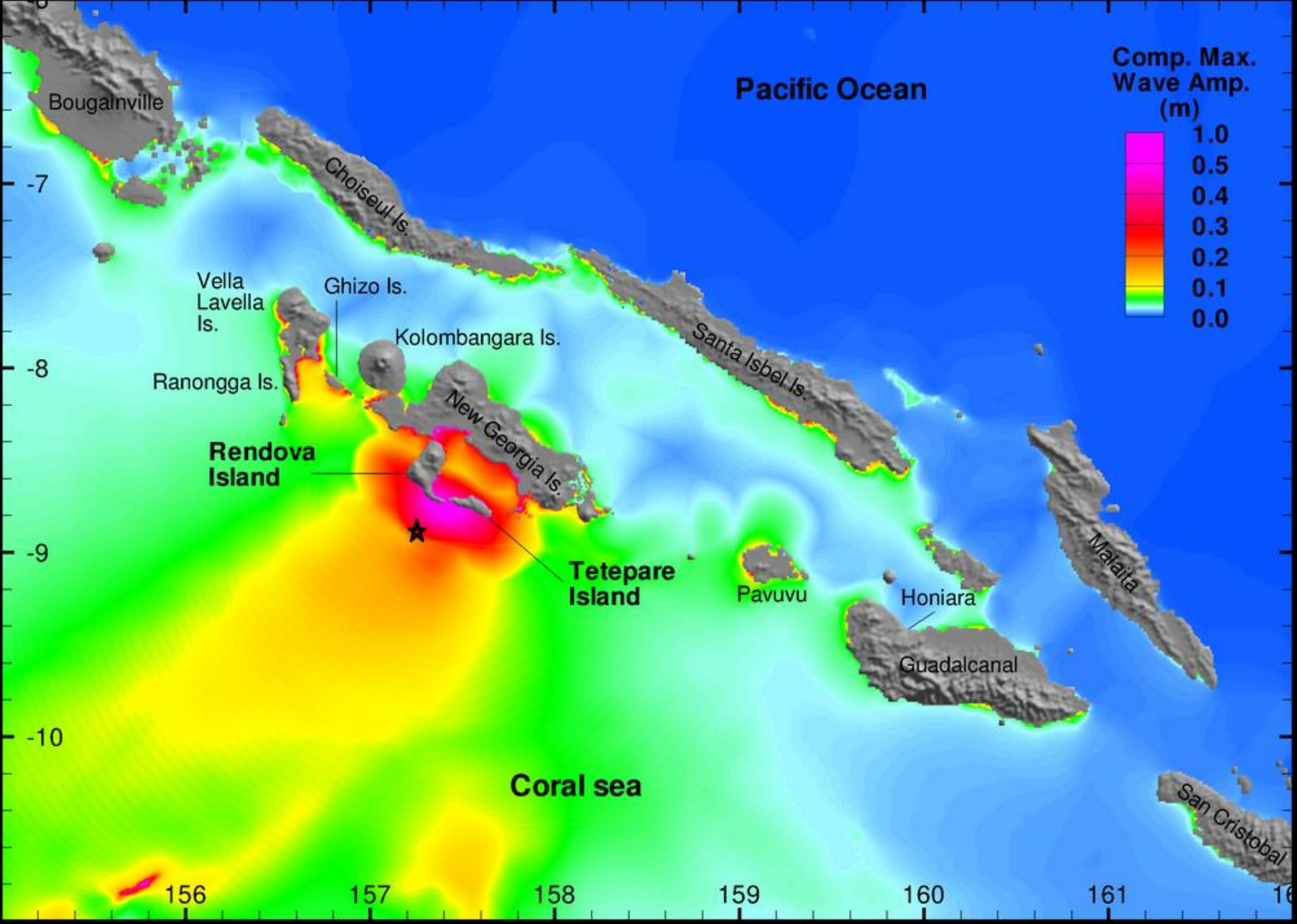
EARTH 270 – DISASTERS AND NATURAL HAZARDS (v. 2018)

PROFESSOR S.G. EVANS, PhD, PEng (Room 303, Earth Science and Chemistry (ESC) Building)

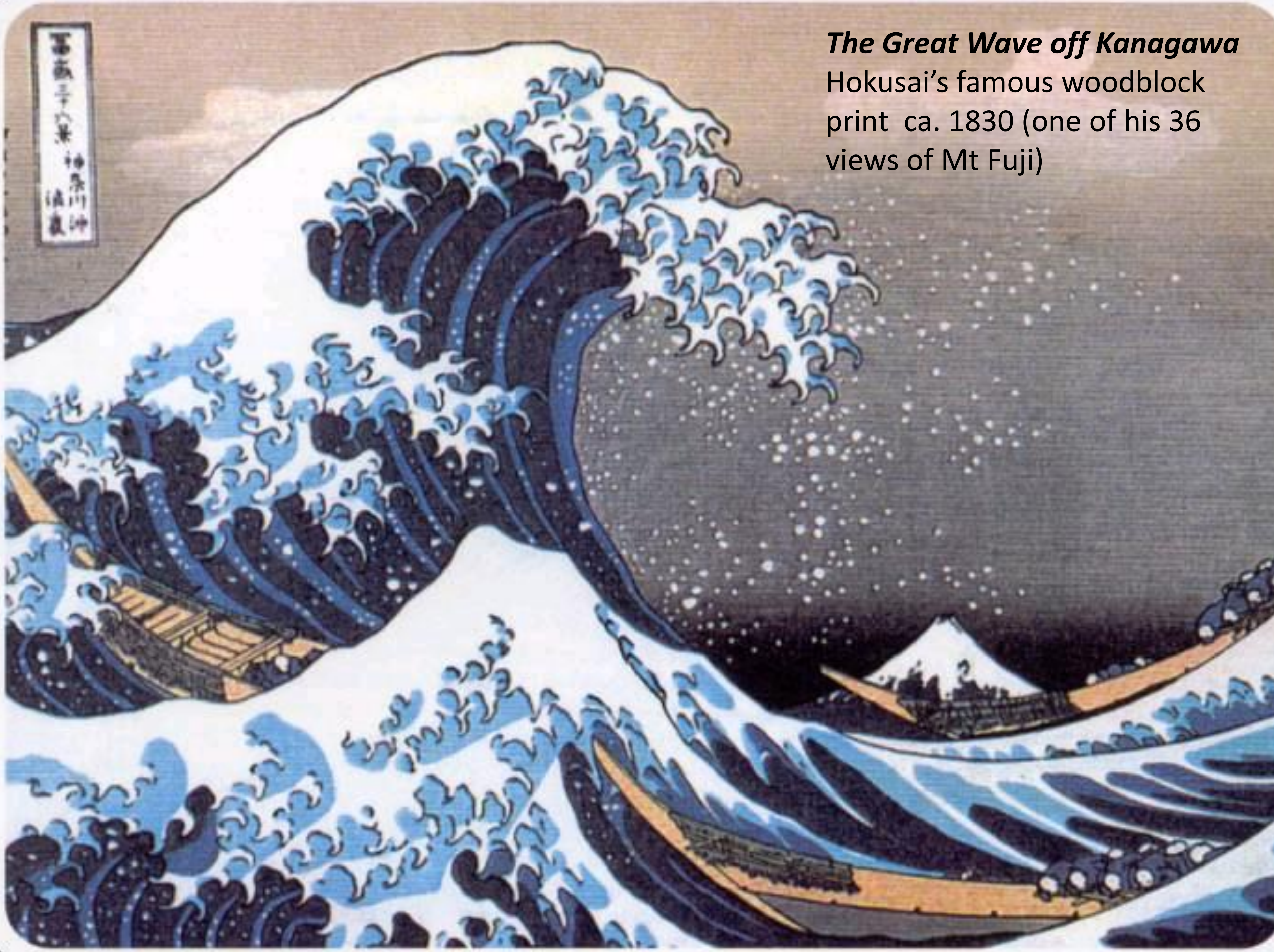
UNIVERSITY OF WATERLOO

TSUNAMI

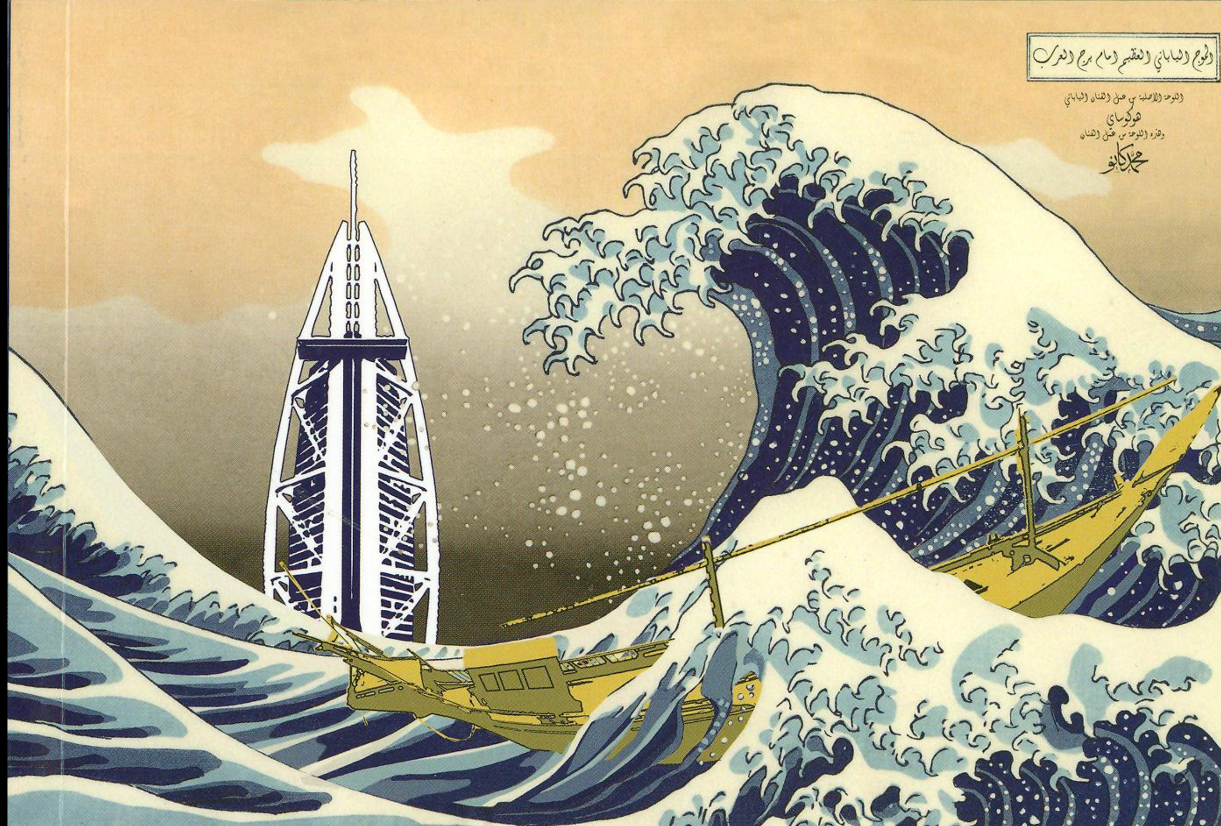
US Geological Survey



JANUARY 3, 2010 SOLOMON ISLANDS TSUNAMI (M7.2); COMPUTED WAVE AMPLITUDE-NOAA



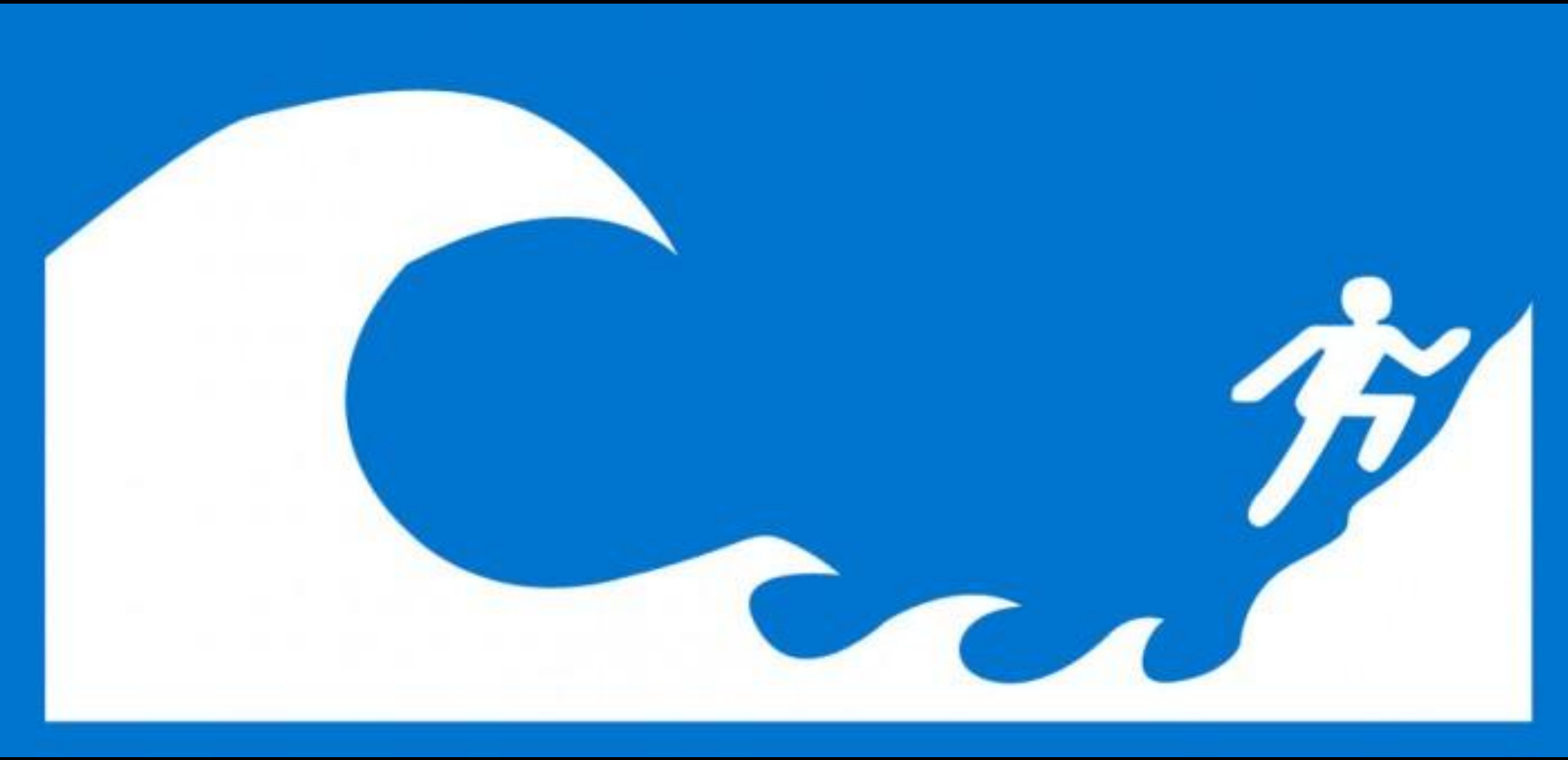
The Great Wave off Kanagawa
Hokusai's famous woodblock print ca. 1830 (one of his 36 views of Mt Fuji)



HOKUSAI'S GREAT WAVE

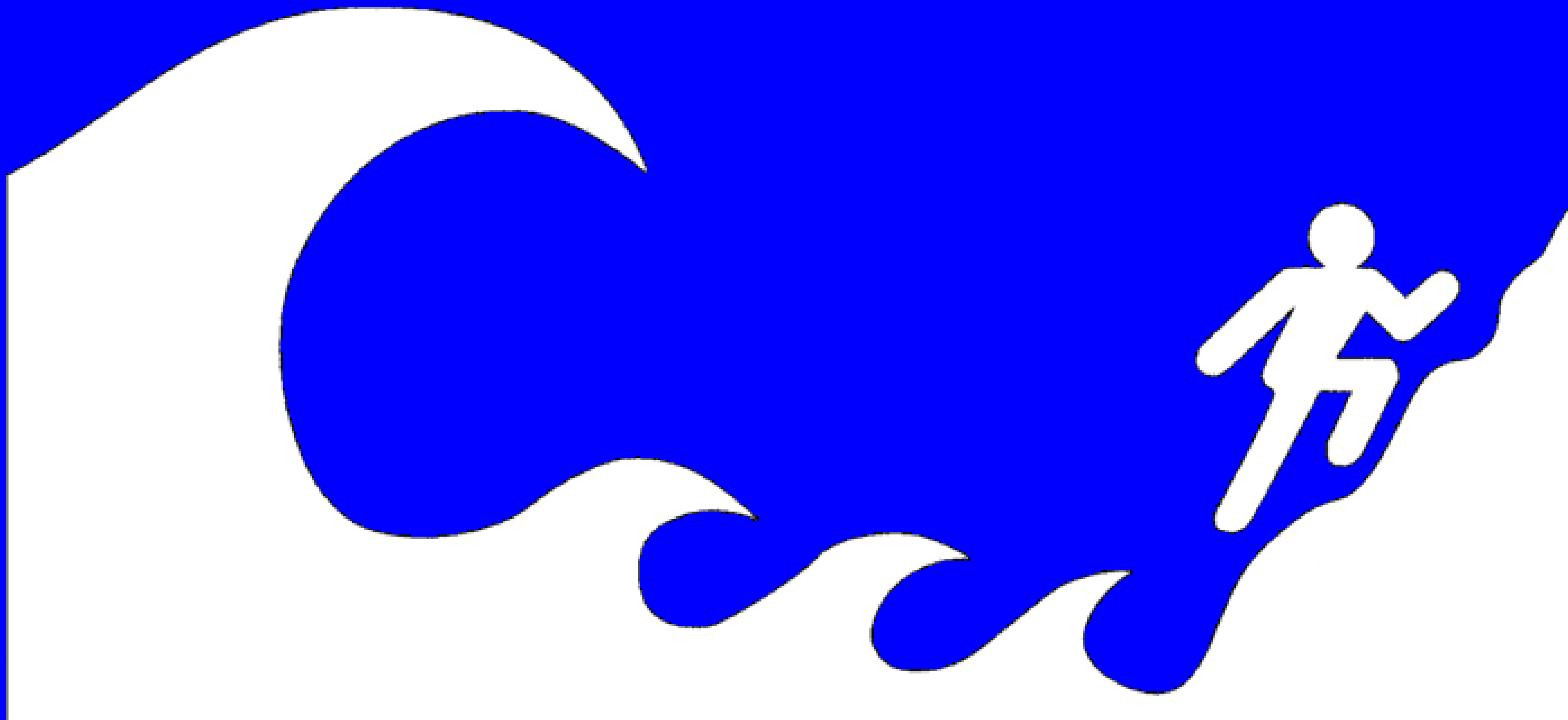
BIOGRAPHY OF A GLOBAL ICON

CHRISTINE M. E. GUTH



TSUNAMI WARNING/EVACUATION ROUTE BASED ON HOKUSAI’S WAVE

TSUNAMI HAZARD ZONE

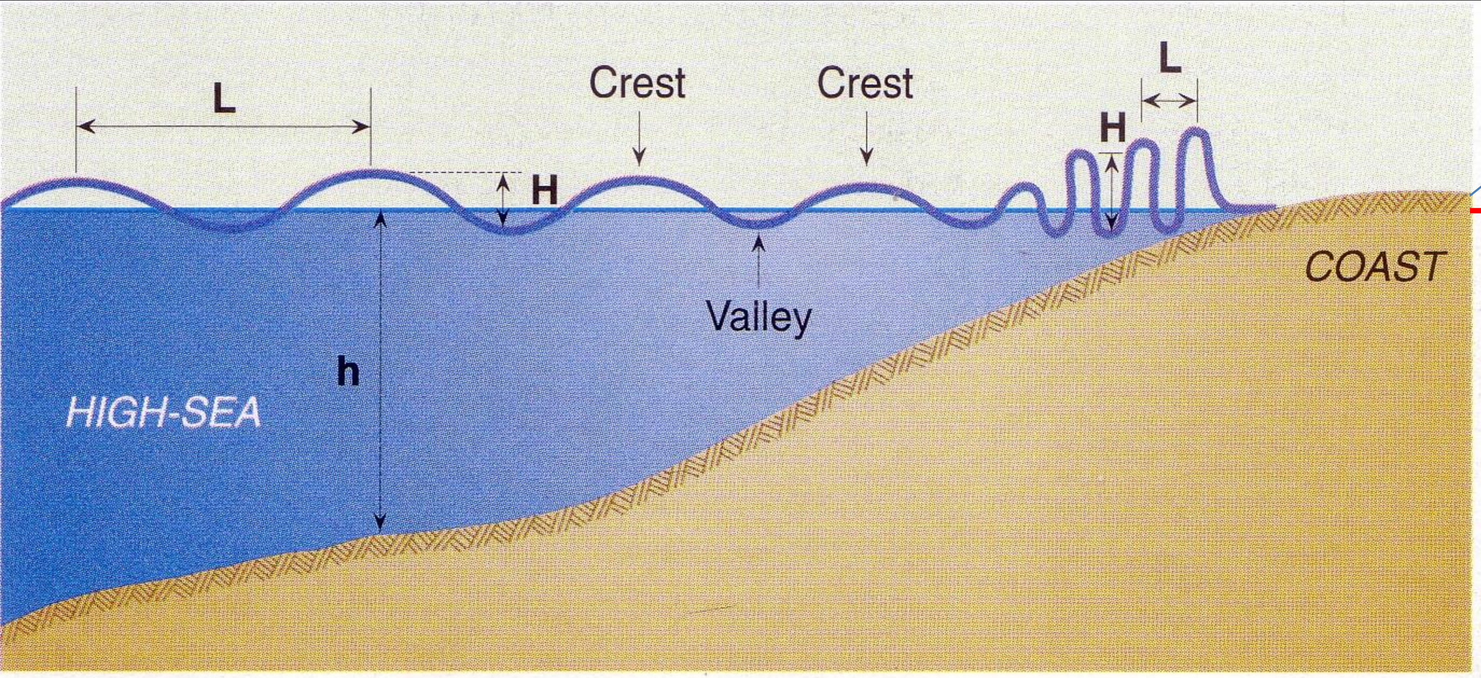


IN CASE OF EARTHQUAKE, GO TO HIGH GROUND OR INLAND

1946 TSUNAMI , HILO, HAWAII

DESTRUCTION IN BANDA ACEH, SUMATRA - 2004 INDIAN OCEAN TSUNAMI

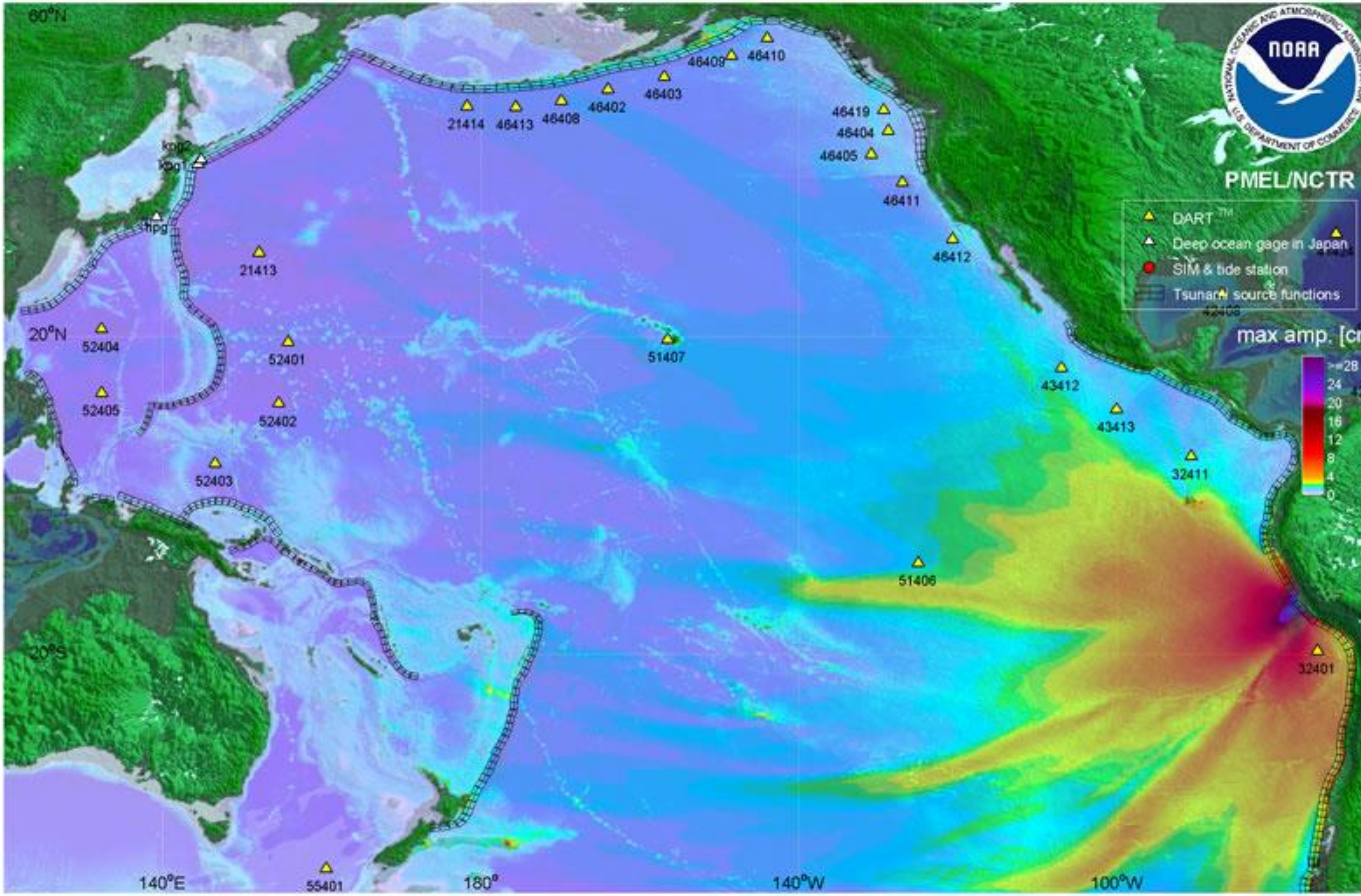
WHY ARE TSUNAMIS DESTRUCTIVE TO COASTAL ENVIRONMENTS ?



F-4TS3 Graph representing the tsunami at sea and on the coast.

