THE MISSING EARTHQUAKES OF HUMBOLDT COUNTY: RECONCILING RECURRENCE INTERVAL ESTIMATES, SOUTHERN CASCADIA SUBDUCTION ZONE

Jason R. Patton [1,2] and Tom H. Leroy [2,3]

1. COAS, Oregon State University, Corvallis, OR, United States.
2. Cascadia GeoSciences, Cascadia GeoSciences, McKinleyville, CA, United States.
3. Pacific Watershed Associates, McKinleyville, CA, United States

S41A-1899

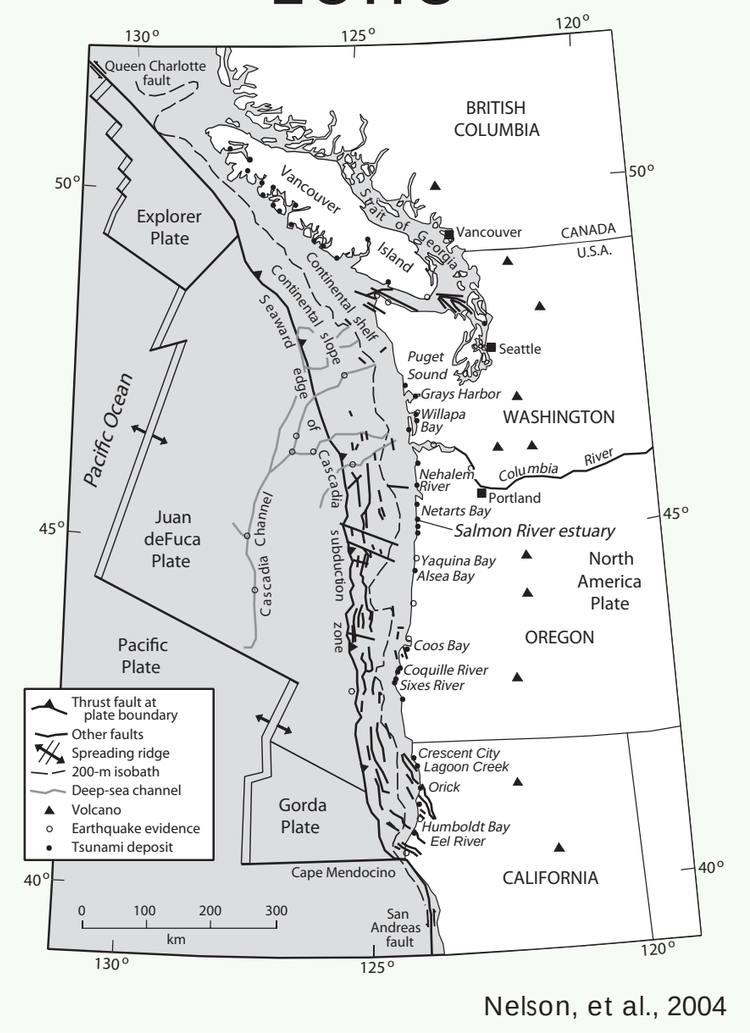
Earthquake and tsunami hazard for northwestern California and southern Oregon is predominately based on estimates of recurrence for earthquakes on the Cascadia subduction zone and upper plate thrust faults, each with unique deformation and recurrence histories. Coastal northern California is uniquely located to enable us to distinguish these different sources of seismic hazard as the accretionary prism extends on land in this region. This region experiences ground deformation from rupture of upper plate thrust faults like the Little Salmon fault. Most of this region is thought to be above the locked zone of the megathrust, so is subject to vertical deformation during the earthquake cycle. Secondary evidence of earthquake history is found here in the form of marsh soils that coseismically subside and commonly are overlain by estuarine mud and rarely tsunami sand. It is not currently known what the source of the subsidence is for this region; it may be due to upper plate rupture, megathrust rupture, or a combination of the two. Given that many earlier investigations utilized bulk peat for 14C age determinations and that these early studies were largely reconnaissance work, these studies need to be reevaluated.

Recurrence Interval estimates are inconsistent when comparing terrestrial (~500 years) and marine (~220 years) data sets. This inconsistency may be due to 1) different sources of archival bias in marine and terrestrial data sets and/or 2) different sources of deformation. Factors controlling successful archiving of paleoseismic data are considered as this relates to geologic setting and how that might change through time. We compile, evaluate, and rank existing paleoseismic data in order to prioritize future paleoseismic investigations. 14C ages are recalibrated and quality assessments are made for each age determination. We then evaluate geologic setting and prioritize important research locations and goals based on these existing data.

Terrestrial core transects are located in each of eight archival domains in order to evaluate archival bias and potential deformation sources for the southern Cascadia subduction zone. These domains are located in the Eel River, Humboldt Bay, Humboldt Lagoons, and Crescent City regions. In any given domain, evidence of earthquakes can be regional, local, or both. Core transects are designed to capture archival bias due to 1) interseismic deformation in the upper plate or the megathrust, 2) rupture on upper plate thrust faults, 3) rupture on the megathrust, or 4) rupture on both. Modern biogeochemical transects are used to calibrate paleontologic estimates.

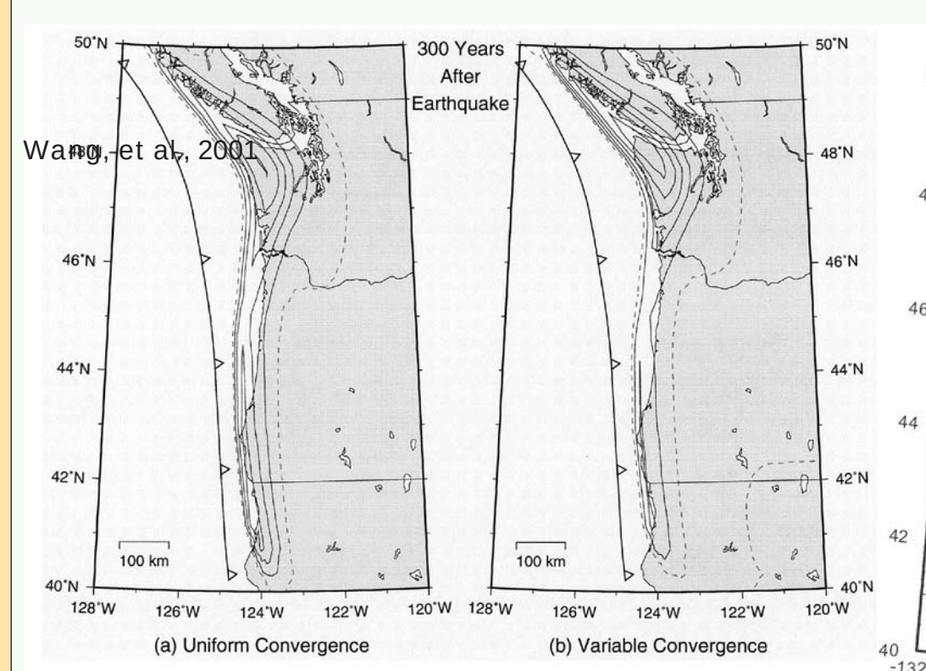
Based on our assessment, we determine which sites need better age control, which sites need supplemental coring, and key new research areas that need to be investigated.

