Geodetic Observations at the Overlapping Southern Cascadia and Northern San Andreas Fault Systems

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Abstract

Global eustatic sea-level changes are modulated regionally by plate tectonic land-level changes due to the earthquake cycle along the Cascadia subduction zone, the San Andreas plate boundary fault system, and crustal faults in the North America and Gorda plates, but the degree to which each of these forcing factors drives this modulation is not well resolved.

We use tide gage data obtained from National Oceanographic and Atmospheric Administration tide gages, as well as 'campaign' style tide gages, to infer interseismic vertical ground deformation. We autocorrelate tide gage data from Crescent City to Humboldt Bay, California and, after regional sea level is removed, we estimate rates of vertical land-level change. We also use first-order leveling data collected by the National Geodetic Survey in 1931, 1945, 1968, and 1988 as a measure of land-level changes. EarthScope and United States Geological Survey Global Positioning System permanent site data are also used to evaluate vertical interseismic deformation in this region.

Subtracting eustatic sea-level rise (~2.3 mm/yr, 1977-2010) from Crescent City (CC) and North Spit (NS) relative sea-level rates reveals that CC is uplifting at ~3mm/yr and NS is subsiding at ~2.5 mm/yr. GPS vertical deformation reveals similar rates of ~3 mm/yr of uplift at Crescent City. GPS and leveling observation based vertical land motion rates show a gradient of southwards increasing subsidence between Trinidad (in the north) to Cape Mendocino (in the south). First order leveling observations are more densely spaced, yet are consistent with the other measures of vertical land motion.

Land subsidence in and around Humboldt Bay, California contributes to sea-level rise up to 2-3 times greater than anywhere else in California. Sea-level observations and highway level surveys confirm that land is subsiding in Humboldt Bay, in contrast to Crescent City where the land is rising. Rates of sea-level rise are 5.84 mm/yr in South Humboldt Bay (Hookton Slough), 3.76 mm/yr at Fields Landing, 4.61 mm/yr at the North Spit, 2.53 mm/yr at Samoa, and 3.39 mm/yr in Arcata Bay (Mad River Slough). Rates of land subsidence are -3.56 mm/yr in South Humboldt Bay (Hookton Slough), -1.48 mm/yr at Fields Landing, -2.33 mm/yr at the North Spit, -0.25 mm/yr at Samoa, and -1.11 mm/yr in Arcata Bay (Mad River Slough). There is an East-West trended variation in vertical land motion that is primarily due to Cascadia subduction zone plate tectonics. There exists a heterogeneous North-South trend in vertical land motion that we associate to crustal fault related strain.

Cascadia subduction zone

Chaytor et al. (2004)
Nelson et al. (2004)

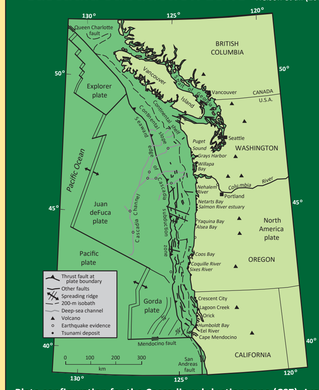
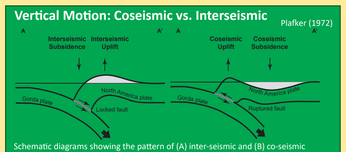


Plate configuration for the Cascadia subduction zone (CSZ). Juan de Fuca and Gorda plates are subducting northeastwardly oblique beneath the North America plate at ~36 mm/yr in the Humboldt Bay region. Paleoseismic core sites (marine and terrestrial) are plotted as circles.

Vertical Motion: Coseismic vs. Interseismic

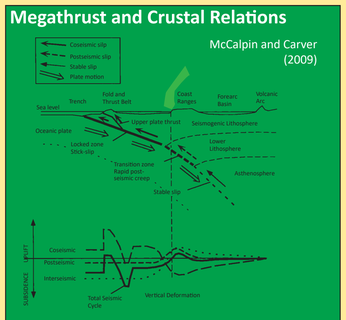
Plafker (1972)



Schematic diagrams showing the pattern of (A) inter-seismic and (B) co-seismic deformation associated witha subduction zone earthquake during an earthquake deformation cycle. Adapted from Plafker (1972) to reflect the spatial pattern of tectonic deformation during the earthquake cycle in Cascadia.

