Recurrence of Deformation in the Southern Cascadia subduction zone

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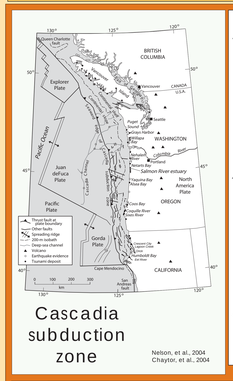
PART I PLATE SETTING



Nelson, et al., 2004
Chaytor, et al., 2004

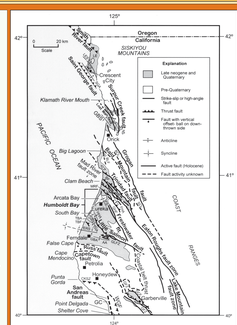
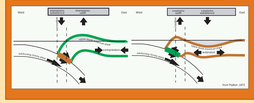
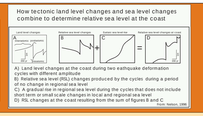


Figure 2

Figure 2. Kelsey, H.M., 2001, Active faulting associated with the southern Cascadia subduction zone in northern California, . Ferris, H. and Anderson, R. (eds), Engineering Geology Practice in Northern California, Division of Mines and Geology Bulletin 210, Association of Engineering Geologists Special Publication 12, p. 259-274.

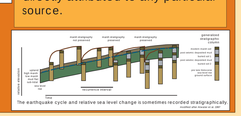


How tectonic land level changes and sea level changes combine to determine relative sea level at the coast



A) Land level changes at the coast during two earthquake deformation events and interseismic
B) Relative sea level (RSL) changes produced by the cycles: during a period of no change in regional sea level
C) A gradual rise in regional sea level during the cycles that does not include short term or small scale changes in local and regional sea level
D) RSL changes at the coast resulting from the sum of figures B and C.

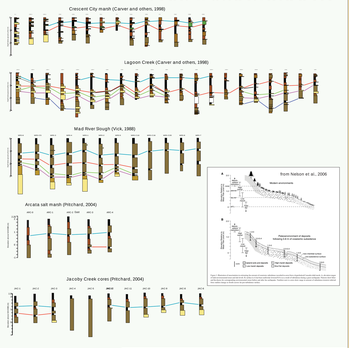
Dura Nelson, 1998

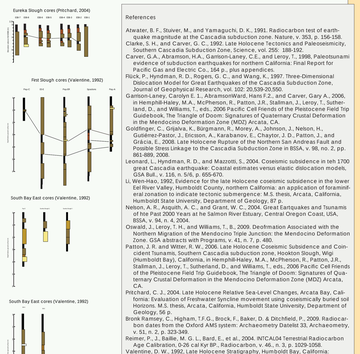


The earthquake cycle and relative sea level change is sometimes recorded stratigraphically.

