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Cascadia megathrust (Class A) No. 781

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Synopsis	The Cascadia megathrust (regional-scale thrust fault) that forms the collisional plate boundary between the subducting Explorer, Juan de Fuca, and Gorda Plates and the overriding North America Plate, and it extends 1200 km from offshore northern California to southern British Columbia. Subduction is driven by westward migration of the North America Plate and eastward migration of the Explorer, Juan de Fuca, and Gorda Plates due to spreading of the Gorda-Juan de Fuca-Explorer Ridge system. The latter three plates are the remnants of the Farallon Plate, which originally underlay much of the eastern Pacific and has been converging with the North America Plate since at least the Jurassic. Few if any historical earthquakes have been located on the boundary between the subducting and overriding plates, but geological studies show that repeated great (>M8) earthquakes have occurred in the past 7,000 years, and geodetic studies indicate strain accumulation consistent with the assumption that the Cascadia

	megathrust is locked beneath offshore northern California, Oregon, Washington, and southern British Columbia. Numerous geological and geophysical studies suggest that the Cascadia megathrust may be segmented, but the most recent studies suggest that, at least for the most recent great earthquake on January 26, 1700, much of the megathrust ruptured in a single M9 earthquake.
Name comments	The Cascadia megathrust forms the plate boundary between the subducting Explorer, Juan de Fuca, and Gorda Plates and the overriding North America Plate. The existence of the fault zone was established in the late 1960s and early 1970s (Byrne and others, 1966 #4273; McKenzie and Parker, 1967 #4270; Tobin and Sykes, 1968 #4256; Morgan, 1968 #4271; Silver, 1969 #4268; Atwater, 1970 #1199; Silver, 1971 #4240). The zone was originally referred to as the Juan de Fuca (e.g., Ando and Balazs, 1979 #4184; Heaton and Kanamori, 1984 #4231) or Oregon subduction zone (Kulm and others, 1986 #4272), but the term Cascadia subduction zone, named after the adjacent Cascadia basin, came into use because subduction of other plates (Explorer Plate and Gorda Plate or block) takes place along the northern and southern ends of the zone (Heaton and Hartzell, 1986 #4230; Rogers, 1988 #4179); in the literature, Cascadia subduction zone is sometimes used in a more general sense to mean the region above the plate boundary as well as the boundary itself. Herein we restrict the term Cascadia megathrust to the east-dipping zone of deformation along the plate boundary and do not include, for example, shallow structures in the upper plate.
County(s) and State(s)	CLATSOP COUNTY, OREGON (offshore) COOS COUNTY, OREGON (offshore) CURRY COUNTY, OREGON (offshore) DOUGLAS COUNTY, OREGON (offshore) LANE COUNTY, OREGON (offshore) LINCOLN COUNTY, OREGON (offshore) TILLAMOOK COUNTY, OREGON (offshore) PACIFIC COUNTY, WASHINGTON (offshore) DEL NORTE COUNTY, CALIFORNIA (offshore) HUMBOLDT COUNTY, CALIFORNIA (offshore)
Physiographic province(s)	PACIFIC BORDER (offshore)
Reliability of location	Poor Compiled at 1:500,000 scale.

	Comments: The mapped trace of the megathrust is defined by the western margin of the deformation front of the accretionary wedge, which is taken from 1:500,000-scale mapping of Goldfinger and others (1992 #464).
Geologic setting	This structure is the megathrust that forms the collisional plate boundary between the subducting Explorer, Juan de Fuca, and Gorda Plates and the overriding North America Plate. The Cascadia megathrust extends from offshore northern California to northern Vancouver Island. Subduction is driven by westward migration of the North America Plate and eastward migration of the Explorer, Juan de Fuca, and Gorda Plates due to spreading of the Gorda-Juan de Fuca-Explorer Ridge System. The latter three plates are the remnants of the Farallon Plate, which originally underlay much of the eastern Pacific and has been converging with the North America Plate since at least the Jurassic (Atwater, 1970 #1199; Duncan and Kulm, 1989 #4242). Tectonic elements associated with the subduction zone include: (1) an accretionary wedge of Eocene (?) through Quaternary sediments deformed by a broad fold and thrust belt [#784] and several easterly-striking strike-slip faults [faults 785–799]; (2) a forearc of sedimentary and igneous rocks that accumulated during plate collision, broken in places by minor Quaternary faults and folds [faults 859–861 and 869–898]; and (3) a volcanic arc (Cascade Range) consisting of Eocene through Quaternary volcanic rocks, several active andesitic volcanoes, and numerous, mostly extensional Quaternary faults. Few if any historical earthquakes have been located on the interface between the subducting and overriding plates (Weaver and Shedlock, 1996 #4293), but geological studies show that great earthquakes have occurred in the past 7,000 years (e.g., Atwater and others, 1995 #4215; Clague, 1997 #5042), and geodetic studies (e.g., Hyndman and Wang, 1995 #4228; Savage and others, 2000 #4274) indicate strain accumulation consistent with the assumption that the Cascadia megathrust is locked beneath offshore northern California, Oregon, Washington, and southern British Columbia (Fluck and others, 1997 #6285; Wang and others, 2001 #6295). Numerous geological and geophysical studies suggest that the Cascadia megathrust may be segmented (Hughes and Carr, 1980 #4173; Weaver and Michaelson, 1985 #4222; Guffanti and Weaver, 1988 #4174; Goldfinger, 1994 #3972; Kelsey and others, 1994 #4110; Mitchell and others, 1994 #4227; Personius, 1995 #4130; Nelson and Personius, 1996 #4128; Witter, 1999 #4194), but the most recent studies suggest that for the last great earthquake in A.D. 1700, much of the

