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Faults and Earthquakes in Washington State

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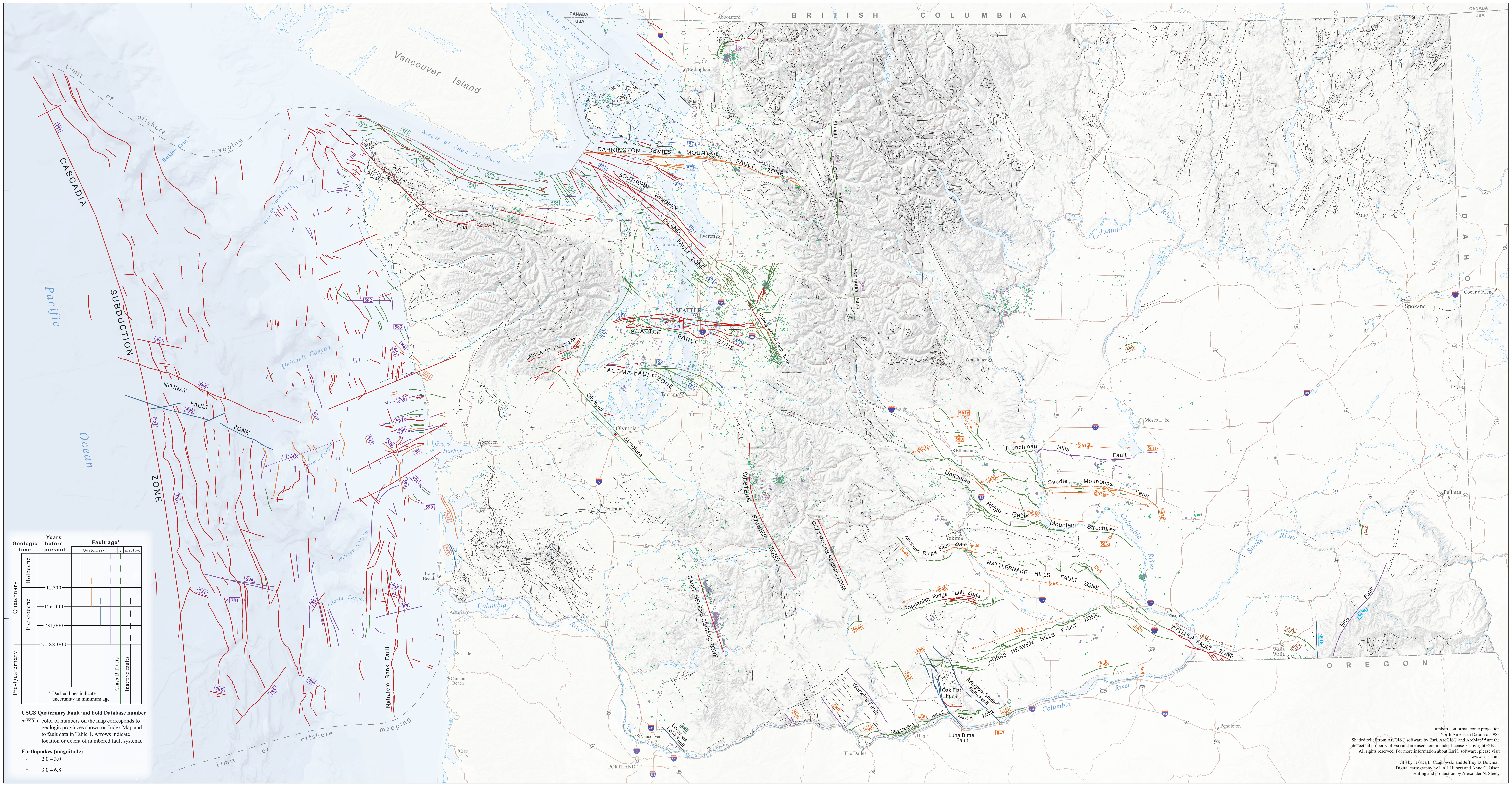

Lambert conformal conic projection
North American Datum of 1983
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This plate includes mapped faults and hypocenters of earthquakes that are magnitude 2.0 or greater and at depths less than 25 km in Washington State. The location and distribution of earthquakes can be used to locate unmapped faults by identifying linear trends of earthquakes within a region.