Scottish Lake Project, n.d. 2007

PART II STRATIGRAPHY





References

Atwater, B. F., Stuiver, M., and Yamaguchi, D. K., 1991, Radiocarbon test of earthquake magnitude at the Cascadia subduction zone: Nature, v. 353, p. 156-158.
Clarke, S. H., and Carver, G. C., 1992, Late Holocene Tectonics and Paleoseismicity, Southern Cascadia Subduction Zone, Science, vol. 255: 188-192.
Carver, G. A., Abramson, H. A., Garrison-Laney, C.E., and Leroy, T., 1998, Paleotsunami evidence of subduction earthquakes for northern California: Final Report for Pacific Gas and Electric Co., 164 p., plus appendices.
Flick, P., Hyndman, R. D., Rogers, G. C., and Wang, K., 1997, Three-Dimensional Dislocation Model for Great Earthquakes of the Cascadia Subduction Zone, Journal of Geophysical Research, vol. 102: 20,539-20,550.
Garrison-Laney, Carolyn E. 1., AbramsonWard, Hans F.2., and Carver, Gary A., 2006, in Hemphill-Haley, M.A., McPherson, R., Patton, J.R., Stallman, J., Leroy, T., Sutherland, D., and Williams, T., eds., 2006 Pacific Cell Friends of the Pleistocene Field Trip Guidebook, The Triangle of Doom: Signatures of Quaternary Crustal Deformation in the Mendocino Deformation Zone (MDZ) Arcata, CA.
Goldfinger, C., Grijalva, K., Bunn, D. E., Morey, A., Johnson, J., Nelson, H., Gutierrez-Pastor, J., Erkes, K., Karabanov, E., Kayen, R., Chaytor, J. D., Patton, J., and Grácia, E., 2008, Late Holocene Rupture of the Northern San Andreas Fault and Possible Stress Linkage to the Cascadia Subduction Zone in BSIA, v. 98, no. 2, pp. 861-889, 2008.
Leonard, L., Hyndman, R. D., and Mazzotti, S., 2004. Coseismic subsidence in teh 1700 great Cascadia earthquake: Coastal estimates versus elastic dislocation models, GSA Bull., v. 116, n. 5/6, p. 655-670.
Li, Wen-Hao, 1992, Evidence for the late Holocene coseismic subsidence in the lower Eel River Valley, Humboldt County, northern California: an application of foraminiferal zonation to indicate tectonic submergence: M.S. thesis, Arcata, California, Humboldt State University, Department of Geology, 87 p.
Nelson, A. R., Asquith, A. C., and Grant, W. C., 2004, Great Earthquakes and Tsunams of hte Past 2000 Years at he Salmon River Estuary, Central Oregon Coast, USA, BSIA, v. 94, n. 4, 2004.
Oswald, J., Leroy, T. H., and Williams, T., 8., 2009. Deafmitation Associated with the Great Cascadia Earthquake on the Mendocino Triple Junction: the Mendocino Deformation Zone. GSA abstracts with Programs, v. 41, n. 7, p. 480.
Patton, J. R. and Witter, R. W., 2006. Late Holocene Coseismic Subsidence and Coincident Tsunamis, Southern Cascadia subduction zone, Hookton Slough, Wigi (Humboldt Bay), California, in Hemphill-Haley, M.A., McPherson, R., Patton, J.R., Stallman, J., Leroy, T., Sutherland, D., and Williams, T., eds., 2006 Pacific Cell Friends of the Pleistocene Field Trip Guidebook, The Triangle of Doom: Signatures of Quaternary Crustal Deformation in the Mendocino Deformation Zone (MDZ) Arcata, CA.
Pritchard, C. J., 2004, Late Holocene Relative Sea-Level Changes, Arcata Bay, California: Evaluation of Freshwater Syncline movement using coseismically buried soil Horizons. M.S. thesis, Arcata, California, Humboldt State University, Department of Geology, 56 p.
Brook Ramsey, C., Higham, T.F.G., Brock, F., Baker, D. & Ditchfield, P., 2009. Radiocarbon dates from the Oxford AMS system: Archaeometry Datelist 33, Archaeometry, v. 51, p. 173–187.
Reimer, P. J., Baillie, M. G. L., Bard, E., et al., 2004. INTCAL04 Terrestrial Radiocarbon Age Calibration, 0-26 cal kyr BP., Radiocarbon, v. 46., n. 3, p. 1029-1058.
Valentine, D. W., 1992, Late Holocene Stratigraphy, Humboldt Bay, California: Evidence for Late Holocene Paleoseismicity of the Southern Cascadia Subduction Zone: M.S. thesis, Arcata, California, Humboldt State University, 82 p.
Verdonck, D., 2006. Contemporary vertical crustal deformation in Cascadia. Tectonophysics, v. 417, p. 221-230.
Vick, G., 1988, Late Holocene Paleoseismicity and relative vertical crustal movements, Mad River Slough, Humboldt Bay, California: M.S. thesis, Arcata, California, Humboldt State University, 88 p.
Wang, K., He, J, Dragert, H., and James, T., 2001. Three-dimensional viscoelastic interseismic deformation model for hte Cascadia subduction zone, Earth Planets Space, v. 53, p. 295-306.
Wang, K., Wells, R., Mazzotti, S., Hyndman, R. D., 2003, A revised dislocation model of interseismic deformation of the Cascadia subduction zone, J. G. R., v. 108, n. B1.
Witter, R. C., Patton, J. R., Carver, G. A., Kelsey, H. M., Goldfinger, C., Lettis, W. R., and Hemphill-Haley, M., 2002, Focal Technical Report, Upper Plate Earthquakes on the Western Little Salmon Fault and Contemporaneous Subsidence of Southern Humboldt Bay over the past 3,600 Years, Northwestern California. United States Geological Survey, National Earthquake Hazards Reduction Program, Award No. 01HQGR0215, 37 p.

