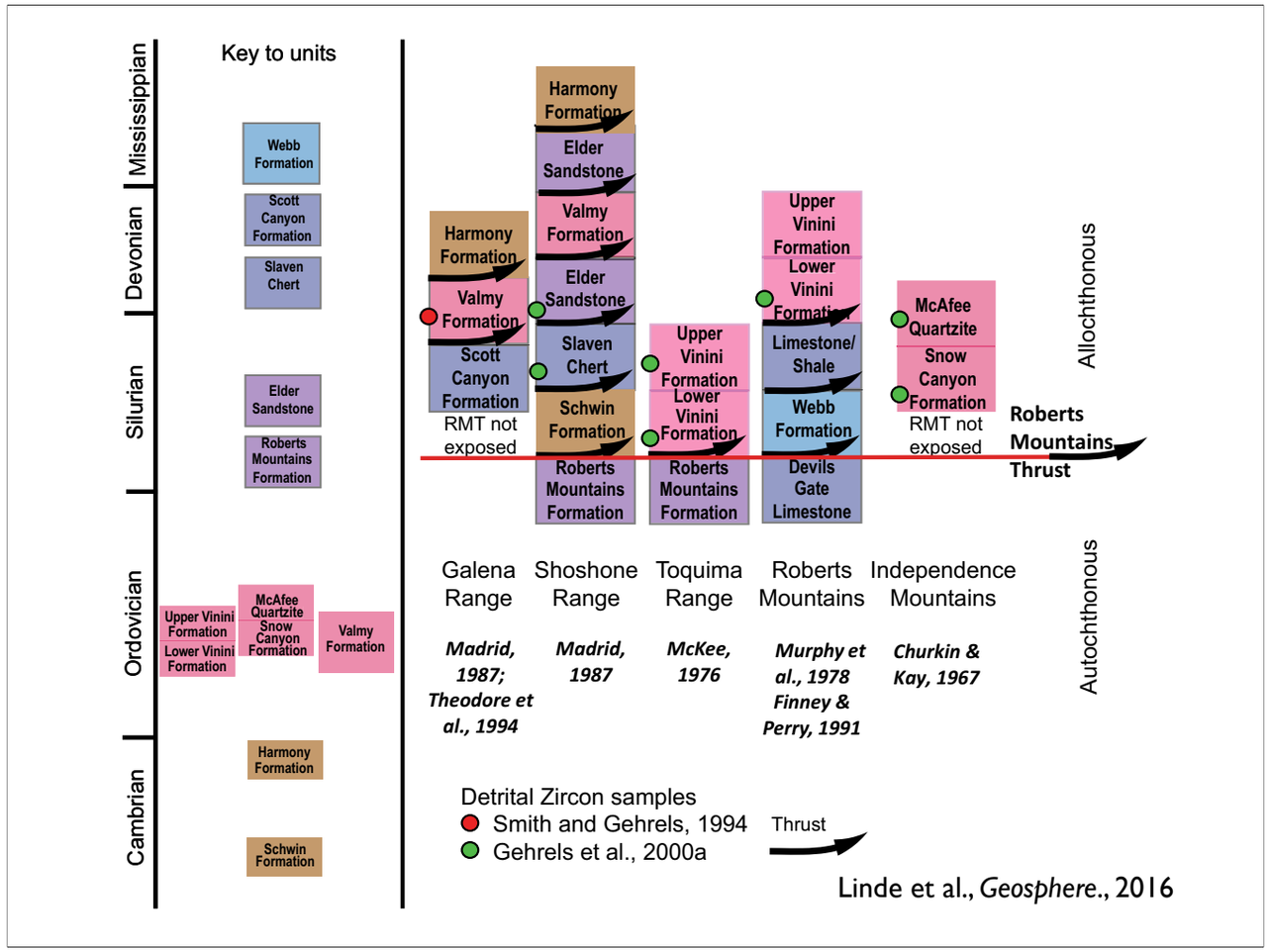
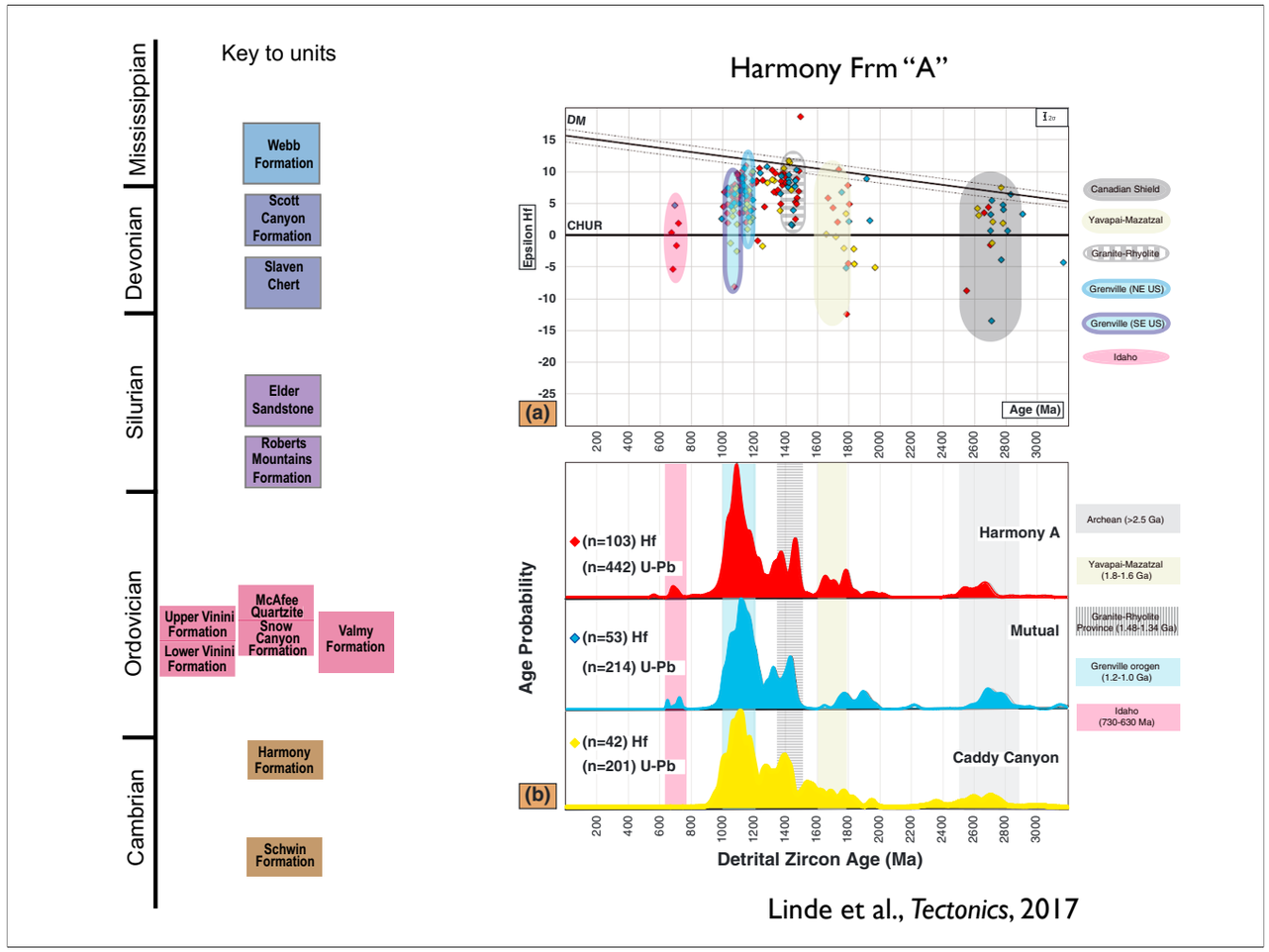


Figure 4. Tectonostratigraphic diagram of units of the Roberts Mountains allochthon (RMA) in selected north-central Nevada mountain ranges, showing locations of detrital zircon samples. Units are shown in their physical, structurally superimposed, order. Most units are internally disrupted with multiple imbricate thrusts not shown on this chart. Units are color coded for geologic period as indicated on left margin of chart.