Cascadia subduction zone

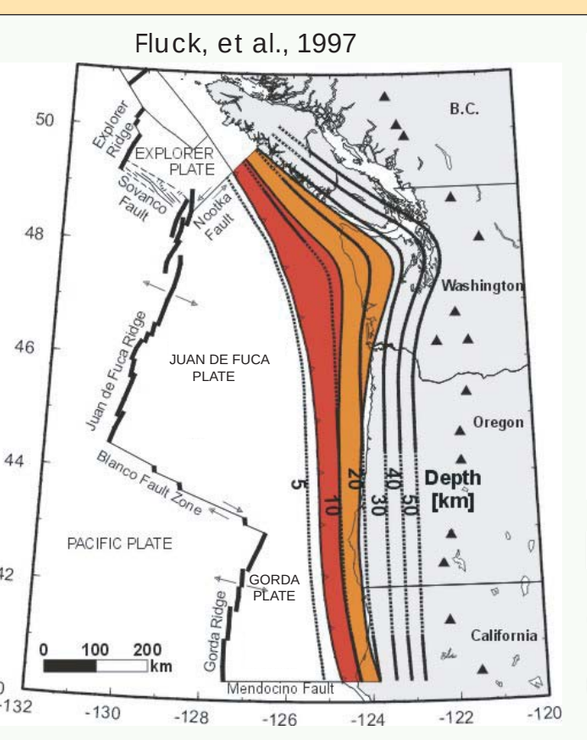


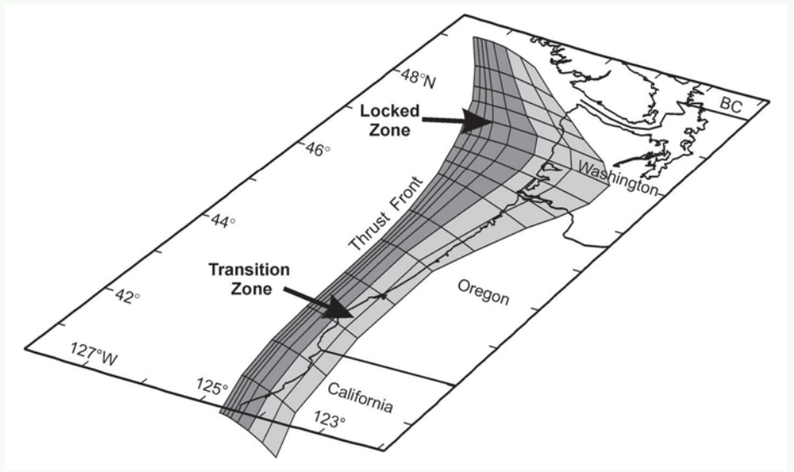
Nelson, et al., 2004

Locked Zone



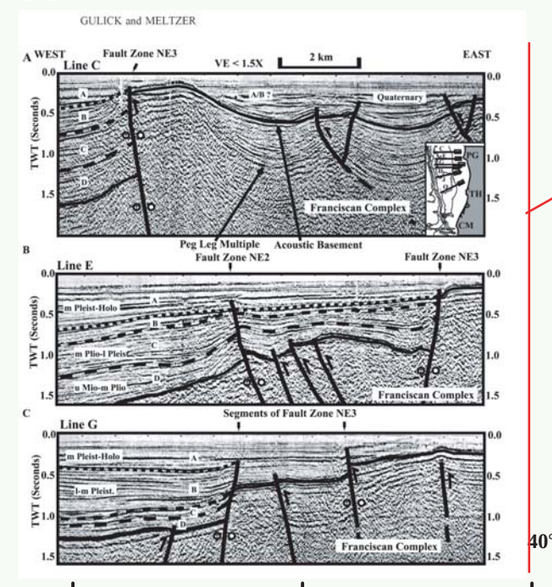
Uplift rates at 300 yr. after the great earthquake

