GEOLOGIC HAZARDOUS AREAS IN WASHINGTON STATE

LANDSLIDES, EARTHQUAKES, VOLCANOES, TSUNAMIS – THEY ALL HAPPEN IN WASHINGTON

SW Washington Section American Planning Association – July 21, 2016

Stephen Slaughter, LEG

Landslide hazards program coordinator
Washington Geological Survey
Washington Department of Natural Resources

Geologists are never at a loss for paper weights.

-Bill Bryson, author

Geologic hazards

- **Earthquakes**
- **Tsunamis**
- Landslides

We learn geology the morning after the earthquake.
-Ralph Waldo Emerson

HAZARD AND RISK

- Many ways to define risk
- Risk composed of three components
  - Consequences (hazard or expected negative outcome)
  - Likelihood (probability)
  - Context of the situation under consideration (human health and safety, social, economic, environment, etc.)

VH	Very high	Risk is imminent; short-term reduction required; long-term reduction plan must be developed and implemented
H	High	Risk is unacceptable; long-term risk reduction plan must be develop and implemented in a reasonable time frame. Planning should begin immediately
M	Moderate	Risk may be tolerable; more detailed review required; reduce risk to as low as reasonably practicable (ALARP)
L	Low	Risk is tolerable; continue to monitor and reduce risk to as low as reasonably practicable (ALARP)
VL	Very low	Risk is broadly acceptable; no further review or risk reduction required

Likelihood	Likelihood Descriptions	Indices	Probability Range	Multi-hazard Risk Evaluation Matrix					
Likelihood	Event typically occurs at least once per year	Almost certain	>0.9	M	H	H	VH	VH	VH
	Event typically occurs every few years	Very likely	0.1 to 0.9	L	M	H	H	VH	VH
	Event is expected to occur every 10 to 100 years	Likely	0.01 to 0.1	L	L	M	H	H	VH
	Event is expected to occur every 100 to 1,000 years	Possible	0.001 to 0.01	VL	L	L	M	H	H
	Event is expected to occur every 1,000 to 10,000 years	Unlikely	0.0001 to 0.001	VL	VL	L	L	M	H
	Event is expected to occur less than every 10,000 years	Very unlikely	<0.0001	VL	VL	VL	L	L	M
			Indices	1 Incidental	2 Minor	3 Moderate	4 Major	5 Severe	6 Catastrophic
			Description of expected negative outcomes (Consequences)						

Multi-hazard Risk Evaluation Matrix

Likelihood	Likelihood Descriptions	Indices	Probability Range	1	2	3	4	5	6
Likelihood	Event typically occurs at least once per year	Almost certain	>0.9	M	H	H	VH	VH	VH
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	Event is expected to occur every 10 to 100 years	Likely	0.01 to 0.1	L	L	M	H	H	VH
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Indices	1 Incidental	2 Minor	3 Moderate	4 Major	5 Severe	6 Catastrophic
Heath and Safety	No impact	Slight impact; recoverable within days	Minor injury	Serious injury or personal hardship; recoverable within weeks or months	Fatality or serious personal long-term hardship	Multiple fatalities
Environment	Insignificant	Localized short-term impact; recovery within days or weeks	Localized long-term impact; recovery within weeks or months	Widespread long-term impact; recoverable within months or year	Widespread impact; not recoverable within the lifetime of the project	Irreparable loss of a species
Social and Cultural	Negligible impact	Slight impact to social and cultural values; recoverable within days	Moderate impact to economic to social and cultural values; recovery within weeks or months	Significant impact to social and cultural values; recoverable within months or years	Partial loss of social and cultural values; not recoverable within the lifetime of the project	Complete less of social and cultural values
Economic	Negligible; no business interruption	<$10,000 business interruption loss or damage to public or private property	<$100,000 business interruption loss or damage to public or private property	<$1M business interruption loss or damage to public or private property	<$10M business interruption loss or damage to public or private property	>$10M business interruption loss or damage to public or private property

Description of expected negative outcomes (Consequences)

RISK MANAGEMENT

- Mitigate the hazard
  - Retaining walls, seismic retrofit…
- Avoid the hazard
  - Build elsewhere, change zoning…

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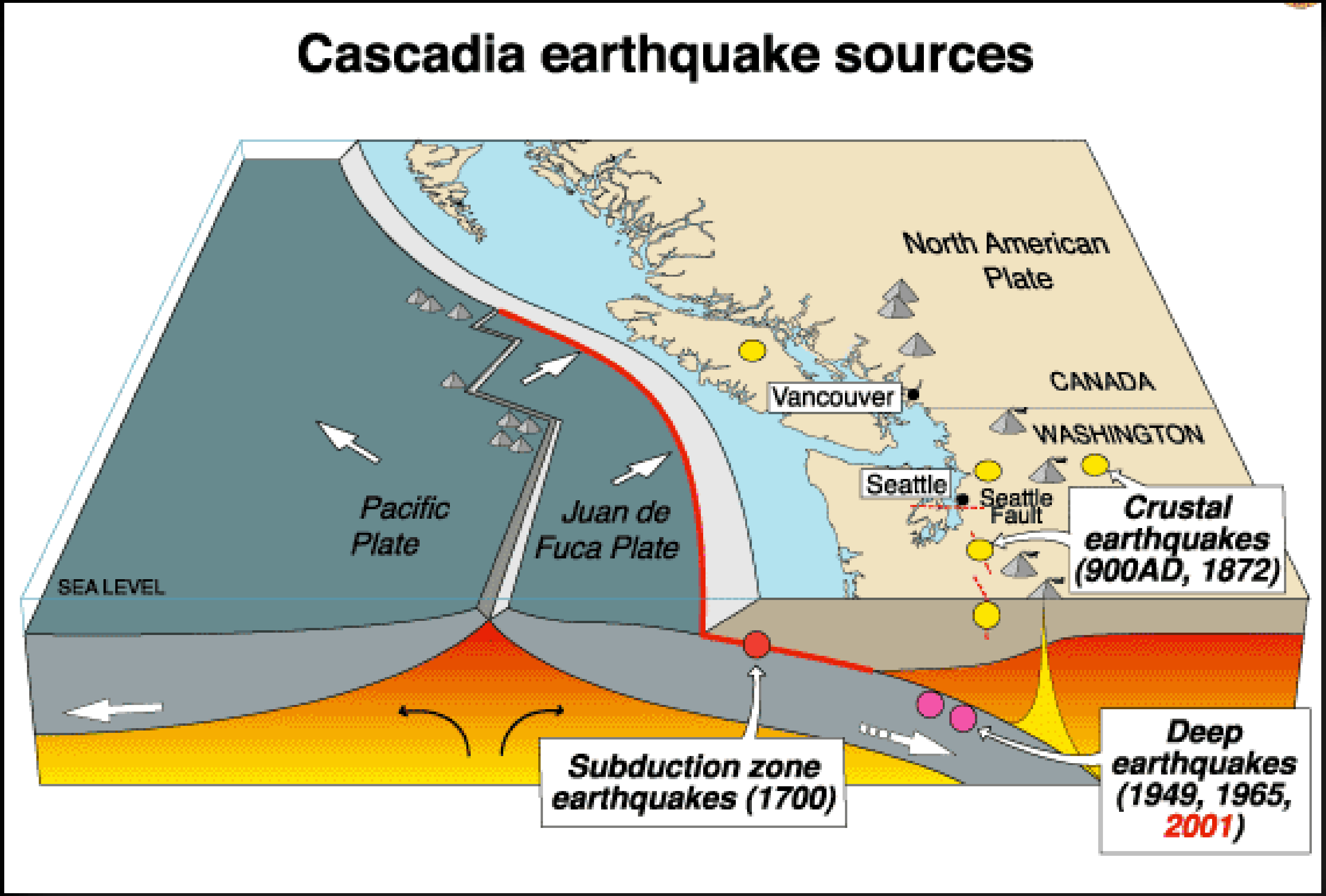
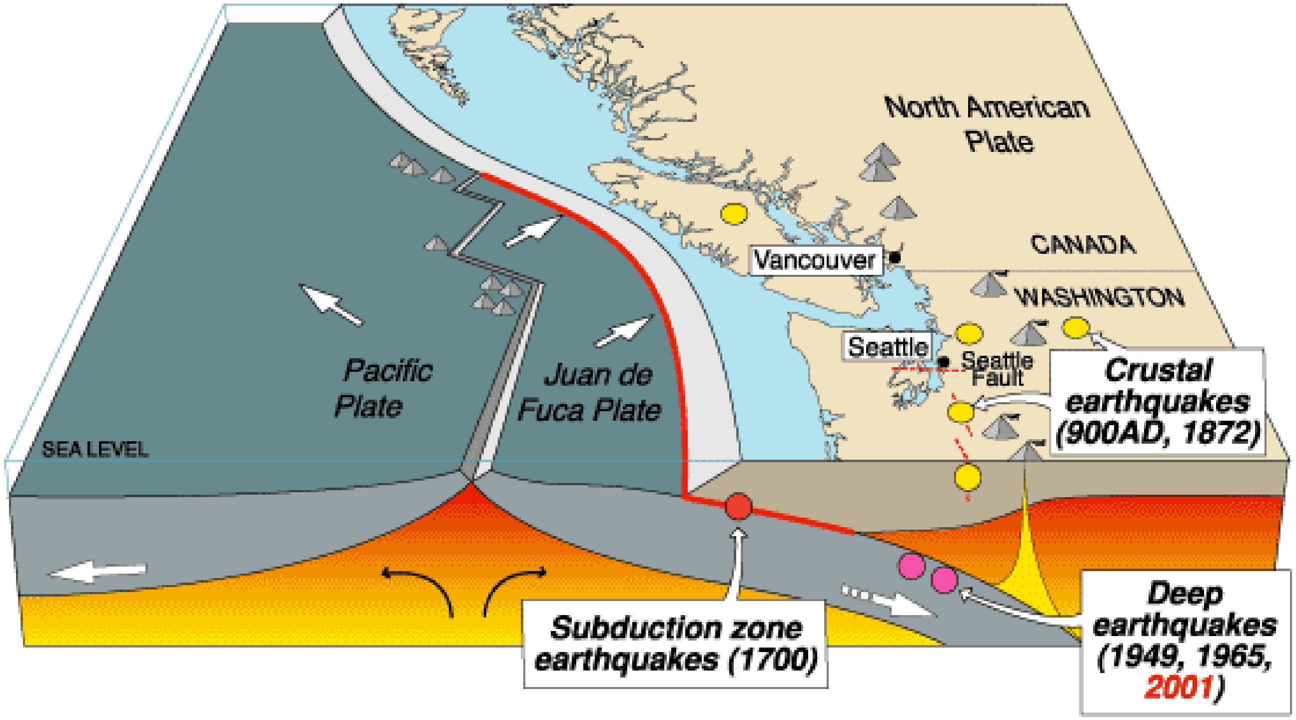
Plate motions give rise to earthquake hazards from three different source zones, each with different recurrence intervals and potential consequences



Cascadia earthquake sources



	Source	Affected area	Max. Size	Recurrence
●	Subduction Zone	W.WA, OR, CA	M 9	500-600 yr
●	Deep Juan de Fuca plate	W.WA, OR,	M 7+	30-50 yr
●	Crustal faults	WA, OR, CA	M 7+	Hundreds of yr?

Deep earthquakes

Two Full Pages Quake Pictures | Quake News and Pictures On Nine Additional Pages

EXTRA

Seattle Post-Intelligencer

SUNRISE EDITION

SEATTLE, THURSDAY, APRIL 14, 1949 — 40 PAGES — 5c PER COPY

SEVEN DEAD, 59 INJURED: EARTHQUAKE LOSS HEAVY

Temblor Lasts Two Minutes; Olympia Area Is Evacuated

Military Police Patrol Downtown Seattle

By Lloyd Stackhouse

Seven persons were killed and at least 59 were injured seriously in an earthquake that rocked the Pacific Northwest and caused ...

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3 Full Pages Quake Pictures Inside

THE WEATHER

Seattle Post-Intelligencer

THE QUALITY NEWSPAPER OF THE GREAT NORTHWEST

SUNRISE EDITION

102nd Year—No. 241 — 10c — SEATTLE, FRIDAY, APRIL 30, 1965 — 52 PAGES

Quake Damage In Millions

Five Dead, Many Hurt In Quake

BY CHARLES DUNSIRE

Western Washington may be declared a disaster area by Gov. Dan Evans, following yesterday's earthquake which left five dead, dozens injured and millions of dollars in property damage in the Pacific Northwest.

The Olympian

SERVING WASHINGTON'S SOUTH PUGET SOUND

THURSDAY, MARCH 1, 2001 — www.theolympian.com

GOOD MORNING — HIGH 51 — LOW 38 — FORECAST, D8

Epicenter 11 miles northeast of Olympia | More than two dozen buildings damaged | Dozens of injuries; no South Sound deaths

6.8 QUAKE

WHAT YOU NEED TO KNOW NOW

BRIDGE DAMAGE

■ The Fourth Avenue bridge has been closed indefinitely because of visible bowing.

BUILDING DAMAGE

■ 19 Capitol Campus and other state buildings have been closed until they can be assessed.

■ 13 buildings in Olympia have been evacuated and will remain closed pending structural evaluations.

■ 14 buildings in Olympia have been yellow-tagged for a structural assessment. They can only be entered to secure offices or retrieve medicines.

ROAD CLOSURES

■ Washington Street from Fifth to Legion

■ Fifth Avenue from Capitol Way to Washington Street

■ Deschutes Parkway, Lakeridge Drive to Fifth

■ Martin Way limited to two lanes between Ensign and Lilly roads

■ Northbound lanes of U.S. Highway 101 north of state Route 8 were closed Wednesday night, but officials hope to have them open today. Call (800) 695-7623 or go to www.wsdot.wa.gov/traveler.

SCHOOL CLOSURES

■ The Olympia, North Thurston and Tumwater schools will be closed today, as will The Evergreen State College. Saint Martin's College and South Puget Sound Community College will be open.

■ The Olympia Center will be closed today and Friday.

WORKERS

■ School district employees and state workers who work on the Capitol Campus have the day off, but Thurston County workers will work normal shifts today.

INDEX

THE OLYMPIAN STAFF

OLYMPIA — South Sound today will begin to assess the long-term cost from a powerful earthquake that caused widespread damage and left thousands shaken — but, miraculously, few seriously injured.

Many residents will have an unexpected day off as schools and most state offices remain closed while buildings are inspected.

The magnitude 6.8 earthquake struck at 10:55 a.m., lasted about 45 seconds and was centered 30 miles beneath the Nisqually Delta, according to the National Earthquake Information Center in Golden, Colo.

The quake, the area's strongest since 1949, wreaked havoc across South Sound.

■ **The city of Olympia** evacuated 13 buildings and tagged 14 more as potentially dangerous because of quake damage.

■ **The Fourth Avenue bridge** in downtown Olympia was closed indefinitely because of damage.

■ **The stone exterior** of the Capitol dome cracked.

■ **Debris** from the facades of downtown Olympia buildings littered streets.

■ **Northbound lanes** of U.S. Highway 101 were closed because of a landslide.

■ **Rail traffic** ground to a halt after six miles of track were damaged. Sea-Tac Airport also was closed for hours, with planes diverted to Portland, which also felt the quake.

■ **More than 50 Olympia** residents were at least temporarily displaced from their homes.

In addition to the damage, the quake left thousands of people unnerved.

"It felt like the end of the world," said Casey McKee, an employee of the Fifth Avenue Fabric and Clothing Gallery. "It felt very frightening."

At first McKee thought people upstairs were doing work on the floor, but then she realized it was a quake and ran for the nearest door.

See **QUAKE**, Page A2

Rubble from the downtown Washington Federal Savings building rests on the sidewalk off Fifth Avenue.

State buildings shut till Monday

BY PATRICK CONDON, BRAD SHANNON AND LAUREN WALSH
THE OLYMPIAN

OLYMPIA — The earthquake that struck South Sound on Wednesday morning shook Washington government to its core, cracking the stone shell of the state Capitol dome and damaging more than 20 state office buildings.

State leaders quickly canceled the legislative session until at least Monday, and more than 10,000 state employees were left without phones or offices to work when the 6.8 magnitude quake hit at 10:55 a.m.

"There was smoke, and then the sprinklers came on and then there was water running down the marble steps," said Rep. Gigi Talcott, R-Tacoma, describing the chaos on the fourth floor of the John L. O'Brien office building, where many state representatives have their offices.

There were only minor injuries reported on the Capitol Campus, according to the Olympia Fire Department.

See **CAPITOL**, Page A2

4th Ave. bridge

Residents: 'Our building was dancing

Olympia, 1949

Olympia, 2001

Pioneer Square, 1949

Pioneer Square, 2001


Deschutes Parkway, 1965


Deschutes Parkway, 2001
28. 2. 2001


Salmon Beach, 1949

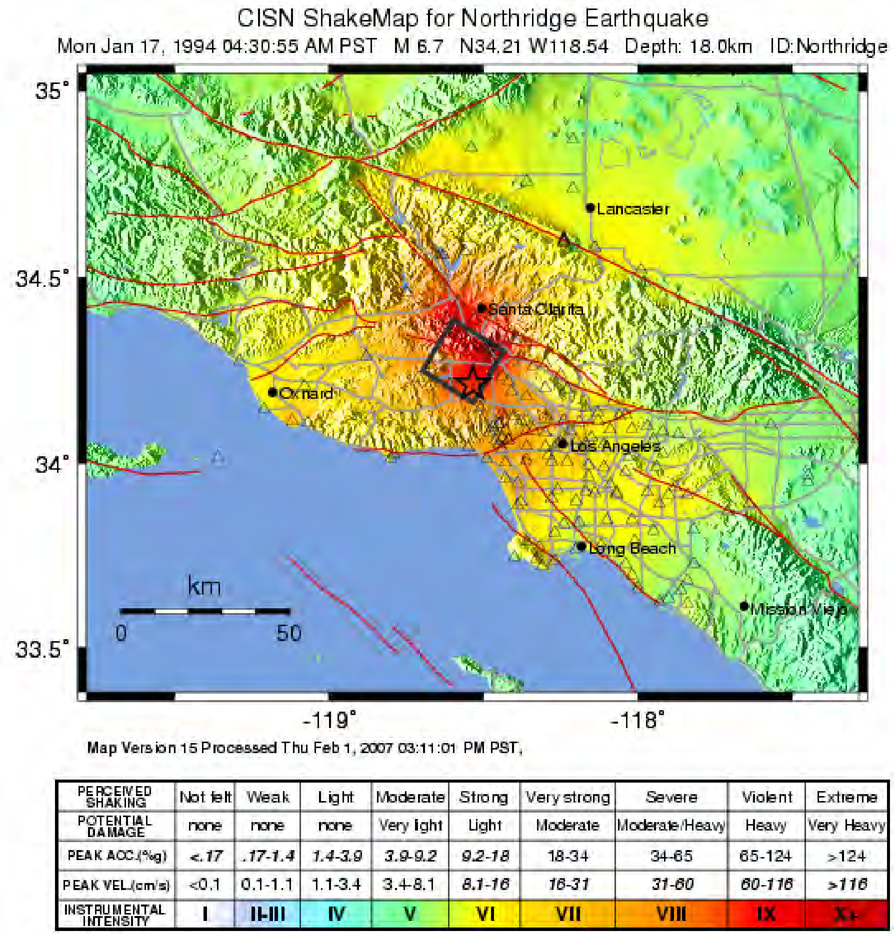

Salmon Beach, 2001

The Bayview market in Olympia lost stock from unsecured merchandise toppling off the shelves