	megathrust ruptured in a single M9 earthquake (Satake and others, 1996 #4281; Atwater and Hemphill-Haley, 1997 #4216; Clague and others, 2000 #4332).
Length (km)	754 km.
Average strike	N4°W
Sense of movement	Thrust *Comments:* The megathrust is a gently dipping megathrust, or regional-scale thrust fault (Atwater, 1970 #1199; Silver, 1971 #4240).
Dip	9–11° E *Comments:* Earthquake (Taber and Smith, 1985 #4229; Michaelson and Weaver, 1986 #4226; Crosson and Owens, 1987 #4224; Weaver and Baker, 1988 #4186; Rasmussen and Humphreys, 1988 #4220; Rieken and Thiessen, 1992 #4225), geodetic (Savage and Lisowski, 1991 #4180; Savage and others, 1991 #4181; Dragert and others, 1994 #4185; Mitchell and others, 1994 #4227; Dragert and Hyndman, 1995 #4177; Hyndman and Wang, 1995 #4228) and seismic reflection and refraction data (Taber and Lewis, 1986 #4223; Trehu and others, 1994 #4234; Trehu and others, 1995 #4236; Parsons and others, 1998 #4175) indicate that the Juan de Fuca Plate is being subducted beneath the Oregon continental margin with a dip of 9–11°.
Paleoseismology studies	Because the surface trace of the subduction zone megathrust is located many tens of kilometers offshore in hundreds to thousands of meters of water, paleoseismic studies include off-fault indicators of earthquakes, such as coseismic uplift and subsidence, earthquake-induced turbidite and tsunami records, and liquefaction features caused by seismic shaking. Some of these paleoseismic features may be related to displacements on crustal faults, which may or may not deform synchronously with subduction-interface earthquakes (McNeill and others, 1998 #4089; Yeats and others, 2001 #5050; Kelsey and others, 2002 #5043; Witter and others, 2003 #6298). In addition to the detailed study sites listed below, which are located along and near the coast of Oregon and Washington State, a few other sites may also show evidence for earthquakes along the Cascadia megathrust (*e.g.*, Schuster and others, 1992 #600; Williams and Hutchinson,

2000 #6296; Williams and others, 2004 #6297; Karlin and others, 2004 #6713). These other sites are located in the regions of the Straight of Juan de Fuca and Puget Lowland and in the southeastern Olympic Mountains. They include evidence for tsunamis, rock avalanches, and turbidites and landslides in Lake Washington, which may be effects of large earthquakes in the Cascadia subduction zone. These other sites are included with paleoseismolgy site descriptions in the unnamed faults of the Straight of Juan de Fuca and Puget Sound [551], the Seattle fault zone [570], and the Saddle Mountain faults [575]. Paleoseismic study sites along and near the Washington-Oregon coast are listed and described below.

