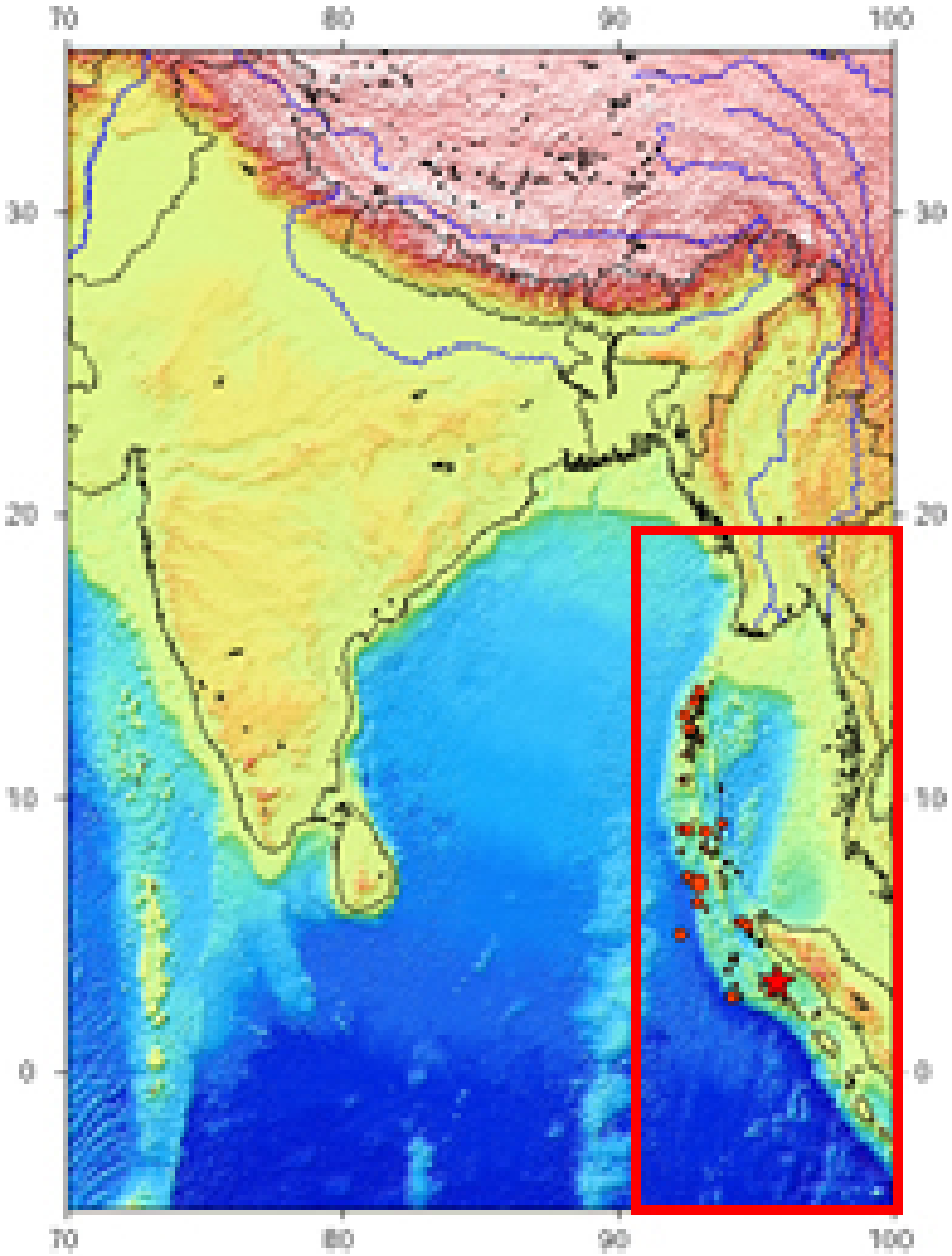
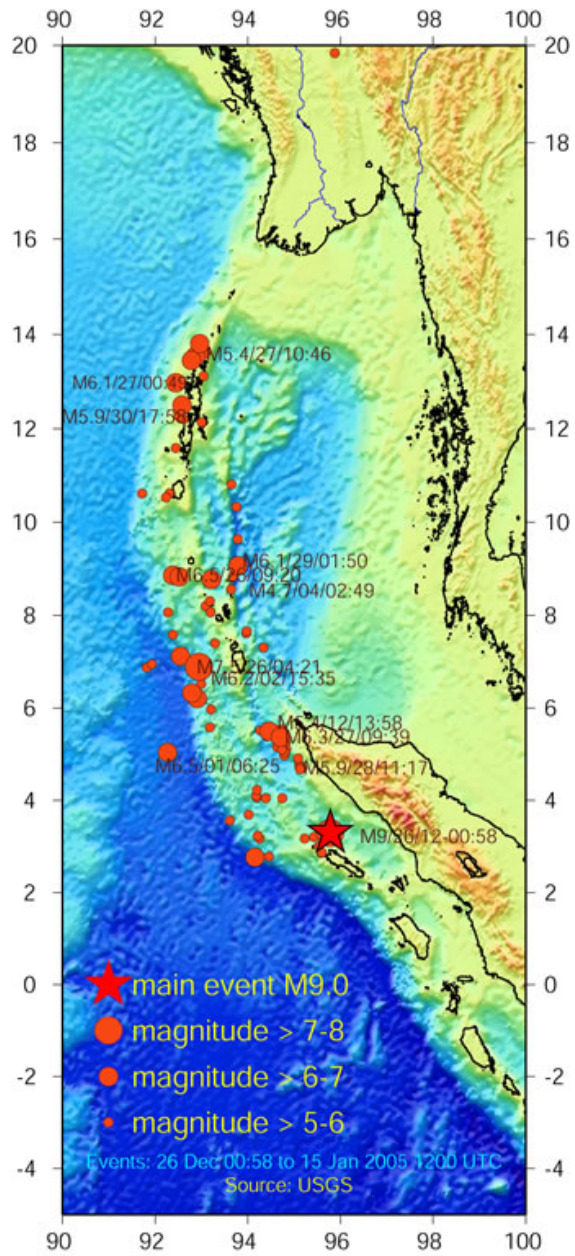
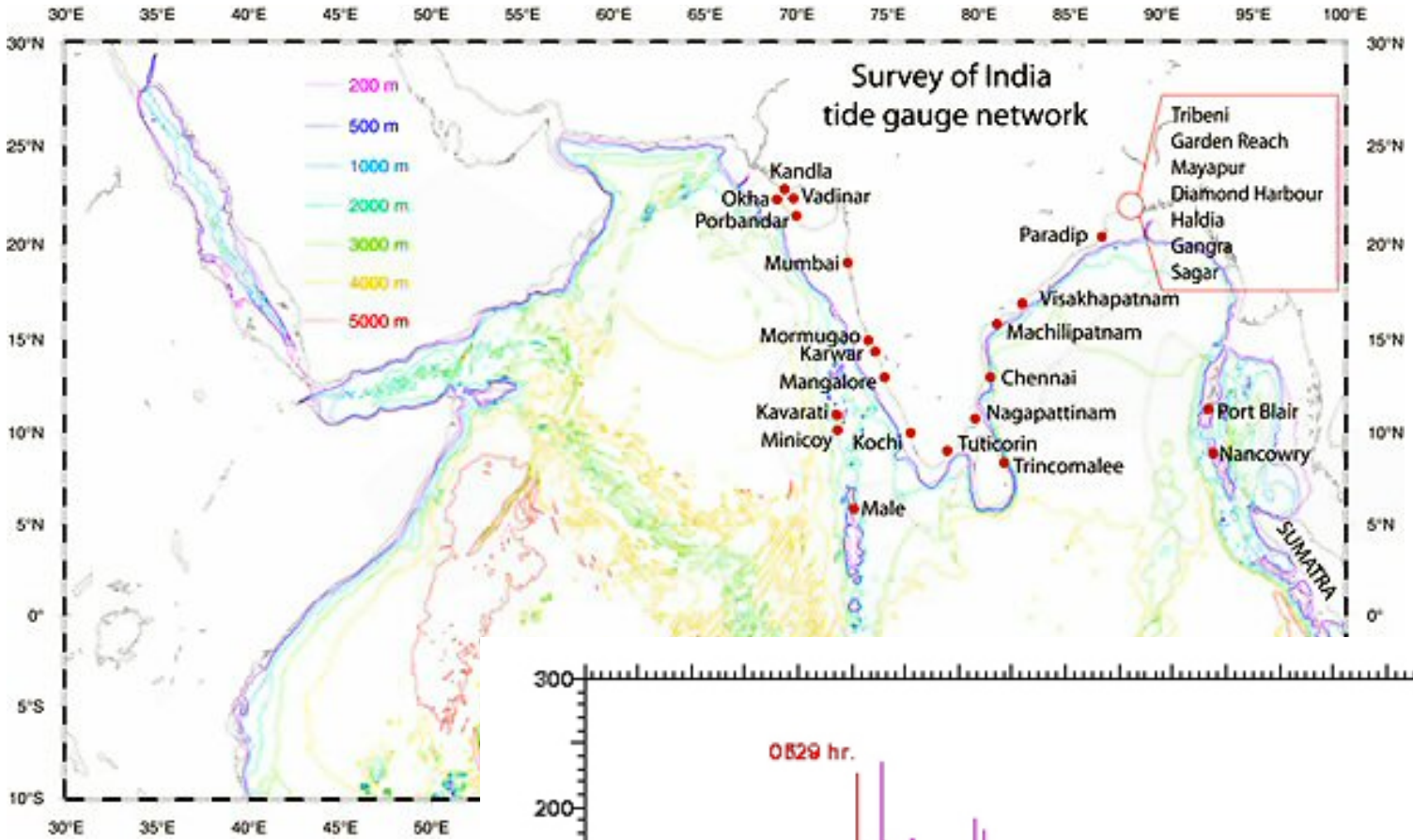
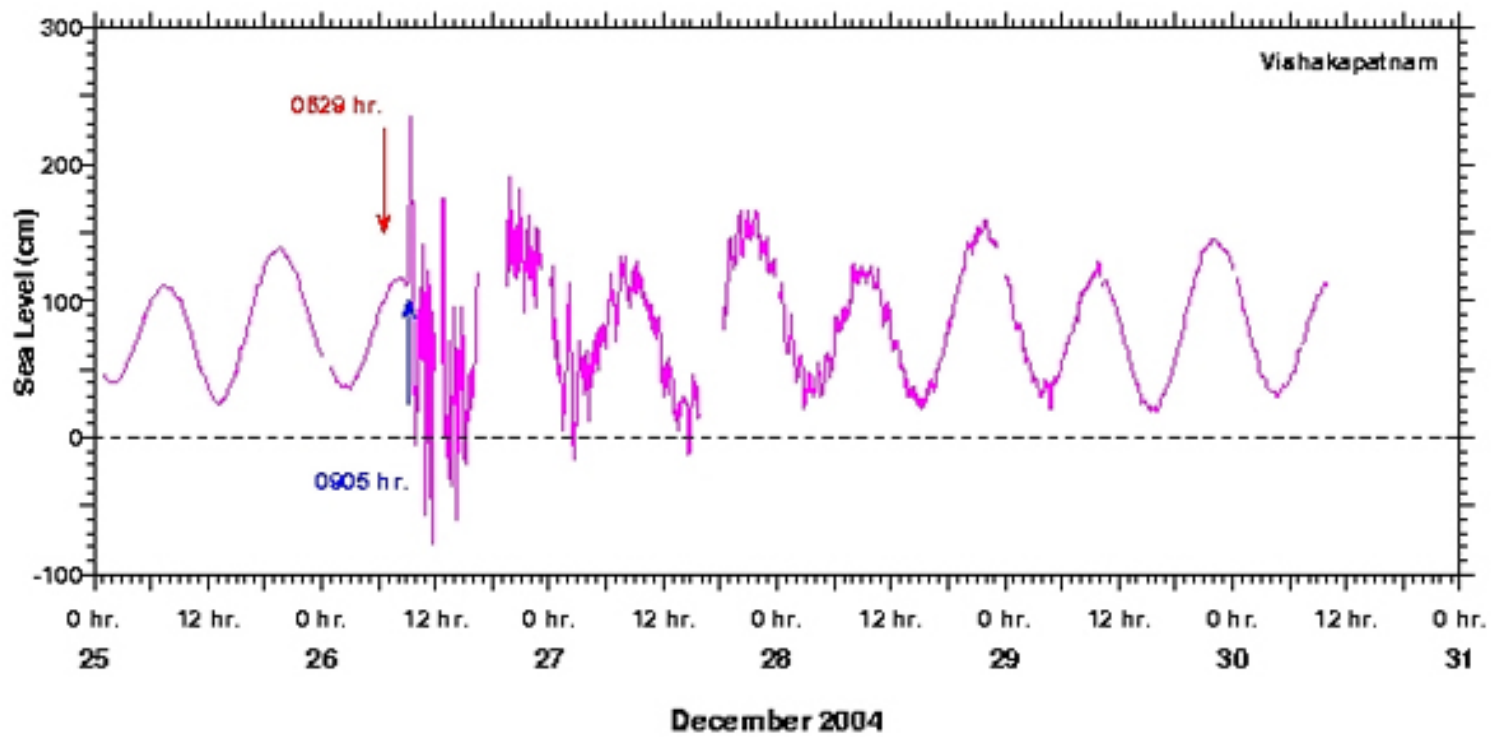
▪Indian Ocean Event 12/26 - 3:59 PM Alaska time

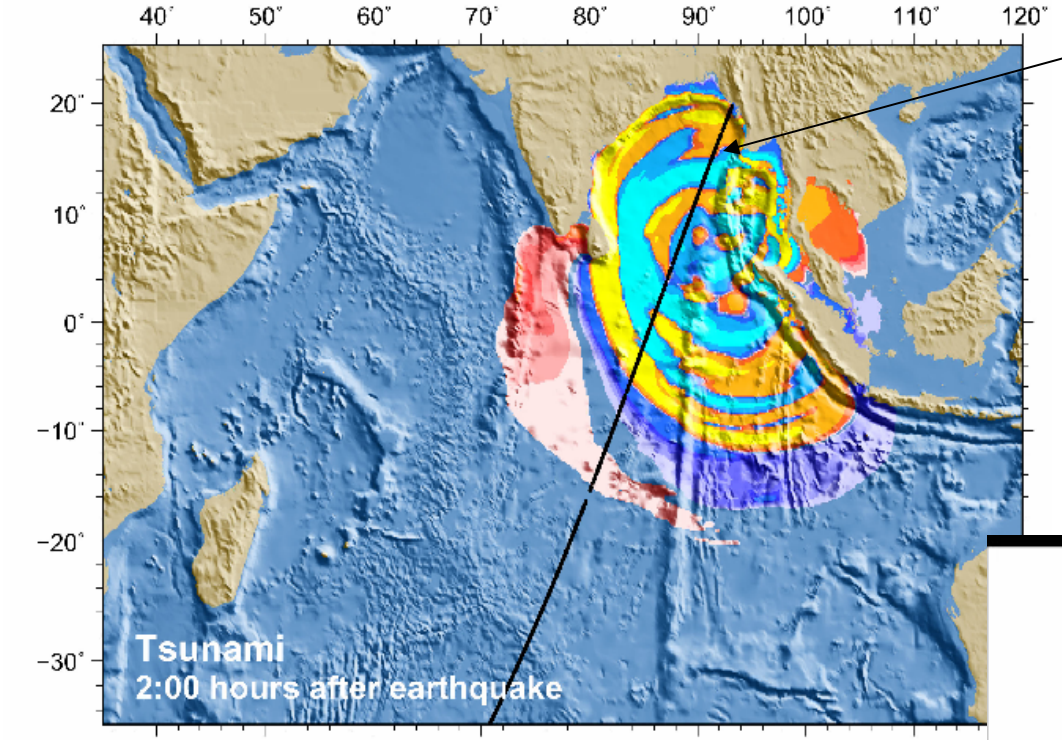


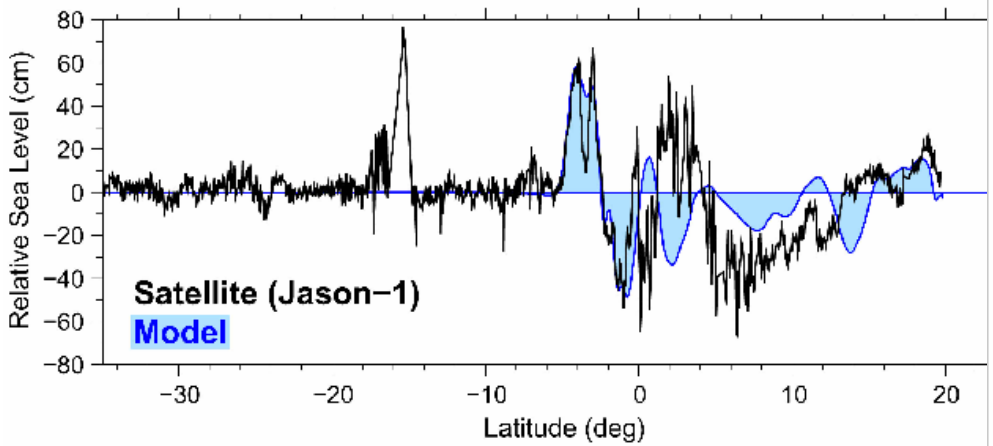




Tide gauges respond during the Indian Ocean Event



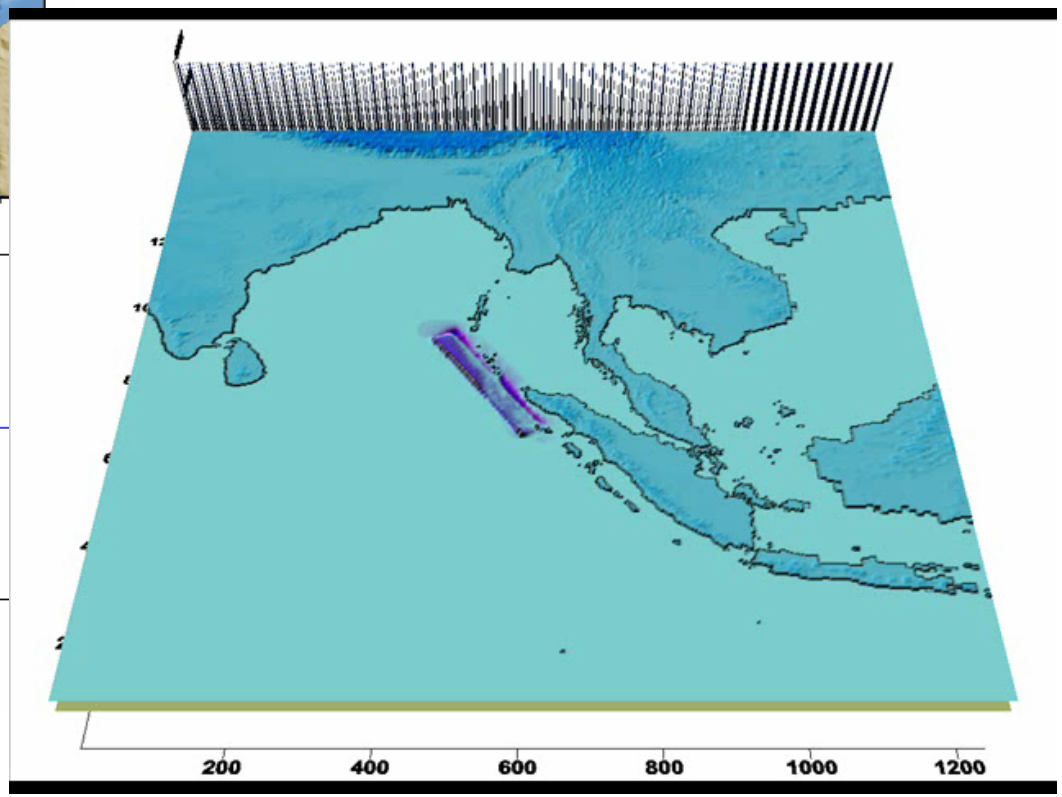




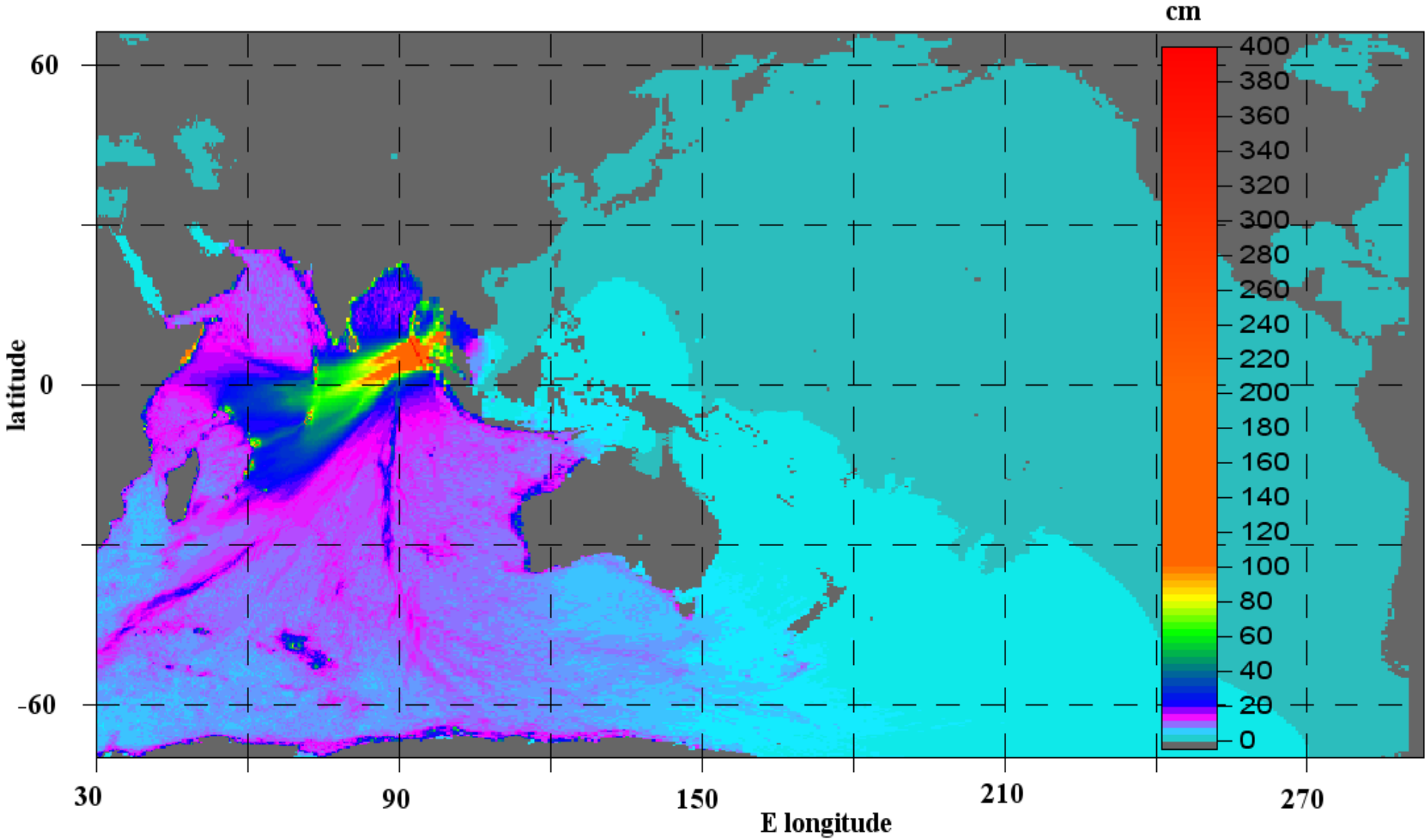
▪ogrish

▪pacific

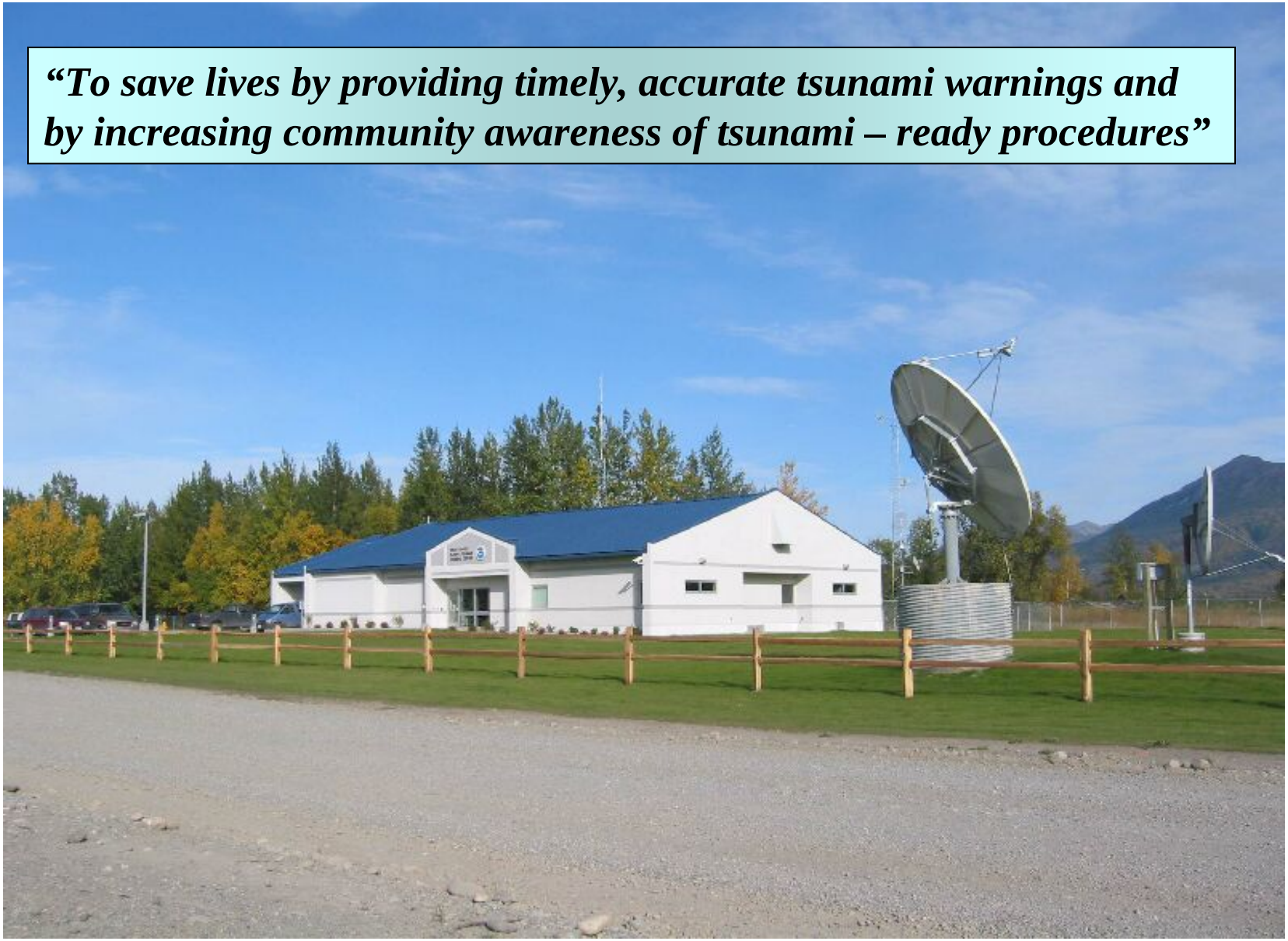
▪**Click on image below, buttons above**



▪Predicted maximum wave height for the Indian Ocean Event



West Coast and Alaska Tsunami Warning Center

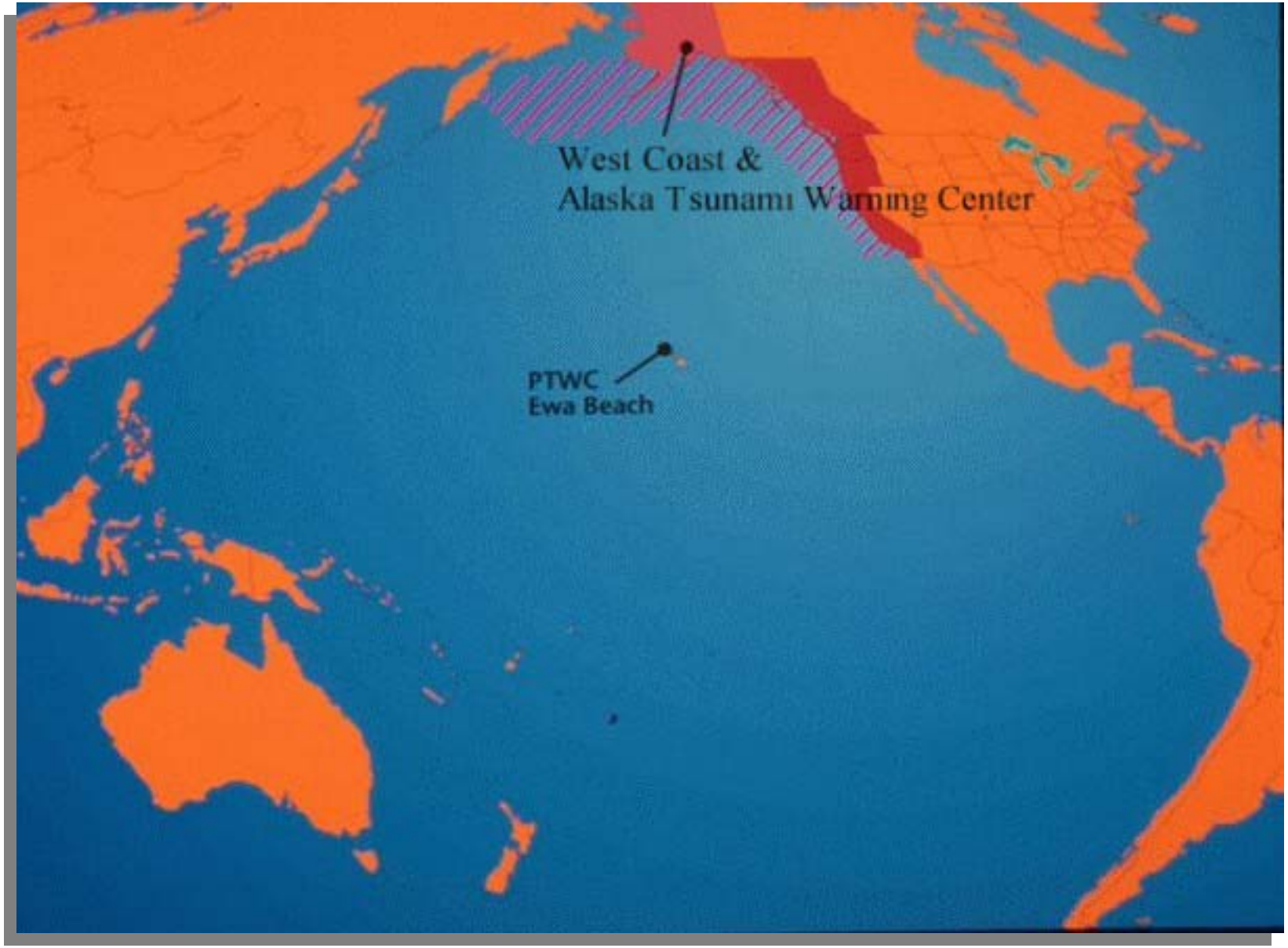


"To save lives by providing timely, accurate tsunami warnings and by increasing community awareness of tsunami – ready procedures"

