Typical subduction

Volcanic arc

Sedimentary basin

Oceanic Slab

Continent

Thrust fault

Side view of “normal” subduction of ocean floor as often illustrated
Side view of “normal” subduction of ocean floor with more of the kind of terminology typical in the literature.
<table>
<thead>
<tr>
<th>Old words we still sometimes use</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Miogeoclone</strong></td>
</tr>
<tr>
<td>Usually as an adjective, this refers to a thick wedge-shaped sequence of sedimentary rock with few or no volcanics. Basically, a passive margin sequence.</td>
</tr>
<tr>
<td><strong>Eugeoclone</strong></td>
</tr>
<tr>
<td>Usually as an adjective, this refers to a sequence of deep-water sediments (cherts, pelagic limestones) and volcanics (dominantly pillow basalts). Basically, ocean floor material.</td>
</tr>
<tr>
<td><strong>Tertiary</strong></td>
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<tr>
<td>The Cenozoic minus the Quaternary. (Left over from when the Paleozoic was the Primary and the Mesozoic the Secondary. The Quaternary continues, but as a Period within the Cenozoic).</td>
</tr>
</tbody>
</table>
A broad overview

Precambrian (Proterozoic)  
- Accretion of island arcs
- Magmatic episodes
- Rifting
  - Passive margin (except for exotic terranes to the west)

Paleozoic  
- Contractional tectonics (arcs, fold-and-thrust belts, accretion)

Mesozoic  
- Transition to strike-slip (transform) tectonics, extensional tectonics

Cenozoic
Dickinson, Geosphere, 2006
Precambrian assembly of the continent...
Slave-Rae collision, Arc accretion: Rimbey, Taltson, Thelon arcs

1.96-1.92 Ga
Juvenile arcs form during ocean closure: Great Bear, La Ronge, Torngat, Little Belt arcs.
Continued juvenile arc accretion: Narsajuaq, Pembine-Wausau; Wopmay orogen; Southeast thrusting along Snowbird tectonic zone

1.86-1.84 Ga
Trans Hudson orogen: Superior-Rae-Hearne continent-continent collision, includes accretion of Sask craton; Elves Chasm arc outboard of Mojavia
Continued shortening across Trans Hudson orogen; closure of Great Falls Tectonic Zone and Vulcan Zone; accretion of Medicine Hat Block, and Wyoming Province

1.82-1.80 Ga
Accretion of Archean (?) Grouse Creek Block and Selway Terrane; Mojave Province and Yavapai arcs outboard

1.80-1.76 Ga
1.76-1.72 Ga

Accretion of Mojavia(?) and Yavapai Province, as a Banda Sea style assembly of arcs
Yavapai province:
Yavapai granitoids stitch juvenile terranes with older provinces;
~1700 Ma quartzite deposition;
Mazatzal arcs outboard
1.69-1.65 Ga
Accretion of Mazatzal and Labradorian Provinces, as juvenile crust
1.65-1.60 Ga

Mazatzal province:
Mazatzal granitoids stitch juvenile terranes with older provinces;
~1650 Ma quartzite deposition
1.55-1.35 Ga
Accretion of Granite-Rhyolite Province, Elzevir Block & Pinware terrane, as juvenile crust
Granite-Rhyolite Province:
A-type plutons stitch much of southern Laurentia
Grenville orogen:
Continent-continent collision of Laurentia with African and South American cratons;
SE transfer of Caborca block
Grenville orogen:
Granitoids intrude juvenile belts as far west as Colorado
1.2-1.1 Ga

Midcontinent Rift system:
Keweenawan, Ft. Wayne rifts;
Intrusion of MacKenzie and Animikie dikes
Rifting along western margin of Laurentia; Intrusion of Gunbarrel dikes, Deposition of Windermere Supergroup.
Rifting along eastern margin of Laurentia; Opening of Rome Trough

0.62-0.55 Ga
~ 0.535 Ga

Rifting of Argentine Precordillera from Ouachita embayment; Opening of Oklahoma Aulacogen, Reelfoot Rift
Summary of the Phanerozoic history of the western U.S. (Taphrogens are extensional belts). On the right, arc magmatism is in red, compressional shortening is light purple, green are exotic terranes.
Modern extent of the miogeocline (passive margin sedimentary package)
The truncation of the miogeoclinal. Note the NNE trending isopachs (left) and the same pattern of thicknesses in Sonora (the Caborca block). Facies of these rocks shown at right. Big box–dashed line is the proposed left–lateral fault (“Mojave–Sonora megashear”) that most likely was active in the late Paleozoic, though some have proposed this was active as late as the Jurassic.
This was the start of tectonic activity in the western U.S. The Antler is a curious orogeny as there is no arc in the vicinity (the Klamath arc was well to the west; the Havallah Basin was basically a small ocean basin).
The Antler orogeny was followed by the Ancestral Rockies, which grew at the end of the assembly of Pangea.
Another view of the truncation fault (“Mojave–Sonora megashear”) and Permian shortening in eastern California.
Foreland fold-and-thrust belts of the Mesozoic and early Cenozoic.
Isopachs of the Morrison Formation and its apparent position as a "backbulge" basin.
Fold-and-thrust belts typically have a wedge shape in cross section; the Sevier belt probably looked like this.
Almost “peak” Andean orogen with a volcanic arc, a high hinterland, a foreland fold–and–thrust belt, and a foredeep.
The hinterland had areas with evidence of extension or decompression of deep crust (black areas in figure at right).
The Laramide orogeny followed the Sevier (though both belts were active at the same time in SW Montana/N Utah/NWmost WY).
Basins of the Laramide and younger volcanic centers.
Tanya Atwater’s animation of the evolution of the plate boundary and inception of transform motion
Figure 2. Time-space diagram of lithic assemblages in the Great Basin and adjoining areas (note time-scale breaks at 50 Ma, 400 Ma).