Lower Columbia River Site (781-1). Atwater (1994 #4248), Peterson and Madin (1997 #5062), and Obermeier and Dickenson (1997 #4266) studied paleoliquefaction features along the lower reach of the Columbia River in Washington and Oregon that were probably formed during the most recent great earthquake on the Cascadia megathrust. Atwater (1994 #4248) compiled geologic and geotechnical data collected from exposures along six islands in the Columbia River, and concluded that most of the observed features probably were caused by lateral spread failure and/or forceful injection induced by shaking during a megathrust earthquake about 300 years ago. Obermeier and Dickenson (1997 #4266) compared the size, number, location, and geotechnical properties of Columbia River intrusion features with similar features associated with other large earthquakes, and concluded that the most recent large earthquake on the megathrust was likely no larger than M8 and was accompanied by only moderate levels of ground shaking. However, the banks of the Columbia River have retreated 100–600 m since nautical charting began in the 1870s, so the presently exposed features may not reflect the most intense liquefaction that occurred during the earthquake (Atwater, 1994 #4248). Preliminary results of more recent investigations of large cores in this area support the interpretation that the liquefaction features formed as a result of great megathrust earthquakes (Takada and others, 2001 #5046; Atwater and others, 2001 #5053; 2002 #5047). Atwater (1992 #443, figs. 1 and 6) identified localities on the north shore of the Columbia River estuary with buried wetland soils interpreted as suggestive of coseismic subsidence (Atwater, 1992 #443, figs. 6 and 7; Atwater and others, 1995 #4215, fig. 2). No detailed descriptions of localities or stratigraphy have been published, but radiocarbon ages from the Deep Creek locality (table 1 of Atwater, 1992 #443, table not published with paper but available as microfiche from AGU) are typical of those from soils buried during earthquakes Y, W, and S at Willapa Bay (site 781-24). Tree rings in roots of cedar snags rooted in the youngest buried wetland soil date tree death from submergence to between August 1699 and May 1700 (Atwater and Yamaguchi, 1991 #4212; Yamaguchi and others, 1997 #4203; Jacoby and others, 1997 #4276; Benson and others, 2001 #6284). Japanese historical documents and trans-Pacific tsunami modeling show that the tsunami from a great Cascadia earthquake was generated by a M9 earthquake on the megathrust about 9 P.M. on 26 January 1700 (Satake and others, 1996 #4281; 2003 #6293).

Upper Columbia River Site (781-2). Volker and others (1994 #5075), Siskowic and others (1994 #5074), and Peterson and Madin (1997 #5062) studied liquefaction features along the upper reach of the Columbia River upstream of Portland. Peterson and Madin (1997 #5062) found small dikes and sills of intruded sand that did not reach the modern ground surface along cut banks at Government, North and South McGuire, East and West Reed, and Pierce Islands and the Sandy River delta. They used limited radiocarbon ages and tephra correlations to tentatively correlate these features to the A.D. 1700 earthquake on the megathrust, and noted generally decreasing maximum size and abundance of liquefaction features up from the lower Columbia River.

Necanicum River Site (781-3). Darienzo (1991 #4294), Darienzo and others (1994 #4287), and Darienzo and Peterson (1995 #4286) used gouge-core stratigraphy and qualitative diatom analyses in the estuary of the Necanicum River and Neawanna Creek and other estuaries in northern Oregon to identify and correlate six buried marsh soils. They attributed the sudden burial of each soil to regional coseismic subsidence during great megathrust earthquakes in the late Holocene. Sandy beds that cap three of the soils in the Necanicum/Neawanna estuary are evidence for accompanying tsunamis. Seven 14C ages on bulk peat loosely constrain the ages of five of the six buried soils. Barnett (1997 #5068) used lithologic and quantitative diatom analyses to justify the amounts of subsidence estimated for some of the younger subsidence events.

Ecola Creek Site (781-4). Darienzo and Peterson (1995 #4286) used stratigraphic data of P.J. Galloway and others (unpublished report, 1992 referenced in Darienzo and Peterson, 1995 #4286) from the estuary of Ecola Creek to identify six buried marsh soils (unpublished report, 1992 referenced in Darienzo and Peterson, 1995 #4286) attributed the sudden burial of each soil to regional coseismic subsidence during great megathrustearthquakes in the late Holocene. Sandy beds that cap three of the soils along Ecola Creek are evidence for accompanying tsunamis. Three 14C ages on bulk peat loosely constrain the ages of three of the six buried soils.

Nehalem River Site (781-5). Grant and McLaren (1987 #4283) and Grant (1989 #4284; written communication, 1994) studied four buried wetland soils in extensive outcrops and gouge-core transects in the estuary of the Nehalem River. Rapidly buried growth-position fossils at the tops of the youngest and oldest soils and similarities with better exposed soils in Washington led these authors to infer at least two and probably four great megathrust earthquakes in the past 2000 yr. Additional supporting archeological and stratigraphic data from this estuary include that of (Grant and McLaren, 1987 #4283; Grant, 1989 #4284; Grant and Minor, 1991 #4282; Goldfinger and others, 1992 #464). The original 29 14C ages of Grant (1989 #4284; written communication, 1994) that were used to estimate the times of soil burial have been supplemented by 22 ages on plants rooted in buried soils (Nelson and others, (1995 #4196).

Netarts Bay Site (781-6). A series of stratigraphic and biostratigraphic studies in the marshes of the Netarts Bay estuary has not led to consensus regarding the number of great megathrust earthquakes recorded there. Darienzo and Peterson (1990 #4209), Darienzo (1991 #4294), and Darienzo and Peterson (1995 #4286) used gouge-core stratigraphy and qualitative diatom analyses in the estuary of Netarts Bay and other estuaries in northern Oregon to identify and correlate six buried marsh soils. They attributed the sudden burial of each soil to regional coseismic subsidence during great megathrust earthquakes in the late Holocene. Sandy beds that cap four of the soils at Netarts Bay are evidence for accompanying tsunamis. Darienzo and Peterson (1995 #4286) loosely constrained the ages of four of the six buried soils with six 14C ages on bulk peat, and Nelson and others (1995 #4196; 1996 #4199) better defined the ages of three soils with 17 additional 14C ages on plants rooted in the tops of soils. In the most detailed coastal biostratigraphic study in Oregon, Shennan and others (1998 #4201) used quantitative pollen, diatom, and foraminiferal data to question a coseismic subsidence origin for four of the six buried soils at Netarts Bay.