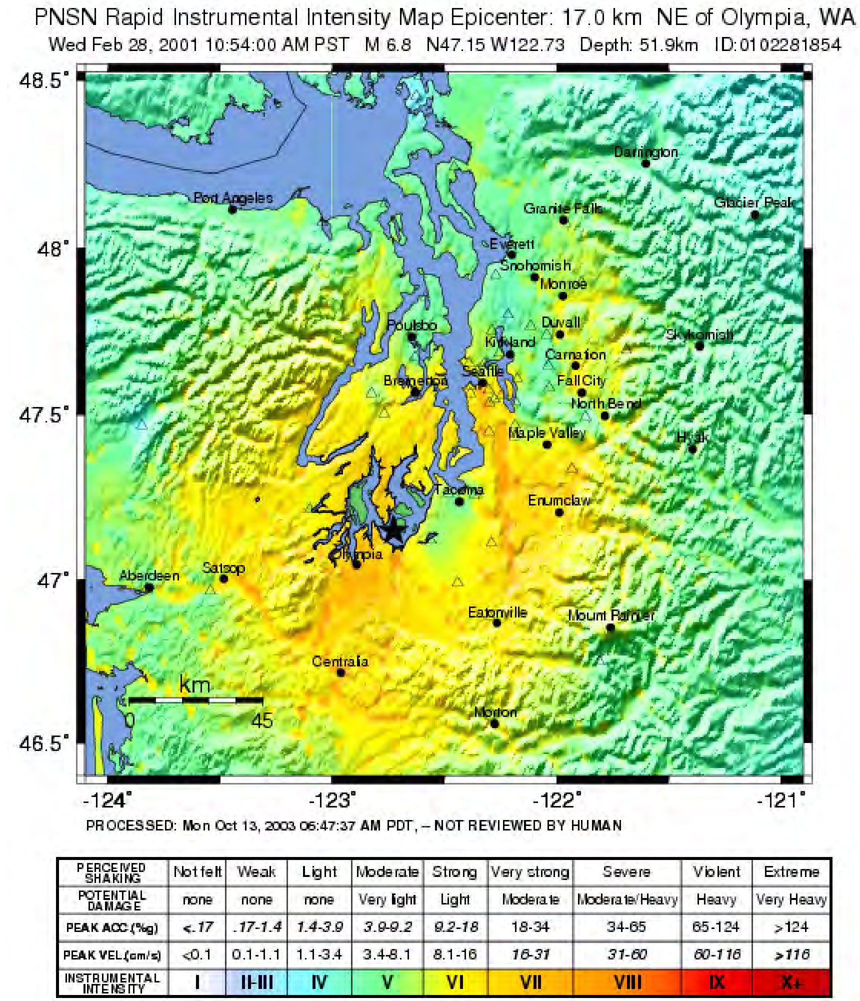
Nonstructural hazards can be mitigated easily and cost-effectively

These examples of nonstructural damage are from the Natural Resources Building in Olympia from the Nisqually earthquake

Simple restrainers are an effective mitigation



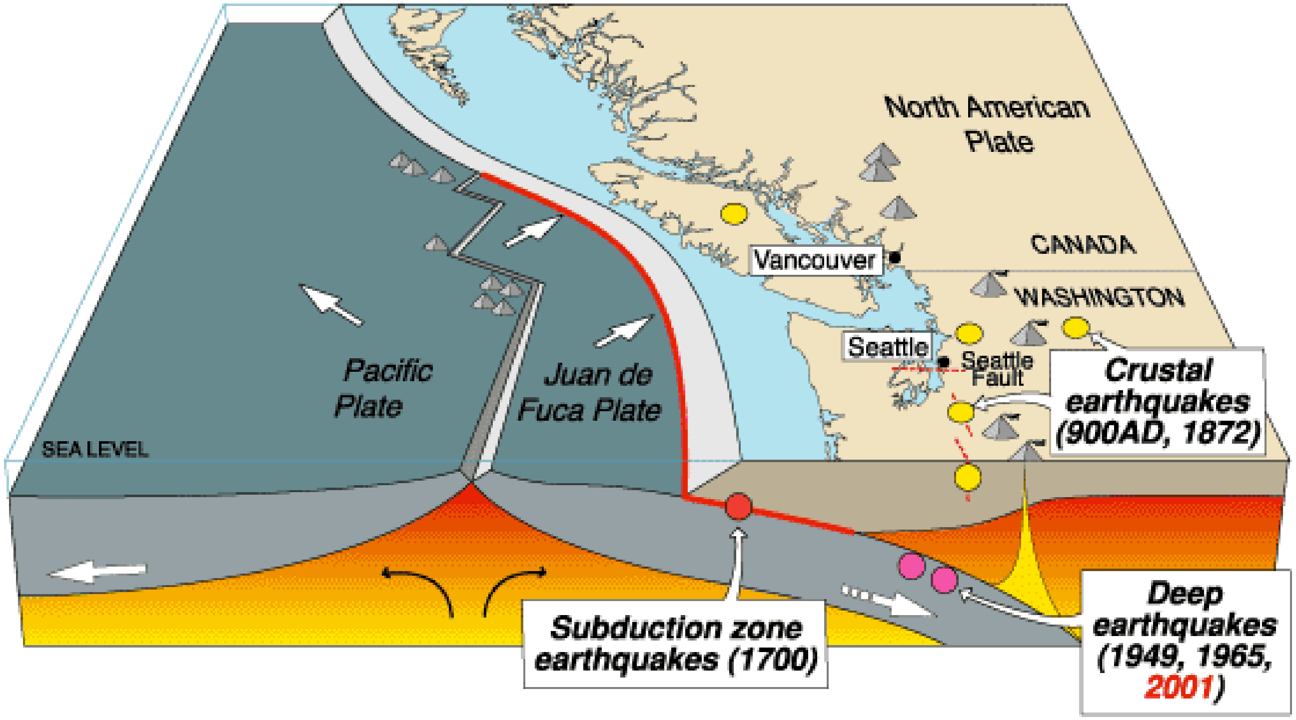
M6.7, depth 12 miles



M6.8, depth 35 miles

Because these earthquakes are deep, they are less damaging than shallow events like the Northridge in California

Cascadia earthquake sources



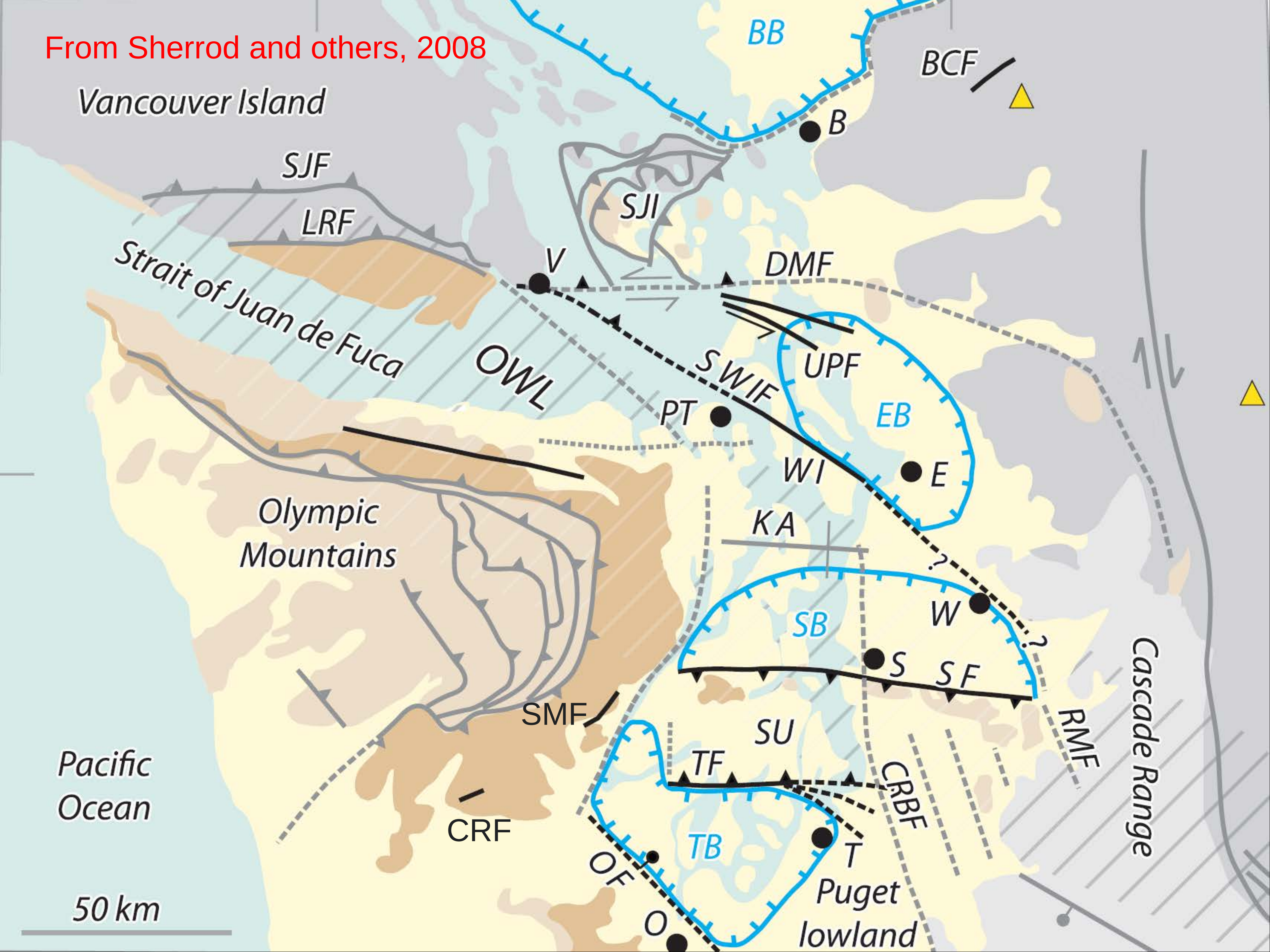
	Source	Affected area	Max. Size	Recurrence
●	Subduction Zone	W.WA, OR, CA	M 9	500-600 yr
●	Deep Juan de Fuca plate	W.WA, OR,	M 7+	30-50 yr
●	Crustal faults	WA, OR, CA	M 7+	Hundreds of yr?

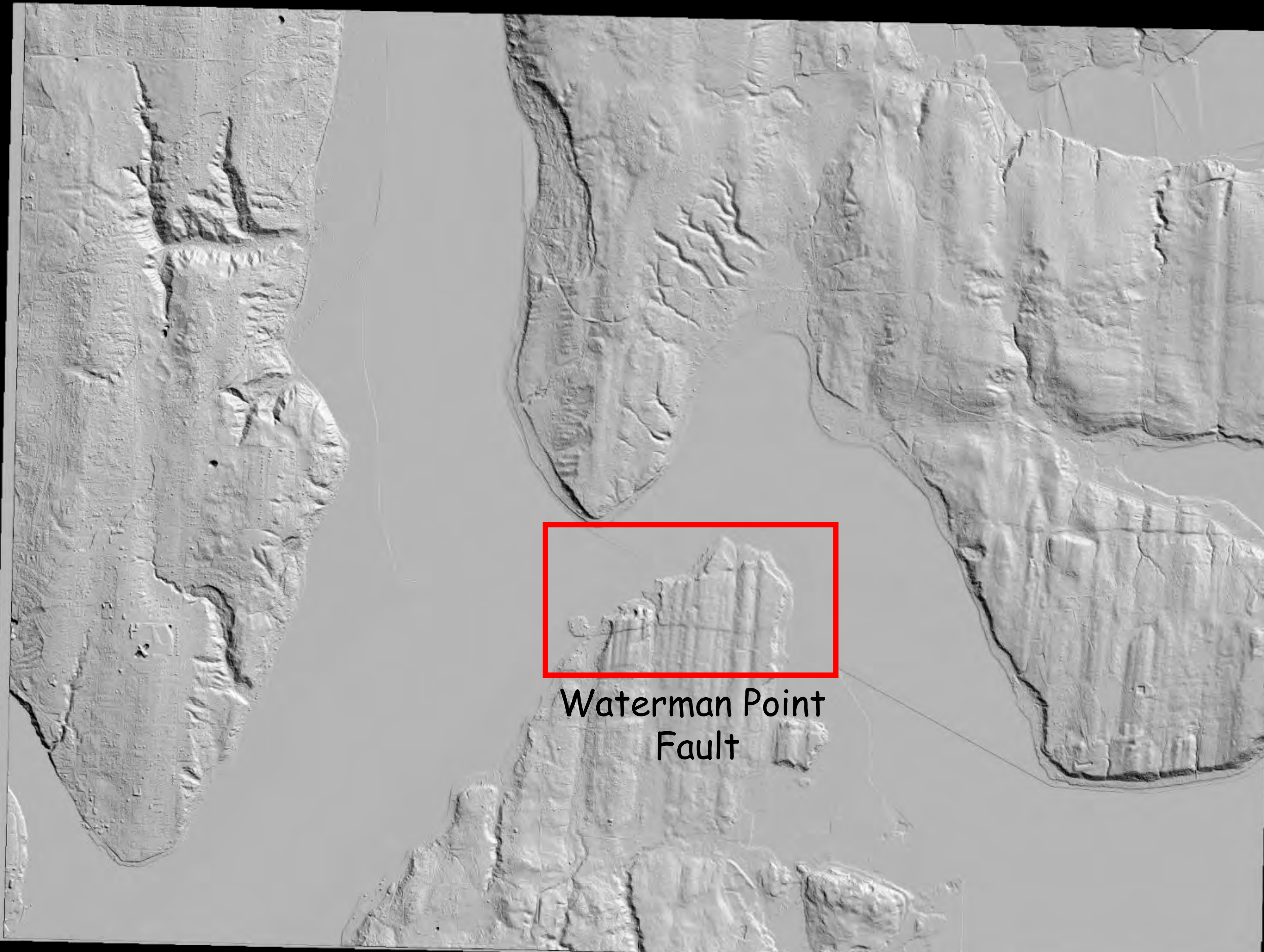
Crustal earthquakes

Washington’s earthquake history is spotty before ~1850s

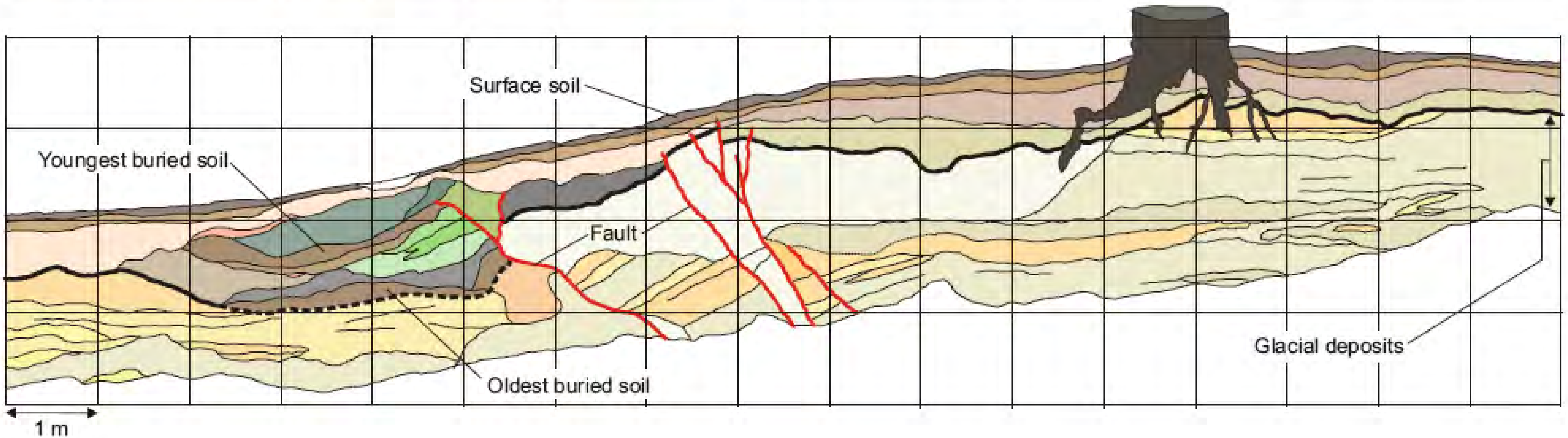
- Very large earthquakes have long recurrence intervals, on the order of hundreds to thousands of years
- Evidence demonstrates substantial hazard from faults that have not ruptured since European settlement in the PNW
- Fault include the Seattle, Tacoma, southern Whidbey Island, Devil’s Mountain, Canyon River, Boulder Creek, Toppenish Ridge, Saddle Mountain, etc.
- All are capable of >M6.5 at shallow depths and therefore highly damaging