Lower Harmony Formation, very limited exposures. Looks very Laurentian. Mutual & Caddy Canyon in north-central UT,

Figure 9. (a) Hf isotope data and (b) U-Pb ages for Harmony A samples and selected western Laurentian passive margin strata, showing the similarities between the U-Pb ages and Hf isotope analyses of the Harmony A and these passive margin strata. Data from the upper Neoproterozoic Mutual Formation and Caddy Canyon Quartzite are from Gehrels and Pecha (2014). Colored age bars that correspond to Laurentian basement terrane ages are superimposed over the U-Pb ages on the normalized probability plots. The ages are from references cited in Figure 3. Colored Hf isotope range areas that correspond to the same Laurentian terranes are shown on the (upper) Hf evolution diagram (Grenville: Bickford et al., 2010; Mueller et al., 2008; Granite-rhyolite province: Goodge & Vervoort, 2006; Mueller et al., 2008; Yavapai-Mazatzal: Holm et al., 2013; Archaean: Rohr et al., 2008; Rohr et al., 2010; and Idaho: Gaschnig et al., 2013). Diagrams and symbols are as in Figure 9.

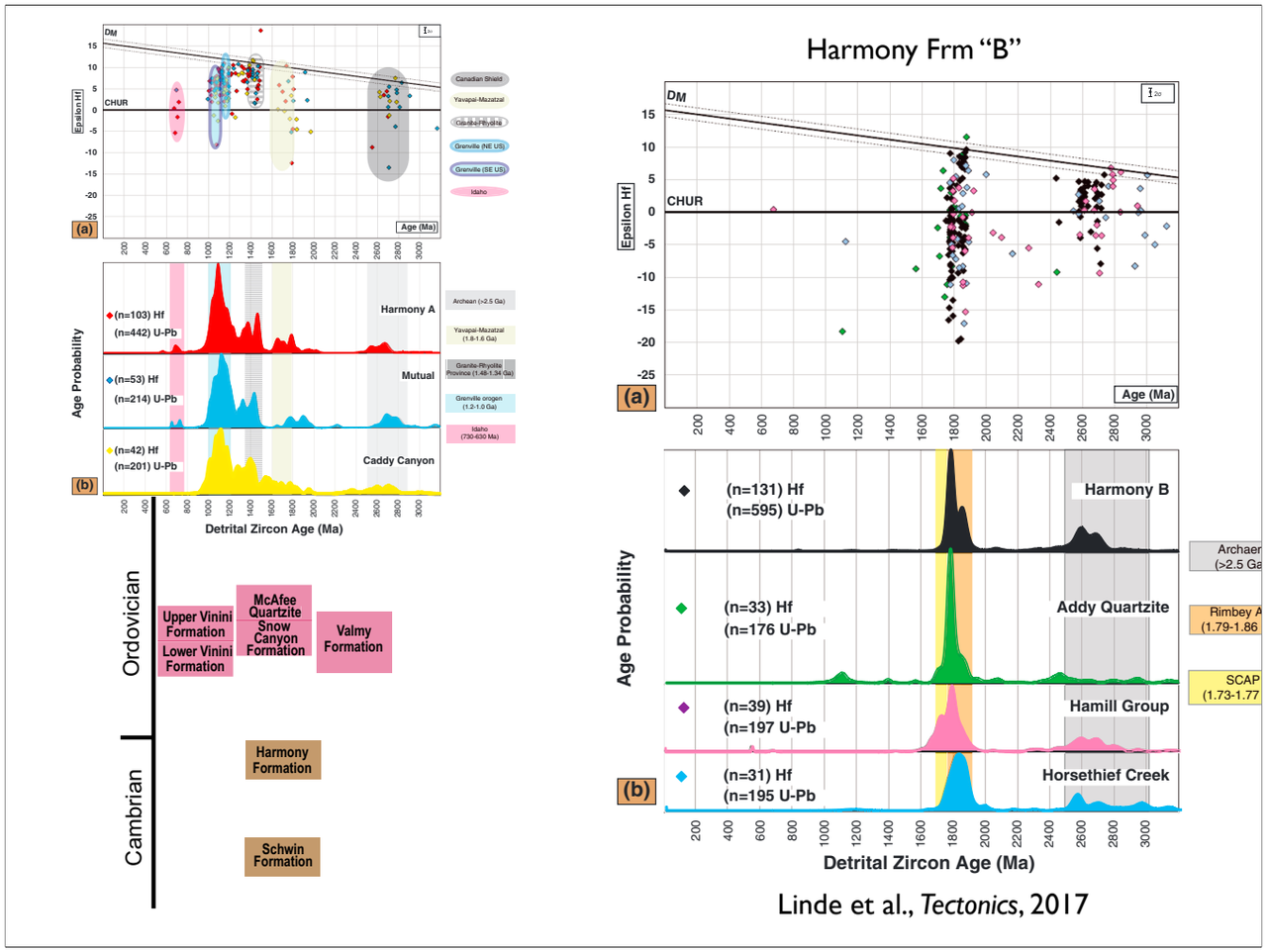
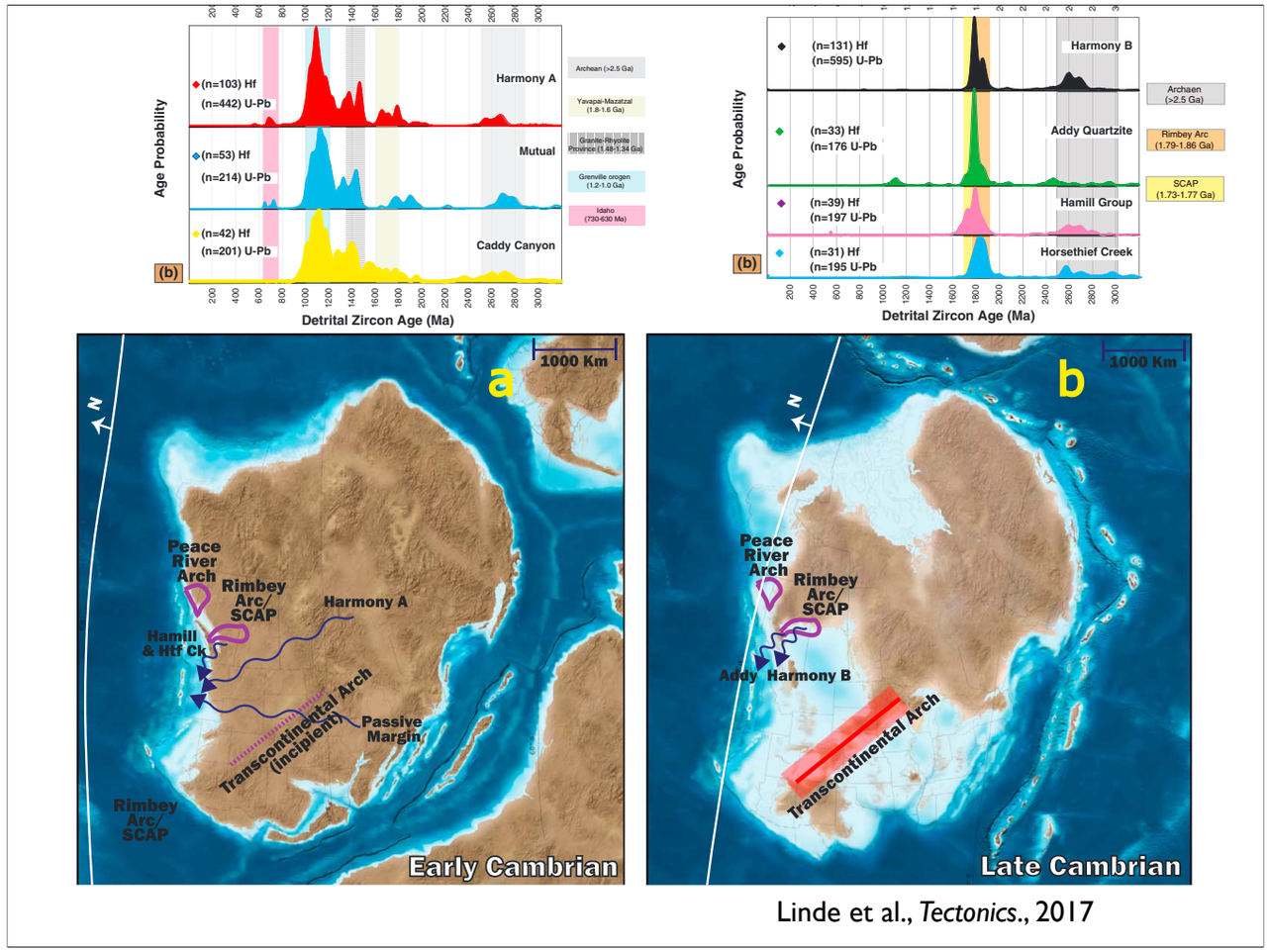
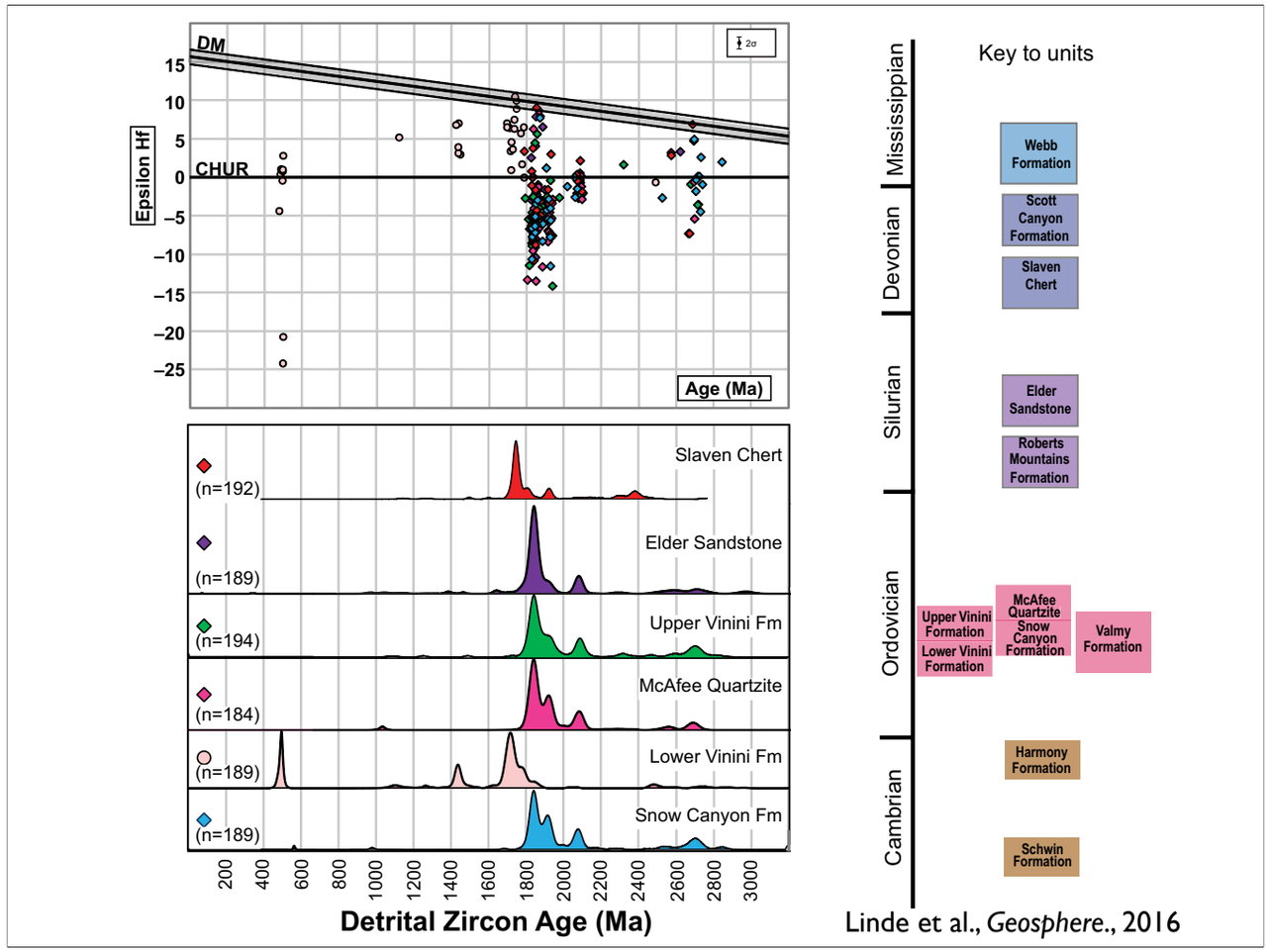