Nestucca Bay Site (781-7). Darienzo (1991 #4294), Darienzo and others (1994 #4287), and Darienzo and Peterson (1995 #4286) used gouge-core stratigraphy and qualitative diatom analyses in the estuary of Nestucca Bay to identify as many as 12 buried marsh soils, the six most recent of which they correlated to similar soils in other estuaries in northern Oregon. They attributed the sudden burial of the six soils to regional coseismic subsidence during great megathrust earthquakes in the late Holocene. A sandy bed that caps the most recent soil is evidence for an accompanying tsunami. Five 14C ages on bulk peat loosely constrain the ages of three of the six buried soils.

Salmon River Site (781-8). Grant and McLaren (1987 #4283) and Grant (1989 #4284; written communication, 1994) studied a prominent buried wetland soil in extensive outcrops and gouge-core transects and 3–4 older buried soils in two transects in the estuary of the Salmon River. Rapidly buried growth-position fossils at the top of the prominent soil, 9 14C ages, and a thick overlying bed of tsunami-deposited sand led these authors to attribute burial of the prominent soil to a great megathrust earthquakes in the past 300–500 years. Additional supporting archeological and stratigraphic data from this estuary include that of (Grant and McLaren, 1987 #4283; Grant, 1989 #4284; Grant and Minor, 1991 #4282; Goldfinger and others, 1992 #464). Nelson and others (1995 #4196;) used eight 14C ages on plants rooted in the prominent soil to date soil burial to about 300 years ago. Because of limited stratigraphic data, no earthquake origin was claimed for the three older soils identified by Grant (1989 #4284; written communication, 1994). But in a later biostratigraphic study by Asquith (1996 #5064), pollen data was used to infer sudden, probably coseismic subsidence for two of the older soils and gradual nonseismic submergence for the third.

Siletz River Site [781-9]. Darienzo (1991 #4294), Darienzo and others (1994 #4287), and Darienzo and Peterson (1995 #4286) used gouge-core stratigraphy and qualitative diatom analyses in the estuary of the Siletz River to identify as many as seven buried marsh soils. They correlated six of the soils to other estuaries in northern Oregon and attributed the sudden burial of each soil to regional coseismic subsidence during great megathrust earthquakes in the late Holocene. Sandy beds that cap five of the six soils in the Siletz River estuary are evidence for accompanying tsunamis. Nine 14C ages on bulk peat loosely constrain the ages of the six buried soils. Barnett (1997) used lithologic and quantitative diatom analyses to justify the amounts of subsidence estimated for some of the younger subsidence events.

Yaquina Bay Site (781-10). Darienzo (1991 #4294), Darienzo and others (1994 #4287), and Darienzo and Peterson (1995 #4286) used gouge-core stratigraphy and qualitative diatom analyses in the estuary of the Yaquina River to identify as many as twelve buried marsh soils. They correlated six of the soils to other estuaries in northern Oregon and attributed the sudden burial of each soil to regional coseismic subsidence during great megathrust earthquakes in the late Holocene. Nine 14C ages on bulk peat loosely constrain the ages of the six buried soils.

Alsea Bay Site (781-11). Darienzo (1991 #4294), Darienzo and Peterson (1995 #4286), and Peterson and Darienzo (1996 #4304) studied extensive outcrops and 21 gouge and vibracores from the marshes of the Alsea River estuary. They identified as many as ten buried marsh soils and four tsunami-deposited sheets of sand. Through correlation of six of the soils to other estuaries in northern Oregon, Darienzo and Peterson (1995 #4286) attributed the sudden burial of each of the six soils to regional coseismic subsidence during great megathrust earthquakes in the late Holocene. Nine radiocarbon ages on bulk peat loosely constrain the ages of nine of the ten buried soils. Nelson and others (2000; written communication, 2000) studied the five most recent buried soils, four capped by extensive sheets of tsunami-deposited sand, in more detail (40 cores). They used 13 radiocarbon ages to date four of the five buried soils to the past 3000 yr and inferred minimal coseismic subsidence just prior to the deposition of three of the four tsunami sand sheets through study of foraminiferal assemblages above and within buried soils.