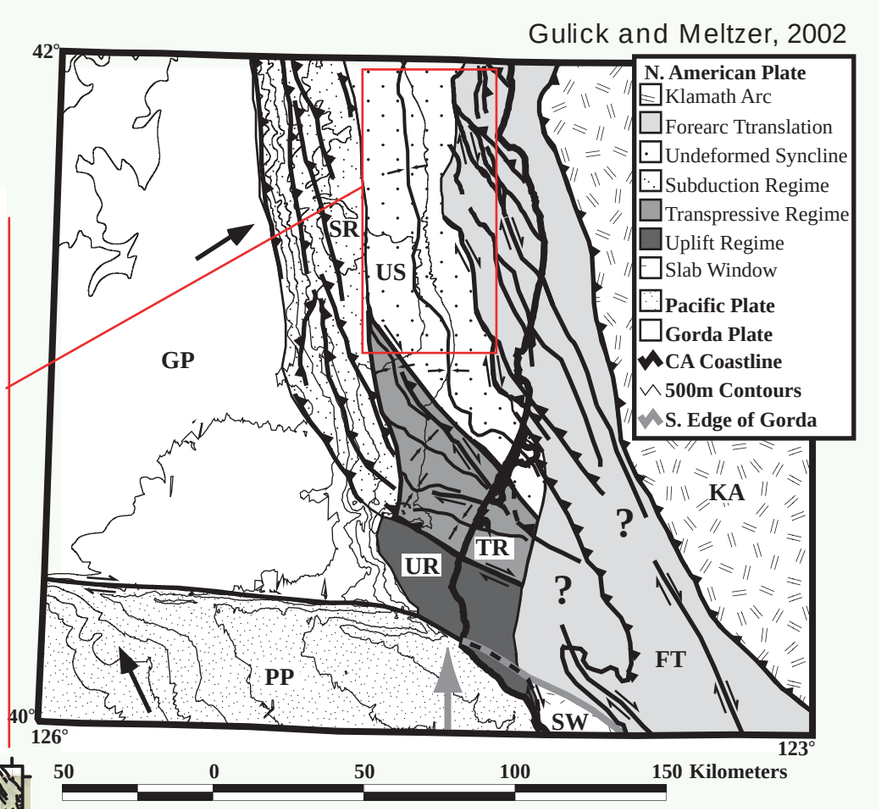


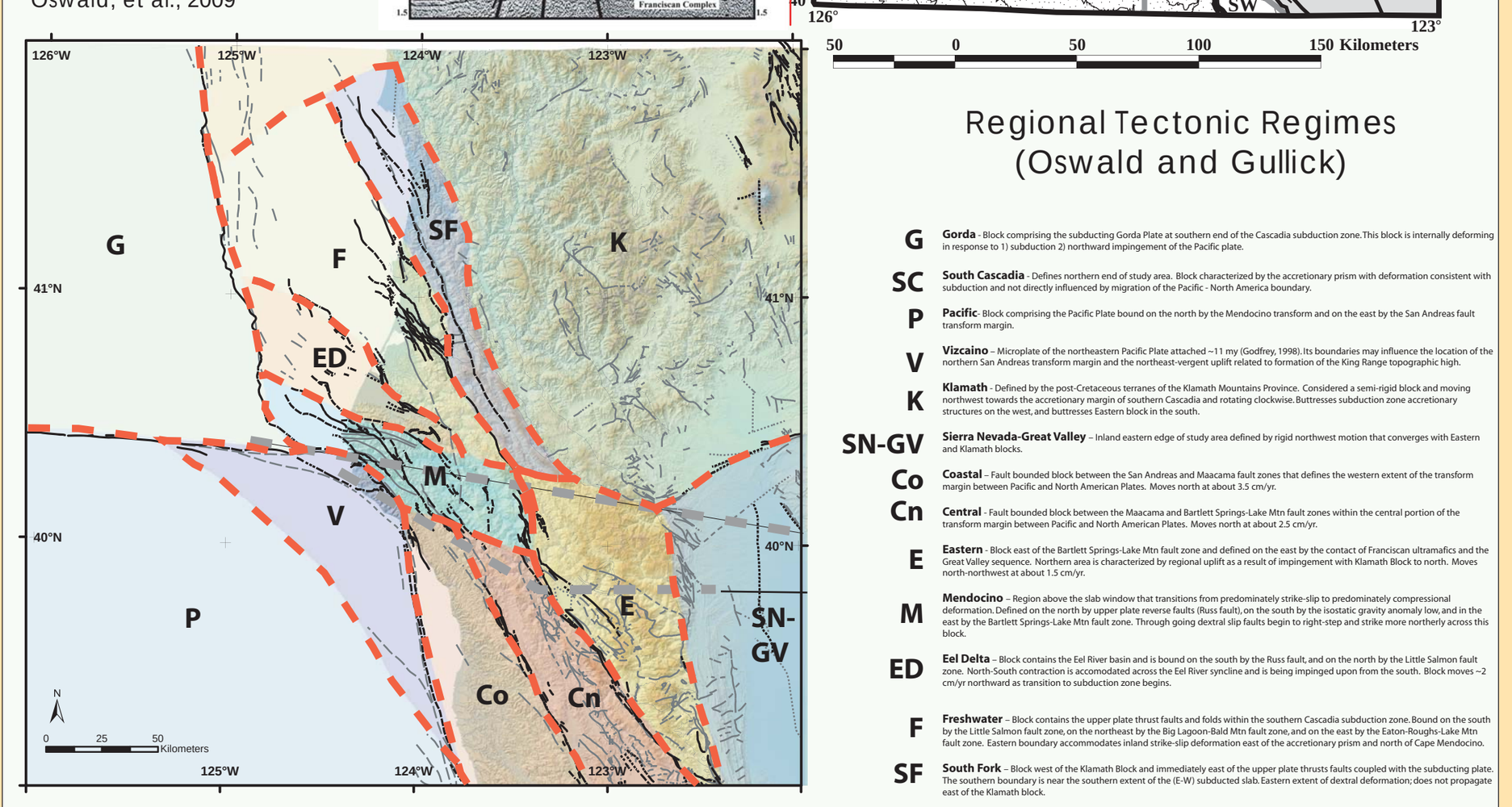


Locked and transition zones of Cascadia Megathrust (based on thermal constraints and geodetic data) used in elastic dislocation model.

Mendocino Deformation Zone





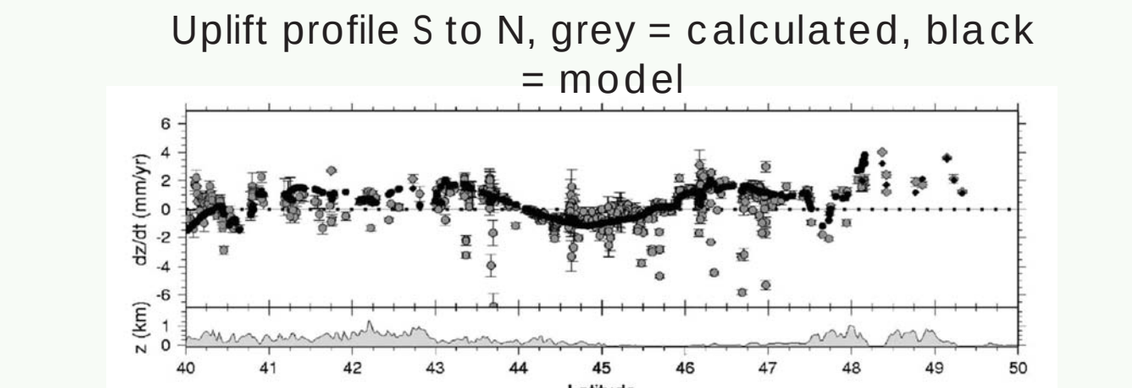


Regional Tectonic Regimes (Oswald and Gulick)

