Meanwhile, somewhere out west: Terranes

- A crustal block or fragment bounded by faults
- Preserves a geologic history that is distinct from adjacent terranes
- Accreted to a continent by tectonic processes
Cape Sebastian-Lower Cretaceous SS over Otter Point Fm

Otter Point Fm metamorphics
UK Hornbrook Fm
I-5 at Siskiyou Pass

Hornbrook Fm
Outcrop
At Siskiyou Pass
Southern Klamath Mountains

Dickinson 2008
Dickinson 2008
Figure 6. Speculative plate tectonic history of the central portion of the Western Paleozoic and Triassic belt, based on detailed mapping, petrology, and geochemistry of the Sawyers Bar area. View is to the north. Abbreviations: A—asthenosphere; L—lithosphere; WHF—Western Hayfork terrane; EHF—Eastern Hayfork terrane; NF—North Fork terrane; and SF—Stuart Fork terrane. (A) Triassic-earliest Jurassic time; eastern subduction zone becomes inactive and Stuart Fork terrane is sequestered at midcrustal levels by ca. 227 Ma; (B) Early and Middle Jurassic time; Western Hayfork is juxtaposed against inboard Eastern Hayfork through consumption of intervening basin or due to transpression; (C) late Middle Jurassic time; outer subduction zone is still active (X indicates relative movement into the plane of section, i.e., northward; bull's eye indicates relative movement out of the plane of section, i.e., southward); and (D) early Late Jurassic time; local termination of convergence and thermal relaxation. See text for discussion.

Ernst 1999
Figure 6. Speculative plate tectonic history of the central portion of the Western Paleozoic and Triassic belt, based on detailed mapping, petro-tectonics, and geochemistry of the Sawyers Bar area. View is to the north. Abbreviations: A—asthenosphere; L—lithosphere; WHF—Western Hayfork terrane; EHF—Eastern Hayfork terrane; NF—North Fork terrane; and SF—Stuart Fork terrane. (A) Triassic-earliest Jurassic time; eastern subduction zone becomes inactive and Stuart Fork terrane is sequestered at midcrustal levels by ca. 227 Ma; (B) Early and Middle Jurassic time; Western Hayfork is juxtaposed against inboard Eastern Hayfork through consumption of intervening basin or due to transpression; (C) late Middle Jurassic time; outer subduction zone is still active (X indicates relative movement into the plane of section, i.e., northward; bull's eye indicates relative movement out of the plane of section, i.e., southward); and (D) early Late Jurassic time; local termination of convergence and thermal relaxation. See text for discussion.
Great Valley Monocline, west of Willows CA
A. 170-165 Ma
Genesis of Coast Range ophiolite (CRO) in nascent arc setting (nascent arc crust shaded)

B. 170-165 Ma
Continuing rapid roll back of subduction (nascent arc crust shaded)

C. 165-160 Ma
Continental margin blocks subduction zone. East-dipping Franciscan subduction initiates beneath the CRO. Metamorphic sole forms (precursor to Franciscan high grade blocks). Nascent arc crust shaded.

D.