From Sherrod and others, 2008



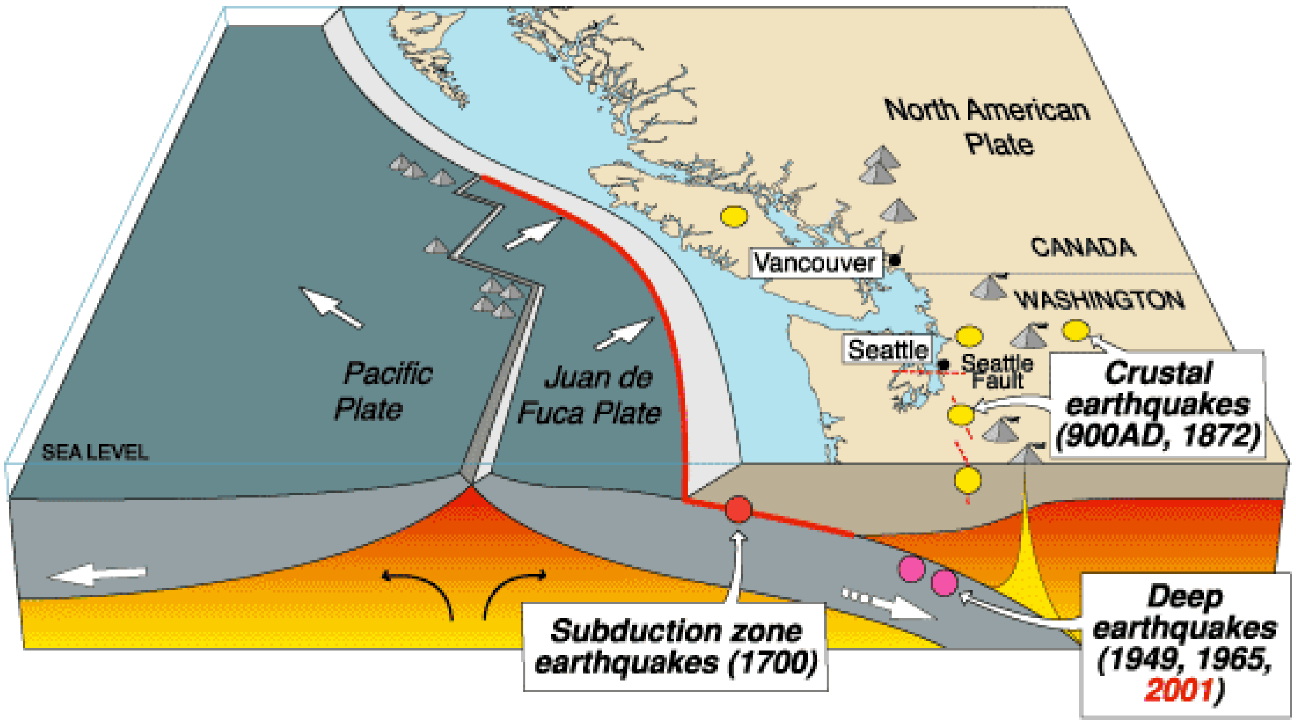

Waterman Point
Fault


Bedrock
Holocene soil
USGS



Boulder Creek Trench Log

Cascadia earthquake sources



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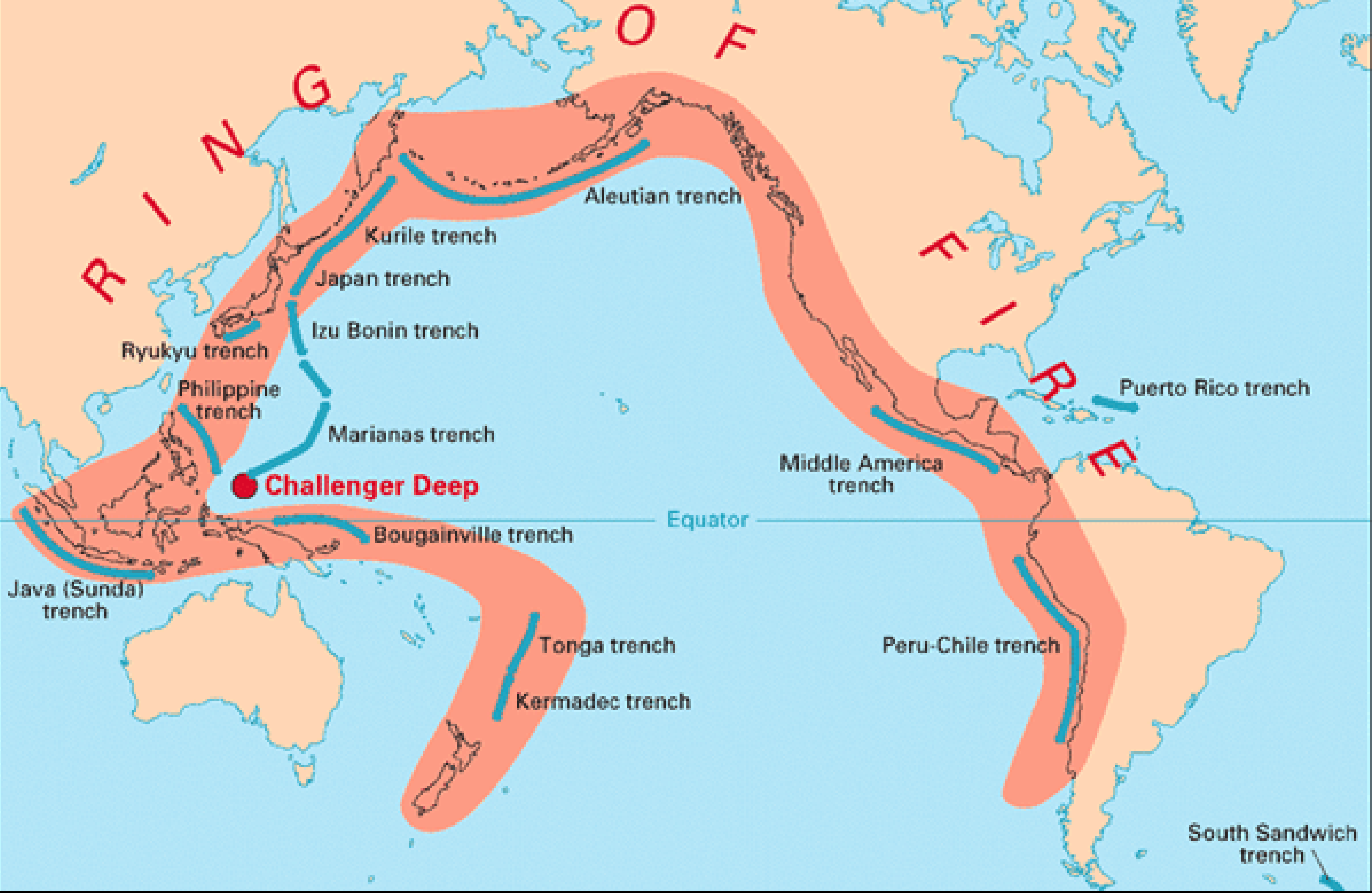
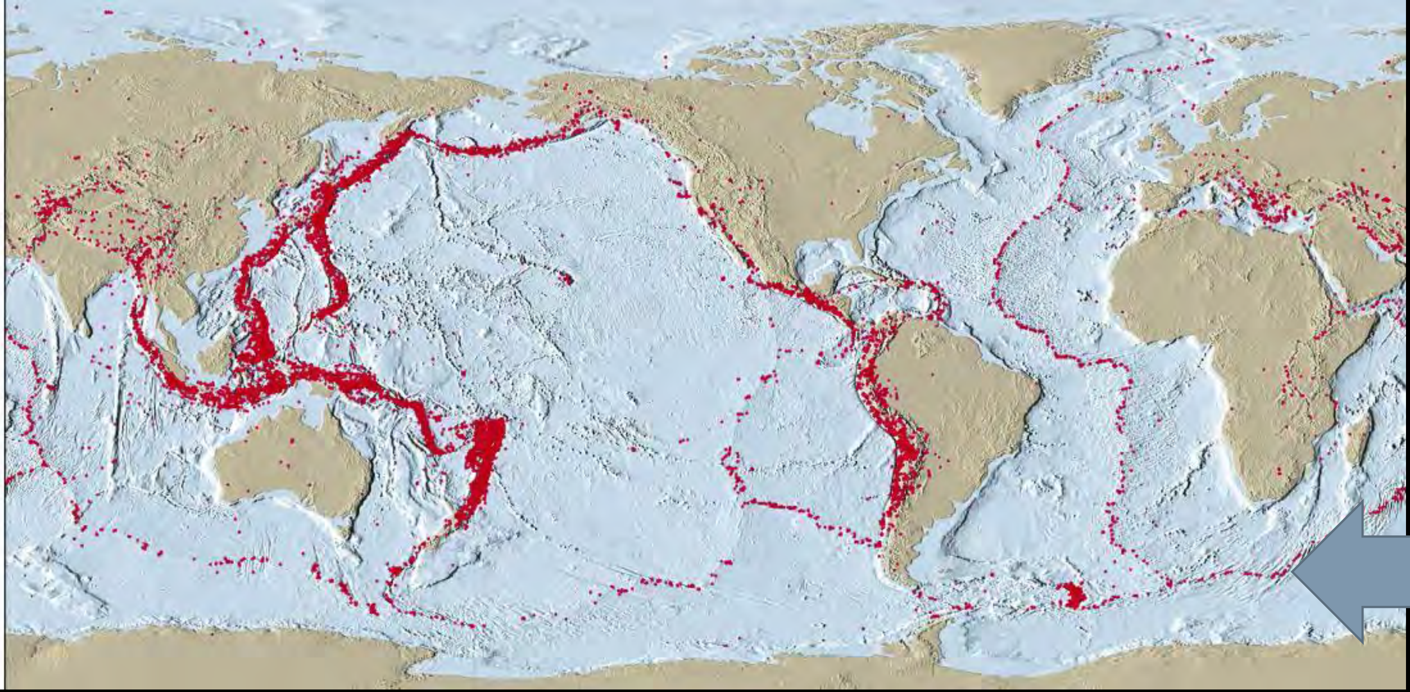
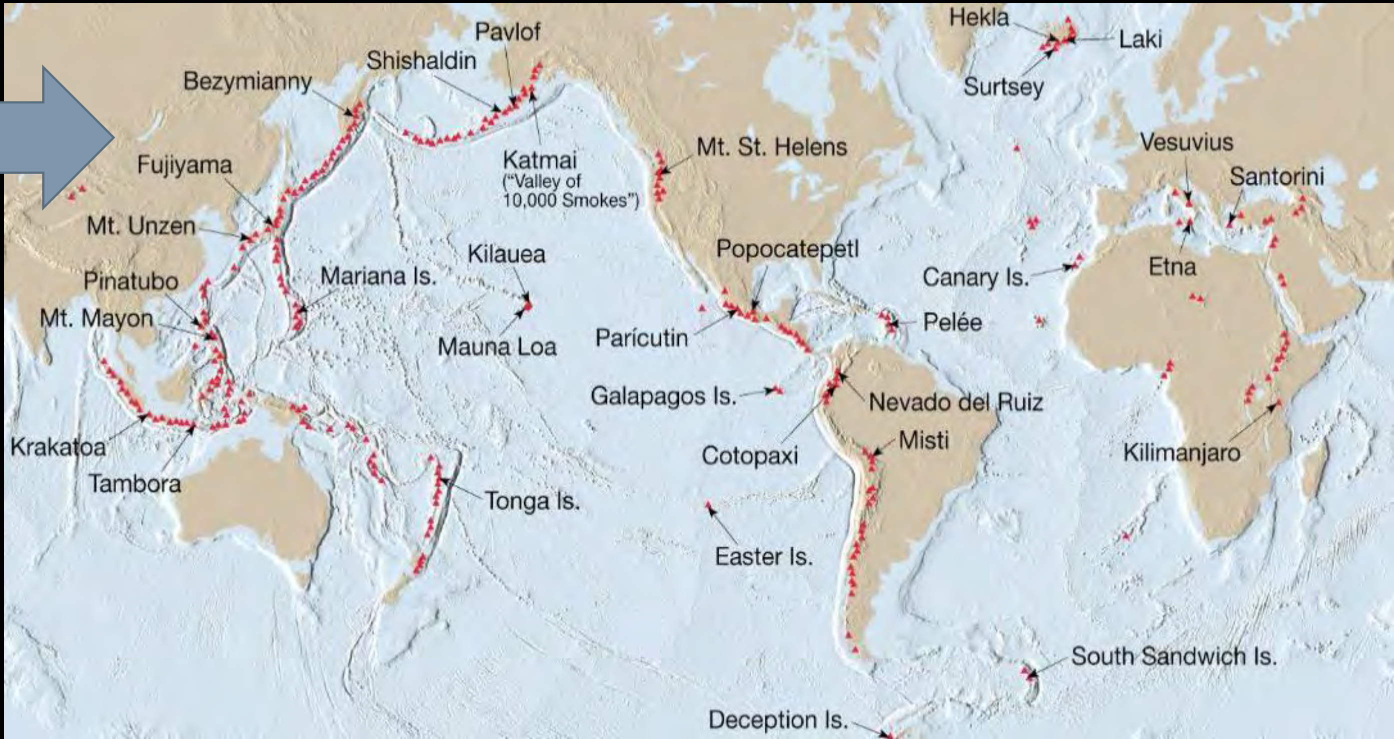
Subduction zone earthquakes



How do we know that Cascadia makes earthquakes? Some background.
Washington is located in the northeast corner of the Ring of Fire.



Distribution of magnitude 5 or greater earthquakes 1980-1990



Distribution of some of the world's major volcanoes

Geologic hazards

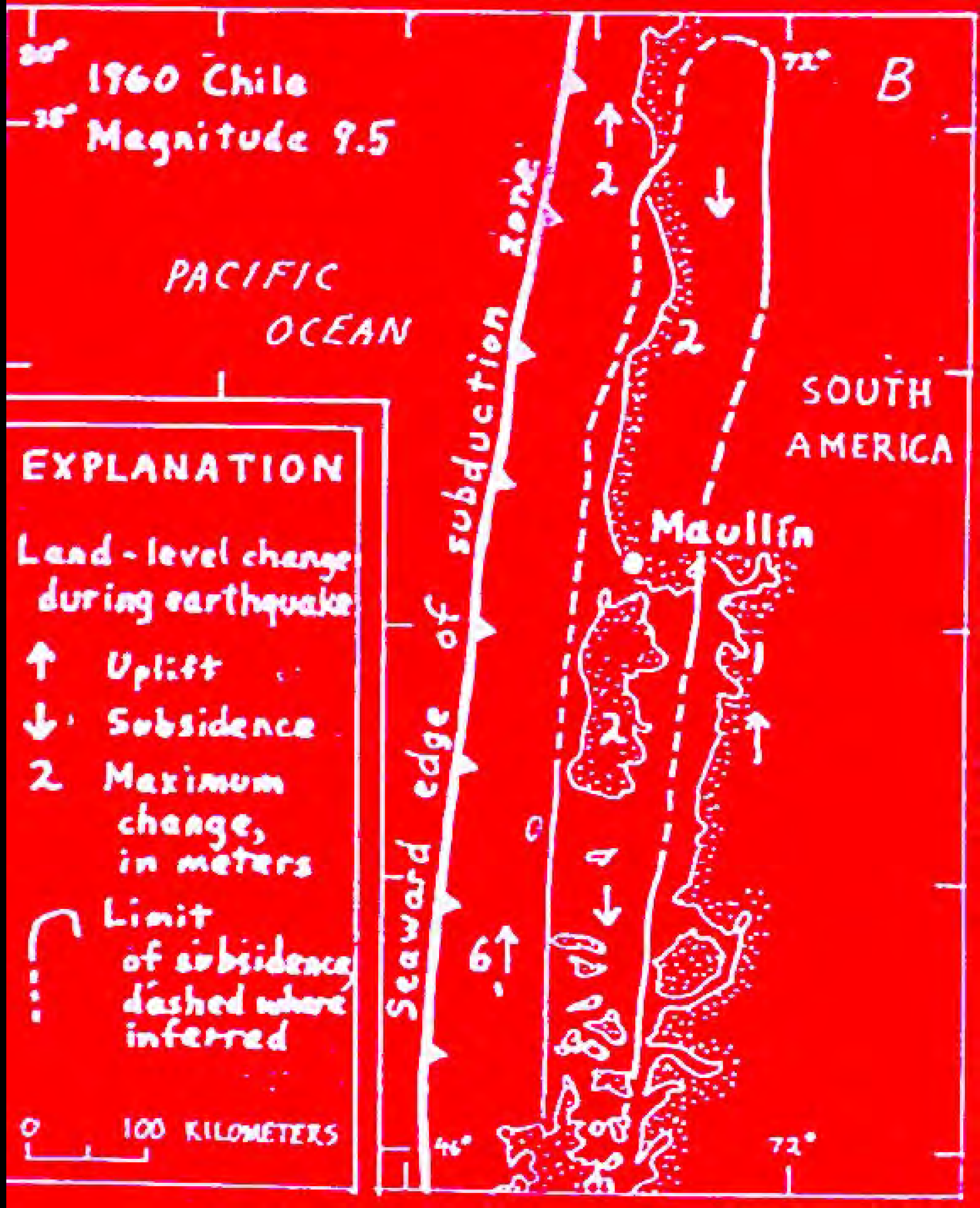
- Earthquake
- **<u>Tsunami</u>**
- Landslide

If you can see or hear water, you're probably living too close.
-Stephen Slaughter

Note also that the coast of Washington has very few earthquakes, and none on the subduction zone. It was long thought that Cascadia was not active.

1960 M9.5 Chile earthquake

- Land level dropped up to 6 ft.
- Other places uplift was as much as 18 ft.

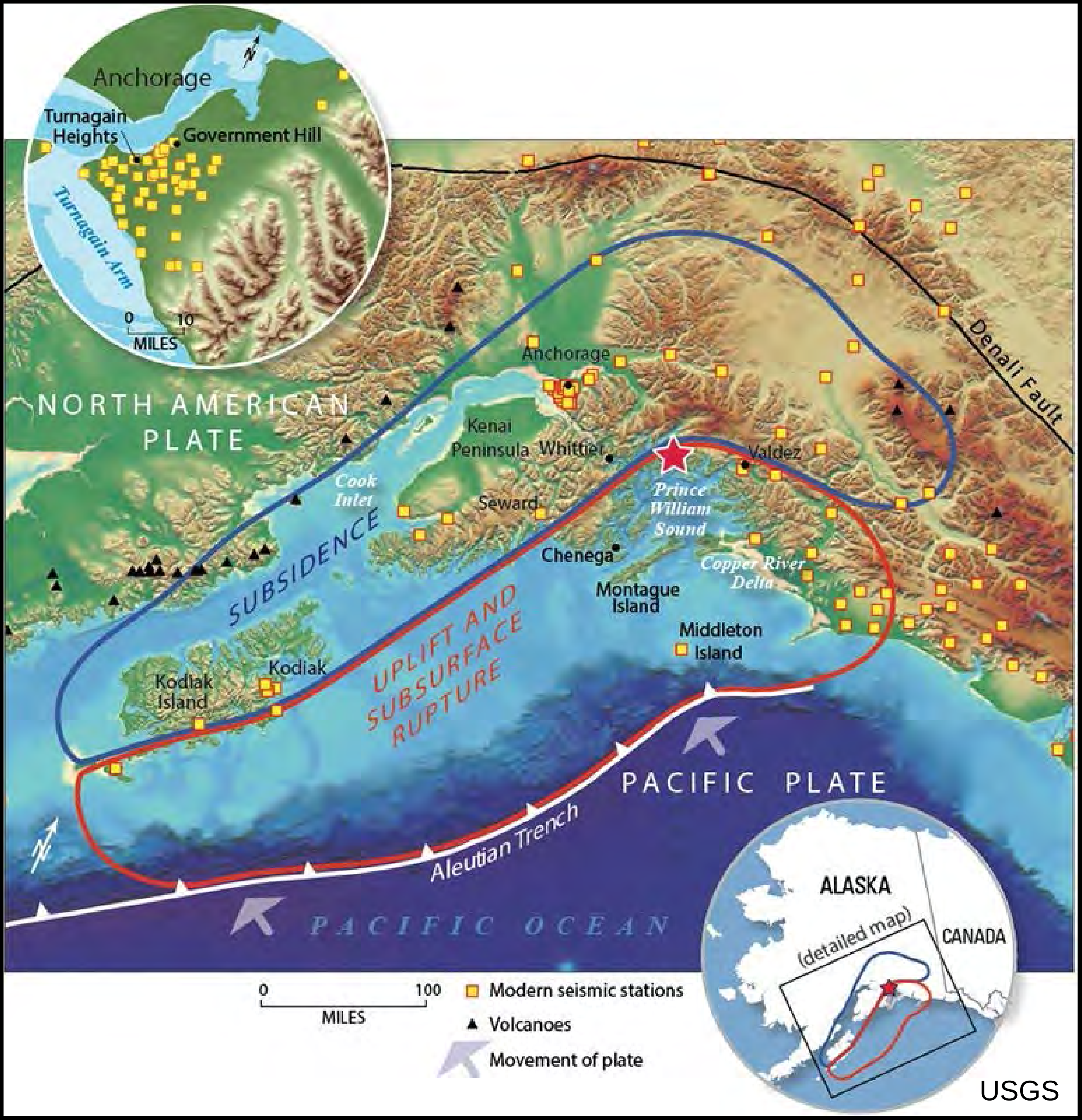


Queule Chile - Before

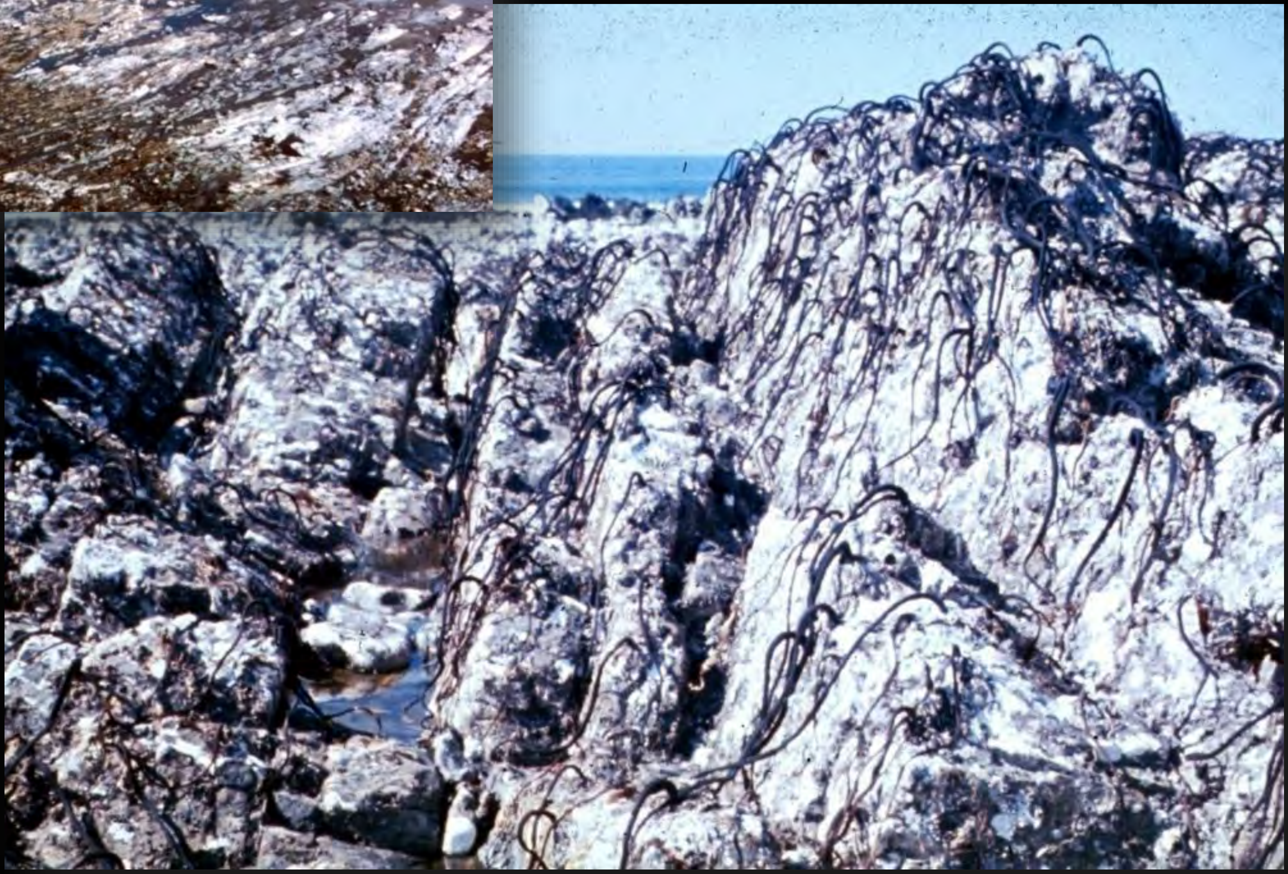
Queule Chile - After

1964 M9.2 Alaska

- Subsidence up to 6 feet
- Uplift as much as 30 ft.