Vertical Deformation

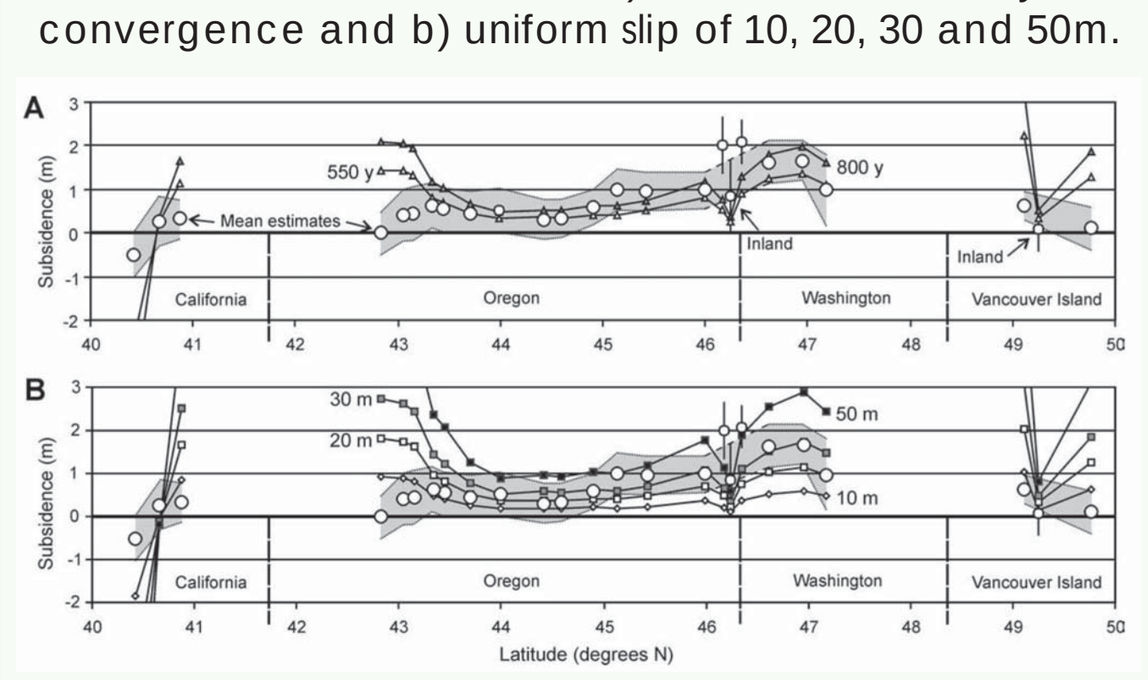
Verdonck, 2007

Uplift profile S to N, grey = calculated, black = model



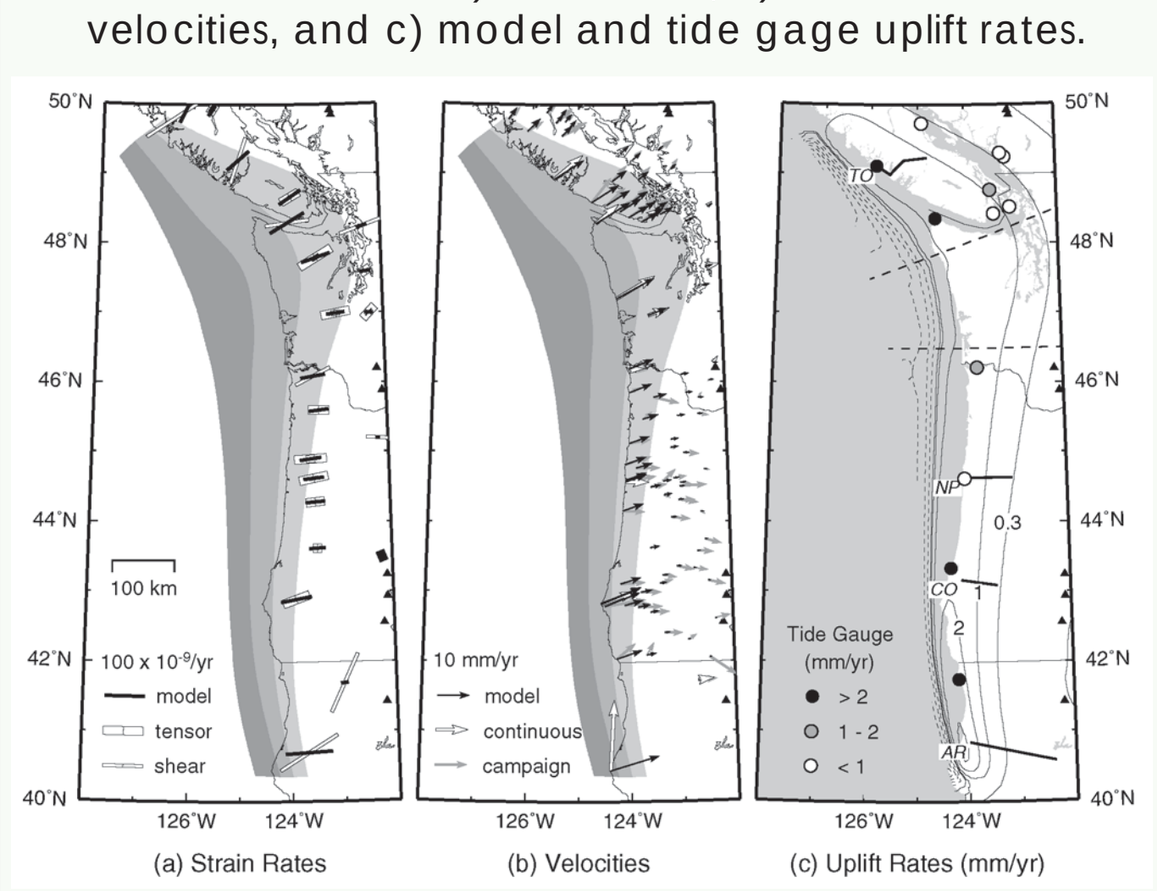
Leonard, et al., 2004

Mean subsidence estimates a) after 800 and 550 yrs of convergence and b) uniform slip of 10, 20, 30 and 50m.



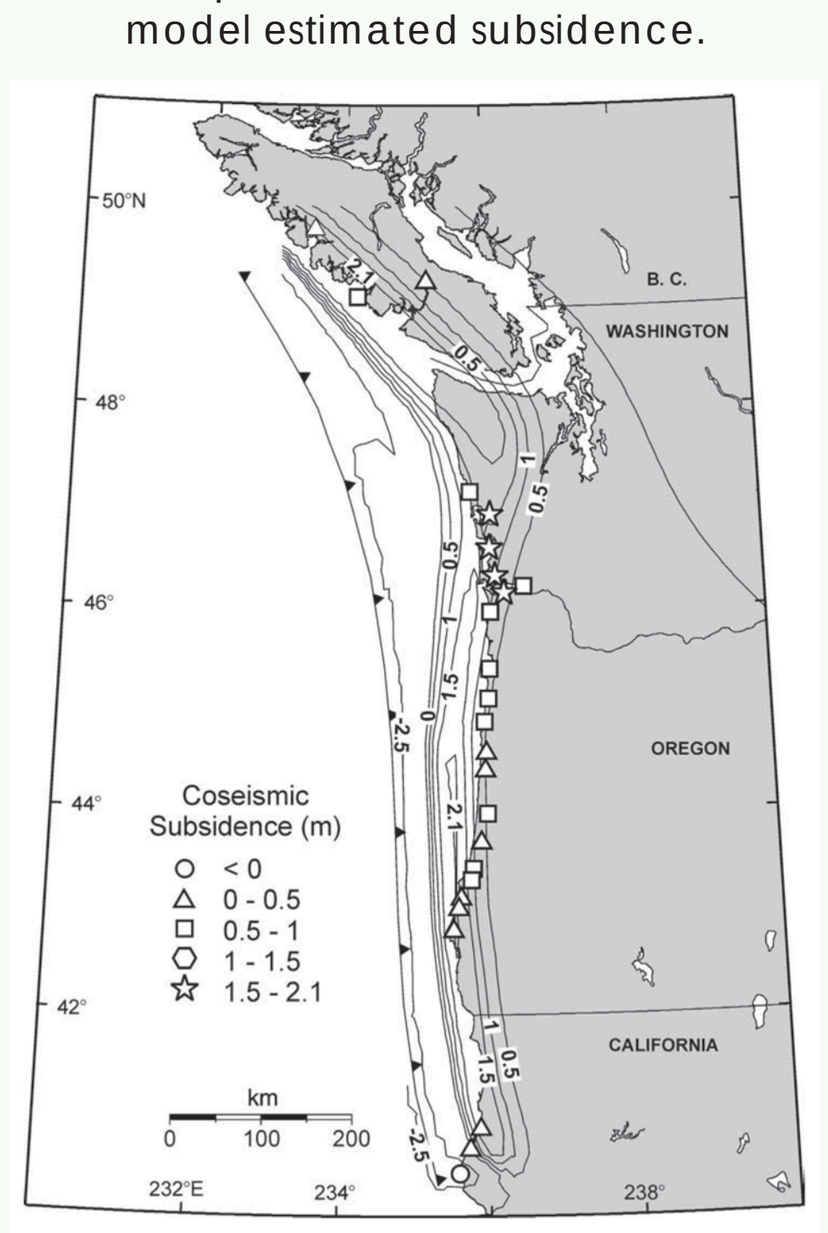
Wang, et al., 2003

CASC3D-2 model: a) strain rates, b) model and GPS velocities, and c) model and tide gage uplift rates.

