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Tree-Ring Dating of Coseismic Coastal Subsidence in the Pacific Northwest Region

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TREE-RING DATING OF COSEISMIC COASTAL SUBSIDENCE IN THE PACIFIC NORTHWEST REGION

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TECHNICAL ABSTRACT:

Estuaries, bays and rivers along the Pacific northwest coast were investigated to try and obtain samples of trees killed or damaged by prehistoric earthquakes. Sites where potential trees had been reported and other coastal sites were visited. Samples from previous studies were assembled through cooperation with researchers conducting earlier studies. Material was mounted, surfaced and examined. New collections and older samples were measured and crossdated to establish the years of rings where possible. Some of the earlier samples were in such poor conditions for a variety of reasons that they were not processed or dated.

The samples from new and previous collections along the coast of the Cascadia Subduction Zone were analyzed for evidence of disturbance by prehistoric earthquakes. Precise dating of the annual rings indicate tree disturbances between 1780 and 1820 with several trees showing disturbance in 1700 and 1701 at two sites about 100 km apart. This evidence of possible seismic disturbance supports tsunami records from Japan indicating a possible west coast America earthquake in 1700. Other years cannot be excluded until more samples are studied. Root sections and dead trees from submerged sites are being processed to determine year of death.

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NON-TECHNICAL PROJECT SUMMARY:

Annual rings of tree samples from along the coastal Cascadia Subduction Zone were analyzed for evidence of disturbance by prehistoric earthquakes. Precise dating of the annual rings indicate tree disturbances between 1780 and 1820 with several trees showing disturbance in 1700 and 1701 at two sites about 100 km apart. This evidence of possible seismic disturbance supports tsunami records from Japan indicating a possible west coast America earthquake in 1700. Other years cannot be excluded until more samples are studied. These studies will help reveal the magnitude of earthquake hazard for the Pacific Northwest coast.

A. INTRODUCTION

Estuaries, bays and rivers along the Pacific northwest coast were investigated to try and obtain samples of trees killed or damaged by prehistoric earthquakes. Sites where potential trees had been reported and other coastal sites were visited. Samples from previous studies were assembled through cooperation with researchers conducting earlier studies. Material was mounted, surfaced and examined. New collections and older samples were measured and crossdated to establish the years of rings where possible. Some of the earlier samples were in such poor conditions for a variety of reasons that they were not processed or dated. The results are presented below. Root sections from previous collections are still under analysis.

Accumulation of evidence for seismic-related subsidence and probable subduction earthquakes continues for the Pacific Northwest (Atwater et al., 1995). New consideration of tsunami documentation is interpreted as evidence of possible large earthquakes on the west coast of the Americas (Kerr, 1995). Tree-ring studies dating possible subsidence might coincide with the tsunami record (Yamaguchi et al., 1989; Atwater and Yamaguchi, 1991; Jacoby et al. 1995; and described below).

The most recent event is tentatively placed about 300 years ago (e. g. Atwater et al., 1991 and Nelson and Atwater, 1993). This event is within the lifetime of some living trees and within the preservation limit of some relict or buried trees, stumps, and roots. We are focusing on the interval 1680 to 1720. However, we are also looking for any unusual signal outside these boundaries in case the radiocarbon dating is off or other limits are not correct. The post-1687 limit by Yamaguchi et al. (1989) is based on one tree and should be confirmed. Sampling and analysis of these tree-ring materials offers the best opportunity for calendar dating of event(s) and testing for simultaneity at different locations. This dating and crossdating will allow comparison to tsunami records (Soloviev and Go, 1974) or any other calendar-dated information that may be forthcoming. It will be the composite of dating and geologic information that is likely to establish the probable magnitude of the event(s) and thus the earthquake hazard for the region.

Definition: crossdating: "the procedure of matching ring-width variations among trees that have grown in nearby areas, allowing the identification of the exact year in which each ring was formed" (Fritts, 1976) [exact meaning to the calendar year or exact year relative to each other].