FACTOIDS

- **Part of the National Weather Service, NOAA, DOC**
- **Established in 1967 – 3 years after the great Alaska earthquake**
- **One of two Tsunami Warning Centers in the U.S.**
  - **WC/ATWC – Palmer, Alaska – AOR is Alaska, BC and West Coast States**
  - **PTWC – Ewa Beach, Hawaii – AOR is Hawaii and International Pacific coasts**
- **Staffed by 4 Scientists and 2 Electronic Technicians**
- **Physically manned 8 hours/day – 6:30AM to 4:30PM**
- **Standby Personnel respond to EQ alarms after hours**
- **Standby Personnel must live within 5 minutes of the Center**

The WCATWC "Area of Responsibility" (AOR)



General presentation

Tsunami images 1964

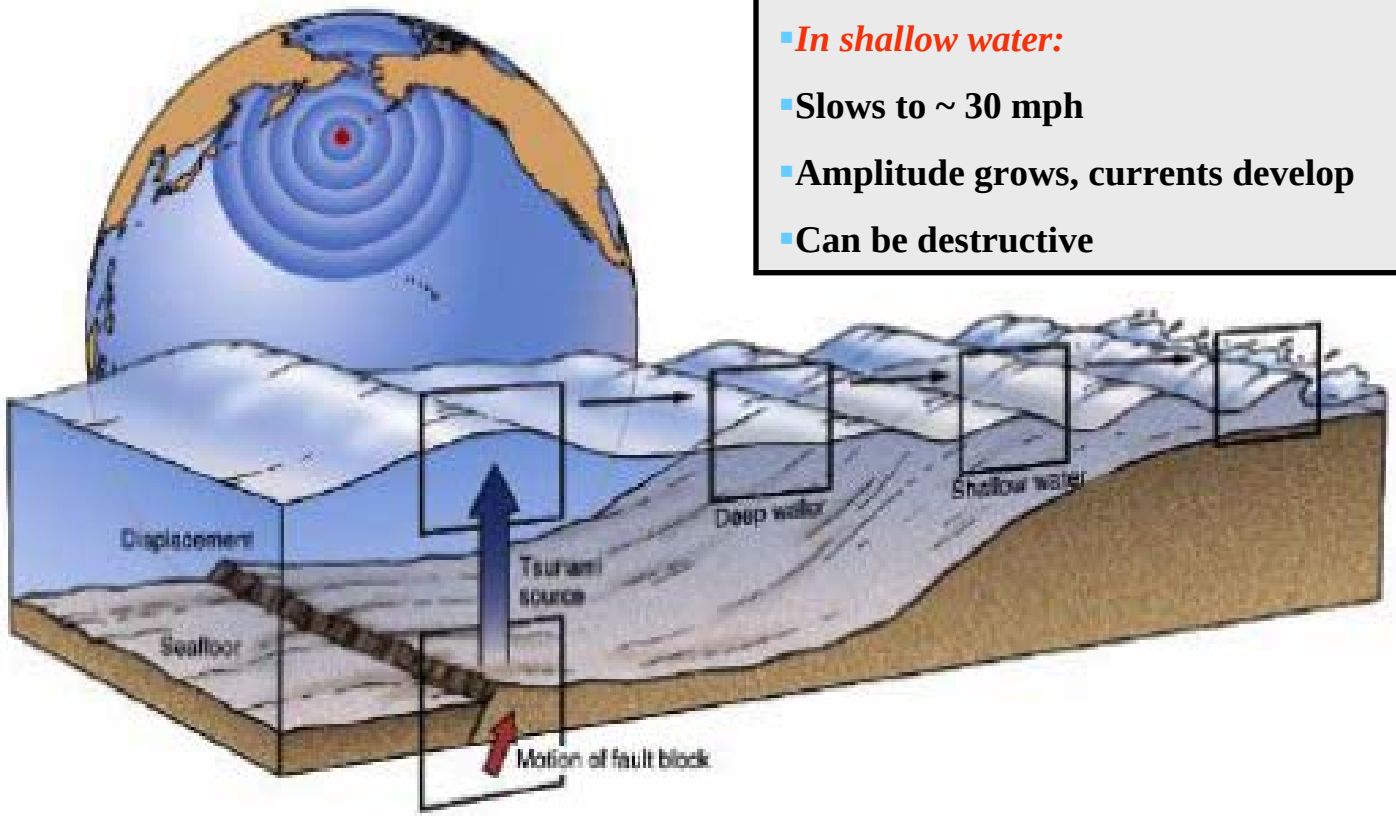
Community response – tsunami -ready

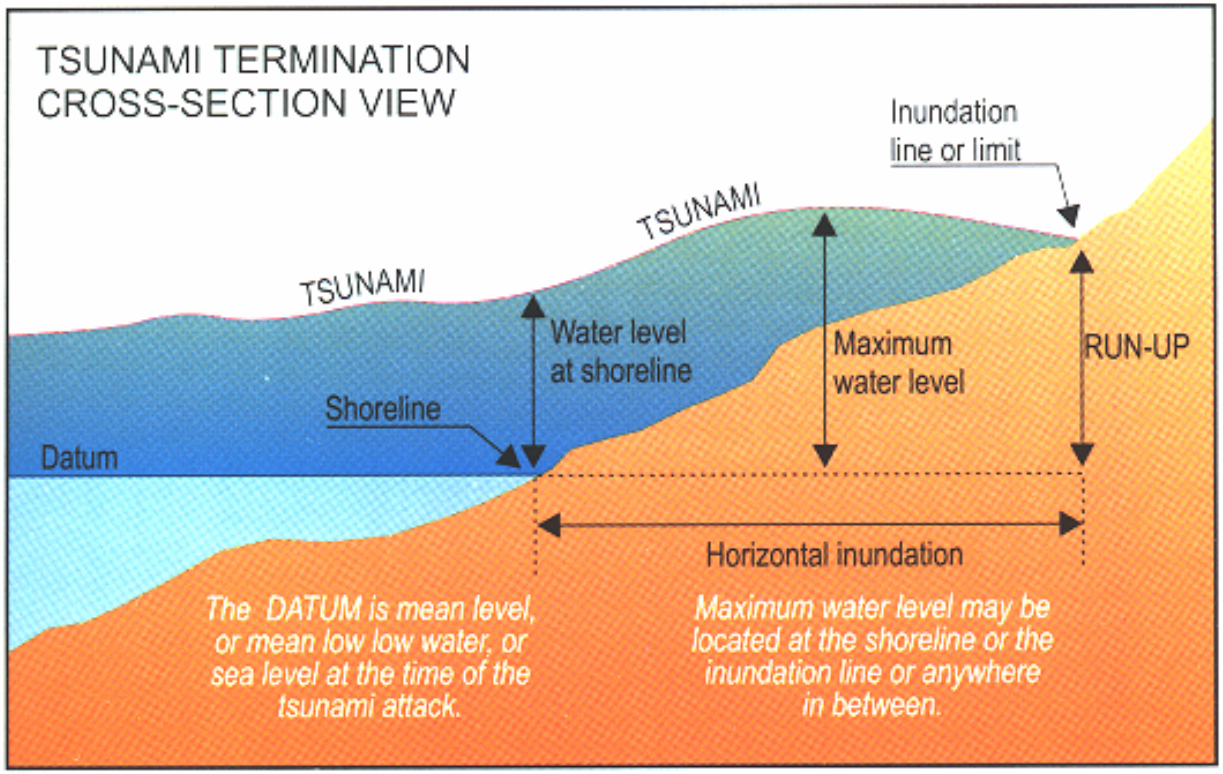
Tsunami science

the Life of a Tsunami

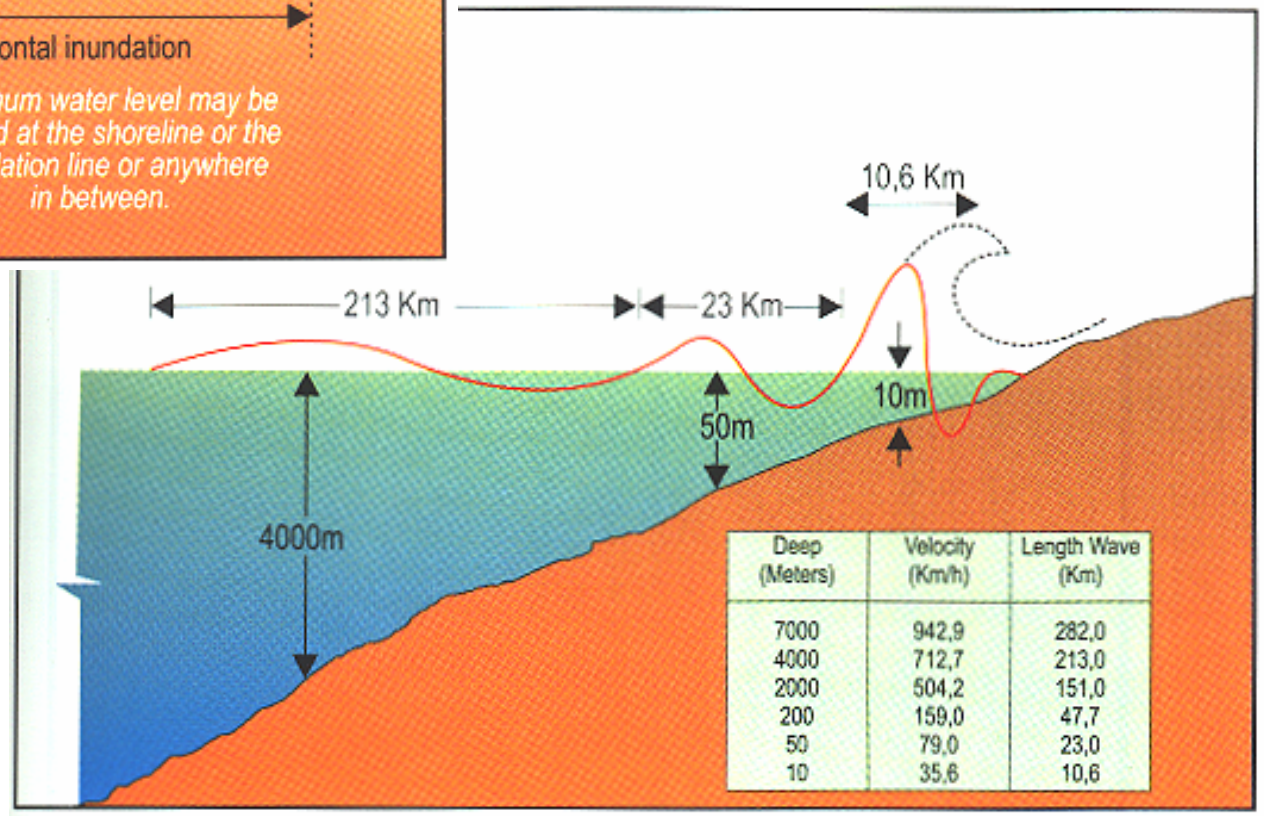
▪Characteristics

- Entire water column set in motion by seafloor disturbance
- Waves can transit the entire ocean
- Cannot predict wave height – only time of arrival
- *In deep water:*
- Cannot be seen, moves at ~500 mph
- Forms several low amplitude crests ~100 km apart
- *In shallow water:*
- Slows to ~ 30 mph
- Amplitude grows, currents develop
- Can be destructive





- **Evolution of a tsunami as it approaches the coast**

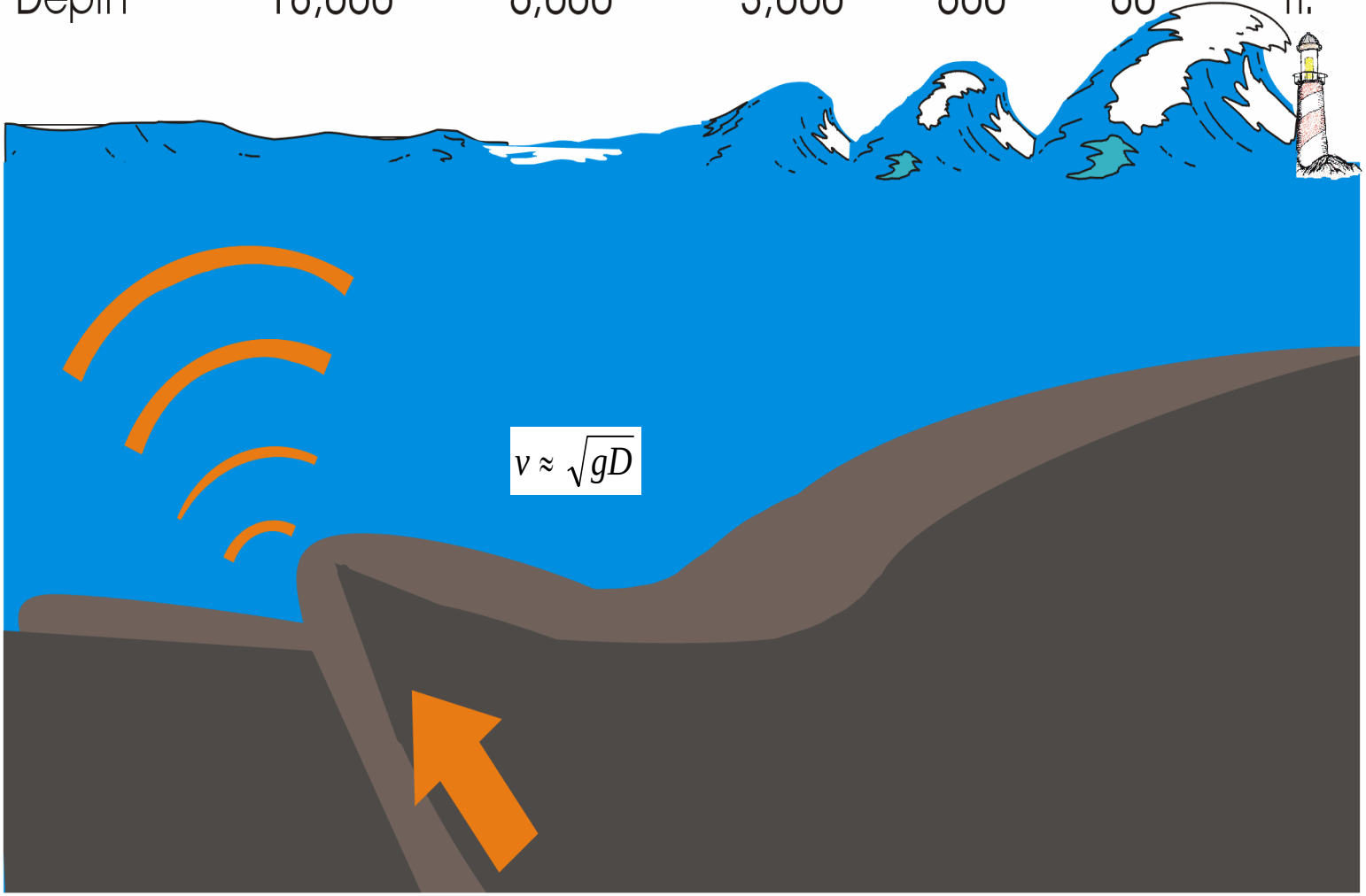


Deep (Meters)	Velocity (Km/h)	Length Wave (Km)
7000	942,9	282,0
4000	712,7	213,0
2000	504,2	151,0
200	159,0	47,7
50	79,0	23,0
10	35,6	10,6

Images from 'Tsunami Glossary', ITIC

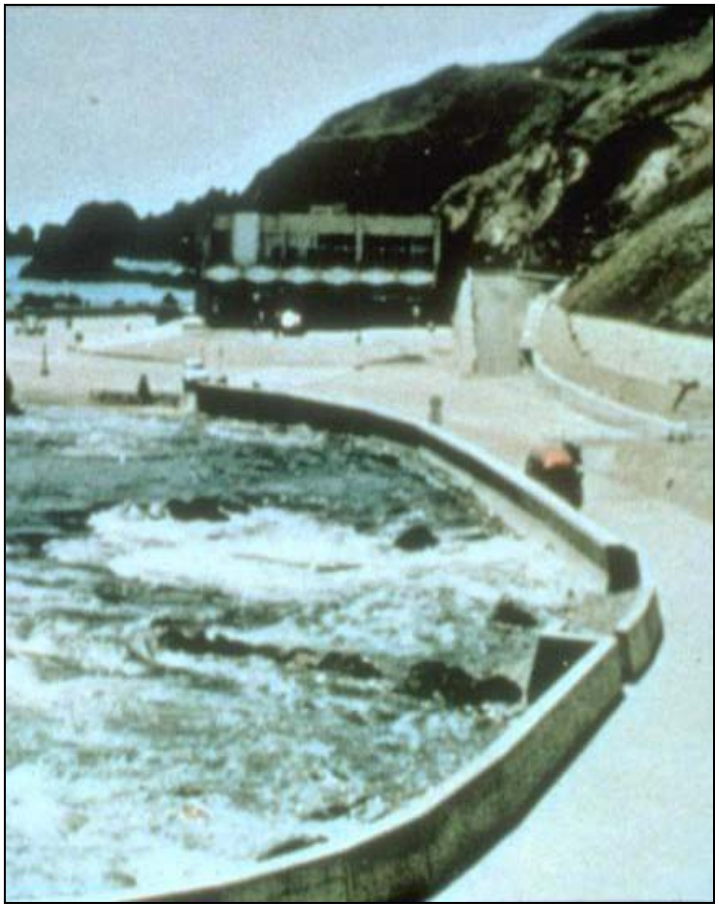
Tsunami Velocity as a function of water depth
(illustration by Elizabeth Percak-Denett)

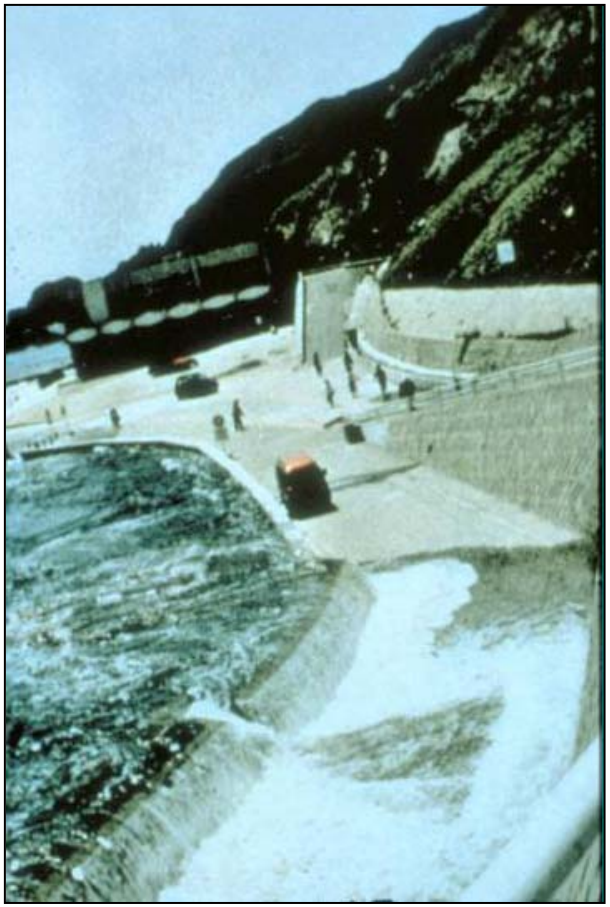
Speed	520	300	212	94	30	mph
Depth	18,000	6,000	3,000	600	60	ft.

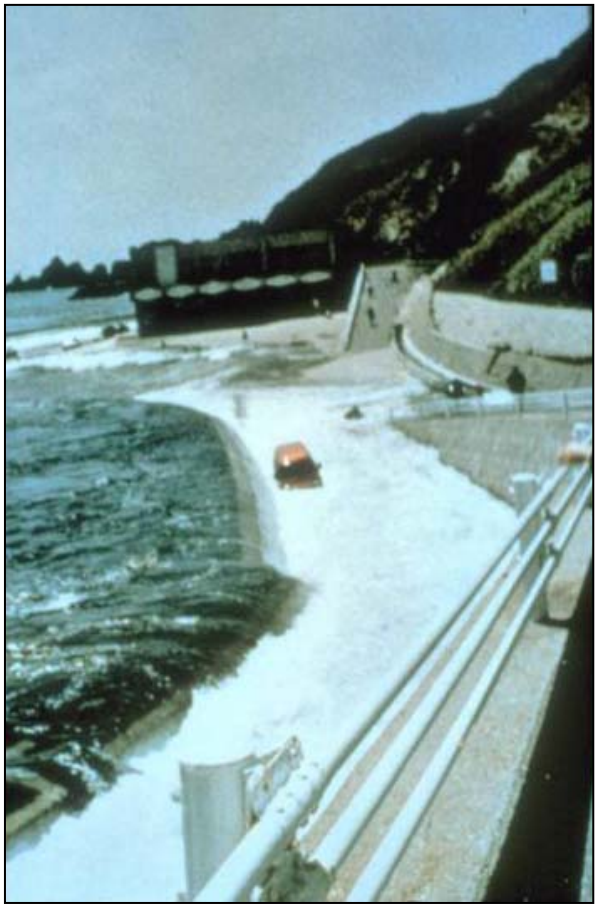


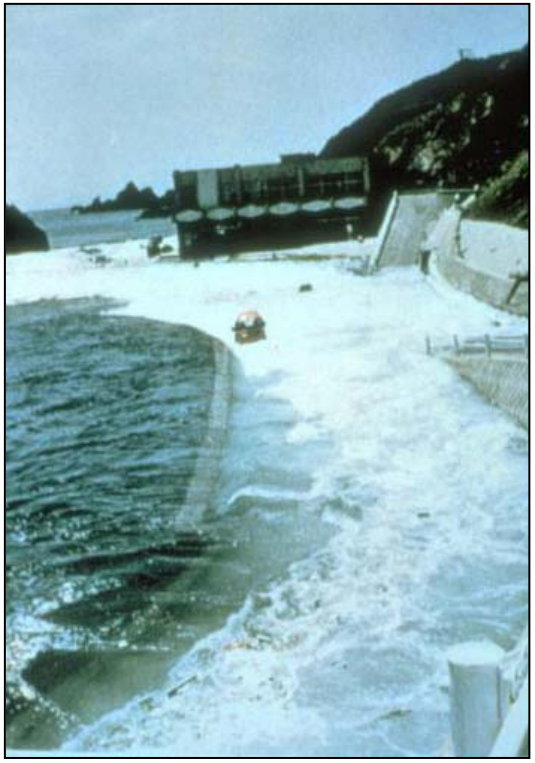
- A tsunami arrives on the west Hokkaido coast on 5/26/1983–

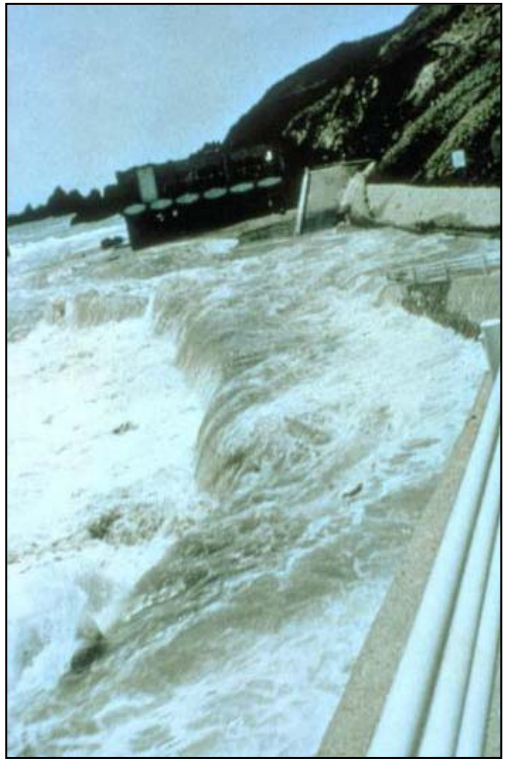
(the result of the magnitude 7.7 Sea of Japan earthquake -- 104 fatalities in Japan, 3 in Korea)



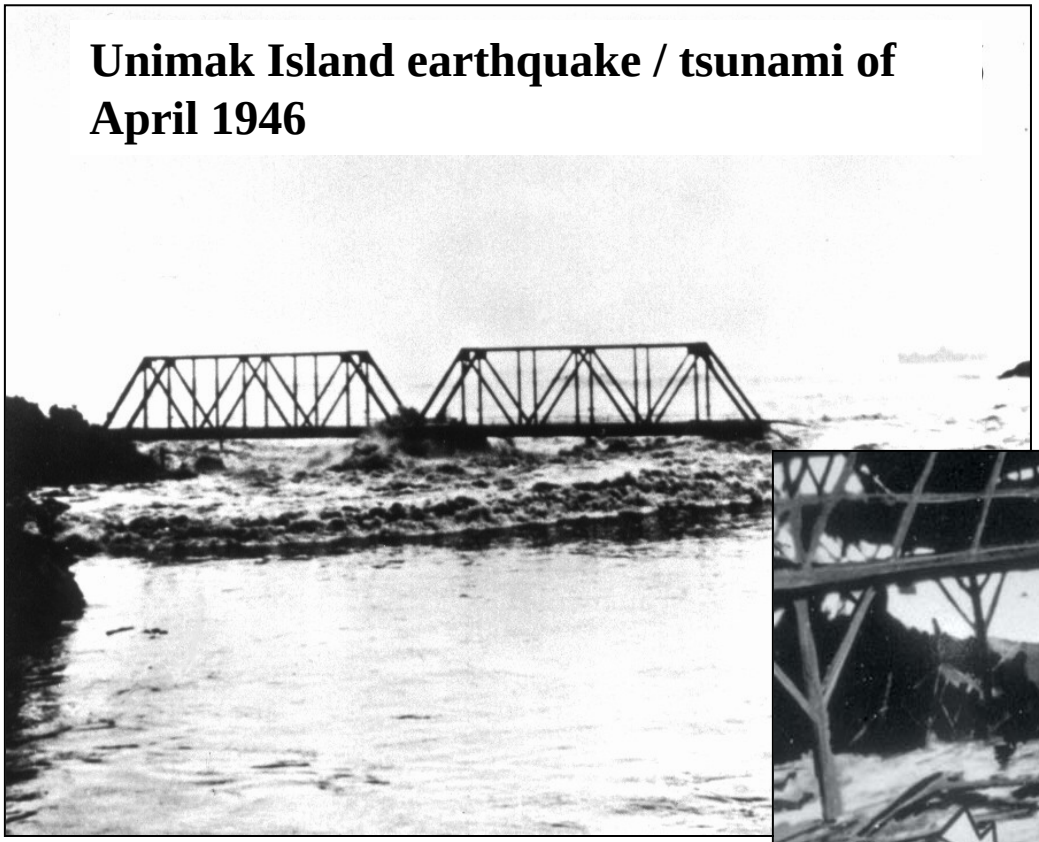




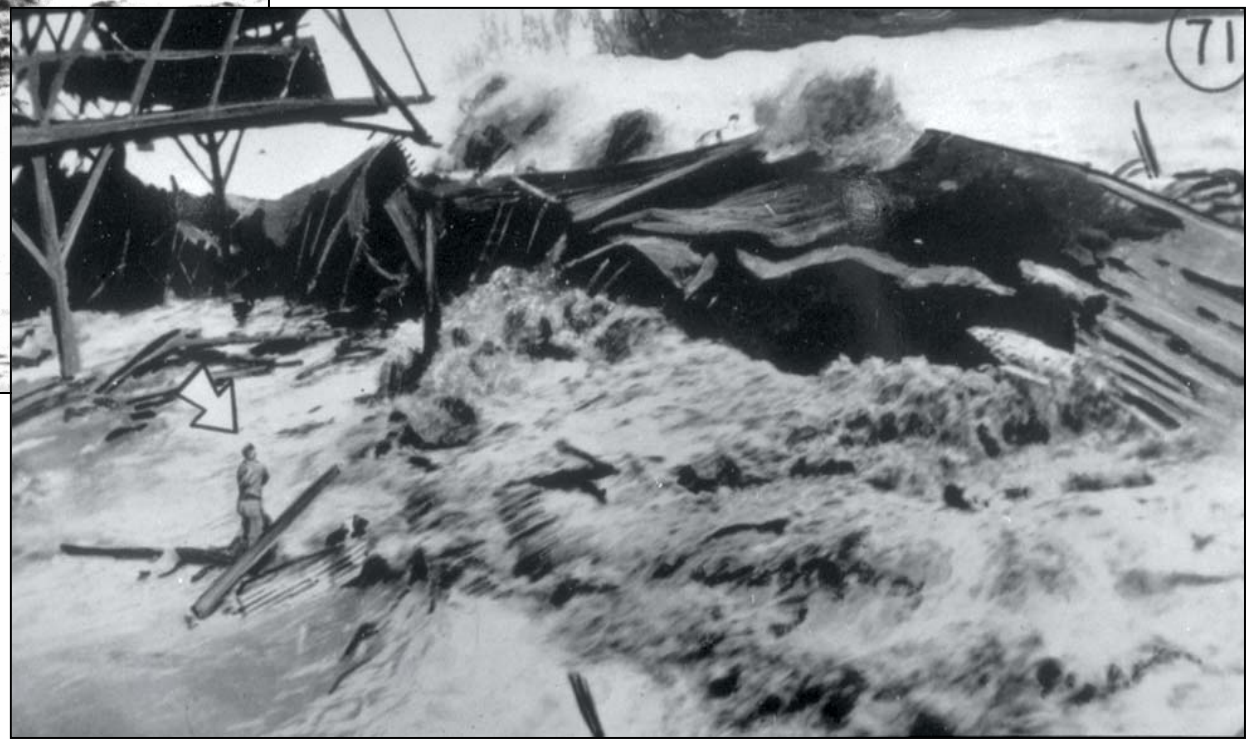




What do other destructive tsunamis look like up close ?