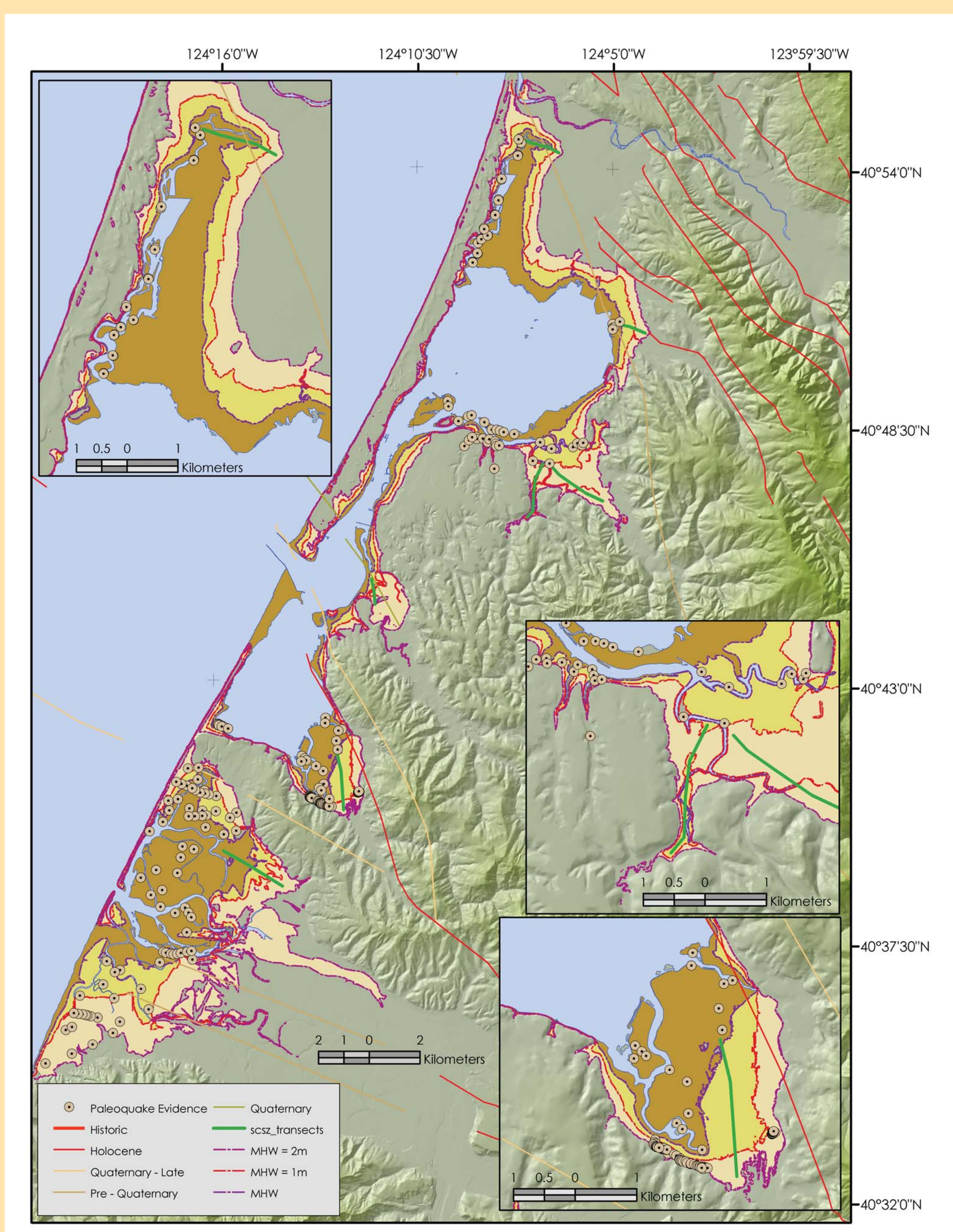


Leonard, et al., 2004

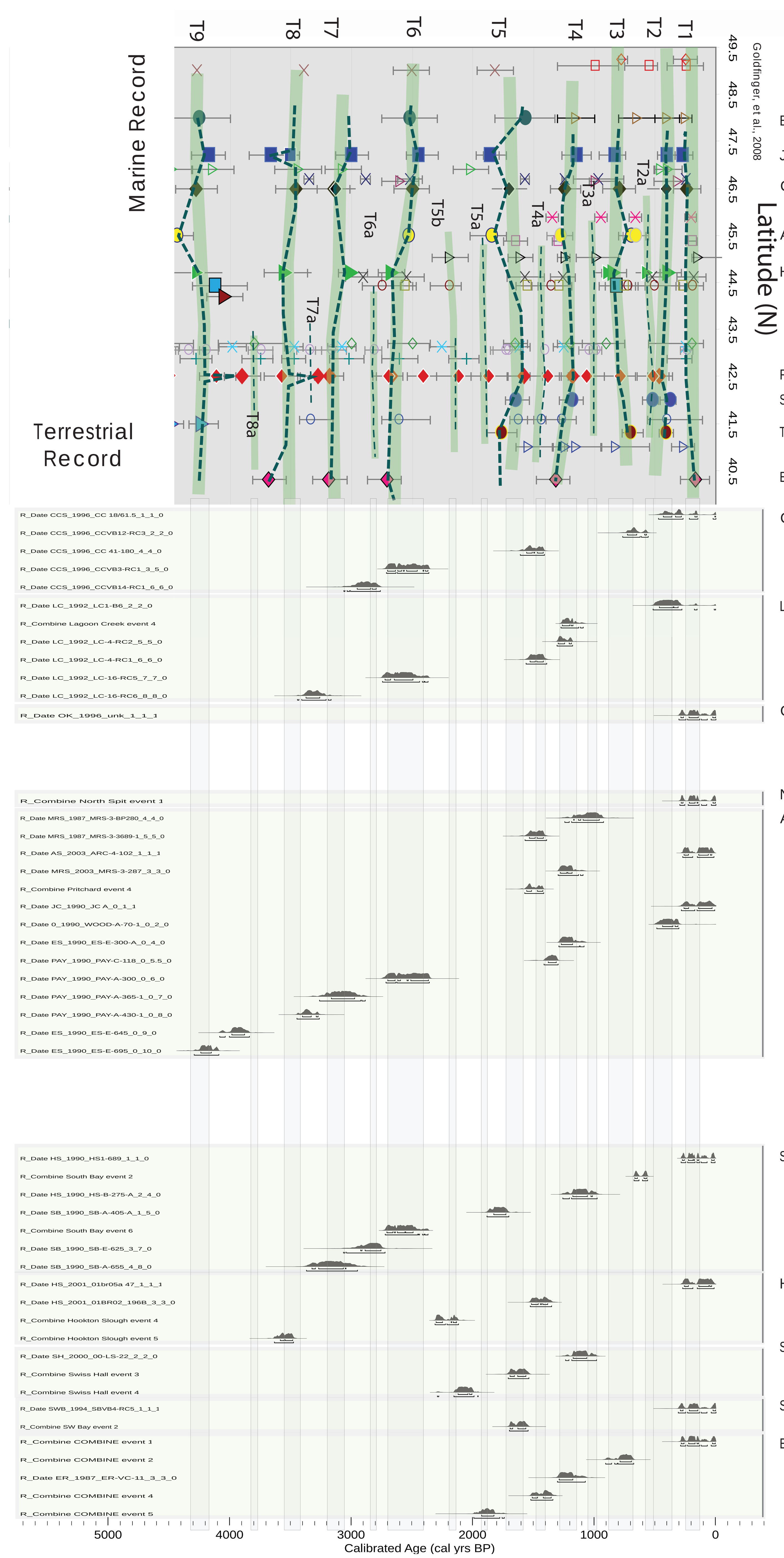
Mean subsidence rates calculated at sites compared with elastic dislocation model estimated subsidence.