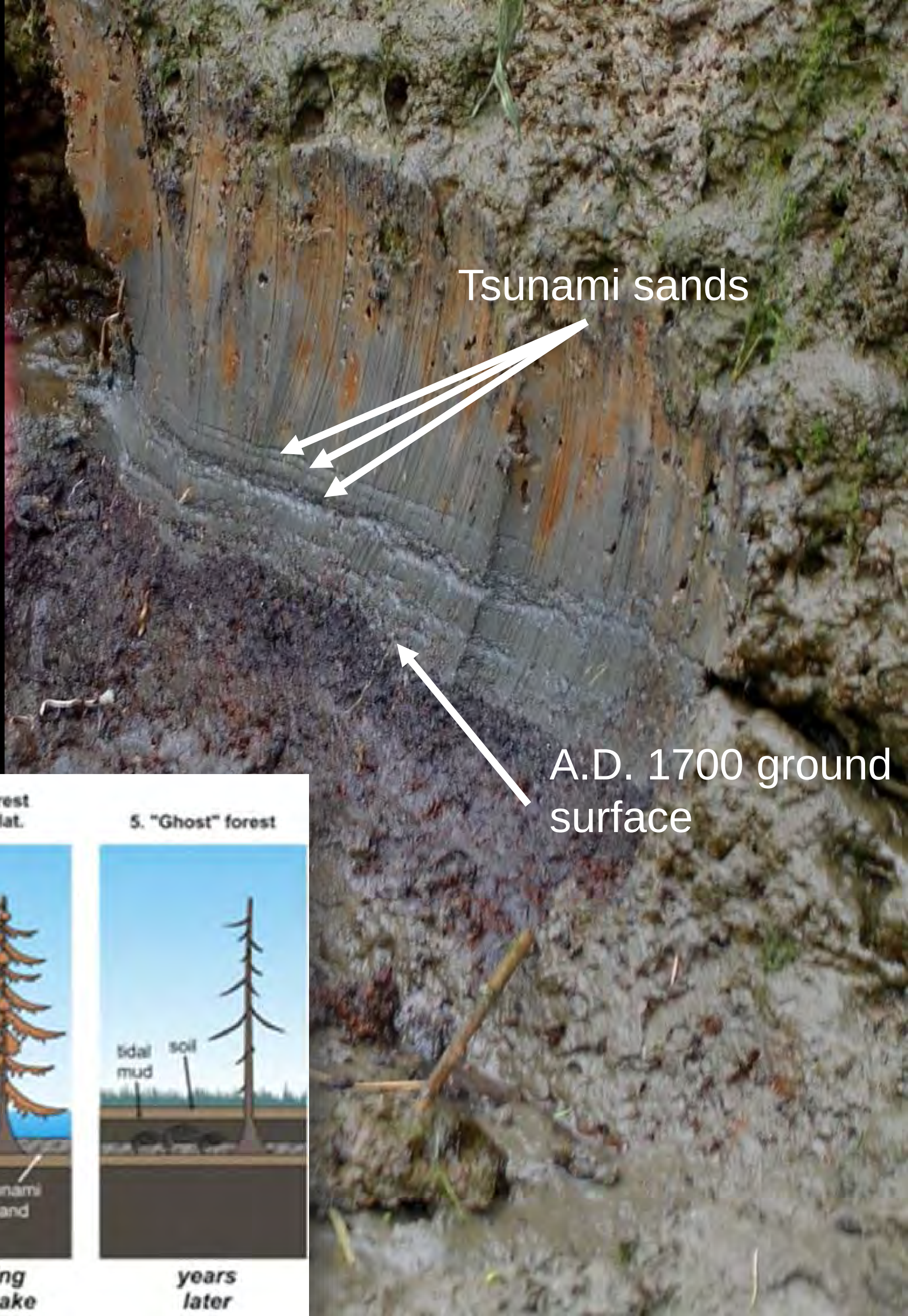
This area in Prince William Sound was uplifted 33 feet, stranding seaweed high above the beach.

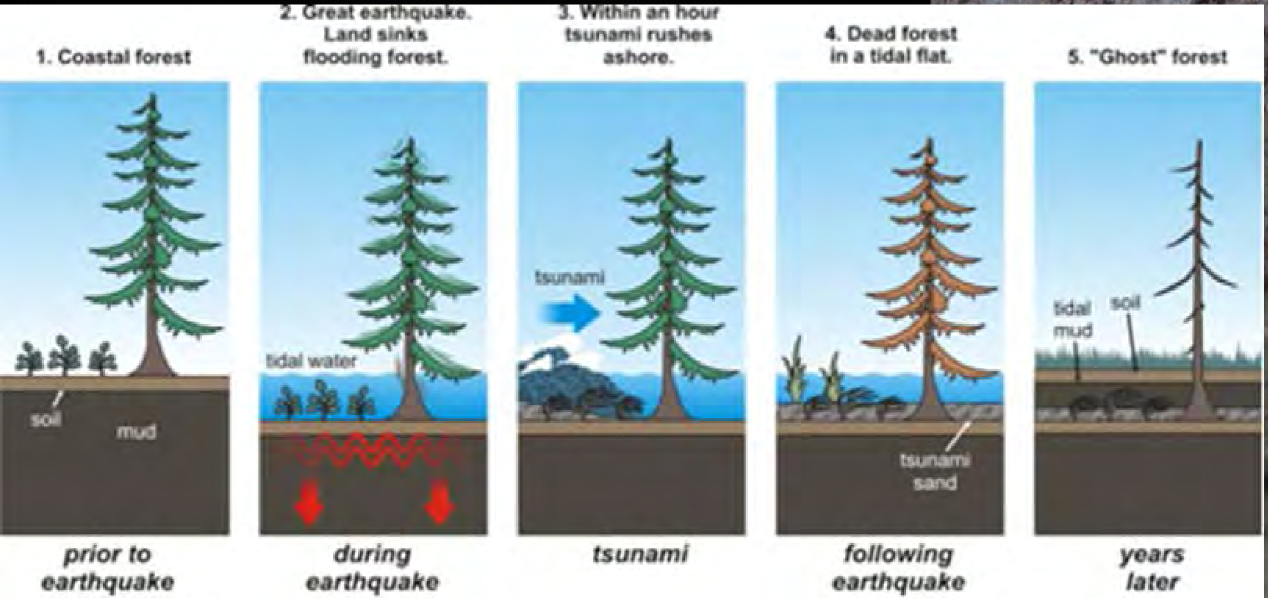


Drowned forest in Girdwood, AK - killed 1964

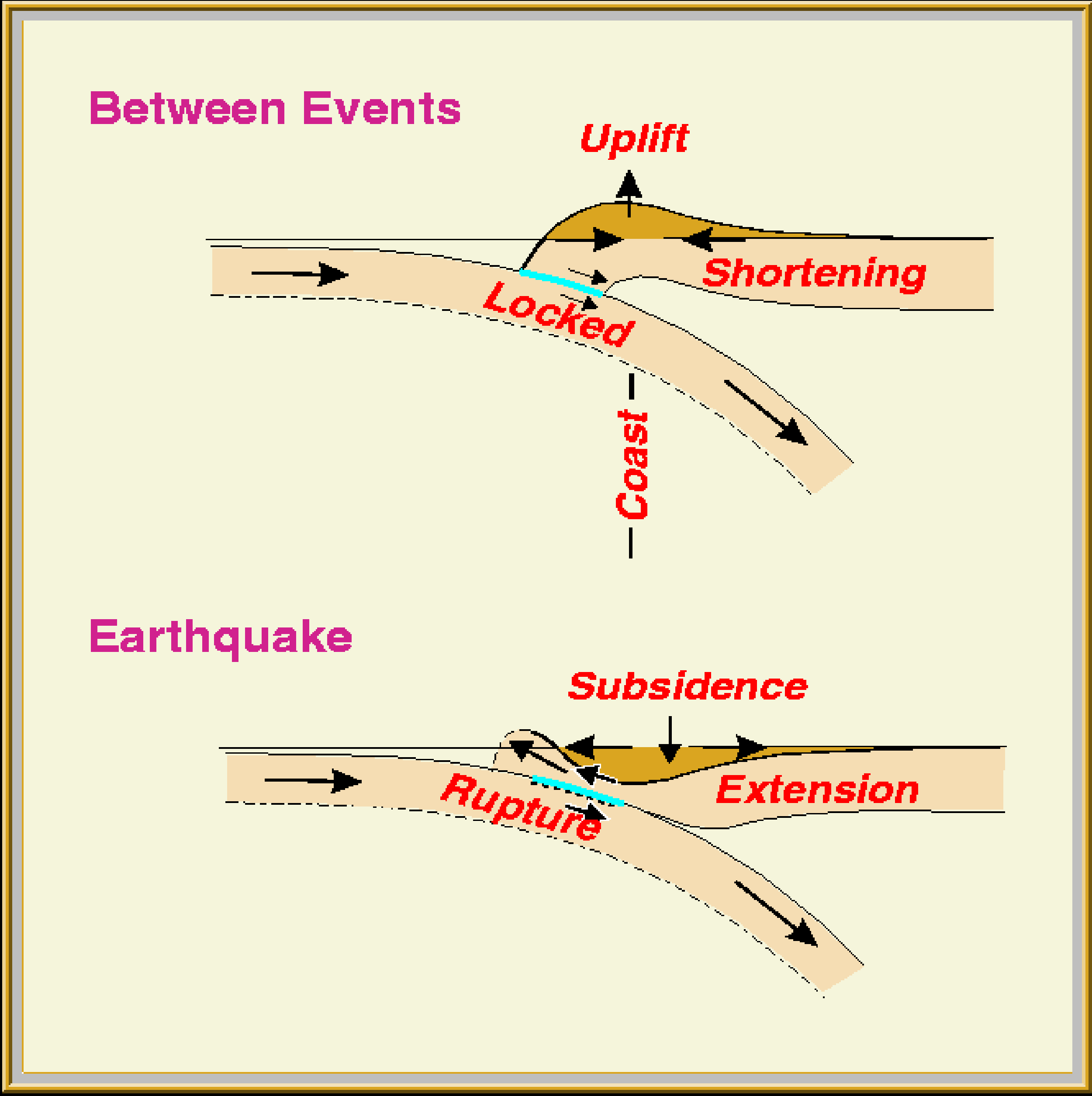
Drowned forest along the Copalis River, WA - killed 1700

Subsided marsh along the Niawiakum River, with tsunami-deposited sand



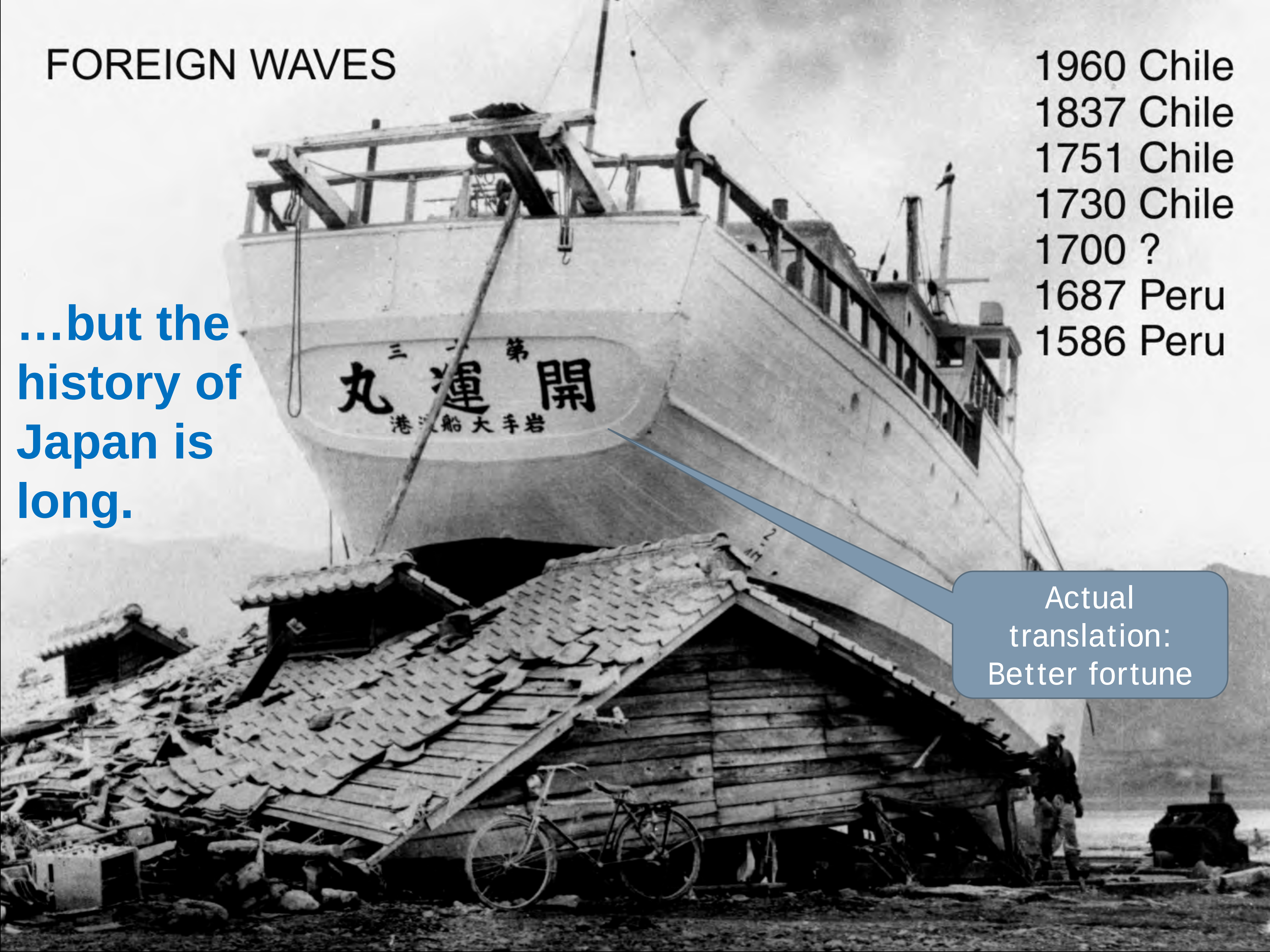


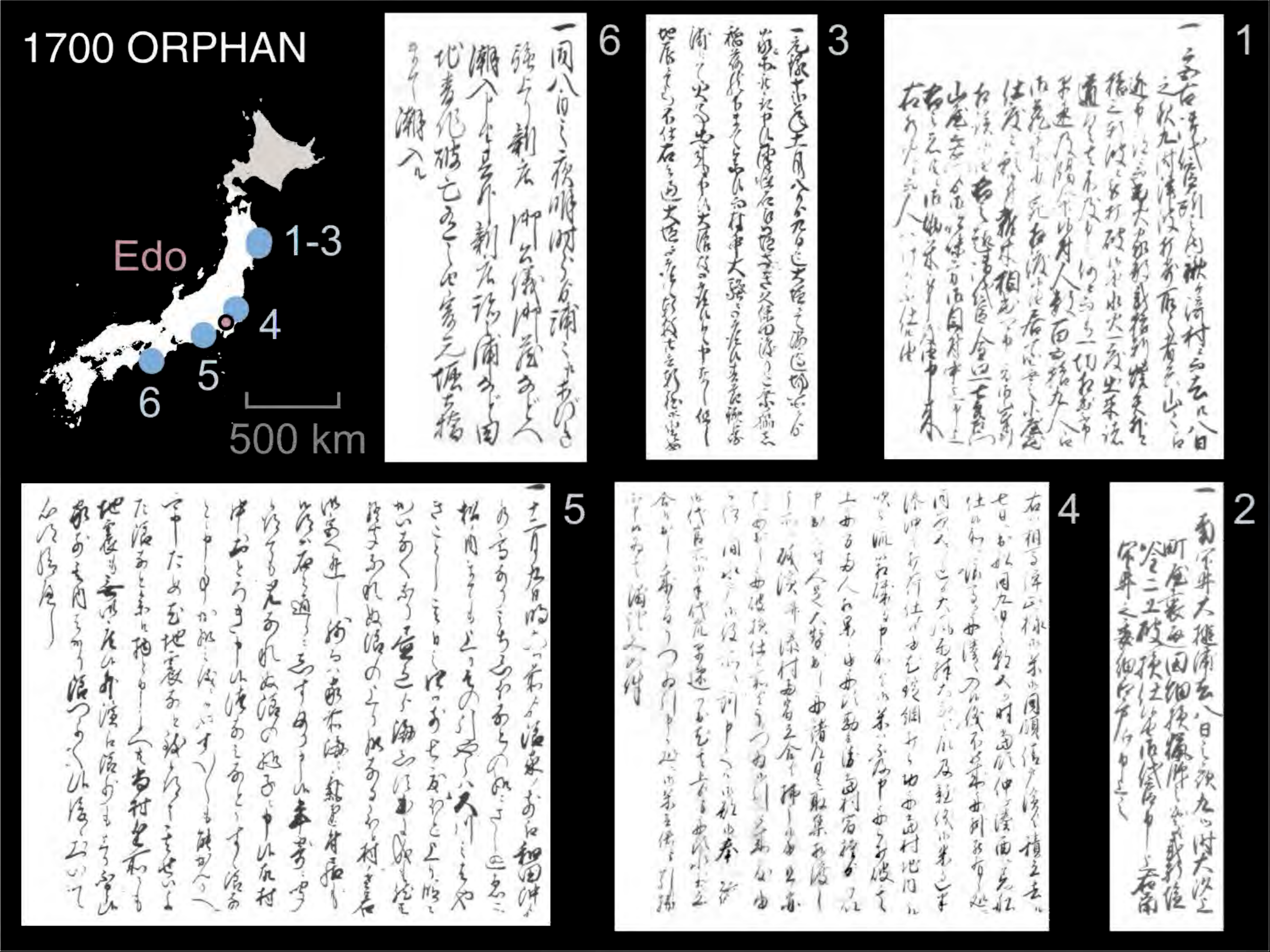
What's going on? Between earthquakes, shortening due to convergence causes uplift along the coast. The earthquake causes the abrupt subsidence of that uplift and stretching causes uplift closer to the fault.



We know a "big" earthquake occurred in the past, but how big an earthquake was this?

The history of the PNW is short...