B. REVIEW OF RESULTS

This research involved: (1) assembly and processing of existing samples; (2) obtaining and processing new samples from key locations or reconnaissance sites; and (3) utilization of existing tree-ring data in efforts to verify dating of samples. Figure 1 shows the general locations and Table 1 lists the worthwhile samples and numbers of total samples. Of the samples collected previously by others, two thirds of the cores from living trees were either too young to be of use or in such poor condition as to be useless for analysis. Some new samples were taken at various locations to improve quality and increase coverage. Several locations did not have significant sample opportunities due to poor preservation or absence of old-aged wood at any strategic locations.

New samples were taken and others processed from the South Fork of the Willapa River (Figure 1 and Table 1). Four trees were old enough to span the time estimated by radiocarbon dating (Atwater et al., 1991; Carver et al., 1992; and Nelson and Atwater, 1993). All four showed changes to a greater or lesser degree around 1700. There are problems with missing rings and the dating is not finalized. The changes are not uniform even within cores from one tree. Figure 2 shows plots of ring widths from two trees on the South Fork of the Willapa River and Figure 3 shows the location of these trees. Tree F-179 shows obvious growth reduction now dated as beginning in 1700 in core D and 1701 in core C. This is the type of growth deterioration one might expect if a near-sea-level site subsided and became a more saturated, poorer growth site. Directly across the river from F179 is tree F181 showing an unusually wide ring in 1700 and subsequent decrease in growth. The decrease is not as dramatic as F-179. Tree F-177 also shows possible disturbance in 1711 and F-183 has several abrupt changes in growth from 1700 to 1720. There are samples from 19 other trees in the vicinity that are too young to show evidence of an event during 1680 to 1720 AD.

The most productive sampling area for old-aged trees was Price Island on the Columbia River (Figures 1 and 4). Sites located along the banks of major rivers can have added complications due to flooding or other fluvial disturbances. Thus caution must be exercised in interpretations of such samples but one can still read the imprint or overprint of possible seismic disturbance in tree-ring samples from these sites. All estuaries may have storm or tide-induced disturbance events in the tree-rings but are still good sites