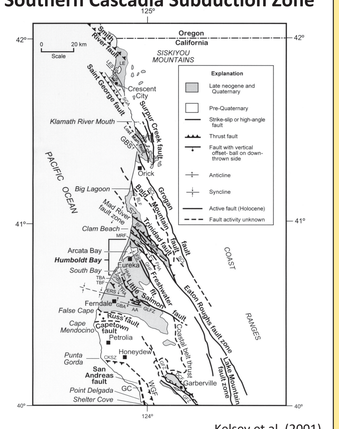
Megathrust and Crustal Relations

McCalpin and Carver (2009)



Pattern of deformation across for interseismic, coseismic, and postseismic parts of the seismic cycle. During megathrust earthquakes, coseismic slip on the locked zone produces uplift above the megathrust rupture and elastic relaxation and subsidence between the downdip end of rupture and the arc. Slip on upper plate thrusts can generate localized and permanent uplift and subsidence in the fold and thrust belt. Rapid creep accommodates the slip deficit on the megathrust in the transition zone during the relatively short postseismic interval following the earthquake.

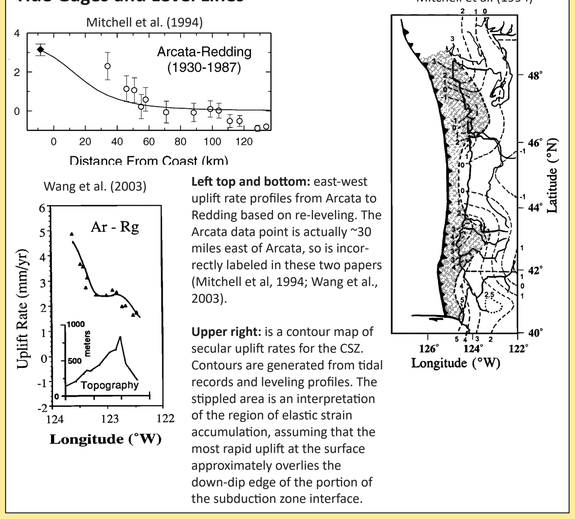
Active Faulting Associated with the Southern Cascadia Subduction Zone



Kelsey et al. (2001)

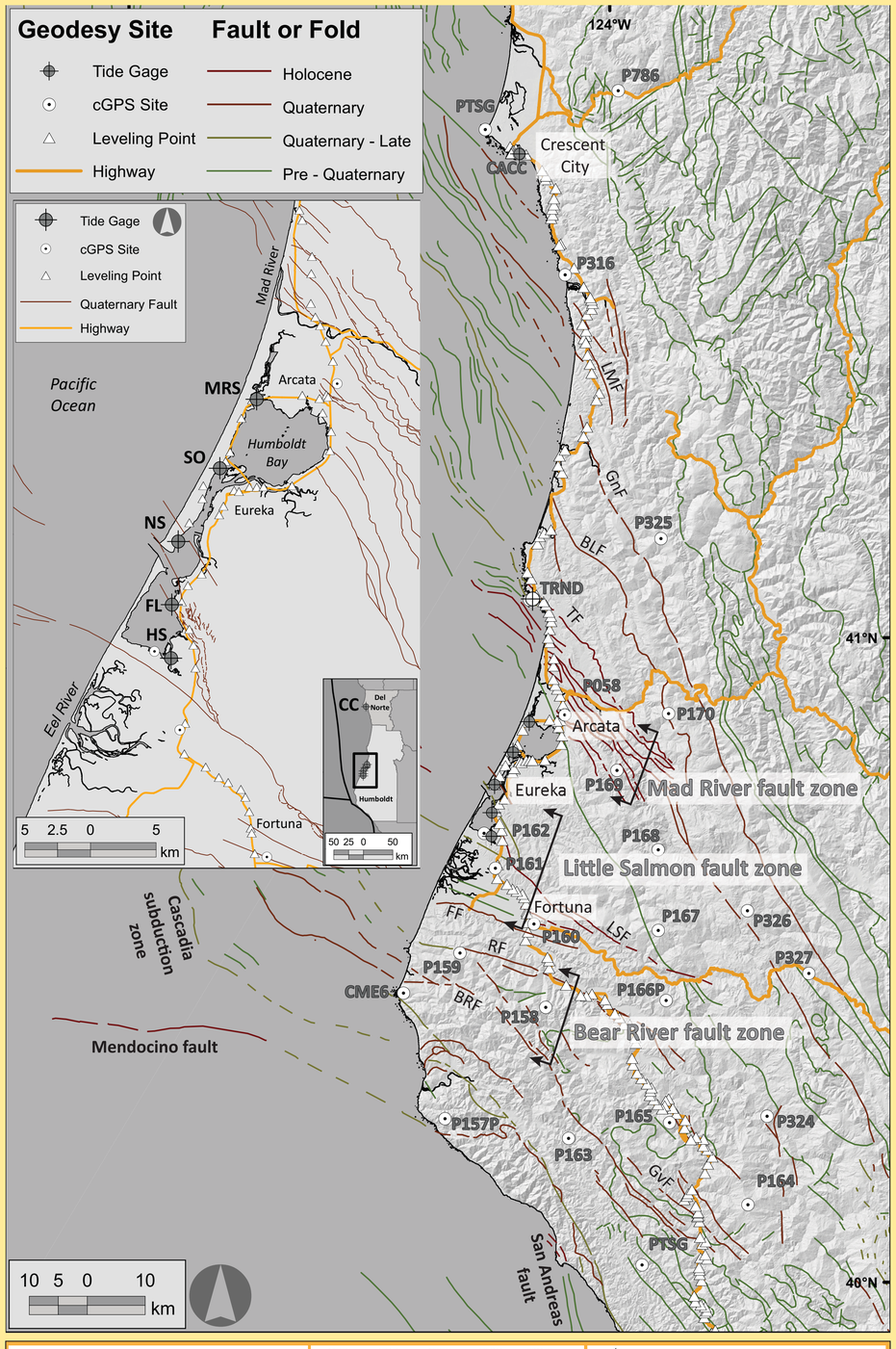
Based on earthquake fault slip-rates and marine terrace uplift-rates, crustal faults in the North America plate may account for between 20% and 30% of the plate convergence in the Humboldt Bay region.