E. <160 Ma

Saha et al 2005
Figure 7. This series of diagrams summarizes the general tectonic development of the high-grade blocks, similar to those found at Ring Mountain. (A, B) West-dipping subduction begins, and the slab rapidly rolls back eastward, with lithospheric extension above and the formation of nascent arc crust, including that of the Coast Range Ophiolite and the protoliths of the high-grade blocks such as at Ring Mountain. (C) East-dipping Franciscan subduction initiates as a result of the blockage of the west-dipping subduction zone. The new subduction zone initiates within the infant-arc crust. (D, E) Enlargements of the young Franciscan subduction zone, showing the offscraping of nascent arc basalt to form the high-grade blocks and later subduction of oceanic crust of MORB and OIB affinity. The initial subduction of the high-grade blocks results in high-temperature metamorphism, which varies in temperature and pressure as a function of how close the rock is to the hanging wall of the subduction zone and how far it is down the dip of the subduction zone when it is offscraped (F). This results in a variety of pressure-temperature (P-T) conditions for high-grade metamorphism found in the blocks. As subduction continues, the offscraped basaltic material quickly cools and a counterclockwise P-T path results (G). The pressure increase (vertical scale) shown in (G) may result from thrust imbrication of the upper plate, or partial resubduction of the blocks after peak (temperature) metamorphism. Note that the width of the slab of basalt, the subject of high-grade metamorphism, is greatly exaggerated in (D), (E), and (F) so that it is visible. Following the underplating of the metamorphic rocks, the metamorphic sheet was dismembered, so that most of this material is found now only as blocks in shear zones. In (G): Z/P-P—zeolite—pumpellyite-prehnite facies; Bsch—blueschist facies; Ec—eclogite facies; Gr—granulite facies; EA—epidote-albite facies; Am—amphibolite facies; Gsch—greenschist facies. Note initially high temperature of metamorphism (horizontal scale), as would be expected in the subducted nascent arc crust as proposed in this study. Subsequent cooling during subduction results in the counterclockwise P-T path as shown in this diagram, which is based on previous studies. Diagrams based in part on Wakabayashi (1999).
Figure 1. Montage of tectonic models of the Great Valley forearc basin and Coast Range subduction complex. Rock unit abbreviations: CRF—Coast Range fault; CRO—Jurassic Coast Range ophiolite; EUMW—extended upper mantle wedge; FCX—Cretaceous Franciscan Complex; GVH—Great Valley monoclinal; GVO—Great Valley ophiolite; GVOM—Great Valley ophiolite mantle; GVS—Upper Jurassic-Cretaceous Great Valley Group; HF—Hayward fault; SA—Sierran arc; SAF—San Andreas fault; SB—Salinian block; SS/UP—stalled slab/underplate; UM—upper mantle (A, B, and E are modified from Ring and Brandon, 1994).
How do the Klamaths and Western Sierran Terranes Relate?
Dickinson 2008
And what is happening to the north?

Dickinson 2004

Figure 7  Mid-Early Triassic (~247.5 Ma) to mid-Early Cretaceous (~120 Ma) geotectonic features of the Cordilleran arc-trench system, including intraoceanic arc structures accreted to the Cordilleran continental margin between Middle Jurassic and Early Cretaceous time.
Izee-Suplee area

modified from Dickinson and Thayer (1978)
Vester (Carnian) and Fields Creek (Norian) Fms

Bedded turbidites, argillite, cgl, slumps, & breccias w/ large olistostromes (submarine slide blocks) ... clasts include chert, serpentine, and plutonic rocks from adjacent Baker terrane.

Unstable steep margin of tectonically active marine basin

Dickinson and Thayer (1978)
Martin Bridge L.S.

Widespread regional unit: shallow platform carbonate w/ diverse fauna (corals, sponges, crinoids) and sedimentary structures.

Records end of Mid Triassic arc volcanism ... end of subduction due to collision of accretionary prisms.
Transition to Hurwal Fm

Carbonate turbidites record deepening and foundering of carbonate platform ... why?

Rise and fall of the Martin Bridge LS may record migration of a flexural bulge due to loading in the Baker terrane thrust belt.
**Hurwal Fm**
**Late Triassic - Early Jurassic**

Fine-gr. turbidites & argillite, deep marine basin, partially equivalent to Martin Bridge L.S.