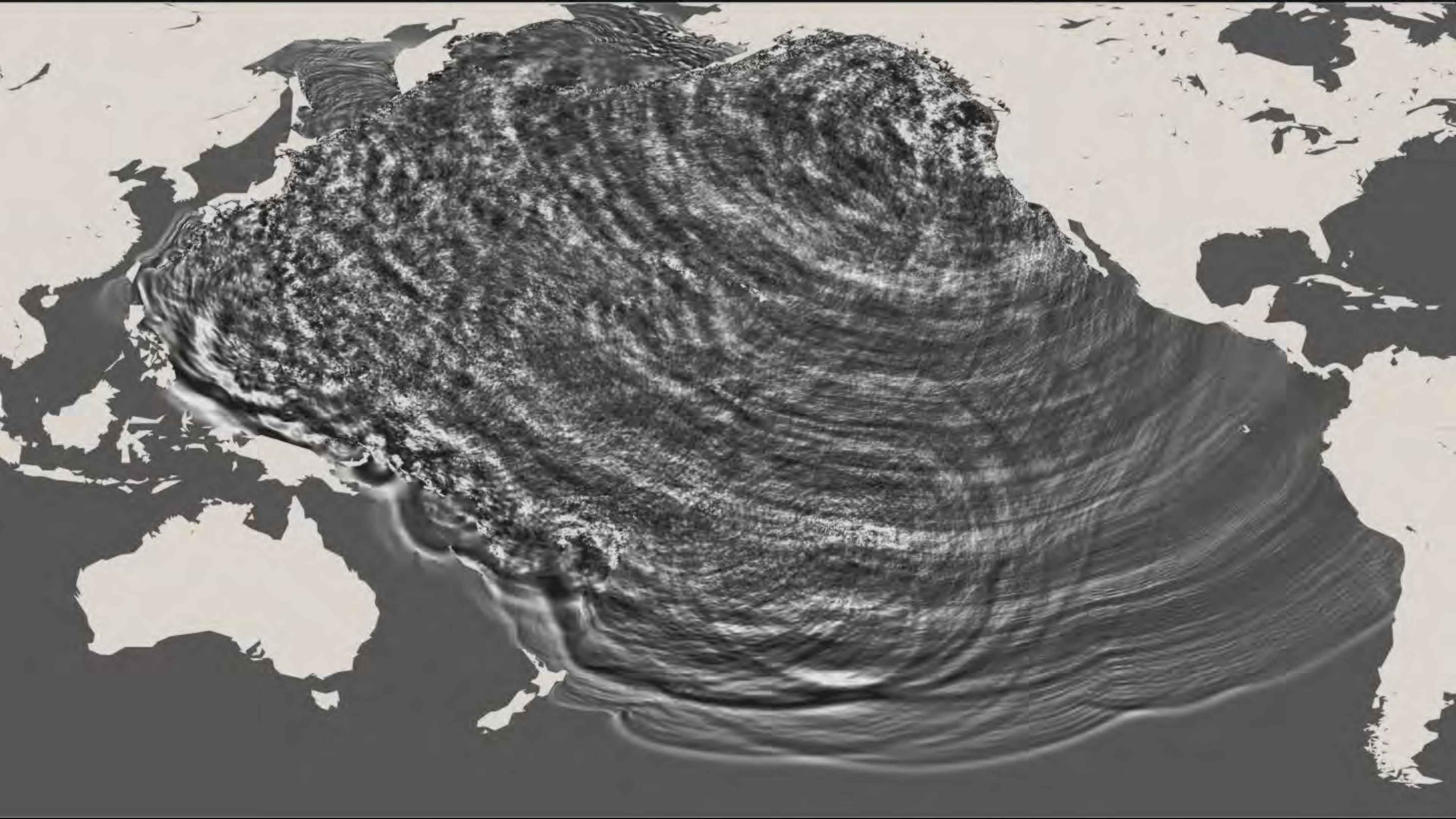

FOREIGN WAVES
1960 Chile
1837 Chile
1751 Chile
1730 Chile
1700 ?
1687 Peru
1586 Peru
…but the history of Japan is long.
開運丸
Actual translation: Better fortune


1700 ORPHAN
Edo
1-3
4
5
6
500 km
6
3
1
5
4
2

1 hour after earthquake

Model by Kenji Satake

14 hours

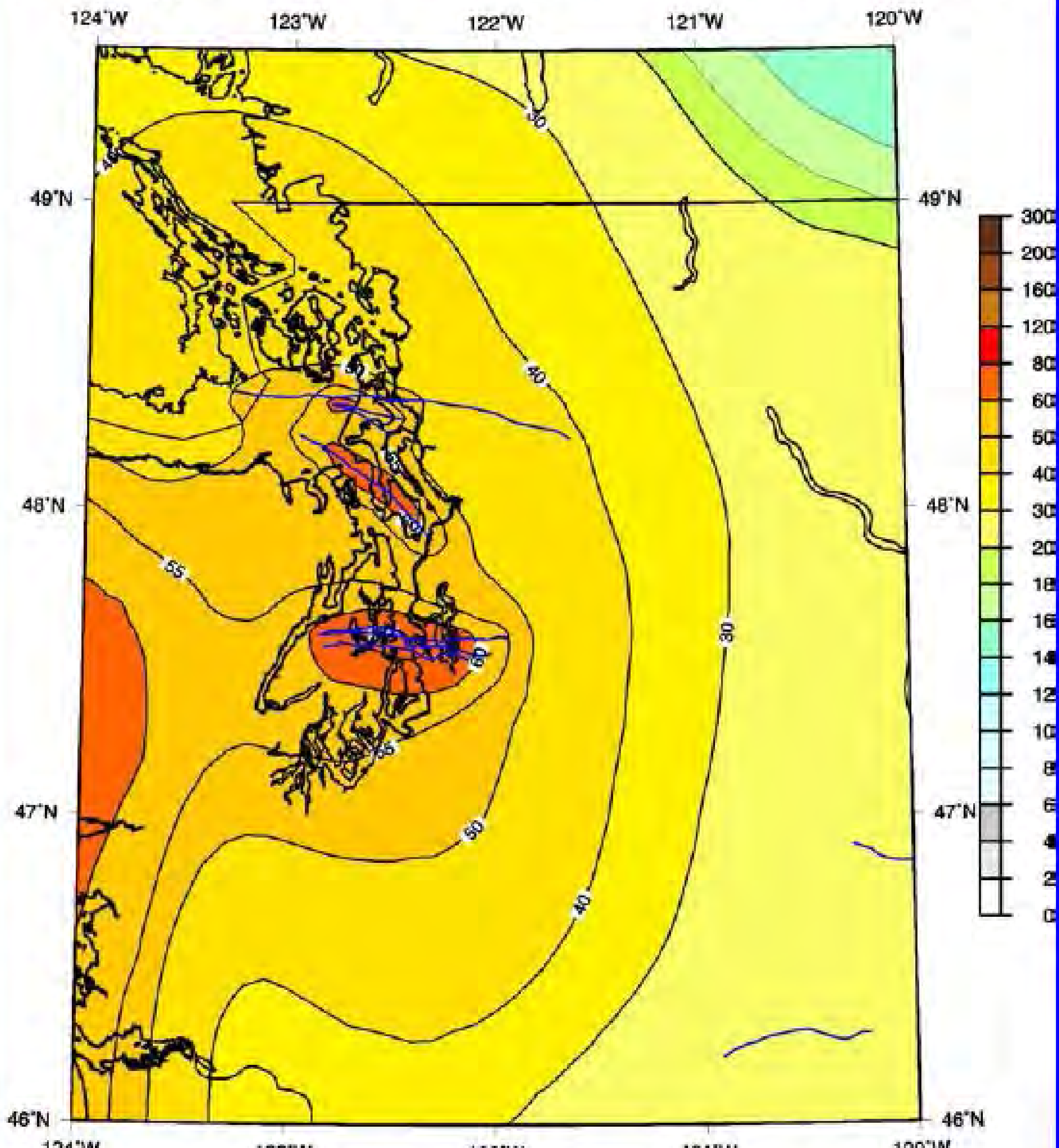


This demonstrated that the earthquake that generated the tsunami ruptiured the entire subduction zone, requiring a magnitude of about 9

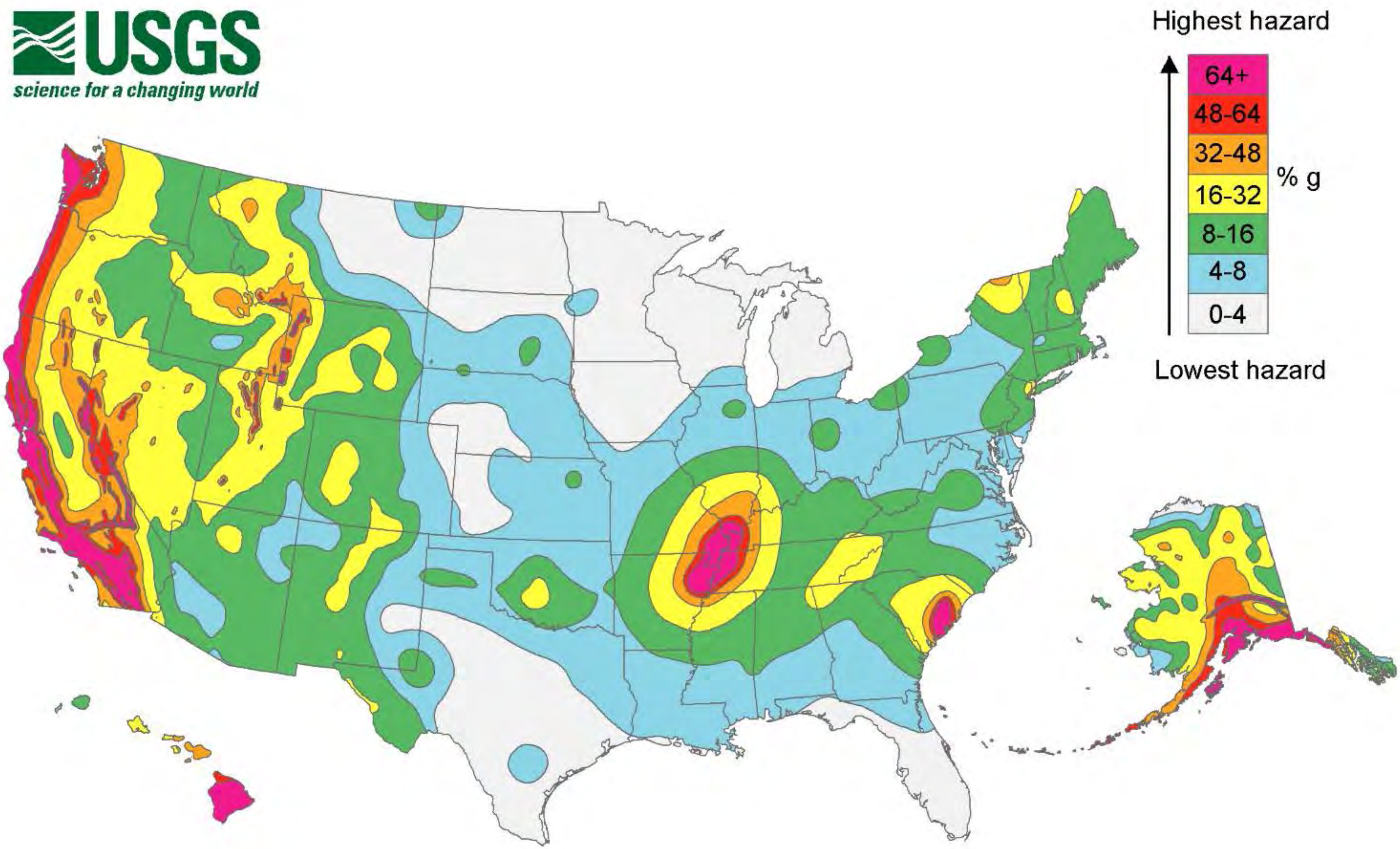
Model by Kenji Satake

The USGS takes all of these potential sources and combines them into a probabilistic map of the expected level of ground shaking that is expected during the life of a building

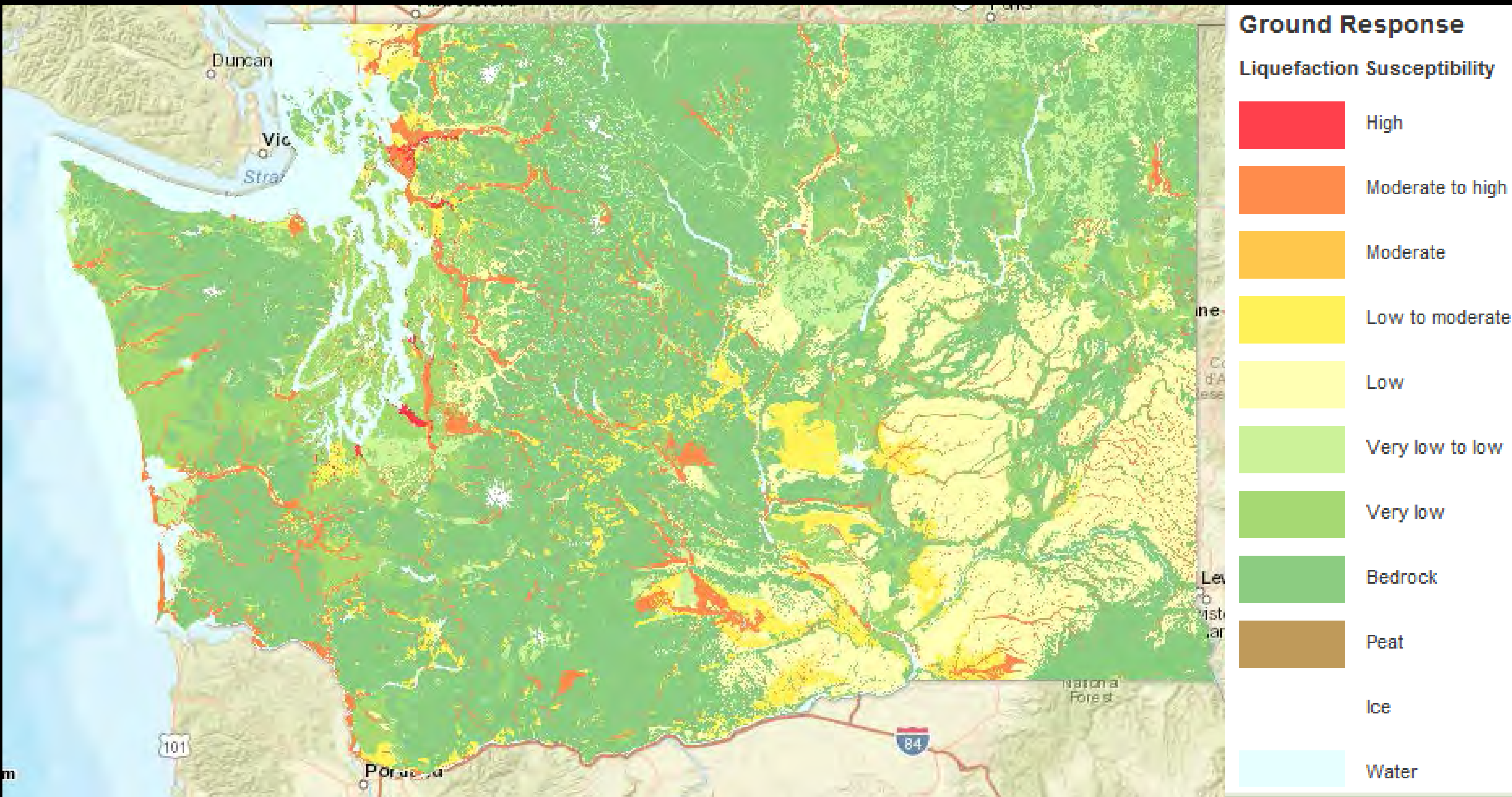
From 2002 USGS National Seismic Hazard Map
PGA (%g) with 2% Prob. Of Exceedance in 50 Years



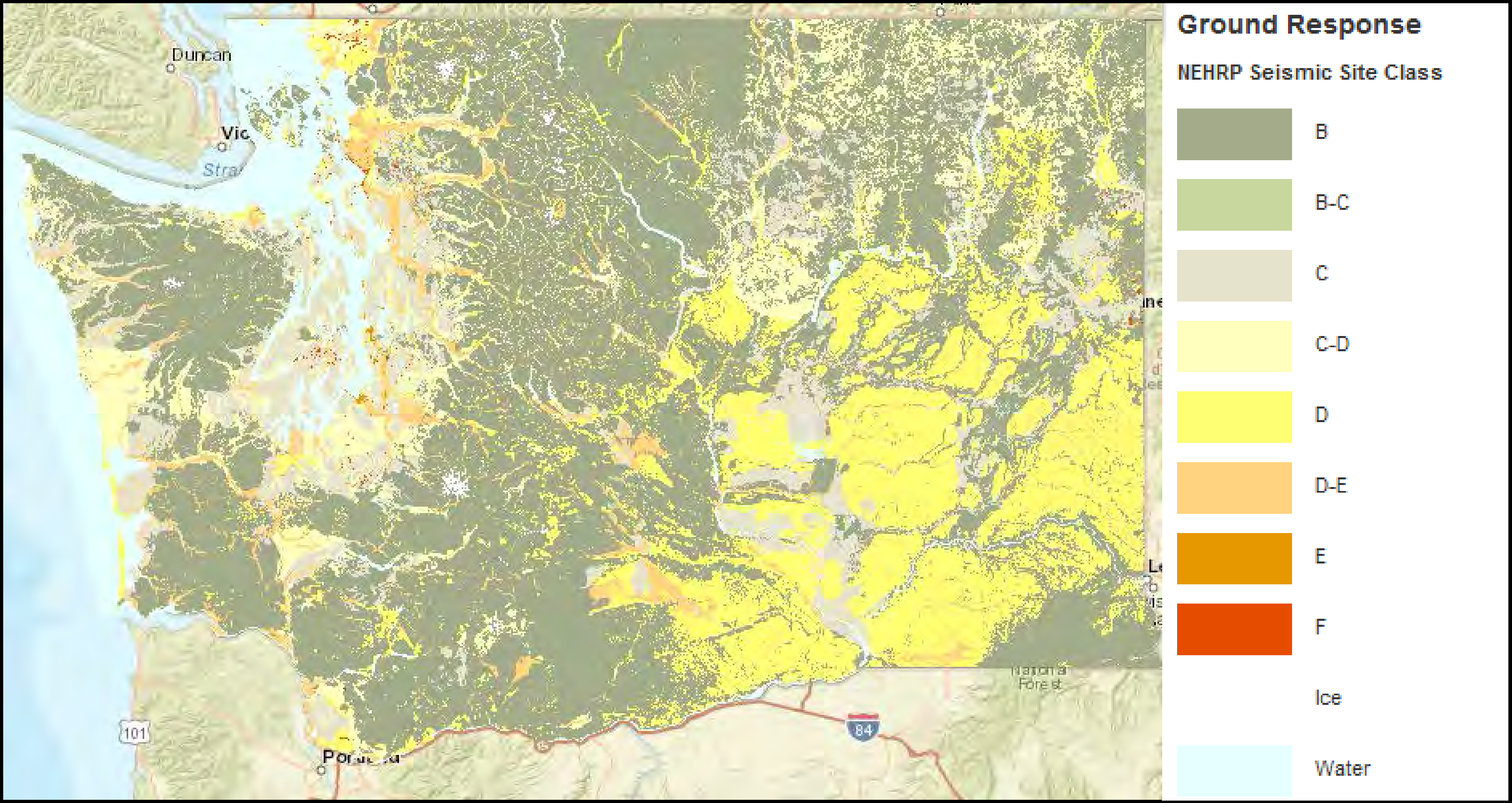
Simplified 2014 Hazard Map
2% probability of exceedance in 50 years of peak ground acceleration