Tide Gages and Level Lines

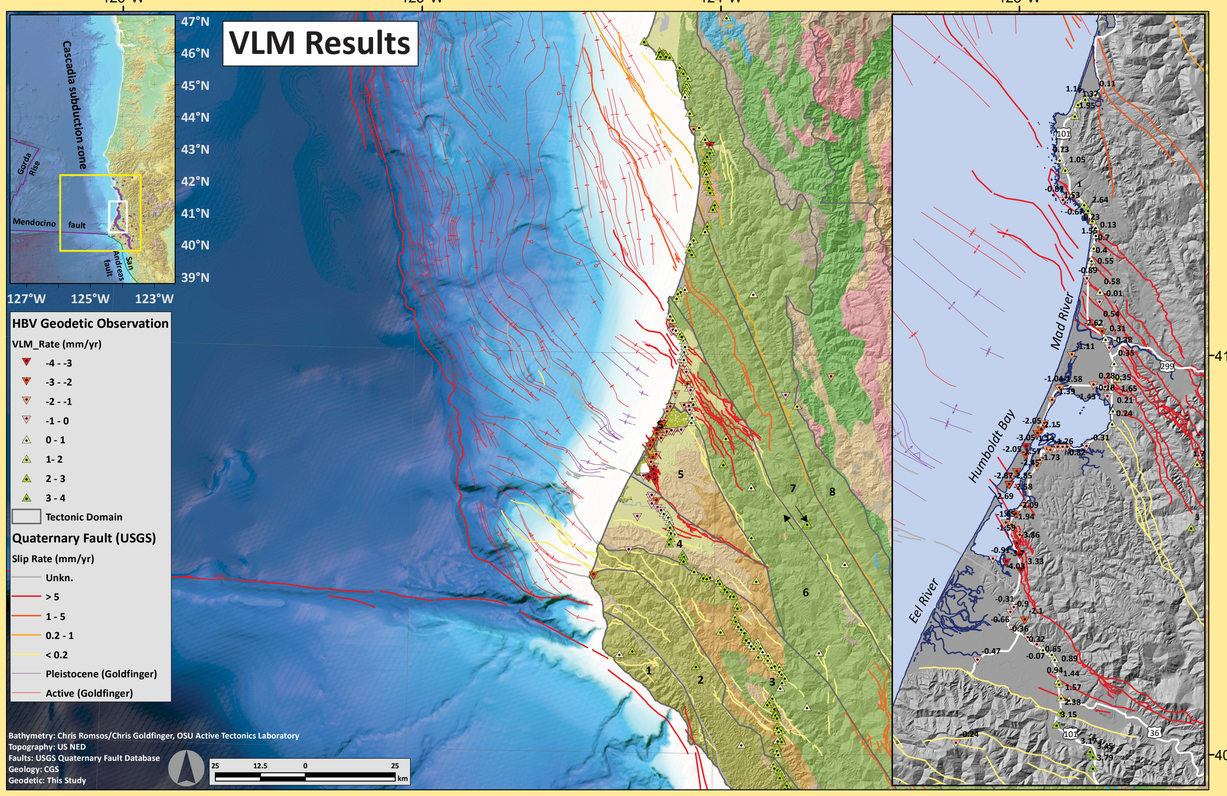


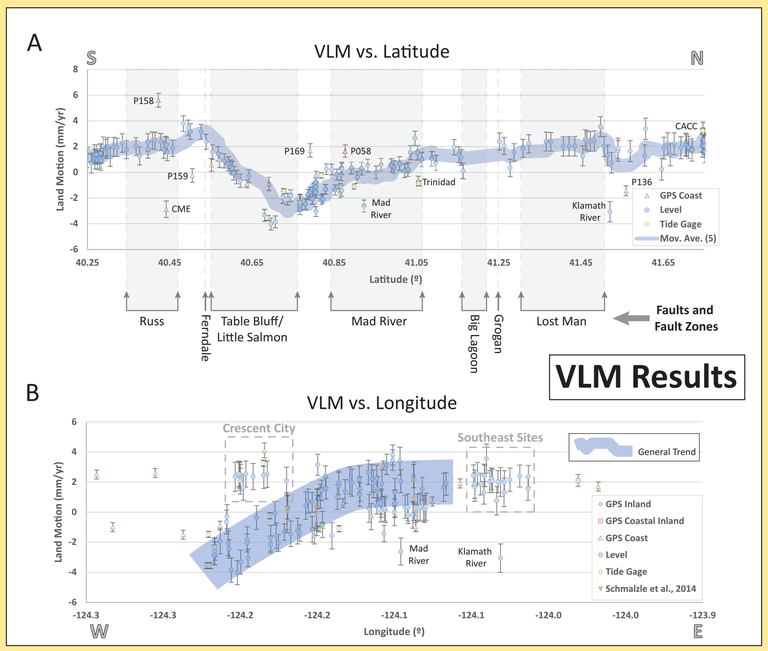
Left top and bottom: east-west uplift rate profiles from Arcata to Redding based on re-leveling. The Arcata data point is actually ~30 miles east of Arcata, so is incorrectly labeled in these two papers (Mitchell et al, 1994; Wang et al., 2003).

Upper right: is a contour map of secular uplift rates for the CSZ. Contours are generated from tidal records and leveling profiles. The stippled area is an interpretation of the region of elastic strain accumulation, assuming that the most rapid uplift at the surface approximately overlies the down-dip edge of the portion of the subduction zone interface.



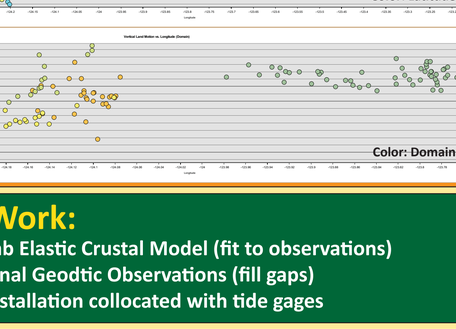
VLM Results



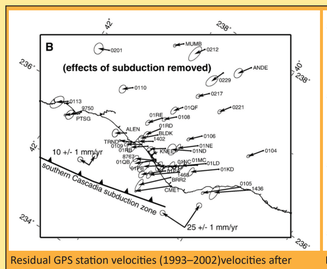


VLM Results

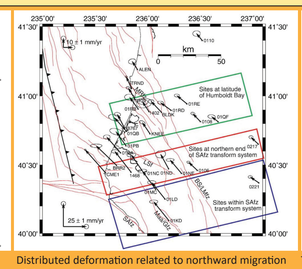
Tectonic Domains



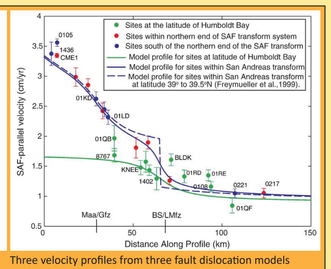
Entire Dataset / Domains 3, 4, 5, 6



Residual GPS station velocities (1993–2002)velocities after subtracting the modeled interseismic strain accumulation on the southern Csz; barbed fault represents modeled subduction fault of Flück et al. (1997).