Siuslaw River Site (781-12). Nelson (1992 #4277) and Nelson and Personius (1996 #4128) interpreted the nearly 4 m of continuous peat and the gradual boundaries between peat and mud beneath the marshes of the Siuslaw River estuary as evidence of slow submergence, rather than sudden coseismic rises in relative sea level. Briggs (1994 #4189) identified as many as five possible buried marsh soils and one liquefaction feature in gouge cores in the upper Siuslaw River estuary. Cores from the lower estuary contained as many as three anomalous sand layers that he interpreted as possible evidence of tsunamis.

Umpqua River Site (781-13). Reconnaissance coring by Nelson (1992 #4277) in the lower estuary of the Umpqua River did not allow him to preclude repeated coseismic subsidence during megathrust earthquakes, but gradual boundaries between most units were more typical of slow changes in relative sea level. Briggs (1994 #4189) interpreted interbedded sand, mud, and peat in gouge cores in the lower estuary near the coast as evidence of coseismic uplift; further inland he found continuous peaty sediment in the lower estuary and interbedded peats and muds with sharp boundaries in the upper estuary. From this evidence he inferred as many as four coseismic subsidence events, three accompanied by the deposition of anomalous sand beds probably by tsunamis.

Eastern Coos Bay Site (781-14). From reconnaissance gouge coring in thirteen marshes in the eastern part of the Coos Bay estuary, Nelson (1992 #4200; 1992 #4277) concluded that inconsistencies in the distinctness of late Holocene peat-mud contacts were more consistent with displacements on local folds and faults than with regional subsidence duringmegathrust earthquakes. Nor did he find evidence of tsunami-deposited sand, probably because all sites were in the middle and upper reaches of the estuary more than 15 km from the coast. Briggs (1994 #4189) described both continuous peaty sediment and interbedded peat and mud in the Coos Bay estuary, with sharp contacts being more common in the eastern part of the estuary. He inferred as many as six times of subsidence during megathrust earthquakes, with as many as two accompanying tsunamis.

South Slough Site (781-15). Nelson (1992 #4200; 1992 #4277), Ota and others (1995 #5066), Nelson and others (1996 #4198; 1998 #4197), and Nelson and others (1998 #4197) summarized detailed (over 100 gouge and vibracores) studies of tidal marsh stratigraphy at 16 sites in the South Slough arm of Coos Bay. Quantitative diatom studies and detailed radiocarbon dating (48 ages) supplemented with thorough lithologic descriptions of selected cores. Although the sequence of interbedded peat and mud in South Slough records as many as ten times of rapid submergence in the late Holocene, only three of these events were extensive enough for Nelson and others (1998) to conclude that they were the result of megathrust earthquakes. Correlation of the South Slough sequence with more recent detailed studies along the Coquille and Sixes rivers (below) suggests that at least seven of the rapid submergence events in South Slough were caused by great earthquakes. In reconnaissance studies at several sites in South Slough, Briggs (1994 #4189) inferred that as many as six buried marsh soils and two tsunami deposits were evidence for coseismic subsidence on either local structures or the megathrust.

Coquille River Site (781-16). Nelson (1992 #4277), Nelson and others (1995 #4196), Witter and others (1997 #4193), and Witter (1999 #4194) have studied the stratigraphy of the Coquille River estuary. Nelson (1992 #4277) and Nelson and others (1995 #4196) used 12 14C ages to date rooted plants at the top of a prominent buried soil that marks regional subsidence and tsunami deposition during a great megathrust earthquake about 300 years ago. In a far more detailed study of the estuary employing 46 gouge and vibracores, quantitative diatom analyses, and 36 radiocarbon ages, Witter and others (1997 #4193), and Witter (1999 #4194/ pers. commun., 2003) identified sudden subsidence from as many as 12 great megathrust earthquakes and sandy beds from as many as 11 accompanying tsunamis in the past 6700 yr.

Bradley Lake Site (781-17). Detailed stratigraphic studies (14 piston cores, 13 vibracores) at Bradley Lake (Nelson and others, 1996 #4263; Kelsey and others, 1998 #4275; Nelson and others, 1998 #4278) identified deposits from 17 periods of lake disturbance in the past 7500 yr caused by shaking from offshore earthquakes or inundation by tsunamis generated by movement on the Cascadia megathrust. Detailed lithologic analyses and quantitative diatom studies (Hemphill-Haley and others, 2000) of the 6.7-m section of largely laminated lake sediment indicate that 12 of the disturbance events were probably due to inundation by local tsunamis. Nelson and others (2000) compared ages determined for each of the 17 disturbance events (57 radiocarbon ages) with independently derived sedimentation-rate ages calculated from varve counts to obtain the most precise ages for past great earthquake in Oregon. The longest interval between inferred tsunamis is about 800 yr and the shortest is as little as 11 yr.

Sixes River Site (781-18). Detailed stratigraphy (two outcrops and 49 gouge and vibracores), quantitative diatom analyses, and extensive 14C dating (46 ages) in the lower reaches of the Sixes River documented 11 times of sudden coseismic subsidence, nine accompanied by tsunamis, in the past 6000 yr (Kelsey and others, 1996 #4188; Kelsey and others, 1998 #4187; Kelsey and others, 2002 #5043).