Vertically Restricted Regions



Time-Space Relations

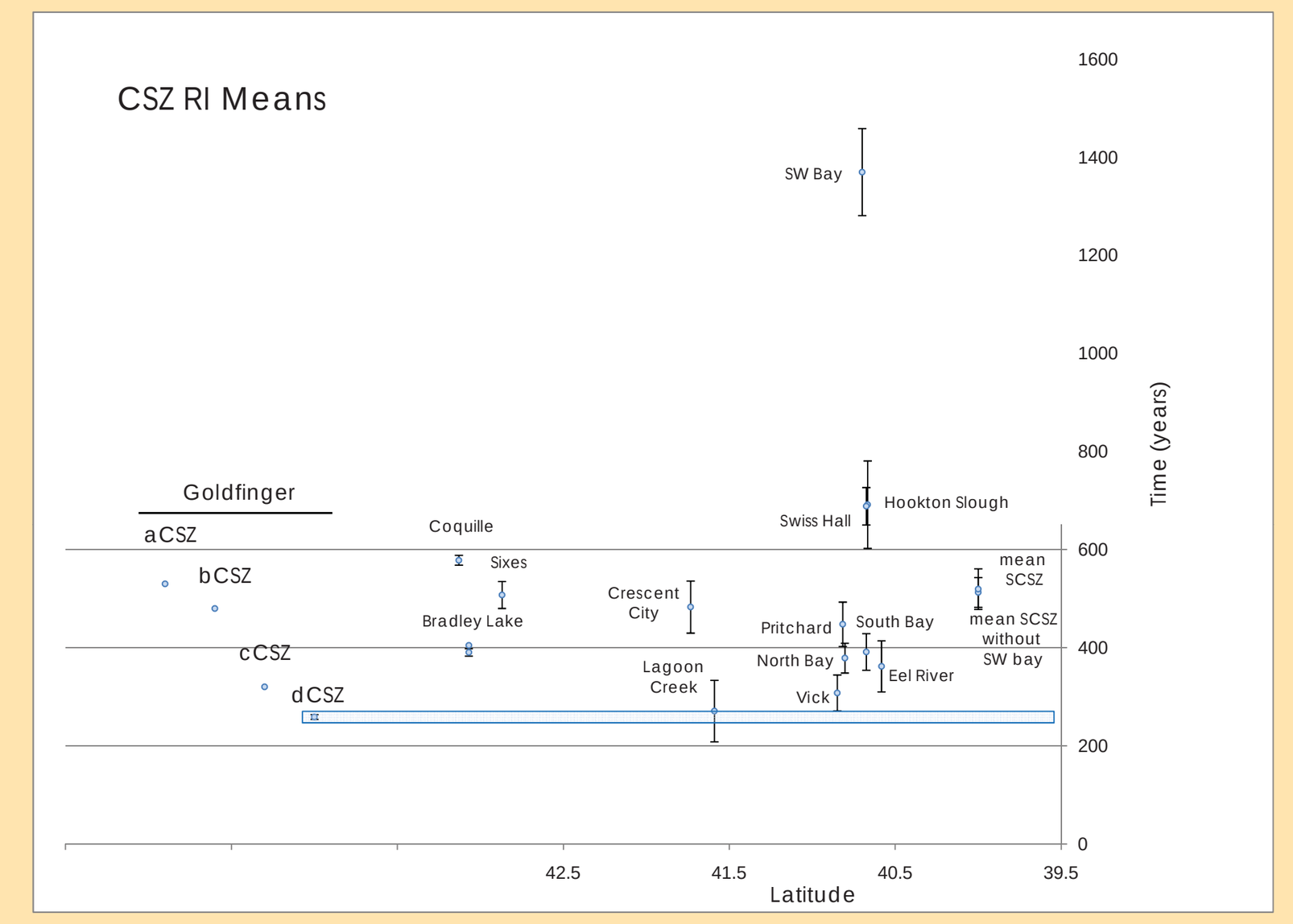


Recurrence

Recurrence Intervals

reference	region	oldest age ^ min	oldest age ^ max	events included *	events total ++	RI mean	+/-	R. I. rounded #	RI reported $	EQ missing %	RI new
Goldfinger, et. al., 2008	aCSZ			19	19	530		530	530	0	530
Goldfinger, et. al., 2008	bCSZ					480		480	480	0	
Goldfinger, et. al., 2008	cCSZ					320		320	320	0	
Goldfinger, et. al., 2008	dCSZ	10010	9650	38	38	259	5	260	220	0	260
Nelson, et. al., 2006	Bradley Lake	4700	4700	12	12	405	0	400	440	9	229
Kelsey, et. al., 2005	Bradley Lake	4630	4460	12	12	390	8	390	390	9	223
Witter, et. al., 2003	Coquille	6720	6500	12	12	578	10	580	580	19	225
Kelsey, et. al., 2002	Sixes	5600	5050	11	11	508	28	510	510	14	224
Carver, et. al. 1998	Crescent City	3060	2760	1, 2, 4, 5, 6	6	483	53	480		7	222
Abramson, et. al., 2007	Lagoon Creek	3440	3164	2, 4, 5, 6, 7, 8	8	271	63	270		1	240
Vick, et. al., 1988	North Bay	1568	1390	4, 5	5	308	37	310		2	221
Pritchard, et. al., 2004	North Bay	1684	1410	2, 3, 4	4	448	45	450		4	225
Valentine, 1992	North Bay	4290	4087	1, 2, 4, 6, 7, 8, 9, 10	10	379	30	380	320	7	224
Carver, et. al. 1998	South Bay	1695	1542	2	2	1369	89	1370		10	228
Valentine, 1992	South Bay	3366	2946	1, 2, 4, 5, 6, 7, 8	8	391	37	400	320	6	229
Witter, et. al., 2002	South Bay	2289	1954	2, 3, 4	4	691	89	690		8	230
Patton, et. al., 2006	South Bay	3631	3474	3, 4, 5	5	688	38	900	900	15	225
Li, 1992	Eel River	1990	1739	2, 3, 4, 5	5	362	52	360		3	225
			without SW bay	mean		513	30	513	421		
			all events	mean		519	41	540	494		

^ cal yrs BP, years before 1950.
* events included in RI estimate.
++ total events at site.
\# Recurrence Interval (RI) based on events with radiocarbon based age control.
% number of earthquakes required to shorten RI to match marine RI (result in the next column over).
% number of earthquakes required to shorten RI to match marine RI (result in the next column over).