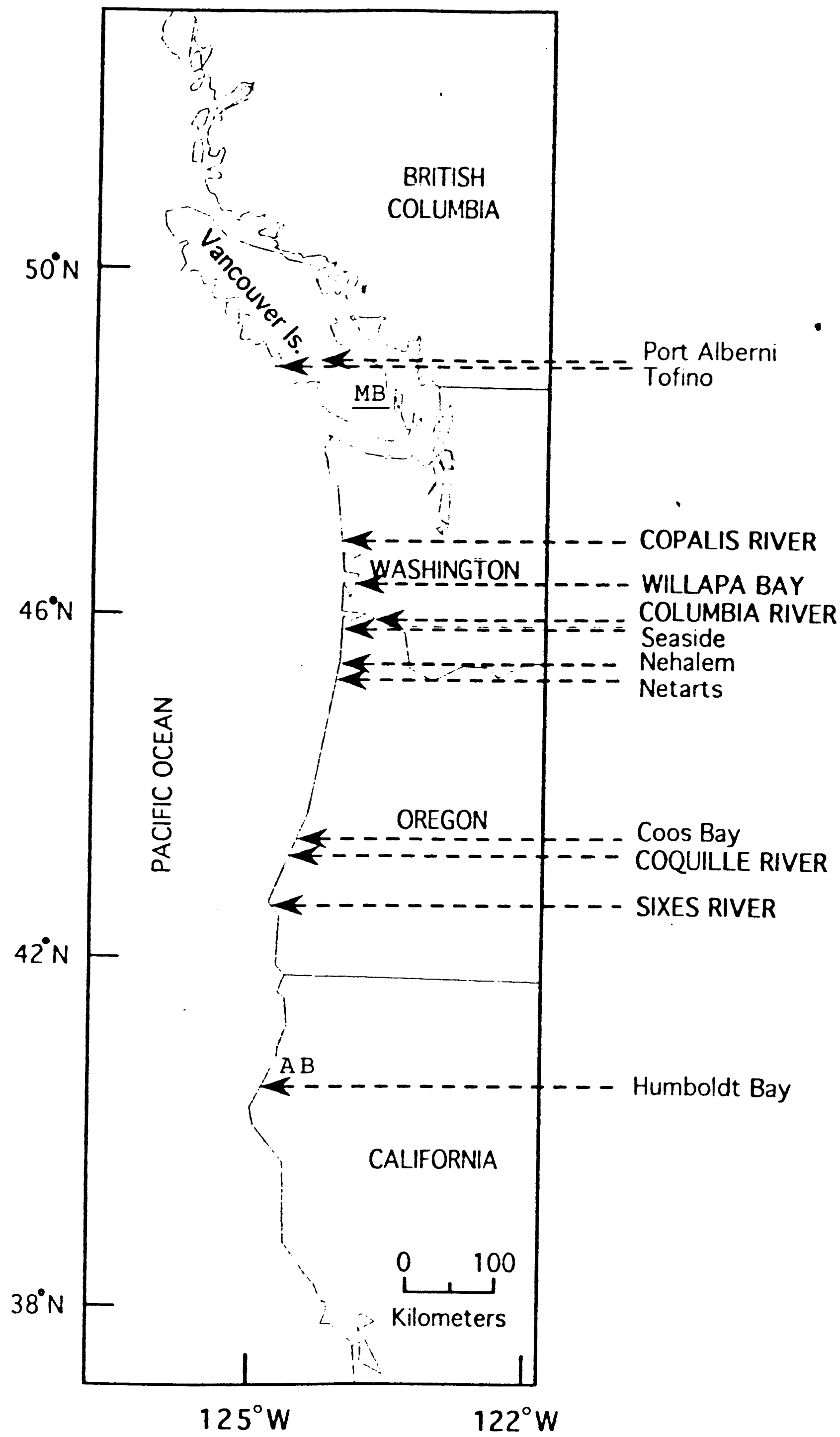


Figure 1: Map of Pacific Northwest coast encompassing Cascadia Subduction Zone. Trees, stumps or buried remnants of trees will be sampled at locations in capitals. Other sites may be checked on a reconnaissance basis. Letters MB (MacMillan-Bloedel) and AB (Agate Beach) are old-aged, undisturbed, living trees sampled for purposes of dating disturbed trees or dead trees, stumps or roots.

TABLE 1: CORES FROM LIVING TREES

Willapa River, South Fork:

TREE	TAG #	YEAR CORED	No. of RINGS	DIA. (cm)	DATED TIME SPAN	REMARKS
F-177 five cores	5	1992	321	91	1669?-1958?	C&D: 2 narrow ~1700, 1711
F-179 four cores	99	1994	322	151	1639-1992	abrupt decrease ~1700
F-181 three cores	63	1992	354	138	1657-1991	C&E wide 1700
F-183 three cores	18	1992	334	100	1658-1991	abrupt changes 1700-1720

Three trees 200 to 290 years old; reserved for possible use in crossdating
Eleven trees 1992 less than 200 rings

Willapa River, Main Fork:

Five trees 1992 All too young

Columbia River: Price Island

TREE	TAG #	YEAR CORED	No. of RINGS	DIA. (cm)	DATED TIME SPAN	REMARKS
PI-1-E	10	1994	382		1612-1978	nil, dead
(G-502	10	1993	334	99	1655-1978	Blew down 93-94)
PI-2-W&NE	99	1994	372	107	1622-1993	narrow ~1700
(F-166	99	1992	~352	107	undated, many pieces)	
PI-3-E&W	70	1994	370	135	1618-1993	abrupt decrease
(F-165	70	1992	359	135	1615-1868)	~1700
PI-4-SW&N		1994	349		1645-1993	injury 1700, decrease ~1700
PI-7NW&SE	100	1994	360	103	1634-1993	reaction wood
(F-167	100	1992	~281	103	too short)	~1705-08
PI-9N&ESE		1994	441		1553-1993	slight change ~1700-1710
PI-10-N&NW		1994	376		1618-1992	missing ring between 1675 to 1700
PI-11-NE		1994	337		1657-1993	wide 1684
PI-14-SE&W		1994	339		1655-1993	W: slight wide 1700