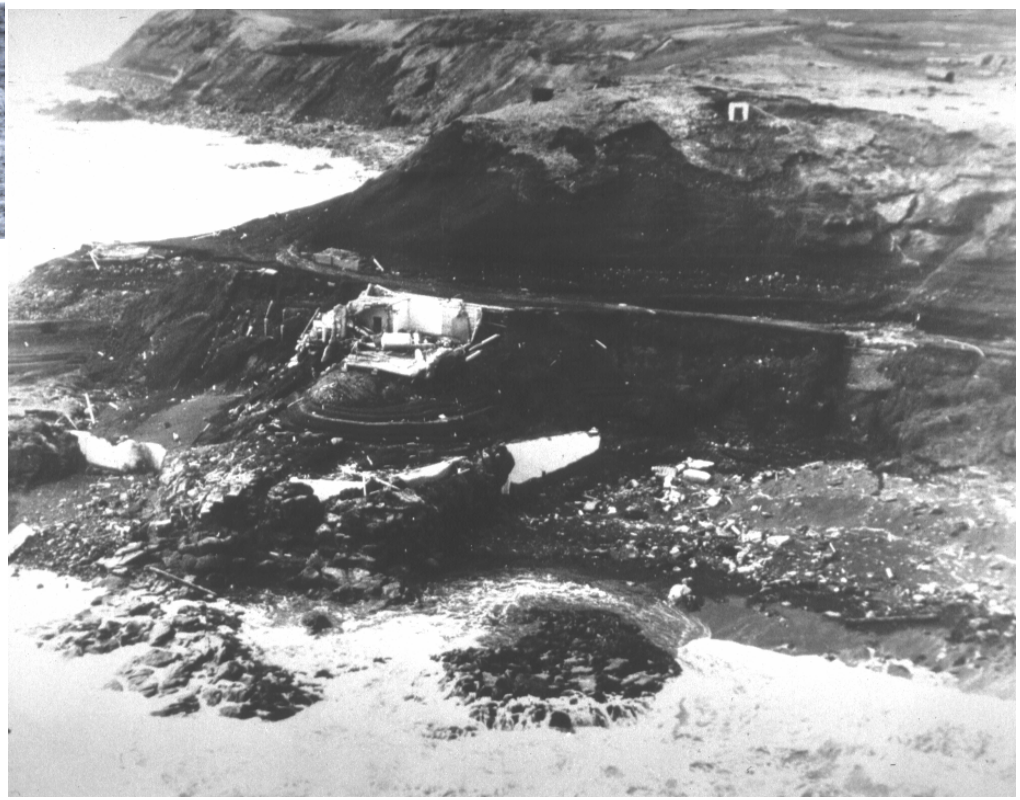


- Oahu: 11 meter runup
- Kauai: 14 meter
- Maui: 10 meter
- Unimak Island: 37 meter
- Honolulu: 20 sea level fluctuations in 4 hours



Unimak Island, Alaska
Scotch Cap
Lighthouse
Built in 1943

After Tsunami
April 1, 1946



Recent Local and Regional Tsunamis

Date	Source Location	Estimated Lives Lost
Nov 1975	Hawaii	2
Aug 1976	Philippines	*5000
Aug 1977	Sunda Is., Indonesia	100
Sep 1979	Irian Jaya, Indonesia	*100*
Dec 1979	Columbia	*259*
May 1983	Sea of Japan	*107*
Aug 1988	Solomon Is.	*1*
Sep 1992	Nicaragua	*168*
Dec 1992	Flores Is. Indonesia	*1654*
Jul 1993	Okushiri Is, Japan	*230*
Jun 1994	Java, Indonesia	*222*
Oct 1994	Shikotan Is, Russia	*11*
Nov 1994	Philippines	*74*
Oct 1995	Manzanillo, Mexico	*1*
Feb 1996	Irian Jaya, Indonesia	*174*
Feb 1996	Peru	*12*
Jul 1998	Papua New Guinea	*2192*
May 2000	Sulawesi, Indonesia	*9*
Jun 2001	Peru	*69*
Sep 2002	Papua New Guinea	*60*

Major Pacific-wide Tsunamis since 1800

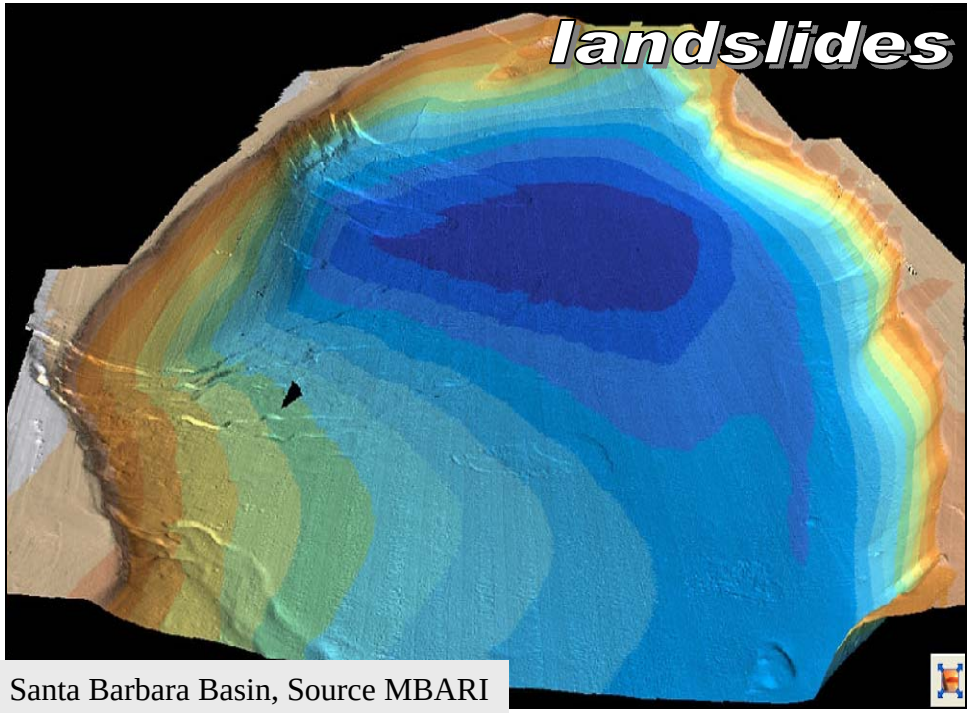
Date	Source Location	Estimated Lives Lost
Feb 1835	Chile	*2*
Nov 1837	Chile	*62*
Aug 1868	Chile	**25000*
May 1877	Chile	*500*
Jun 1896	Sanriku, Japan	*22000*
Jan 1906	Columbia	*500*
Aug 1906	Chile	
Sep 1918	Kuril Is., Russia	*47*
Nov 1922	Chile	*100*
Feb 1923	Kamchatka, Russia	*2*
Mar 1933	Sanriku, Japan	*3000*
Apr 1946	Aleutian Is., Alaska	*179*
Nov 1952	Russia	
Mar 1957	Aleutian Is., Alaska	*5*
May 1960	Chile	*2000*
Mar 1964	Alaska	*112*
Feb 1965	Aleutian Is., Alaska	

Primary Tsunami Sources

Augustine volcano – Cook Inlet, AK

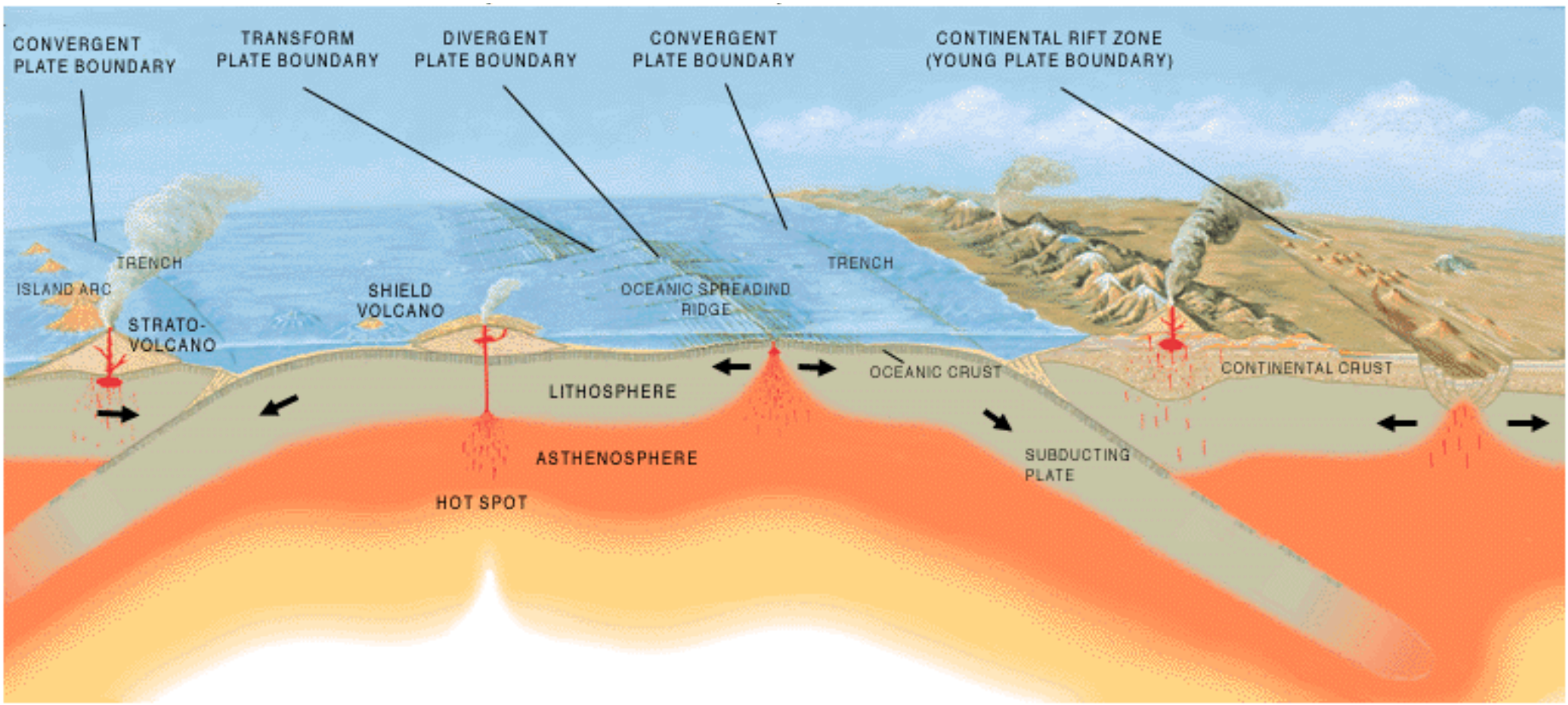
seismic displacement

Montague Is, AK Prince William Sound 11 m uplift:
Source USGS



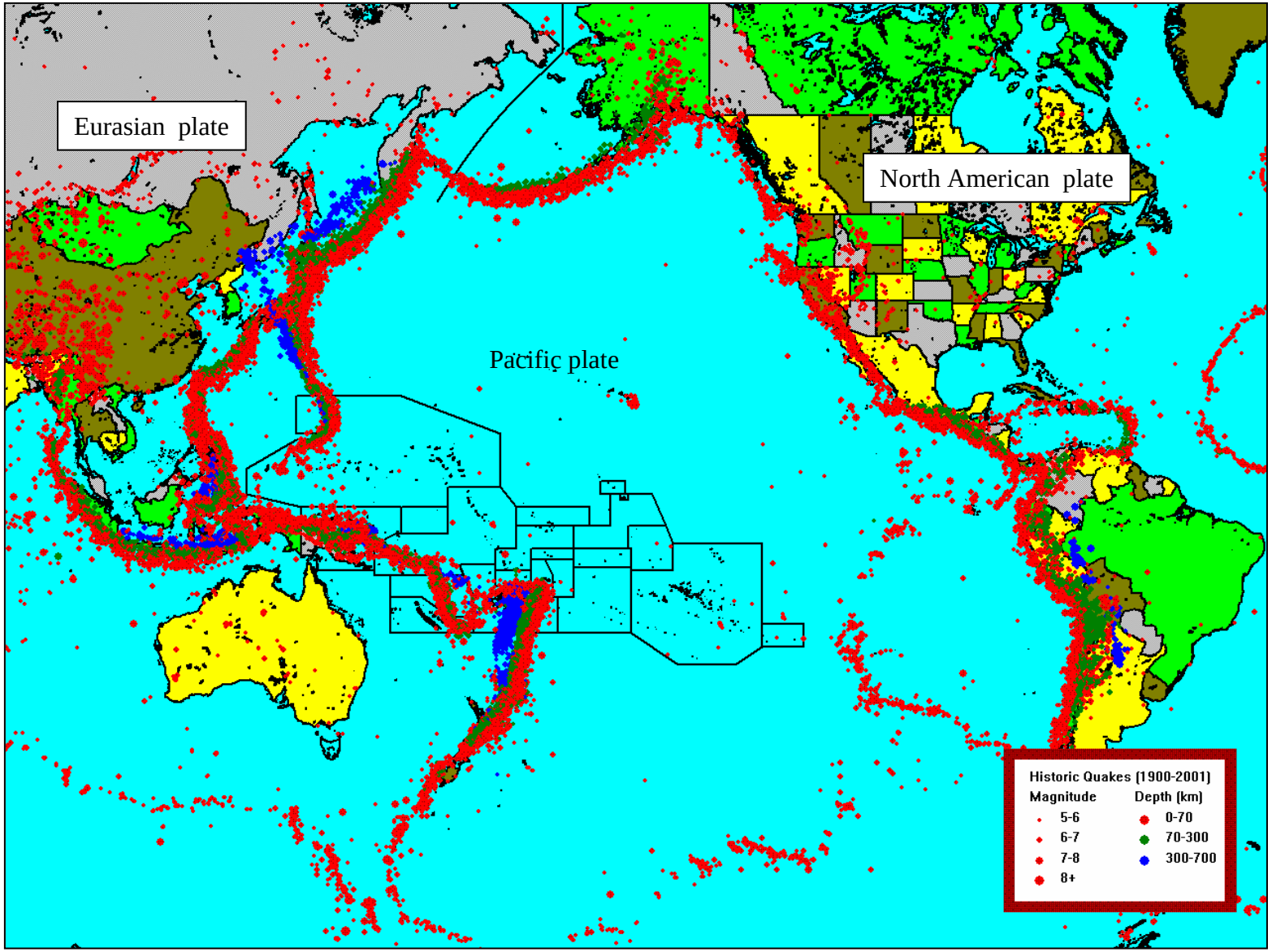
Santa Barbara Basin, Source MBARI

- **Plate tectonics sets the stage for 98% of tsunamis**
- This could be a N-S cross-section of the earth's crust, looking westward from Anchorage

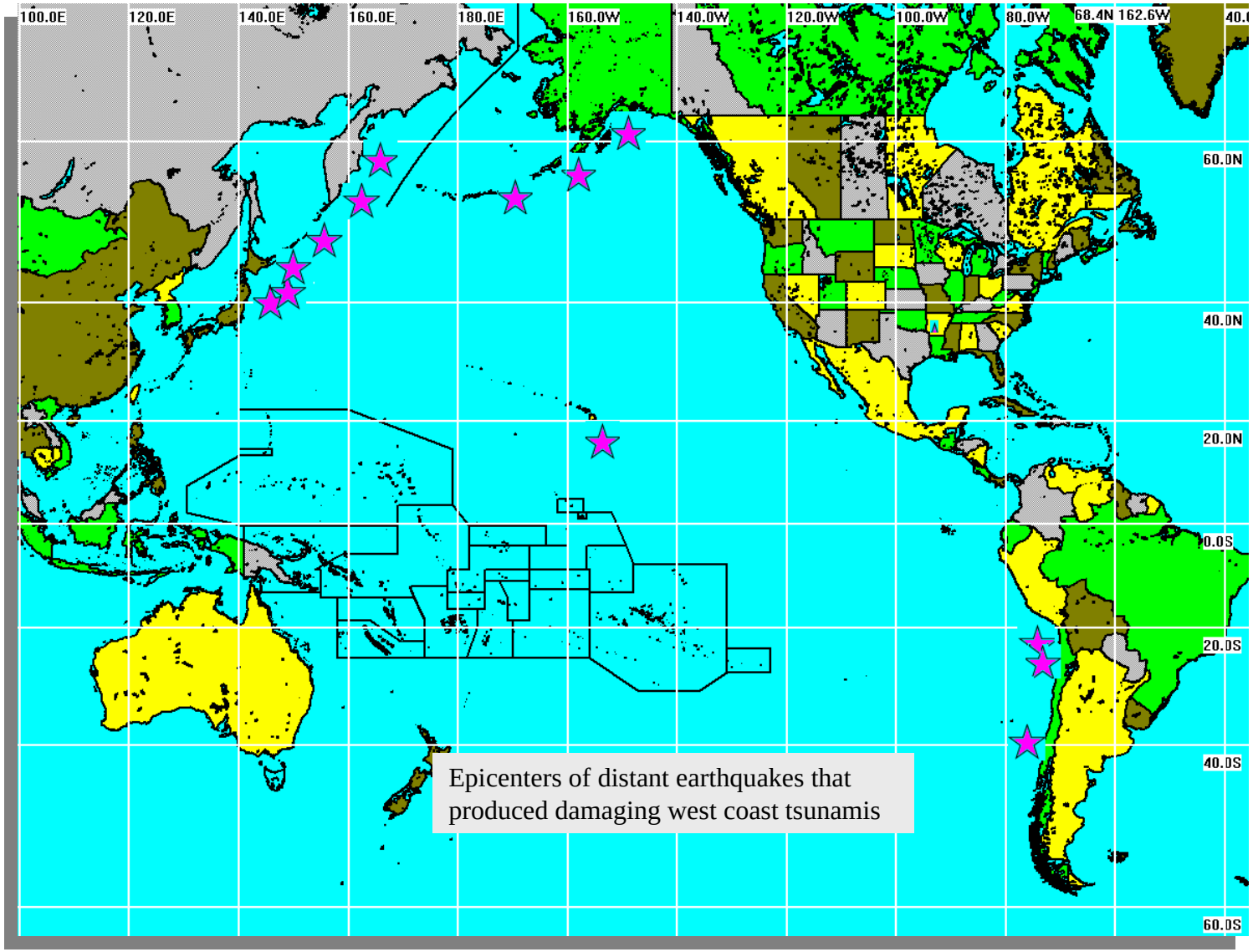


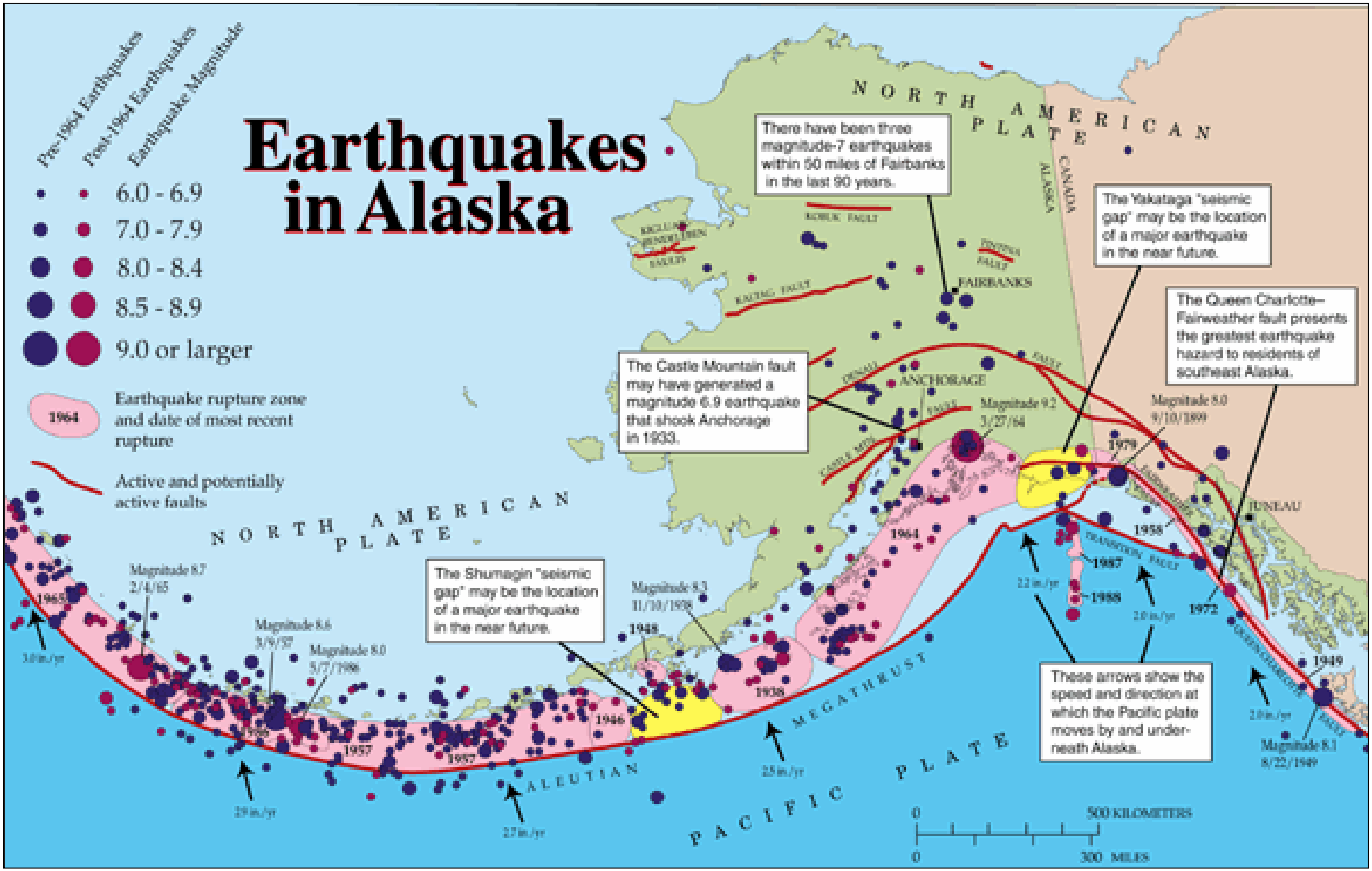
Tsunamis are often generated in trenches through the process of Plate Tectonics

Seismicity of the Pacific 1900-2003

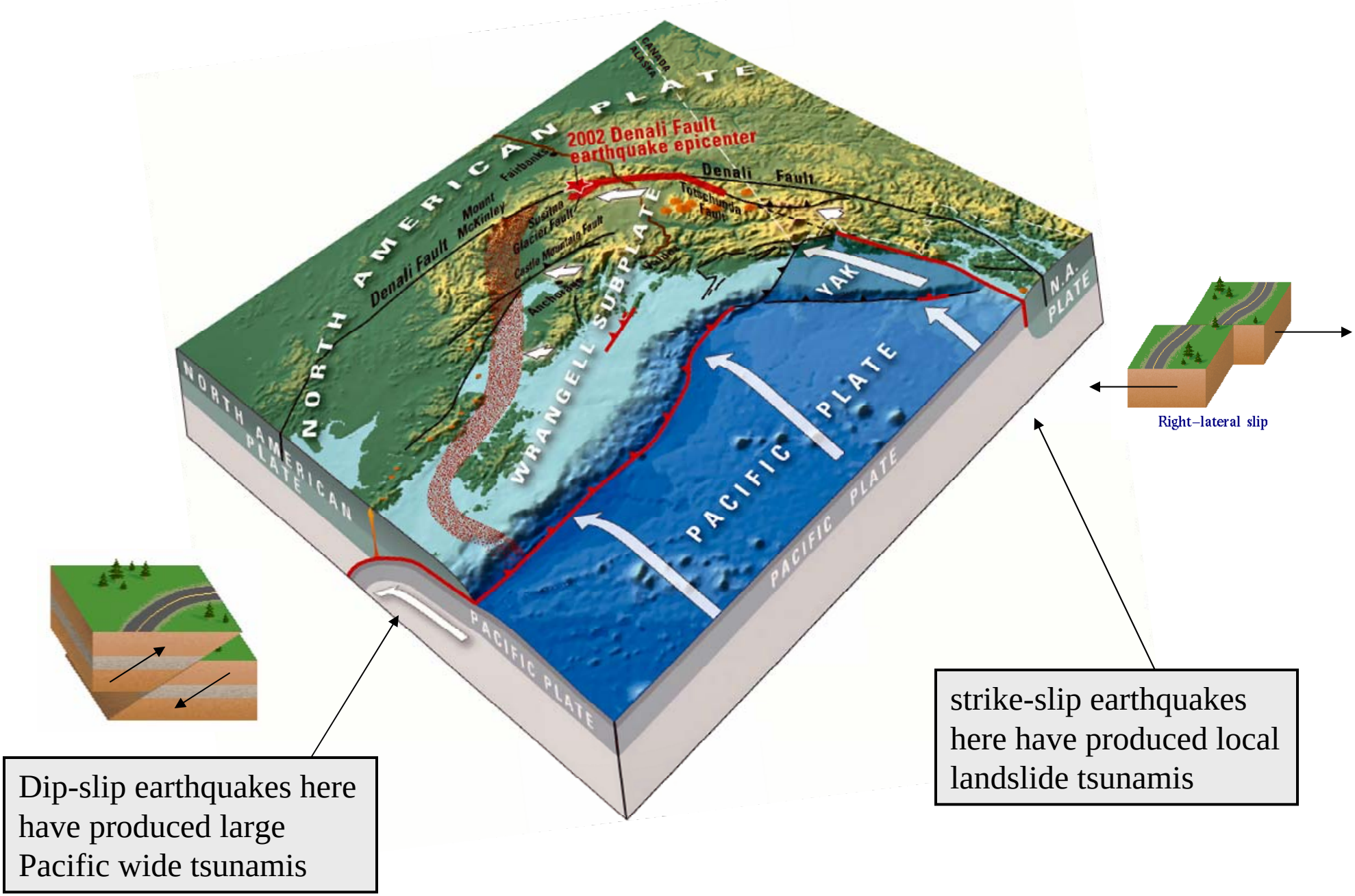


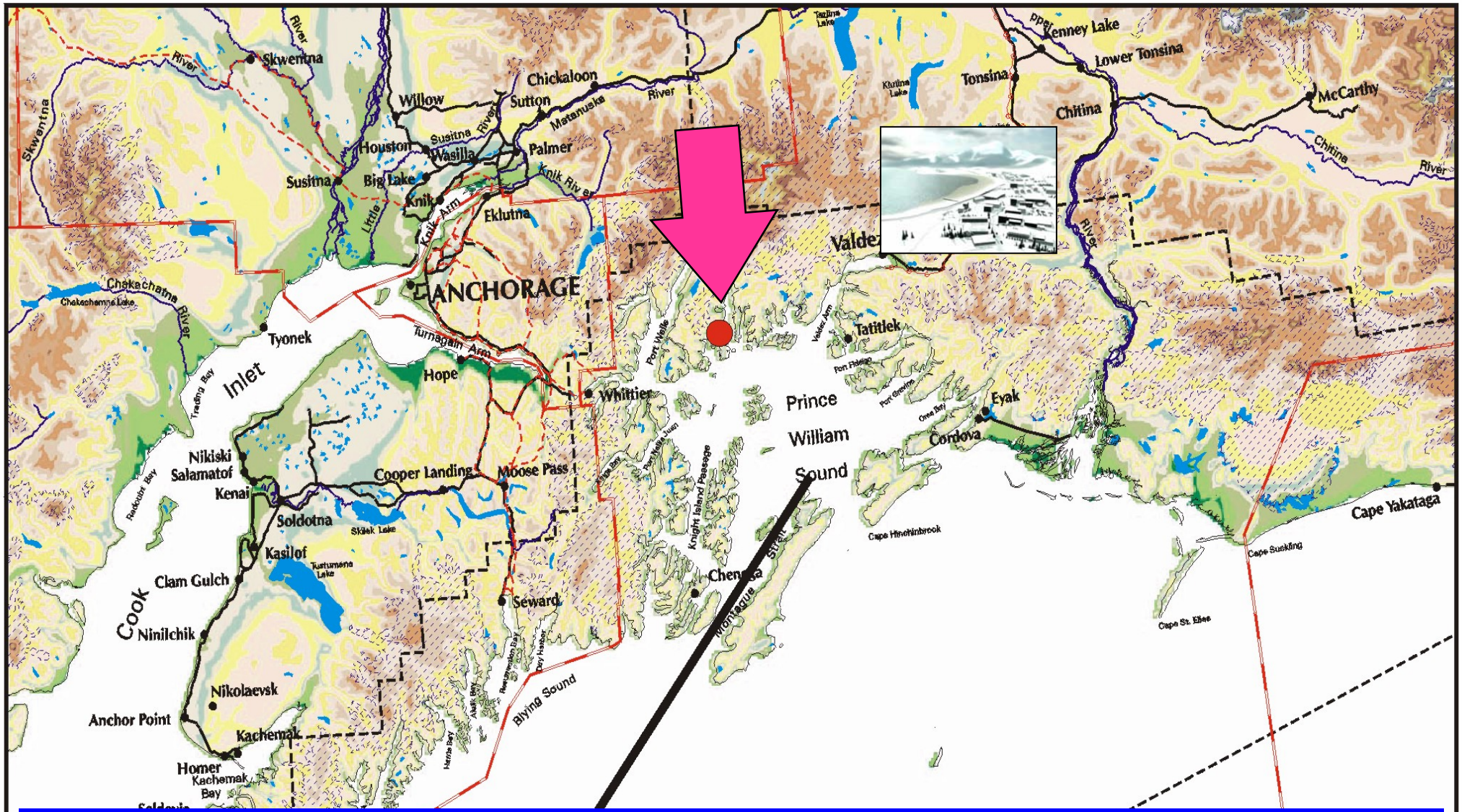
The SOURCES OF Tsunamis HAVE BEEN 1000s OF KILOMETERS DISTANT