Euchre Creek Site (781-19). Witter (1999 #4194) identified four storm or tsunami-deposited sand beds dating from the last 600 yr in a small marsh at the mouth of Euchre Creek. Although none of the beds are evidence for coseismic subsidence, the thickest was probably deposited by the tsunami of the AD 1700 great earthquake.

Cascadia and Astoria submarine channels site (781-20) (offshore locations). Although it has been recognized for many years that some of the turbidites in submarine channels of the continental shelf and slope offshore of Oregon and Washington (c.f., Griggs and Kulm, 1970 #4244) may have been earthquake induced, Adams (1984 #4120) first suggested that the timing of turbidite sequences might yield recurrence intervals from great earthquakes on the Cascadia megathrust. Adams (1990 #4238; 1996 #4289) used the presence of thirteen post-Mazama-eruption (younger than 6850 yr B.P.) turbidites along much of the Cascadia margin to calculate an average recurrence interval of about 600 yr for great earthquakes. Preliminary data from more recent studies support the 13 turbidite scenario in the Cascadia Channel, but indicate a more complicated turbidite history in the Astoria and other channels offshore of Oregon and northern California (Nelson and others, 1996 #4264; Nelson and others, 1999 #4279; Nelson and others, 2000 #5084). The latest studies indicate 13 great earthquakes since deposition of the Mazama ash about 7.6 ka, and 18 great earthquakes since deposition of a 12.7 ka biostratigraphic marker; these records yield average recurrence intervals of about 600 yr and 690 yr, respectively (Goldfinger and others, 2002 #5140).

Strait of Juan de Fuca Sites (781-21). Along the south shore of the strait east of Neah Bay, Atwater (1992 #443, figs. 1 and 6) located two localities at the Waatch River and one at the Pysht River with radiocarbon ages from buried peat and peaty mud interpreted as suggestive of coseismic subsidence of wetland soils (Atwater, 1992 #443, figs. 6 and 7; Atwater and others, 1995 #4215, fig. 2). No descriptions of localities or stratigraphy have been published. Ages (in table 1 of Atwater, 1992 #443, table not published with paper but available as microfiche from AGU) from the Waatch River are typical of those from soils buried during earthquake W at Willapa Bay (Atwater and Hemphill-Haley, 1997 #4216, see site 781-24); the two ages from Pysht River are typical of those from soils buried during earthquake Y at Willapa Bay. At Discovery Bay, Washington, about 132 km east of Neah Bay, Williams and others (2004 #6297) inferred that four of six sand beds deposited by tsunamis in the past 2500 yr were generated by great earthquakes on the megathrust. Williams and Hutchinson (2000) made the same inference for two sand beds in peat on Whidbey Island, Washington, about 143 km east of Neah Bay.

Copalis River Site (781-22). Atwater (1992 #443) inferred three great earthquakes on the megathrust in the past 2000 yr from widespread buried wetland soils at the Copalis River estuary. The two younger soils were capped by sand deposited by local tsunamis. The two older soils correlate with similar soils buried during earthquakes U and S, studied in more detail at Willapa Bay (Atwater and Hemphill-Haley, 1997 #4216, fig. 32, see site 781-24 description). Precise radiocarbon dating of tree-ring wood and herb leaves on plants killed by earthquake-induced subsidence at the Copalis River indicates plant death after AD 1680, probably between AD 1700 and 1720 (Nelson and others, 1995 #4196). Tree rings in roots of cedar snags rooted in the youngest buried soil at the Copalis River date tree death from subsidence to between August 1699 and May 1700 (Atwater and others, 1991 #4211; Atwater and Yamaguchi, 1991 #4212; Yamaguchi and others, 1997 #4203; Jacoby and others, 1997 #4276; Benson and others, 2001 #6284). Japanese historical documents and trans-Pacific tsunami modeling show that the tsunami from a great Cascadia earthquake was generated by a M9 earthquake on the megathrust about 9 P.M. on 26 January 1700 (Satake and others, 1996 #4281; 2003 #6293). Atwater (1992 #443) discussed several possible sources for the extensive liquefaction sills and dikes beneath the youngest buried soil at the Copalis River and noted that no coastal subsidence coincided with intrusion of the sills. In a note added in proof, Atwater (1992 #443) concluded that the sills and dikes were emplaced as a result of aquifer pressurization during folding and faulting in the upper plate and so do not record shaking from a megathrust earthquake.