FAULTS

Faults were compiled from several digital sources (Bowman and Czajkowski, 2013; Washington Division of Geology and Earth Resources, 2010a,b) and several recent 7.5-minute geologic quadrangle maps (Dragovich and others, 2012, 2013, 2014; Contreras and others, 2013; Polenz and others, 2013) and indicate the known or suspected age of faulting. Faults were identified through geologic field investigations, shipborne and terrestrial seismic surveys, earthquake data, gravity and magnetic surveys, and (or) through examination of lidar (Light Detection and Ranging) for the presence of fault scarps. Paleoseismic trenches have been dug across several active or suspected fault zones to aid in determining slip rates and recurrence intervals.

Colored faults indicate if Quaternary-age activity (rupture within the last two million years) is known or suspected. These faults are shown in red (Holocene), orange (latest Pleistocene), blue (mid to late Pleistocene), and purple (Pleistocene). There are numerous faults for which Quaternary-age deformation is suspected, but for which insufficient evidence has been gathered to support this determination. These are considered Class B faults (USGS, 2010) and are shown in green. Many of the Quaternary-age and Class B faults or fault systems are catalogued in the U.S. Geological Survey (USGS) Quaternary Fault and Fold Database—these are labeled on the map with their USGS database number. See Table 1 for fault names, USGS database numbers, and mapping method used to identify faults; additional information for these faults or fault systems can be found by following the embedded hyperlinks within the table or by looking up the database number on the USGS website.

The remainder of the faults (shown in black) have an indeterminate age or show no evidence of activity within the Quaternary (Washington Division of Geology and Earth Resources, 2010a,b).

EARTHQUAKES

Earthquake data obtained from the Pacific Northwest Seismic Network (PNSN) catalog were analyzed using the earthquake hypocenter relocation program, *hypoDD* (Waldhauser, 2001). The program relocates a cluster of earthquakes relative to one another, and in some cases, a linear trend can be seen that was not previously visible. A certain number of events are required for processing in order to more accurately relocate an earthquake using the double-difference method. Because of this, not all earthquakes throughout the state could be relocated. In most areas of eastern Washington and along the coast, the insufficient density of either events or seismic stations prevented earthquake hypocenter relocation. For the area around the summit of Mount St. Helens, a 1-km-diameter area was filtered out of the relocation process due to the extremely large number of events, small magnitudes, and processing power required for relocation. Both original and relocated earthquakes (where available) are shown on the map above.

Earthquake Relocation Method

Earthquake hypocenter relocation is a three-step process: (1) obtain detailed earthquake information in the form of pickfiles, (2) identify and select a cluster of earthquakes for relocation based on spatial distribution and geologic data, and (3) use the earthquake hypocenter relocation program, *hypoDD*, to process the data and relocate each cluster of earthquakes. The pickfiles were obtained from PNSN and filtered to include only earthquakes from 1970 to 2011 with a magnitude greater than 1.0, a depth less than 25 km, and those not reported as blasts. Each pickfile includes information such as: date and time, latitude/longitude, depth, magnitude, P- and S-phase data, and the identity and distance of seismic stations that detected the earthquake.

The earthquake locations, along with digital fault data, were brought into ArcGIS version 10.0 to help draw relocation processing polygons. Each batch polygon was drawn with the goal of grouping clusters of earthquakes along the same fault system while still maintaining a meaningful geophysical distance. Unfortunately, in some areas, it was unavoidable that batch polygons crossed multiple fault systems due to the distance between faults or the lack of clustered events.