Excelsior Gulch Conglomerate: clasts include limestone, chert, volcanics, plutonic rx ... eroded from Baker terrane T.B. (Follo, 1986; 1992; 1994)

$\varepsilon$Nd +4 to +2, some mixing with continental clay.
View looking northwest from Washington County, Idaho into Oregon across the Snake River (hidden in foreground). Paleozoic and Mesozoic argillaceous melange, serpentinites and mafic ophiolitic rocks overlie the Jurassic Weathery Formation, forearc basin volcaniclastic turbidite deposits, along the steeply northwest-dipping Connor Creek Fault.
The Wallowas

(Flickr image)
Early to Late Jurassic: growth and subsidence of collisional basin; thick overlap assemblage
Stratigraphy of the Blue Mountains

Substrate crust

<table>
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<th>Period</th>
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<th>Triassic</th>
<th>Permain</th>
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WALLOWA ARC TERRANE

N. SNAKE RIVER

PITTSBURG LANDING

WALLOWA MTS.

SNAKE RIVER at MCGRAW CREEK

Mega-Sequence 1

Mega-Sequence 2

BAKER TERRANE

IZEE-SUPEE AREA

OLDS FERRY ARC TERRANE

HUNTINGTON AREA

- Indicates positions of samples to be collected for provenance analysis

5. Brooks et al. (1976), Brooks (1978a)

Compiled by Todd LaMasi
Dorsey et al 2004 : Blue Mountains
Terrane

- A crustal block or fragment bounded by faults
- Preserves a geologic history that is distinct from adjacent terranes
- Accreted to a continent by tectonic processes
Paleomagnetism of Permian Wallowa Terrane

Harbert et al. 1994
Figure 5.5: a) Picture of lava flow courtesy of Daniel Staudigel. b) While the lava is still well above the Curie temperature, crystals start to form, but are non-magnetic. c) Below the Curie temperature but above the blocking temperature, certain minerals become magnetic, but their moments continually flip among the easy axes with a statistical preference for the applied magnetic field. As the lava cools down, the moments become fixed, preserving a thermal remanence. [b) and c) modified from animation of Genevieve Tauxe available at: http://magic.ucsd.edu/Lab_tour/movs/TRM.mov.
5.6 Chemical Remanent Magnetization

Figure 5.7: Grain growth CRM. a) Red beds of the Chinji Formation, Siwaliks, Pakistan. The red soil horizons have a CRM carried by pigmentary hematite. b) Initial state of non-magnetic matrix. c) Formation of superparamagnetic minerals with a statistical alignment with the ambient magnetic field (shown in blue).
Sometime in the geological past …

Magnetic Declination

Magnetic Inclination

http://www.nature.com/nature/journal/v421/n6918/fig_tab/421027a_F1.html
Plate tectonics moves the plate from (1) to (2)

Magnetic Declination

Paleo-Magnetic Inclination

http://www.nature.com/nature/journal/v421/n6918/fig_tab/421027a_F1.html
NB difference in magnetic declinations

Magnetic Declination

Paleo-Magnetic Inclination

Modern Declination at (2)

http://www.nature.com/nature/journal/v421/n6918/fig_tab/421027a_F1.html
Magnetic Declination

Magnetic Inclination

End small digression

http://www.nature.com/nature/journal/v421/n6918/fig_tab/421027a_F1.html
Paleomagnetism of Permian Wallowa Terrane

Harbert et al 1994
Regional geology

Hell’s Canyon sites
Open square: Paleo-pole this study
1=135MA, 2=131MA, 3-7=OTHER POLES
Inverted triangle=Blue Mt L Jur-E Cret pole
Expected and Observed Paleolatitudes
Hunsaker Creek formation, Hells Canyon

![Graph showing paleolatitudes vs age](image-url)
Permian Paleo-pole and Hell’s Canyon Permian paleo-poles: this study suggests Wallowa Terrane formed to NORTH of its present location.
Cache Creek Terrane
Entrapment: Oroclinal Paradox
Within the Canadian Cordillera