Dickinson, Geosphere, 2006
Extensional faulting included metamorphic core complexes which juxtapose metamorphosed middle and lower crust with unmetamorphosed upper crust.
Magmatic evolution of the western U.S.
ARM•RONG AND WARD: CENOZOIC MAGMATISM IN THE NORTH AMERICAN CORDILLERA.

10-25 Ma
Animation of igneous activity on a palinspastic base.
Figure 2. Linear velocity vectors along San Andreas fault at lat 35°N. A: Slip along San Andreas fault (SAF, alternating dash-dot vector) takes up only part of Pacific-North America motion predicted by global-plate-motion model NUVEL-1 (thick solid vector). Vector difference between the two, termed San Andreas discrepancy (SAD, thick solid vector), equals 14 ± 2 mm/yr toward N25°E. Circle and ellipse indicate 95% confidence limits for San Andreas fault slip and for Pacific-North America (PA-NA) motion. B: Vector sum of strike slip along San Andreas fault and Sierra Nevada-North America motion (SN-NA; dashed vector; VLBI = very long baseline interferometry) differs little from Pacific-North America motion. Modified San Andreas discrepancy (MSAD), which equals difference between these two quantities, is 6 ± 2 mm/yr toward N20°W. Ellipses indicate 95% confidence limits for Sierra Nevada-North America motion and for modified San Andreas discrepancy.

Argus and Gordon, Geology, 1991
We express depth-integrated vertical stress, \( s_{zz} \), or equivalently gravitational potential energy (GPE) per unit area, as

\[
\frac{1}{C_0} g \frac{Z}{C_0} h \frac{Z}{C_0} \frac{r}{C_1} \frac{d}{C_2} d\frac{z}{C_3} \frac{d}{C_4} dz; \tag{3}
\]

where \( z' \) is a variable of integration, \( h \) is elevation with respect to sea level, and \( L \) is the depth to the approximate base of the seismogenic layer. The depth \( L \) in equation (3) also defines the reference level for the depth integrals of vertical stress, or GPE.

### 3.1. Estimation of Depth-Integrated Vertical Stress Within the Seismogenic Layer

Our first step is to estimate depth-integrated vertical stress distributions (GPE) in the upper crust of western North America. Spatial variations of these quantify the magnitude of the depth-integrated horizontal deviatoric stress (equation (2)). This requires \( r(z) \), which we assign empirically from scaling seismic velocity to density data. We develop simple velocity to density conversion by constructing a fifth-order polynomial curve to interpolate \( P \)-wave velocity and density data presented by Lowry and Smith [1995]. The densities produced by our method (Figure 5) are consistent with expected densities at depth within western U.S. Cordillera [Lowry and Smith, 1995; Kaban and Mooney, 2001] and the Earth’s crust in general [Ludwig et al., 1970; Brocher, 2005]. We then use this empirical relation to obtain densities from the large seismic data set for North America from Chulick and Mooney [2002].

We smooth the resulting vertical density distributions laterally throughout the entire grid space. If more than one density estimate exists at a particular grid location depth, we compute the mean density there before smoothing. A density value within a given grid area corresponds to the weighted average of the densities of its immediate neighboring grid areas. The weights assigned to the density values reflect the surface area of each grid location. The smoothing procedure is repeated until each grid area is assigned a nonzero density value. We specify uniform density values to crustal rock in grid areas above sea level. Such density values are defined to

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**Figure 3.** Estimate for the continuous long-term model velocity field (black vectors), along with GPS data (white vectors) from Bennett et al. [1999] plotted relative to a North American frame of reference. The remaining GPS and VLBI data used in this model are plotted as white dots for clarity. Error ellipses represent the 95% confidence limits.
program Slippery.f90 is described briefly in section 2.1, and fully by Bird [2007]. The target offset rates and uncertainties for Neokiniema are the median rate and the formal standard deviation, respectively, from the combined rate lines of Bird [2007, Tables 1 and 2]. Rates for California fault trains come from Table 2 of Bird [2007], which was based on the PaleoSites database addition to the USGS Quaternary Fault and Fold Figure 2. Traces of 1472 active and potentially active faults included in these models. Traces are colored according to prior expectations of their predominant sense(s) of slip. Faults with oblique slip have a green or brown trace to indicate dextral or sinistral component plus dip ticks of a different color and shape to indicate the primary mode of dip slip. Offset type D is used for both low-angle detachment faults and magmatic spreading centers.