Julio Kuroiwa - **Disaster Reduction**

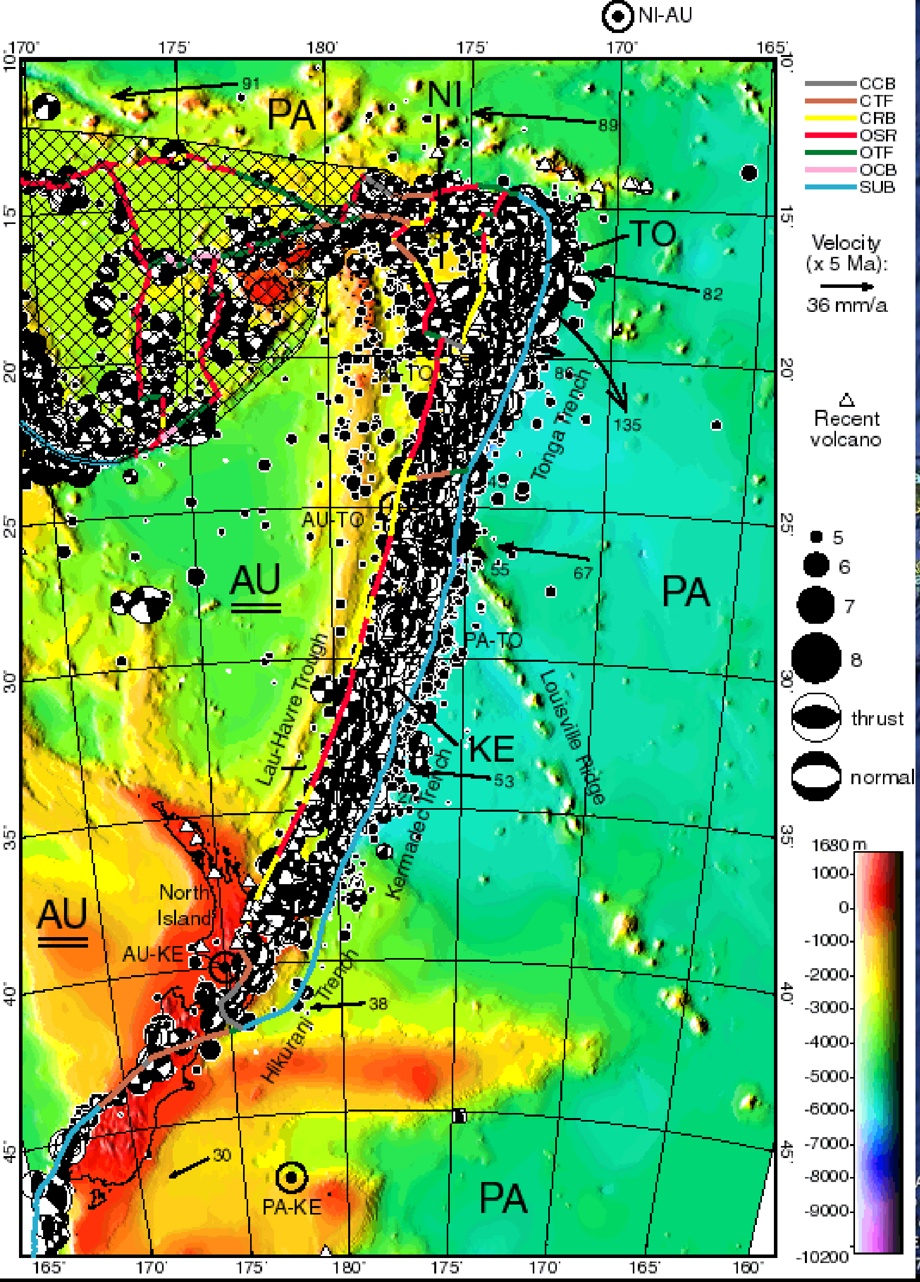
HEIGHT & VELOCITY

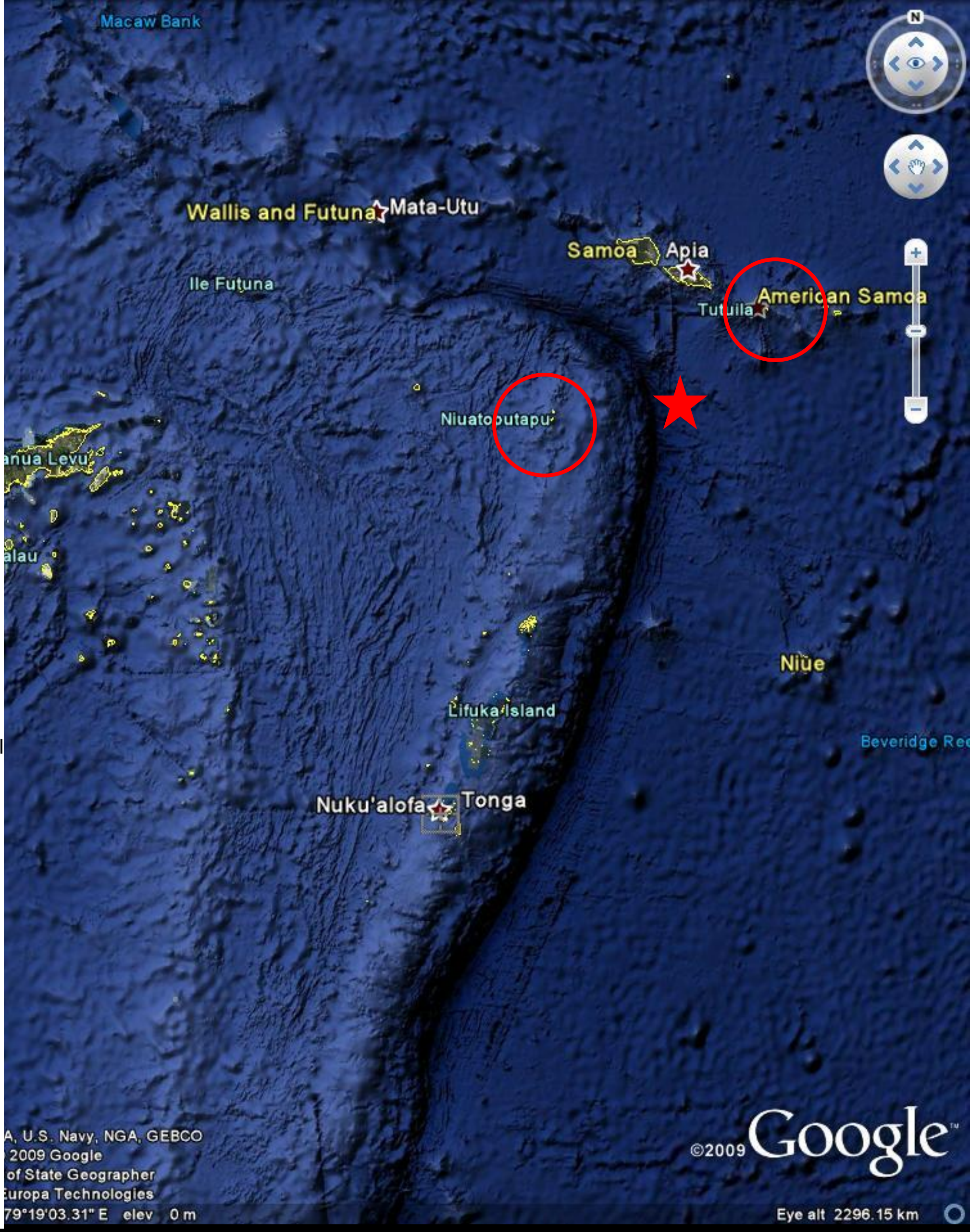


TSUNAMI GENERATED BY AUGUST 15, 2007 PERU EARTHQUAKE (M8.0)

DigitalGlobe satellite image shows M8.1 earthquake-triggered tsunami waves crashing over American Samoa's Tafuna International Airport, September 29, 2009; 115 deaths in region (max wave height 4.11 m)

Devastation on coast of Niutoputapu, Tonga – September 2009

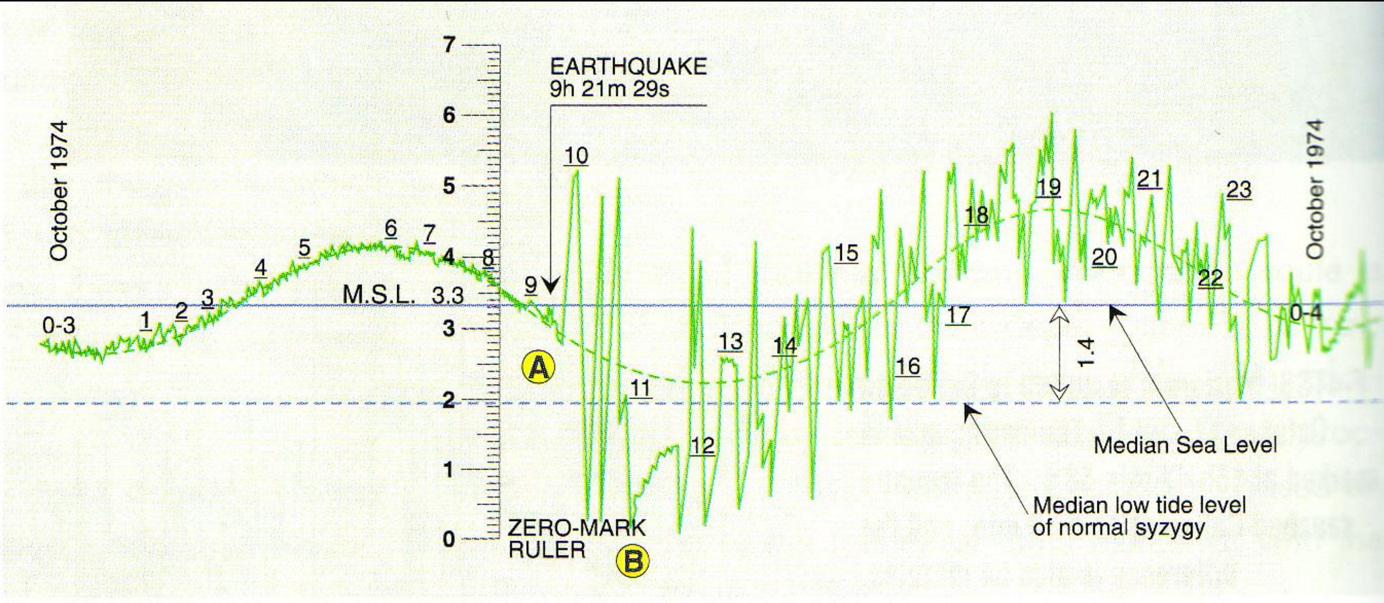




HISTORICAL SEISMICITY (1964-1998) OF TONGA TRENCH (WHITE TRIANGLES =VOLCANOES) AND EPICENTRE OF TSUNAMIGENIC 2009 SAMOA EARTHQUAKE (RED STAR), SOUTHWEST PACIFIC

EFFECT OF TIDAL STAGE ON TSUNAMI MAGNITUDE – LOW TIDE

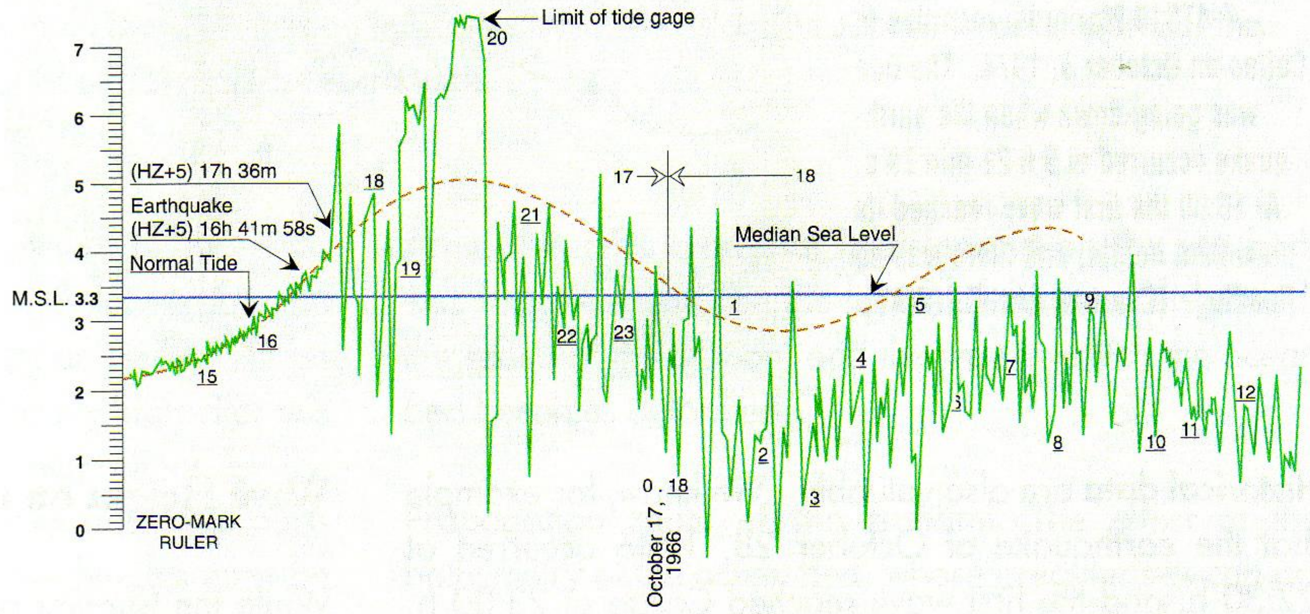
F-4TS10 Marigram recorded in Callao on October 3, 1974. The tide was going down when the earthquake occurred at 9 h 21 min 29 s. At 10:00 the first wave reached its maximum height, and there was no flooding. (Courtesy of HIDRONAV).



1974 PERU EARTHQUAKE

EFFECT OF TIDAL STAGE ON TSUNAMI MAGNITUDE – HIGH TIDE

F-4TS8 Marigram recorded in Callao on October 17, 1966. The earthquake is marked at 16h 41 min 58 s. The tsunami reached Callao at 17 h 36 min, and the difference is also 54 minutes. Note that the arrival of the highest wave coincides with the highest tide which exceeded the range of the ruler. (Courtesy of HIDRONAV).



1966 PERU EARTHQUAKE

TABLE 5.1

Notable Tsunami in Recent Times

Date		Cause	Height	Site	Deaths
1 November	1755	Earthquakes	10 m	Lisbon, Portugal	30,000
21 May	1792	Volcano avalanche	10 m	Japan (Unzen)	>14,000
11 April	1815	Volcano eruption	10 m	Indonesia (Tambora)	>10,000
27 August	1883	Volcano eruption	35 m	Indonesia (Krakatau)	36,000
15 June	1896	Earthquake	29 m	Japan	27,000
11 October	1918	Subsea landslide	6 m	Puerto Rico	116
2 March	1933	Earthquake	20 m	Japan	3,000
1 April	1946	Earthquake	15 m	Alaska	175
22 May	1960	Earthquake	10 m	Chile	>1,250
27 March	1964	Earthquake	6 m	Alaska	125
1 September	1992	Earthquake	10 m	Nicaragua	170
12 December	1992	Earthquake	26 m	Indonesia	>1,000
12 July	1993	Earthquake	31 m	Japan	239
2 June	1994	Earthquake	14 m	Indonesia	238
17 July	1998	Subsea Landslide	15 m	Papua New Guinea	>2,200
26 December	2004	Earthquake	10 m	Indonesia, Sri Lanka, India	~245,000
17 July	2006	Earthquake	7 m	Indonesia	>600

MECHANISMS FOR GENERATING TSUNAMIS

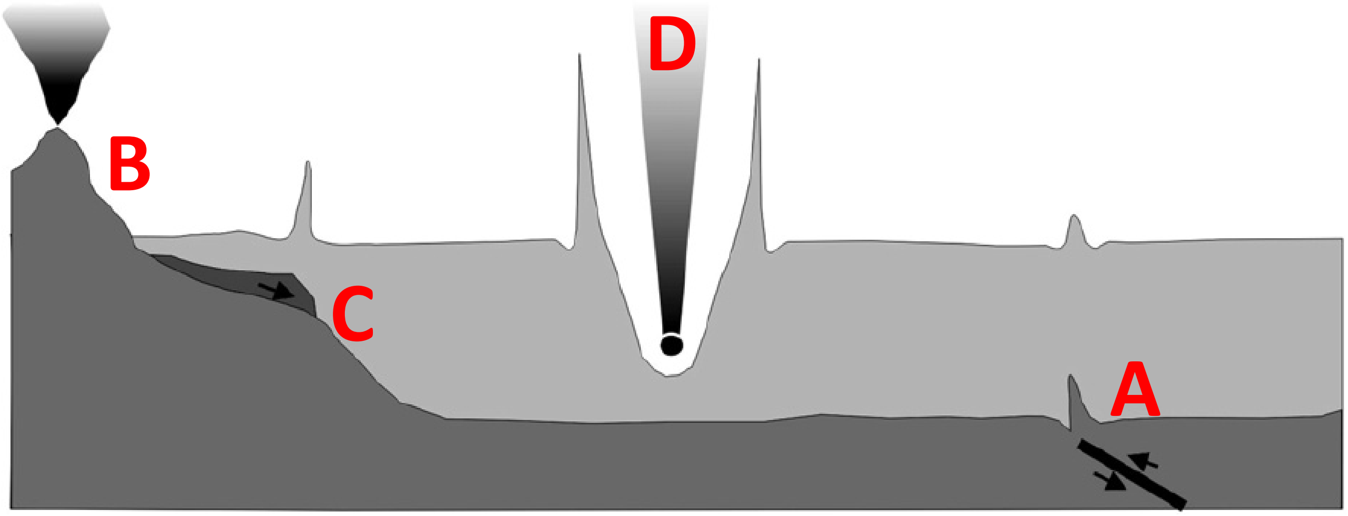
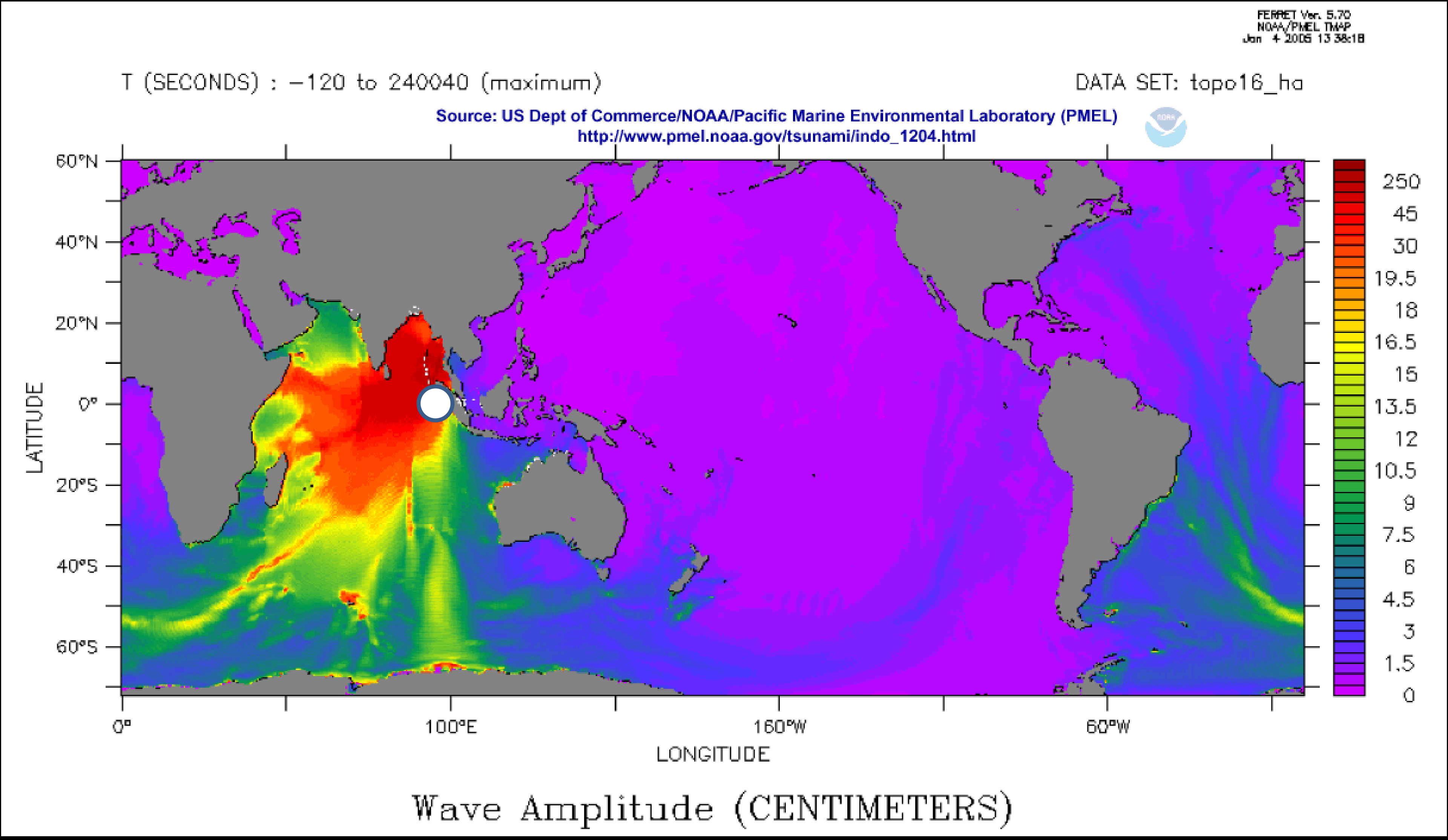


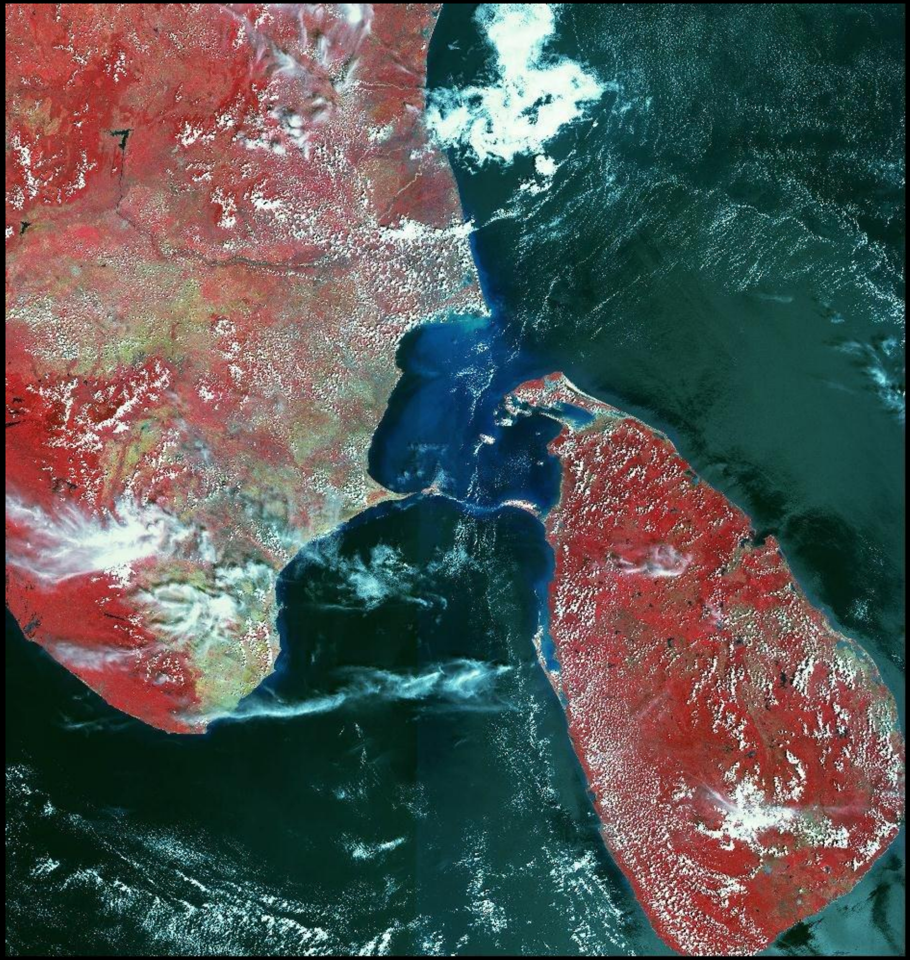
Fig. 2. Cartoon showing three main mechanisms for generating tsunamis: great earthquakes, giant slope failures and large bolide impacts. Displacement of the sea floor by large earthquakes produce an initial wave pulses several metres high, roughly equivalent to the amount of vertical seabed displacement. Sliding masses from steep continental shelves of coastal and island volcanoes build waves tens of metres high above their leading edges. Bolide impacts larger than 1 km in size can penetrate to the deep-ocean floor and instantly displace the entire water column, generating in the first moments of the impact tsunami amplitudes equivalent to the ocean depth.

A. DISPLACEMENT OF OCEAN FLOOR IN GREAT EARTHQUAKE
B. VOLCANO ERUPTION AND/OR INSTABILITY
C. SUBMARINE LANDSLIDE FROM CONTINENTAL SHELF MARGIN
D. BOLIDE IMPACT

TSUNAMI GENERATED BY GREAT EARTHQUAKE



FACTORS AFFECTING THE MAGNITUDE OF AN EARTHQUAKE-TRIGGERED TSUNAMI



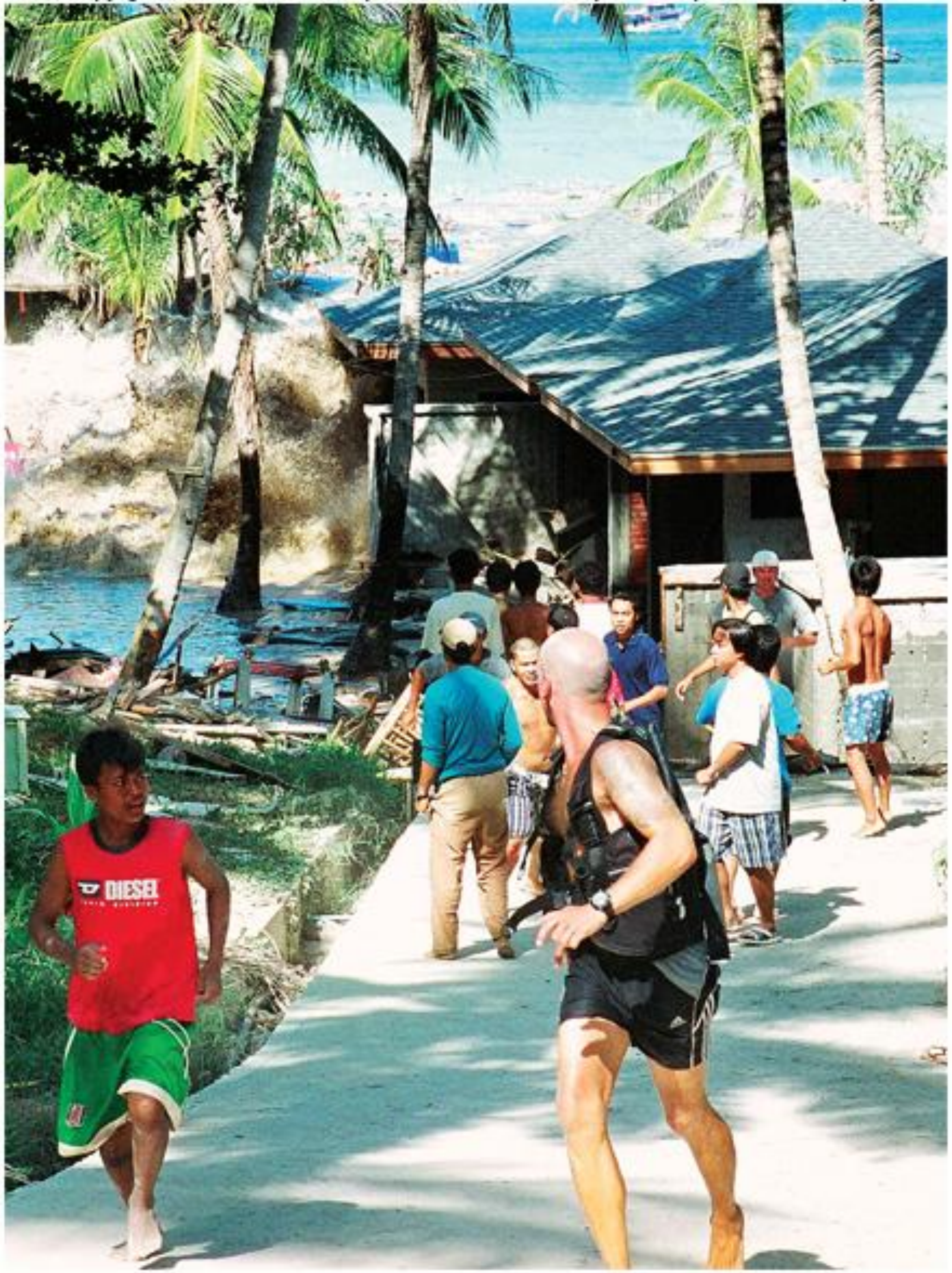
1. MAGNITUDE OF EARTHQUAKE AND FOCAL DEPTH
2. AREA OF CRUST DISLOCATED ON SEA BED
3. PROPAGATION ROUTE
4. ORIENTATION OF SHORELINE RELATIVE TO TSUNAMI APPROACH
5. BAY CONFIGURATION
6. TOPOGRAPHY OF FLOODED AREA
7. TIDAL STAGE
8. BATHYMETRY OF SHORELINE ZONE