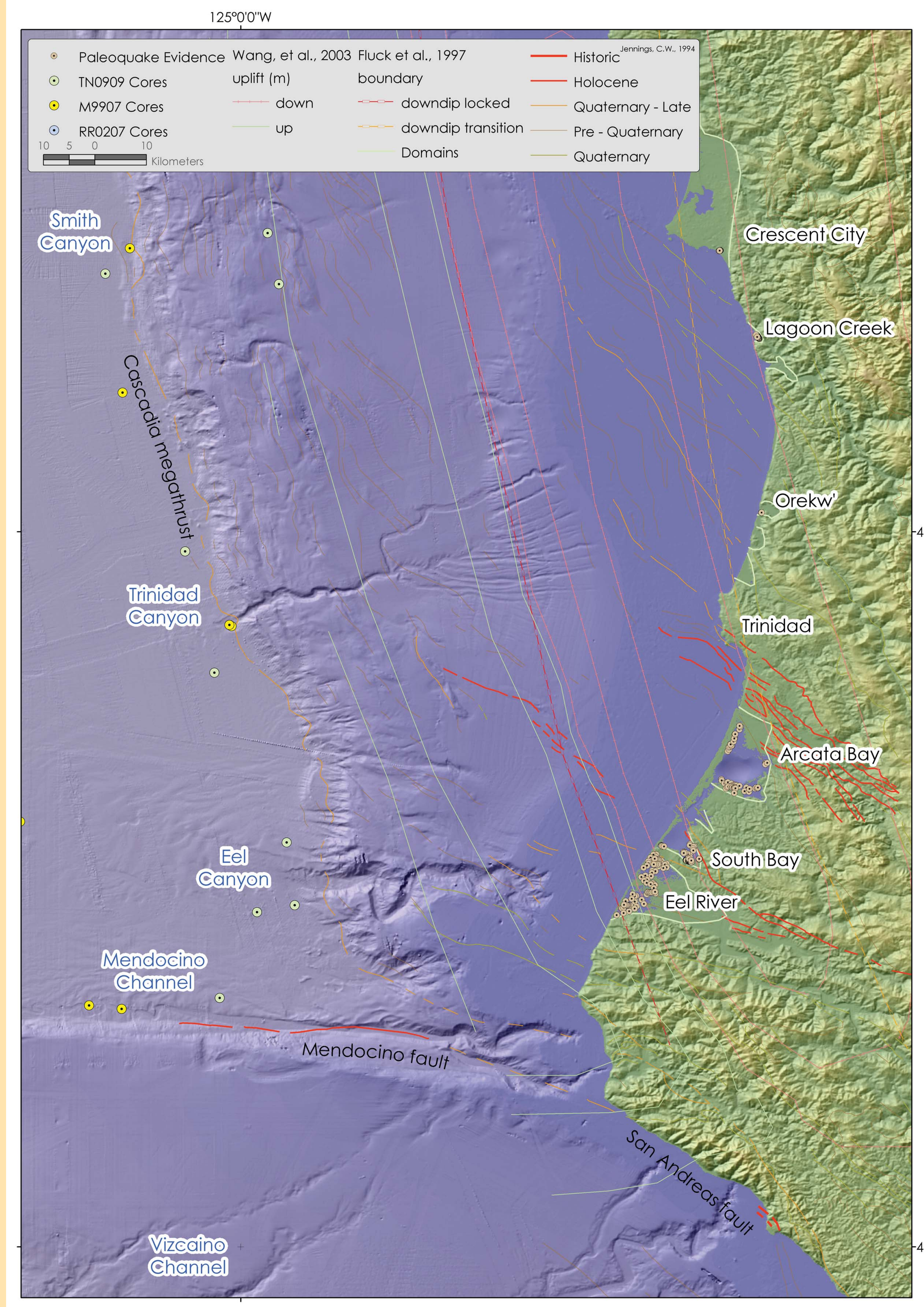
Site Evaluation and Ranking

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

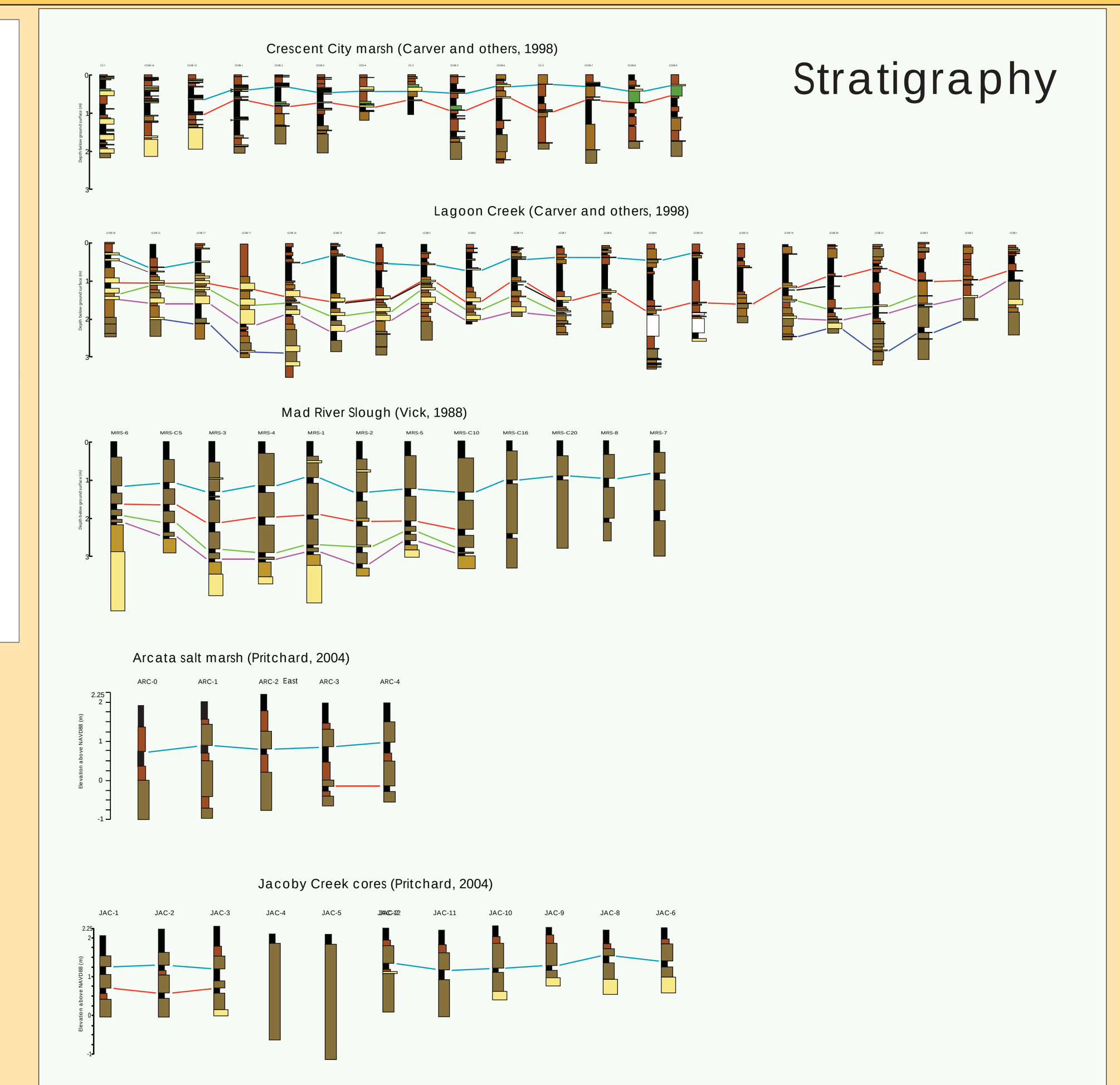
Project Location	Surveyed Elevation Control?	Biostratigraphy?	All Events Dated and Correlated?	^{14}C Limitations[1]	Descriptive Limitations[2]	Scientific Value of the Site[3]	Prioritization for Conducting Additional Studies	Notes
Crescent City marsh	no	diatoms	no	N,L	A	1	5	The event horizons at the Crescent City marsh are poorly constrained. There is a high likelihood that the marsh archives teletsunami evidence.
Lagoon Creek	no	diatoms	yes	I	A	3	12	The data there is mostly sufficient and the lagoon was found to contain dangerous levels of dioxin.
Mad River Slough	no	radiolarians	yes	B,L,I	S	1	1	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. This location is also occupied by critical transportation infrastructure and a public water treatment facility vulnerable to relative sea-level changes.
Arcata Marsh	yes	diatoms	yes	A,L	A	1	2	
Jacoby Creek	yes	no	yes	A,L	A	1	3	
Eureka Slough	no	no	yes	B,L	S	2	6	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. This area is also occupied by critical transportation infrastructure and an airport protected by tidal levees.
First Slough	no	no	yes	B,L	S	2	7	
Fay Slough	no	no	no	B,L	S	2	8	
South Bay (west)	no	diatoms	yes	A	A	3	10	The data here is mostly sufficient, occupying a new site would be more prudent.
South Bay (east)	no	no	no	B,L,N,D	S	2	9	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	The data here is mostly sufficient, occupying a new site would be more prudent.
Hookton Slough	yes	diatoms	yes	A	A	3	13	The data here is mostly sufficient, occupying a new site would be more prudent.
Eel River	no	forminifera	yes	B,L,N	S	1	4	The Eel river valley lies just north of the triple junction and has the potential to record paleosiesmic and paleotsunami evidence at the southern most Csz. This data would be valuable in understanding how the southern Csz transitions to the San Andreas fault zone.