PI-15-W		1994	310		1684-1993	slight wide 1710-11
PI-16		1994	~300?	~100		bad cores
PI-18-W		1994	381		1613-1993	nil
PI-19-NE&NW		1994	383		1611-1993	decrease 1671 & 17(slight wide 1702
F-168	xx	1992	315	92	1676-1991	
G-18A	60	1993	383	68	1608-1991	• F-169
(F-169	60	1992	381	96	1623-1991	Blew down 92-93)
G-500		1993	328	71	1678-1992	

Five trees 200 to 290 years old; reserved for possible use in crossdating
Four trees 1992 less than 200 rings

Columbia River: misc.

TREE	TAG #	YEAR CORED	NUMBER OF RINGS	DIA. (cm)	DATED TIME SPAN	REMARKS
F-161	71	1992	286	105	in process	@Woody Pt.

Four trees 1992 all too Young

Copalis River:

TREE	TAG #	YEAR CORED	NUMBER OF RINGS	DIA. (cm)	DATED TIME SPAN	REMARKS
F-100	83	1992	331	109	In Process	
F-111	96	1992	295	156	In Process	
F-113	78	1992	303	154	In Process	

Seventeen trees 200 to 290 years old; reserved for possible use in crossdating
Fourteen trees 1992 Less than 200 rings

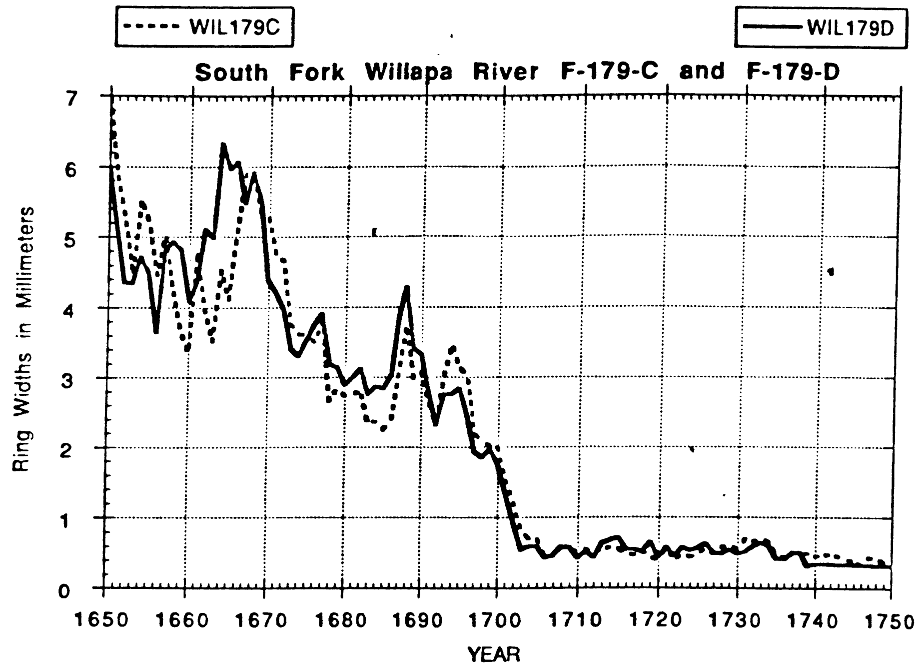
Grays River:

TREE	TAG #	YEAR CORED	NUMBER OF RINGS	DIA. (cm)	DATED TIME SPAN	REMARKS
F-229	33	1992	388	~112	*	

Five trees 1992 Too Young
One tree 1992 May be old but rotten center, no sample

Bear River:	Six trees	1992	All too Young
Cedar River:	One tree	1992	Too Young
Johns River:	Three trees	1992	All too young
Naselle River:	Six trees	1992	All too young and also two rotten
Niawaikum River:	Three trees	1992	All too young