Figure 10. (a) Hf isotope data and (b) U-Pb ages for Harmony B samples and select Laurentian passive margin strata, show- ing the similarities between the U-Pb ages and Hf isotope analyses of the Harmony B and these passive margin strata. Colored age bars that correspond to Peace River Arch region and Swift Current anorogenic province basement terrane ages are superimposed over the U-Pb ages on the normalized probability plots. Data from the Horsethief Creek Group and the Hamill Group are from Gehrels and Pecha (2014). U-Pb analyses of the Addy Quartzite are from Linde et al. (2014b). Hf-isotope analyses of the Addy Quartzite are Linde's unpublished work. Diagrams and symbols are as in Figure .

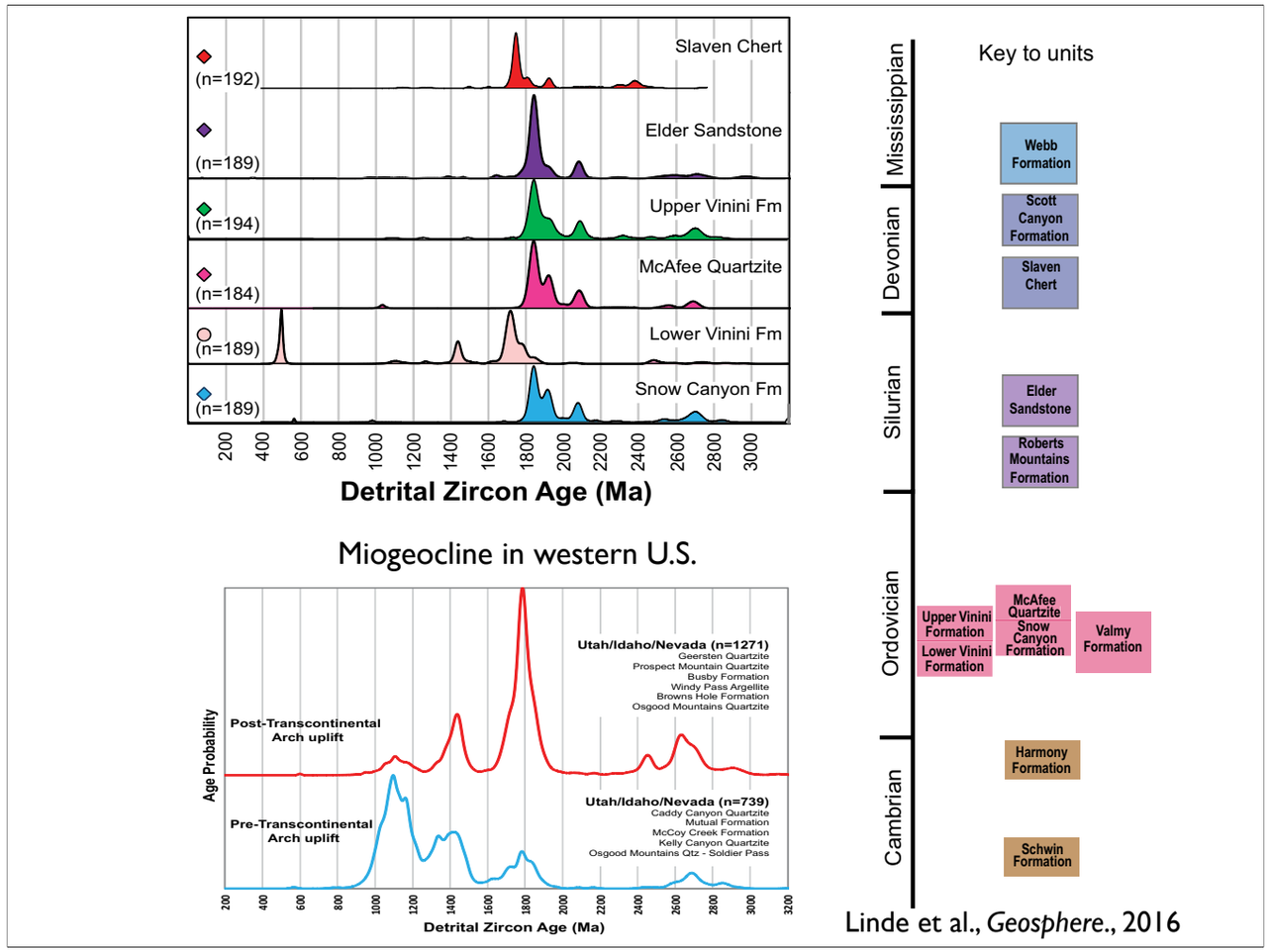


Linde et al., *Tectonics*., 2017

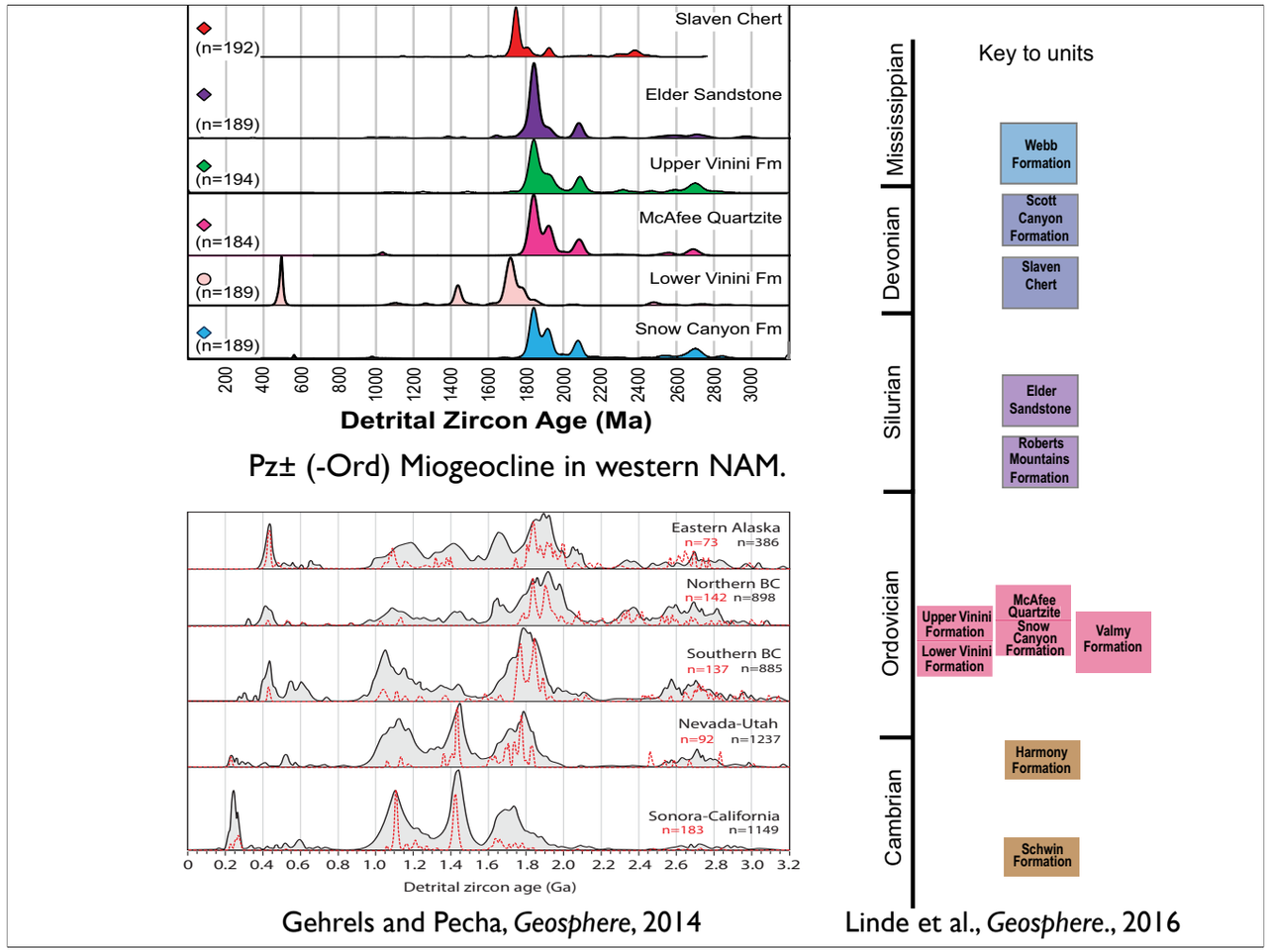