Grays Harbor Site (781-23). Key paleoseismology sites in wetlands fringing the Grays Harbor estuary are located and some basic data summarized in Atwater (1992 #443, figs. 1, 6, and 7, and table 1, table not published with paper but available as microfiche from AGU) and Atwater and Hemphill-Haley (1997 #4216, figs. 1, 3, and 5). Conclusions made byAtwater and

Hemphill-Haley (1997 #4216) regarding the history of great earthquakes at these sites are the same as those for similar sites 30 km to the south in Willapa Bay (figs. 32, 33, and 34 in Atwater and Hemphill-Haley, 1997 #4216, see site 781-24 description). Stratigraphic data and ages from Grays Harbor sites are used in the concluding synthesis of Atwater and Hemphill-Haley (1997 #4216), although no detailed summary of the stratigraphy has been published. In their application of European methods of sea-level analysis (Shennan and Long, 1994 #6294; Long and others, 1999 #6288) to a sequence of intertidal sediment at the Johns River in southern Grays Harbor, Shennan and others (1996 #4202) and Long and Shennan (1998 #6289) identified eight buried wetland soils marking rapid submergence events in the past 5000 yr. Pollen, diatom, foraminiferal, and lithologic data indicate rapid submergence of at least 1.5 m during one event, 1±0.5 m during four others, and <0.5 m during the remaining three events. Only three soils meet most of the stratigraphic criteria of Nelson and others (1996 #4199) for regional coseismic subsidence, although data do not rule out subsidence during a great earthquake for any of the soils. Radiocarbon dating of six of the soils (bulk peat ages) was less precise than the dating of most correlative soils by Atwater and Hemphill-Haley (1997 #4216) in Willapa Bay (site 781-24), but ages obtained at the Johns River are consistent with Willapa Bay ages, and two soils older than those of Atwater and Hemphill-Haley (1997 #4216) were dated (4830–4440 and 5310–4870 cal yr BP). Tree rings in roots of cedar snags rooted in the youngest buried soil at the Grays Harbor estuary date tree death from subsidence to between August 1699 and May 1700 (Atwater and Yamaguchi, 1991 #4212; Yamaguchi and others, 1997 #4203; Jacoby and others, 1997 #4276; Benson and others, 2001 #6284). Japanese historical documents and trans-Pacific tsunami modeling show that the tsunami from a great Cascadia earthquake was generated by a M9 earthquake on the megathrust about 9 P.M. on 26 January 1700 (Satake and others, 1996 #4281; 2003 #6293).

Willapa Bay Site (781-24). Much of the most detailed work and the informal type site for the coastal record of great earthquakes in the northern half of the subduction zone are from the estuarine wetlands fringing the mouths of small rivers that drain into eastern Willapa Bay. Atwater and Hemphill-Haley (1997 #4216) summarized extensive studies in northeastern Willapa Bay that applied stratigraphy (Atwater, 1987 #4213; Atwater, 1992 #443, table 1; Ota and Unitsu, 1995 #6290; Atwater, 1996 #6283), sedimentology (Reinhart and Bourgeois, 1989 #6292), macrofossil analysis (Atwater and Yamaguchi, 1991 #4212; Peterson and others, 2000 #6291), microfossil analysis (Hemphill-Haley, 1995 #6286; 1996 #6287), and radiocarbon dating (Atwater and others, 1991 #4211; Atwater, 1992 #443, table 1; Nelson and others, 1995 #4196) in the identification and dating of six or seven great earthquakes and accompanying tsunamis in the past 3500 yr (Atwater and others, 1995 #4215; Nelson and Personius, 1996 #4128; Nelson and others, 1996 #4199; Clague, 1997 #5042). Published (Nelson and others, 1995 #4196; Atwater and Hemphill-Haley, 1997 #4216) age ranges (based on hundreds of calibrated radiocarbon ages, many high-precision ages) for the earthquakes (named with letters) are Y, AD 1703–1715; W, 850–1250(1140–760) cal yr BP; U, 1080–1300(1215–1260) cal yr BP; S, 1450–1650(1540–1610) cal yr BP; N, 2350–2730(2360–2610) cal yr BP; L, 2750–3250(2925–2845) cal yr BP; and J, 3270–3450(3390–3310) cal yr BP. Age ranges in parentheses are the more precise unpublished ages for the earthquakes shown in Figure 12 of Kelsey and others (2002 #5043), obtained by Atwater (written commun., 2002) through reanalysis of old and many new radiocarbon ages from southwestern Washington for all but the most recent earthquake. Tree rings in roots of cedar snags rooted in the youngest buried soil (soil Y) beneath wetlands in eastern Willapa Bay date tree death from subsidence to between August 1699 and May 1700 (Atwater and others, 1991 #4211; Atwater and Yamaguchi, 1991 #4212; Yamaguchi and others, 1997 #4203; Jacoby and others, 1997 #4276; Benson and others, 2001 #6284). Japanese historical documents and trans-Pacific tsunami modeling show that the tsunami from a great Cascadia earthquake was generated by a M9 earthquake on the megathrust about 9 P.M. on 26 January 1700 (Satake and others, 1996 #4281; 2003 #6293). Intervals between the earthquakes average about 500 yr, but range from a century to a millennium. Atwater and Hemphill-Haley (1997 #4216) consider the composite eastern Willapa Bay record to be complete for great earthquakes that caused at least half a meter of widespread coseismic subsidence and followed the preceding earthquake by more than a century.