Note: DATED TIME SPAN is for oldest core, others may be younger



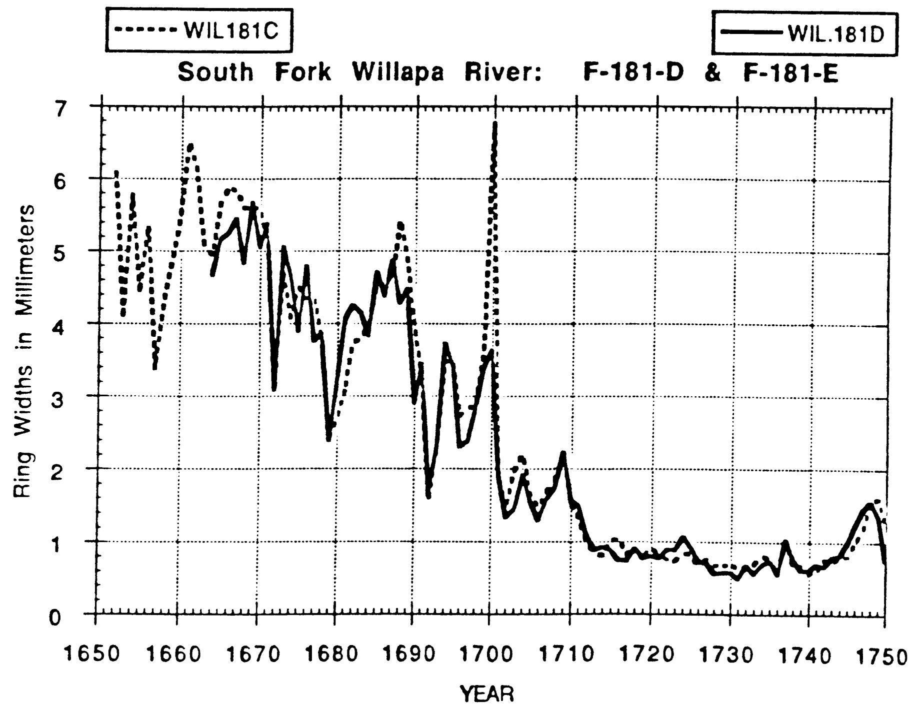


Figure 2: Plots of ring widths of trees from South Fork Willapa River. (a) Two cores from tree F-179. Abrupt growth decline starts in 1700 in core D and1701 in core C but dating is not absolutely certain at this time. (b) Two cores from tree F-181. Growth decline also starts in 1701 in core D. Core E has abnormal large ring in 1700 indicating possible disturbance, followed by gradual decline. There are other features in 1692 and starting in 1710 that must be considered.

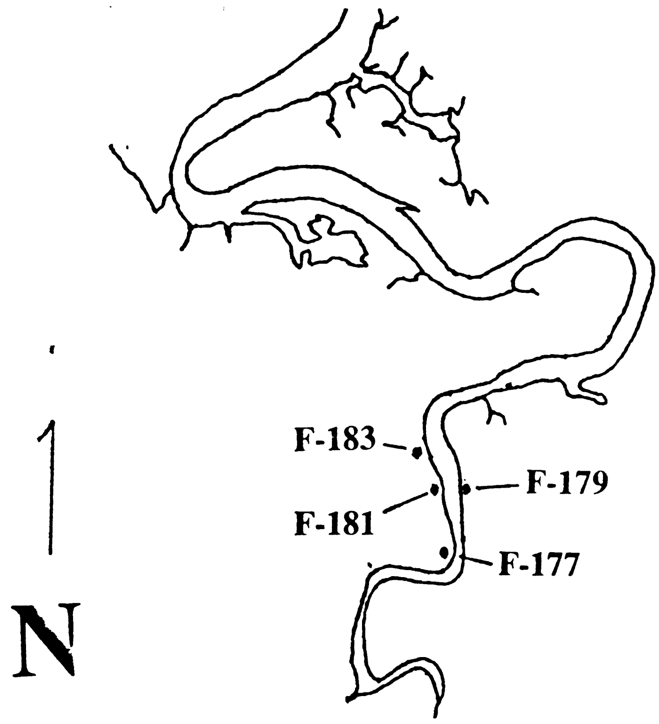


Figure 3: Map of South Fork of the Willapa River showing tree locations.