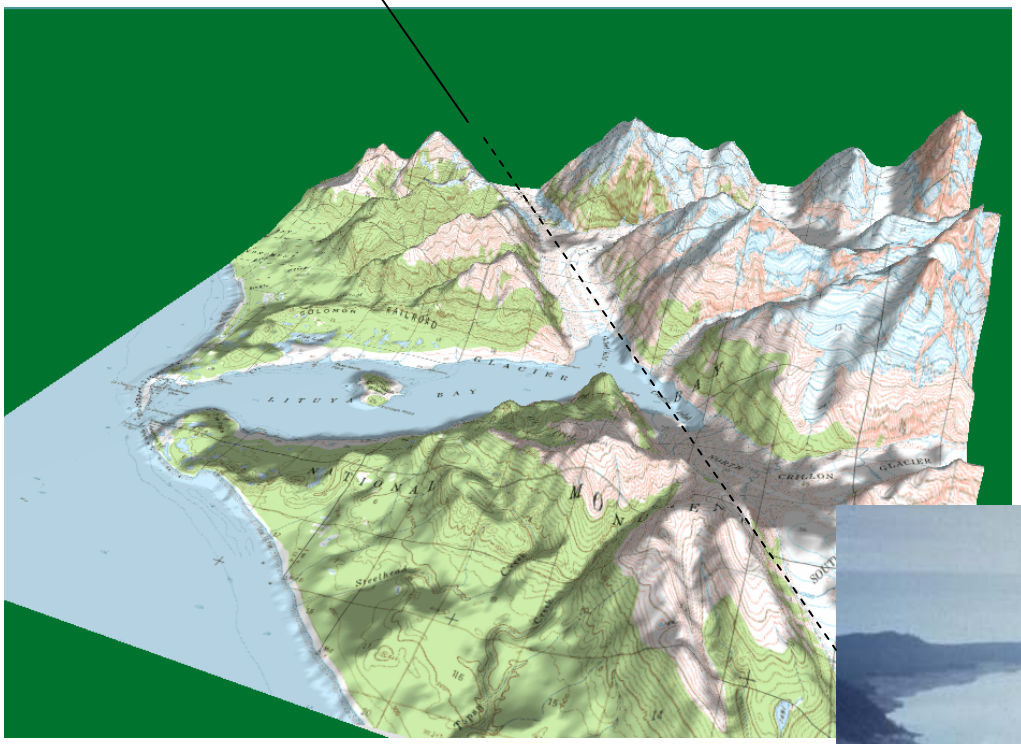
Courtesy of the Alaska Earthquake Information Center


NORTH AMERICAN PLATE
CANADA
ALASKA
2002 Denali Fault earthquake epicenter
Fairbanks
Denali Fault
Mount McKinley
Denali Fault
Susitna Glacier Fault
Castle Mountain Fault
Anchorage
Totschunda Fault
WRANGELL SUBPLATE
YAK
PACIFIC PLATE
N.A. PLATE
NORTH AMERICAN PLATE
PACIFIC PLATE
PACIFIC PLATE
Right–lateral slip
Dip-slip earthquakes here have produced large Pacific wide tsunamis
strike-slip earthquakes here have produced local landslide tsunamis



Good Friday Earthquake
March 28, 1964

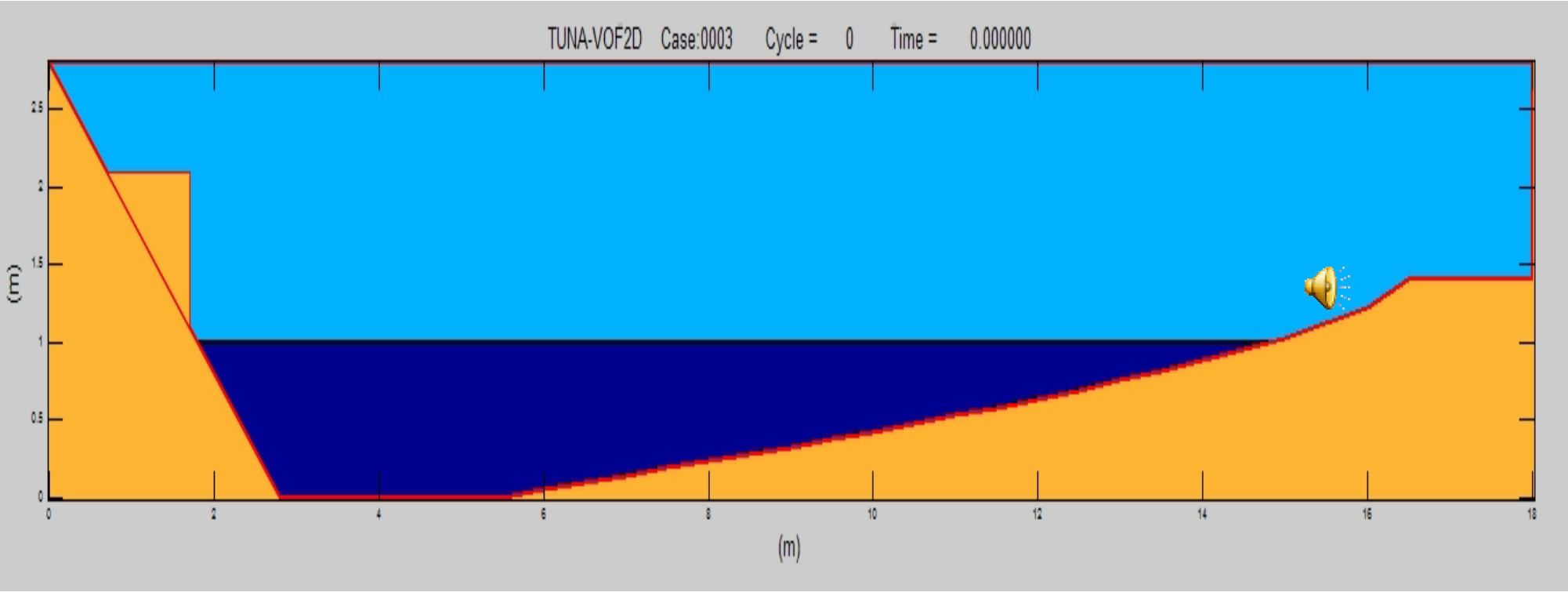
Trace of the Fairweather Fault



The largest known landslide driven tsunami

Lituya Bay, SE Alaska
July 10, 1958
Trees Removed by Waves - up to 1680 feet above sea level, the highest known runup

An animation of a landslide powered tsunami

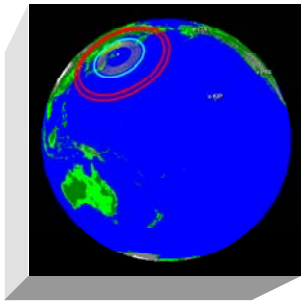


- **Arrow down and then click on button below**

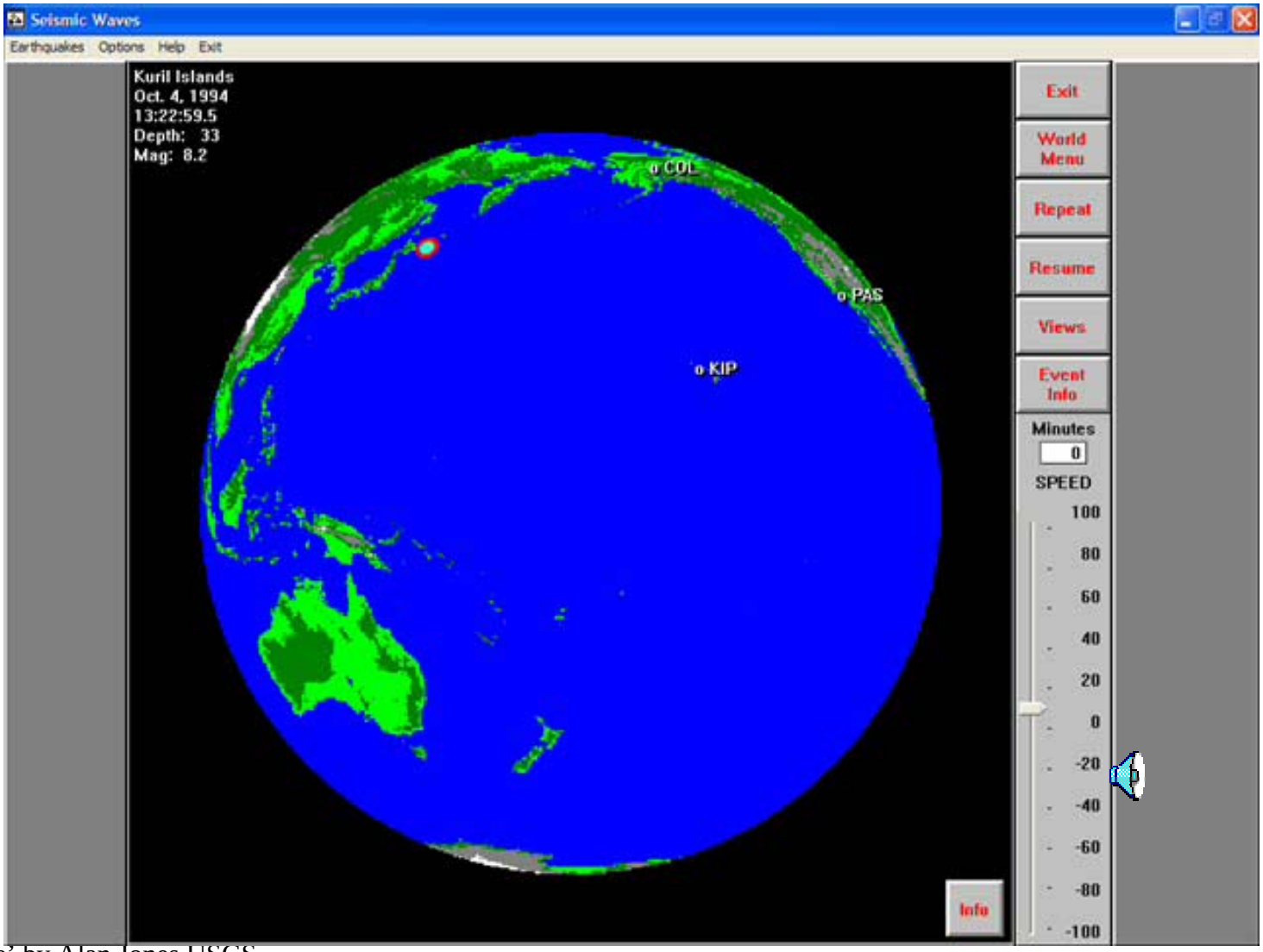
A tsunami generated by volcanic pyroclastic flow -- Sicily

- click on button below

An earthquake creates an expanding seismic wave front traversing the Pacific in less than 20 minutes

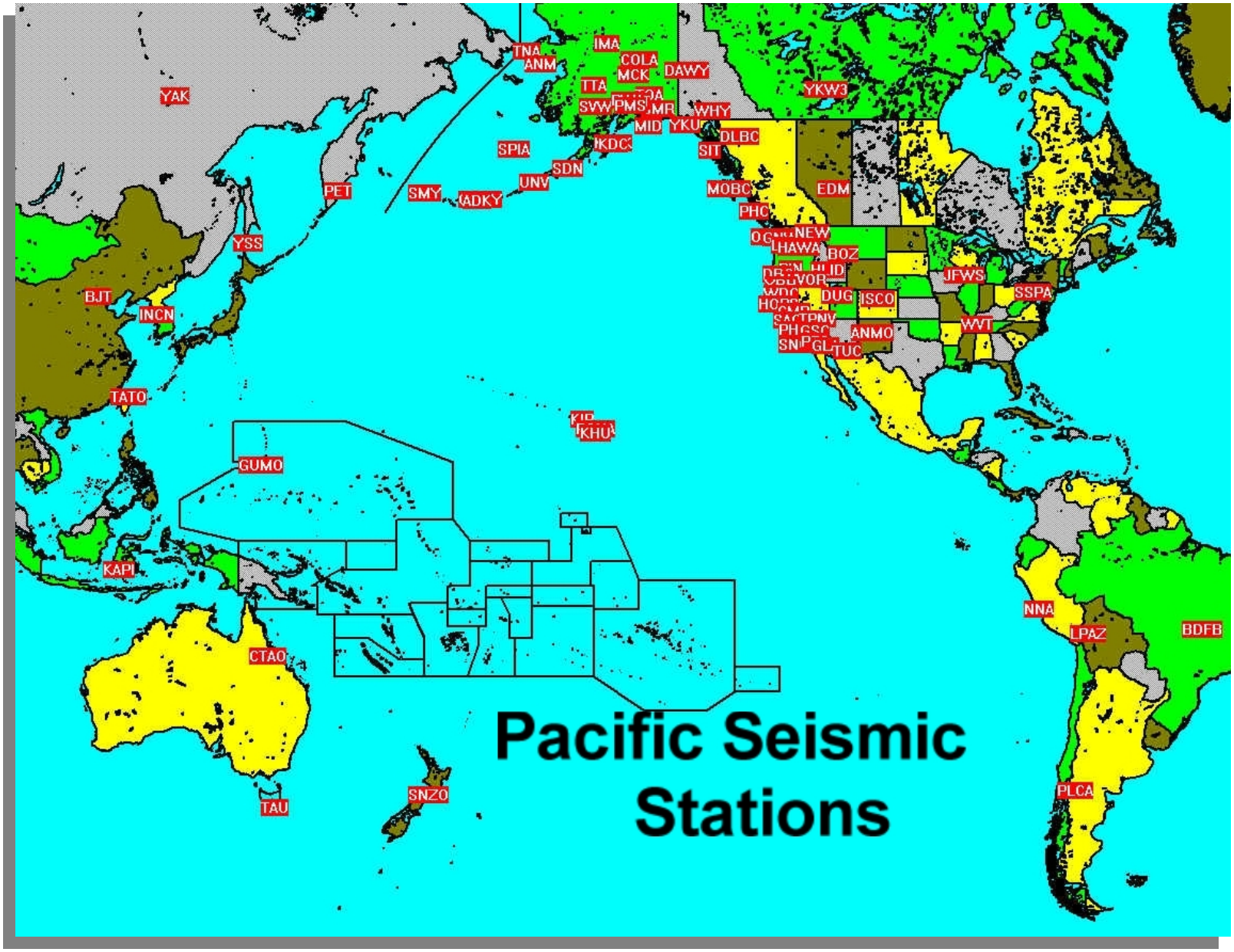


Red circle locates the expanding P-wavefront



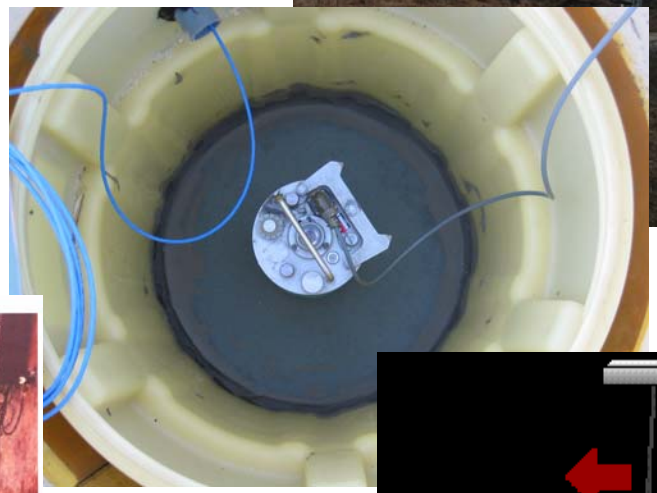
From ‘Seismic Wave’ by Alan Jones USGS

Seismometers around the Pacific respond to the induced ground motion

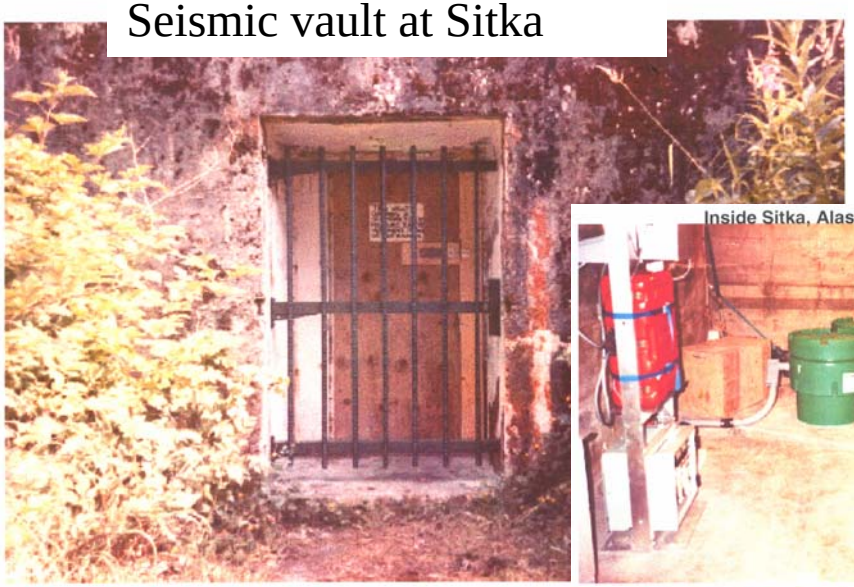


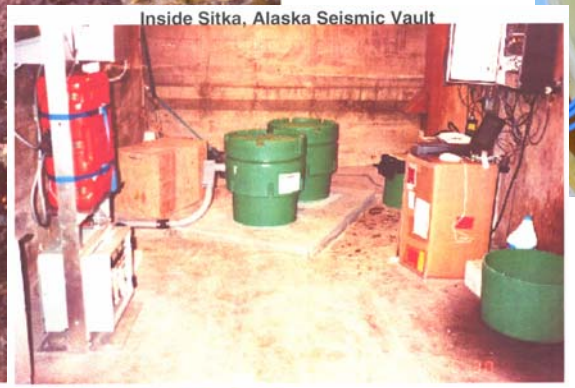
Seismometers and seismometer ‘vaults’ used by the WCATWC

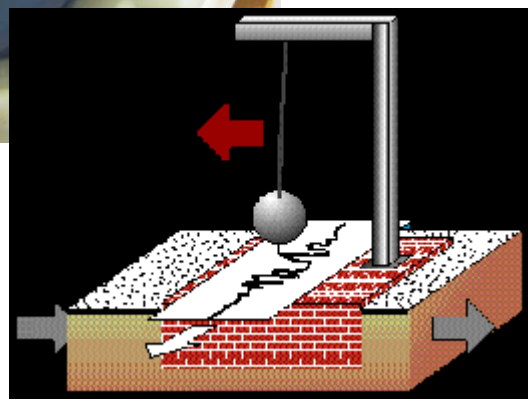
Seismometer installation at Yakutat



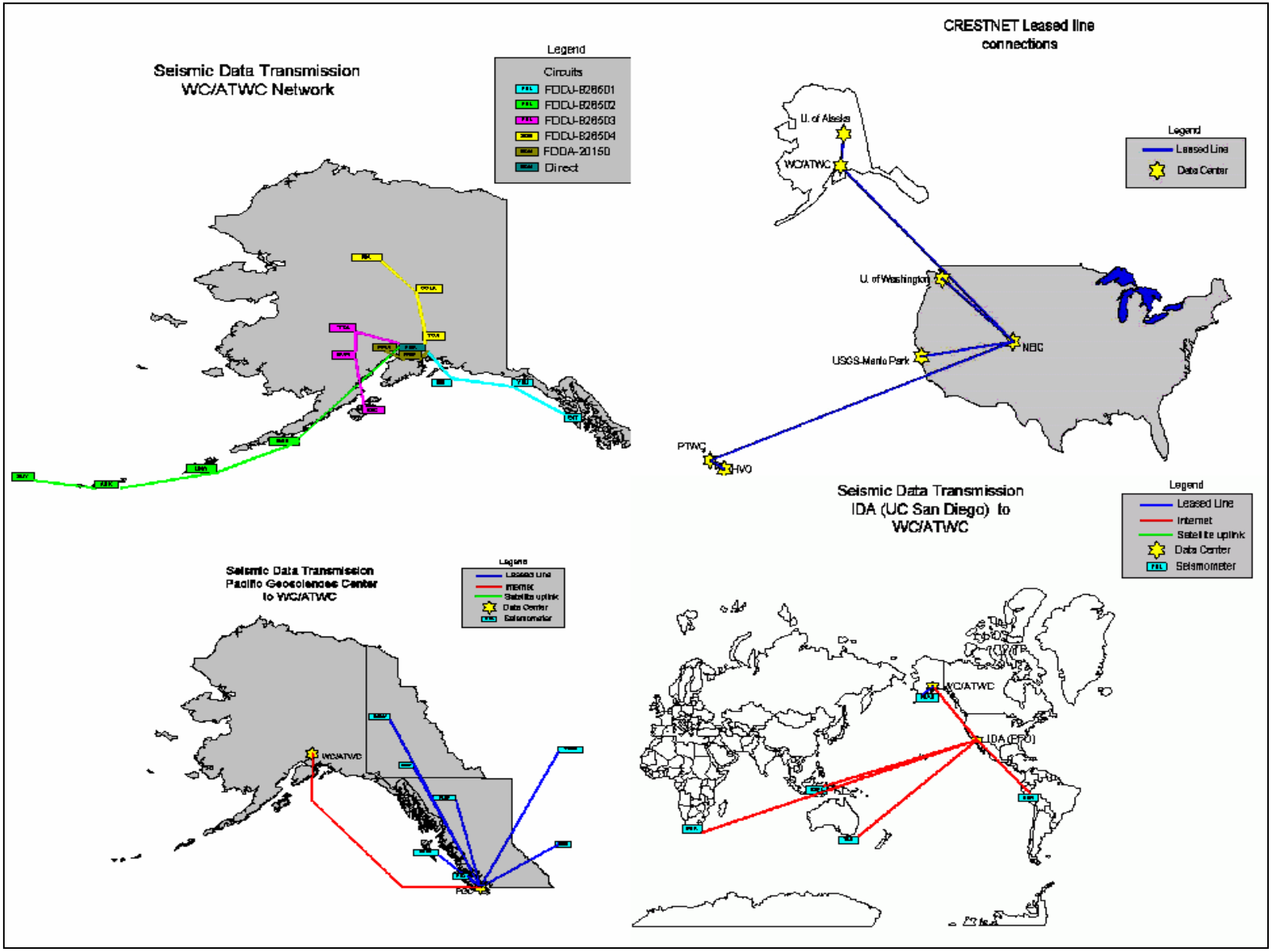
Seismic vault at Sitka





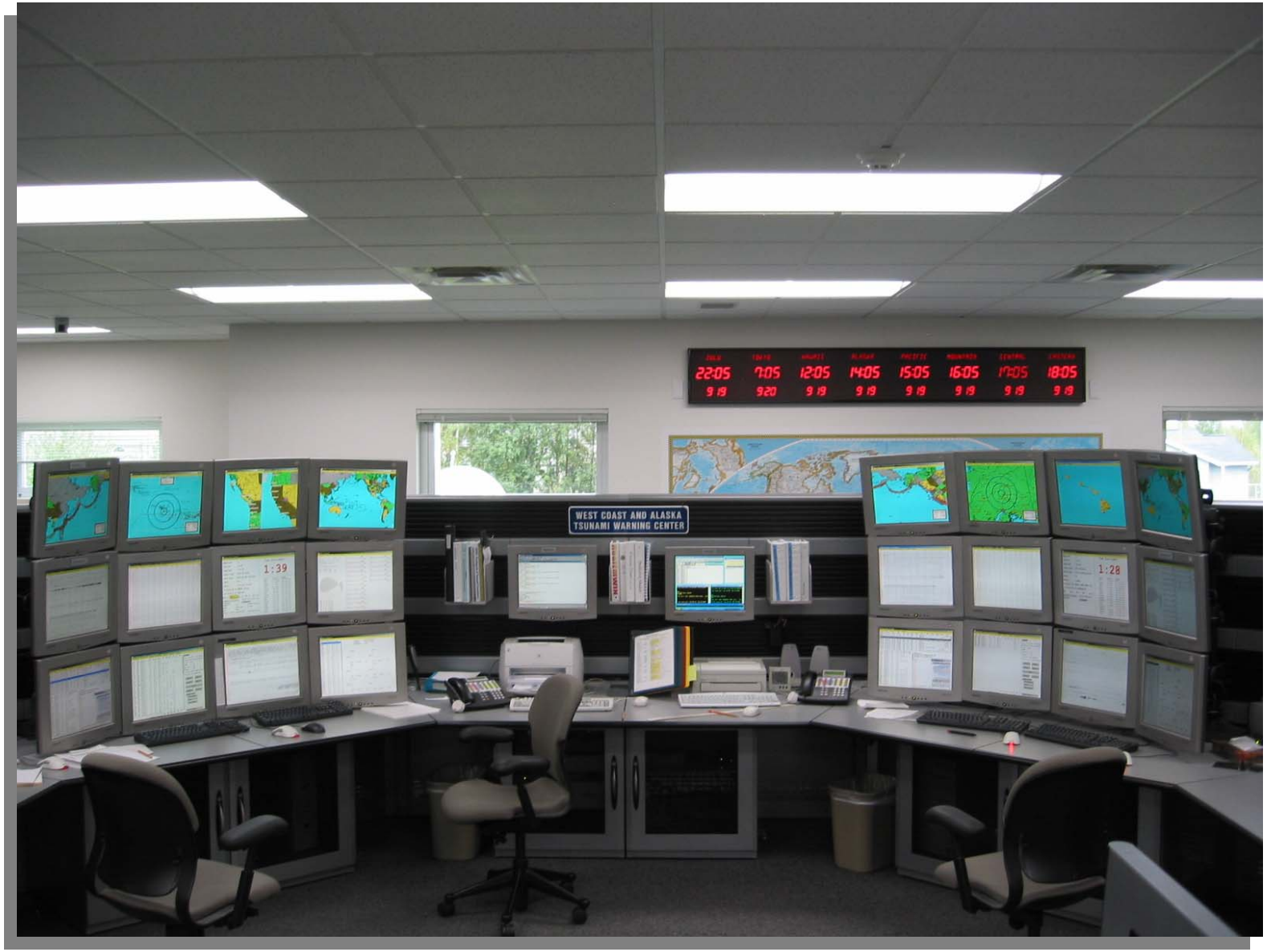


Seismic networks deliver worldwide seismic data to Palmer



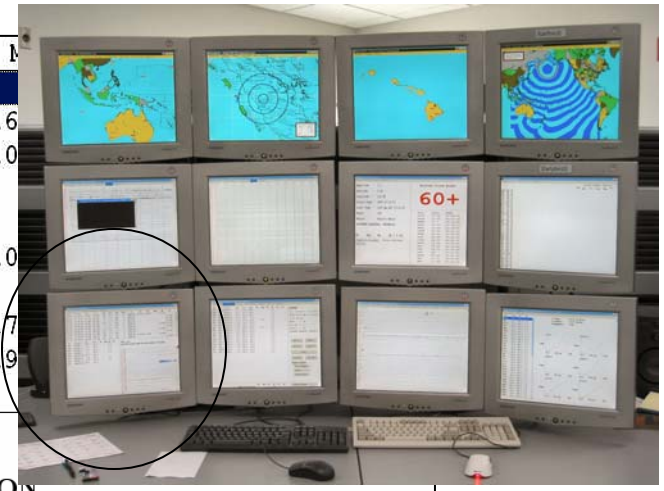
Automatic earthquake location & broadcast of seismic warning indicate a potential tsunami threat is imminent

Seismic and sea level data is displayed at the WCATWC “ops room”



Real-time seismograms are displayed and pick times of ‘first motion’ are adjusted if necessary