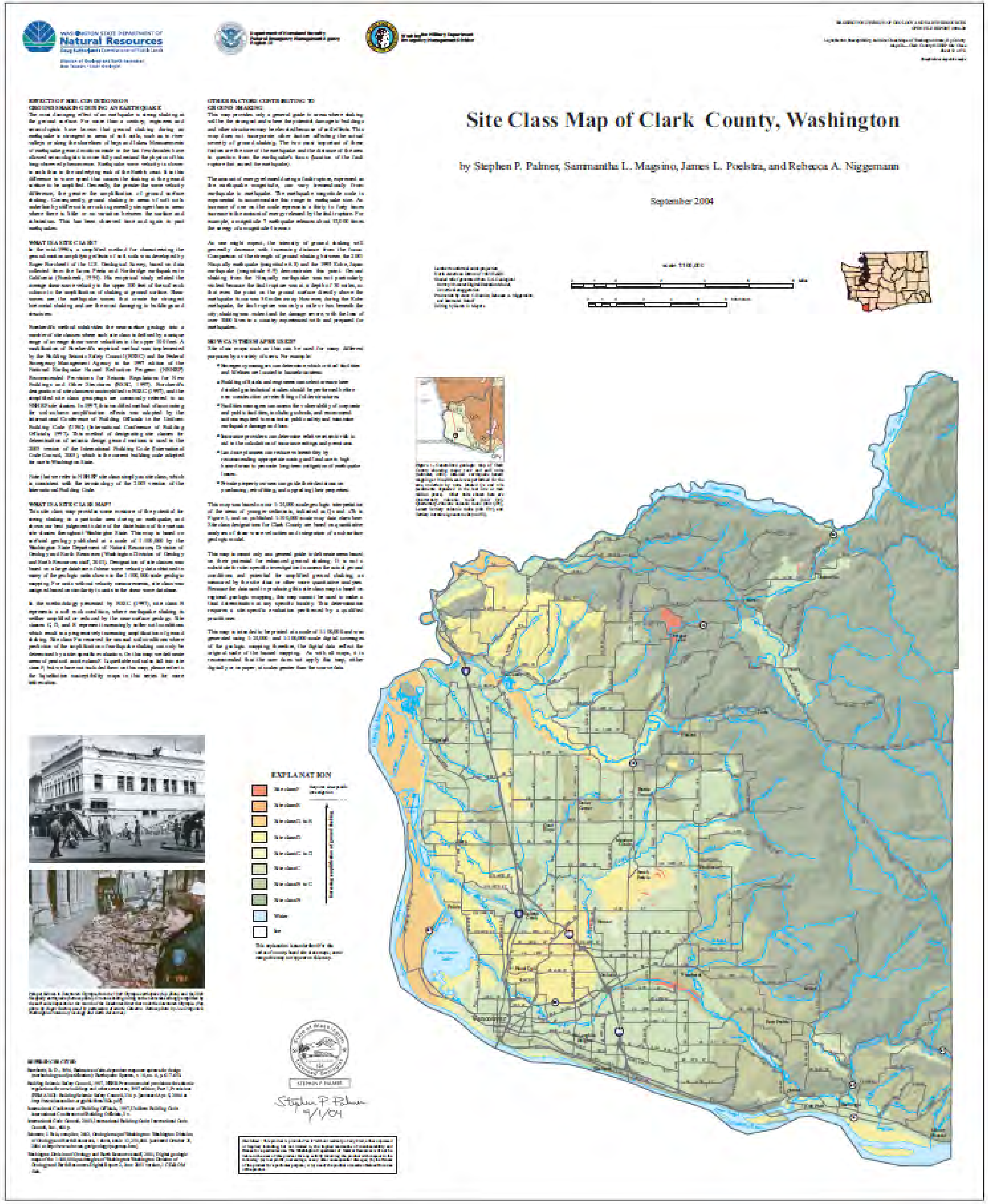


GROUND RESPONSE: LIQUEFACTION



GROUND RESPONSE: SEISMIC SITE CLASS

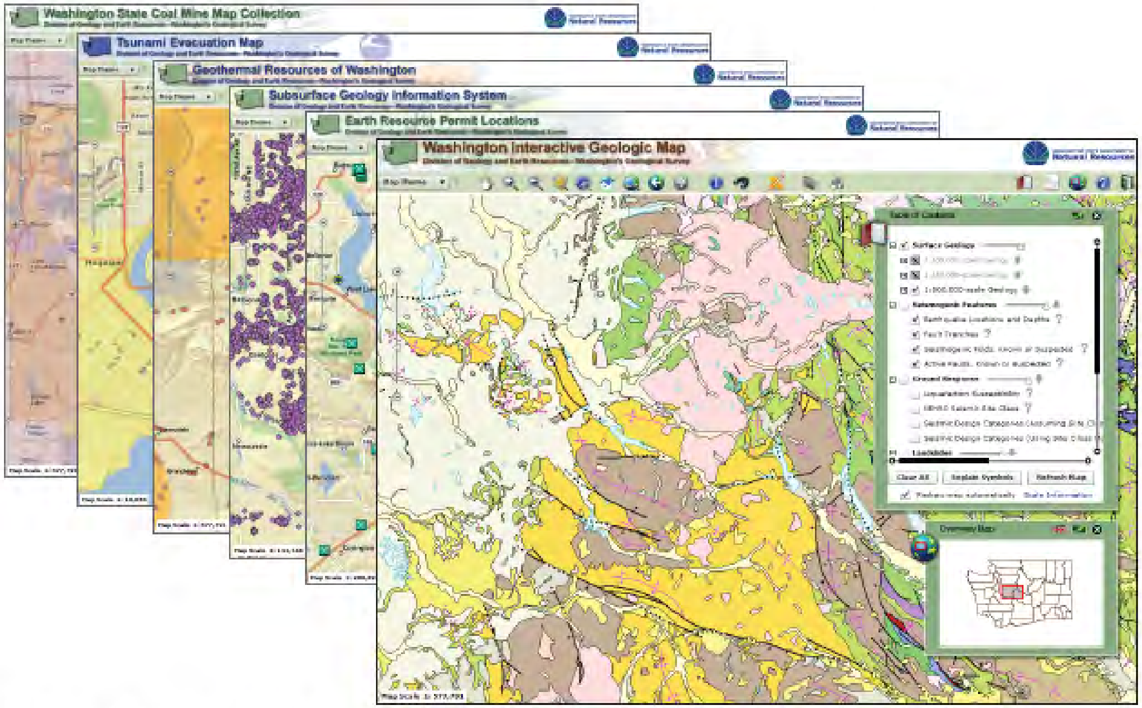




Regardless of the type of earthquake, liquefaction susceptibility and ground shaking amplification maps can help assess local hazard and vulnerability. These need to be used in conjunction with the National Seismic Hazard map.

ftp://ww4.dnr.wa.gov/geology/pubs/ofr04-20/ofr2004-20_sheet12_clark_nehrp.pdf

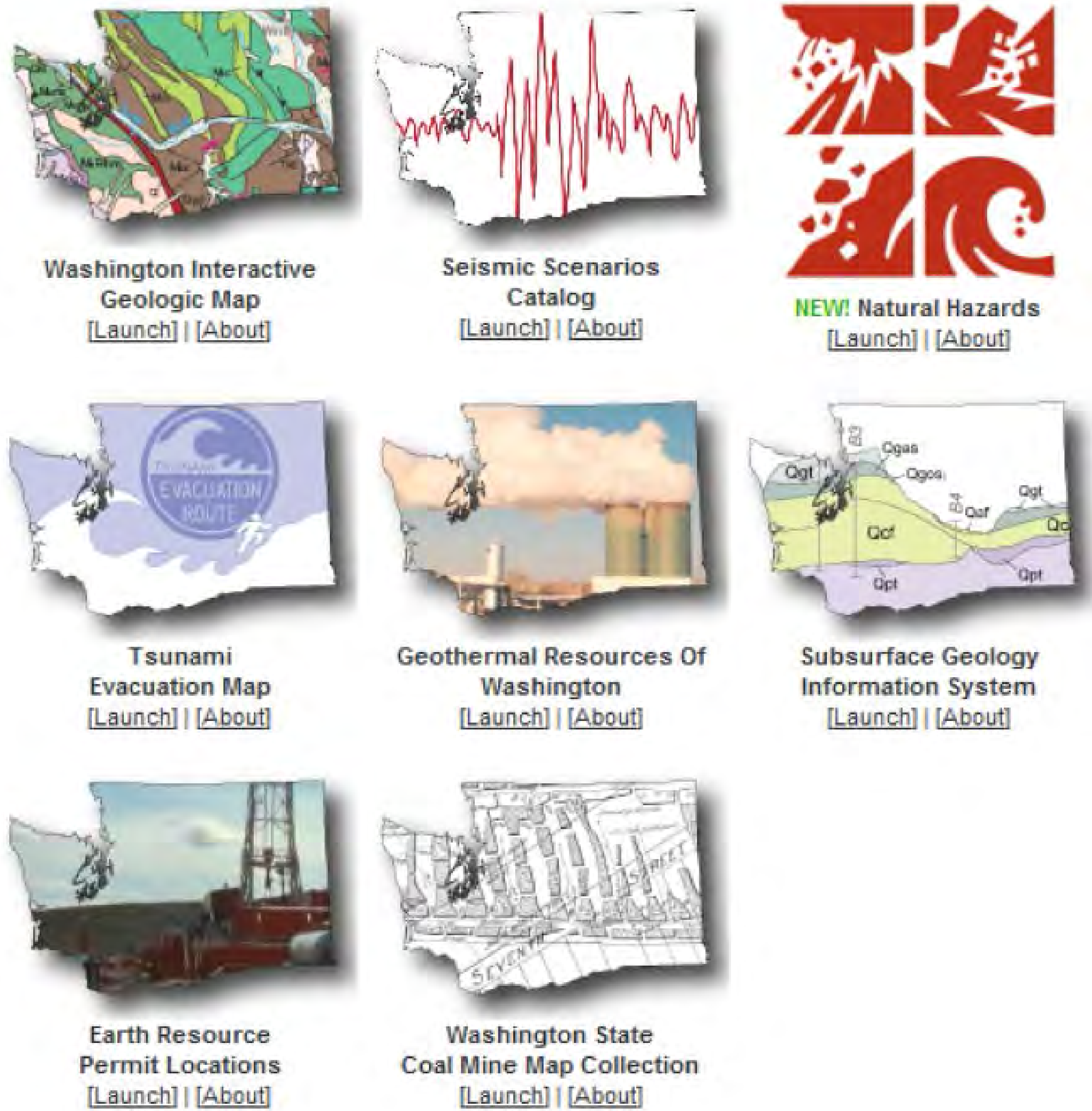
The Washington State Geologic Information Portal

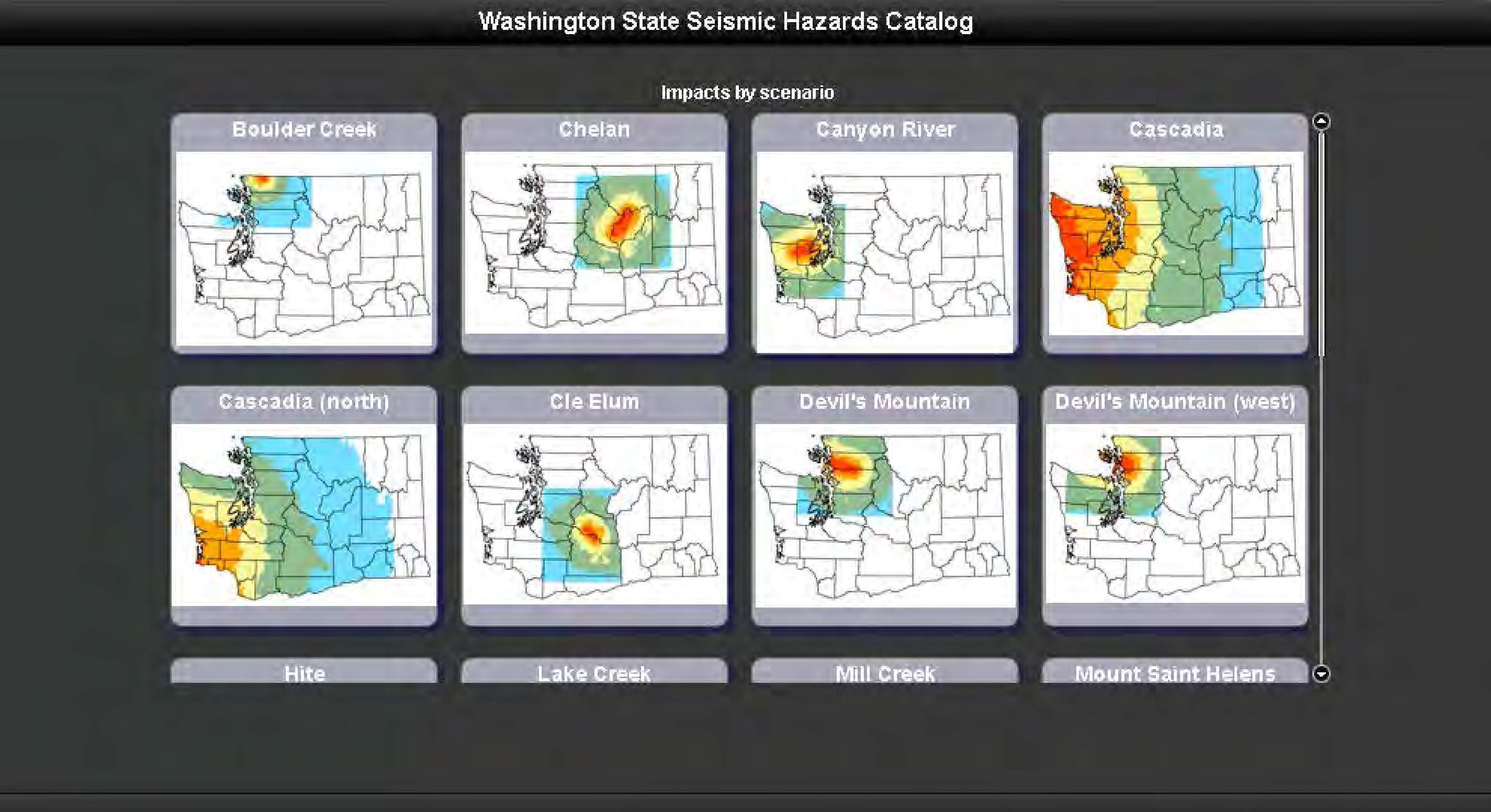


The Portal's interactive map themes can be laid over a geographic base map with roads, towns, etc. Access the Geologic Information Portal at http://www.dnr.wa.gov/geologyportal.

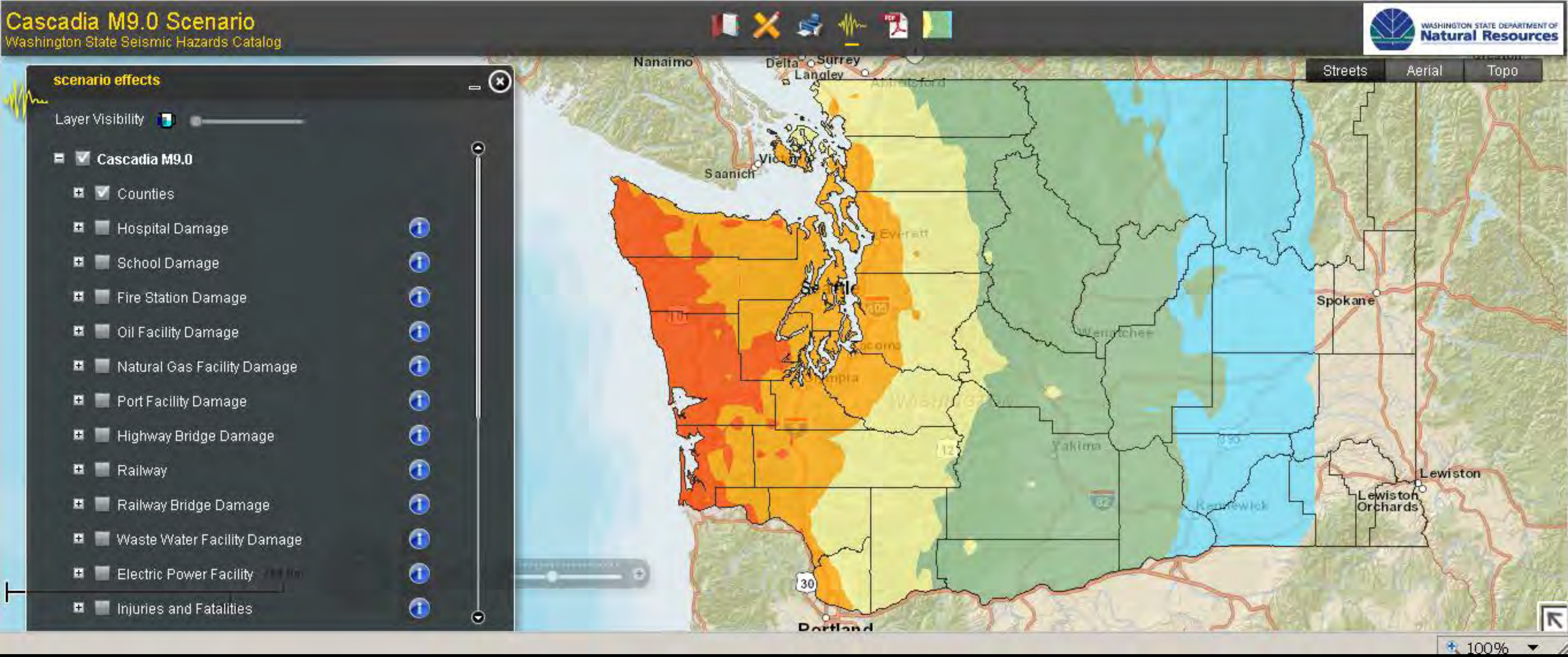
www.dnr.wa.gov/geologyportal

- The interactive map application allows you to choose which layers to overlay.
- The application currently has different map themes, each of which can be accessed through the mapping application itself.

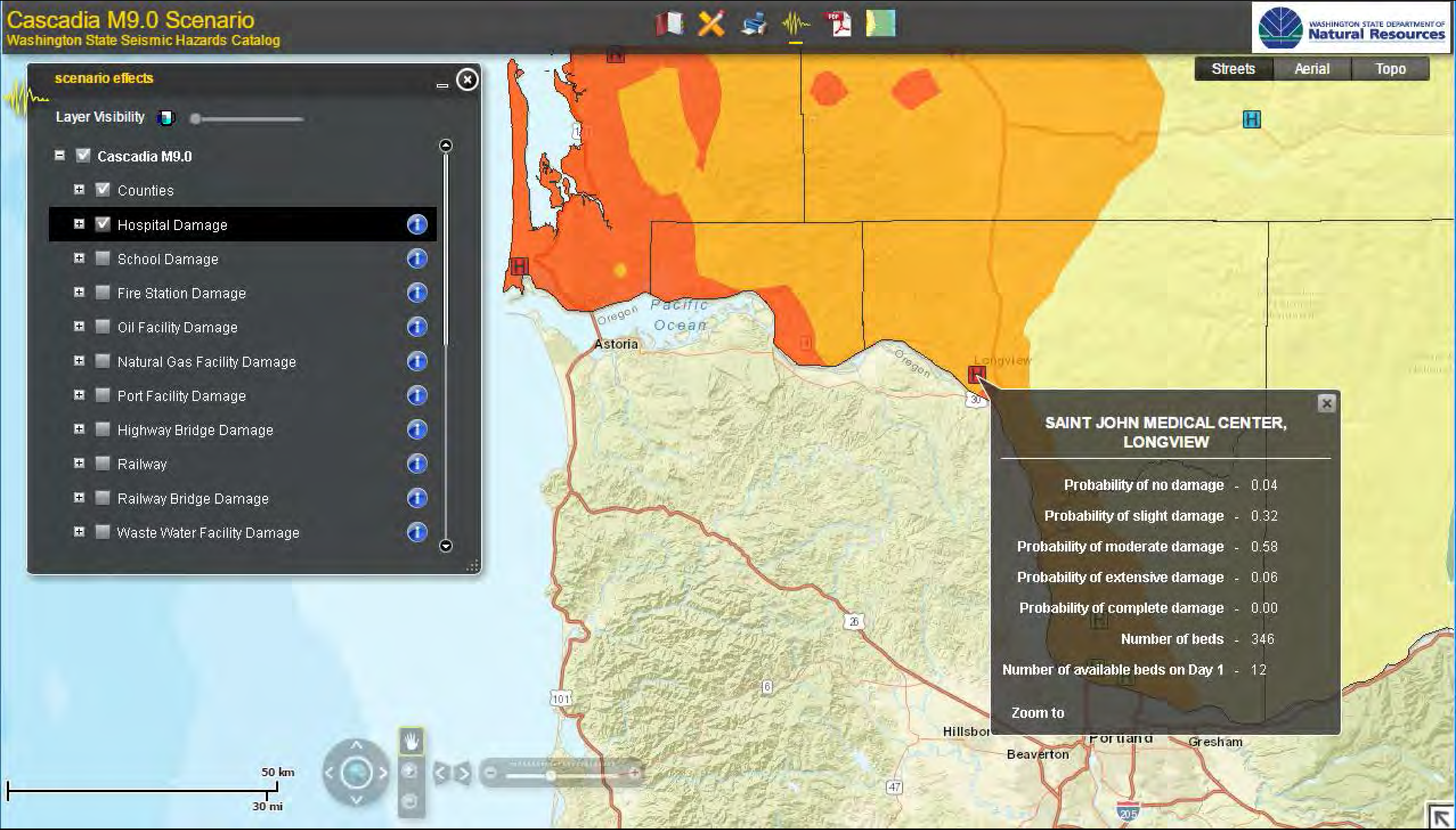




We have developed a seismic scenario catalog that allows every part of the state to investigate the scenario that is likely to be its most damaging.