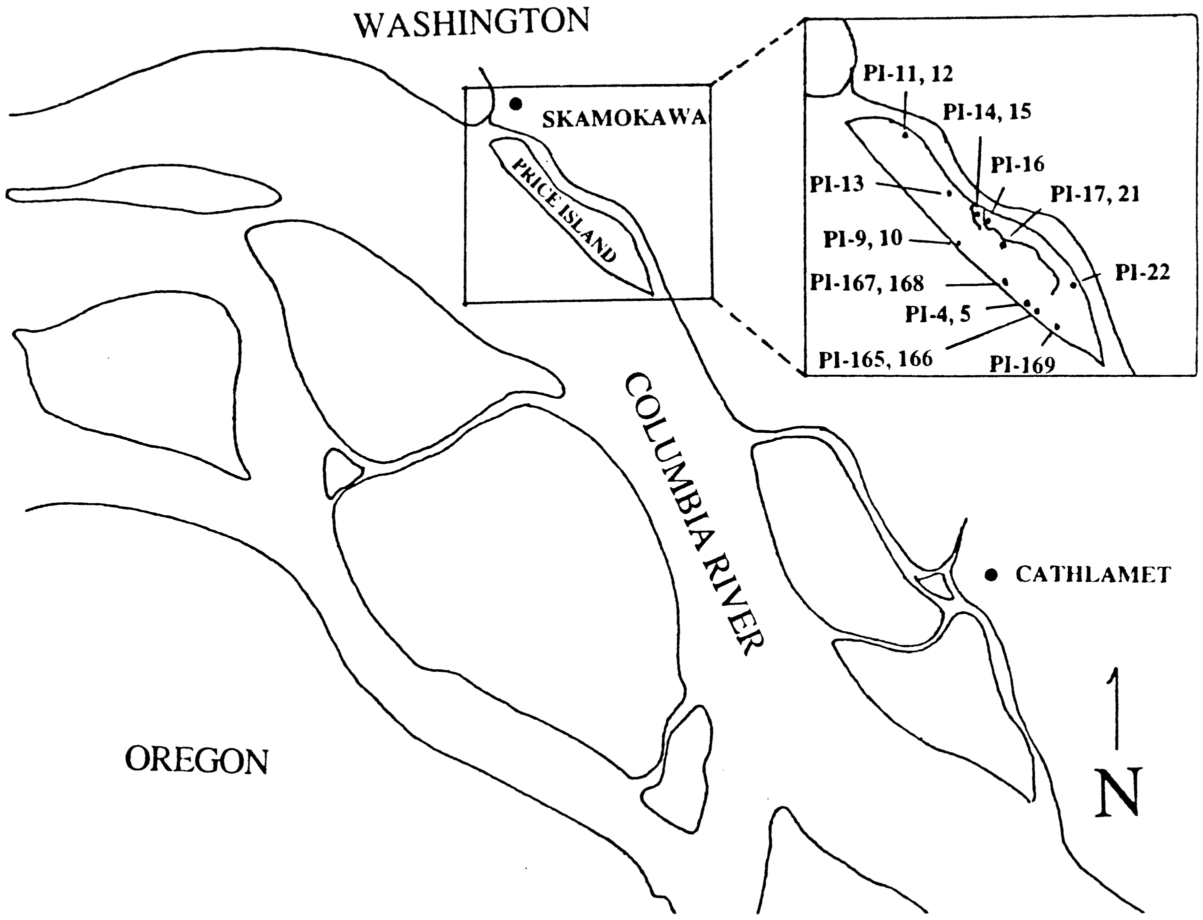


Figure 4: Map of Columbia River and Price Island showing tree locations.