Once a group of events was identified and batch polygons were drawn, the associated pickfiles for the grouped events were converted into the *hypoDD* program pickfile format. This was done using a programming script developed by Renate Hartog from the University of Washington (UW) PNSN, called *uw2hypoDD*. This script converts the pickfiles, assigns unique *hypoDD* IDs, and collects P- and S-phase travel time information for each event. The *hypoDD* relocation program is comprised of two subprograms: (1) *ph2dt* and (2) *hypoDD*. After the event pickfiles were preprocessed using the *uw2hypoDD* script, *ph2dt* was run to search the P- and S-phase data for pairs of events with travel time information at common stations. It then subsampled these data to optimize the quality of the event pairs and the connectivity between events to improve the number of links between events, with the smallest distance possible within a cluster. This linking process can be refined by changing the threshold parameters set in the *ph2dt* input file. A log file was created summarizing the output data (for example, number of events selected, distance between linked events, and number of outliers) used to help determine the optimal parameters. If the results were unfavorable, then parameters were modified and *ph2dt* was run again until successful.

As with *ph2dt*, the second subprogram, *hypoDD*, uses an input file to set threshold parameters and assign the appropriate velocity model (obtained from PNSN) that will most accurately relocate the hypocenters. *HypoDD* uses the travel time differences derived from *ph2dt* to determine the double-difference hypocenter locations. *HypoDD* performs multiple iterations for a single-batch run and reports critical parameters (for example, number of successful iterations, percent of events used, and average absolute value of hypocenter location change) for each iteration performed. These parameters determined the performance of that particular batch run. If any reported parameters fell outside of an accepted value, then the input parameters were modified and *hypoDD* was run again.

Horizontal and vertical accuracy is highly variable and can change on an event by event basis. Many factors contribute to the accuracy of the relocated events, such as the azimuthal distribution and number of seismic stations that detect each event, the number of and distance between events being processed, and data quality weights assigned by the data source.

GIS DATA

GIS-format spatial databases of active faults and folds, paleoseismic trenching locations, original and relocated earthquake locations, and other information, including the processing polygons and input parameters used to relocate earthquakes, can be downloaded directly (Bowman and Czajkowski, 2013). Other digital fault layers at 1:100,000- and 1:250,000-scales are also available at www.dnr.wa.gov/ResearchScience/Topics/GeosciencesData/Pages/gis_data.aspx. These datasets can also be viewed using the Washington State Geologic Information Portal at www.dnr.wa.gov/geologyportal.

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SCALE 1:750,000
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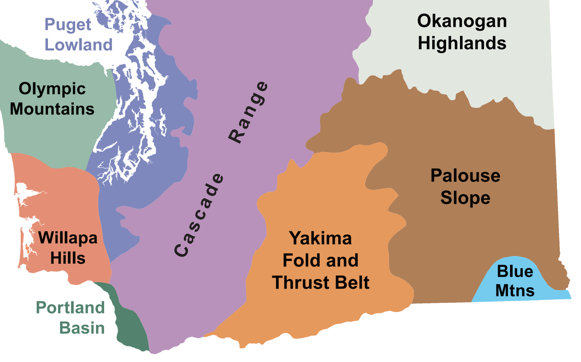

Index Map. Geologic provinces of Washington State—colors of provinces correspond to USGS fault number colors shown on both the map and in Table 1.

Suggested citation: Czajkowski, J. L.; Bowman, J. D., 2014, Faults and earthquakes in Washington State: Washington Division of Geology and Earth Resources Open File Report 2014-05, 1 sheet, scale 1:750,000.

Table 1. Quaternary-age fault or fault system names, USGS fault numbers, and fault detection methods organized by geologic province. Color of number corresponds to its geologic province shown on Index Map at left. Click on colored USGS fault numbers (below) to obtain additional information from the USGS Quaternary Fault and Fold Database.

* Significant fault or fault system not described in the USGS database.