Long Beach Site (781-25). Using ground-penetrating radar, Meyers and others (1996 #4205) identified eight buried scarps in beach deposits near Long Beach, Washington, on the west side of the spit dividing Willapa Bay from the Pacific Ocean. The scarps are attributed to storm erosion of the beach following regional

	coseismic subsidence during great earthquakes on the megathrust. Four AMS ages on wood and charcoal fragments from vibracores penetrating the scarps indicate that the six younger scarps formed in the past 4500 yr.
Geomorphic expression	The geomorphology of the continental shelf and slope above the megathrust has been studied with submersible dives, bathymetric, sidescan sonar, and seismic reflection data, and widely scattered coring and drilling investigations. The area is marked by the juxtaposition of an active fold and thrust belt marked by linear ridges and benches in the accretionary wedge at the base of the continental slope, against the flat topography of the abyssal plain that characterizes much of the eastern margin of the subducting Juan de Fuca Plate (Kulm and others, 1986 #4272; Goldfinger and others, 1992 #464; Goldfinger, 1994 #3972). The leading edge of the deformation front of the subduction zone is not marked by a bathymetric trench as is typical of many other subduction zones, because the subducting plate is covered by turbidite sediments hundreds of meters thick that were deposited from submarine fans emanating from large coastal rivers (Duncan, 1968 #4245; Nelson and others, 1970 #4262; Nelson, 1984 #4243; Peterson and others, 1986 #4133; Carlson and Nelson, 1987 #4251; Yeats and others, 1998 #4085; McNeill and others, 2000 #5060).
Age of faulted surficial deposits	Little detailed information on the ages of faulted deposits at the deformation front of the subduction zone has been described, but the Cascadia megathrust appears to offset late Pleistocene and Holocene sediments of the accretionary wedge against late Pleistocene and Holocene submarine fan sediments (Kulm and Embley, 1988 #4267; Goldfinger and others, 1992 #464; Goldfinger, 1994 #3972; 1997 #4090).
Historic earthquake	
Most recent prehistoric deformation	latest Quaternary (<15 ka) *Comments:* Numerous detailed studies indicate coastal subsidence, tsunamis, liquefaction, and turbidite triggering consistent with a giant earthquake on the Cascadia megathrust about 300 years ago (see summaries in Atwater and others, 1991 #4211; Nelson and others, 1995 #4196; Atwater and others, 1995 #4215; Atwater and Hemphill-Haley, 1997 #4216; Clague and others, 2000 #4332). Tree rings in roots of cedar snags rooted in the youngest buried soil (soil Y) beneath wetlands of

	southwestern Washington date tree death from submergence to between August 1699 and May 1700 (Atwater and others, 1991 #4211; Atwater and Yamaguchi, 1991 #4212; Yamaguchi and others, 1997 #4203; Jacoby and others, 1997 #4276; Benson and others, 2001 #6284). Japanese historical documents and trans-Pacific tsunami modeling show that the tsunami from a great Cascadia earthquake was generated by a M9 earthquake on the megathrust about 9 P.M. on 26 January 1700 (Satake and others, 1996 #4281; 2003 #6293).
Recurrence interval	500–600 years (average for the past 2–7 k.y.) *Comments:* Numerous detailed studies of coastal subsidence, tsunamis, and turbidites yield a wide range of recurrence intervals, but the most complete records (longer than 4000 yr) indicate average intervals of 500–600 yr between great earthquakes on the Cascadia megathrust (Adams, 1990 #4238; Atwater and Hemphill-Haley, 1997 #4216; Witter, 1999 #4194; Clague and others, 2000 #4332; Goldfinger and others, 2002 #5140; Witter and others, 2003 #6298). Individual intervals range from 22 yr (Nelson and others, 2000 #5084) to more than 1000 yr (Atwater and Hemphill-Haley, 1997 #4216; Kelsey and others, 2002 #5043; Witter and others, 2003 #6298).
Slip-rate category	Greater than 5.0 mm/yr *Comments:* Studies of magnetic anomalies in the Juan de Fuca Plate and geodetic studies suggest a rate of oblique convergence of about 35–45 mm/yr in a NE direction across the Cascadia megathrust (Riddihough, 1984 #4176; DeMets and others, 1990 #3186; DeMets and others, 1994 #4285; McCaffrey and Goldfinger, 1995 #4232).
Date and Compiler(s)	2006 Stephen F. Personius, U.S. Geological Survey Alan R. Nelson, U.S. Geological Survey
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