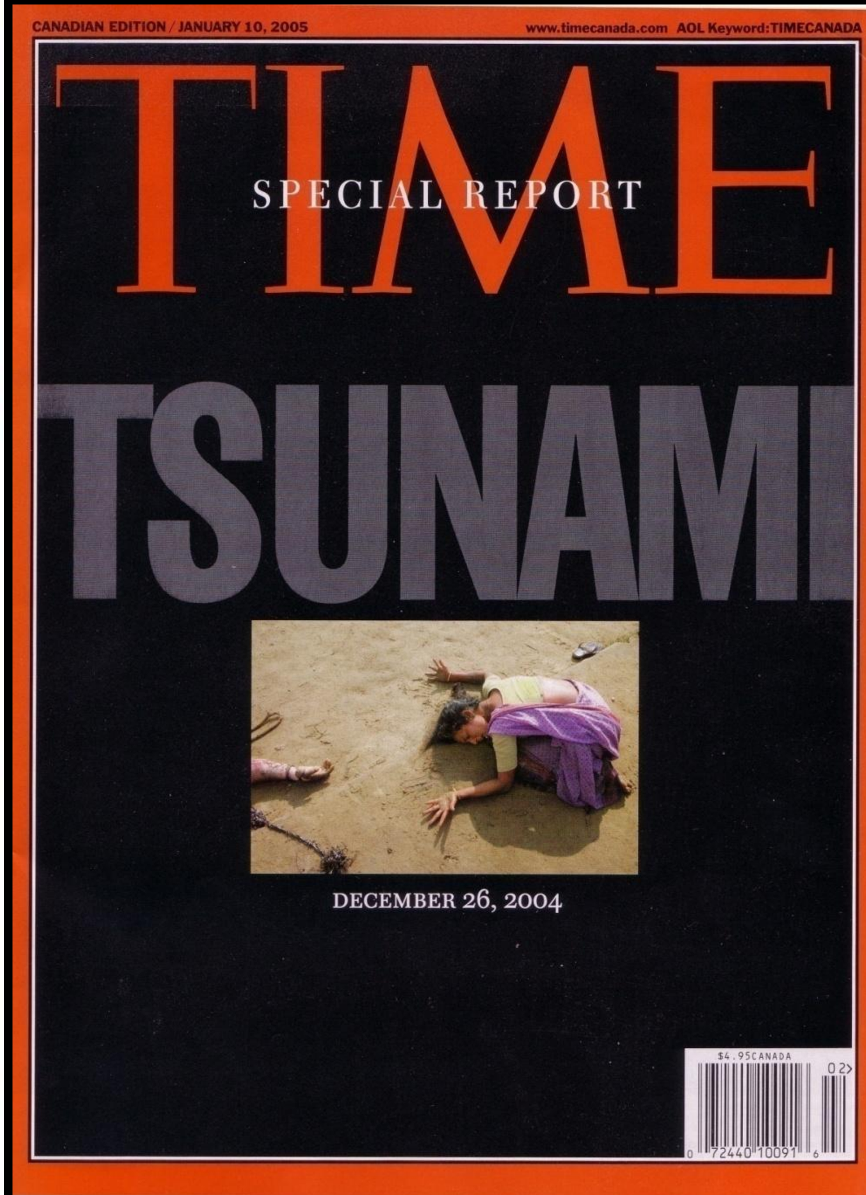
TABLE 5.3

Fault Displacements of Seafloors

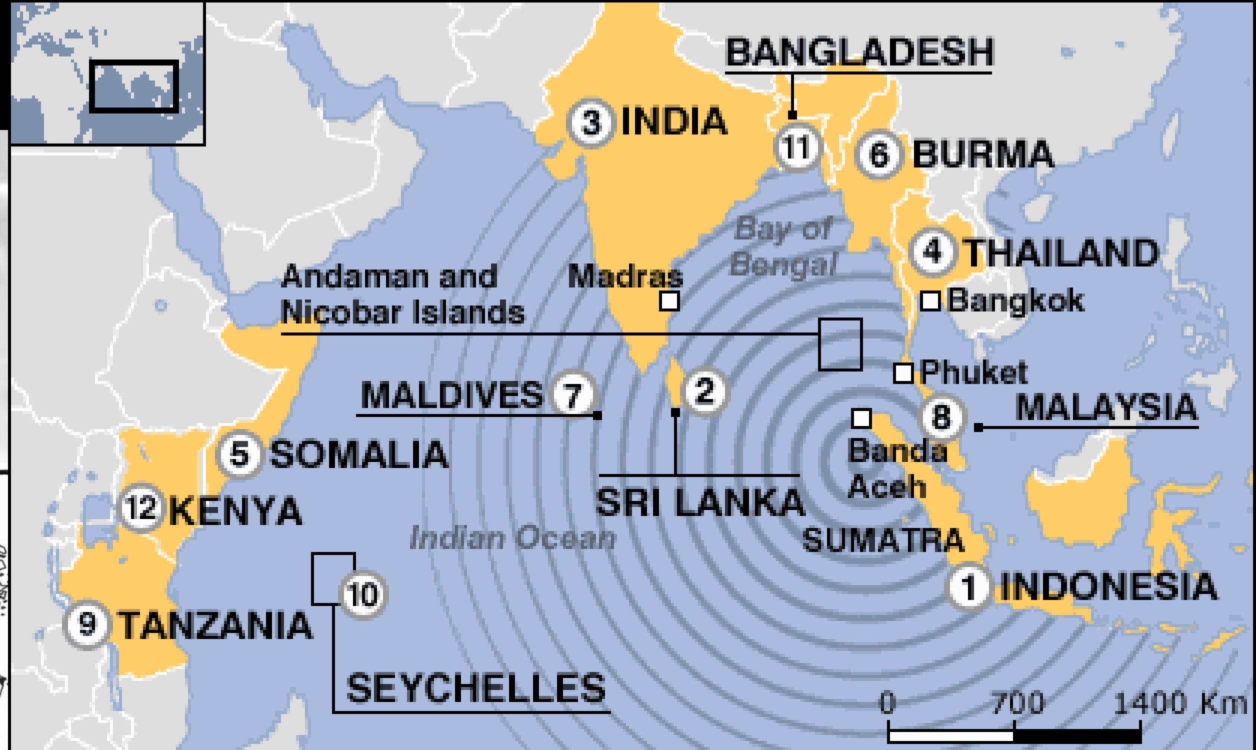
Earthquake Magnitude (M_w)	Fault Slip (m)	Rupture Duration (sec)	Vertical Movement of Seafloor (m)
7	0.6	23	0.2 (0.7 ft)
8	2.7	70	0.7 (2.3 ft)
9	9	200	2.3 (7.5 ft)
9.5	27	330	7 (23 ft)

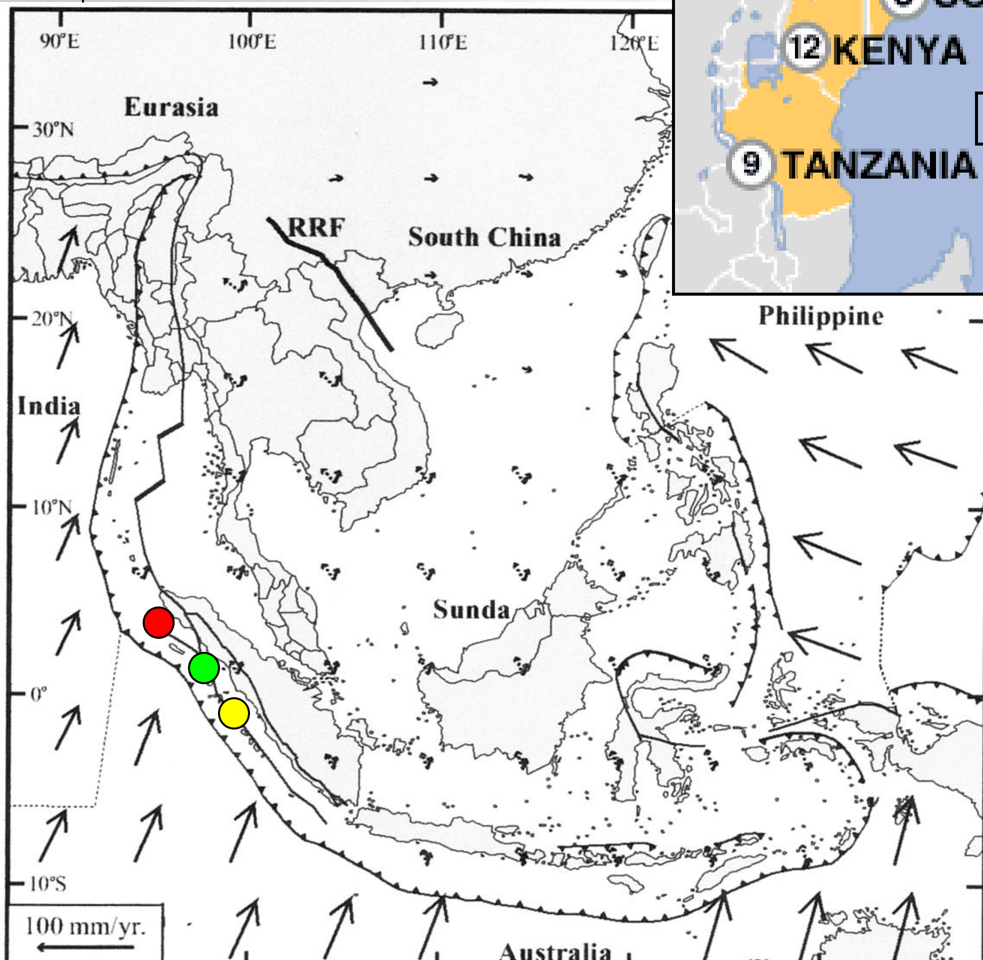
Source: *Science*, v. 78 (1997).


DIESEL


CANADIAN EDITION / JANUARY 10, 2005
www.timecanada.com AOL Keyword:TIMECANADA
TIME
SPECIAL REPORT
TSUNAMI
DECEMBER 26, 2004
$4.95CANADA

2004 EARTHQUAKE (red dot) AND TSUNAMI





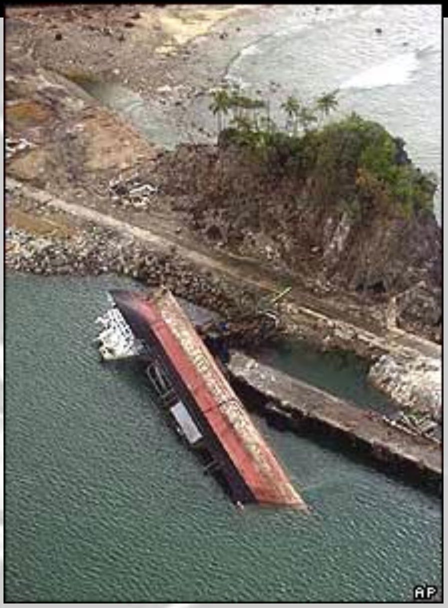
PREVIOUS GREAT MEGATHRUST EARTHQUAKES IN 1797, 1833 (yellow dot) and 1861 (green dot) ALONG SUNDA TRENCH SUBDUCTION ZONE – all generated tsunamis

Quickbird image of Kalutara, Sri Lanka coast, December 26, 2004 (06 31 49N, 79 58 35E)

DAMAGE IN 2004 TSUNAMI

Quickbird image of tsunami damage in Banda Aceh, Indonesia – December 28, 2004

DAMAGE IN 2004 TSUNAMI



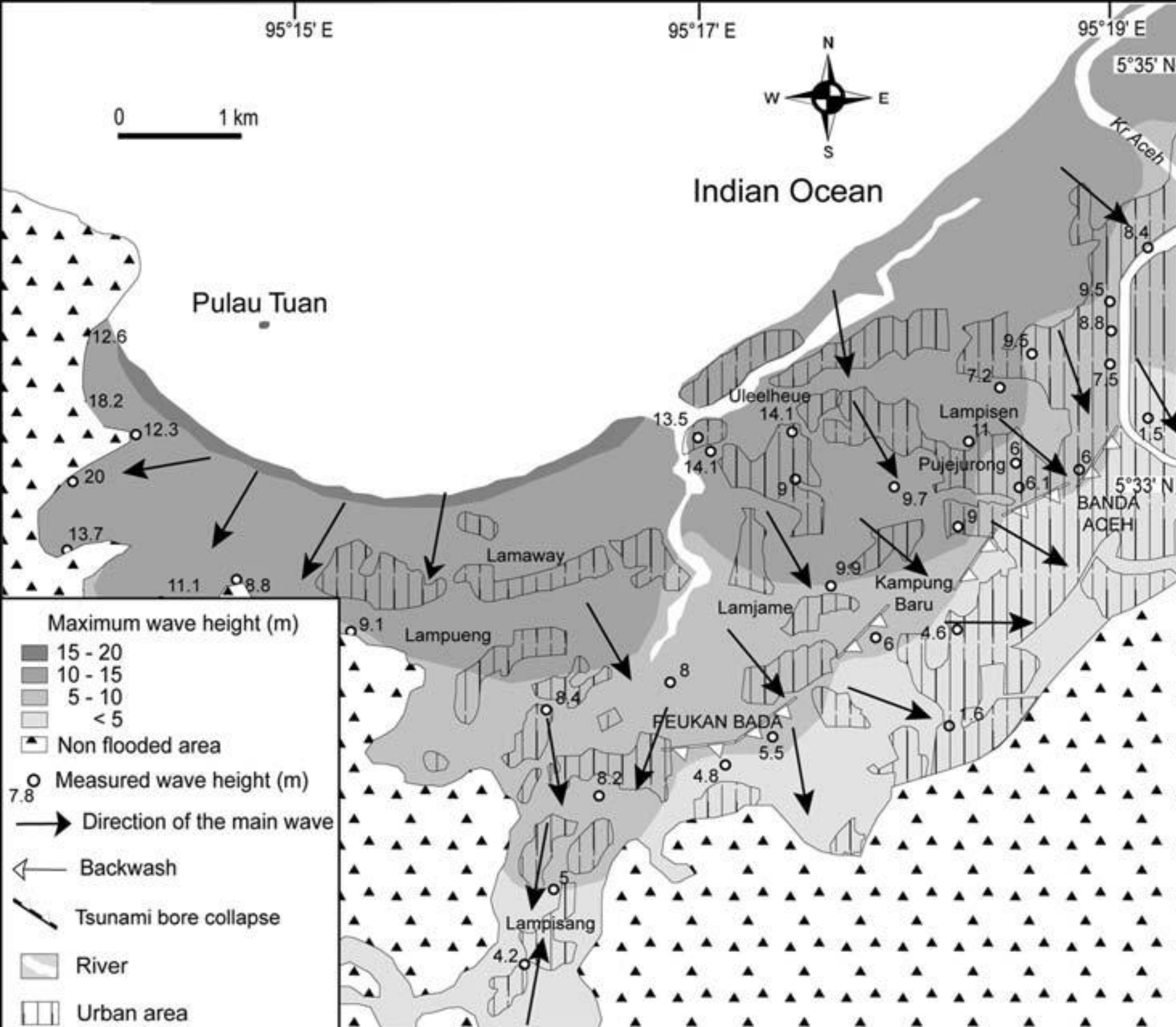
230,000 deaths


AFP

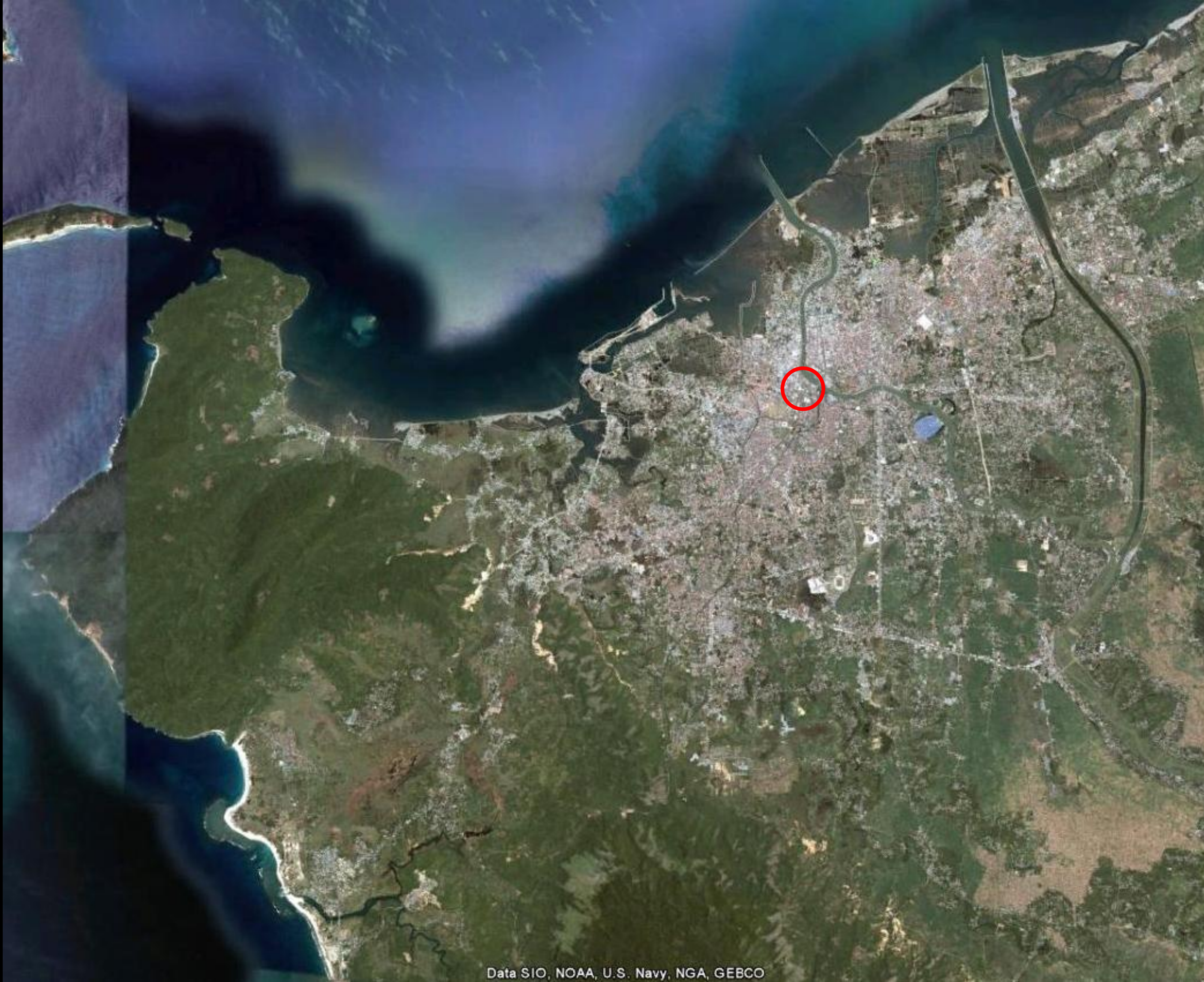

(AP PHOTO)


(AP PHOTO)

Village on the coast of Sumatra



95°15' E
95°17' E
95°19' E
5°35' N
5°33' N
N
W
E
S
0
1 km
Indian Ocean
Kr Aceh
Pulau Tuan
Uleelheue
Lampisen
Pujejurong
BANDA ACEH
Lamaway
Lampueng
Lamjame
Kampung Baru
PEUKAN BADA
Lampisang
12.6
18.2
12.3
20
13.7
11.1
8.8
9.1
13.5
14.1
14.1
9
9.7
9.9
8.4
9.5
8.8
9.5
7.5
7.2
11
6
6.1
6
9
1.5
4.6
6
1.6
8
8.4
5.5
4.8
8.2
5
4.2
Maximum wave height (m)
15 - 20
10 - 15
5 - 10
< 5
Non flooded area
Measured wave height (m)
7.8
Direction of the main wave
Backwash
Tsunami bore collapse
River
Urban area

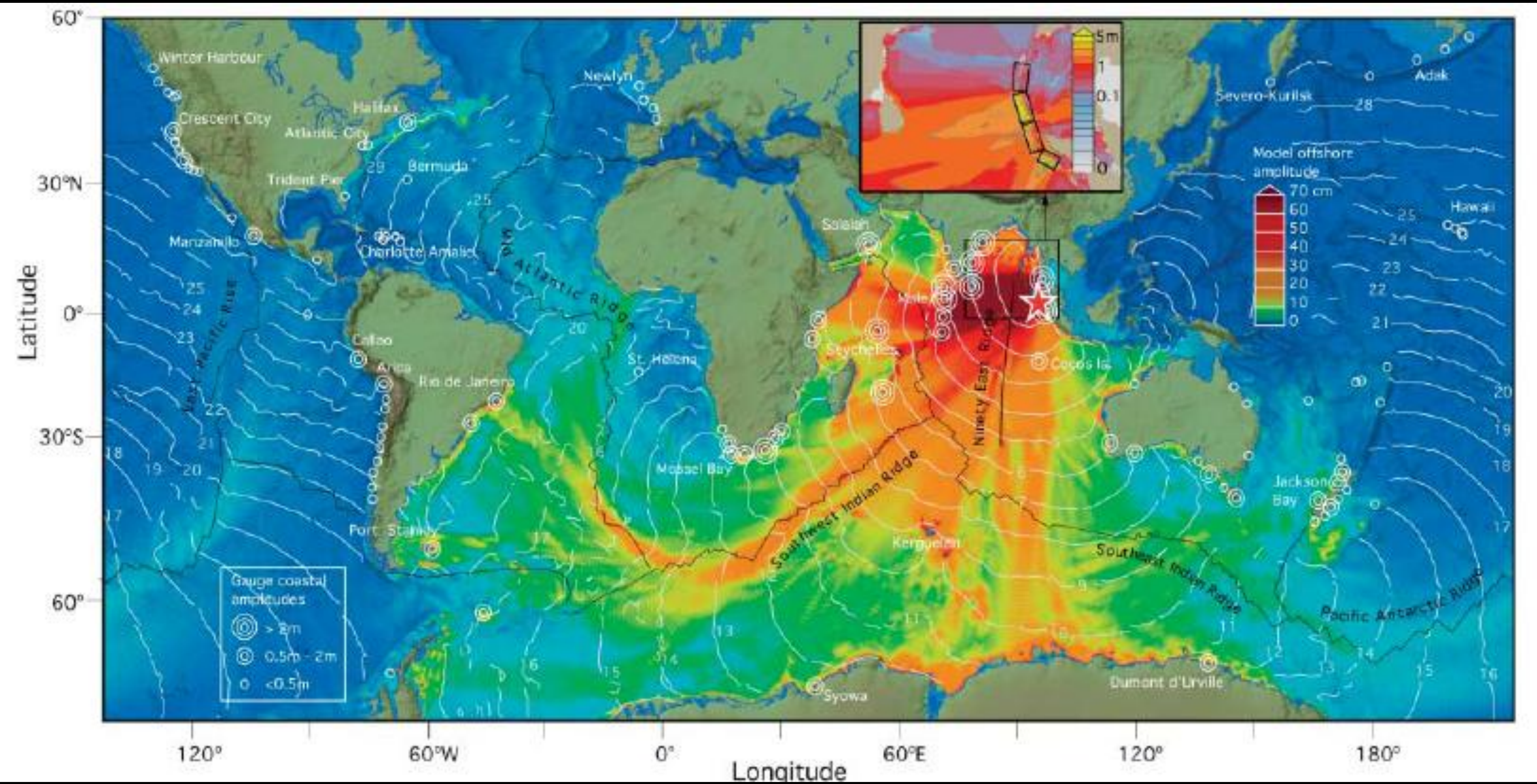

Data SIO, NOAA, U.S. Navy, NGA, GEBCO

Grand Mosque, Banda Aceh, Sumatra on December 28, 2004 (05 33 11N, 95 19 07E)

Damage near the coast of northern Sumatra

Damage near the coast of northern Sumatra

PROPAGATION SPEED AND RUN-UP VELOCITY OF TSUNAMI



PROPAGATION SPEEDS OF AROUND 150-200m/s IN THE OPEN OCEAN

HINDCAST ANALYSIS OF DAMAGED STRUCTURES INDICATE TSUNAMI RUN-UP VELOCITIES OF 15-25 m/s

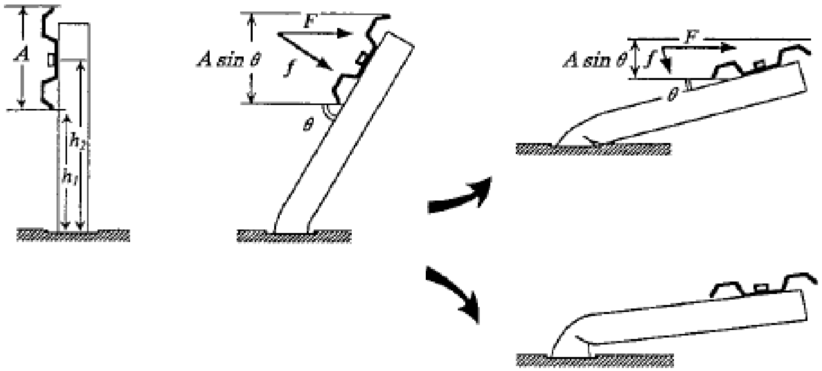
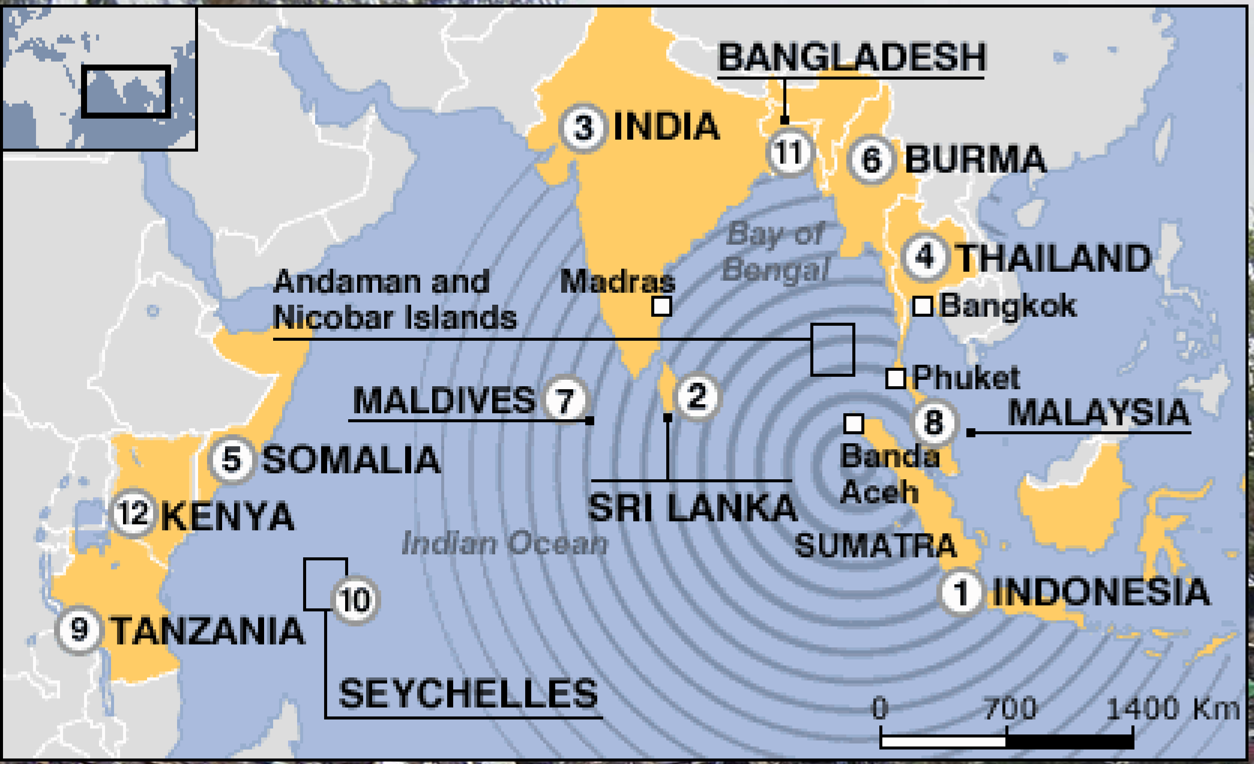