Figure 10. (a) Hf isotope data and (b) U-Pb ages for Harmony B samples and select Laurentian passive margin strata, show- ing the similarities between the U-Pb ages and Hf isotope analyses of the Harmony B and these passive margin strata. Colored age bars that correspond to Peace River Arch region and Swift Current anorogenic province basement terrane ages are superimposed over the U-Pb ages on the normalized probability plots. Data from the Horsethief Creek Group and the Hamill Group are from Gehrels and Pecha (2014). U-Pb analyses of the Addy Quartzite are from Linde et al. (2014b). Hf-isotope analyses of the Addy Quartzite are Linde's unpublished work. Diagrams and symbols are as in Figure .



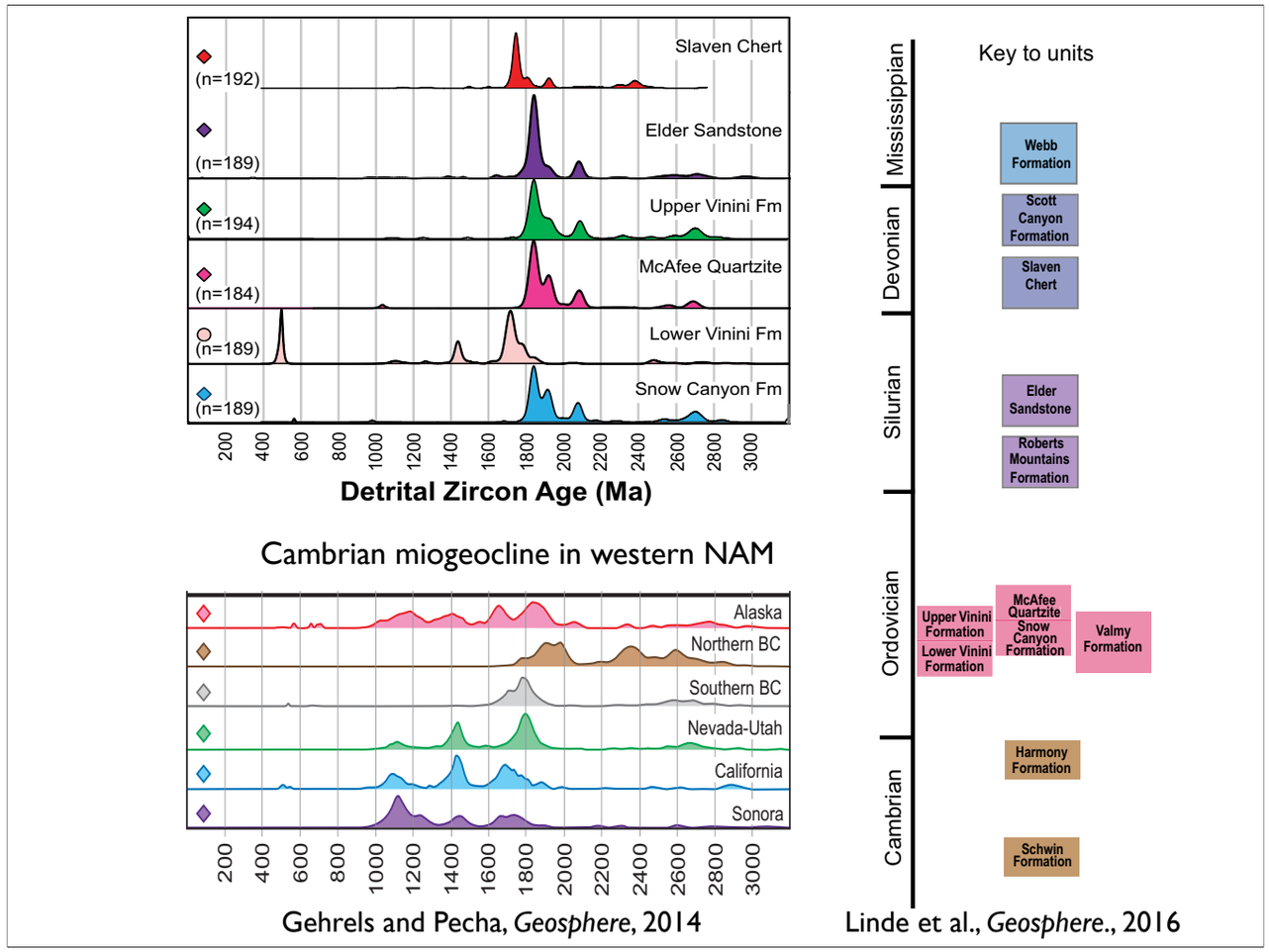
So there are some differences relative to what we usually think of the miogeocline in NV sampling: no 1.4 Ga, no Mazatzal. 500 Ma in Vinini interesting…
Note bottom four are Ordovician, which (as we shall see) is markedly different in miogeocline from older and younger sediments…