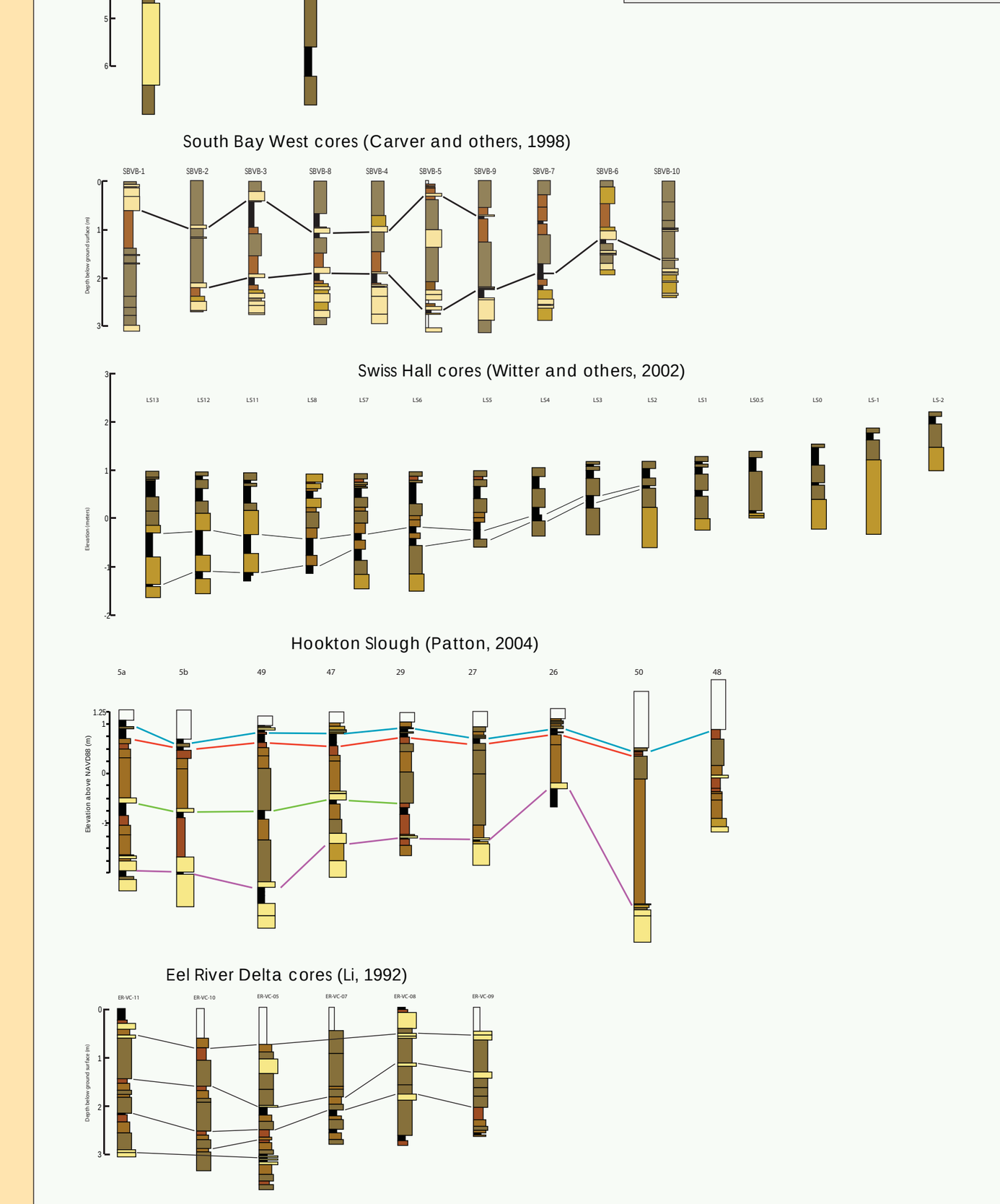
[1] ^{14}C limitations include: **B**-bulk samples of organic material were submitted for analysis; **I**- Inverse dates were encountered after analysis of the data; **N**- Not all of the disturbance events had ^{14}C determinations; **L**- several or all event horizons have a limited number of samples to statistically verify age determinations; **D**-Anomalous age determination within data set; **A**-^{14}C sample collection techniques and analysis meet current scientific standards.
[2] Descriptive limitations include: **A**- Lithologic descriptions of core logs meet current scientific standards; **S**- Lithologic descriptions of core logs are simplified compared to modern scientific standards.
[3] Scientific value of site is a subjective determination based on the specific attributes of the site including: ability to archive disturbance events, the value of the existing data, proximity to large human populations or valuable infrastructure, if it spatially or temporally occupies 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 this time.

Sites



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.
Flück, 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., Bürgmann, R., Morey, A., Johnson, J., Nelson, H., Gutiérrez-Pastor, J., Ericsson, A., Karabanov, E., 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 BSSA, 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 Eartquakes and Tsunamis of hte Past 2000 Years at he Salmon River Estuary, Central Oregon Coast, USA, BSSA, v. 94, n. 4, 2004.
Oswald, J., Leroy, T. H., and Williams, T., B., 2009. Deofrmation Associated with the Northern Migration of 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.
Bronk 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, n. 2, p. 323-349.
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 deformatino 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-dimensinoal viscoelastic interseismic deormation 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 reivsed 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. C., Kelsey, H. M., Garrison-Laney, C., Koehler, R. D., and Hemphill-Haley, E., 2002. Final 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.