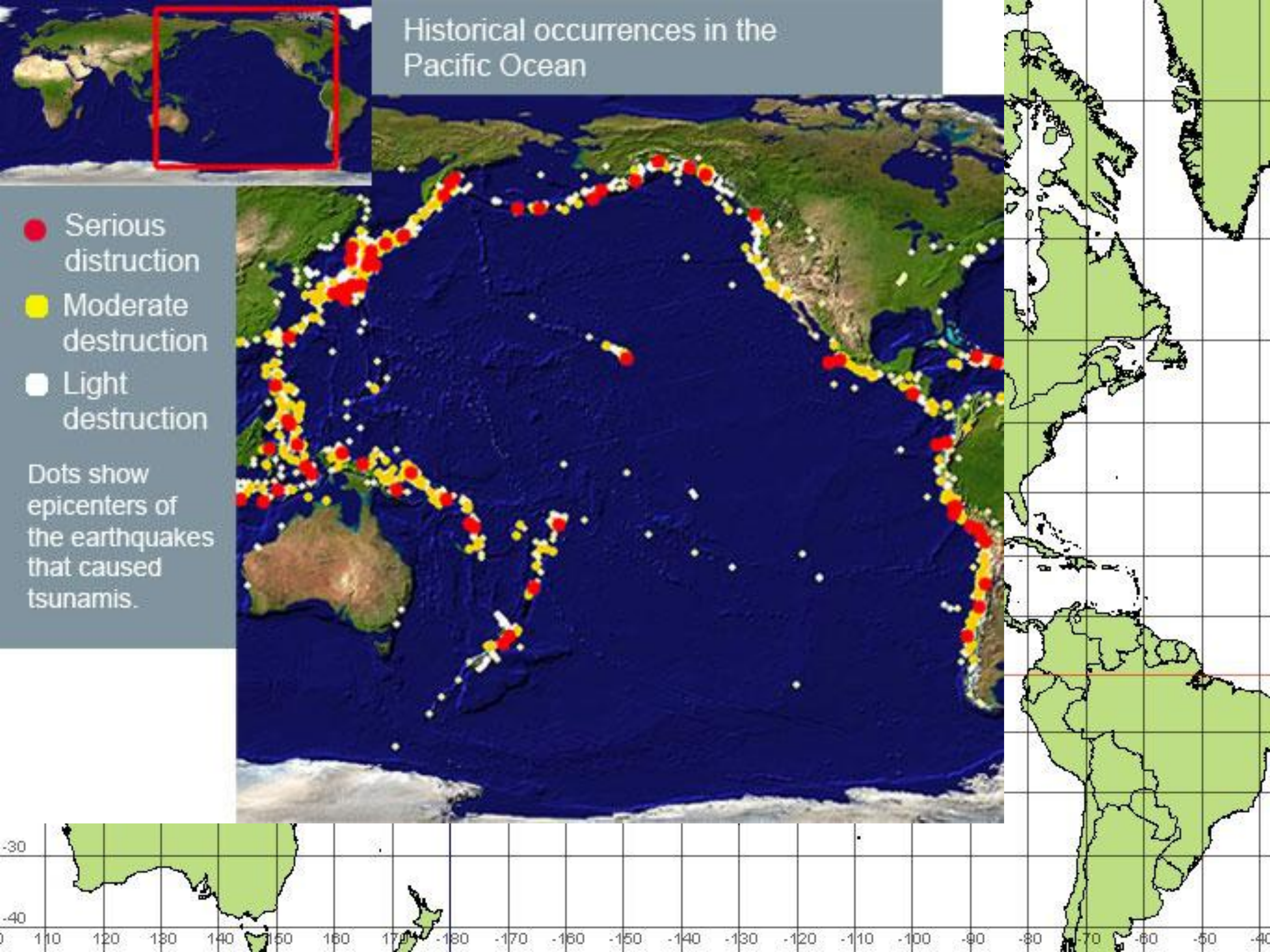
FIG. 11. Schematic Figure Showing Deformation of Guardrail due to Tsunami

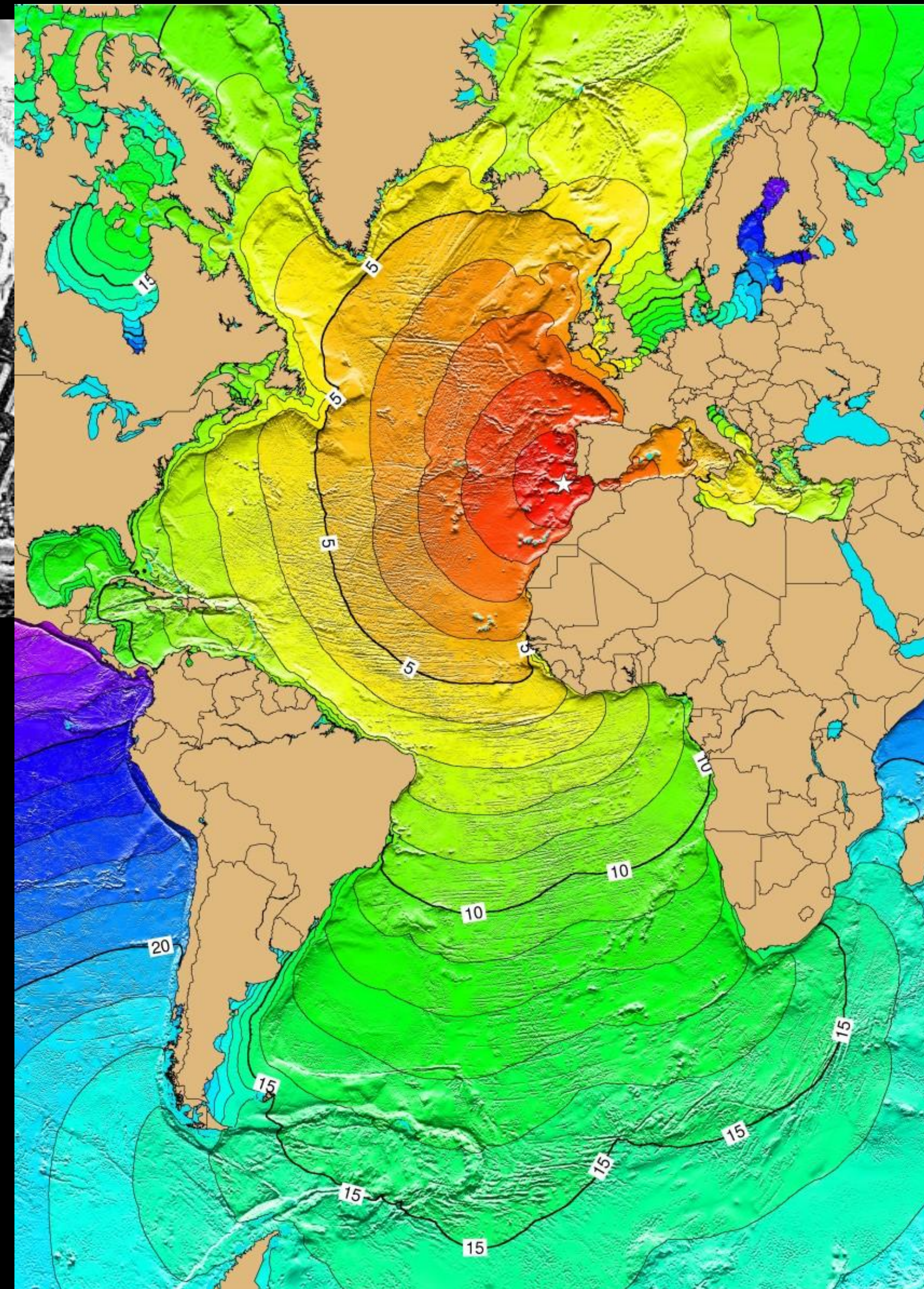


ROUGH ESTIMATES OF FATALITIES IN 2004 INDIAN OCEAN TSUNAMI

INDONESIA - 168,000
SRI LANKA – 35,000
INDIA – 18,000
THAILAND – 8,000
MAYUNMAR – 400
SOMALIA – 200

TOTAL ~ 230,000

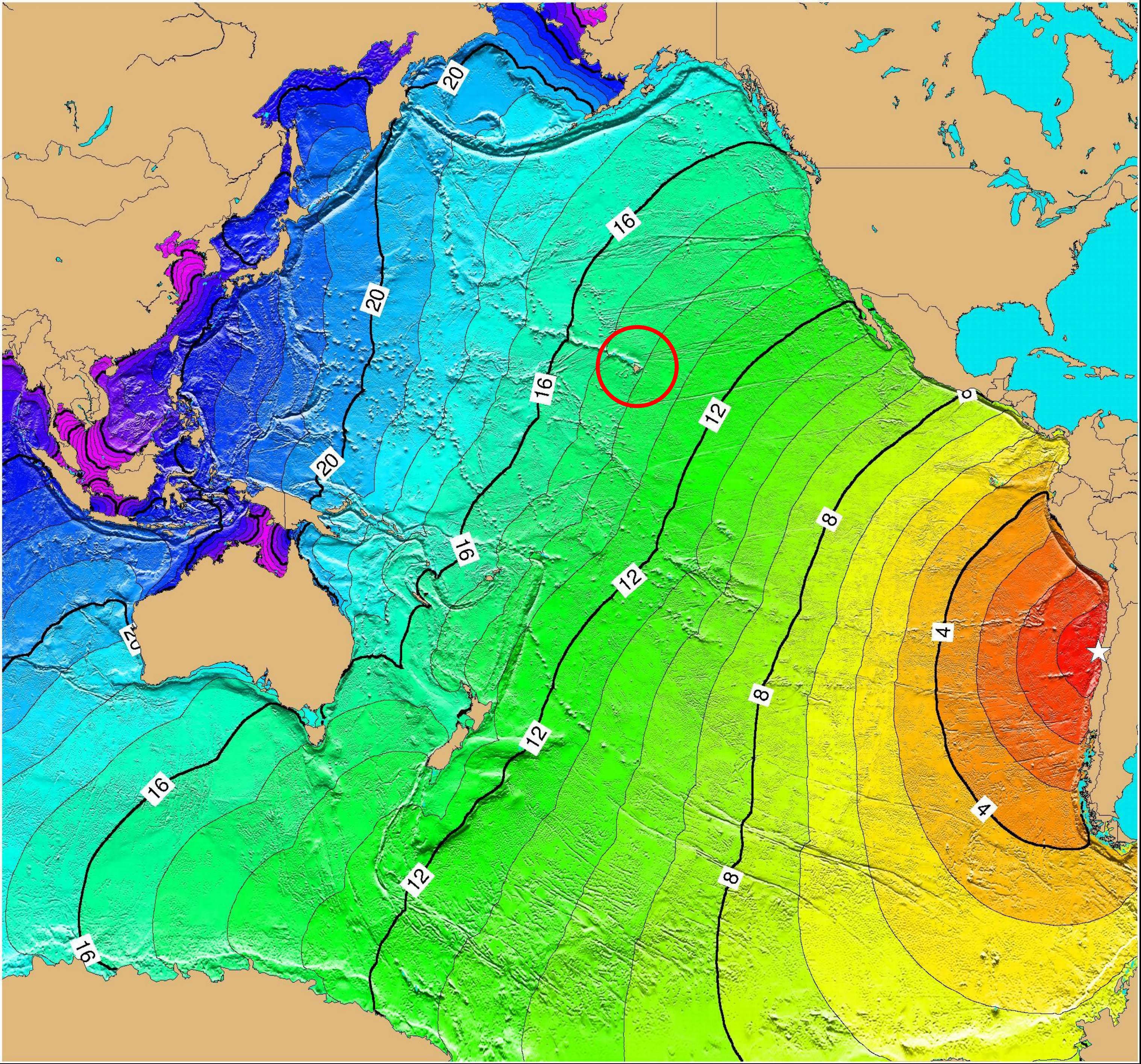

Historical occurrences in the Pacific Ocean
Serious distruction
Moderate destruction
Light destruction
Dots show epicenters of the earthquakes that caused tsunamis.
-30
-40
110
120
130
140
150
160
-180
-170
-160
-150
-140
-130
-120
-110
-100
-90
-80
-70
-60
-50



1755 LISBON EARTHQUAKE TSUNAMI

Reached 6-12 m on coast of Portugal and Morocco; 60,000 – 100,000 deaths

[Map shows travel times in hours – NOAA]

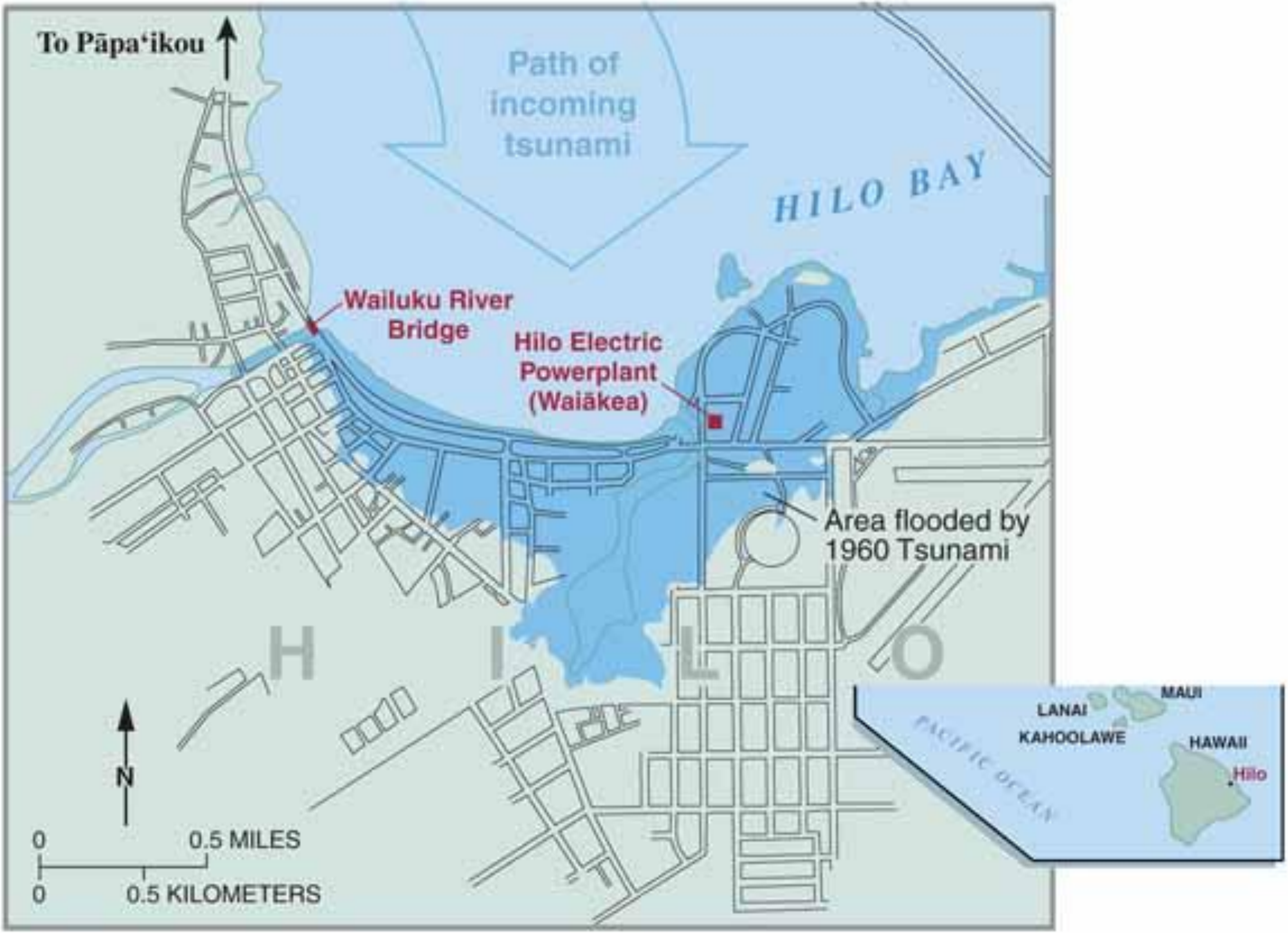


TSUNAMI GENERATED BY 1960 CHILE EARTHQUAKE (M9.5)

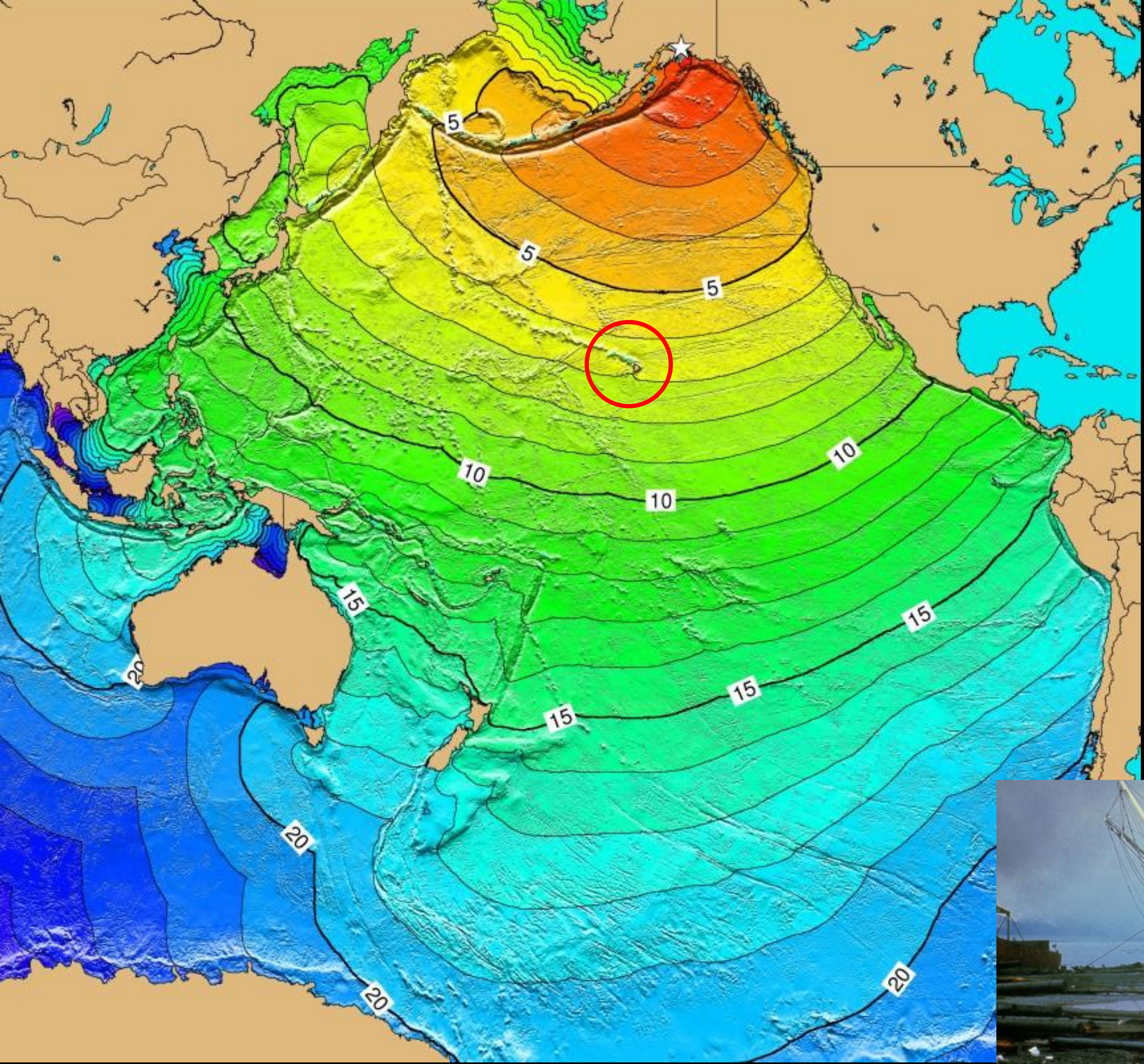
[Map shows travel times in hours – NOAA]

DAMAGE ON HILO, HAWAII, 1960 CHILE EARTHQUAKE TSUNAMI [61 DEATHS; MAX. RUN-UP 10 m; DISTANCE TO EPICENTRE 10,700 KM].

NOAA



To Pāpa‘ikou
Path of incoming tsunami
HILO BAY
Wailuku River Bridge
Hilo Electric Powerplant (Waiākea)
Area flooded by 1960 Tsunami
H I L O
N
0 0.5 MILES
0 0.5 KILOMETERS
LANAI
MAUI
KAHOOLAWE
HAWAII
Hilo
PACIFIC OCEAN

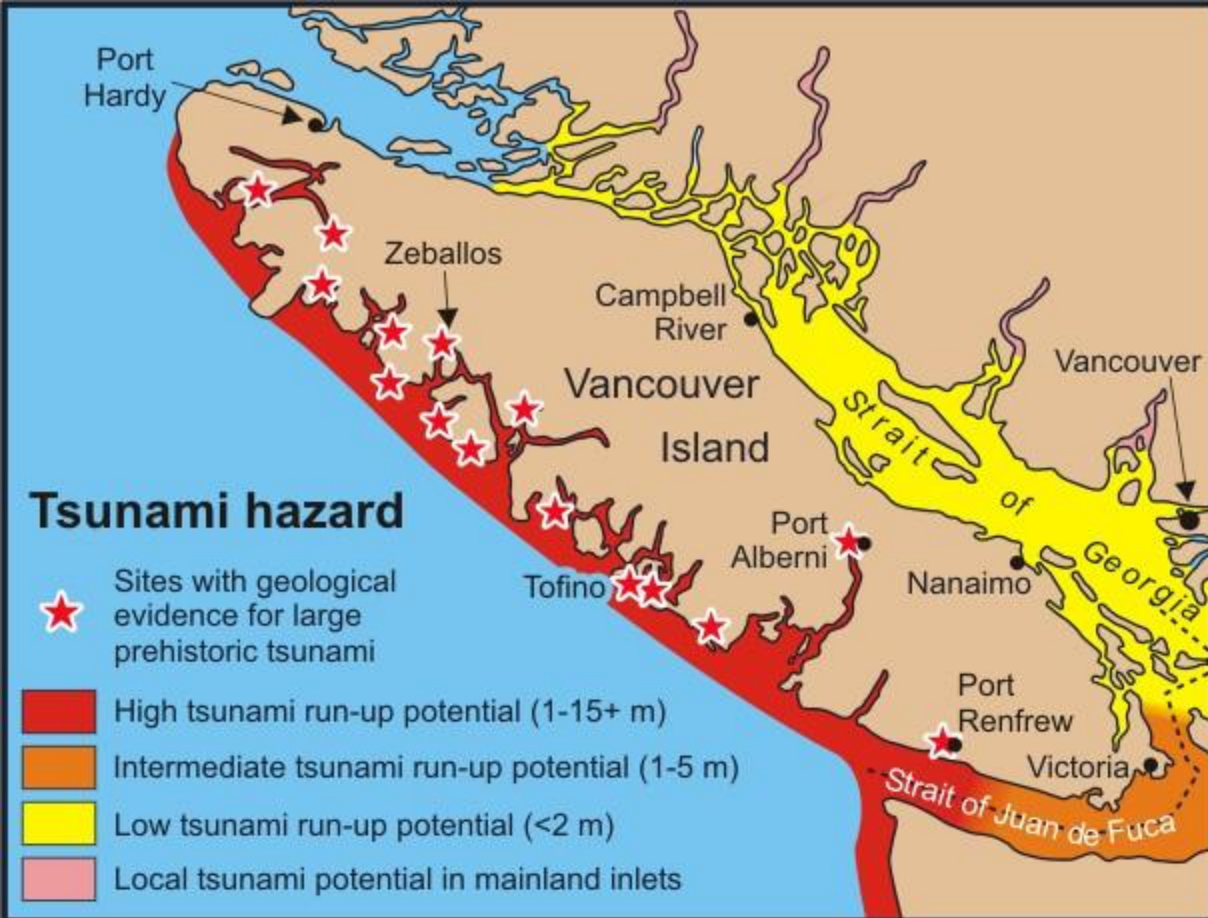


TSUNAMI GENERATED BY 1964 ALASKA EARTHQUAKE (M9.2)

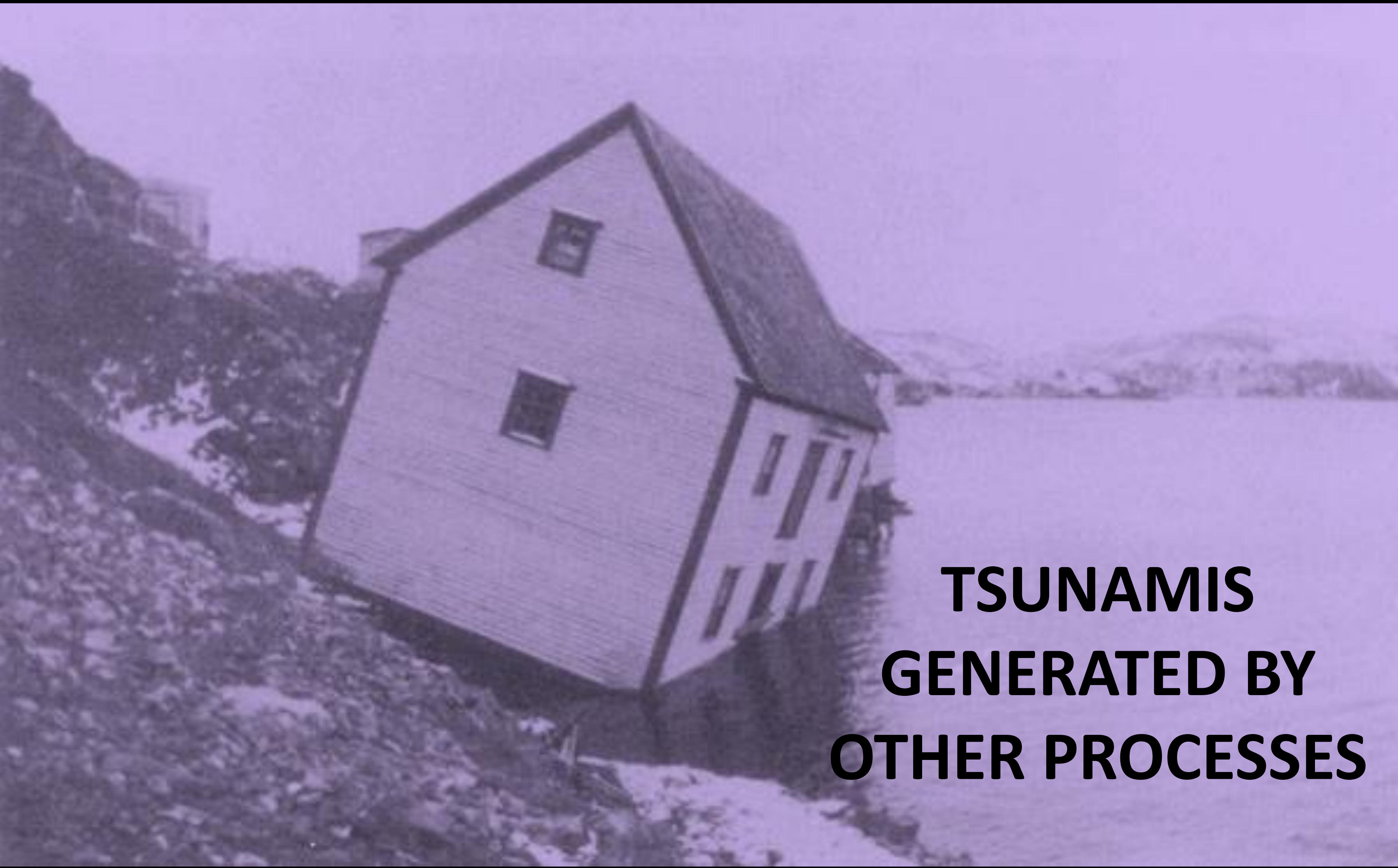
[Map shows travel times in hours – NOAA]