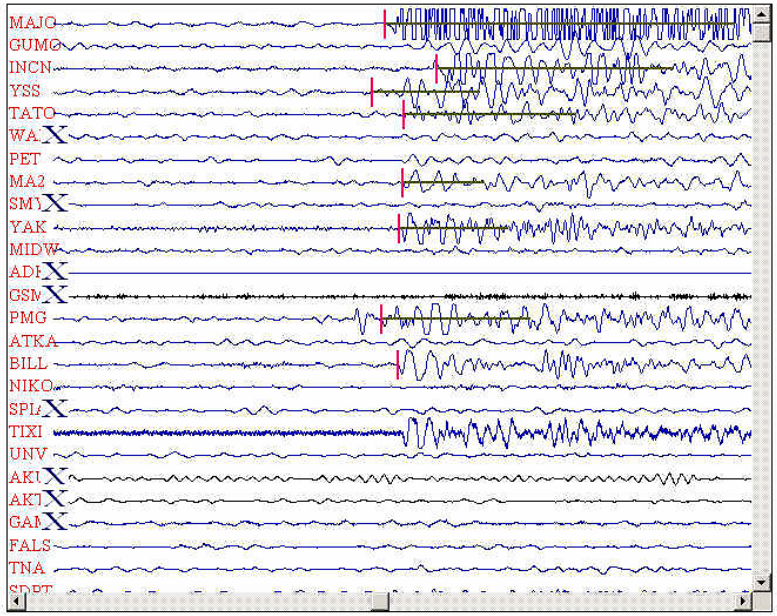
Date	O-time	Lat.	Lon.	Dep	Res	Azm	#Stn	ID	Ms	M
11/02	10:02:17	49.3N	128.6W	88	1.1	207	32	1213-34		
11/02	09:30:45	49.4N	128.7W	1	1.3	186	30	1214-35	5.4-67	5.6
11/02	08:46:01	28.7N	143.2E	40	0.8	241	32	1209-32	5.4-74	6.0
11/01	19:00:39	60.6N	151.9W	63	0.6	261	12	1078-11		
11/01	12:24:26	81.0S	35.1E	40	1.6	42	6	1027-03		
11/01	02:55:57	78.7S	87.3E	40	1.7	137	6	0925-13		6.0
10/31	06:10:44	35.6N	74.7E	40	0.5	17	9	0725-06		
10/31	06:03:03	35.6N	74.6E	38	0.7	223	23	0723-22	5.0-60	5.7
10/30	13:27:09	15.5S	167.9E	158	0.8	234	32	0553-23	5.0-74	5.9
10/30	06:47:20	41.7N	121.9W	40	0.9	225	6	0492-08		



Stn	P-time	Res.	Dist.	Ms	Mwp	Mb	Ml
MAJO	084804.7	-1.5	8.8	5.0	5.5		5.2
INCN	084950.9	2.9	16.4	5.0	6.3	5.8	
YSS	085008.1	-2.6	18.2	4.8	6.0	5.3	
TATO	085027.5	0.1	19.8		6.0	5.8	
MA2	085216.6	-0.1	31.2	4.9	5.5	5.3	
YAK	085244.4	-0.3	34.5	5.1	5.5	5.9	
PMG	085314.1	-1.8	38.1		5.4	5.9	
BILL	085345.2	-0.4	41.7	5.9		5.5	
CTAO	085440.0	-0.7	48.6	4.9	5.4	6.0	
SVW2	085502.5	0.8	51.4				
IMA	085514.8	-0.4	53.2			5.6	
PMR	085524.5	0.0	54.6	5.3		6.0	
MCK	085526.3	-0.7	54.8	5.3		6.0	
COLA	085529.8	-1.3	55.4	5.1		5.6	
PAX	085538.3	0.4	56.3	5.3		6.0	
MENT	085544.1	0.6	57.1				
DAWY	085556.7	-0.3	59.1	5.3		6.1	
SKAG	085614.3	1.2	61.4	5.4		5.9	
BMBC	085702.8	0.0	69.1	5.4		5.8	
YKW3	085709.0	0.0	70.2	5.1		5.7	

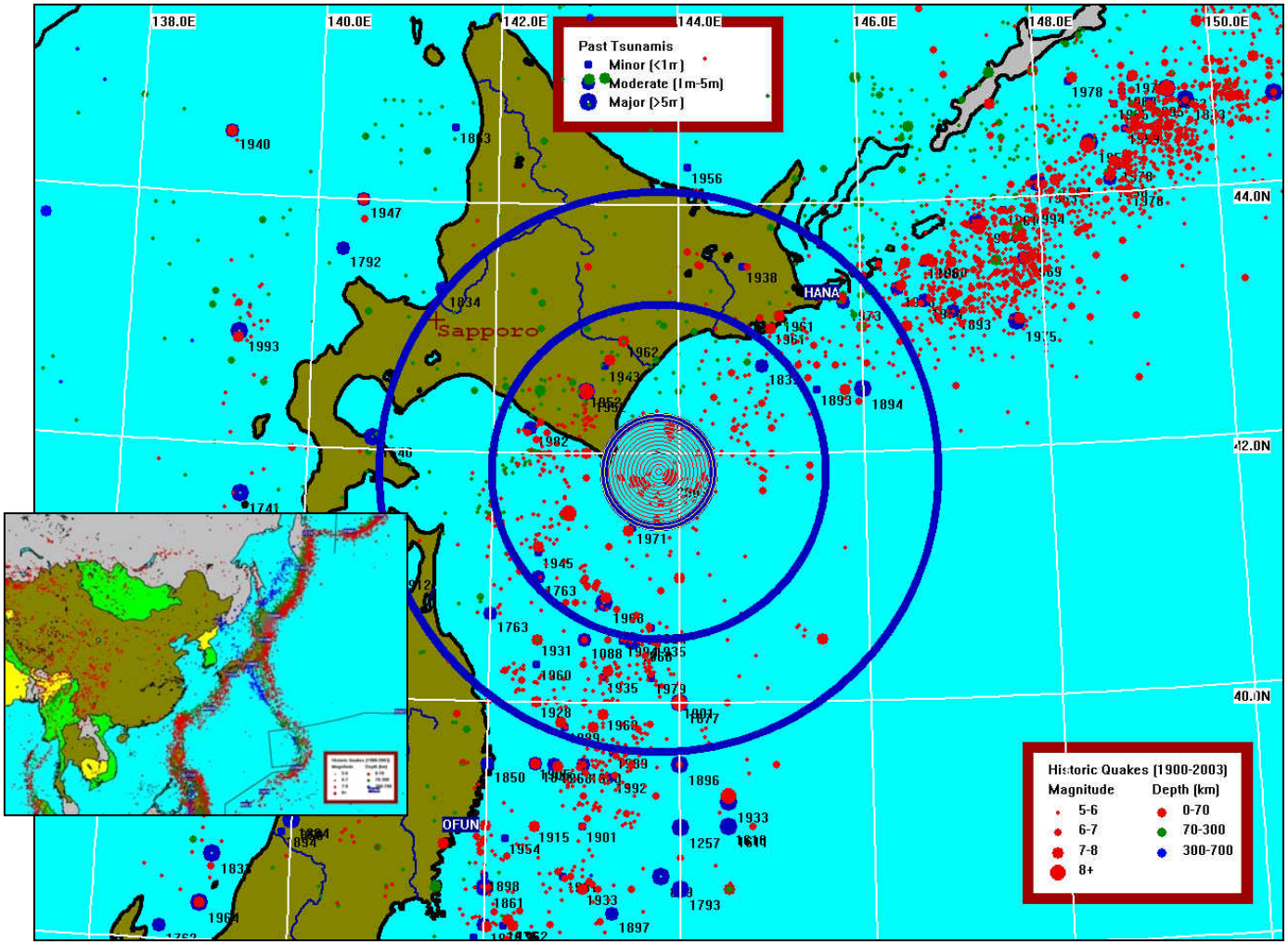
Mwp = 7.9

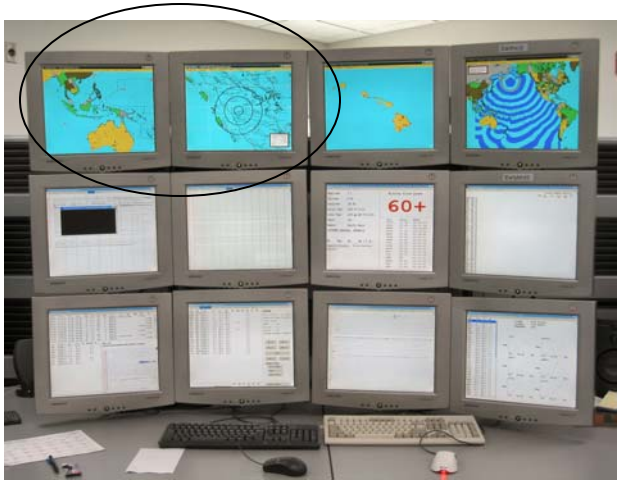
HOKKAIDO, JAPAN REGION



A seismic solution is obtained and verified within 15 minutes

- *Is the epicenter in a seismic zone ?*
- *Is the quake near salt water?*
- *Is the quake location likely to threaten our AOR or the Pacific ?*





Quick review of summary of quake parameters & procedures prior to issue of warning

Magnitude: 7.9

Latitude: 42.0N

Longitude: 143.9E

Origin Time: 1950 09/25/03

Local Time: 1150 am ADT 09/25/03

Depth: 40

Region: Pacific Basin

HOKKAIDO, JAPAN REGION

MS: Mwp:7.9 Mw: Mb: 6.1 Ml: 7.1

Suggested Procedure: WARNING/DANGER ADVISORY

Contacts:

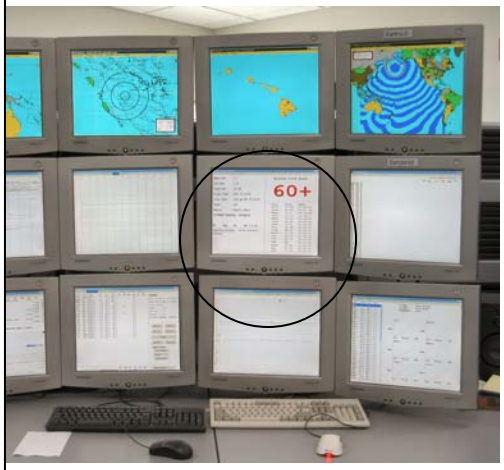
Get Chart

AK WFOs?	NAWAS	NADIN2/Line106
NWWS	Home Page	E-Mail
ECC	AP-if warning	PTWC
NEIC	CORMS	P-times/all

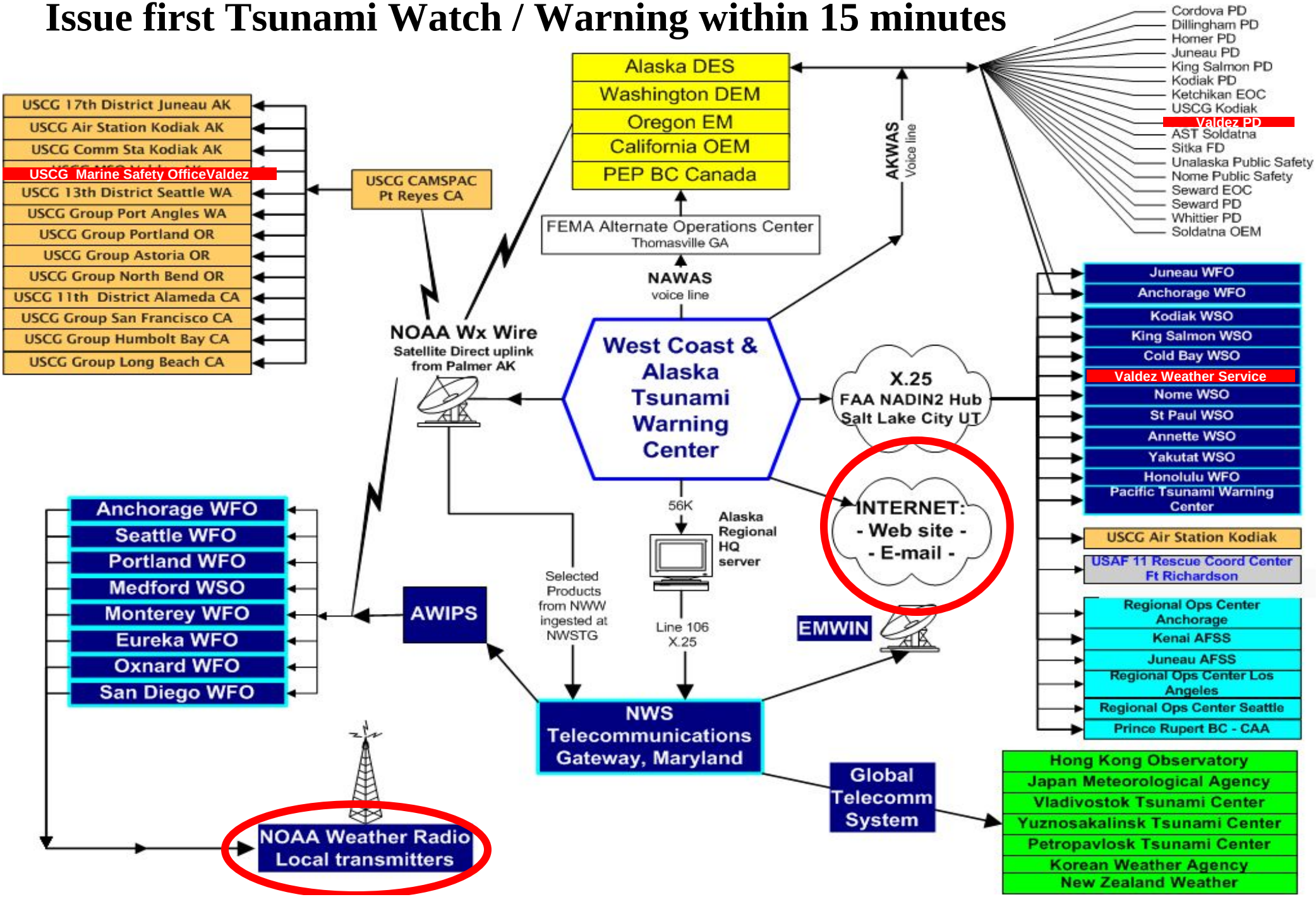
Minutes Since Quake:

10

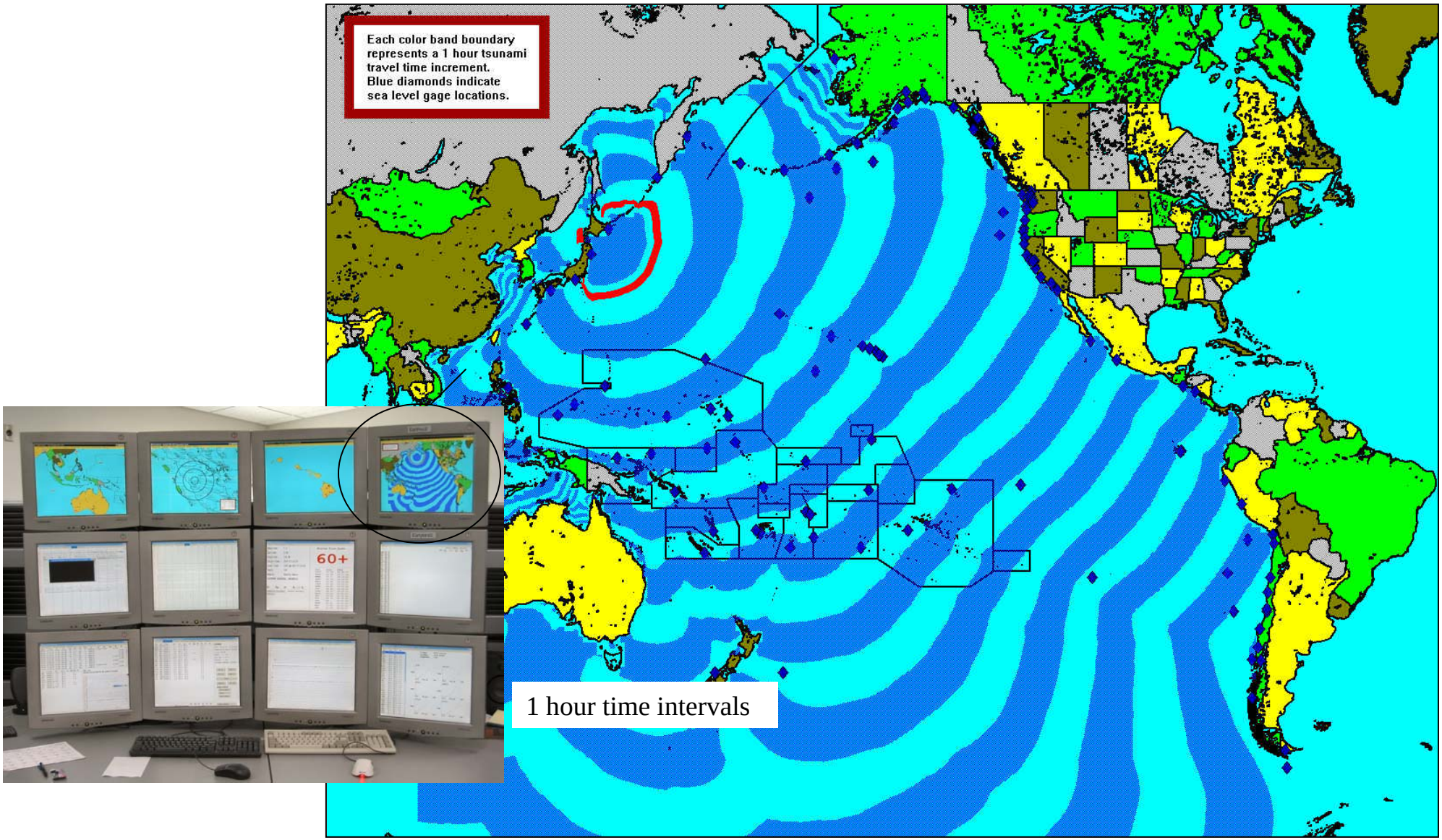
Sta.	Dist.	ETAZ
YSS	5.063	19:52:49
MAJO	7.005	19:53:51
INCN	14.	19:57:29
PET	14.83	19:57:58
MA2	18.1	19:59:43
YAK	21.76	20:01:30
SMY	22.95	20:02:02
TATO	25.12	20:03:01
ULN	26.52	20:03:38
GUMO	28.34	20:04:28
ADK	28.37	20:04:28
BILL	28.78	20:04:39
WAKE	29.8	20:05:04
ATKA	29.92	20:05:07
TIXI	30.62	20:05:27
PMR	43.55	20:11:55



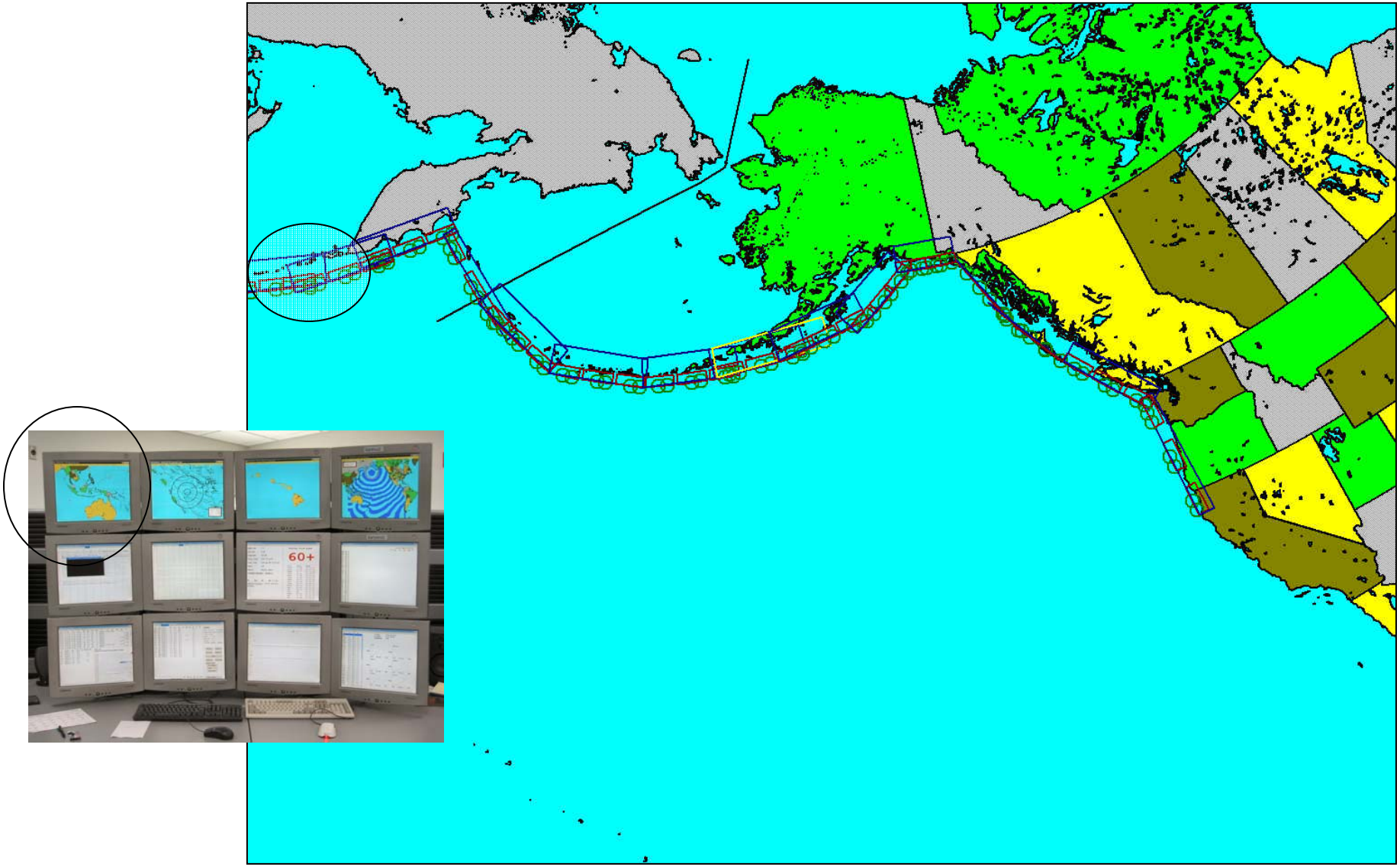
Issue first Tsunami Watch / Warning within 15 minutes



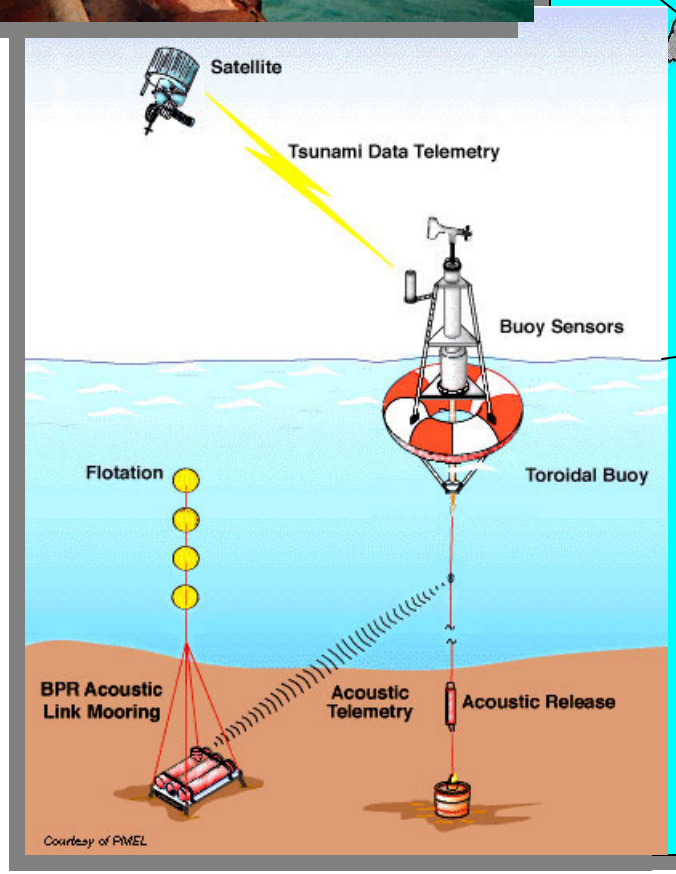
Travel time maps estimate the leading wave arrival time at coastal points and at tide gages / buoys

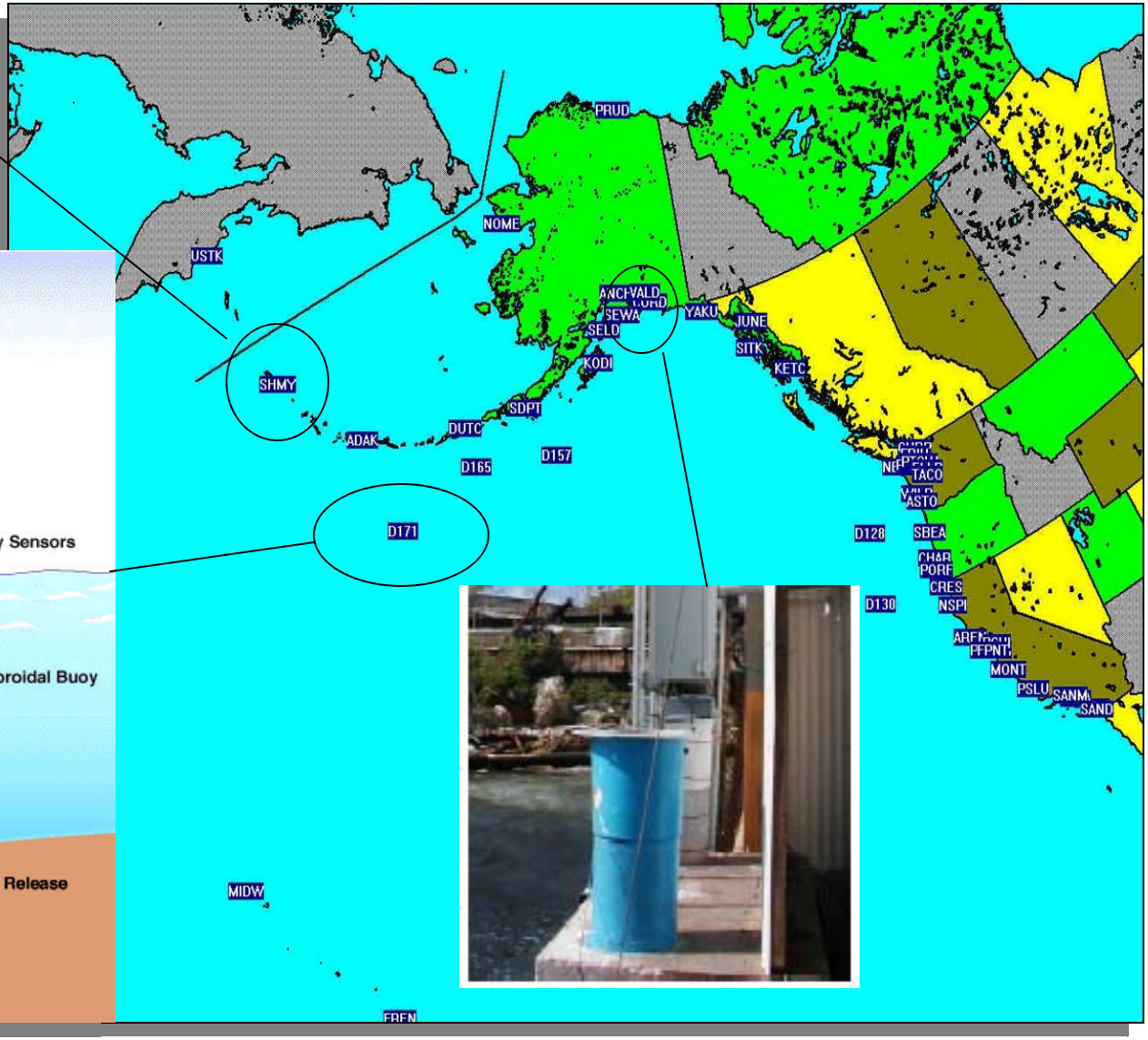


Locate the nearest fault plane (box) with a precomputed tsunami model scenario to predict wave heights along the west coast



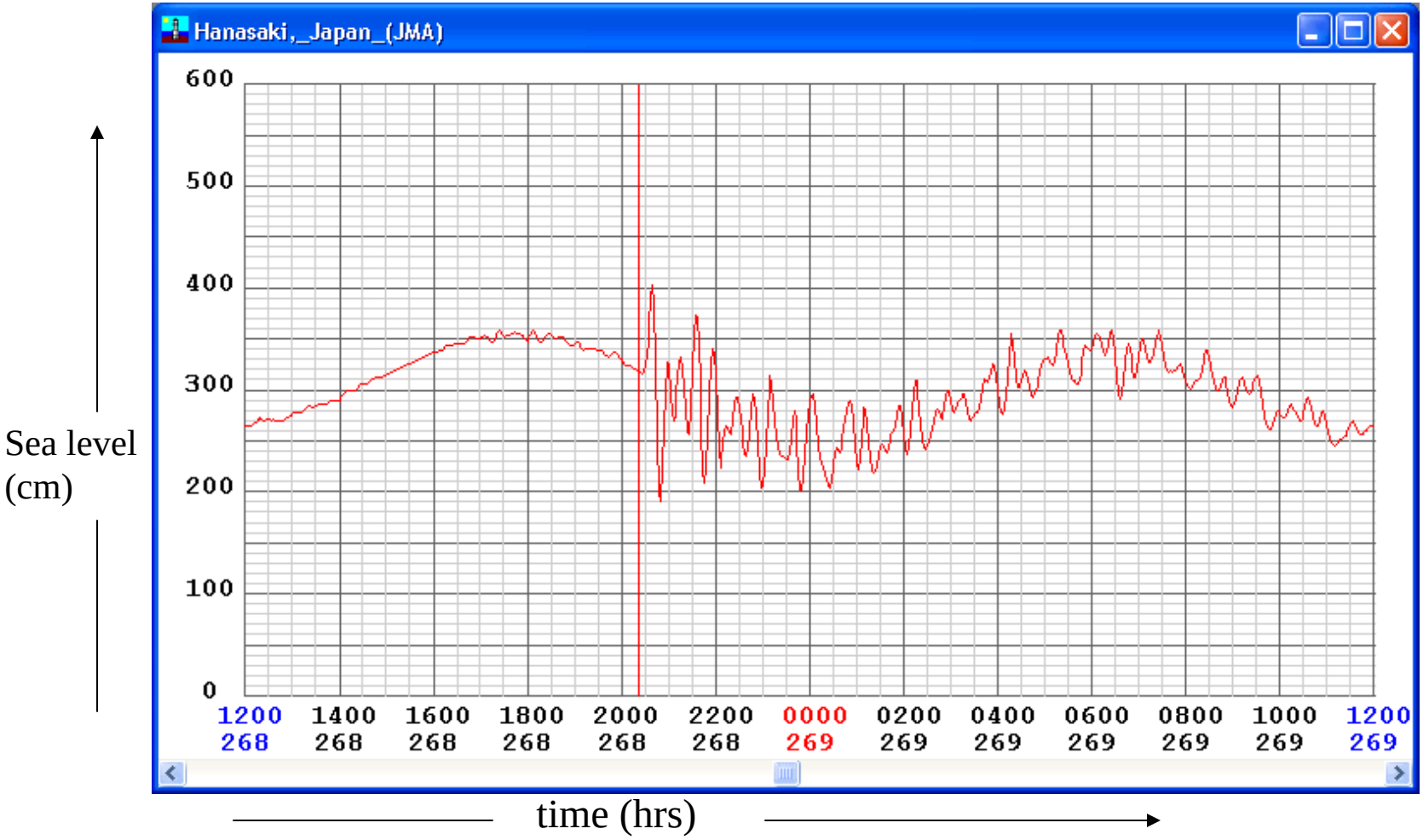
Initiate wave height assessment from tide gauge and buoy data