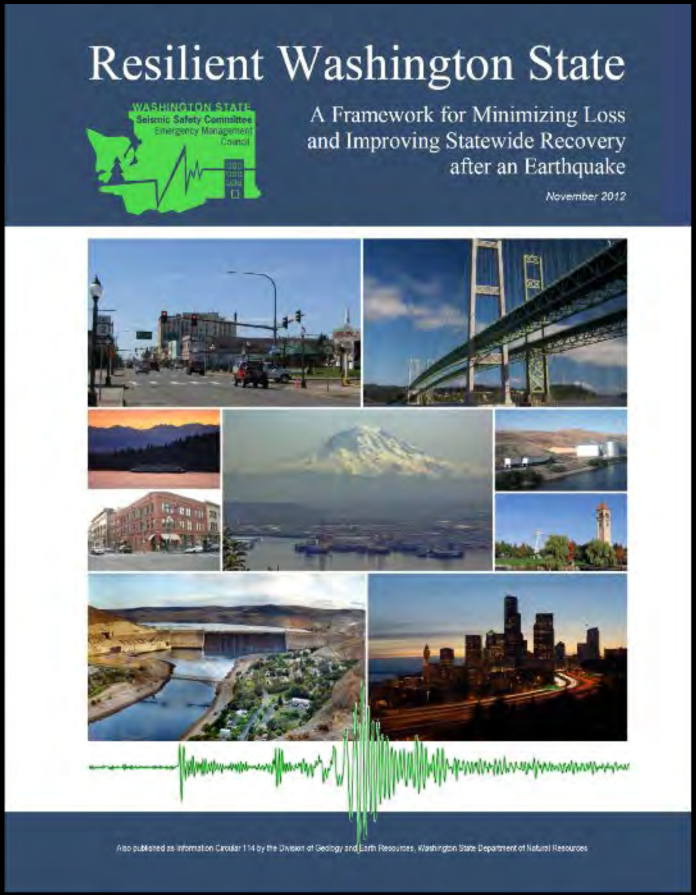


For your area, this is most likely to be a magnitude 9 earthquake on the Cascadia subduction zone

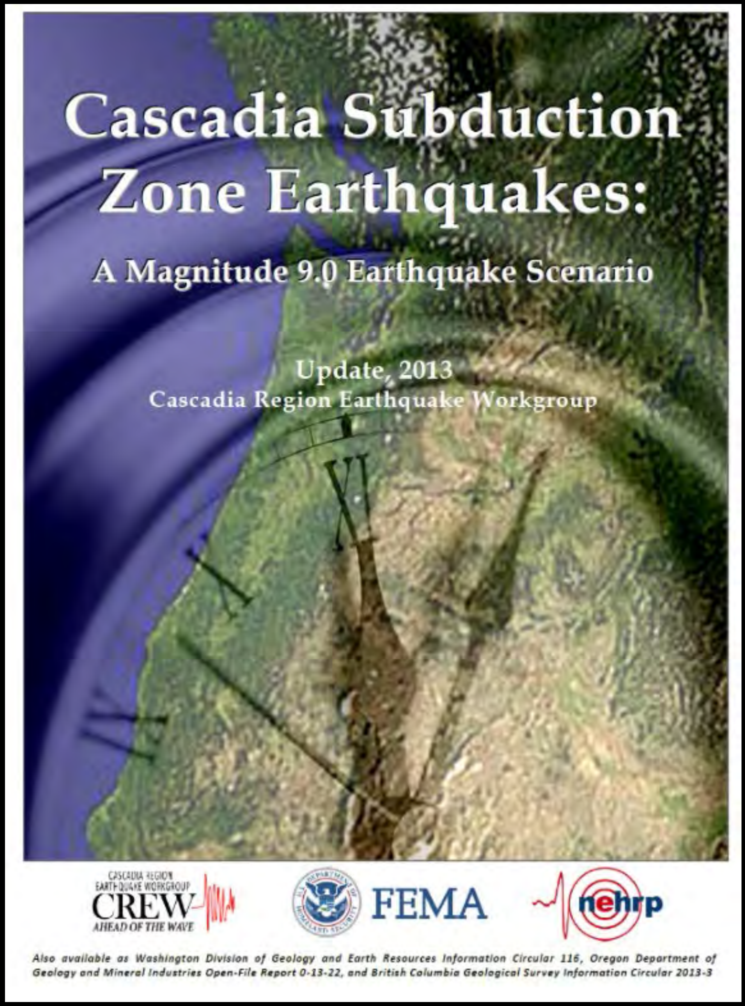


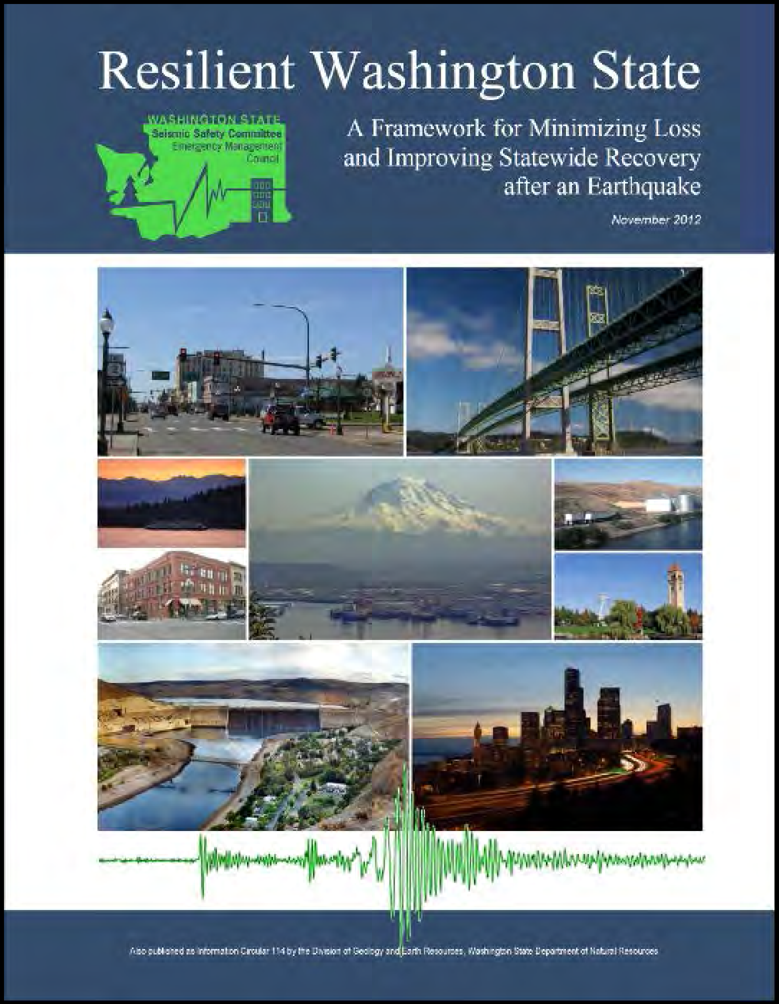
You can look at the Hazus estimates for likely damage to any other infrastructure element in the Hazus inventory

Recently, the Washington Seismic Safety Committee completed a long-range plan to improve our ability to recover from and thrive after an earthquake of statewide significance.



www.dnr.wa.gov/Publications/ger_ic116_csz_scenario_update.pdf





www.dnr.wa.gov/Publications/ger_ic114_resilient_washington_state.pdf

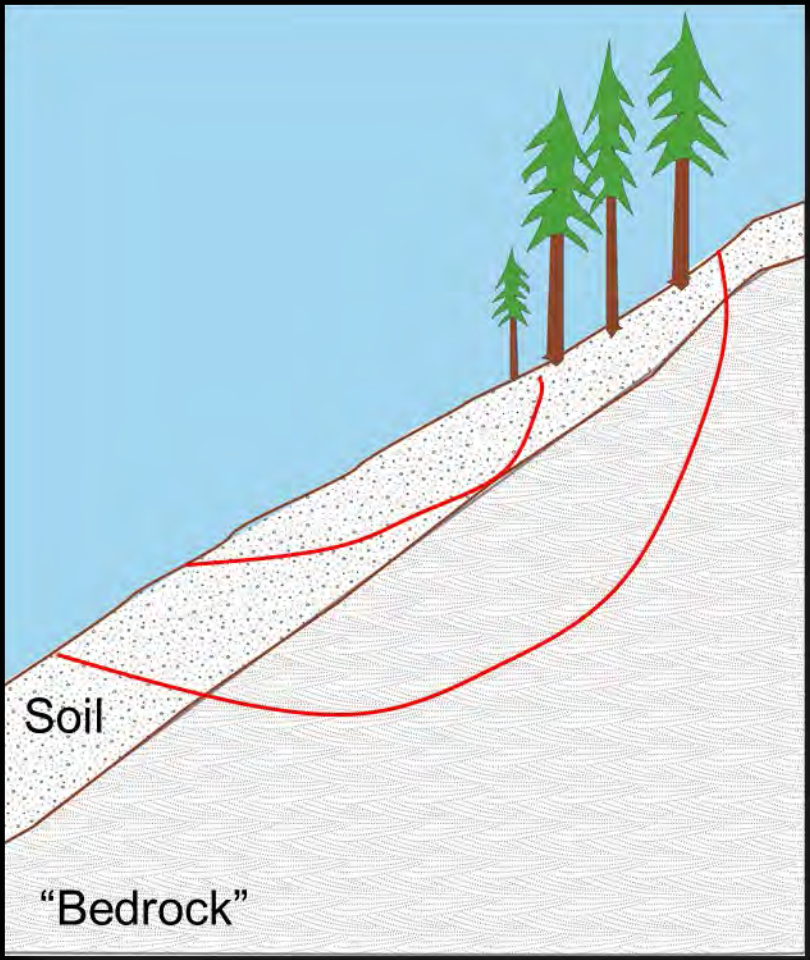
And we assess geologic hazards and assist communities with hazard mitigation

- Earthquakes
- Tsunamis
- **Landslides**

And I saw my reflection in the snow covered hills
Till the landslide brought me down
-Fleetwood Mac

The landslides responsible for most significant damage in Washington are generally either

- Slow moving, deep-seated (bedrock) landslides
- Rapid and shallow (soil/colluvium) landslides



WHAT'S SO IMPORTANT ABOUT LANDSLIDES?

- Landslides are the most poorly understood geologic hazard
  - People are surprised by landslides
- Internationally, between 2004-2010, 2620 fatal landslides killed a total of 32,322 people (Petley, 2012)
  - Excludes seismically-induced landslides
- US doesn't keep statistics on landslides
  - In Washington, the average annual loss from landslides is >>$20 million

- Landslide damage is particularly costly to local government
- All geologic hazards can be insured...
  - Except landslides/earth movement
  - Litigation is often the only recourse left to those with landslide-damaged property



LANDSLIDE TRIGGERS

- Deep-seated
  - Tend to have a delayed response to climatic events
  - Generally triggered by the accumulation of rainfall over weeks or years
- Shallow landslides
  - Tend to respond quickly to climactic events
  - Occur during large storms and may accompany major floods
- Either can be triggered by earthquakes

- Kumamoto earthquake, Japan
- April 16, 2016
- M7.0, 6 mile depth
- >400 aftershocks
- “numerous” landslides


航測株式会社
Image: akiko.co.jp


Image: AP

Image: akiko.co.jp


Image: Asia One

SIGNIFICANT LANDSLIDE EVENTS

- Storm-related, shallow-landslide events
  - 1981-82, 1984, 1996, 1997, 2006, 2007, 2009, and 2015
- Named deep-seated landslides
  - Aldercrest-Banyan, Carlyon Beach, Rock Creek, Ledgewood, Hazel, SR530 “Oso”, Nile, Sunset Falls, etc.

PERKINS LANE LANDSLIDE, 1997

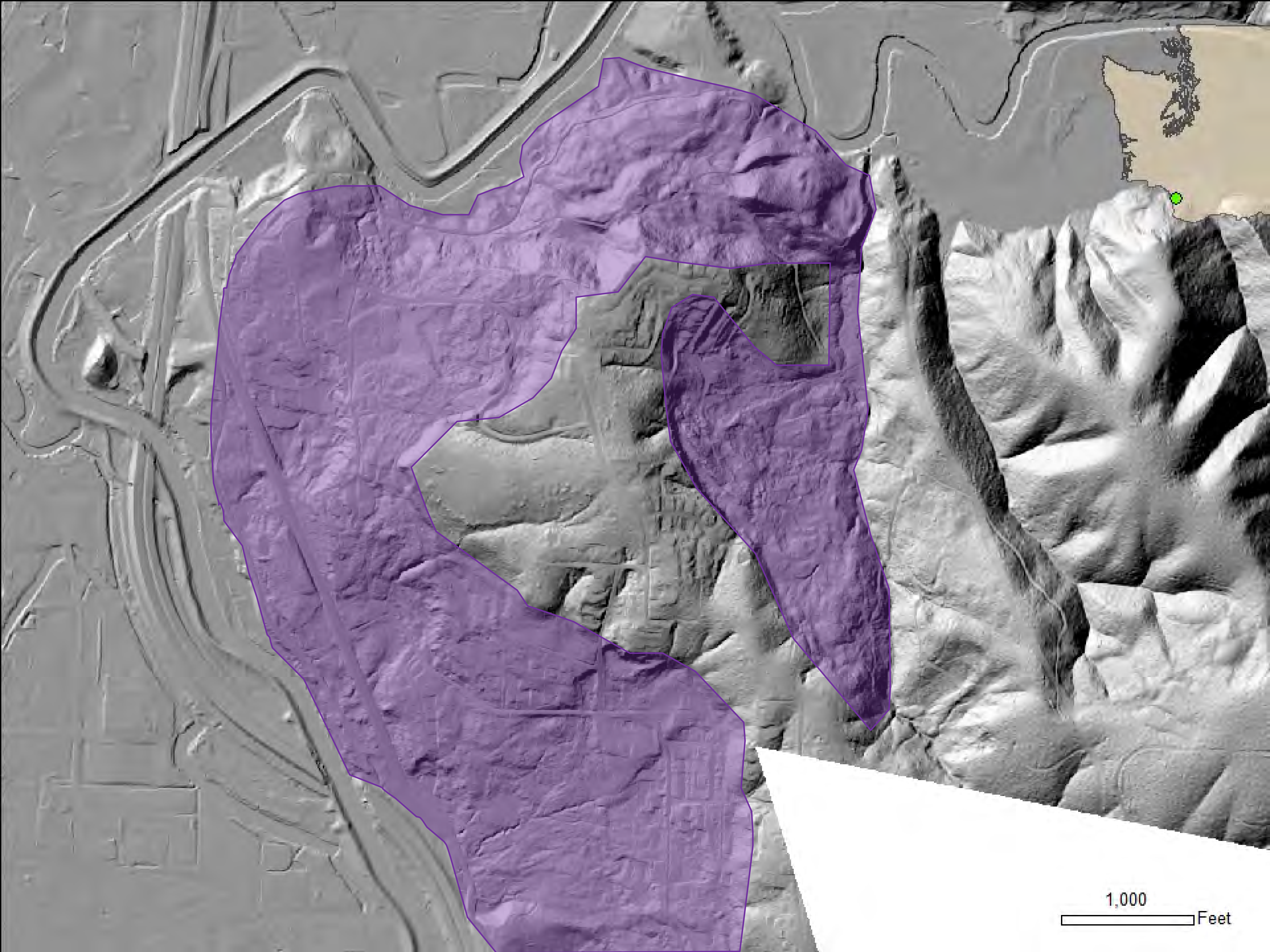
Reactivated deep-seated landslide in the Magnolia District of Seattle claimed five houses

Rolling Bay, Bainbridge Island, 1997

Tragedy struck on January 19, 1997 when a shallow landslide crushed the Herren home, killing all four family members

Aldercrest-Banyan landslide, 1998

Two years of above-average rainfall reactivated a deep-seated landslide and destroyed 135 homes. FEMA buyouts at $0.30 to the dollar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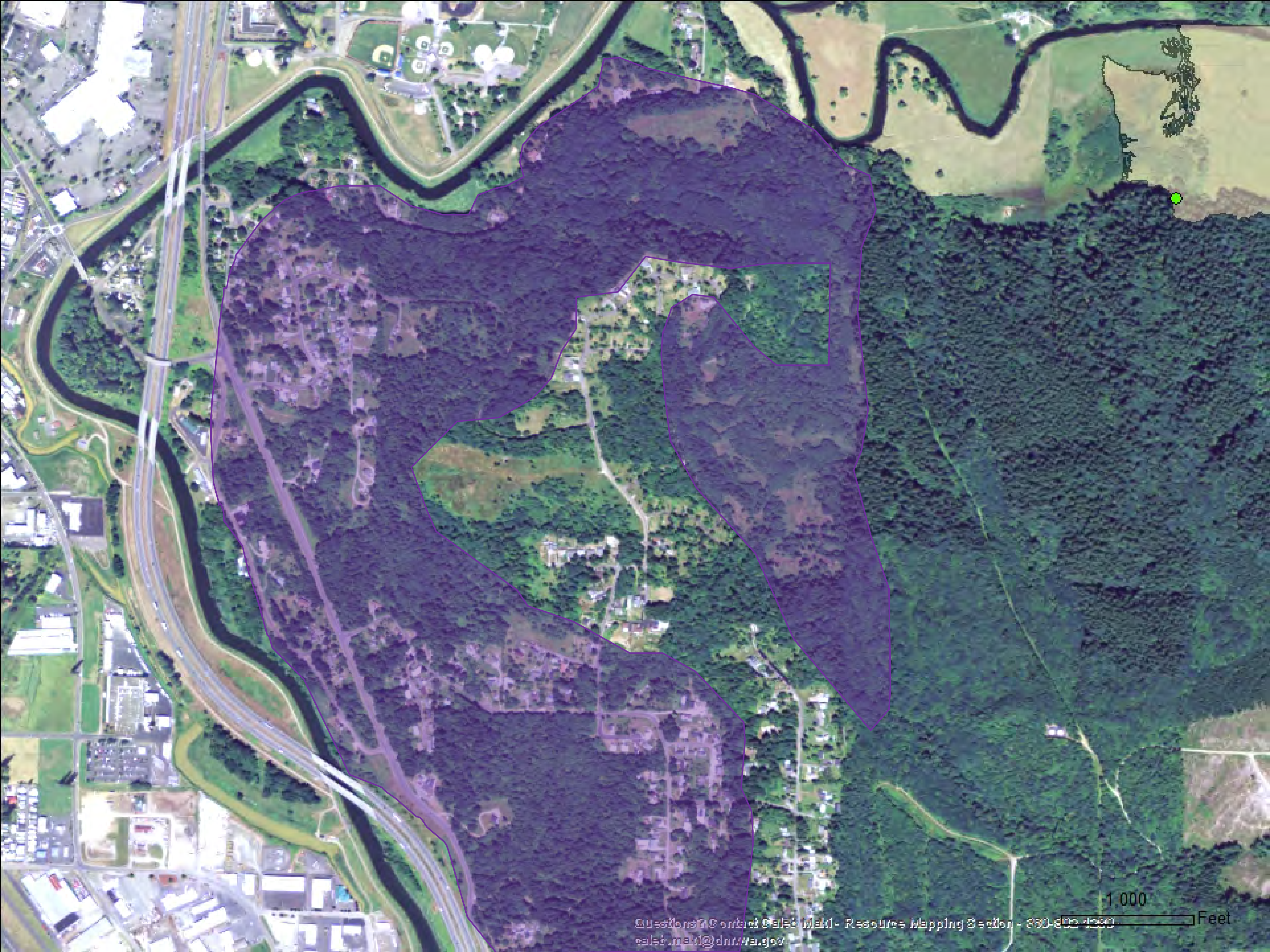
1,000
Feet
Questions? Contact Caleb Maki - Resources Mapping Section
caleb.maki@dnr.wa.gov


~75 feet


3 18 99


Carlyon Beach Landslide

February 1999, after 3 years of above-average rainfall, movement began on a dormant landslide, forcing 36 families from their homes. No buyouts.


1,000
Feet


1,000
Feet
Questions? Contact Caleb Maki - Resource Mapping Section
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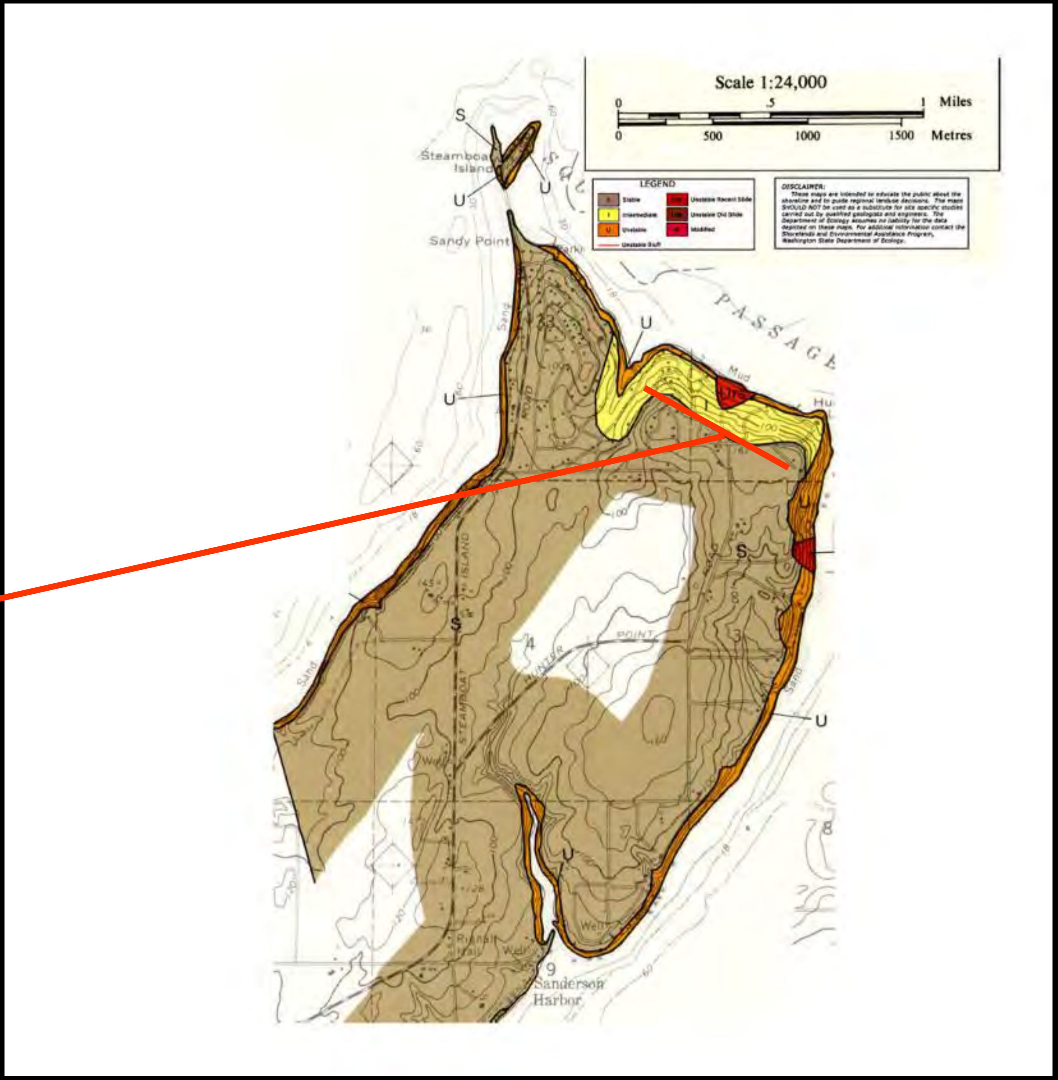
Coastal Zone Atlas, Carlyon Beach

Slope stability map of the Carlyon Beach area, Thurston County (near Olympia), 1980



Carlyon development

Mapped as intermediate to unstable terrain

December 2007, following an intense rain-on-snow event several thousand landslides occurred throughout SW Washington

October 11, 2009 a portion of the Stanford Pasture Landslide reactivated, destroying ¼ mile of SR410, rerouting the Naches River, and forever changing the Nile Valley community

0.5
Miles
410

Over 1000 landslide were triggered in January 2009 due to a Pineapple Express

These houses in Whatcom Co. were damaged by debris flows

Whidbey Island, 2013

March 2013 landslide destroyed one home, two others red-tagged, and cut off access to 13 more homes.