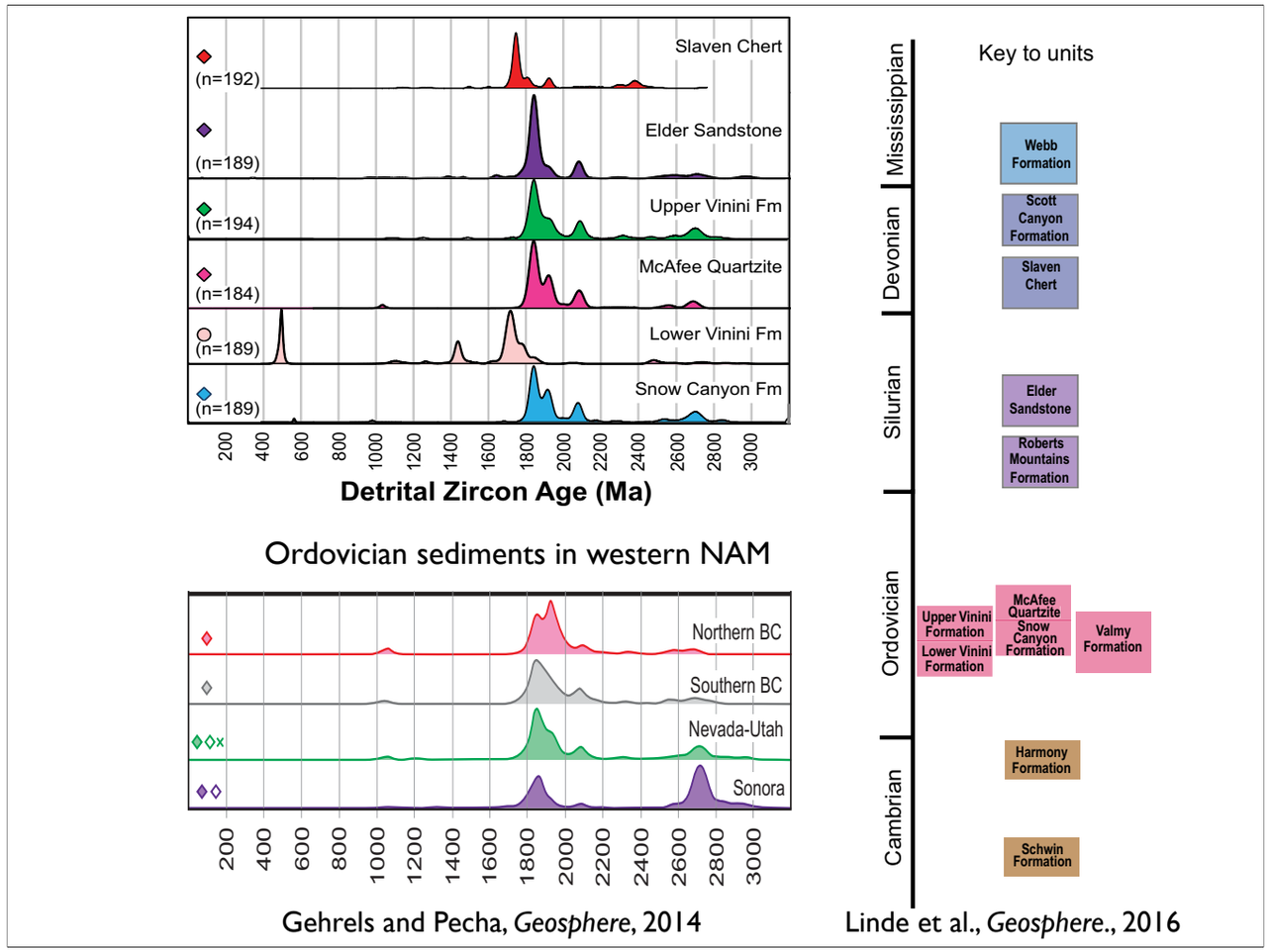
So there are some differences relative to what we usually think of the miogeocline in NV sampling: no 1.4 Ga, no Mazatzal. 1.9, 2.1 Ga peak is absent in miogeocline…



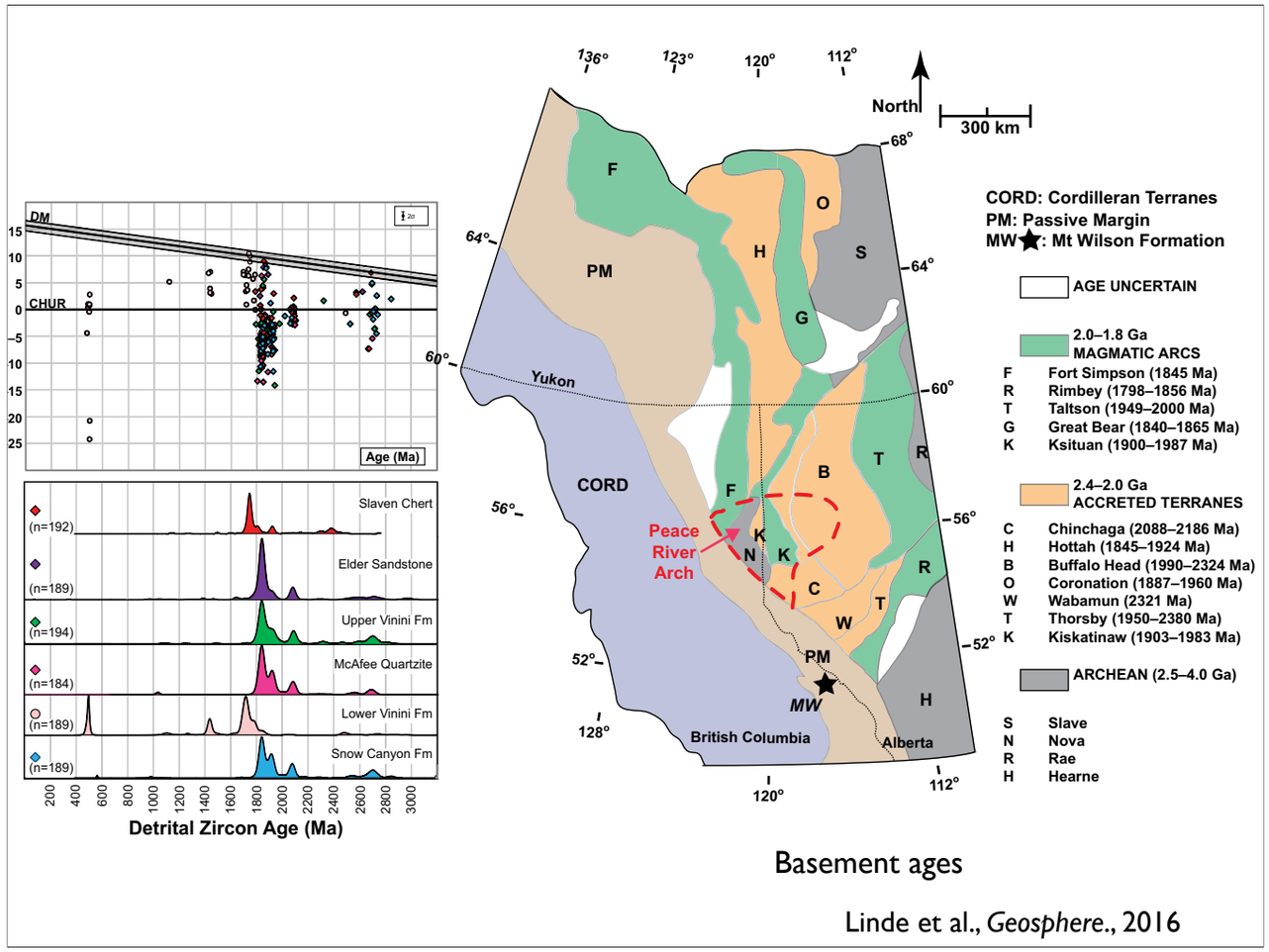
Red lines in Gehrels and Pecha are TIMS dates. Overall, do we see these peaks at any time in W NAM? New plot is all but Ordovician from Tr-Neoprot. seds. Is the 2.1 Ga there? How is the 1.4 missing? Look in more detail…