PART III RADIOCARBON ANALYSIS

What did we do?

+ We evaluate all 14C data associated with paleoseismic and paleotsunami research in northern California.

+ We establish criteria to rank 14C samples in order to
  1) obtain new age control for strata that have none
  2) obtain new age control for strata that have 'bad' ages

+ We further determine which region needs more coring. In addition, we found only some core studies incorporated biostratigraphic control. Local transfer functions have not yet been developed, so estimates of subdidence based on diatom paleoecology are not well constrained.

Radiocarbon Ommission Rationnale

1) For maximum limiting ages: keep only ages within 2 sigma error of the youngest age.

2) inverted ages are removed.

3) Bulk peat ages carry less weight than identifiable plant material, yet are in times the only age control available.

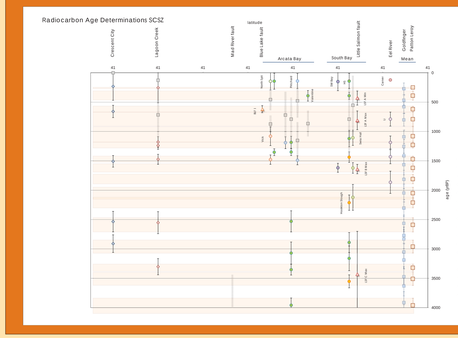
Site Evaluation and Ranking

Table 1. Data limitations and priorities for conducting additional paleoseismic and paleotsunami studies at site specific locations in Northern California.

Project Location	Stratigraphic Control	Isochronal Elevation Control	Biostratigraphy[a]	Dated with ^{14}C Limitations[b]	All Events Dated and Correlated[c]	Descriptive Limitations[d]	Scientific Value of the Site[e]	Priorities for Conducting Additional Studies	Notes
Crescent City marsh	no	diatoms	no	N_L	A	1	5	Yes	The Anna Sanford site is within City marsh and poorly constrained. There is a high-resolution record from a core in the adjacent marsh.
Lagoon Creek	yes	diatoms	yes	I	A	3	12	Yes	The data there is mostly sufficient and the lagoon was found to contain stratigraphy of interest.
Mad River Slough	no	foraminifera	yes	B_U	1	3	7	Yes	Mad River Slough, Arcata Marsh and Jacoby Creek occupy an area subject to repeated Late Holocene coseismic subsidence, the timing and magnitude of the associated land level changes is poorly understood. The area is also occupied by critical transportation infrastructure and an airport protected by tidal levees.
Jacoby Creek	yes	no	no	A_L	A	1	3	Yes	Large incoherent facility vulnerable to relative sea level changes.
Eureka Slough	no	no	yes	B_L	1	2	6	Yes	Eureka Slough, First Slough and Fay Slough occupy an area subject to repeated Late Holocene coseismic subsidence, the timing and magnitude of the associated land level changes is poorly understood. The area is also occupied by critical transportation infrastructure and an airport protected by tidal levees.
First Slough	no	no	no	B_L	1	2	7	Yes	
Fay Slough	no	no	no	B_L	1	2	8	Yes	
South Bay (east)	no	diatoms	yes	A	A	3	10	Yes	The data here is mostly sufficient, occupying a new site would be more prudent.
South Bay (west)	no	no	no	B_L/A_D	1	2	9	Yes	South Bay (east) occupies an area subject to repeated Late Holocene coseismic subsidence, the timing and magnitude of the associated land level changes is poorly understood. This location is also occupied by critical transportation infrastructure and a community college.
Swiss Hall	yes	no	yes	A	A	3	11	Yes	The data here is mostly sufficient, occupying a new site would be more prudent.
Hookton Slough	yes	no	yes	A	A	3	12	Yes	The data here is mostly sufficient, occupying a new site would be more prudent.
Barlow	yes	no	foraminifera	yes	B_L/A	2	7	Yes	The fat-free radiocarbon results are from a single core, and are not consistent with the other data from the site. The data would be valuable in understanding how the Eel River responds to tectonic deformation.