Minor movement continues today, rendering it unsafe to stabilize the temporary road providing limited access to the affected homeowners

And SR530 “Oso” landslide on March 22, 2014

Image: Jay Inslee

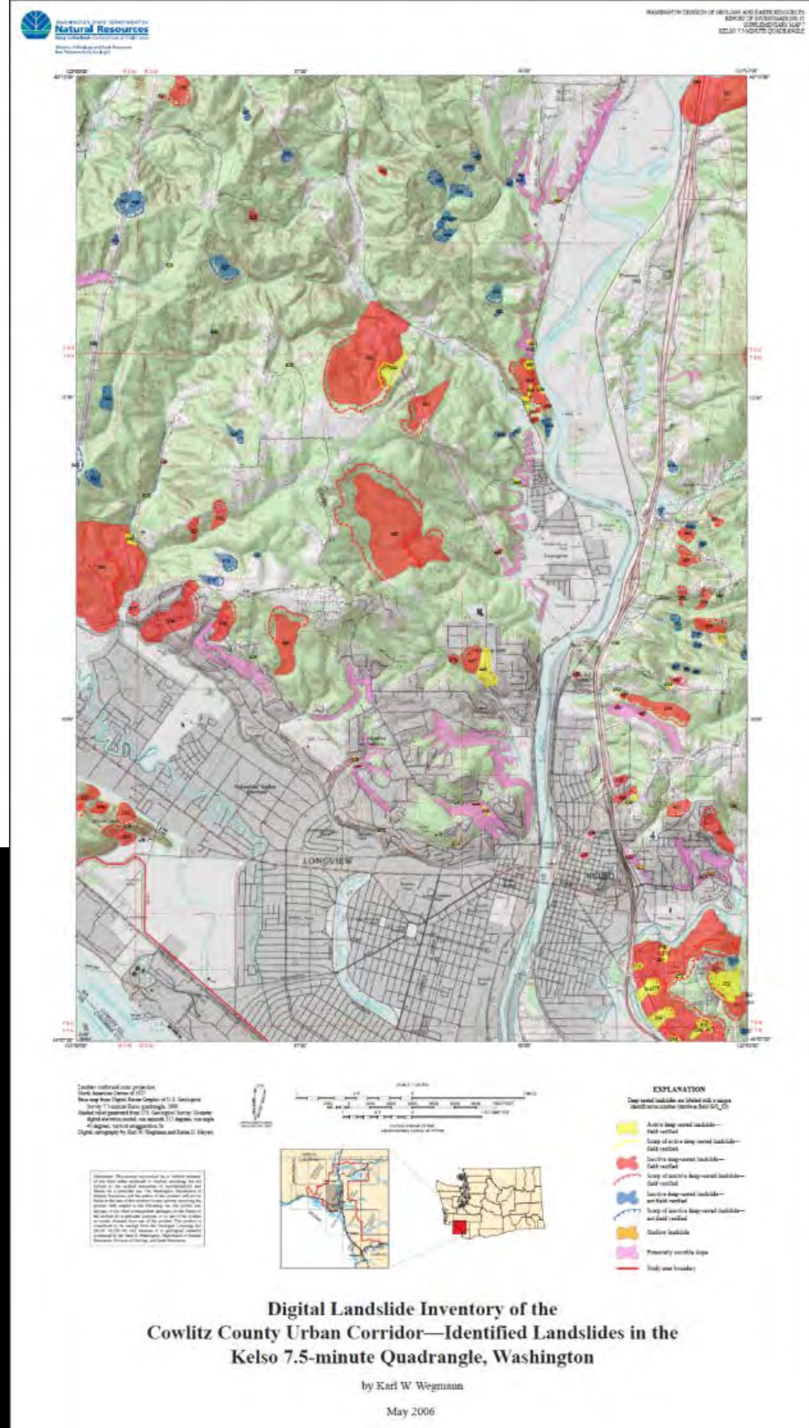
Digital Landslide Inventory for the Cowlitz County Urban Corridor, Washington

by Karl W. Wegmann

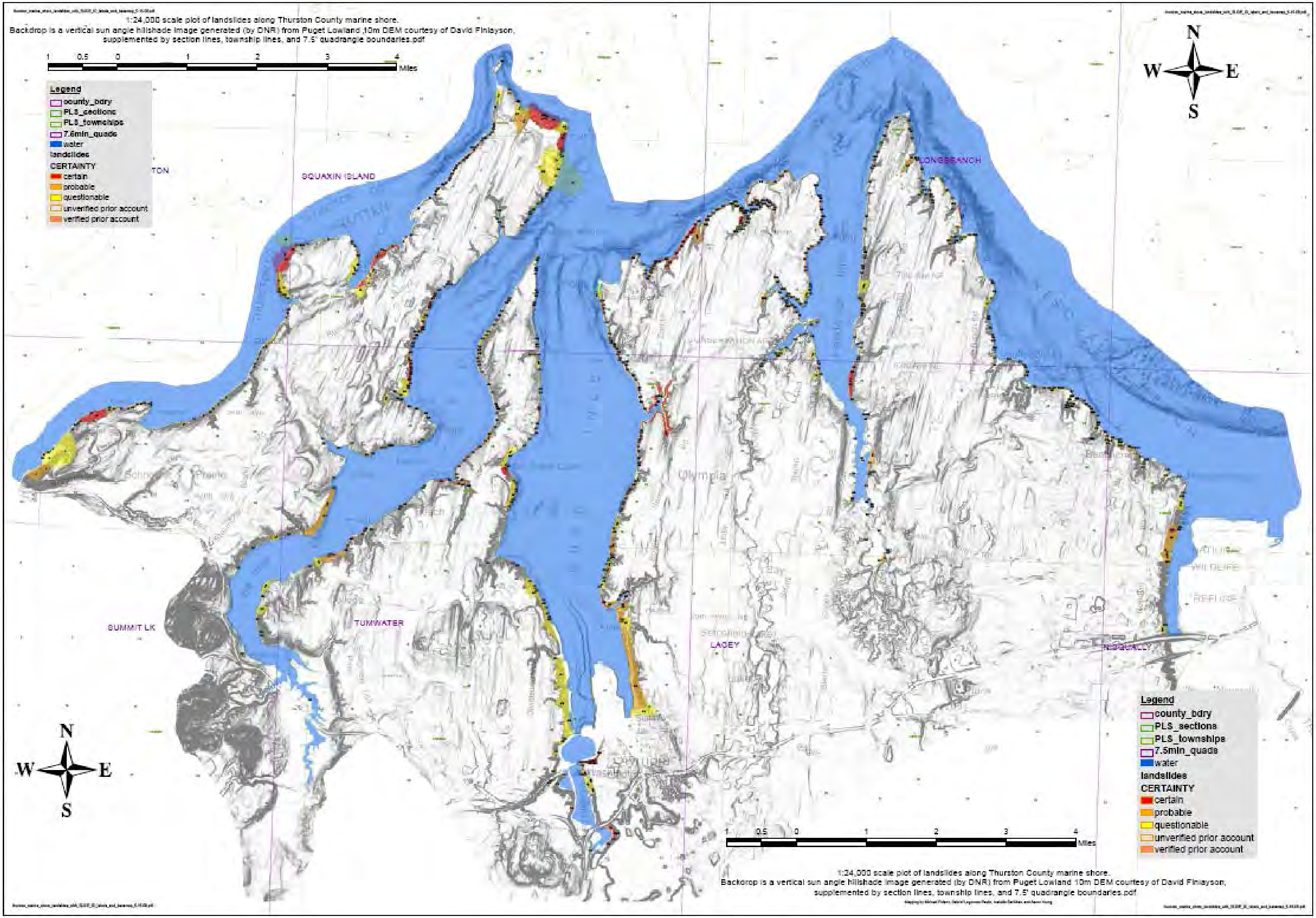
WASHINGTON
DIVISION OF GEOLOGY
AND EARTH RESOURCES

Report of Investigations 35
version 1.0
May 2006

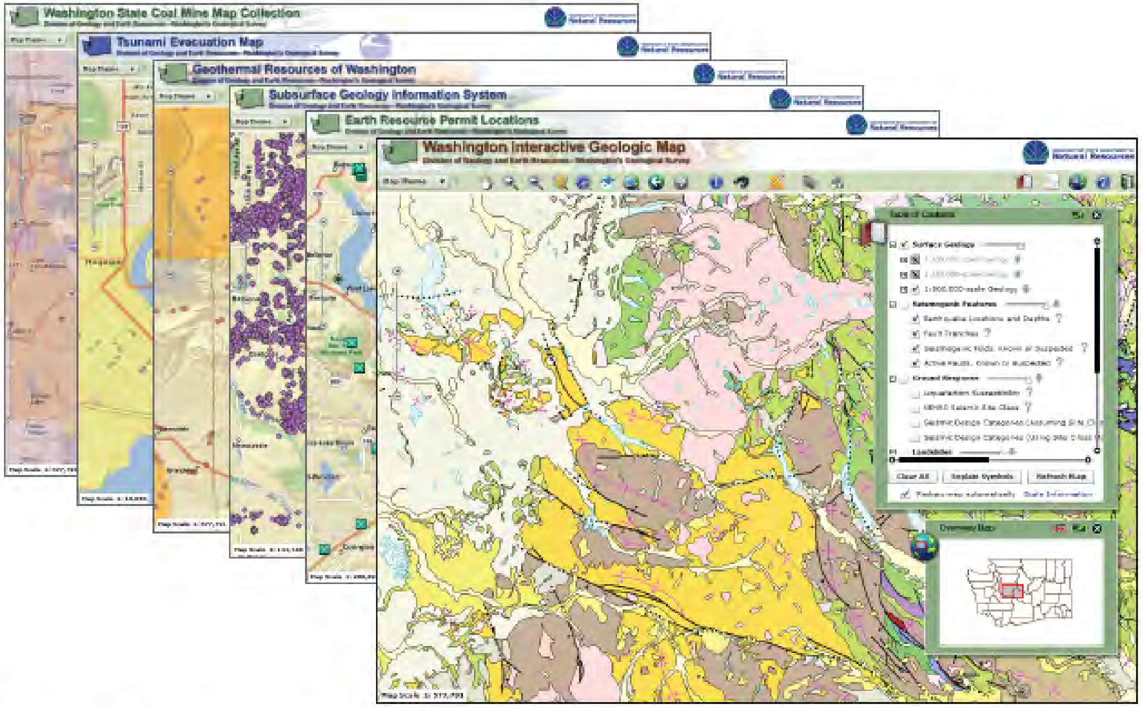
What tools are available for planners to mitigate landside hazards? Unfortunately, the availability and quality are uneven.



Puget Sound coastal bluff landslide hazard maps for Thurston Co.



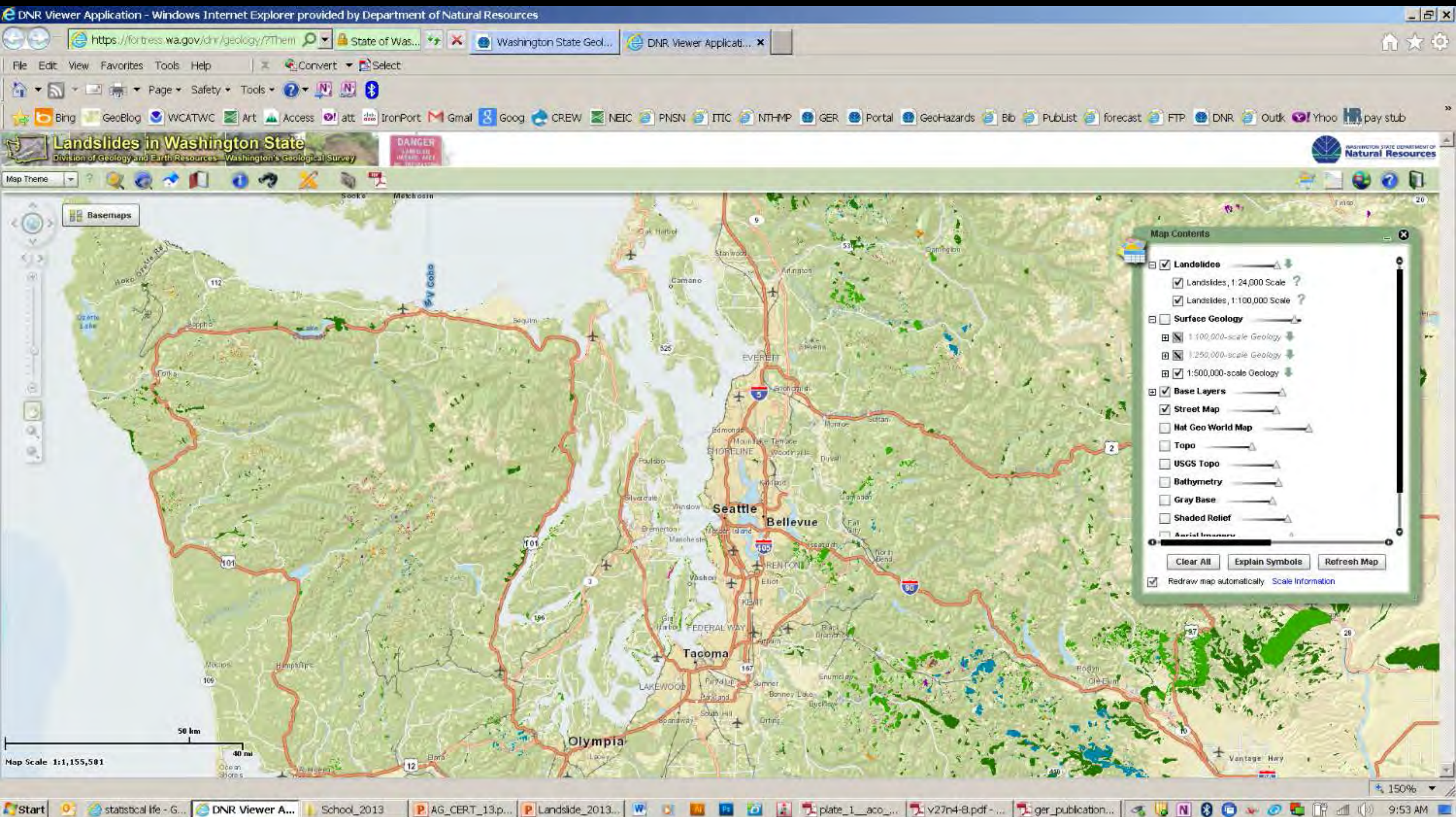
The Washington State Geologic Information Portal

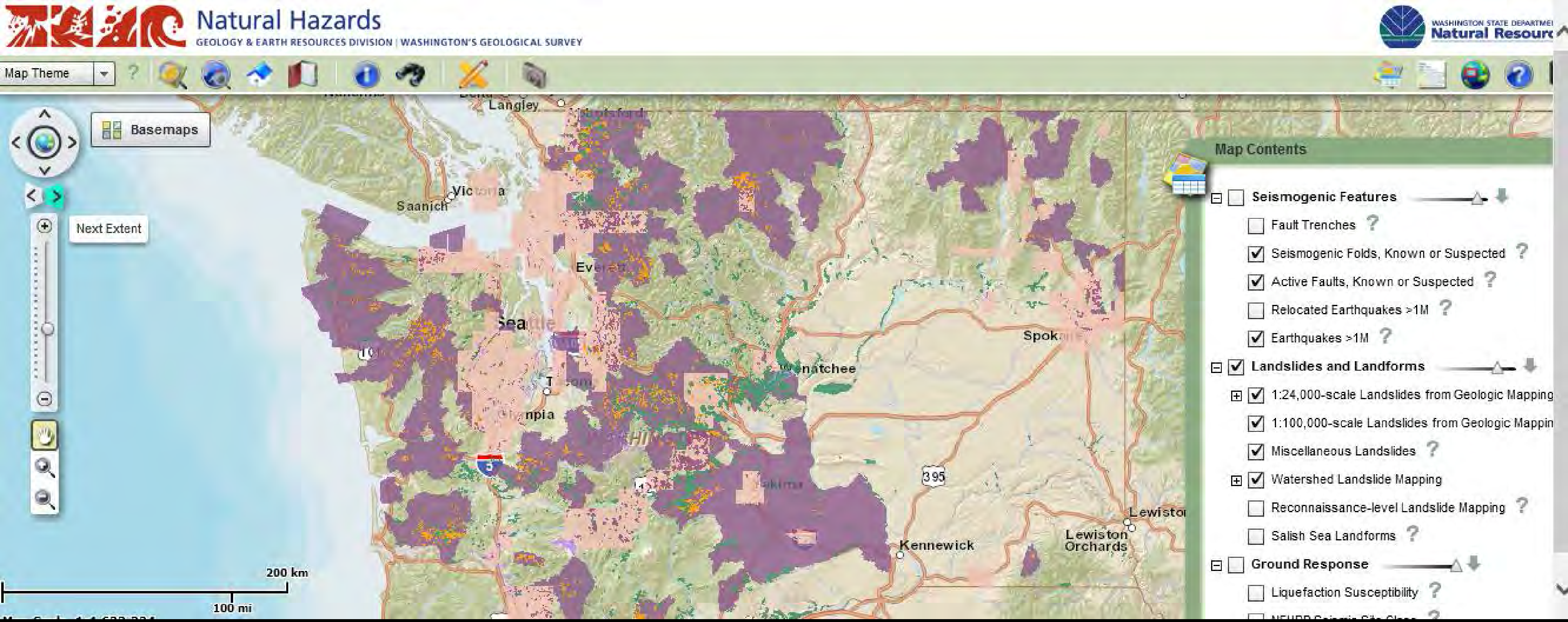


The Portal's interactive map themes can be laid over a geographic base map with roads, towns, etc. Access the Geologic Information Portal at http://www.dnr.wa.gov/geologyportal.

www.dnr.wa.gov/geologyportal

- Landslide hazard mitigation begins with hazard identification





You can, for instance, look at a map of landslides in the state (though it is a work in progress and definitely incomplete)

DNR LANDSLIDE HAZARDS PROGRAM

- Five landslide hazards geologists
- Emphasis is landslide mapping around population, infrastructure, highways
- Inventory, susceptibility, hazard, and vulnerability mapping

AFTERTHOUGHTS…

- Washington is susceptible to every major geologic hazard
- Mitigation of the hazard is one method to reduce your risk
- Avoidance of the hazard is the usually the simplest method to eliminate the risk
- DNR offers a suite of tools that identify geologic hazards and is continually developing new tools and products!

stephen.slaughter@dnr.wa.gov
360-902-1498

Thank you

- DNR Division of Geology and Earth Resources (aka: Washington Geological Survey)
  www.dnr.wa.gov/geology
- DNR Washington State Geologic Information Portal
  www.dnr.wa.gov/geologyportal
- Washington Emergency Management Division
  www.emd.wa.gov/index.shtml
- Cascadia Region Earthquake Workgroup
  www.crew.org/
- USGS Landslide Hazards Program
  www.landslides.usgs.gov/