What looks closest? So there are some differences relative to what we usually think of the miogeocline in NV sampling: no 1.4 Ga, no Mazatzal



Unclear how many of the same samples are in this Ordovician reference, but this is best match. The uniformity of Ordivician ss's along margin suggests strong longshore transport.



Basement ages

Linde et al., *Geosphere*., 2016

Linde et al seem to want to make RMA off Peace River arch (but their maps still show this thing just getting sediment from the far north). We will return to this as we explore the Sonoman and younger exotic terranes. But prompts question: is RMA transported from north, or were just sediments moved that way??

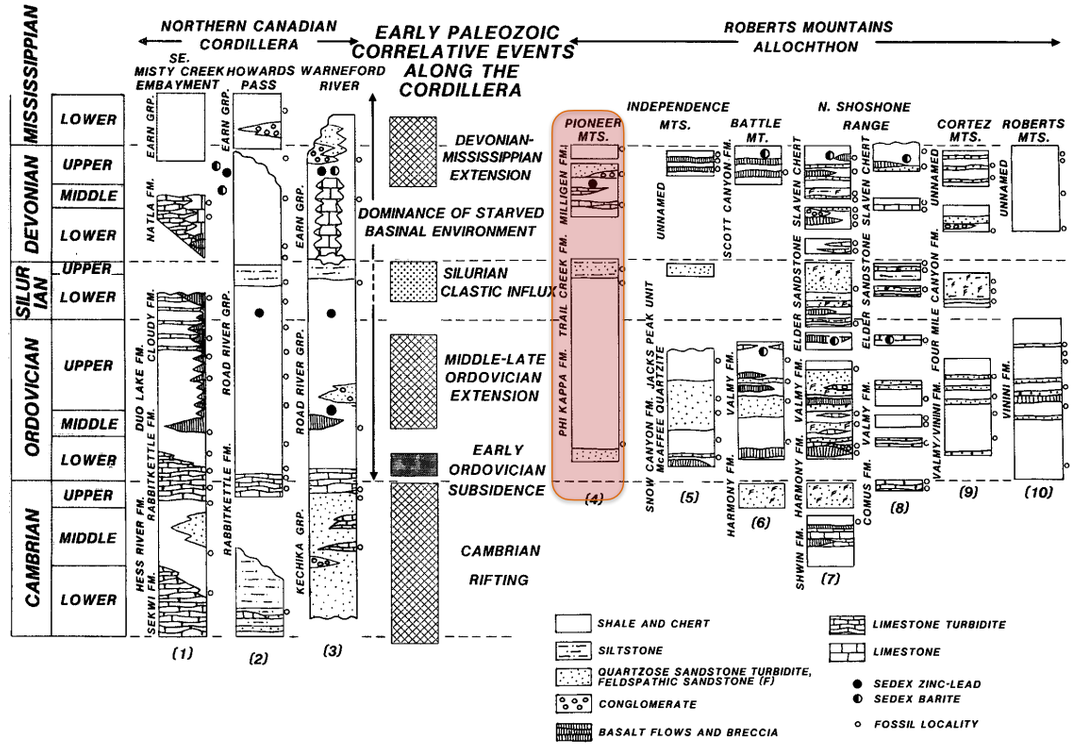
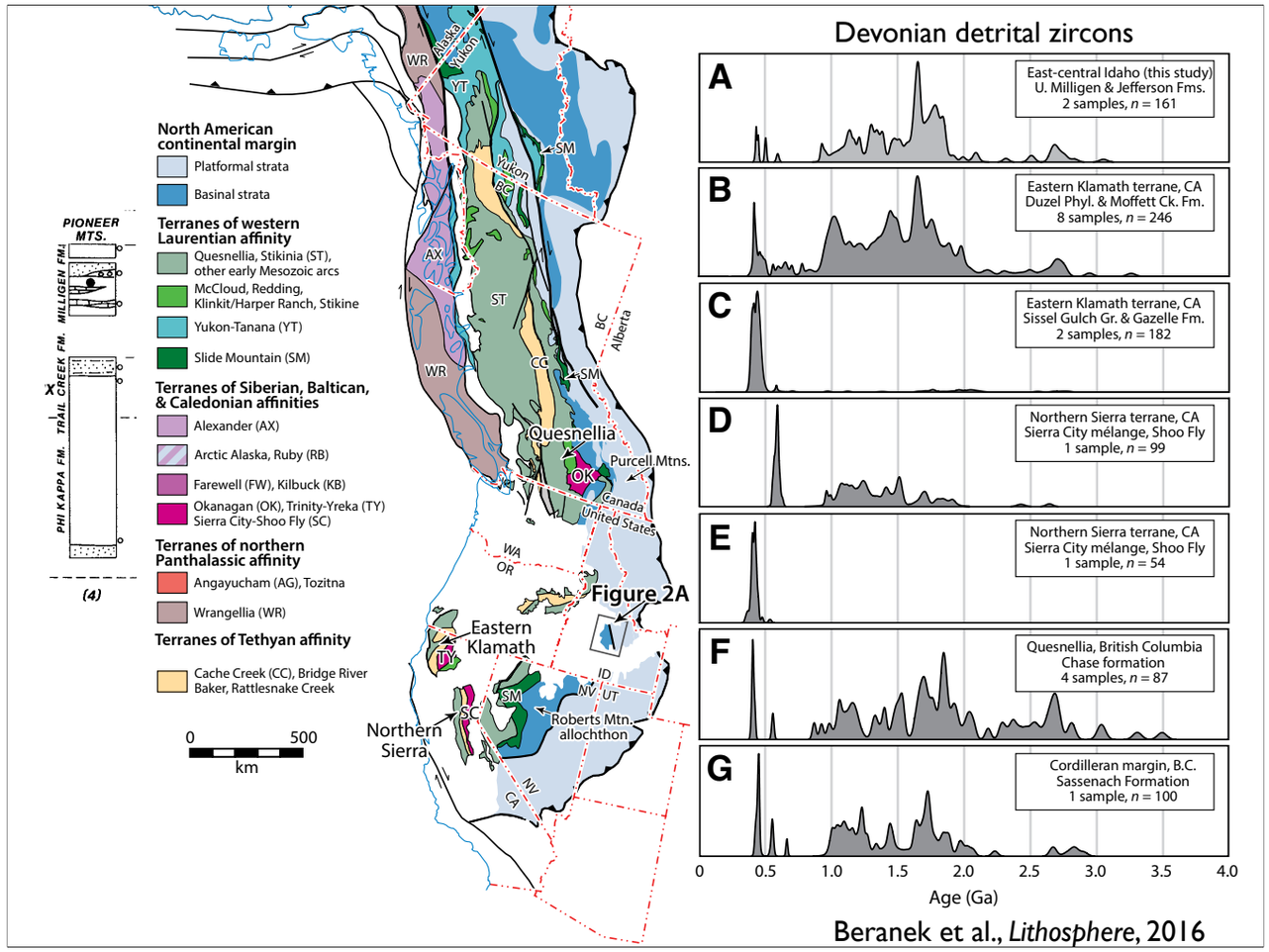


Figure 2. Comparison of stratigraphy of outer continental margin basinal strata of selected areas in northern Canadian Cordillera with strata of Roberts Mountains allochthon. Sources of data for numbered stratigraphic sections: 1—Cecile (1982); 2—Gordey (1981a); 3—Gordey et al (1987); MacIntyre (1983); Fritz (1979); 4—Dover (1981); Turner and Otto (1988); 5—Churkin and Kay (1967); 6, 7, and 9—Madrid (1987); 8—C. T. Wrucke (unpub. data); 10—Murphy et al. (1984); Minnick (1975). Symbols for sedex deposits between stratigraphic columns 1 and 2 represent deposits of Macmillan Pass area, Yukon.