1964 ALASKA EARTHQUAKE (M9.2) – TSUNAMI DAMAGE ON ALASKAN COAST

TSUNAMI HAZARD ON THE COAST OF VANCOUVER ISLAND

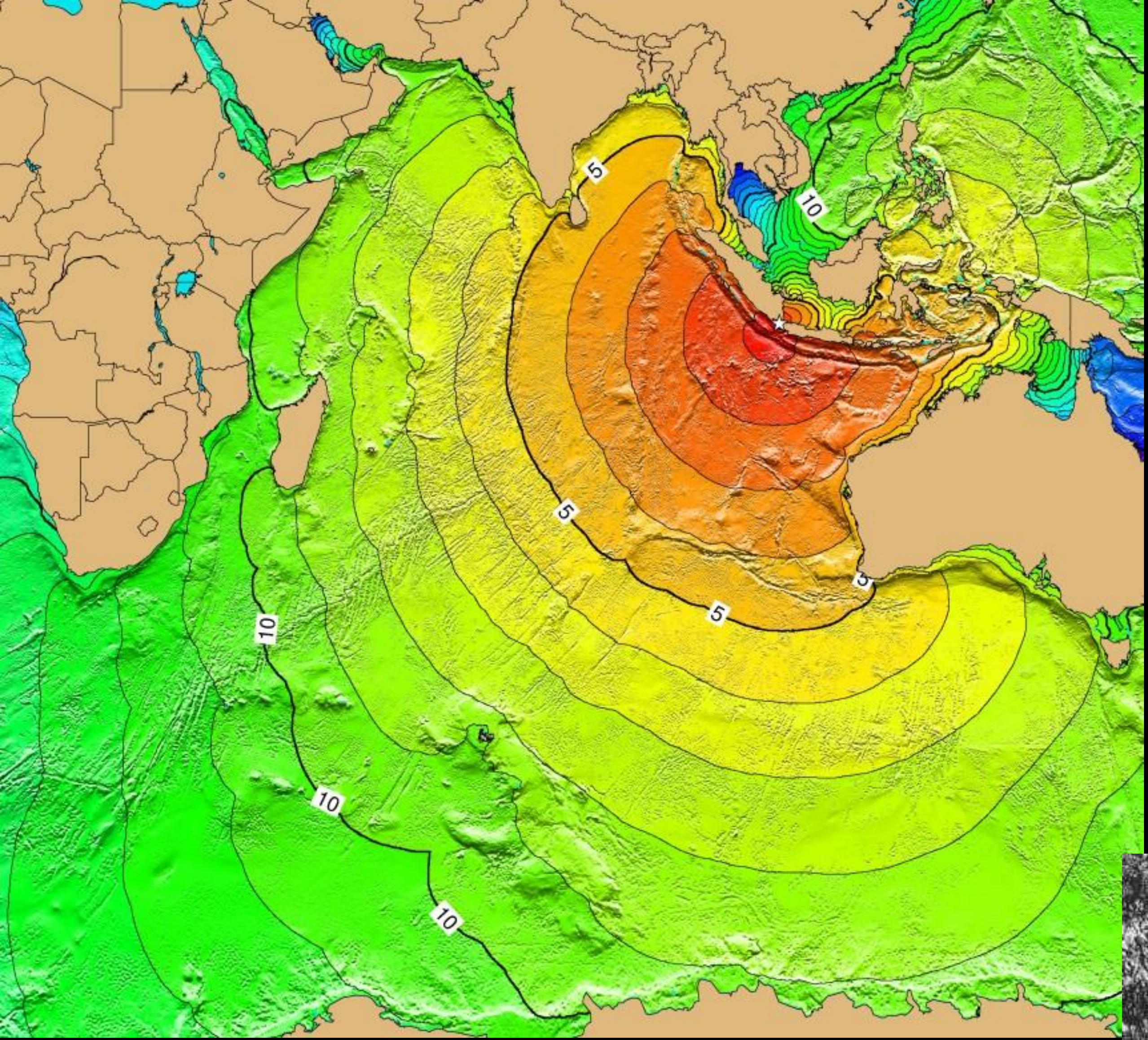

Port Hardy
Zeballos
Campbell River
Vancouver Island
Vancouver
Strait of Georgia
Tsunami hazard
Sites with geological evidence for large prehistoric tsunami
High tsunami run-up potential (1-15+ m)
Intermediate tsunami run-up potential (1-5 m)
Low tsunami run-up potential (<2 m)
Local tsunami potential in mainland inlets
Port Alberni
Tofino
Nanaimo
Port Renfrew
Victoria
Strait of Juan de Fuca


AVES HIT ALBERNIS
Daily Free Press
Today's News Today
Mill Down, Damage Runs Into Millions
'Quake Virtually Ruins Anchorage
Automobiles Sail Down Streets In Port Alberni
Hotel Ahead Of Flood
Earthquakes In History
Boats Washed Into The Bay



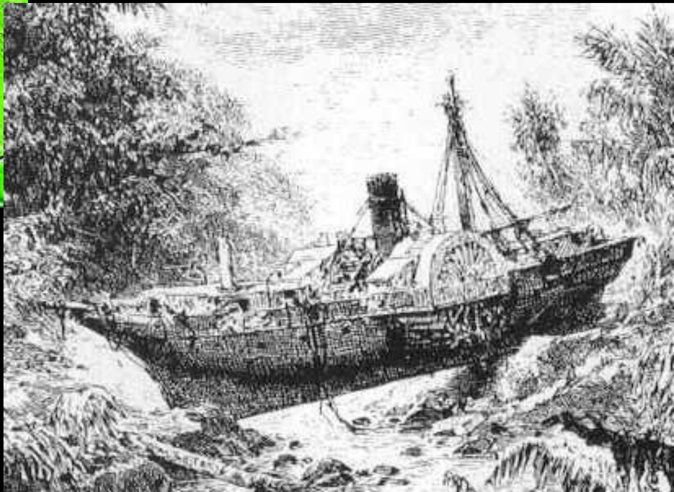
TSUNAMIS GENERATED BY OTHER PROCESSES

Effects of 1929 tsunami on Burin Peninsula, Newfoundland



TSUNAMI GENERATED BY VOLCANIC EXPLOSION AND COLLAPSE

[Map shows travel times in hours – NOAA]



1883 EXPLOSION OF KRAKATOA – 30 m TSUNAMI KILLED 36,000 PEOPLE

TIDAL GAUGE AT BATAVIA (NOW JAKARTA) SHOWING KRAKATOA TSUNAMI, 1883

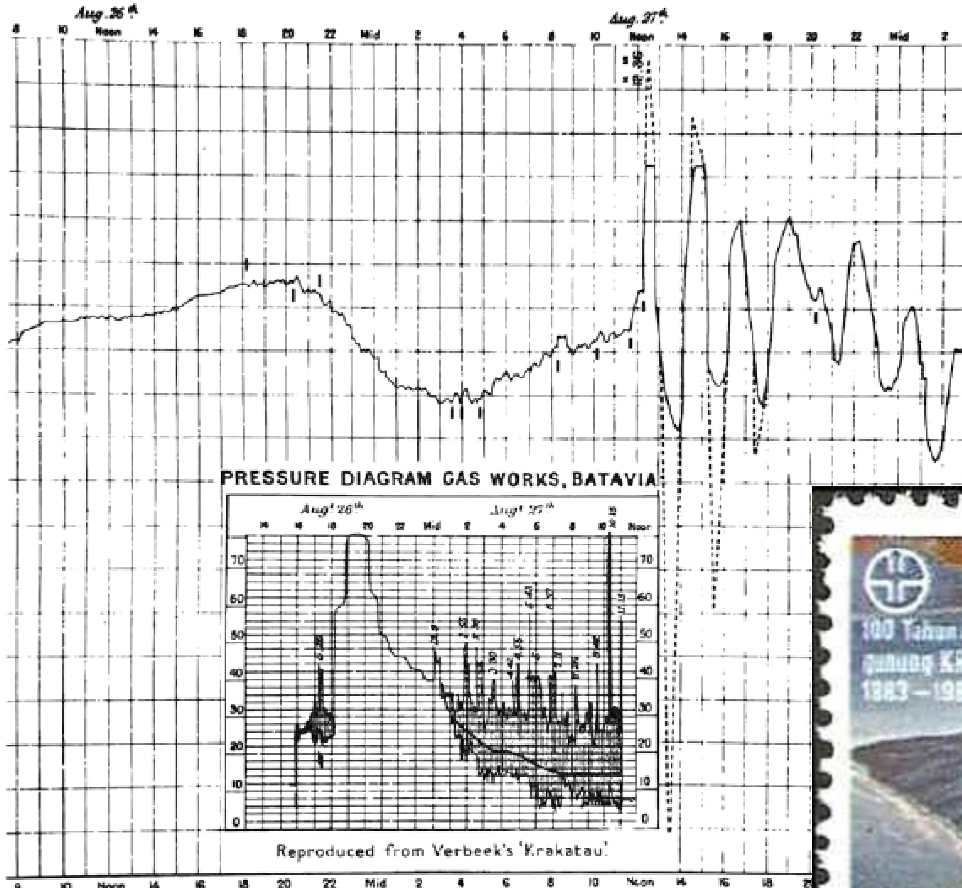
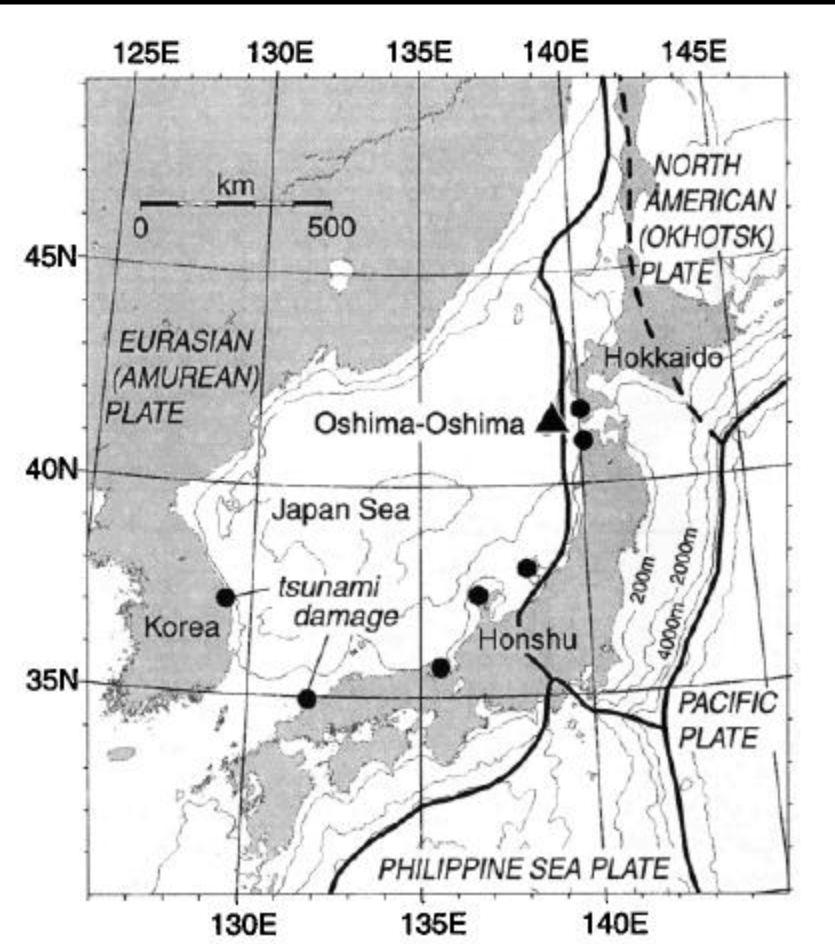
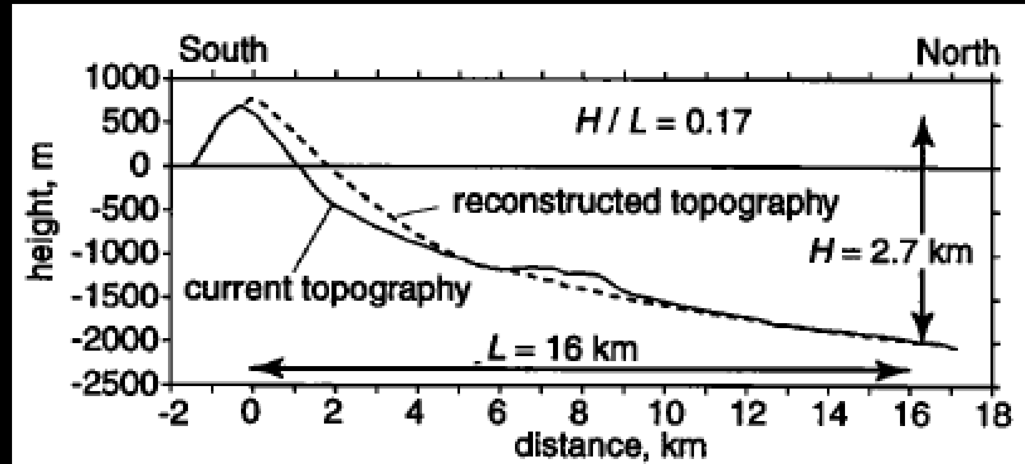


FIG. 3 - Record of tide gauge at Tandjong Priok, 1883 August 26-28, Batavia Time (approximate); with inset showing record of pressure gauge at the Batavia gasworks (the right hand half is the same diagram as in Fig. 2, on a reduced scale: the left hand half shows the pressure variation from mid-afternoon, 1883 August 26). The horizontal divisions on the tide gauge record represent one foot intervals of water level: the scales on the pressure gauge record are as in Fig. 2. Short dashes mark the arrival times read and listed in Table 1: those above the trace indicate a negative (downwards) onset, and those below a positive (upwards) onset: three onsets read on the pressure gauge record for August 26 are also marked. The thin continuous line on the pressure gauge record represents the base line pressure to which the gasometer was regularly adjusted on an hourly basis (VERBEEK, 1886, p. 367). Note that the largest increase on the tide gauge record overloaded the recorder. The sinusoidal waves that follow are due to seiches set up in the bay near Tandjong Priok (YOKOYAMA, 1981). Adapted from WHARTON (1888), and reproduced by permission of the Royal Society, London.

1741 COLLAPSE OF OSHIMA-OSHIMA VOLCANO AND TSUNAMI IN JAPAN SEA





[after Satake and Kato, 2001]

1. Collapse as a result of violent eruption in August 1741
2. Flank collapsed into Japan Sea (estimated volume 2.3 km^3)
3. Tsunami in Japan Sea resulted in ~2000 casualties in western Japan and east coast of Korea
4. Height of tsunami on Hokkaido coast at least 15 m
5. Volcano currently dormant

LANDSLIDE TSUNAMIS CAUSED BY THE COLLAPSE OF OCEANIC VOLCANOES

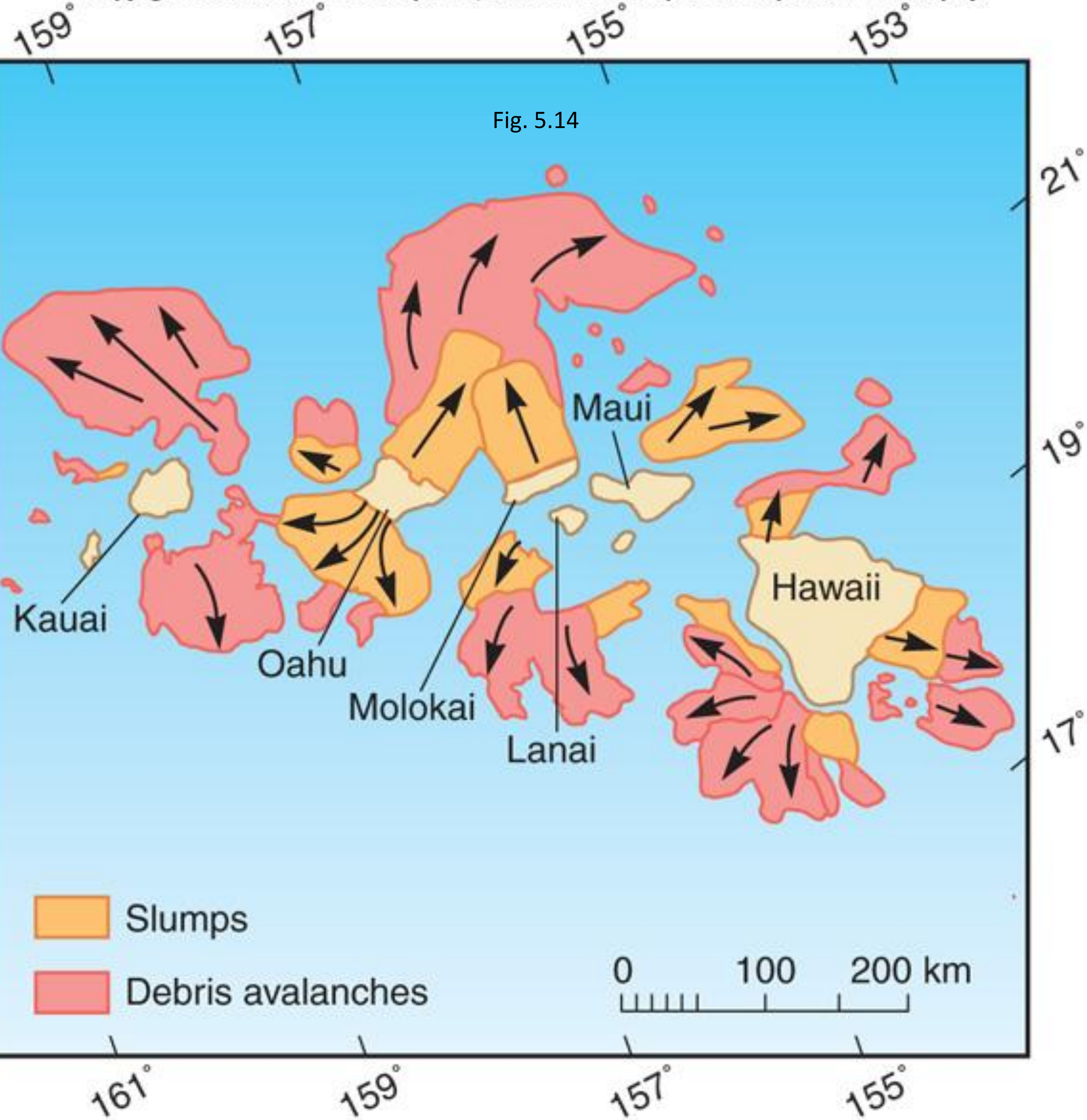


Fig. 5.14

MODELLING TSUNAMI GENERATED IN THE ATLANTIC BY POSSIBLE COLLAPSE OF CUMBRE VIEJA (LA PALMA, CANARY ISLANDS) [After Ward and Day, 2001]

- OCEANIC VOLCANOES
- MODELLING A 500 km^3 LANDSLIDE THAT SPILLS WESTWARD INTO THE DEEP OCEAN
- LANDSLIDE COVERS 3500 km^2
- VELOCITY 100 m/s
- RESULT = TSUNAMI ~ 10-25 m IMPACTS SHORES OF THE AMERICAS

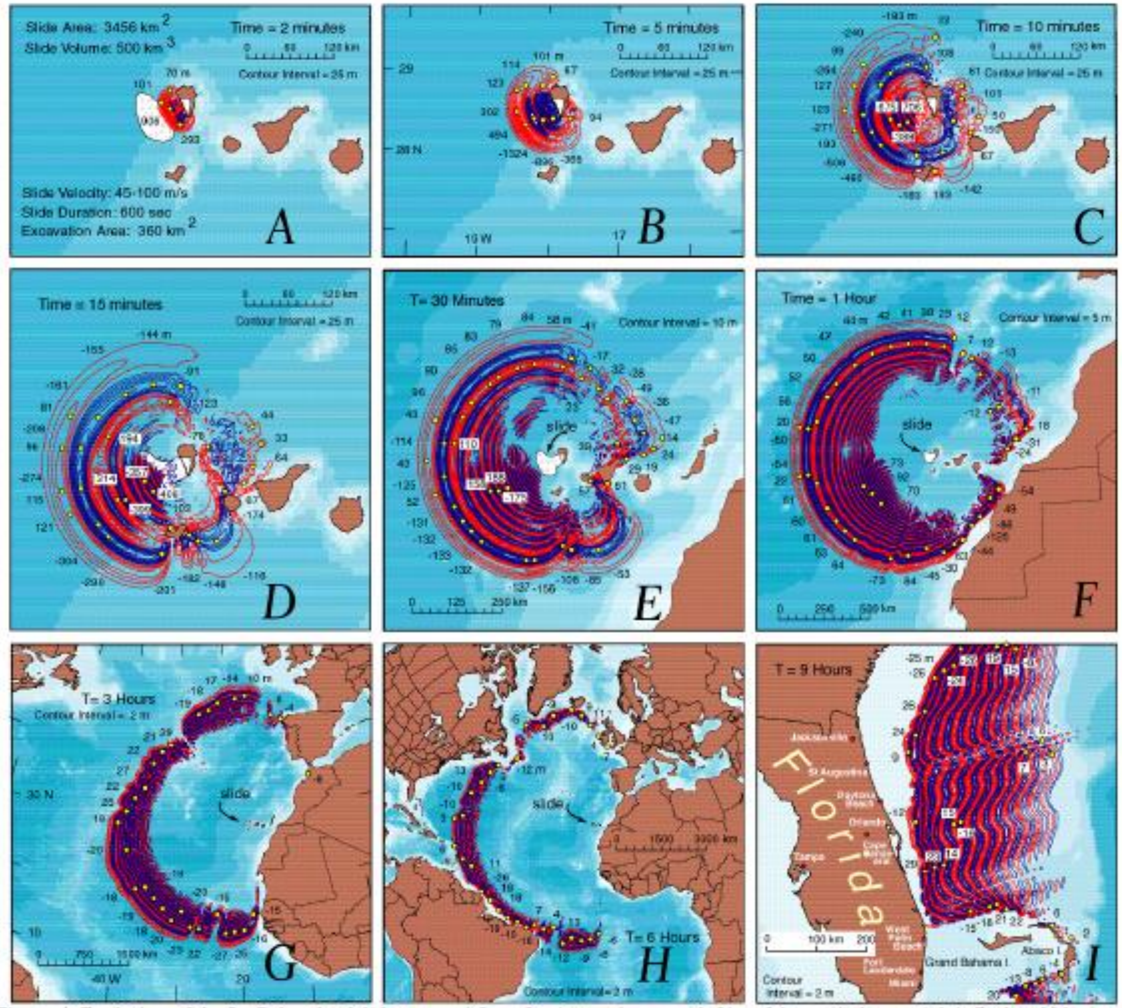
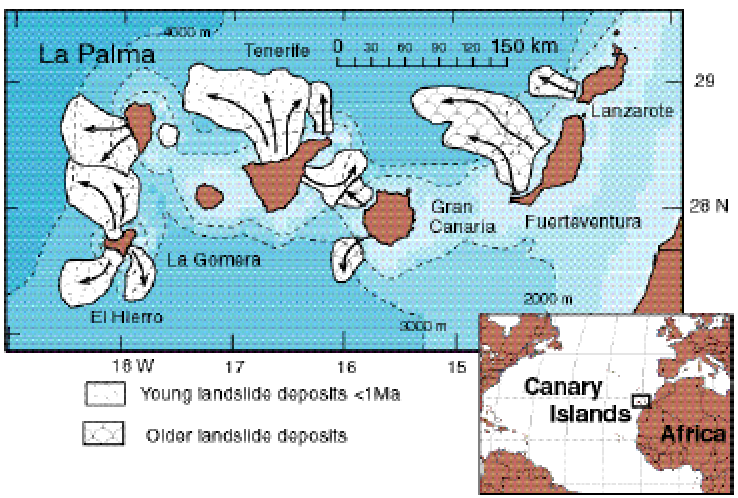


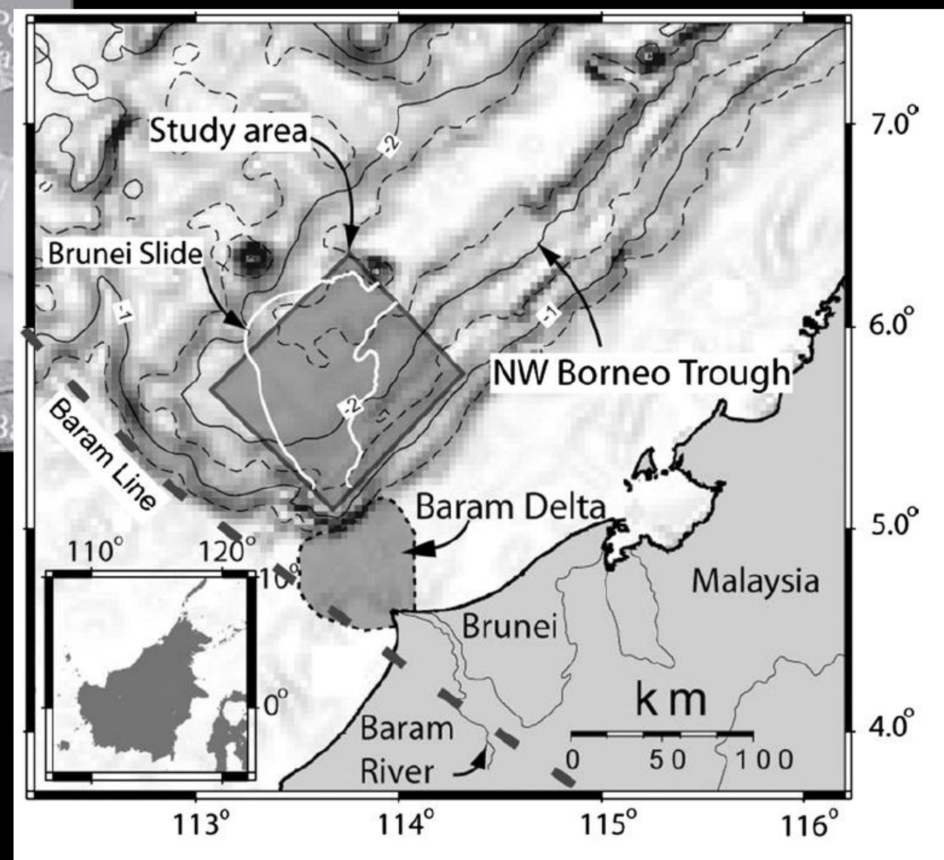
Figure 4. Evolution of the La Palma landslide tsunami from 2 minutes (a, upper left) to 9 hours (i, lower right). Red and blue contours cover elevated and depressed regions of the ocean respectively and the yellow dots and numbers sample the wave height, positive or negative, in meters. Note the strong influence of dispersion in spreading out an original impulse into a long series of waves of decreasing wavelength. See also that the peak amplitudes generally do not coincide with the first wave. Even after crossing the Atlantic, a lateral collapse of Cumbre Vieja volcano could impose a great sequence of waves of 10-25 m height on the shores of the Americas.