[a] Stratigraphic biostratigraphy. [b] Both samples of organic material were submitted for analysis. [c] Inverse dates were encountered after analysis of the data. [d] Not all of the disturbance events have ^{14}C determinations, or several of the event horizons have a limited number of samples to statistically verify age determinations. [e] Accordance age determination within data set. ■ ^{14}C sample collection techniques and analysis meet current scientific standards. ^{14}C Descriptive limitations include: ▲ Lithologic descriptions of core logs meet current scientific standards. ■ Lithologic descriptions of core logs are simplified compared to modern scientific standards. ● Lithologic descriptions of core logs are not adequate to meet current scientific standards. [1] Site is currently occupied by critical transportation infrastructure, a community college, a large population or valuable infrastructure. [2] Is partially or temporally occupied a known or important data gap, or if the data collected at the site meets current scientific standards and does not currently need further analysis. The sites are evaluated on a scale from 1-3 with 1 assigned to locations that are a top priority for further investigation and 3 being locations that do not merit further investigation at the time.

PART V SPACE-TIME RELATIONS



What can we conclude?

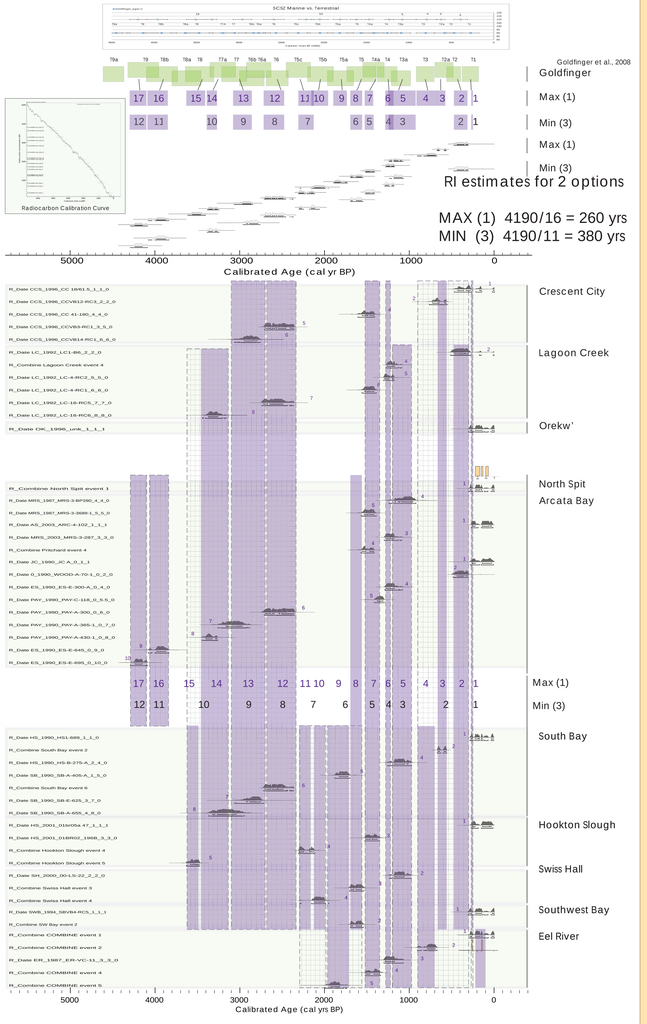
Option A: All terrestrial events are unique.