Turner et al., *Geology*, 1989

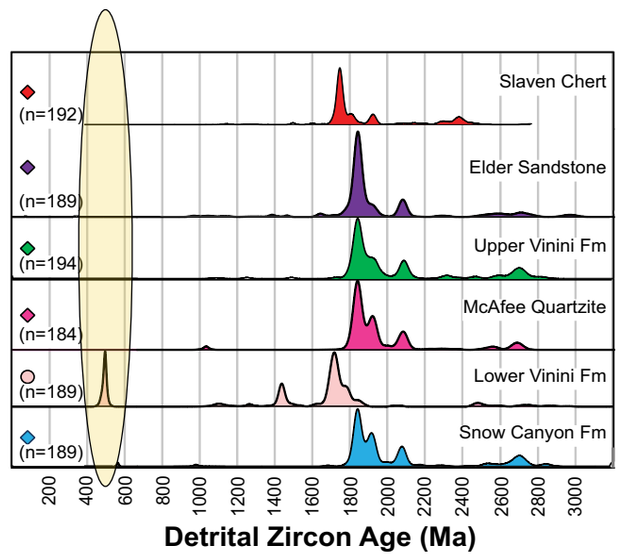
We've focused on Nevada, and pointed out relationships with northern Canada, but what of the middle in Idaho?



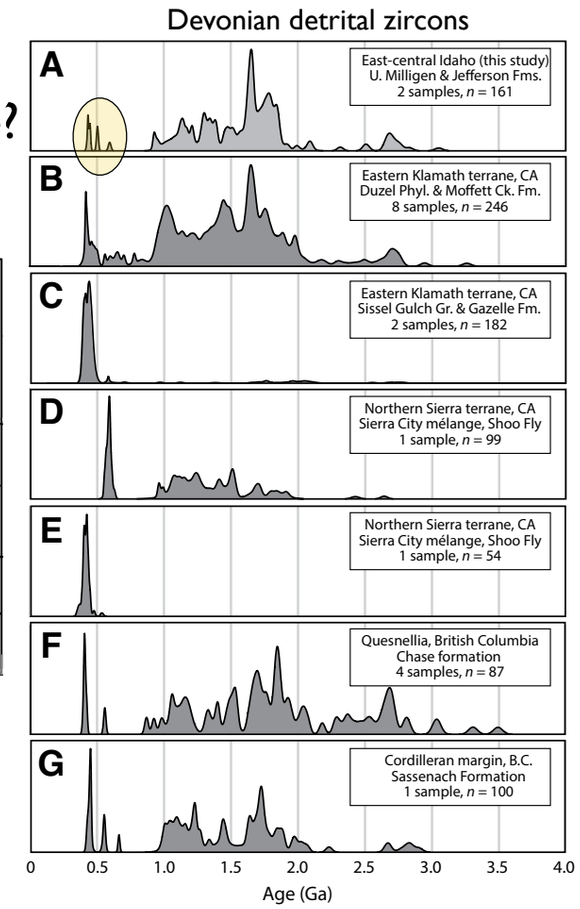
Beranek et al., *Lithosphere*, 2016

Devonian strata here look to have some similarities to the north but also the ~400 Ma zircons point to some volcanic source…

Was there an arc somewhere?

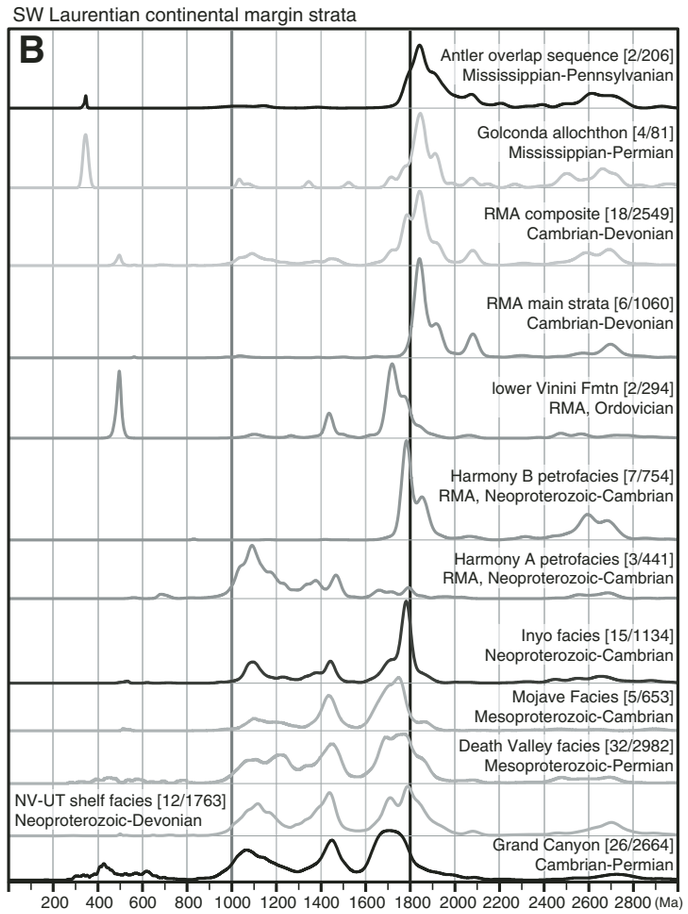


Linde et al., *Geosphere*., 2016



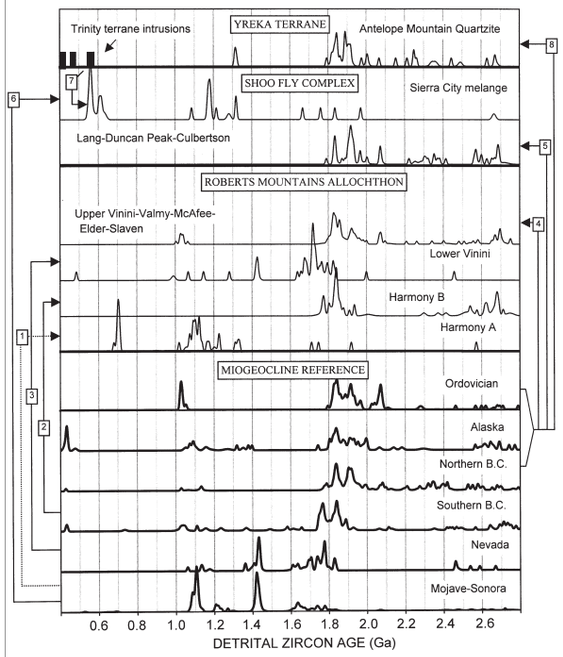
Beranek et al., *Lithosphere*, 2016

Now look at the upper plate…So how extensive is this event (or events?). Some similarities to stuff in Canada, though note that Canadian allocthon is attenuated continental crust while no evidence of such material in Nevada