USGS fault number	Fault or fault system name	Detection method
Olympic Mountains		
550	Calawah fault	mapped trace
551	Unnamed fault	geophysical lineament
555	Unnamed fault south of Port Angeles	mapped trace
556	Lake Creek–Boundary Creek fault	lidar lineament
557	Unnamed fault	mapped trace
575	Saddle Mountain West fault	mapped trace
Palouse Slope		
559	Pinto fault	mapped trace
577	Central Ferry fault	mapped trace
578a	Buroker fault	mapped trace
578b	Promontory Point fault (class B)	mapped trace
846	Wallula fault zone	mapped trace
Continental Shelf		
582	Unnamed faults offshore of Queets River	geophysical lineament
583	Unnamed fault zone near Raft River	geophysical lineament
584	Unnamed faults near Duck Creek	geophysical lineament
586	Unnamed fault zone near Aloha	geophysical lineament
587	Unnamed fault zone near Langley Hill	mapped trace
588	Saddle Hill fault zone	geophysical lineament
589	Grays Harbor fault zone	geophysical lineament
590	Unnamed faults near mouth of Willapa Bay	geophysical lineament
591	Unnamed fault offshore Cape Shoalwater	geophysical lineament

USGS fault number	Fault or fault system name	Detection method
Continental Shelf (cont.)		
593	Unnamed offshore faults near Grays Canyon	geophysical lineament
594	North Nitinat fault zone	geophysical lineament
595	South Nitinat fault zone	geophysical lineament
596	Willapa Canyon fault	geophysical lineament
781	Cascadia subduction zone	geophysical lineament
784	Cascadia fold-thrust belt	geophysical lineament
785	Unnamed offshore faults	geophysical lineament
788	Fault J	geophysical lineament
789	Nehalem Bank fault	geophysical lineament
Portland Basin		
880	Lacamas Lake fault	geophysical lineament
Willapa Hills		
585	Unnamed fault near Wreck Creek	mapped trace
592	Willapa Bay fault zone	geophysical lineament
Cascade Range		
*	Saint Helens seismic zone	geophysical lineament
*	Mount Rainier seismic zone	geophysical lineament
*	Goat Rocks seismic zone	geophysical lineament
553	Straight Creek fault	mapped trace
554	Boulder Creek fault (Kendall scarps)	lidar lineament
576	Devils Dream fault	mapped trace
Blue Mountains		
845a	Hite fault	mapped trace
845b	Hite fault zone	mapped trace

USGS fault number	Fault or fault system name	Detection method
Puget Lowland		
*	Olympia Structure	geophysical lineament
552	Hood Canal fault zone	geophysical lineament
570	Seattle fault zone	lidar lineament
571	Strawberry Point fault	geophysical lineament
572	Southern Whidbey Island fault zone	mapped trace
573	Utsalady Point fault scarps	lidar lineament
574	Darrington–Devils Mountain fault zone	mapped trace
581	Tacoma fault	geophysical lineament
Yakima Fold and Thrust Belt		
560	Kittitas Valley faults	mapped trace
561a	Frenchman Hills structures	mapped trace
561b	Lind Coulee fault	mapped trace
561c	Frenchman Hills structures (class B)	mapped trace
562a	Saddle Mountains fault	mapped trace
562b	Saddle Mountains structures (class B)	mapped trace
563a	Central Gable Mountain fault	mapped trace
563b	Umtanum Ridge–Gable Mountain structures (class B)	mapped trace
564a	Ahtanum Ridge fault zone	mapped trace
564b	Ahtanum Ridge fault zone (class B)	mapped trace
565	Rattlesnake Hills faults	mapped trace
566a	Toppenish Ridge fault zone	mapped trace
566b	Toppenish Ridge fault zone (class B)	mapped trace
567	Horse Heaven Hills fault zone	mapped trace
568	Columbia Hills fault zone	mapped trace
569	Unnamed fault near Service anticline	mapped trace
579	Luna Butte fault	mapped trace
580	Warwick fault	mapped trace
847	Arlington–Shutler Butte fault	mapped trace