TSUNAMIS GENERATED BY SUBMARINE LANDSLIDES

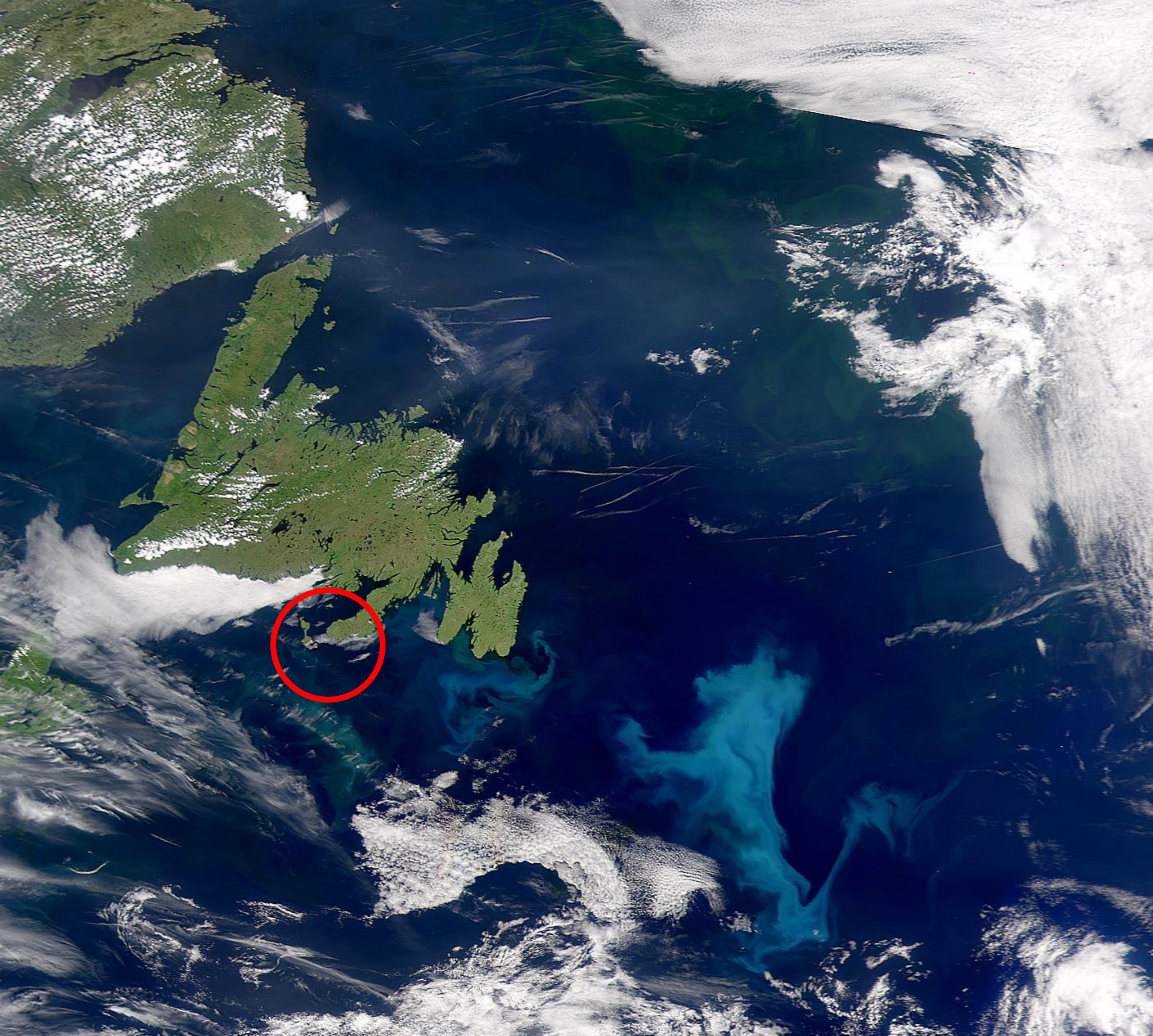
- HIGH VELOCITY (> 20 m/s)
- MASSIVE VOLUME (~10^9 – 10^{12} m^3)

BRUNEI SLIDE – 1200 km^3 in volume; covers an area of 5300 km^2 →



1998 PAPUA NEW GUINEA TSUNAMI – CAUSED BY SUBMARINE LANDSLIDE DEATH TOLL ~2,300 PEOPLE

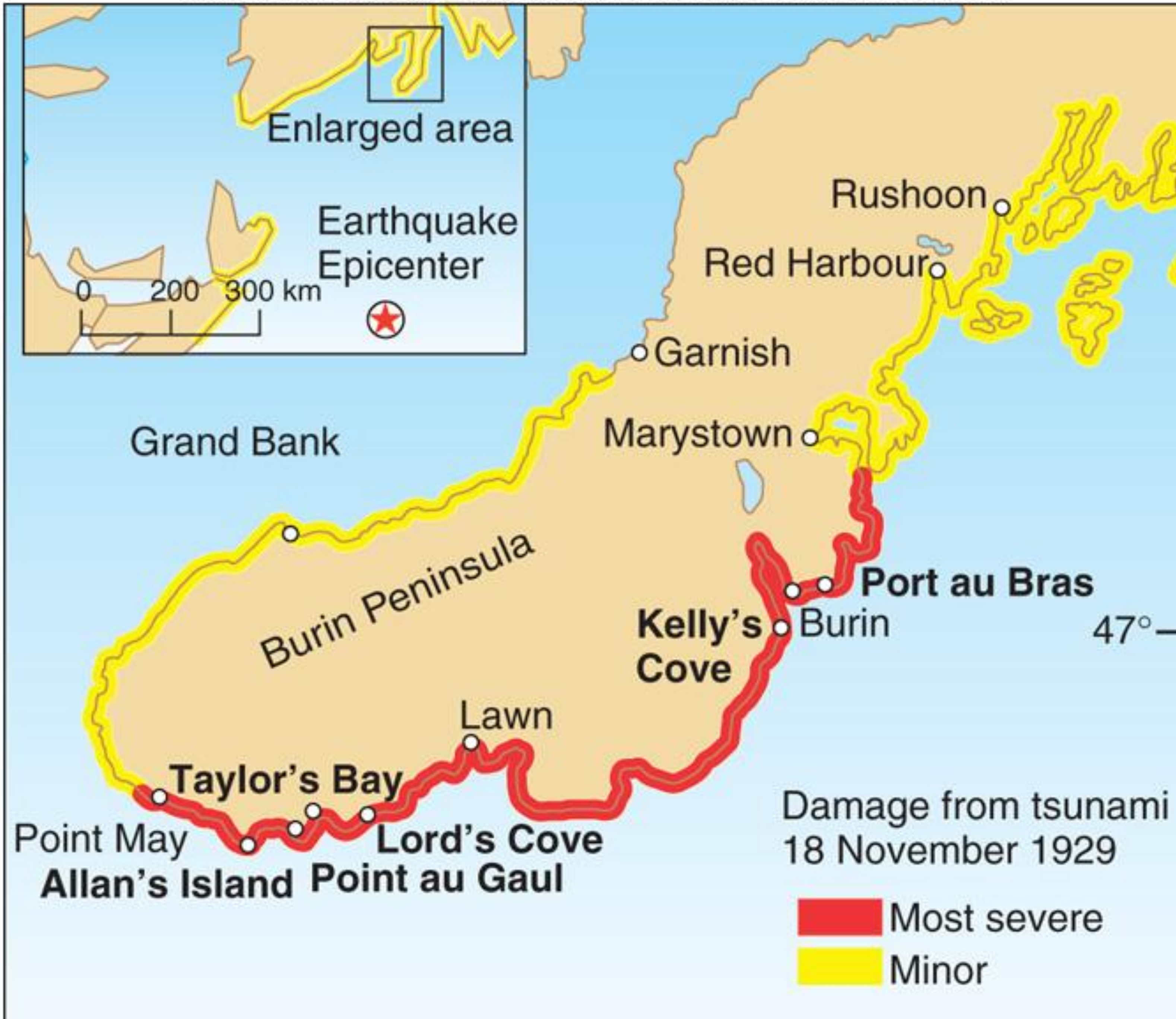
NOAA



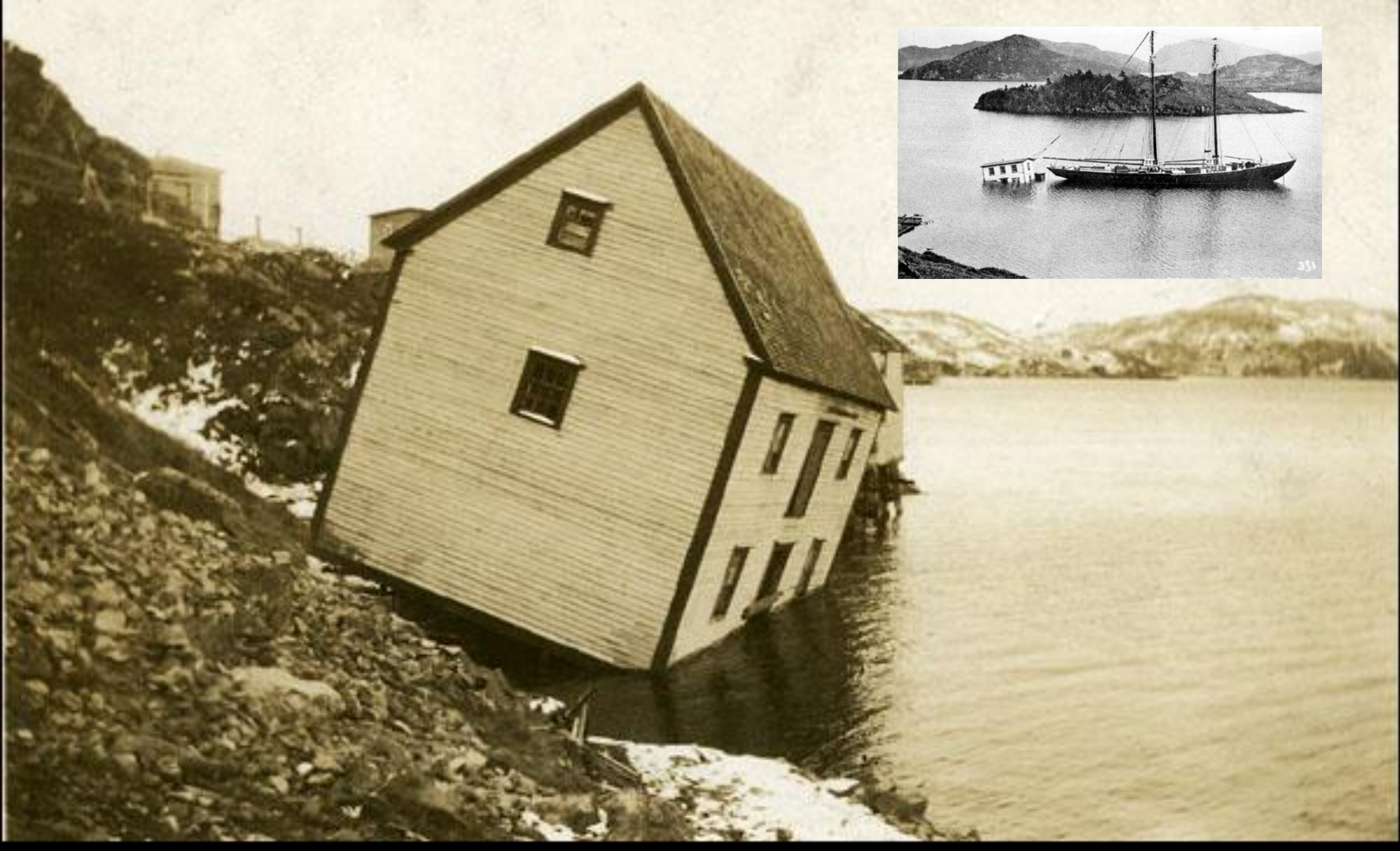
1929 TSUNAMI, BURIN PENINSULA, NEWFOUNDLAND

1929 TSUNAMI, BURIN PENINSULA, NEWFOUNDLAND

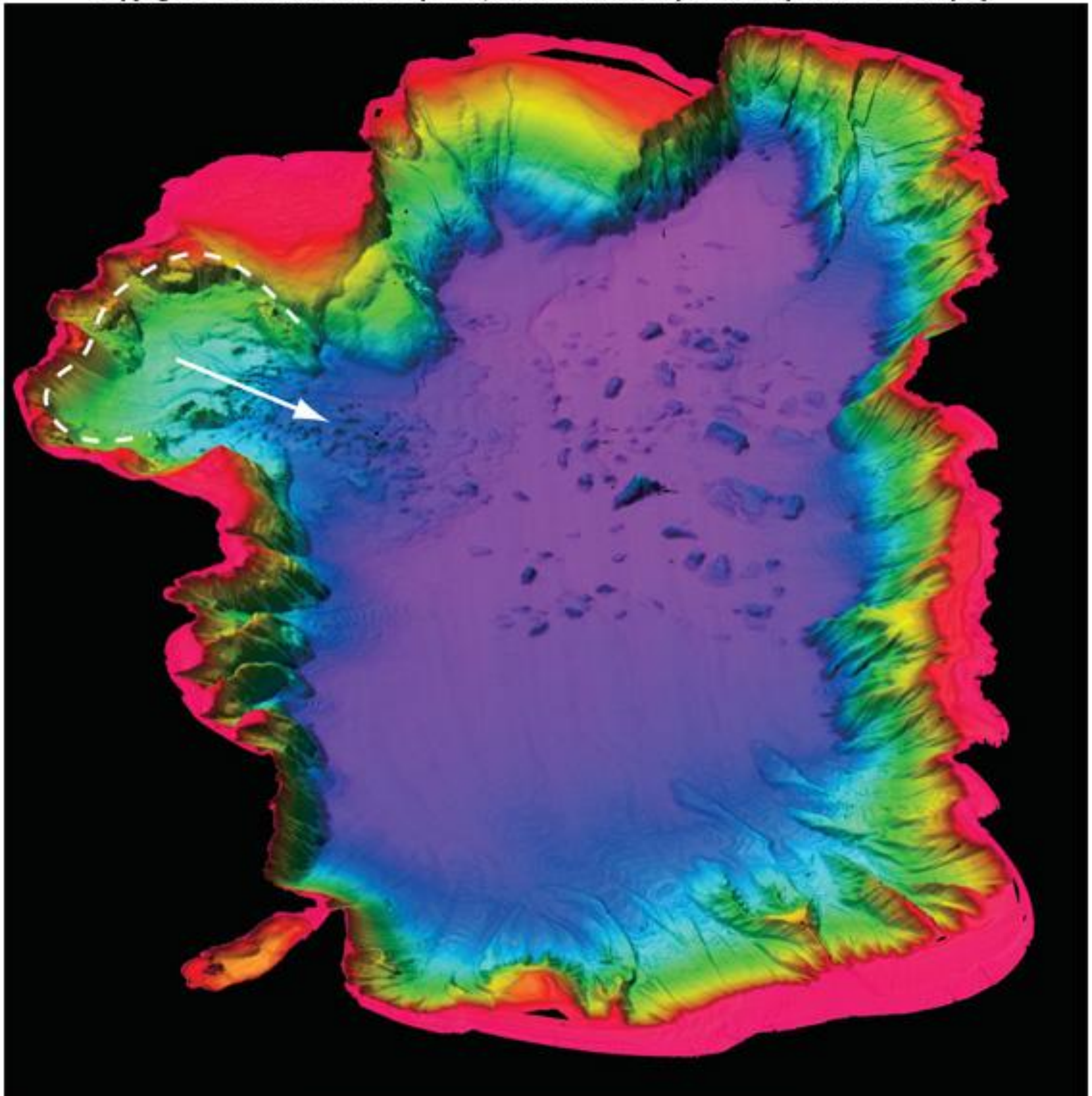
TSUNAMI RESULTED FROM GIANT SUBMARINE LANDSLIDE (200 km^3) TRIGGERED BY EARTHQUAKE – 40 COMMUNITIES DAMAGED, 28 DEATHS


Enlarged area
Earthquake
Epicenter
0
200
300 km
Rushoon
Red Harbour
Garnish
Grand Bank
Marystown
Burin Peninsula
Port au Bras
Kelly's
Cove
Burin
47°
Lawn
Taylor's Bay
Point May
Allan's Island
Lord's Cove
Point au Gaul
Damage from tsunami
18 November 1929
Most severe
Minor

1929 TSUNAMI, BURIN PENINSULA, NEWFOUNDLAND



LANDSLIDE INTO LAKE TAHOE – SUBMARINE LANDSLIDES IN LAKES GENERATE TSUNAMIS



Graham Kent, Scripps Institution of Oceanography

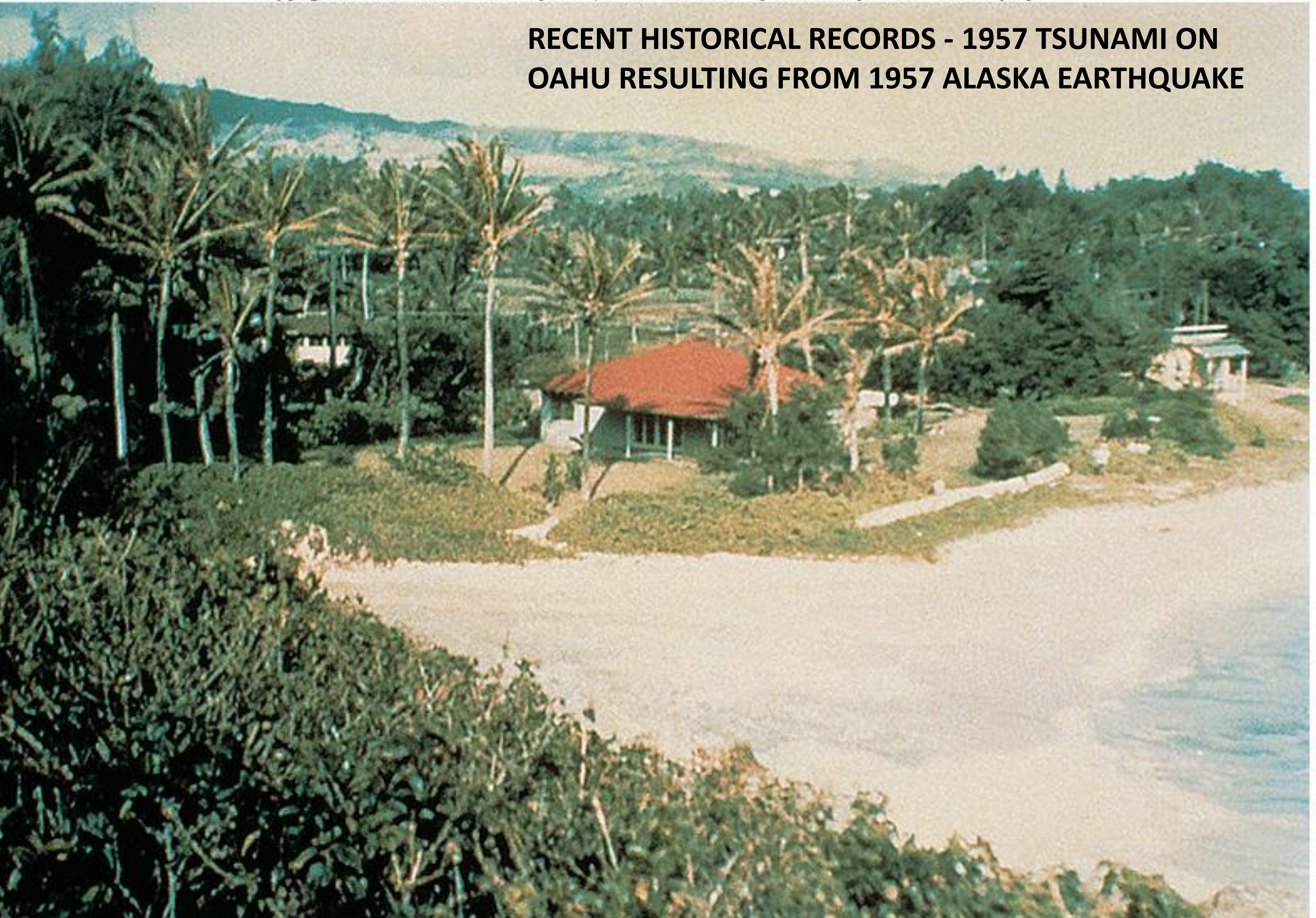
TSUNAMI HAZARD ASSESSMENT

1. **RECORDED EVENTS IN MODERN TIMES (say 1900 ONWARD) IN GEOPHYSICAL DATABASES**
2. **OLDER HISTORICAL RECORDS (ARCHIVAL DATA PRE-1900)**
3. **PREHISTORIC RECORDS RECONSTRUCTED FROM GEOLOGICAL EVIDENCE**

KEY DATA – (1) SOURCE MECHANISM (2) RUN-UP ON SHORE (VERTICAL DISTANCE) (3) INUNDATION OF THE SHORELINE (HORIZONTAL DISTANCE) (4) FREQUENCY IN TIME

NOAA

RECENT HISTORICAL RECORDS - 1957 TSUNAMI ON OAHU RESULTING FROM 1957 ALASKA EARTHQUAKE



NOAA

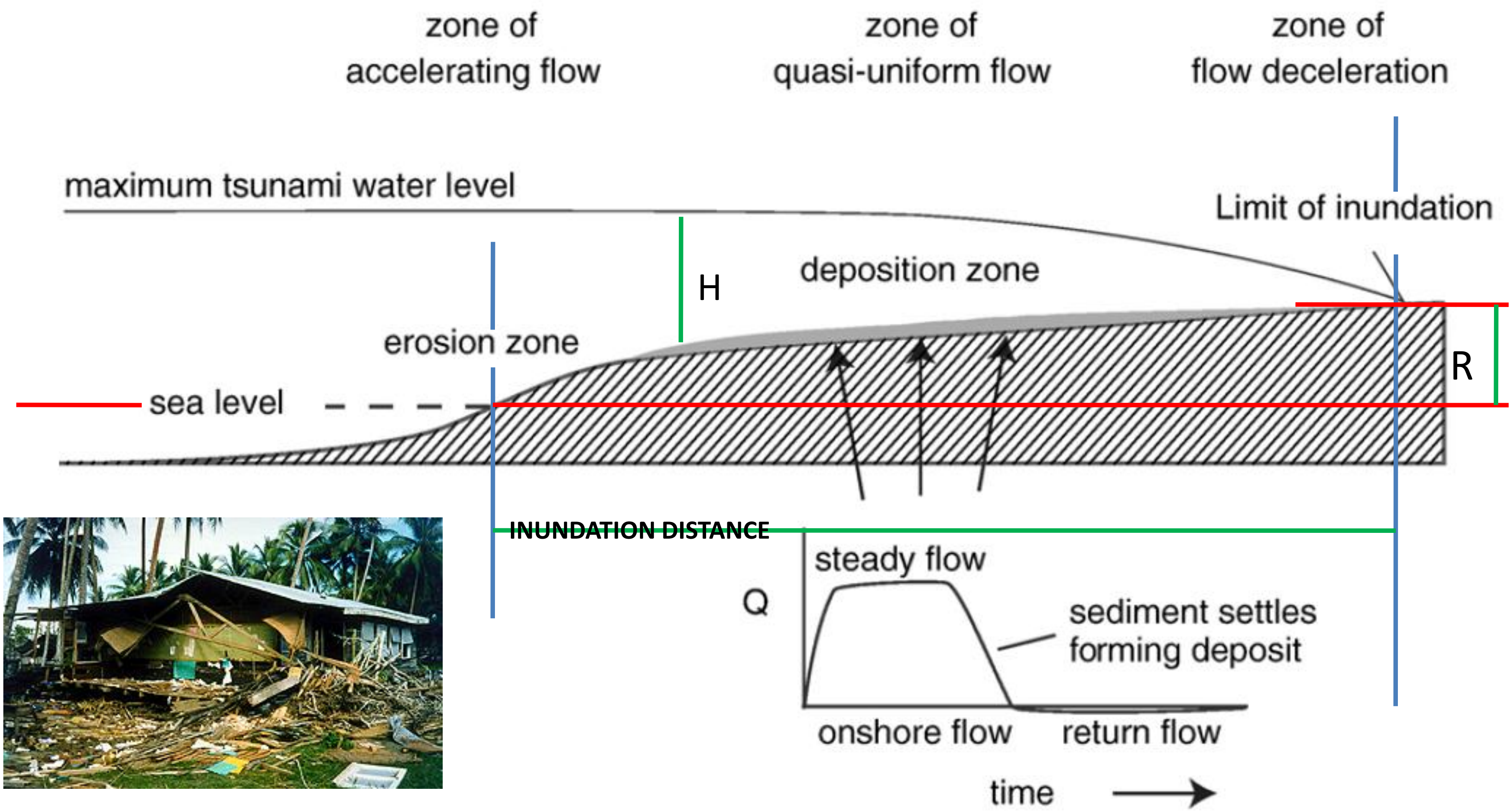
NOAA

NOAA

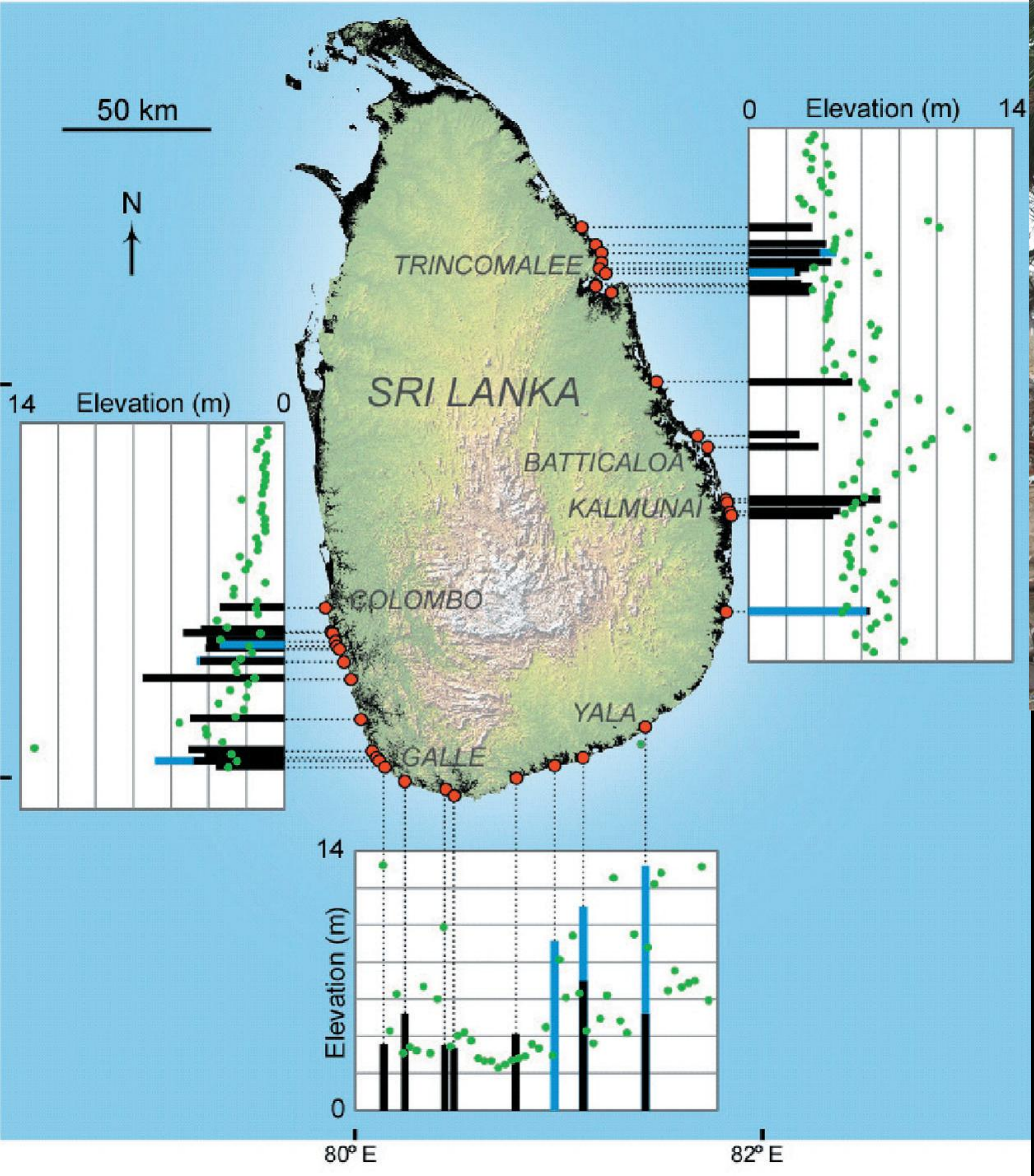

CHILE COAST 1960

SEWARD, ALASKA, 1964

DATA FOR TSUNAMI HAZARD ASSESSMENT AND MITIGATION STRATEGIES



TSUNAMI HEIGHT (H), RUN-UP (R) AND INUNDATION DISTANCE [SAND SHEETS DEPOSITED IN DEPOSITION ZONE]