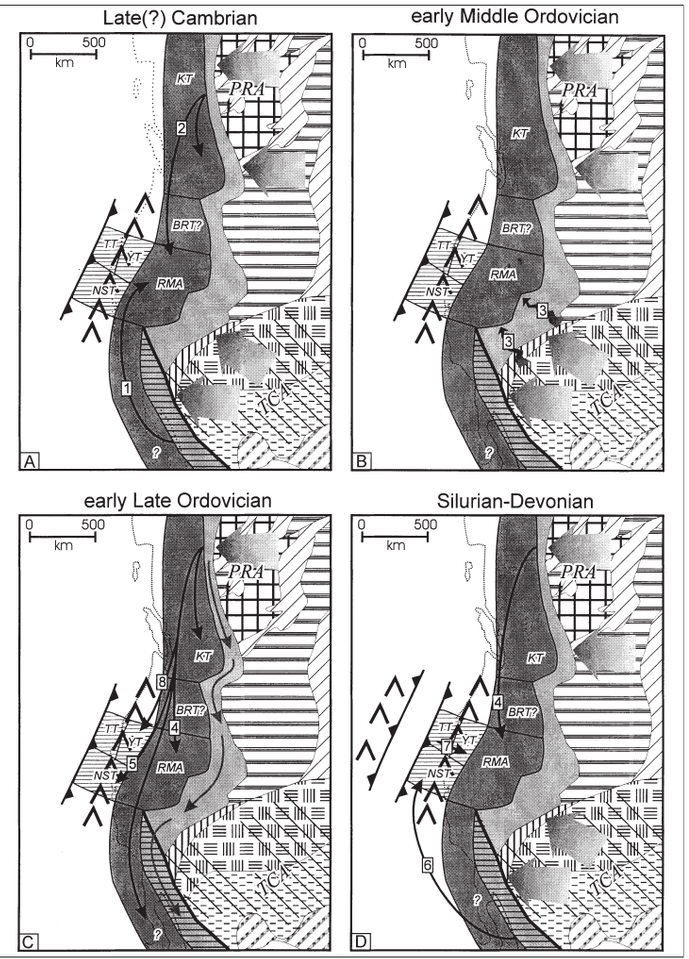


Attia et al., *GSA SP 540*., 2018

2000 interpretation

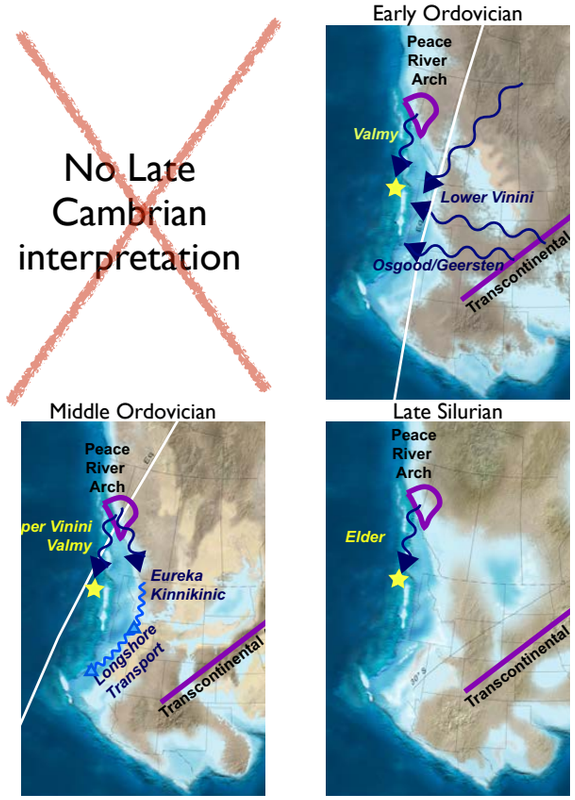


Gehrels et al., GSA SP 347, 133-150, 2000



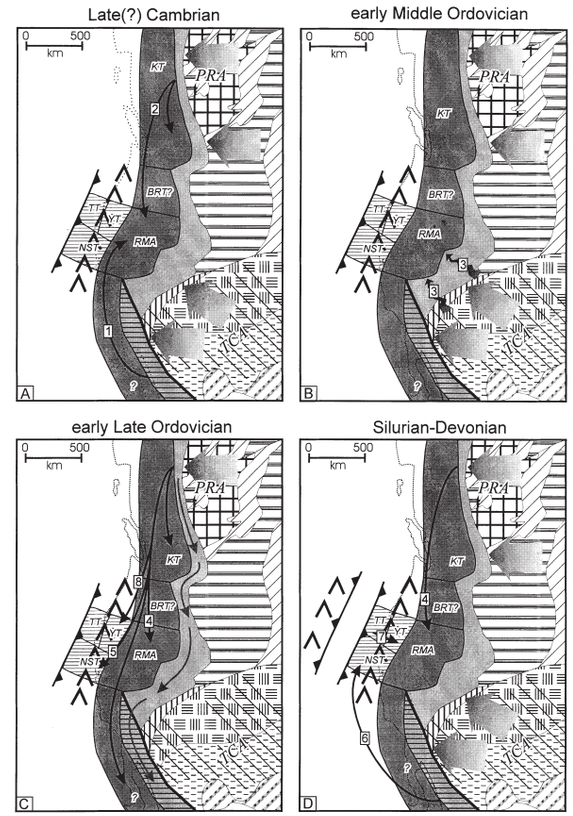
2016 interpretation

Linde et al., *Geosphere*., 2016



2000 interpretation

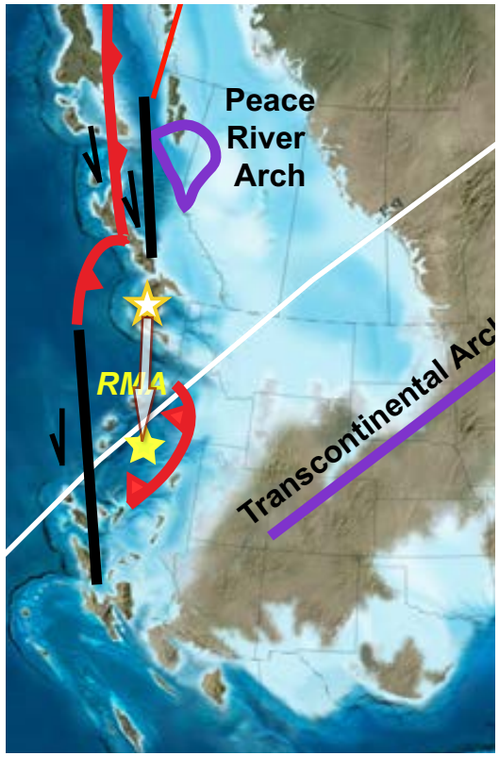
Gehrels et al., GSA SP 347, 133-150, 2000



2016 interpretation

Linde et al., *Geosphere*., 2016

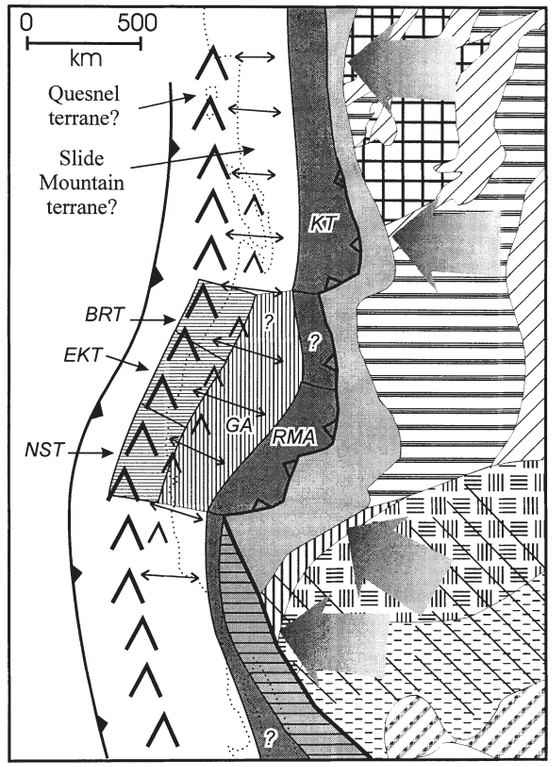
Late Devonian



2000 interpretation

Gehrels et al., GSA SP 347, 133-150, 2000

Mid to Late Paleozoic



So does the detrital zircon population, which everybody seems to think shows a strong Peace RIver Arch source, require tectonic motion, or could it be entirely sediment transport…