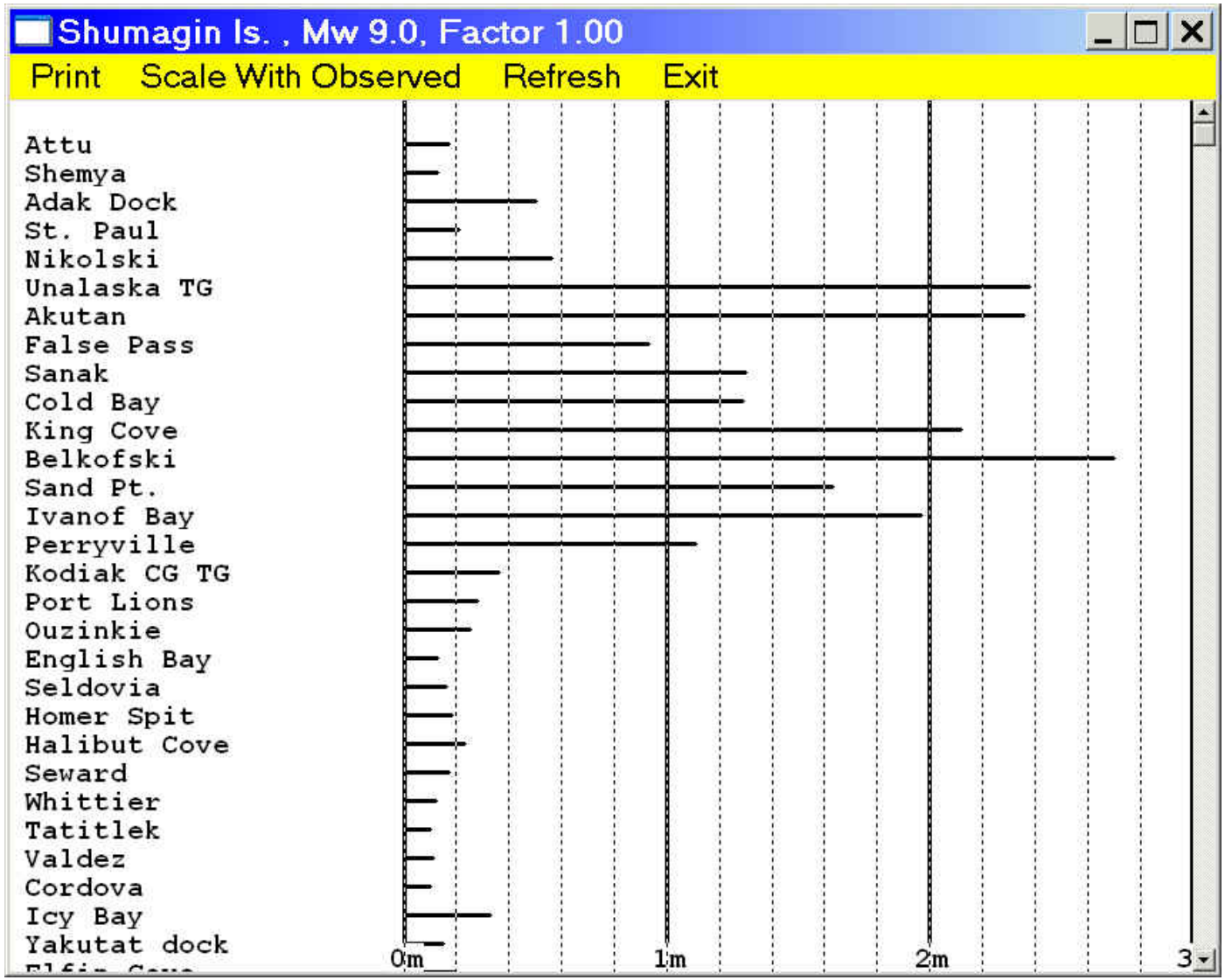


- click on button below

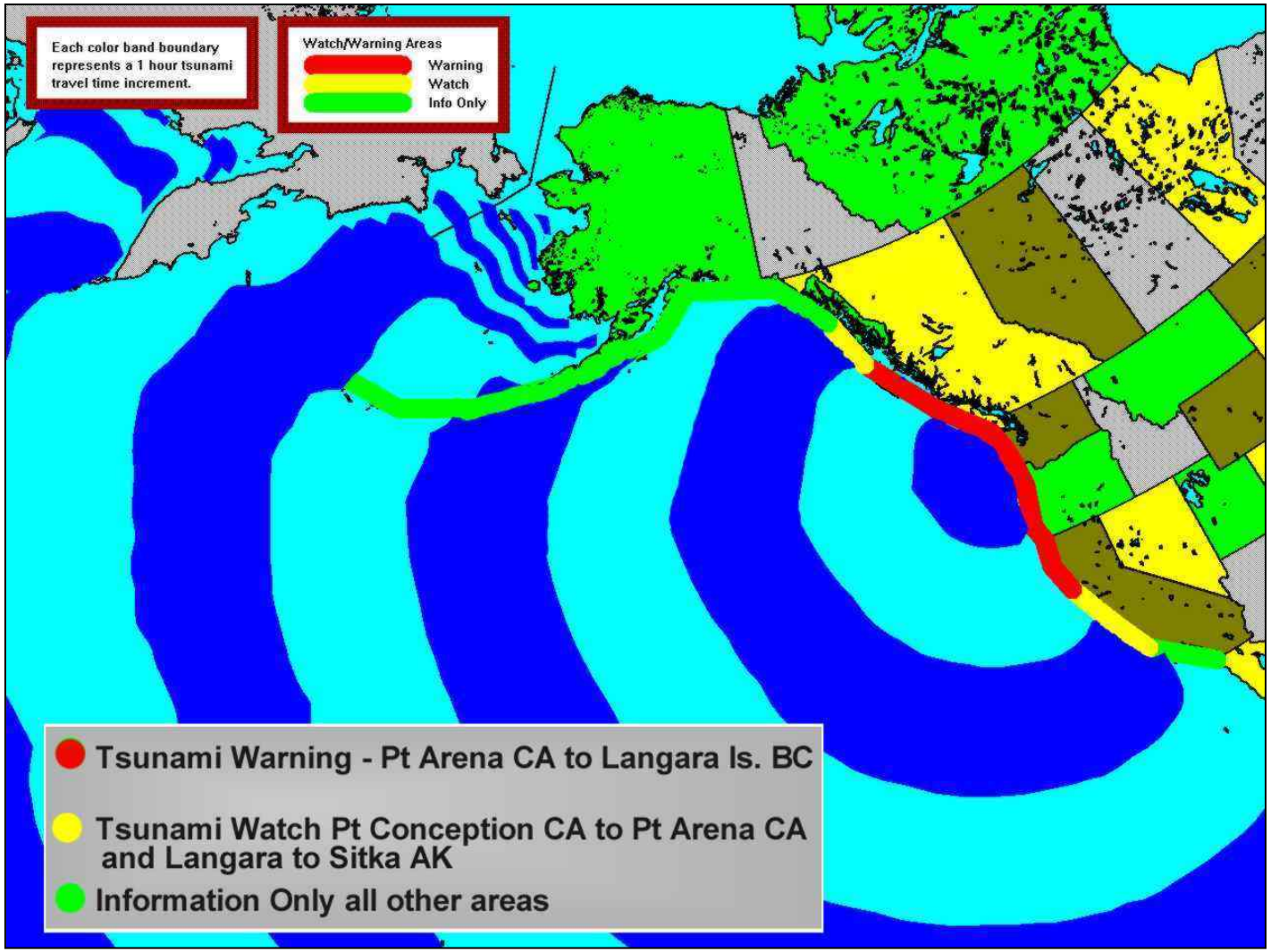
Confirmation that a tsunami was generated: high frequency signal riding on the tidal data, arriving at the predicted time!



Match model estimates of wave heights at west coast warning points with available sea level data



An expanding W/W may be issued



Message Thresholds

- Magnitudes less than 6.5
  Information message
- Magnitudes from 6.5 to 7.0
  Tsunami Information Bulletin
- Magnitudes from 7.1 to 7.5
  2 hour warning / 1 hour watch
- Magnitudes 7.6 and greater
  3 hour warning / 3 hour watch
- Confirmed damaging wave
  Entire Area placed in
  Warning status

End of general presentation

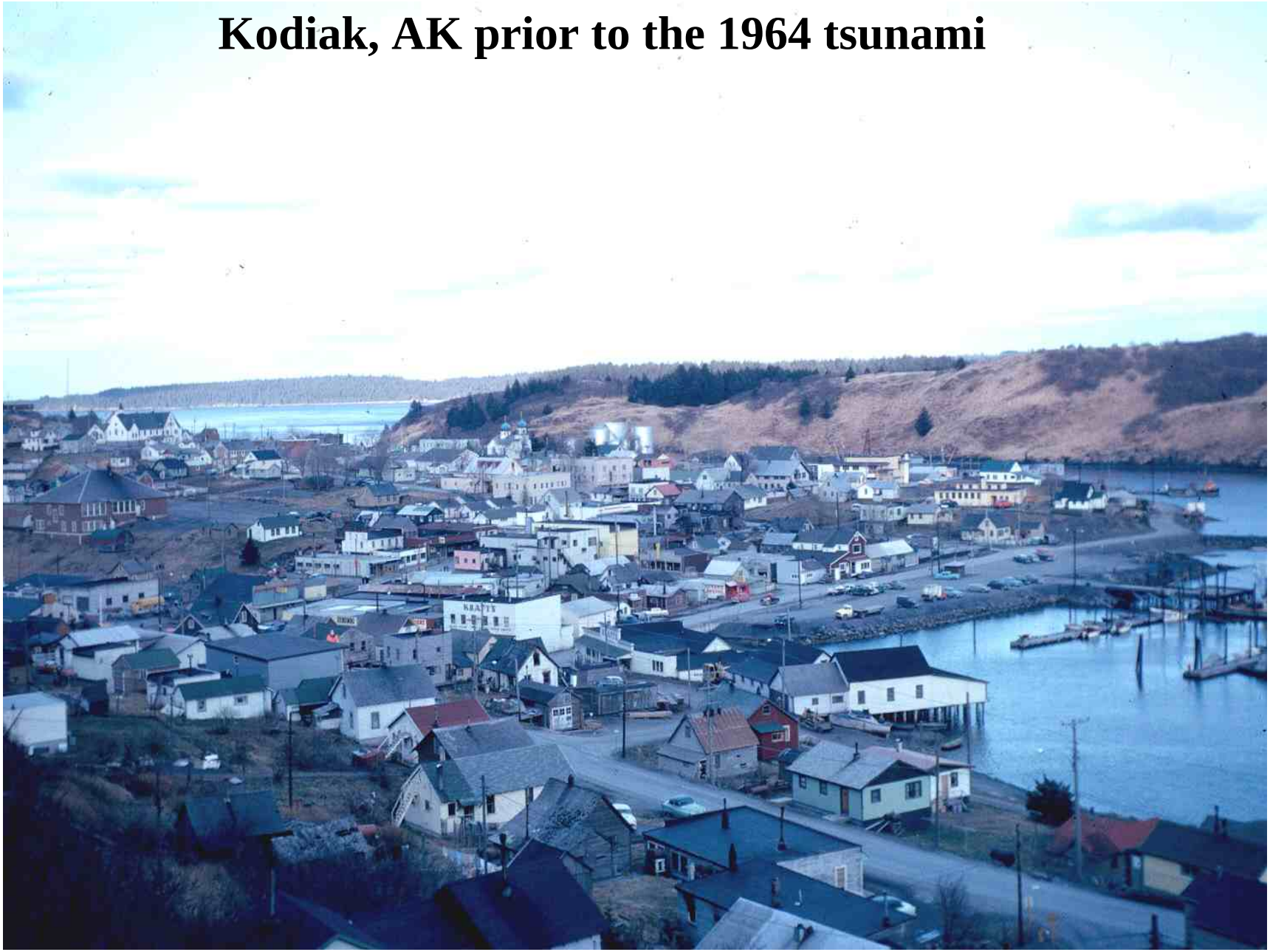
Return to start

Valdez, Alaska
March 28, 1964

Resurrection Bay 1964

Seward 1964

Kodiak, AK prior to the 1964 tsunami



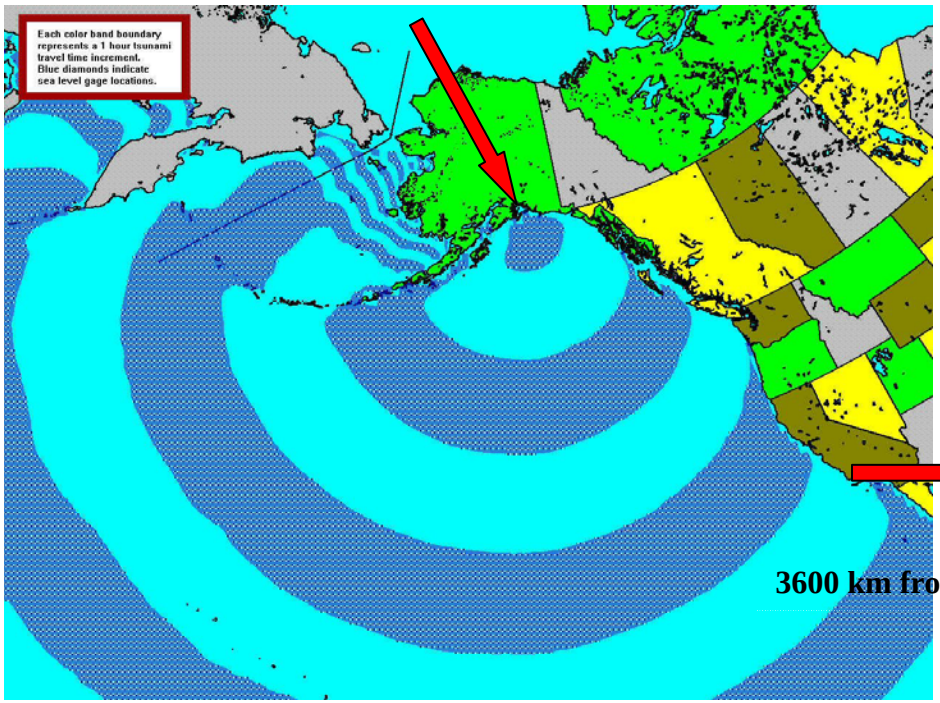
Kodiak, AK after the 1964 tsunami

Kodiak – the high water mark 1964

The ‘reach’ of the 1964 Good Friday Earthquake and Tsunami

Epicenter: College Fjord, Alaska

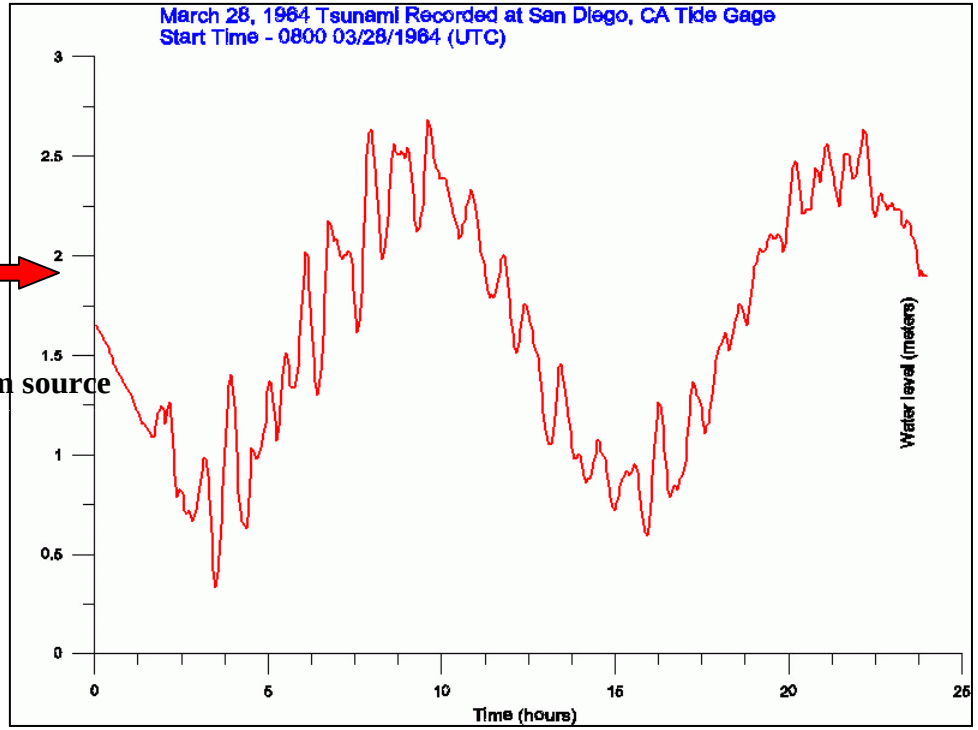
time: 3/28/1964 3:36 UTC



3600 km from source

Southern California damage Summary

- **Santa Monica: harbor damage $100,000**
- **Moro Bay: boats damaged**
- **Los Angeles: 3 boats sunk $200,000**
- **San Diego: minor damage**



End of tsunami images

Return to start

TSUNAMIS ARE AN INTERNATIONAL HAZARD

Photo by:

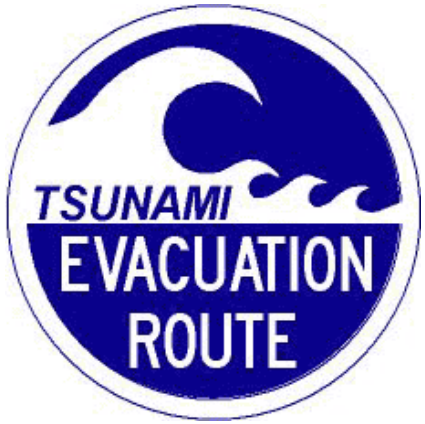
Hubert Chanson

University of Queensland, AU

Entering A
TsunamiReady
Community
IN CASE OF EARTHQUAKE, GO TO
HIGH GROUND OR INLAND

TSUNAMI
EVACUATION
ROUTE

TSUNAMI HAZARD ZONE
IN CASE OF EARTHQUAKE, GO
TO HIGH GROUND OR INLAND


TSUNAMI
EVACUATION
ROUTE

Local Response to a Tsunami Threat

- Be alert to nature's clues

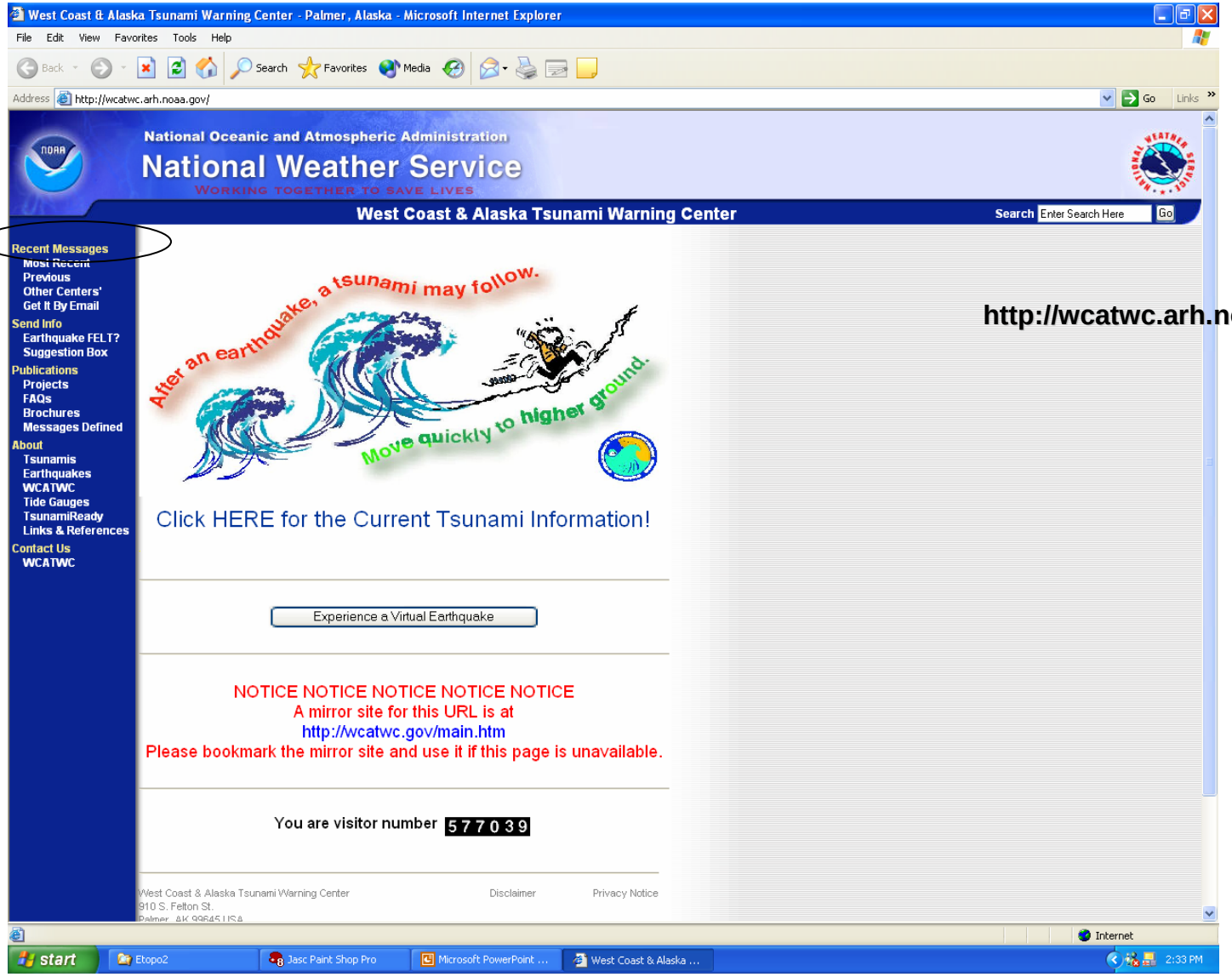
  recession of water

  30s or more severe earth motion

  earthquake followed by a recession of water

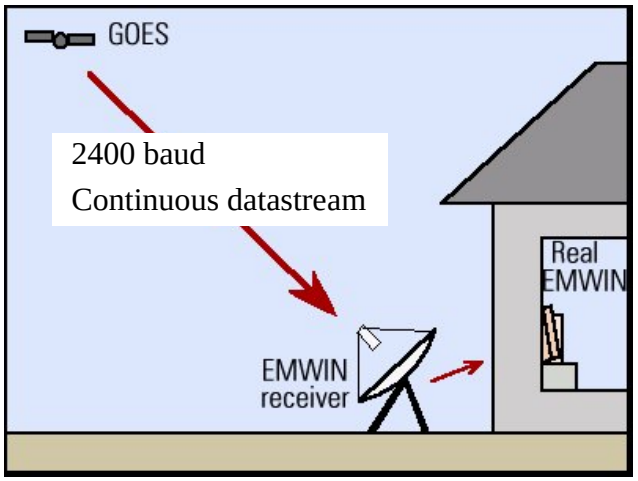
- Listen for sirens, alerts
- Follow EM directions for immediate evacuation
- Use evacuation routes, move 1 mile inland and 100 feet above sea level

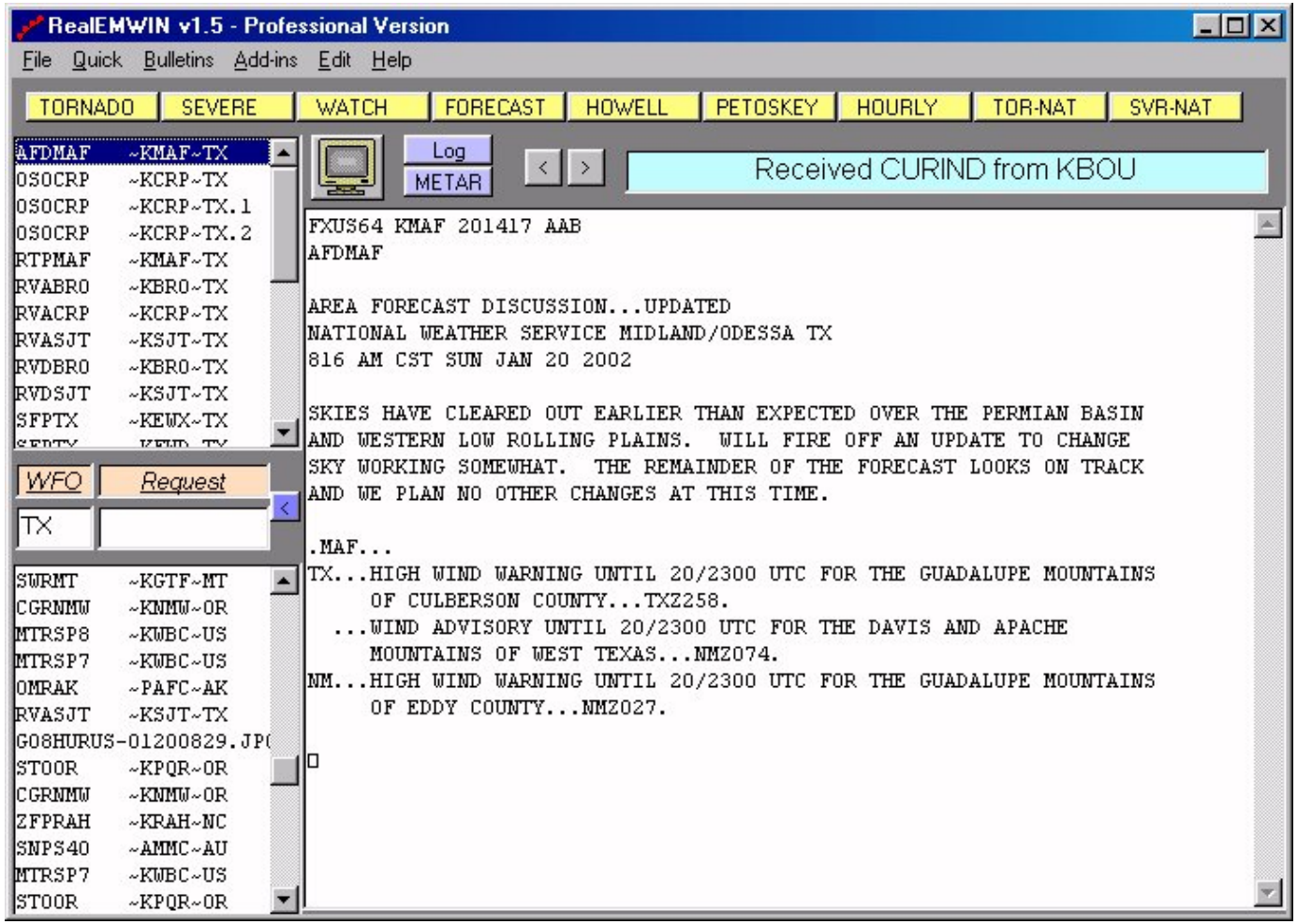
W/W information posted on the WCATWC websites



http://wcatwc.arh.noaa.gov

W/W information arrives on EMWIN systems via satellite or internet





WMO THREAT CODE

AWIPS CODE (WFO)

HOURLY BULLETINS READ OVER NAWAS

EVENT TIME

FIRST MESSAGE BASED SOLELY ON SEISMIC ANALYSIS

UGC CODES

```
WEPA41 PAAQ 162104
TSUWCA

TO      - TSUNAMI WARNING SYSTEM PARTICIPANTS IN
          ALASKA/BRITISH COLUMBIA/WASHINGTON/OREGON/CALIFORNIA
FROM    - WEST COAST AND ALASKA TSUNAMI WARNING CENTER/NOAA/NWS
SUBJECT - TSUNAMI WARNING BULLETIN - INITIAL
BULLETIN NUMBER 1
ISSUED 09/16/2004 AT 2104 UTC

...A TSUNAMI WARNING IS IN EFFECT FOR THE COASTAL AREAS
   FROM SEWARD-AK. TO ATTU-AK. INCLUSIVE...

...A TSUNAMI WATCH IS IN EFFECT FOR THE COASTAL AREAS FROM
   THE CALIFORNIA-MEXICO BORDER TO SEWARD-AK...

EARTHQUAKE DATA
 PRELIMINARY MAGNITUDE - 8.5
 LOCATION -  52.2N  168.7W -  50 MILES S OF NIKOLSKI-AK.
                              340 MILES E OF ADAK-AK.
 TIME     - 0945 ADT 09/15/2004
            1045 PDT 09/15/2004
            1745 UTC 09/15/2004

EVALUATION
 IT IS NOT KNOWN - REPEAT NOT KNOWN - IF A TSUNAMI EXISTS BUT A
 TSUNAMI MAY HAVE BEEN GENERATED.  THEREFORE PERSONS IN LOW
 LYING COASTAL AREAS SHOULD BE ALERT TO INSTRUCTIONS FROM THEIR
 LOCAL EMERGENCY OFFICIALS. PERSONS ON THE BEACH SHOULD MOVE TO
 HIGHER GROUND IF IN A WARNED AREA. TSUNAMI WAVE HEIGHTS CANNOT BE
 PREDICTED. TSUNAMIS MAY BE A SERIES OF WAVES WHICH COULD BE
 DANGEROUS FOR SEVERAL HOURS AFTER THE INITIAL WAVE ARRIVAL.

$$
PKZ176-175-172-170-171-155-150-132-136-138-137-130-141-140-
120-121-AKZ191-185-181-171-145-111-101-121-125-162204-
COASTAL AREAS FROM SEWARD-AK. TO ATTU-AK. INCLUSIVE.
```