POST-TSUNAMI RUN-UP FIELD SURVEY, SRI LANKA FOLLOWING 2004 TSUNAMI

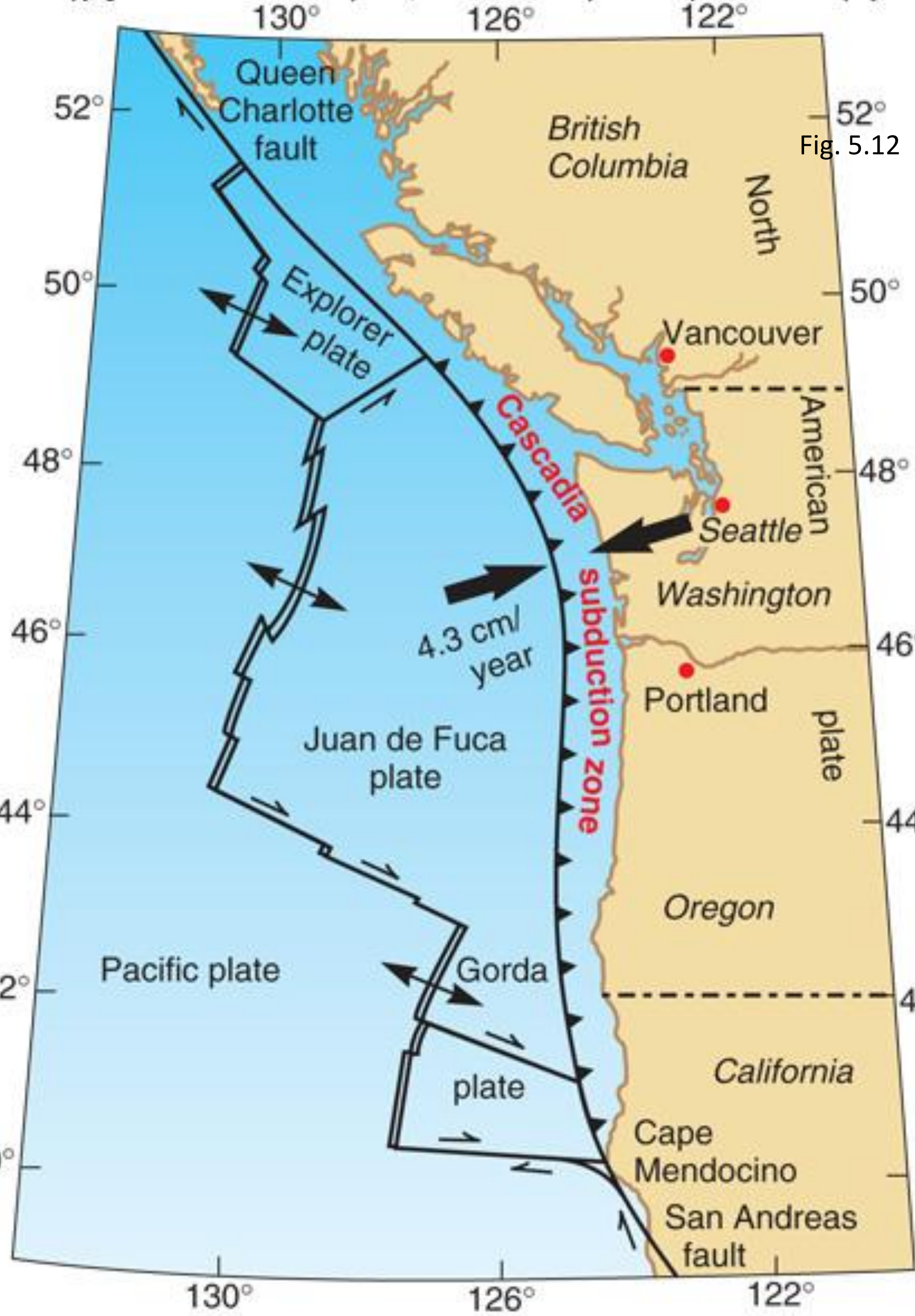
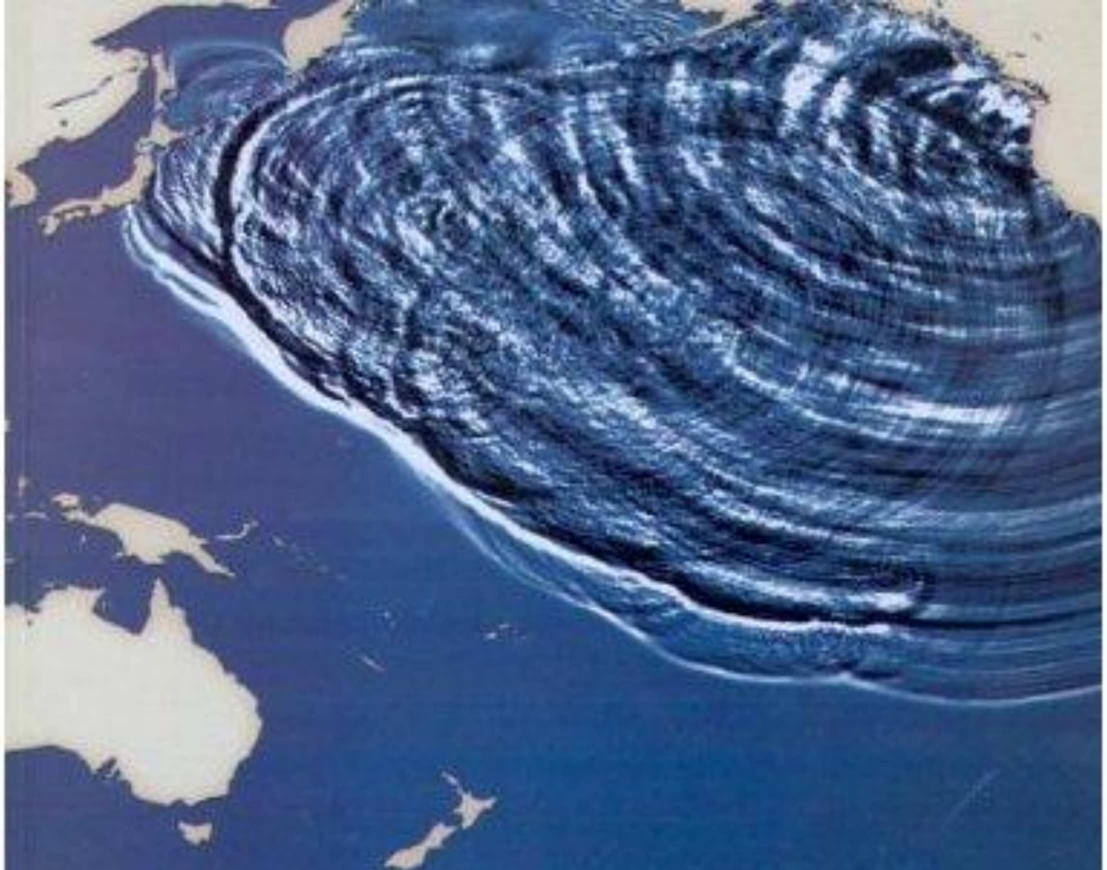


Fig. 5.12

TSUNAMI POTENTIAL OF MEGATHRUST EVENT ON CASCADIA SUBDUCTION ZONE



The ORPHAN TSUNAMI of 1700

みなしご元禄津波

親地震は北米西海岸にいた

Japanese Clues to a Parent Earthquake in North America

OLDER HISTORICAL RECORDS Of TSUNAMI OCCURRENCES CAN BE USEFUL IN ASSESSING TSUNAMI HAZARD

Bulletin of the Seismological Society of America, Vol. 98, No. 6, pp. 2795–2805, December 2008, doi: 10.1785/0120070192

Discrimination of Tsunami Sources (Earthquake versus Landslide) on the Basis of Historical Data in Eastern Sicily and Southern Calabria

by Flavia Gerardi, Maria Serafina Barbano, Paolo Marco De Martini, and Daniela Pantosti

Abstract The source mechanisms responsible for large historical tsunamis that have struck eastern Sicily and southern Calabria are a topic of robust debate. We have compiled a database of historical coeval descriptions of three large tsunamis: 11 January 1693, 6 February 1783, and 28 December 1908. By using accounts of run-up and inundation and employing an approach proposed by Okal and Synolakis in 2004, we can provide discriminants to define the nature of the near-field tsunami sources (fault dislocation or landslide).

ASSIGNING SOURCE MECHANISMS CAN BE UNCERTAIN

A TSUNAMI RECORD BASED ON GEOLOGICAL EVIDENCE

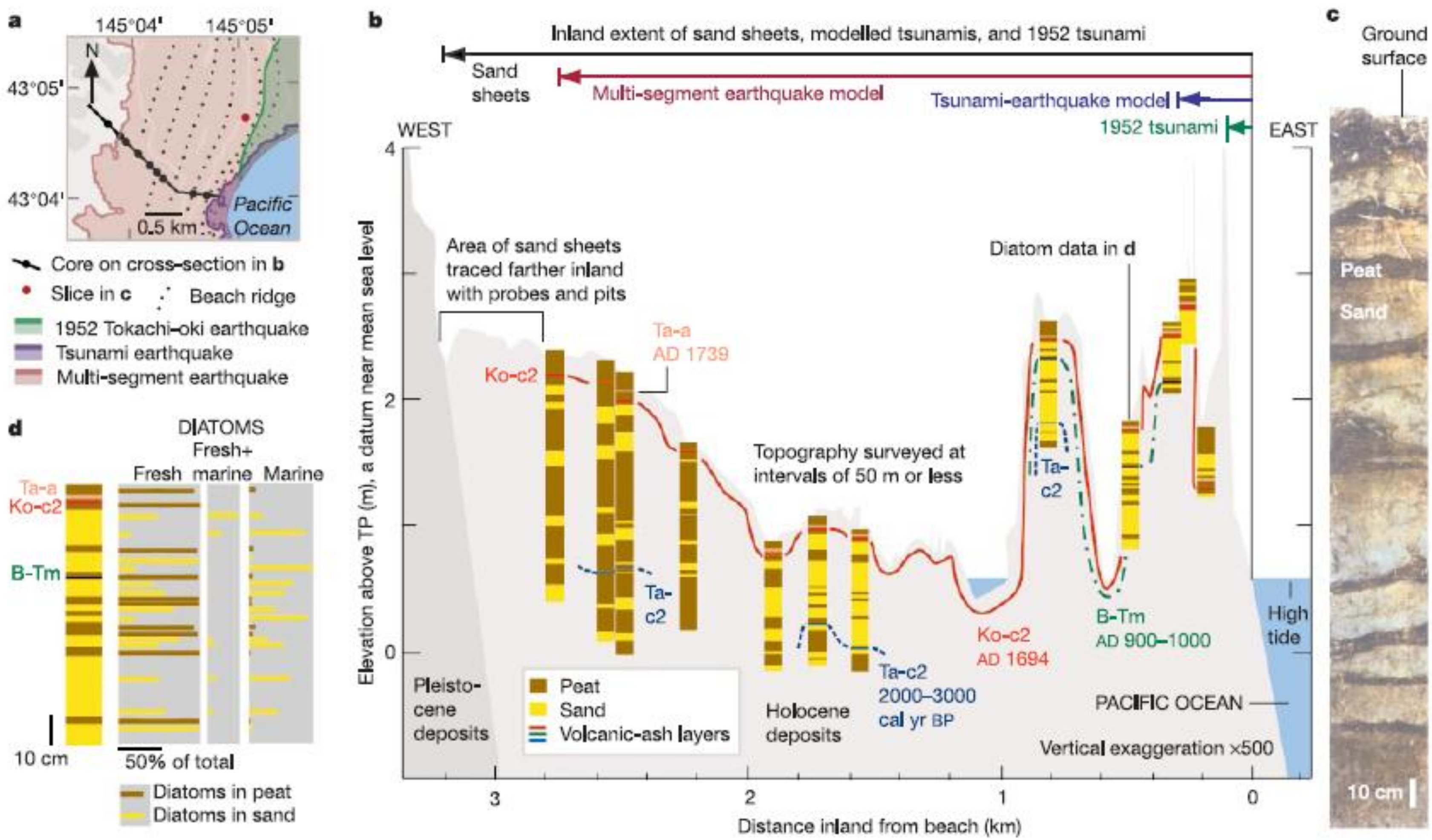


Figure 3 Evidence for outsize tsunamis at Kiritappu. **a**, Index map, showing inundation areas reported for the 1952 tsunami[9] and computed for the two hypothetical earthquakes in Fig. 1b. **b**, Cross-section of cores correlated by volcanic ash from Tarumai (Ta-a, Ta-c2), Komagatake (Ko-c2) and Baitousan (B-Tm) (ref. 17, Supplementary Table S2). Arrows at top compare sand-sheet extent with inundation computed from hypothetical earthquakes and with inundation observed for 1952 tsunami[9]. **c**, Sand interbedded with peat in slice collected 0.5 km from the coast (at red dot in **a**). **d**, Diatom assemblages from a core in **b** (supporting details in Supplementary Table S3).

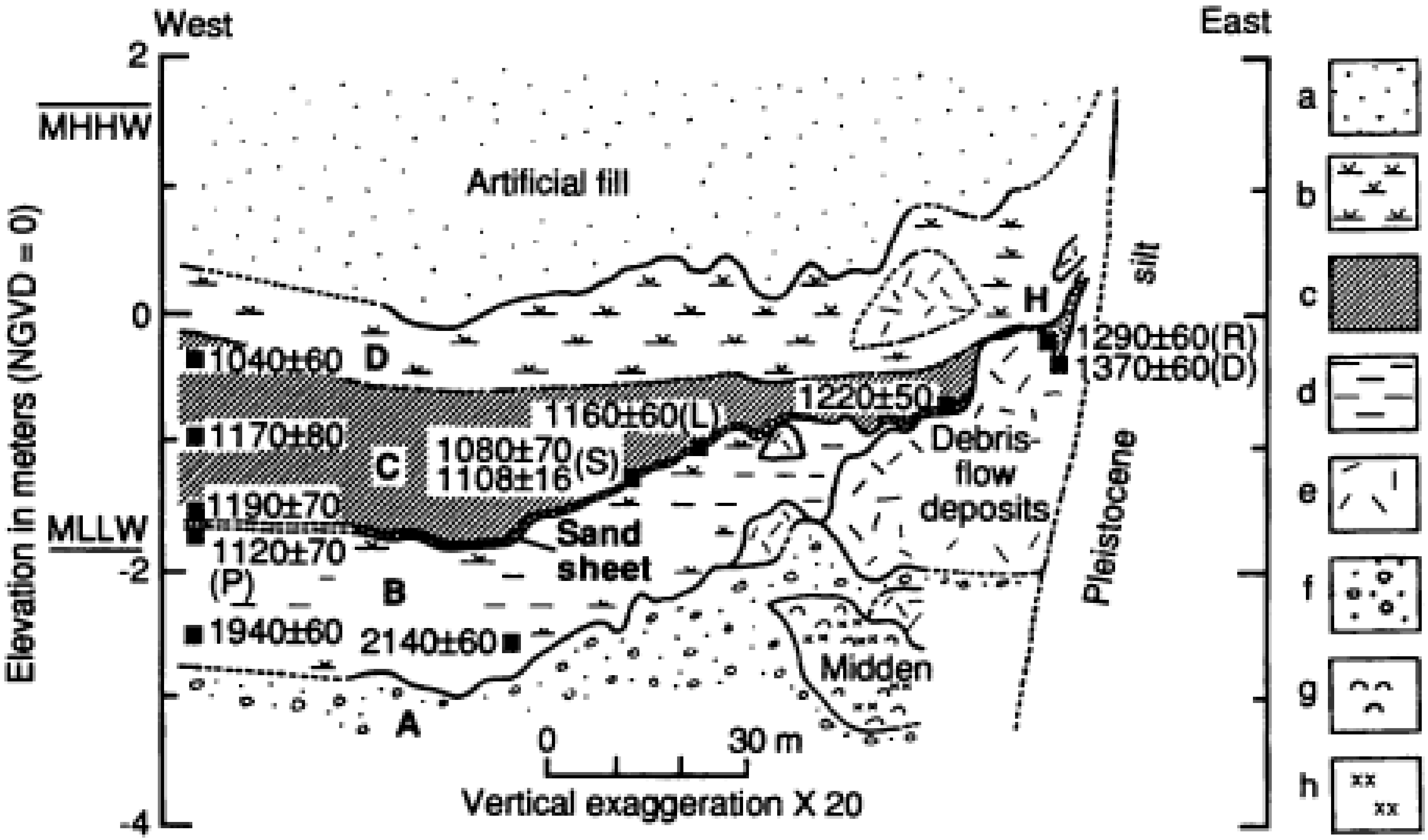
Medieval forewarning of the 2004 Indian Ocean tsunami in Thailand

Kruawun Jankaew[1], Brian F. Atwater[2], Yuki Sawai[3], Montri Choowong[1], Thasinee Charoentitirat[1], Maria E. Martin[4] & Amy Prendergast[5]

Recent centuries provide no precedent for the 2004 Indian Ocean tsunami, either on the coasts it devastated or within its source area. The tsunami claimed nearly all of its victims on shores that had gone 200 years or more without a tsunami disaster[1]. The associated earthquake of magnitude 9.2 defied a Sumatra–Andaman catalogue that contains no nineteenth-century or twentieth-century earthquake larger than magnitude 7.9 (ref. 2). The tsunami and the earthquake together resulted from a fault rupture 1,500 km long that expended centuries' worth of plate convergence[2–5]. Here, using sedimentary evidence for tsunamis[6], we identify probable precedents for the 2004 tsunami at a grassy beach-ridge plain 125 km north of Phuket. The 2004 tsunami, running 2 km across this plain, coated the ridges and intervening swales with a sheet of sand commonly 5–20 cm thick. The peaty soils of two marshy swales preserve the remains of several earlier sand sheets less than 2,800 years old. If responsible for the youngest of these pre-2004 sand sheets, the most recent full-size predecessor to the 2004 tsunami occurred about 550–700 years ago.

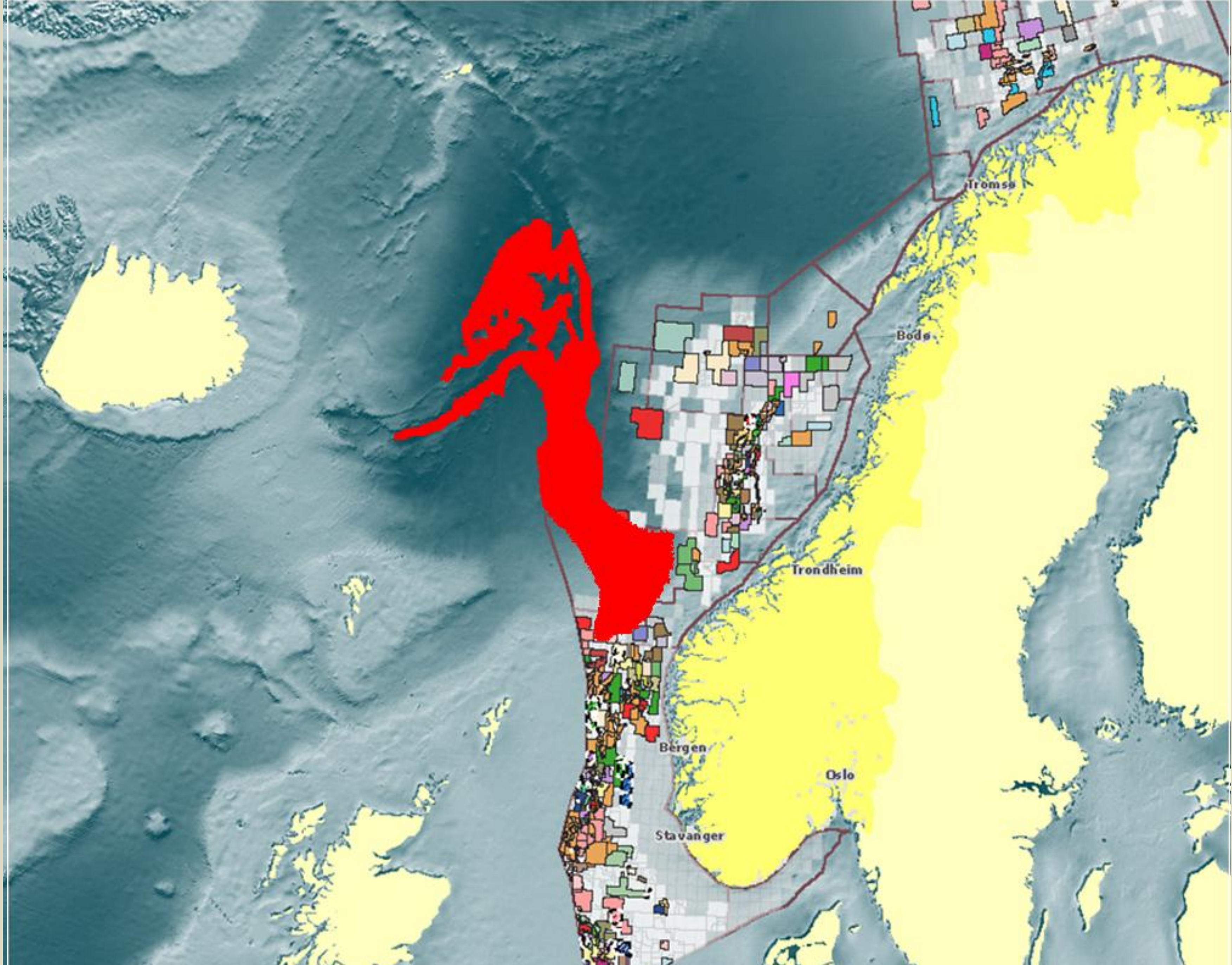
(Figs 1e and 2a, and Supplementary Fig. 3a). These swales formed about 2,500 years ago (bark and shell dates; Fig. 2b, c), when the area's relative sea level was probably within 1–2 m of its present position[13]. Because beaches have built the island westwards, the more westerly of the swales (X) postdates its neighbour (Y). We assembled stratigraphic cross-sections from correlated pits, from auger borings and from a trench 35 m long, estimated particle size in the field, inferred a preliminary chronology from radiocarbon dating of individual plant remains and shells (Figs 2c and 3, and Supplementary Table 2), and made diatom analyses (Supplementary Figs 4 and 5).

Peaty soil in swale X contains two sand sheets (B and C in Fig. 2b, d) that resemble the overlying 2004 deposit. Sheet C, the earlier, is commonly 10 cm thick. Coarse to very coarse sand forms a discontinuous basal layer that fills pre-existing pockets in the underlying soil. The rest of sheet C consists of very fine sand and coarse silt that contains horizontal laminae defined most visibly by leaf fragments (Fig. 3c). The entire sheet formed after 2,200–2,400 sidereal years ago, the age of an isolated piece of bark in the uppermost 1 cm of the



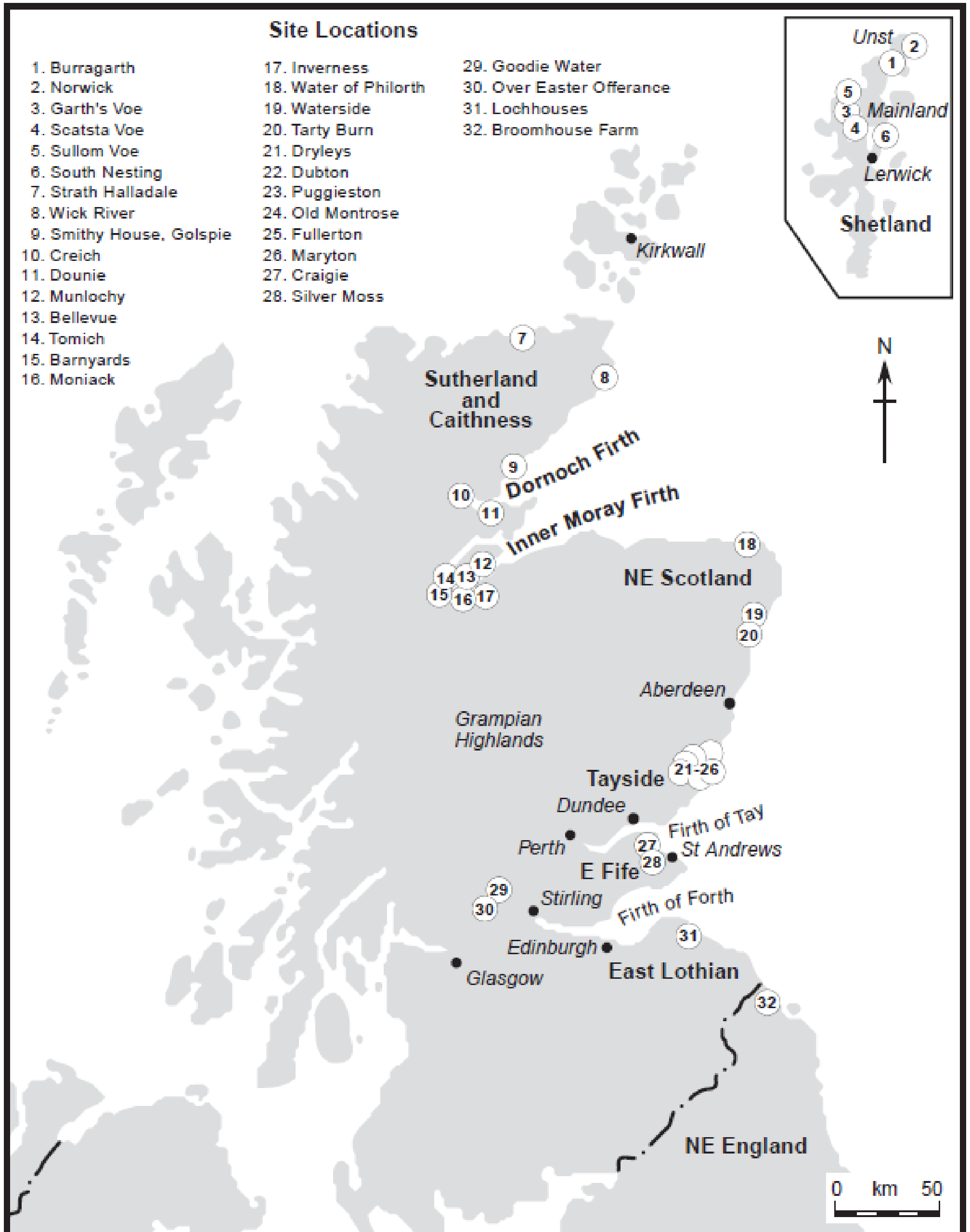
TSUNAMI DEPOSIT DATED BY RADIOCARBON METHOD, SEATTLE, WASHINGTON

NORWEGIAN OIL FIELDS IN THE NORTH SEA (NORWEGIAN CONTINENTAL SHELF)



STOREGGA SLIDE; GIGANTIC TSUNAMIGENIC SUBMARINE LANDSLIDE OFF NORWEGIAN SHELF (occurred 8,150 cal. Years ago; 5,580 km3 of sediment)

STOREGGA SLIDE– OCCURRED 7900 y BP; VOLUME ~ 5580 km^3



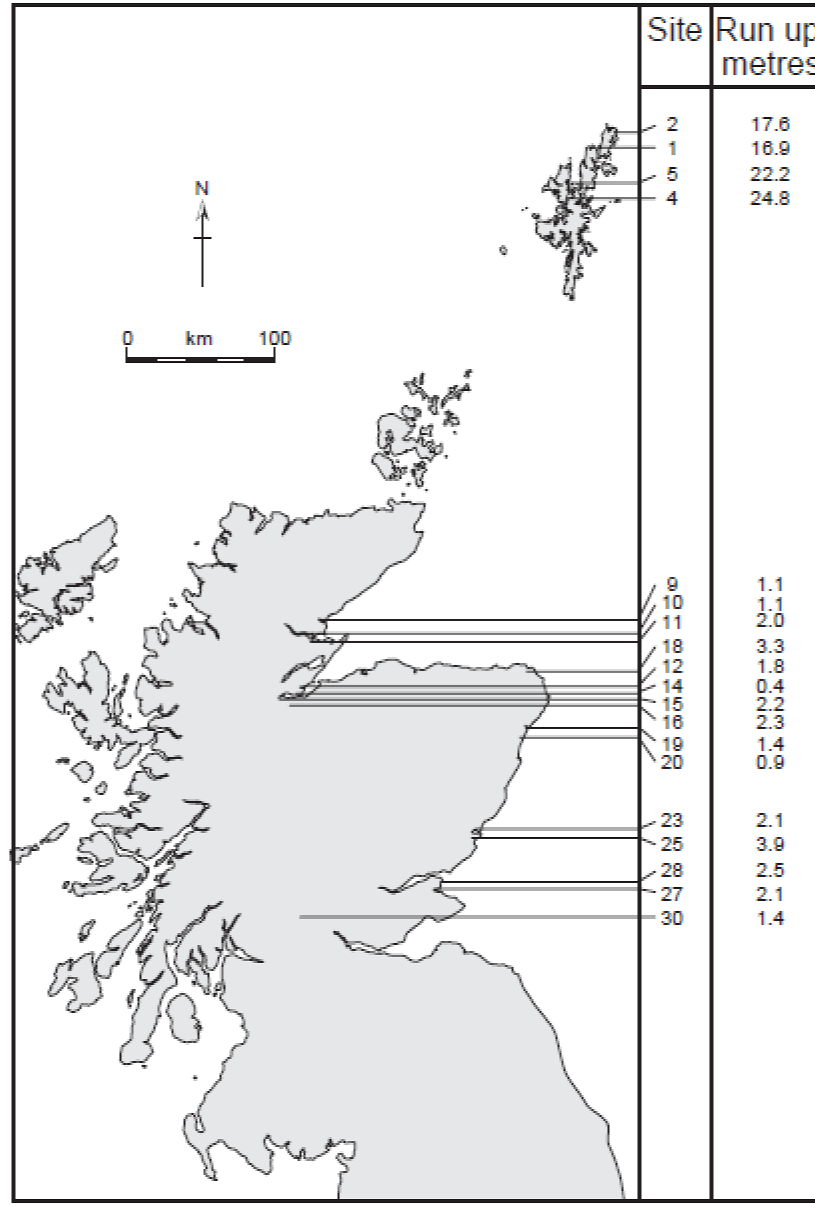
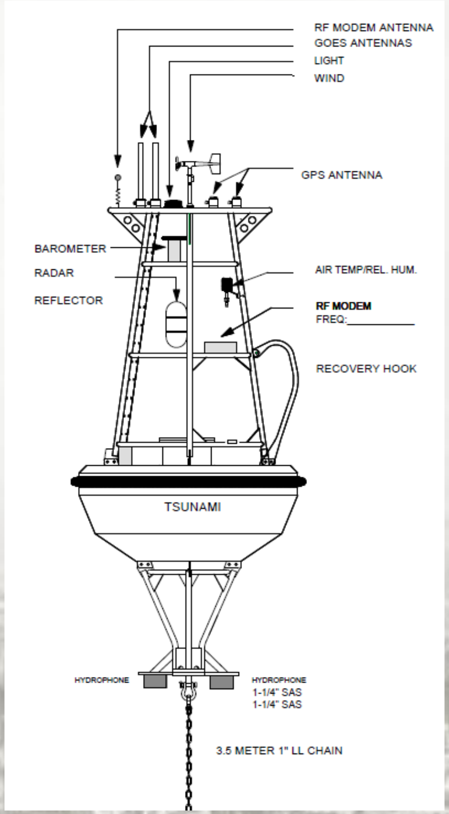


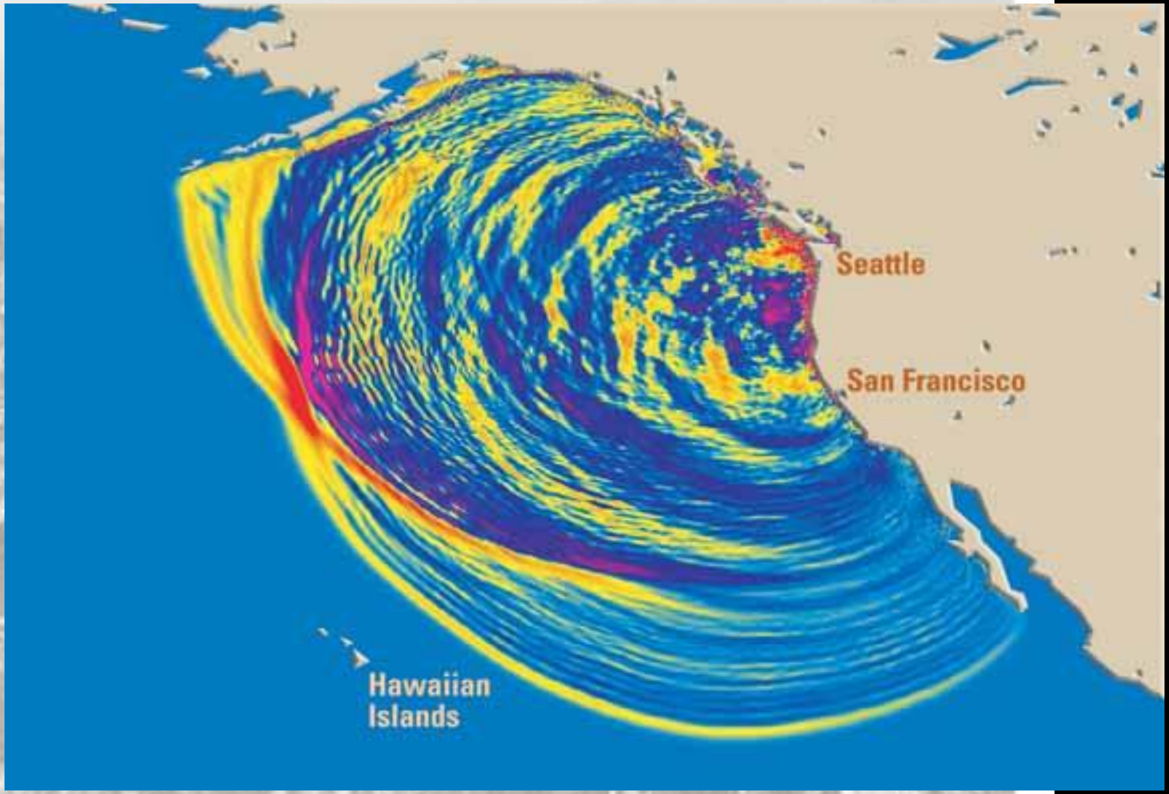
Fig. 13. The distribution of the highest sediment run-up values recorded for sites in the United Kingdom where the tsunami layer has been traced to its inland limit and the altitude of the contemporary shoreline has been measured (the shoreline altitude for Shetland is estimated from Lambeck, 1995, see text).