Distributed deformation related to northward migration of the Mendocino triple junction, based on GPS residual velocities (velocities with subduction signal removed). The three rectangles (green, red and blue) enclose the green, red and blue GPS stations depicted on the profiles in Fig. 5. LSf, Little Salmon fault; MRfz, Mad River fault zone; SAfz, San Andreas fault zone; Maa/Gfz, Maacama/Garberville fault zone; BS/Lmfz, Bartlett Springs/Lake Mountain fault zone.



Three velocity profiles from three fault dislocation models perpendicular to trend of San Andreas fault plate boundary. Distributed strike–slip motion occurs across the two eastern strands of the San Andreas fault system, with velocity increases near surface traces of the Maacama/Garberville fault zone (Maa/Gfz) and the Bartlett Springs/Lake Mountain fault zone (BS/LMfz). The green model curve is fit to the green stations, and the blue model curve is fit to the blue and red stations. The dashed blue model curve, shows the BS/LMfz is creeping.

Prior SAF GPS Geodesy

Take Away Points:

- Secular VLM geodesy provides evidence for seismogenic coupling on the megathrust.
- Variation in VLM may indicate crustal fault related deformation.

Future Work:

- Coulomb Elastic Crustal Model (fit to observations)
- Additional Geodtic Observations (fill gaps)
- cGPS installation collocated with tide gages