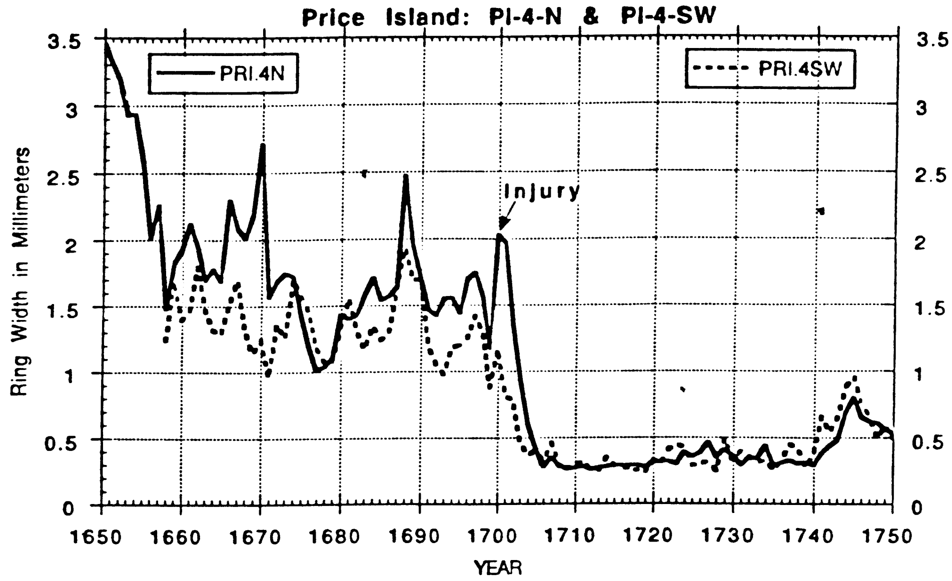
to look for evidence of tsunami and/or subsidence events and possible disturbed trees.

Figure 5 shows plots of ring widths from two trees on Price Island. Trees PI-3 and PI-4 both show growth reduction starting in 1701 and PI-4-N shows an injury in 1700 followed by the reduction (Figure 5a). PI-14 shows an unusual wide ring in 1700 and a gradual decline after 1706 (Figure 5b). Several other trees show indications of disturbance or missing rings between 1670 to 1711 with most effects around 1700. The dating of these samples must be finalized and more samples taken.

PI-9 goes back to 1549 AD and is the oldest living tree cored. Several other trees are older than 350 years. This age is important for two reasons. One; the trees were somewhat mature around 300 years ago when there may have been an event. Two; they may provide a reference chronology against which other samples can be crossdated. Some of the trees from Willapa and trees from Price Island crossdate but even within one site the dating is not completely confirmed. some of these trees are still very young in 1700. Trees in their juvenile stage do not have extended root systems and may be overshadowed by competitors. Their growth can be irregular and crossdating between trees uncertain. A mature tree that is dominant or codominant have more of its ring-width variation be due to climatic factors and thus allow better crossdating.

In a follow-up of the studies by Yamaguchi et al. (1989) and Atwater and Yamaguchi (1991) we conducted further analyses of samples from Copalis River (Figure 1 and Table 1). One earlier study limited the time of possible seismic subsidence to after 1687 (Yamaguchi et al., 1989). Only three trees are old enough to be useful out of thirty-three sampled. We collected more samples from the three trees to try and pin down the date of tree disturbance to a more narrow time span. Dating is extremely weak and difficult with all of these samples. There is erratic growth between about 1690 and 1723. No interpretation is possible from these trees as of now.

Through the generous cooperation of D. Yamaguchi, we have assembled most of the tree-ring samples taken along the coastal lowlands from northern California to the Olympic Peninsula in Washington. Tree-ring information from the International Tree-ring Data Bank is being screened to try and locate data that would aid in crossdating the paleoseismic samples. Several of the most likely data sets were tested but unfortunately none of the data showed reliable crossdating with the coastal lowland samples. There are some indications of crossdating and analyses will continue. This