Option B: Fewer events recorded on land, possibly selectively archiving the largest events. What is the Mw threshold for recording an event? (Nelson et al, 1996 suggest we need ~1m subsidence in order to detect the subsidence)

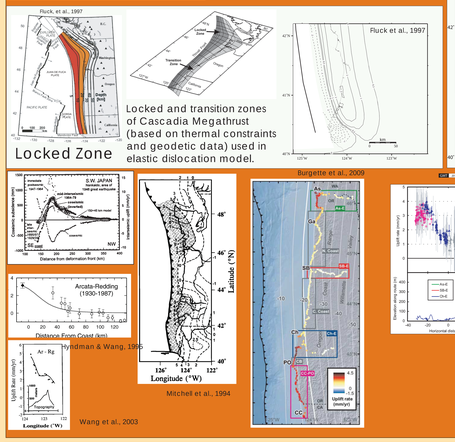
MAX events (1):
the maximum number of events, limited by 1. stratigraphic control, 2. number of ages per event, 3. non-overlap for 2 sigma error

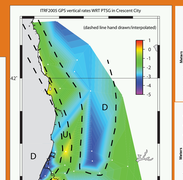
MIN events (3)
the absolute minimum events permissible given stratigraphic relations, regardless of abundance of good acceptable 14C ages.

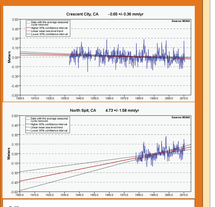
PART IV TIME-SPACE RELATIONS

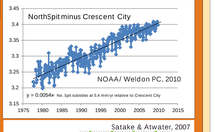


PART V EARTHQUAKE CYCLE DEFORMATION (models vs. measurements)









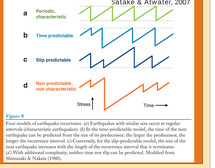
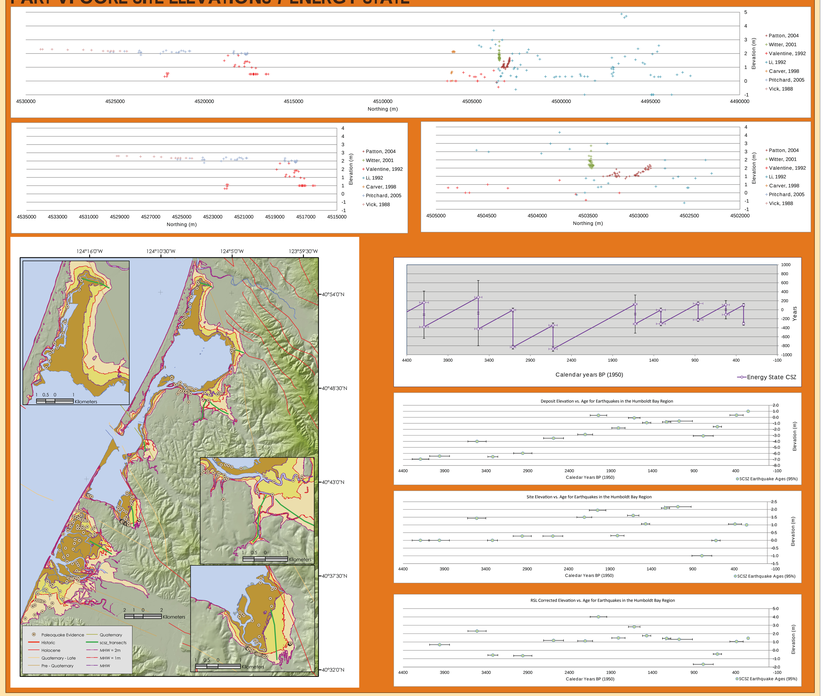


Figure 8

Four models of earthquake recurrence. (a) Earthquakes with similar size occur at regular intervals (characteristic earthquakes). (b) In the time-predictable model, the time of the next earthquake can be predicted from the size of its predecessor; the larger the predecessor, the longer the recurrence interval. (c) Conversely, for the slip-predictable model, the size of the next earthquake increases with the length of the recurrence interval that it terminates. (d) Neither time nor slip predictability, neither time nor slip can be predicted. Modified from Shimazaki & Nakata (1980).

PART VI CORE SITE ELEVATIONS / ENERGY STATE