EACH COUNTY FORMATS ITS OWN MESSAGE

COMPUTED ETAs

```
...A TSUNAMI WARNING IS IN EFFECT FOR THE COASTAL AREAS
   FROM SEWARD-AK. TO ATTU-AK. INCLUSIVE...

ESTIMATED TIMES OF INITIAL WAVE ARRIVAL
DUTCH HARBOR-AK  1051 ADT SEP 15   COLD BAY-AK      1201 ADT SEP 15
ADAK-AK          1053 ADT SEP 15   KODIAK-AK        1223 ADT SEP 15
SHEMYA-AK        1134 ADT SEP 15   SEWARD-AK        1250 ADT SEP 15
SAND PT.-AK      1135 ADT SEP 15   HOMER-AK         1345 ADT SEP 15
$$
PKZ120-121-129-127-125-126-128-052-051-053-022-012-043-013-
011-021-032-031-042-034-033-035-041-036-PZZ130-131-133-134-
132-135-150-153-156-110-250-210-255-350-353-356-450-455-
550-530-535-555-670-673-650-655-750-AKZ125-131-135-017-020-
018-019-021-022-023-024-025-026-028-029-027-WAZ001-002-005-
006-007-008-009-010-011-013-014-015-016-021-ORZ001-002-021-
022-CAZ001-002-005-007-006-075-074-009-034-035-039-040-046-
041-042-043-162204-
COASTAL AREAS FROM THE CALIFORNIA-MEXICO BORDER TO
SEWARD-AK.

...A TSUNAMI WATCH IS IN EFFECT FOR THE COASTAL AREAS FROM
   THE CALIFORNIA-MEXICO BORDER TO SEWARD-AK...

ESTIMATED TIMES OF INITIAL WAVE ARRIVAL
YAKUTAT-AK       1302 ADT SEP 15   NEAH BAY-WA      1547 PDT SEP 15
SITKA-AK         1304 ADT SEP 15   CHARLESTON-OR    1552 PDT SEP 15
LANGARA-BC       1410 PDT SEP 15   CRESCENT CITY-CA 1559 PDT SEP 15
VALDEZ-AK        1312 ADT SEP 15   SEASIDE-OR       1600 PDT SEP 15
CORDOVA-AK       1322 ADT SEP 15   ASTORIA-OR       1623 PDT SEP 15
KETCHIKAN-AK     1423 ADT SEP 15   SAN FRANCISCO-CA 1644 PDT SEP 15
JUNEAU-AK        1425 ADT SEP 15   SAN PEDRO-CA     1709 PDT SEP 15
TOFINO-BC        1537 PDT SEP 15   LA JOLLA-CA      1720 PDT SEP 15
```

Local Response (from Hawaii CD):

- Listen for sirens (beach mounted and on small aircraft)
- Boat owners move boats out to 200 fathoms of water (distant source)
- Swimmers, surfers get out of water immediately
- Surfers: “These waves aren’t surfable”
- Move ½ mile inland, following signage and evacuation maps
- If you’re already safely inland, stay off the road
- Expect coastal power generation to shut down
- Keep an evacuation kit handy (see Red Cross suggestions)

▪Required elements for the "tsunami-ready" designation:

	COMMUNICATIONS	
Emergency Plan		
Local Warning Point	*24/7 receive and disseminate warnings*	
EOC	*staffed during events, multiple comms*	
	communications to NWS or TWC	
Four channels to receive warnings	*Pagers*	*Cellular Services*
	Satellite Phones	*Starband / satellite internet*
	Instant messaging	*Emwin*
	NWWS downlink (CLETS ?)	*NWR with tone alert*
	e-mail from the TWCs	*NAWAS*
	USCG	
Methods of Alerting Community	*Sirens (on cars, planes, at beaches)*	*NWR at: WP*
	Phone messaging	*EOC*
	TV crawlers	*City Hall*
		School District Headquarters
	PREPAREDNESS	
Inundation area Marked	*Signage*	*maps in phone books, in bills*
Evacuation Routes designated	*Topographic survey, inundation mapping*	*traffic analysis*
Provisions for tourists		
Evacuation Shelters		
Information / Maps	*Phone books, utility bills,*	*Public buildings*
Periodic Community Forum	*K-12 curriculum*	*Written information*
	tsunami evacuation drills	*NWS presentations*

End of tsunami-ready

Return to start

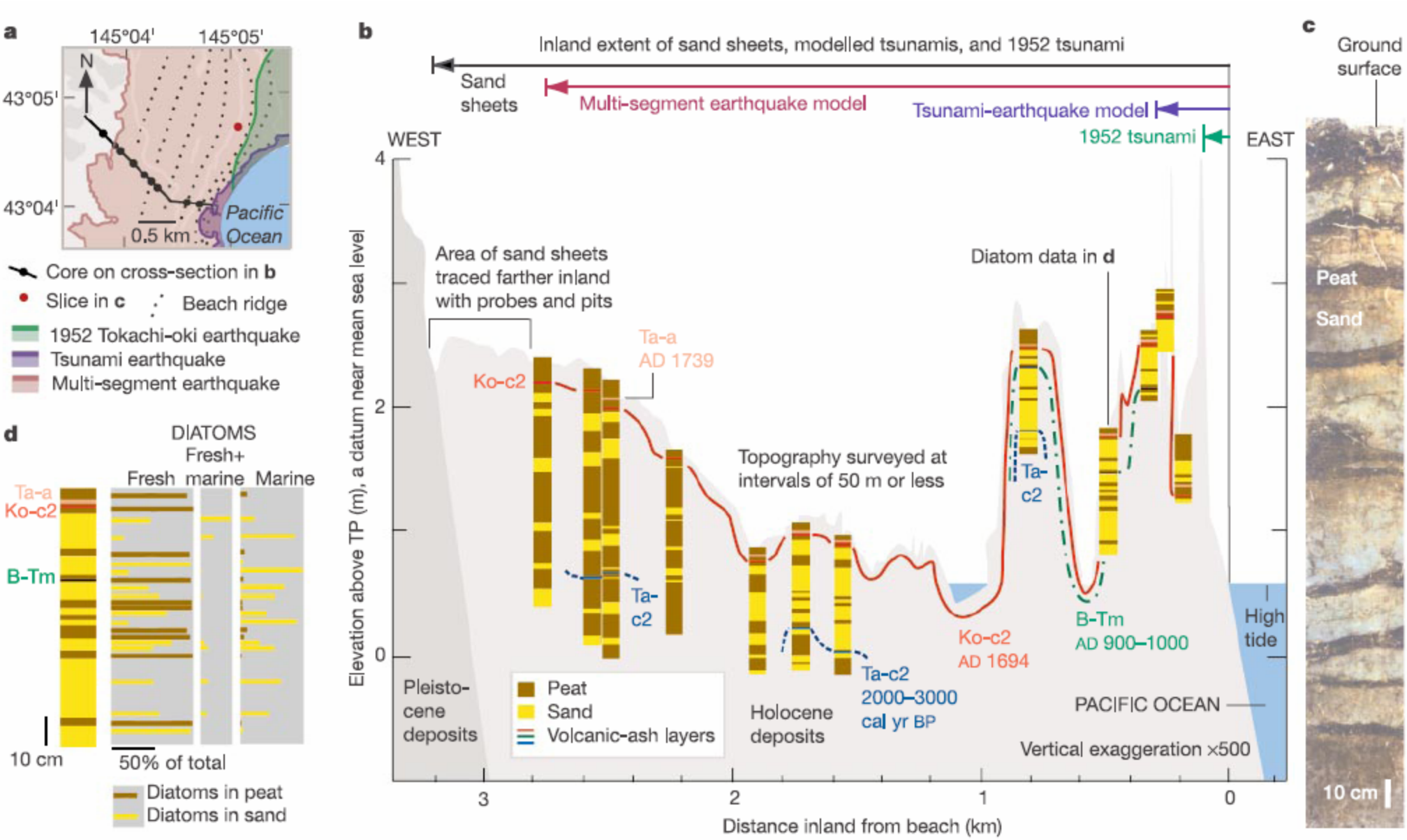


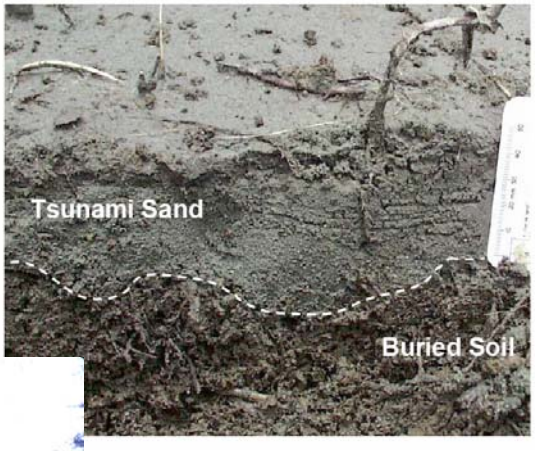
Figure 3 Evidence for outsize tsunamis at Kiritappu. **a**, Index map, showing inundation at top compare sand-sheet extent with inundation computed from hypothetical

Aftermath of a tsunami and earthquake

•Land Uplift / Subsidence affects migratory bird flight paths, forest health (Dusky Canada Geese, Girdwood area trees)

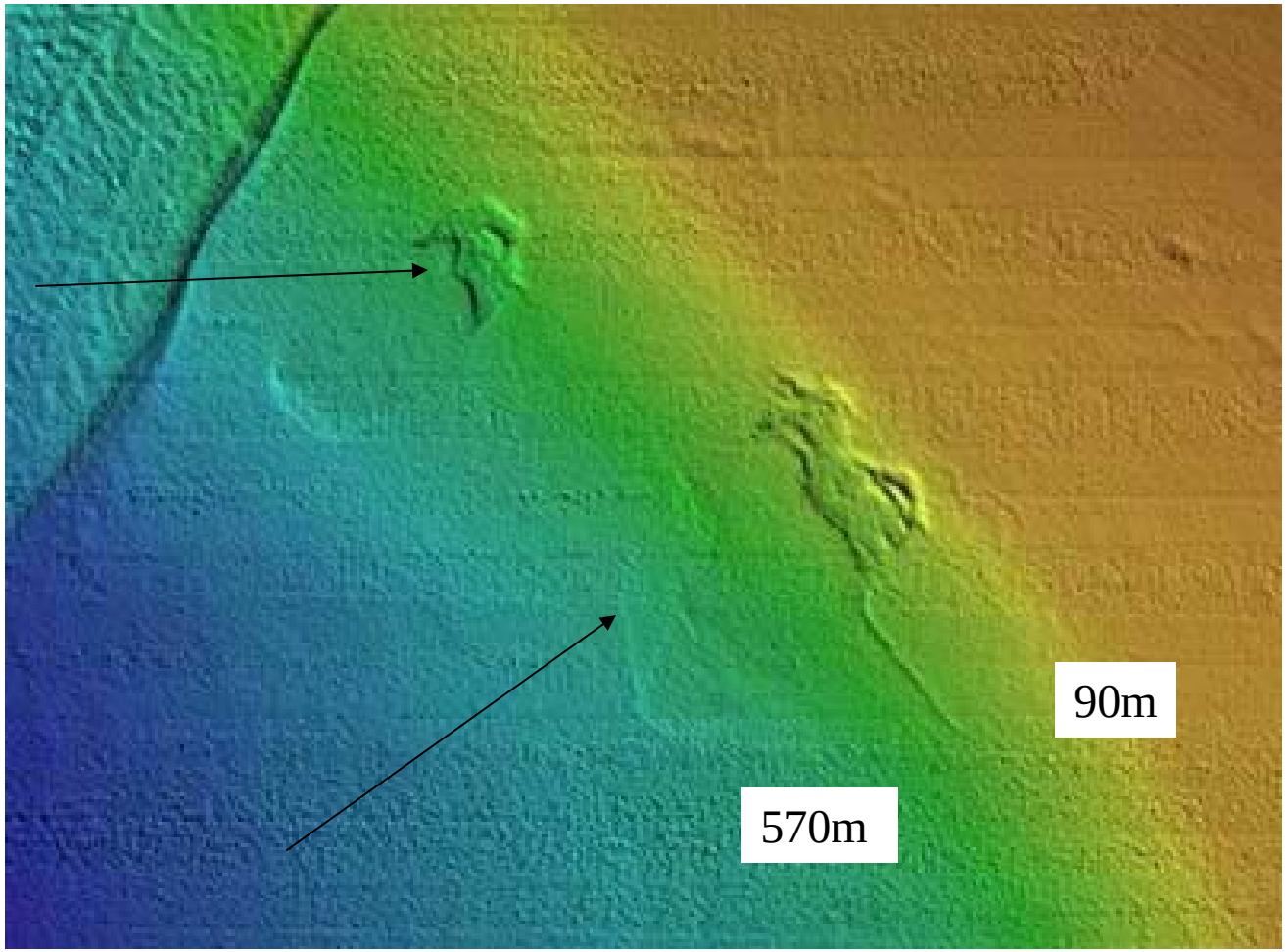
•Slides and sediment transport produce local tsunamis and affect Salmon runs

•Overland flow of saltwater / sand causes loss of cropland

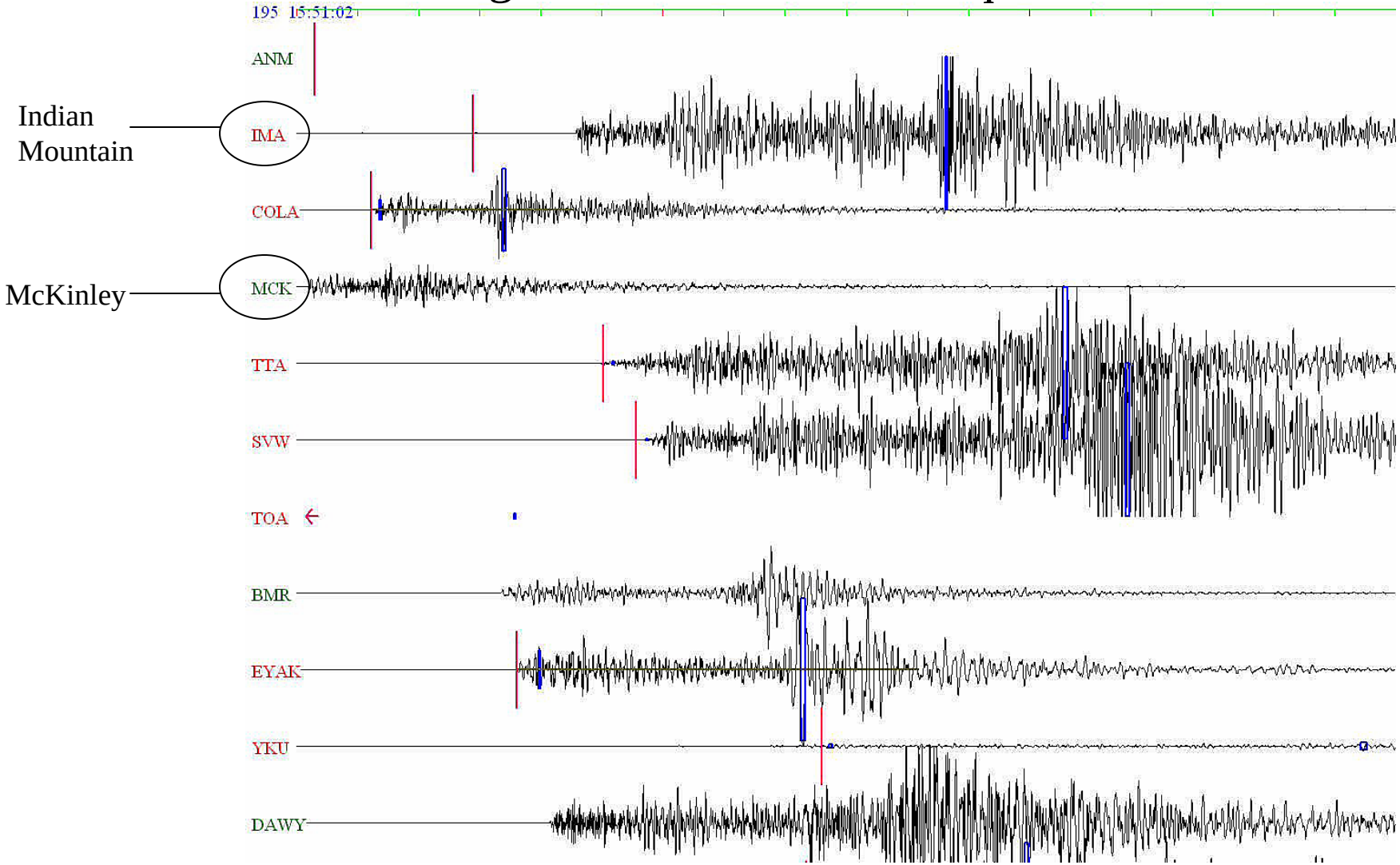


Submarine Slumps off the Santa Barbara coast -- 15 x 10 km

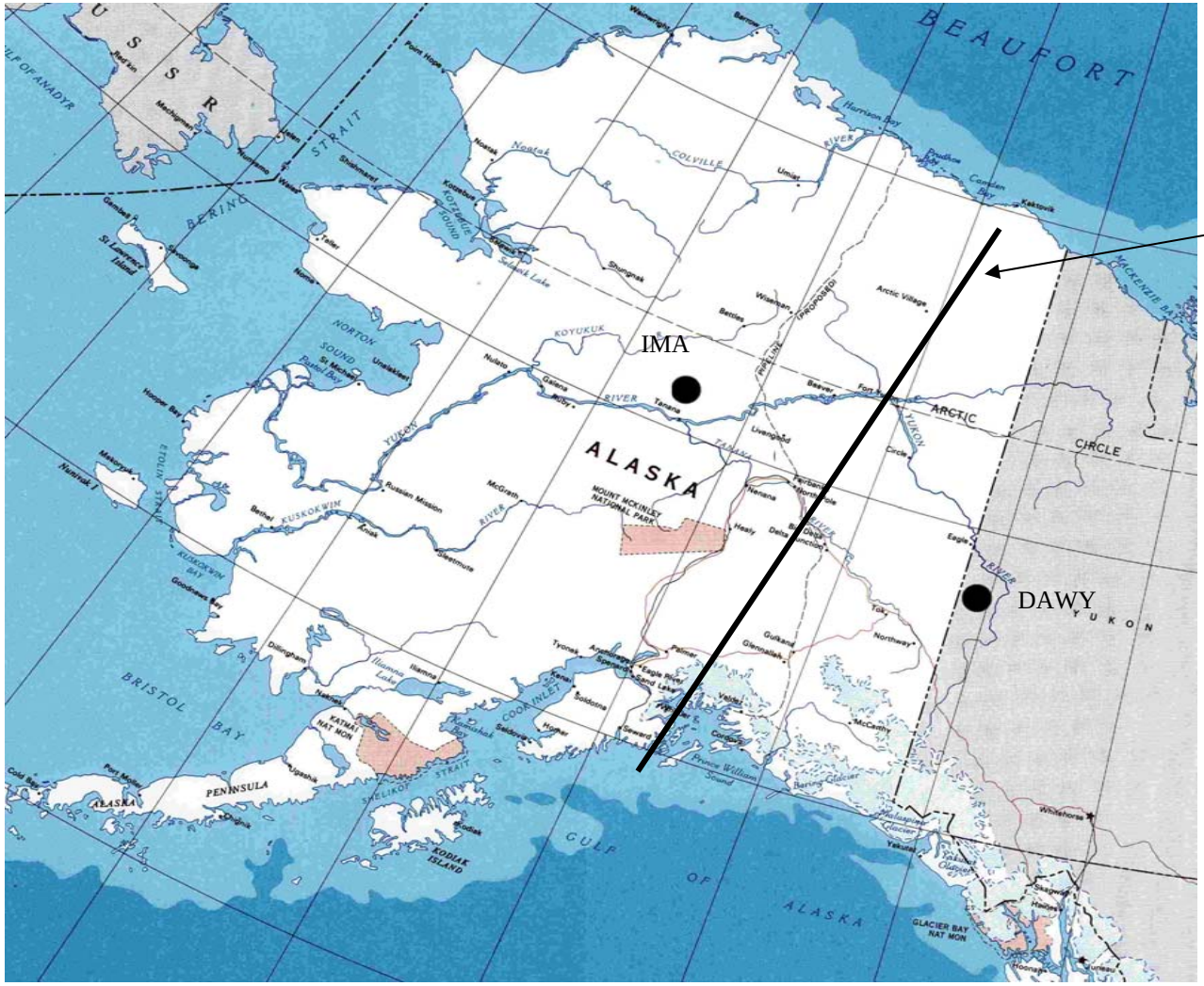
sonar side scan images: Monterey Bay Aquarium Research Institute



Seismograms for a small local quake on 7-13-03

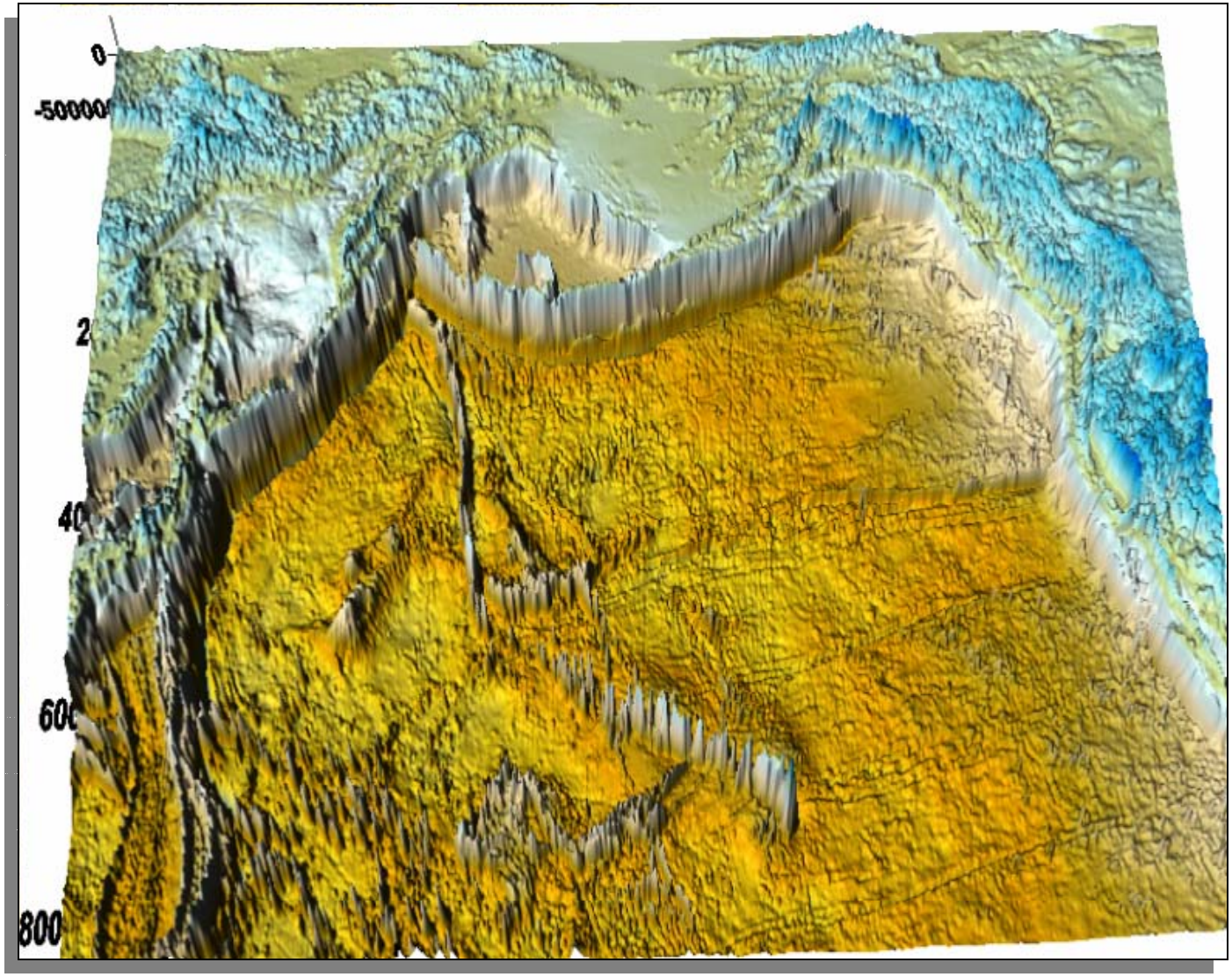


Epicenter location – based on seismograms from previous slide



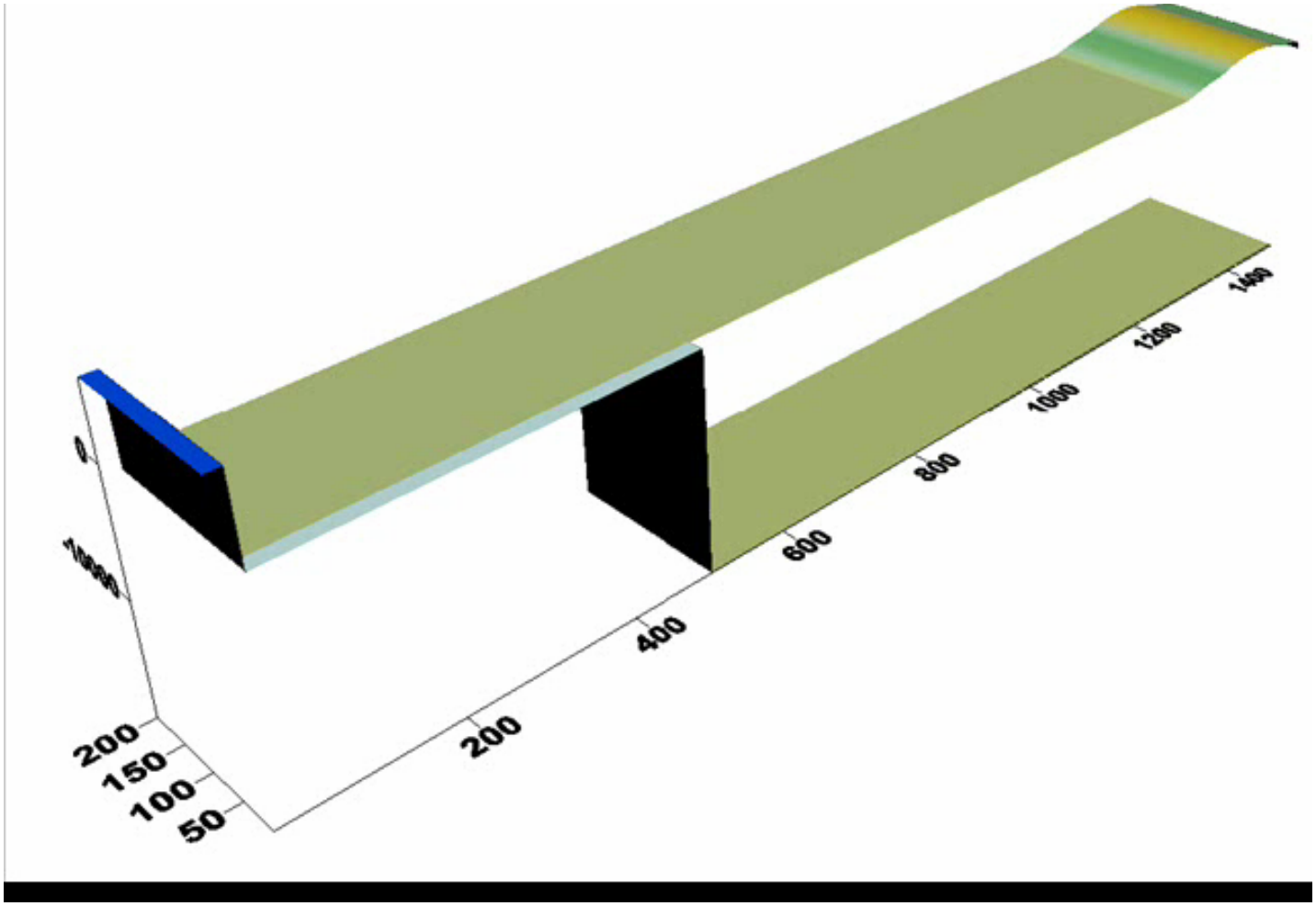
Anywhere along this line gives the same arrival time for IMA and DAWY

Accurate prediction of ETAs and runup depends on locating the source & on high resolution ocean bottom bathymetry