Mihalynuk, Nelson, and Diakow
1994
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<td>NA</td>
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<td>Yukon-Tanana terrane</td>
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<tr>
<td>DY</td>
<td>Dorsey terrane</td>
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Figure 7. Latest Permian to Middle Triassic geological elements that constrain the model. Present-day features shown for reference only are dashed and labeled in italics.
Figure 13. Paleomagnetically indicated rotations and error wedges are shown for (a) the Insular Belt (mainly Wrangellia), (b) Stikinia and the western Intermontane Belt, and (c) Quesnellia and the Omenica Belt. Average rotations within rocks of approximately the same age are denoted by the thick lines. Also shown in 13a and 13b are the effects of removing the pervasive Cretaceous rotations. This crude technique demonstrates the large "residual" rotations recorded by pre-Cretaceous rocks. Rotation data are from Vandyke [1990] and Irving and Wynne [1990].
Figure 2. (a) Diagrammatic terrane associations based on the classical stacked cards on edge model of the northern Canadian Cordillera. (b) A more representative depiction of terrane configurations showing continental margin terranes as they wrap around the northern end of Stikine and Quesnel arc terranes, which in turn envelope the Cache Creek terrane. (c) A schematic cross section displaying the fundamental tenet of the overthrust model with emplacement of Cache Creek and Stikine-Quesnel terranes atop displaced continental margin. Crustal cross-section location is shown in 2b.
<table>
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<tr>
<td>DY</td>
<td>Dorsey terrane</td>
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</tbody>
</table>

Some people will not let well enough alone . . . .
Baja BC and the search for the new worlds . . .
The Northward Translation of Baja-British Columbia

Umhoefer 1987
Umhoefer: Northward Translation of Baja British Columbia
But there are problems:
But there are problems:

Tectonic deformation will change the measured paleo-inclination. Here faulting leads us to infer the faulted blocks were deposited at a southern paleo-location, where inclinations are not as steep.
There are other problems

Differential compaction of sediments leads to change in measured paleo-inclination in the overlying beds.
Neogene Tilting of Crustal Panels near Wrangell, Alaska

Butzer, Butler, Gehrels Davidson, O’Connel, Crawford
2004
Figure 1. Geologic map and paleomagnetic sampling site locations (dots). Patterns: horizontal lines—Cretaceous plutonic rocks; vertical lines—Tertiary plutonic rocks; diagonal lines—Tertiary volcanic rocks. Inset map shows location of map within northwest North America.
Figure 2. Equal-area projections of paleomagnetic directions and dike orientations. A: Site-mean paleomagnetic directions. Filled circles are in lower hemisphere; open circles are in upper hemisphere. Mean of normal (reversed) polarity sites is illustrated with larger filled (open) circle surrounded by 95% confidence limits. B: Mean observed direction is shown by filled circle surrounded by 95% confidence limits. Expected direction is indicated by gray circle. Arrow indicates deflection of expected direction to observed mean direction by 16° east-side-up tilt about horizontal axis with azimuth of 8°. C: Mafic dike orientations. Lower-hemisphere projection of poles to dikes (dots) and mean pole (open square) with trend = 287° and plunge = 16°. D: Projection of poles to dikes (triangles) and mean orientation (open square with trend = 287° and plunge = 0°) after correction for tilt are indicated by paleomagnetic directions.
Figure 3. Model of tilting crustal panels. V pattern indicates volcanic and shallow-level intrusive rocks. Jackstraw pattern indicates plutonic rocks intruded at ~10 km or deeper levels within crust. A: Original configuration of late Oligocene–early Miocene igneous complex extending from Etolin Island to Kului Island. B: Result of ~8° coherent east-side-up tilt of entire igneous complex. C: Result of superimposed ~8° tilt of smaller crustal blocks perhaps represented by individual islands.
Colpron et al 2007
Northern Cordilleran Terranes and their interactions through time
Geology Today
Colpron et al 2007
Data used in terrane analysis

• Stratigraphy
• Paleontology
• Geochemistry
  – Igneous rock correlations
  – Age dating
• Structural relations
• Paleomagnetism