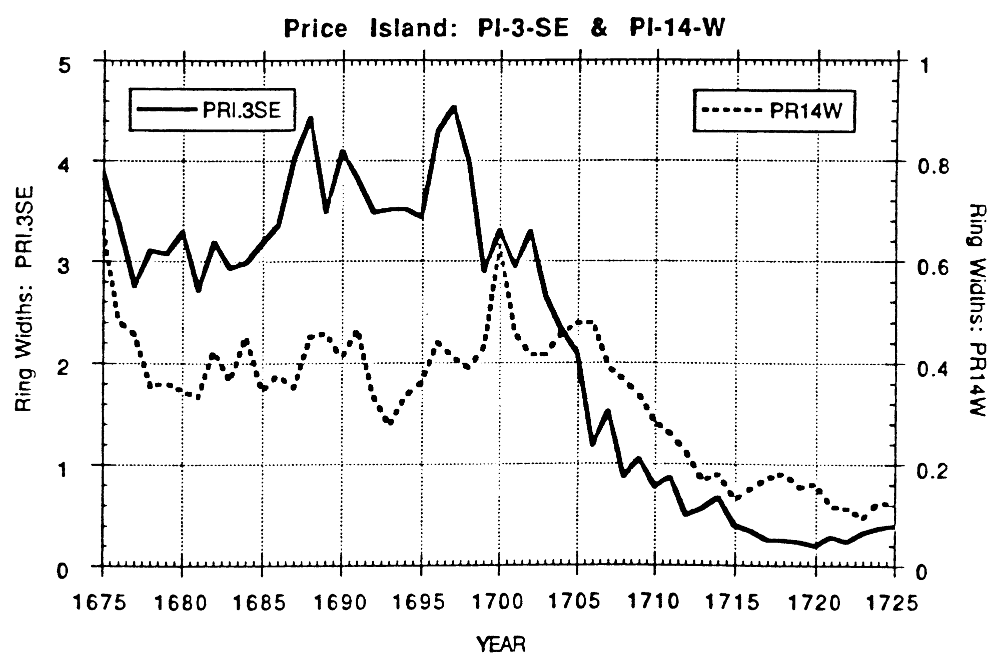


Figure 5: Plots of ring widths of trees from Price Island on the Columbia River. (a) Two cores from tree PI-4. PI-4-N has an injury at beginning of 1700 that causes unusually wide rings for a few years followed by an abrupt growth decline. PI-4-SW starts an abrupt growth decline in 1701. These dates are quite certain but must be confirmed by further analyses. (b) Cores from two different trees. PI-3-W starts an abrupt decline in 1703 but the dating is uncertain at this time. PI-14-W shows an unusually wide ring in 1700 but this is a weak signal. Note the change in scale for the two trees.

result is not too surprising as the other sampling was for dendroclimatology and the sites were chosen where it was believed climate stresses would be strong. The generally more favorable climate and soils of the lowlands can cause a much weaker and different climate response in the tree ring variations.

C. SUMMARY OF RESULTS:

We have a number of samples from Willapa River and Price Island on the Columbia River that indicate possible disturbance around 1700. These results may support the hypothesis set forth by Satake and Shimazaki as reported by Kerr (1995) of a recorded tsunami in Japan being caused by a large earthquake off the northwest coast. However, there are other disturbances in some of the trees and the dating is not finalized for all of the samples examined.

D. PUBLICATIONS:

Jacoby, G. C., Carver, G. and Wagner, W. S., 1995. Trees and herbs killed by an earthquake ~300 years ago at Humboldt Bay, California. Geology 23 (1) 77-80.

Atwater, B. F. and many incl. Jacoby, G. C., 1995. Summary of coastal evidence for past great earthquakes at the Cascadia subduction zone, Earthquake Spectra (in press).

Jacoby, G. C., 1995. Application of tree-ring analysis to paleoseismology: a review (submitted to Reviews of Geophysics, invited paper).

Presentation:

Jacoby, G. C., Dendrochronology, invited presentation at the Workshop on Paleoseismology meeting in at Marshall, Calif. 18-22 Sept. 1994.

Results described in the report above were presented by:

Jacoby, G. C. and Benson, B. E., 1995. Tree-ring applications to paleoseismicity studies: Pacific Northwest, Geological Association of Canada 19 May 1995 in Victoria, B. C., Canada.

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Yamaguchi, D. K., Woodhouse, C. A.and Reid, M. S. 1989. Tree-ring evidence for synchronous rapid submergence of the southwestern Washington coast 300 years B. P. (abst.) EOS Supplement: AGU 1989 Fall Meeting 70 (43) 1332.