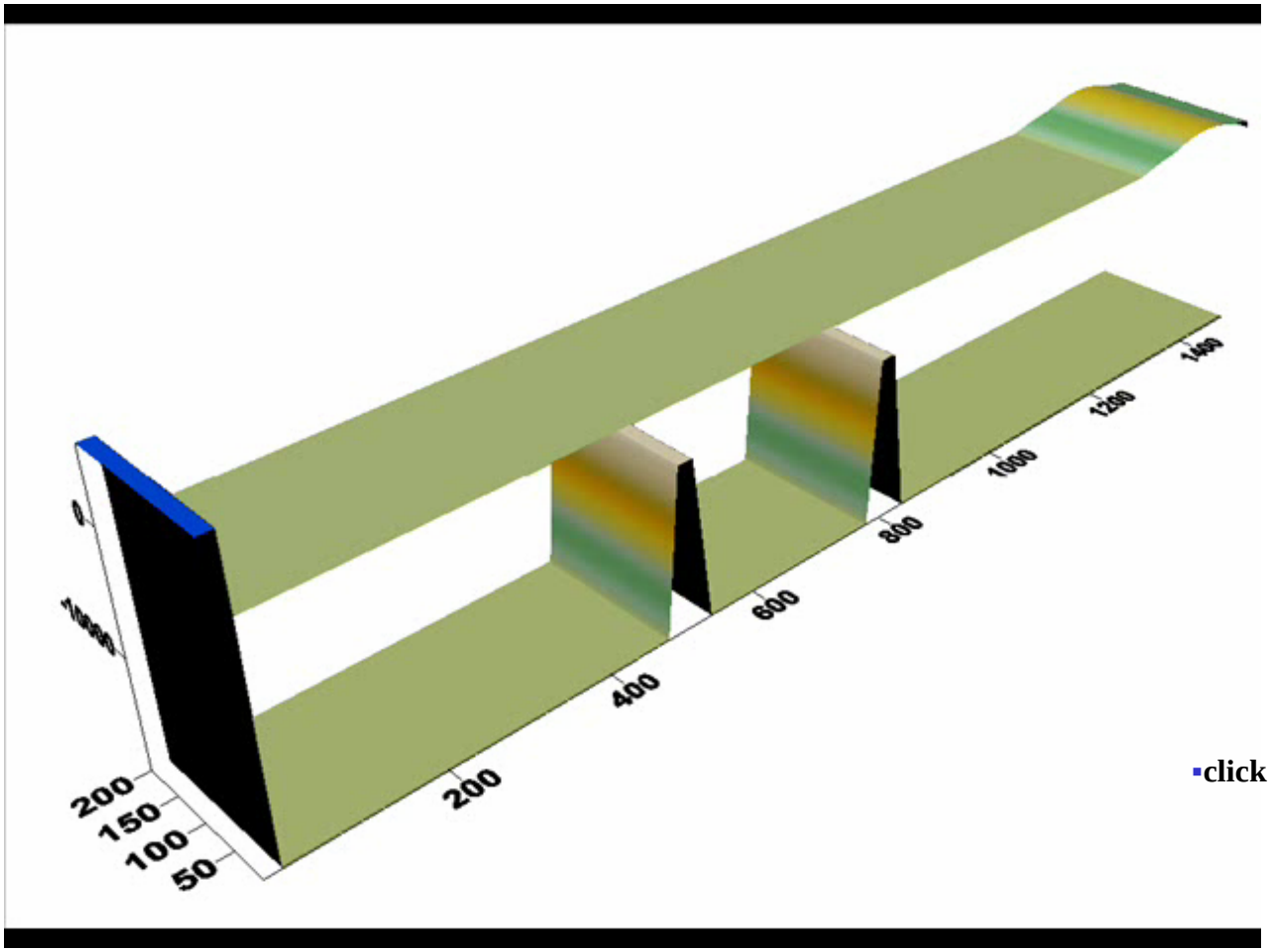
Etopo2 dataset
(NOAA)

- **Wave speed depends on depth**
- **Reflection coefficient depends on depth change**
- **Shallow water damps the waves more quickly than deep water**



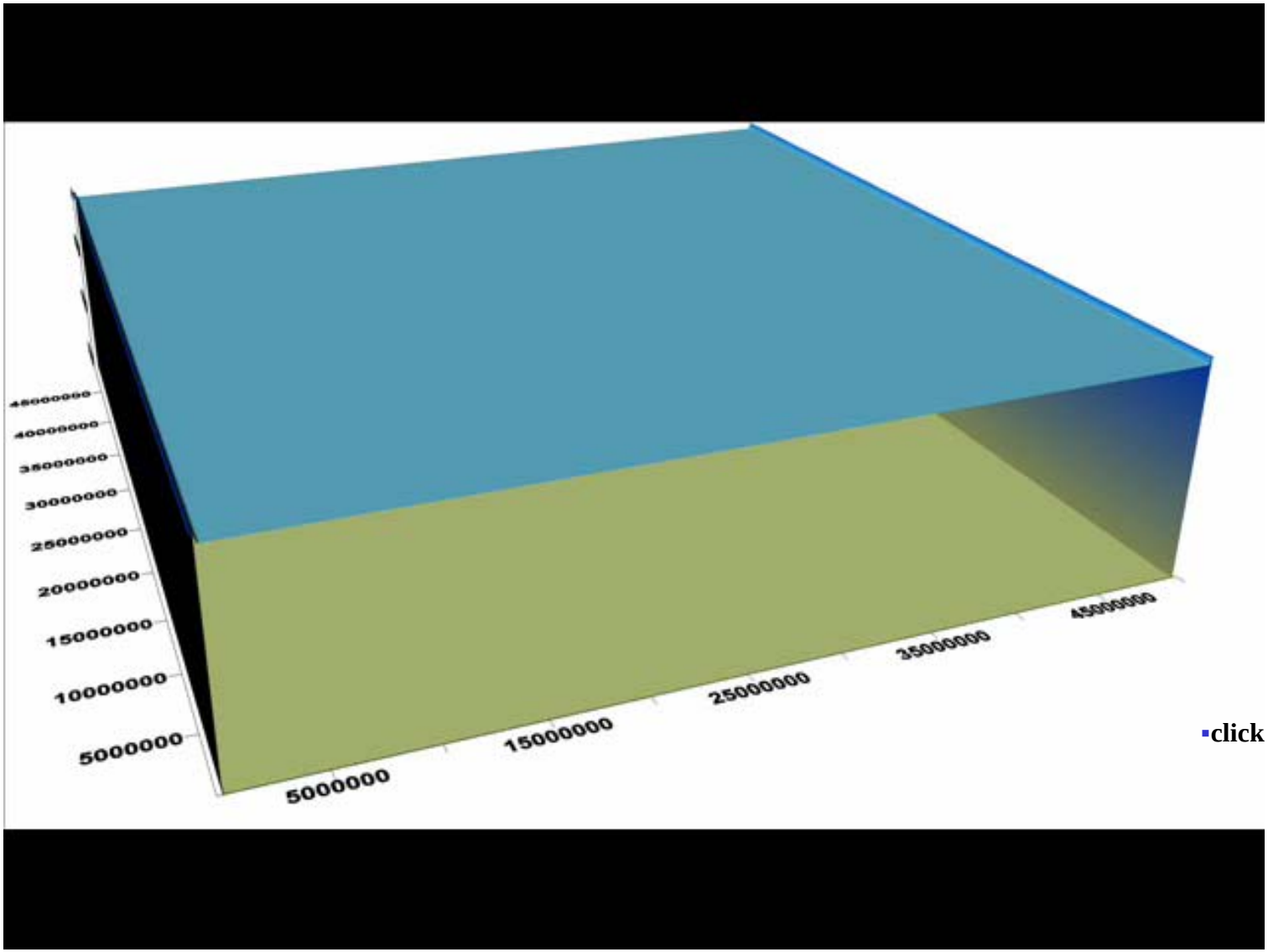
- **click on image**

- **Reflections can even be caused by seamounts**



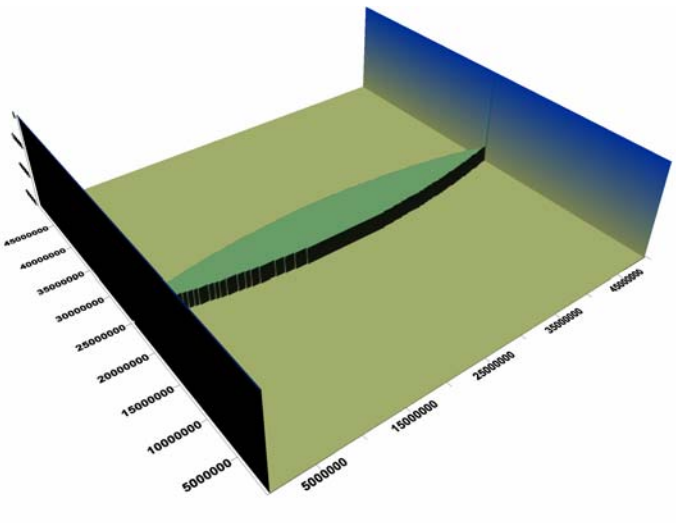
- **click on image**

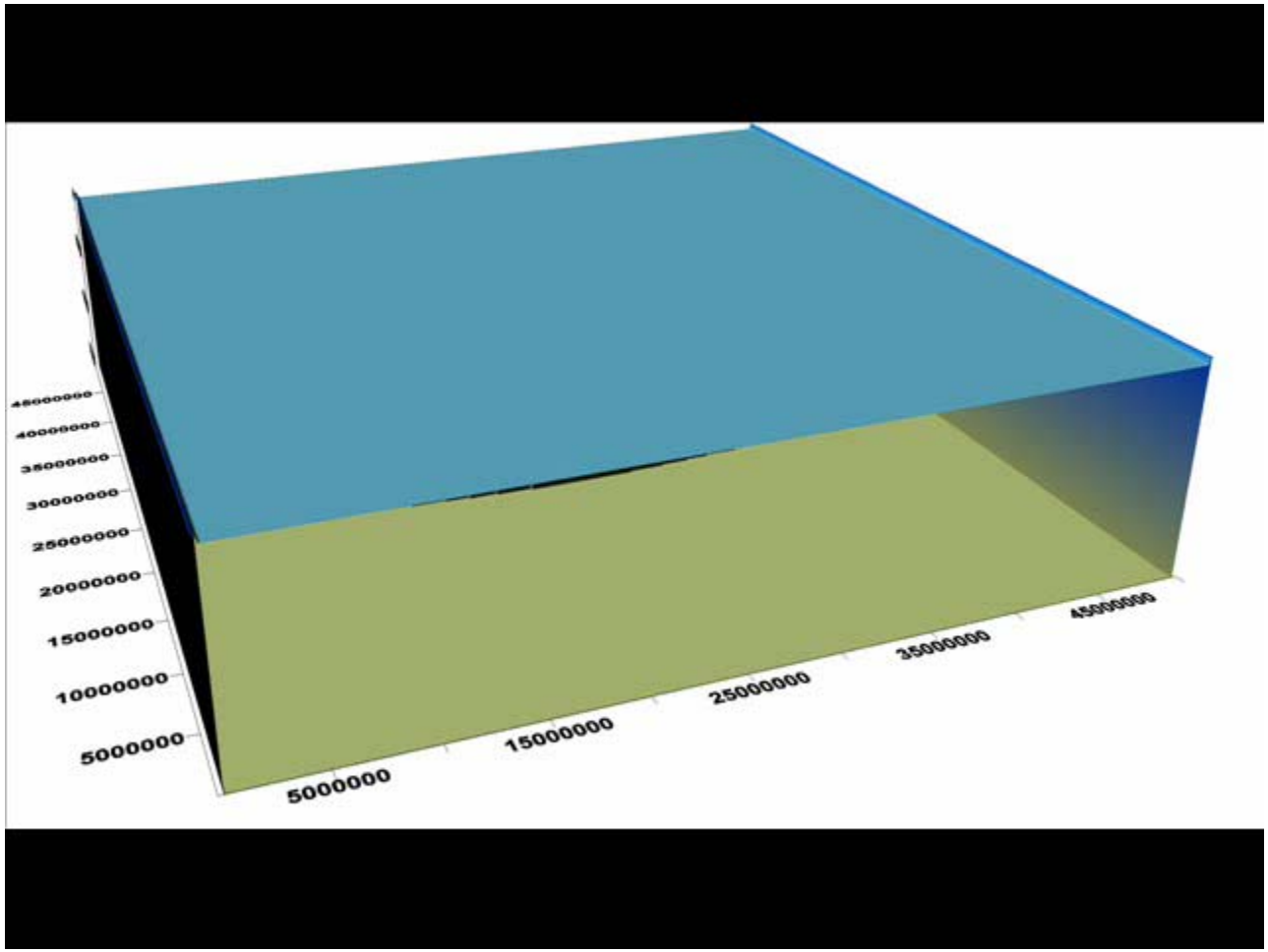
▪A model 500 x 500 km “Ocean” – flat bottom



▪click on image

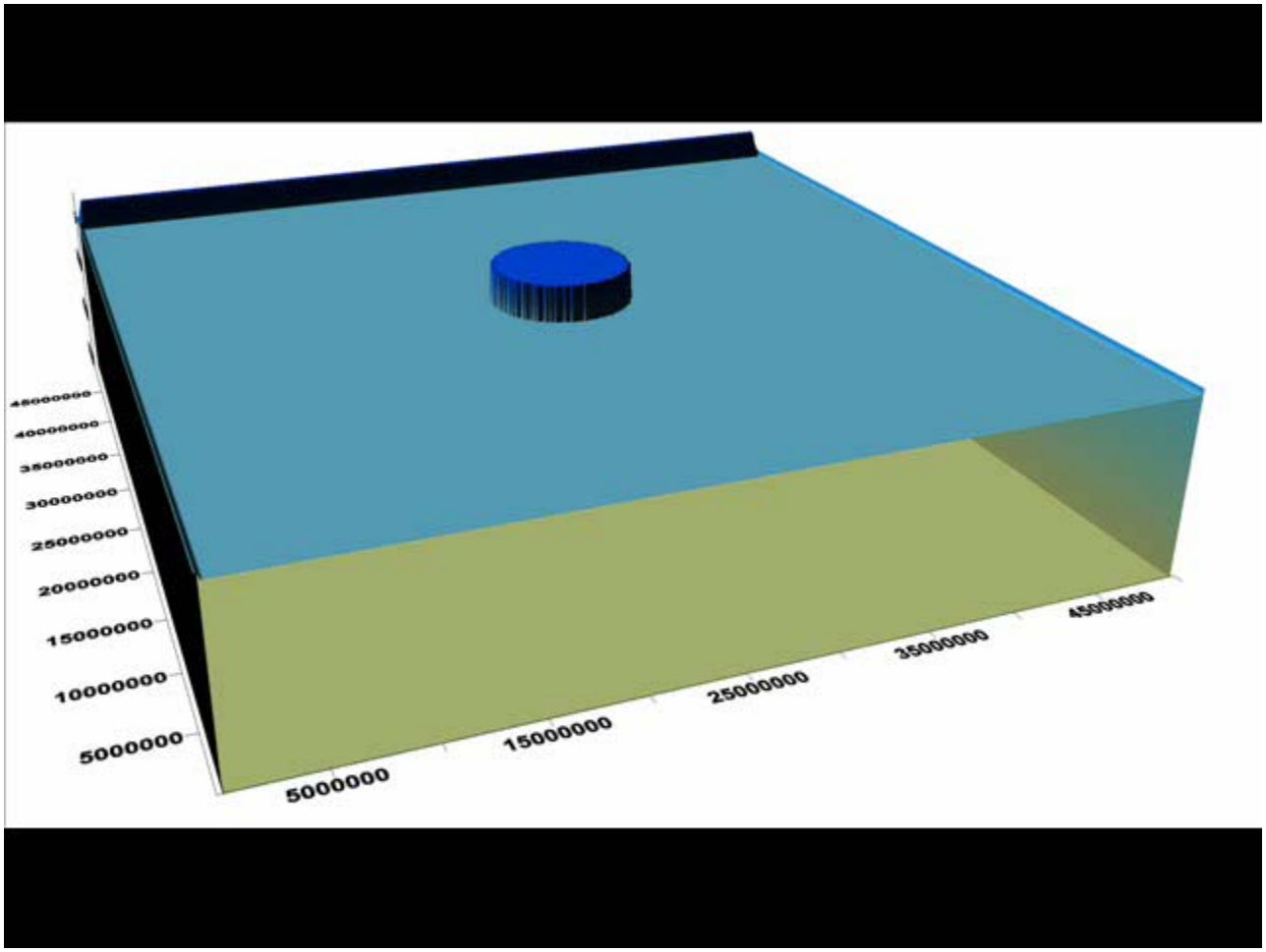
▪The same 500 x 500 km “Ocean” – bottom topography





▪click on image

- **The same 500 x 500 km “Ocean” – flat bottom and simple island**

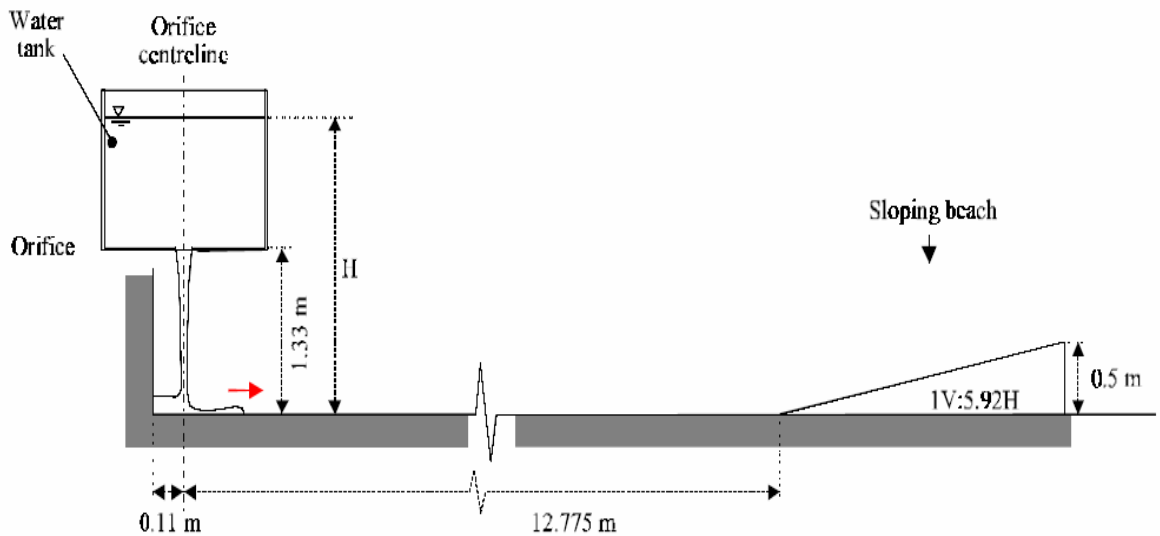


- **click on image**

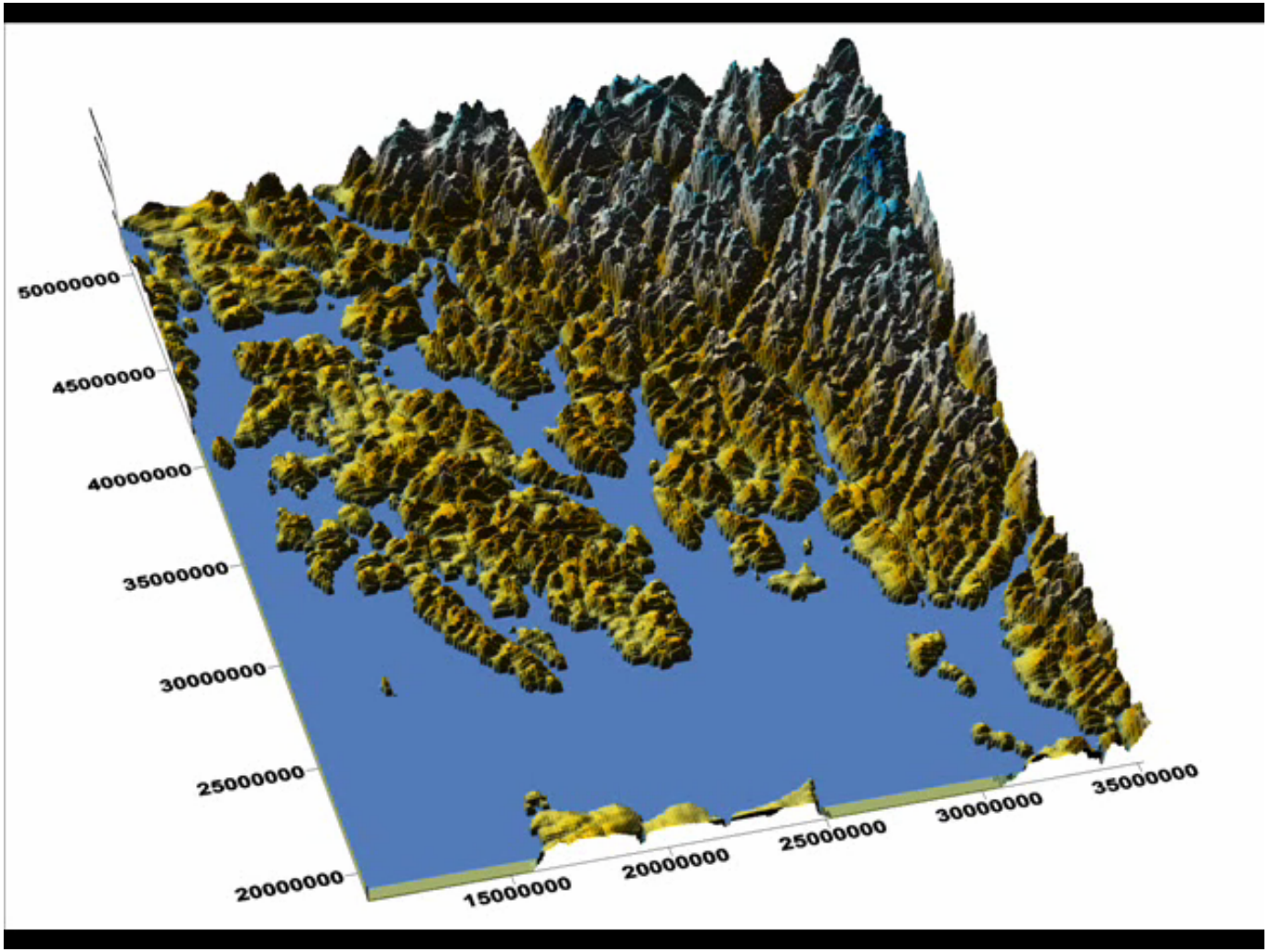
▪**OSU Hinsdale Wave Facility Corvallis, OR**

OSU Hinsdale Wave Facility Corvallis, OR

Scale model Runup Tank, University of Queensland - Brisbane, Australia

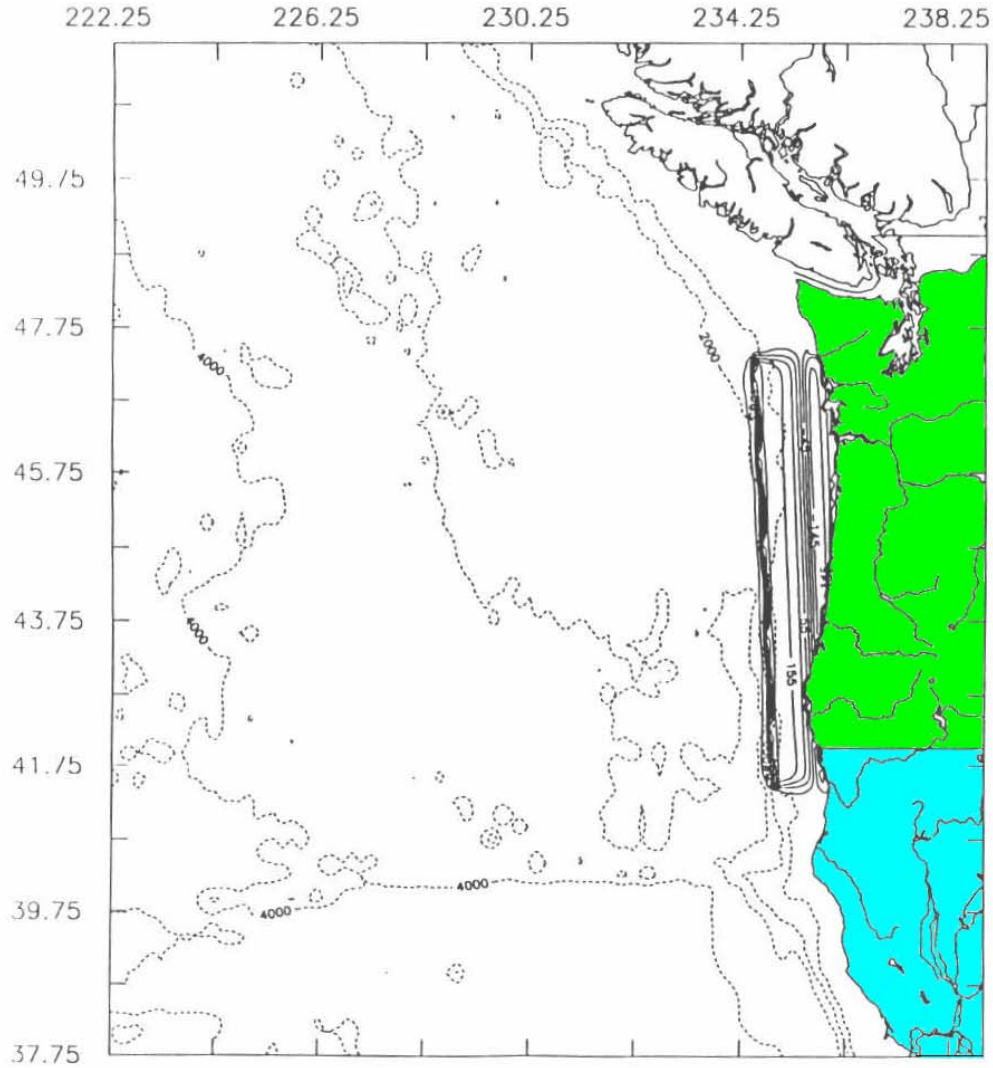


- **3 waves approach a shoreline near Craig, Alaska -- real bathymetry**



- **click on image**

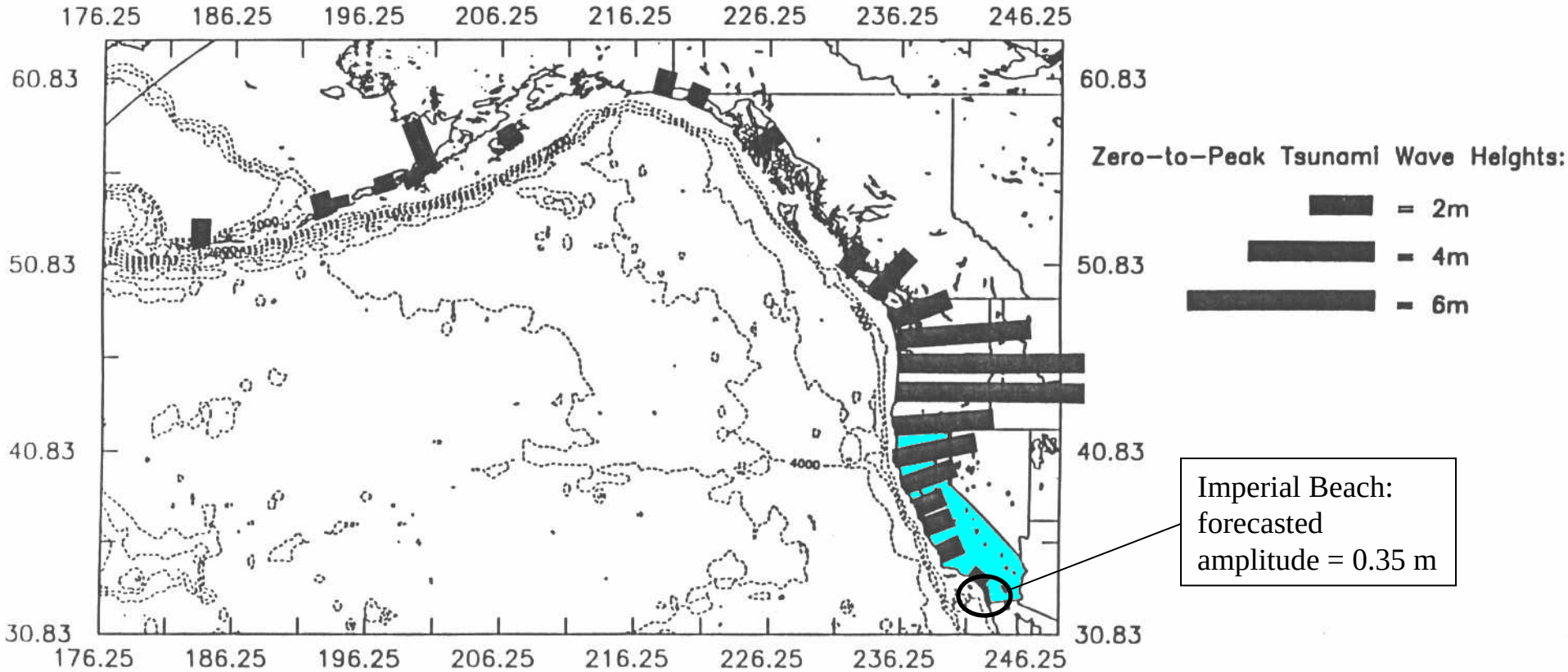
Sample model of a Plausible Mw 8.8 Cascadia Subduction Zone Earthquake (every 300-500 years -- last one in 1700)



Strike = 358° (subduction zone strike)
Dip = 13° (ave. from Spence, Taber, etc.)
Slip = 90° (assume pure dip slip)
Length = 650km (Weaver & Shedlock, 1989)
Width = 80km (trench to 20km deep)
Depth = 20km (from thermal constraints)
Mw = 8.8 (from constraints by Kanamori and Anderson, 1985)

Maximum uplift = 3.7m
Maximum subsidence = 1.8m

Oregon Mw=8.8 Maximum 0–peak Amplitudes



End of tsunami science

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