(d)

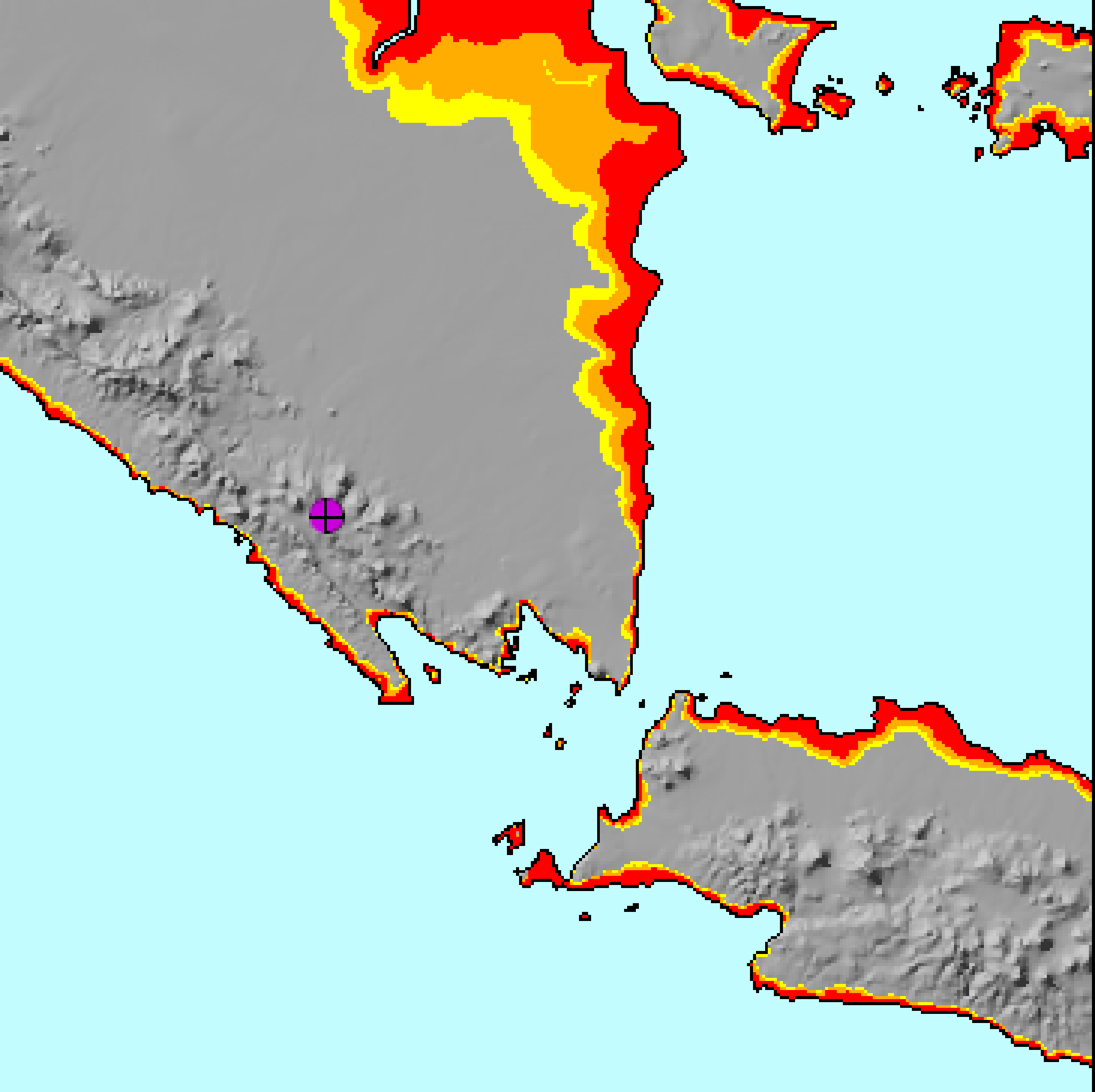
TSUNAMI MITIGATION

- LAND USE CONTROLS
- WARNING AND EVACUATION
- DEFENSIVE STRUCTURES

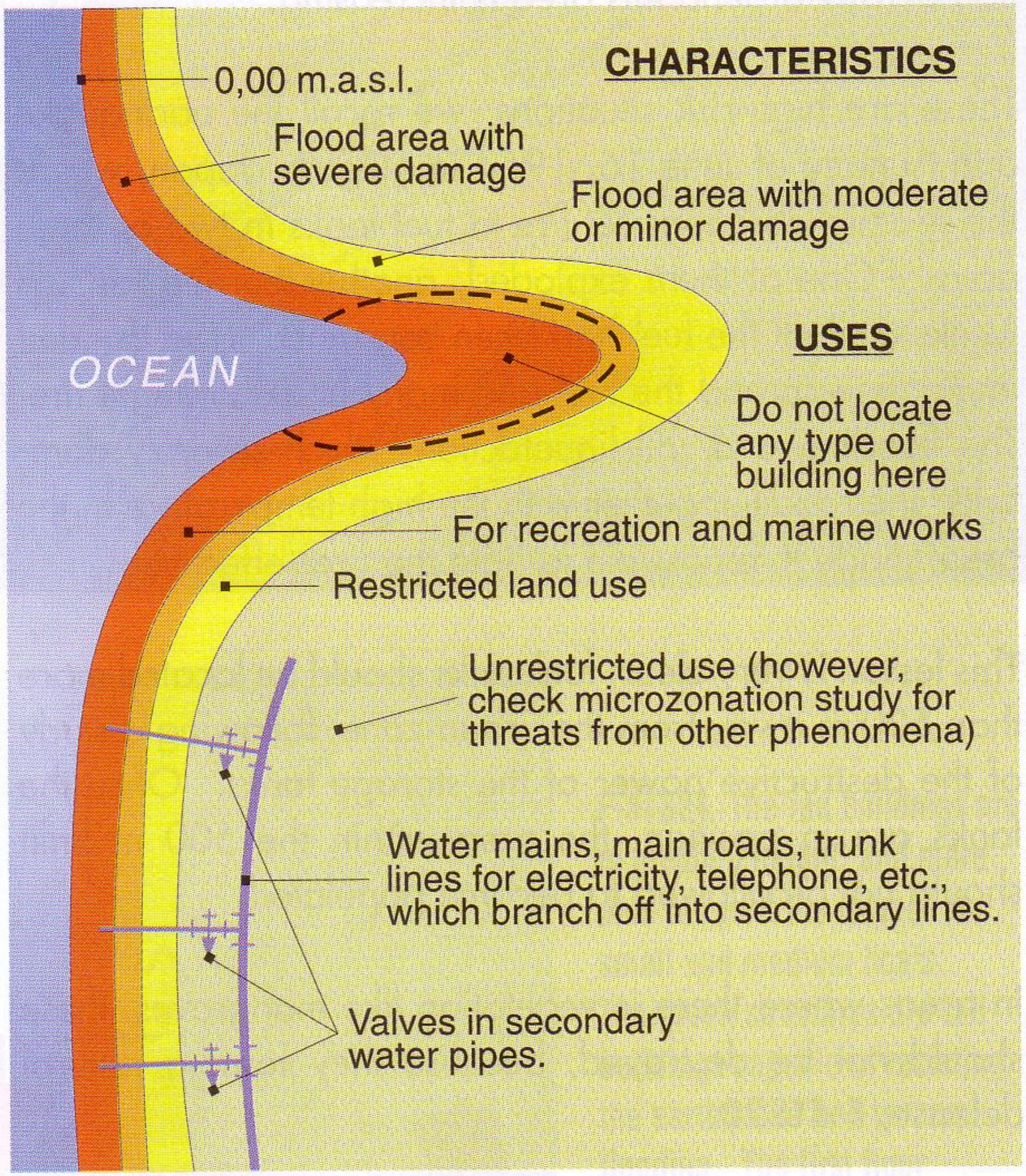




Lawrence Captive Airship 1

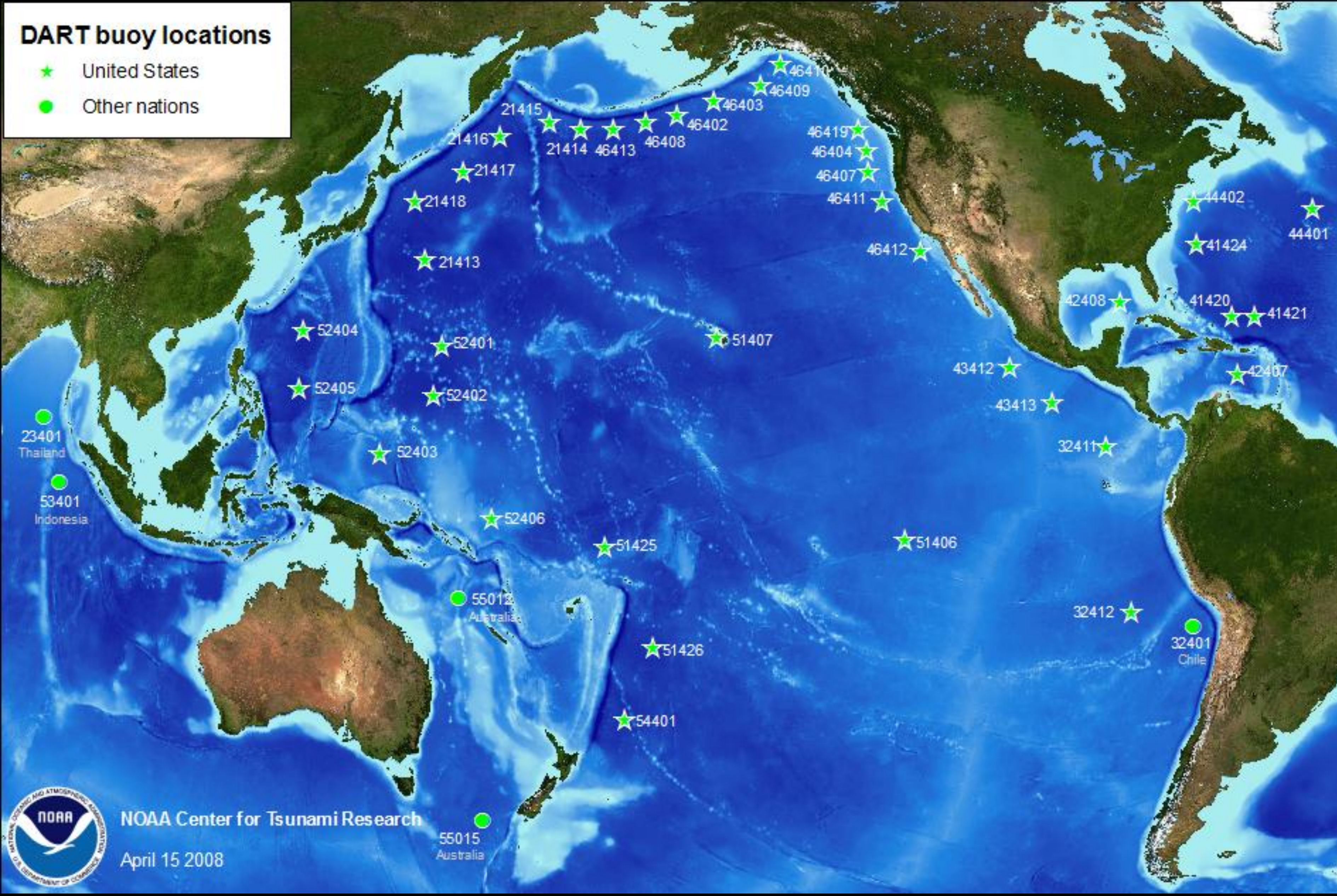


TSUNAMI INUNDATION ZONE MAPPING USING GIS – THE EXAMPLE OF SOUTH SUMATRA AND WESTERN JAVA

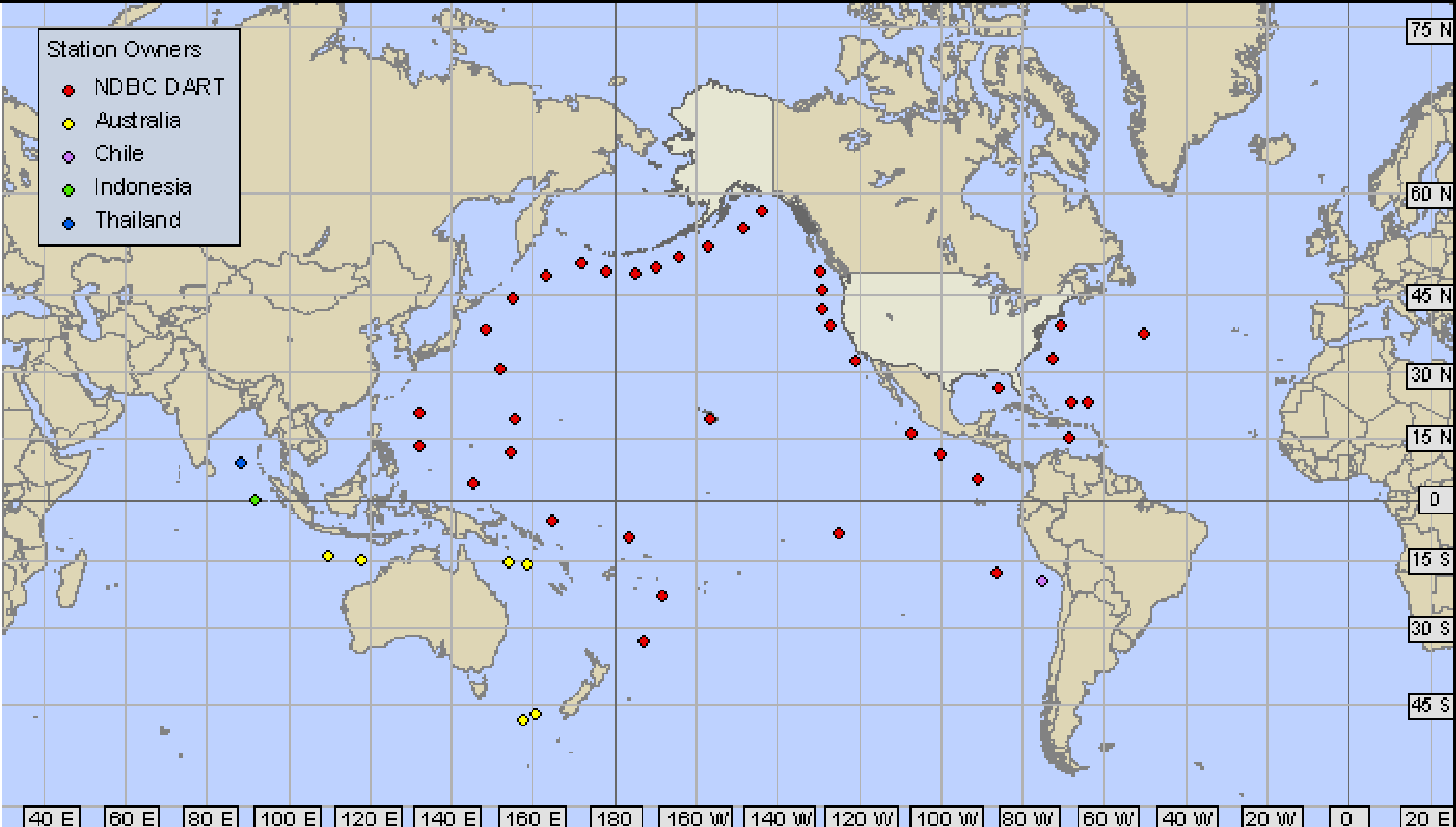


F-4TS19 Land-use planning diagram for the areas prone to tsunami flooding. Note that the lifeline services are given special consideration, because of their importance for survival.


TSUNAMI WARNING
TSUNAMI

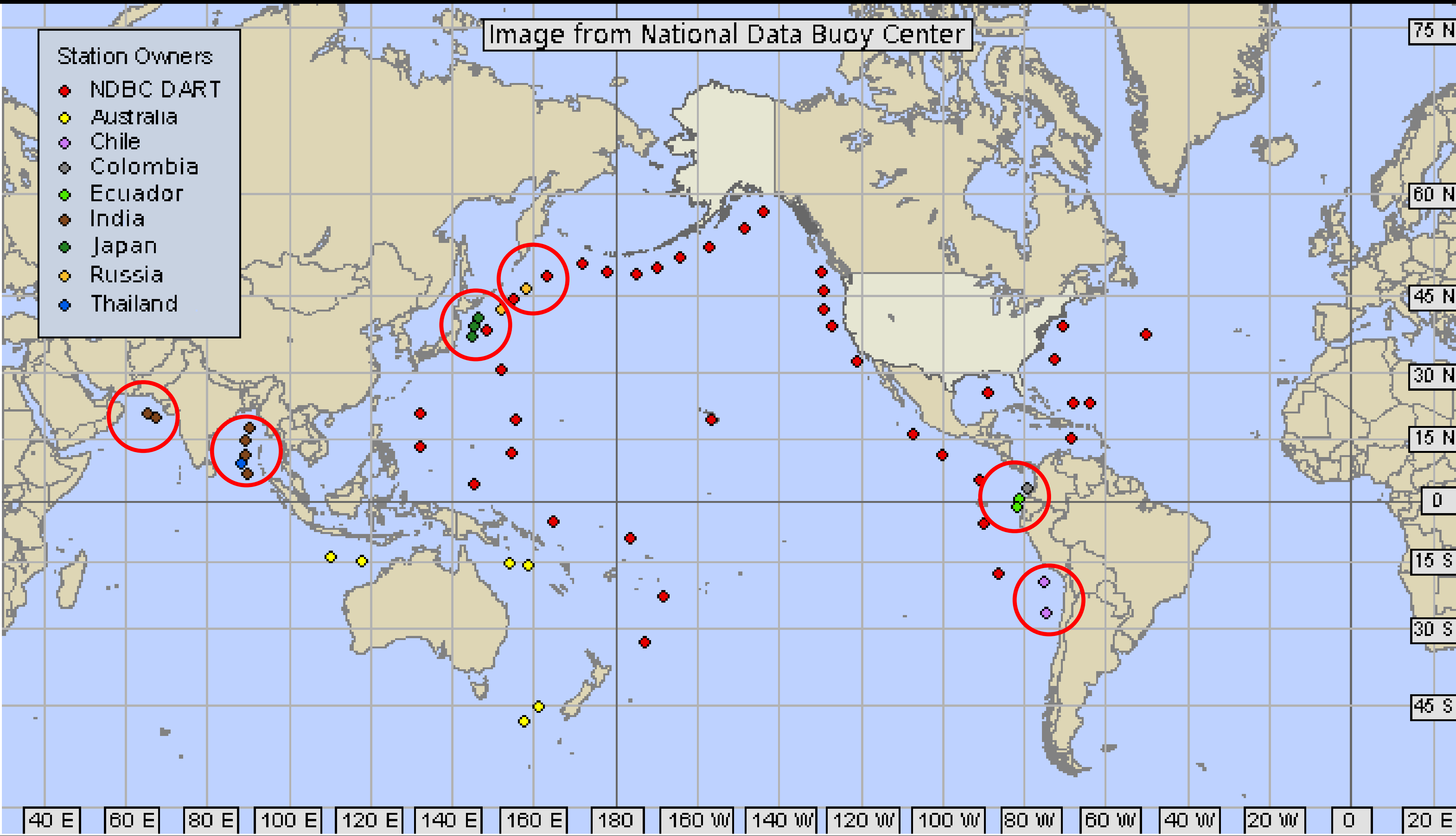


DEEP-OCEAN ASSESSMENT AND REPORTING OF TSUNAMIS (DART)



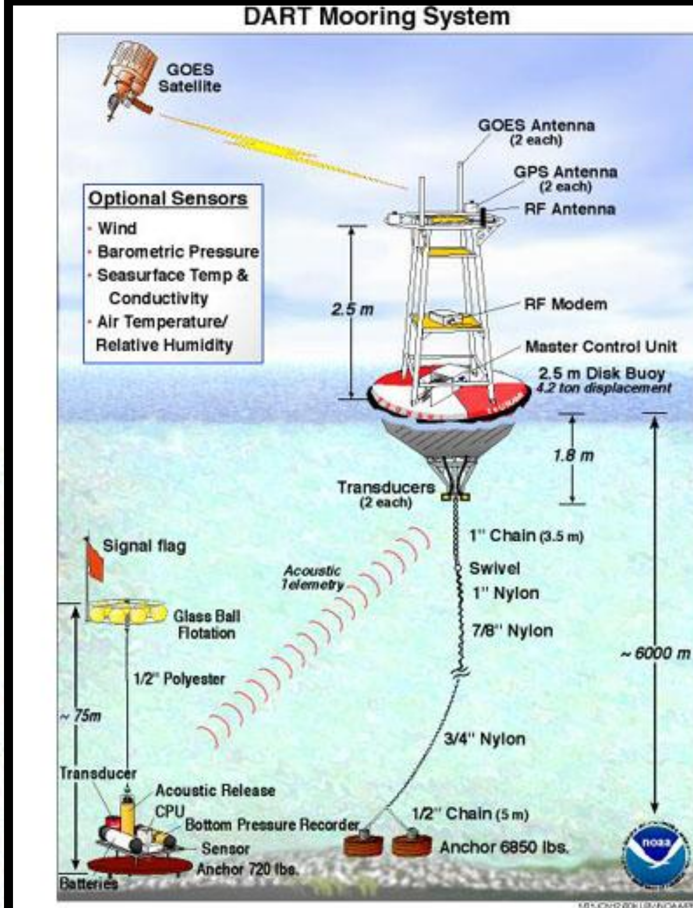
DEEP-OCEAN ASSESSMENT AND REPORTING OF TSUNAMIS (DART)

JANUARY 2017

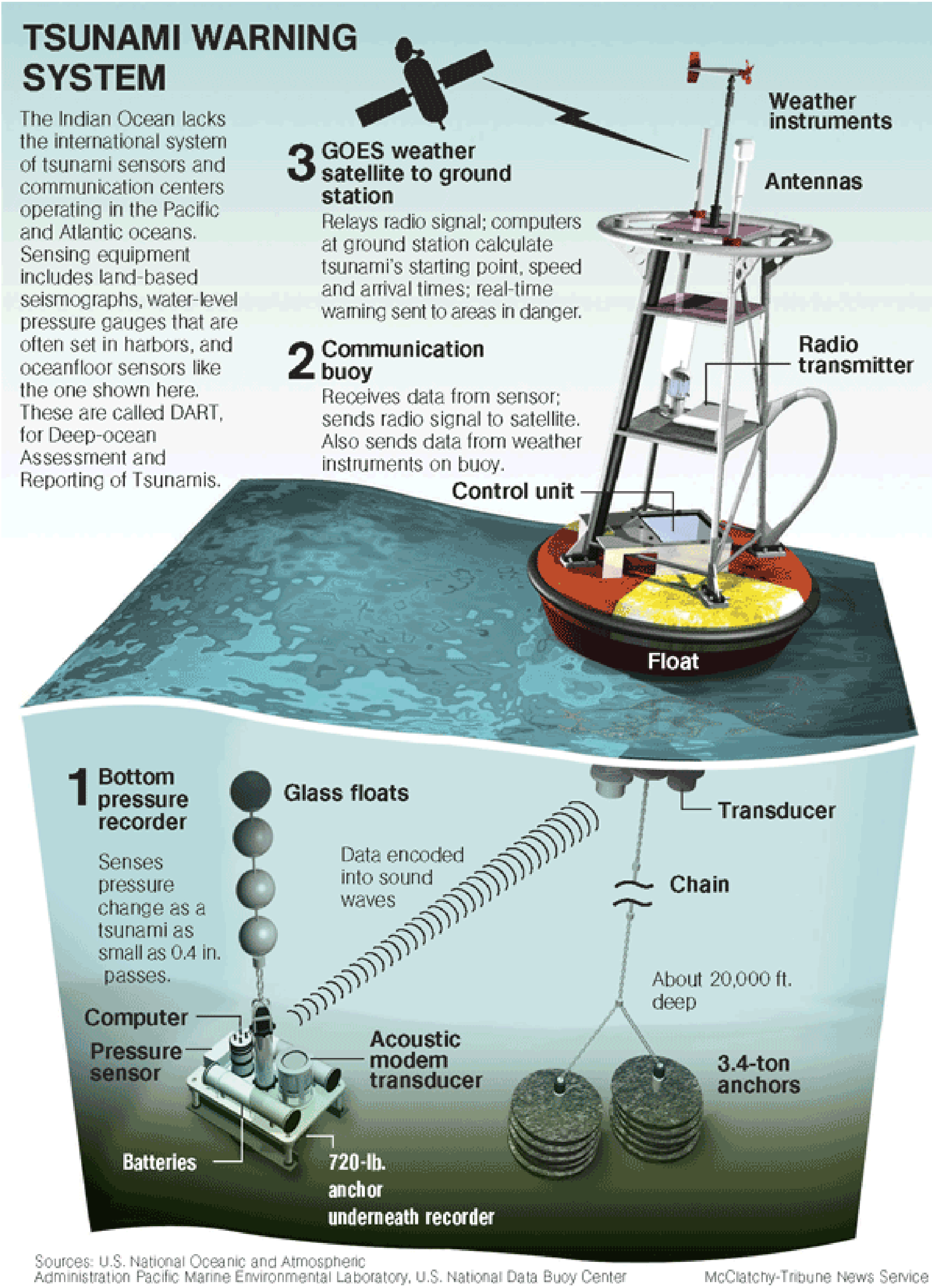


DEEP-OCEAN ASSESSMENT AND REPORTING OF TSUNAMIS (DART)

NOAA

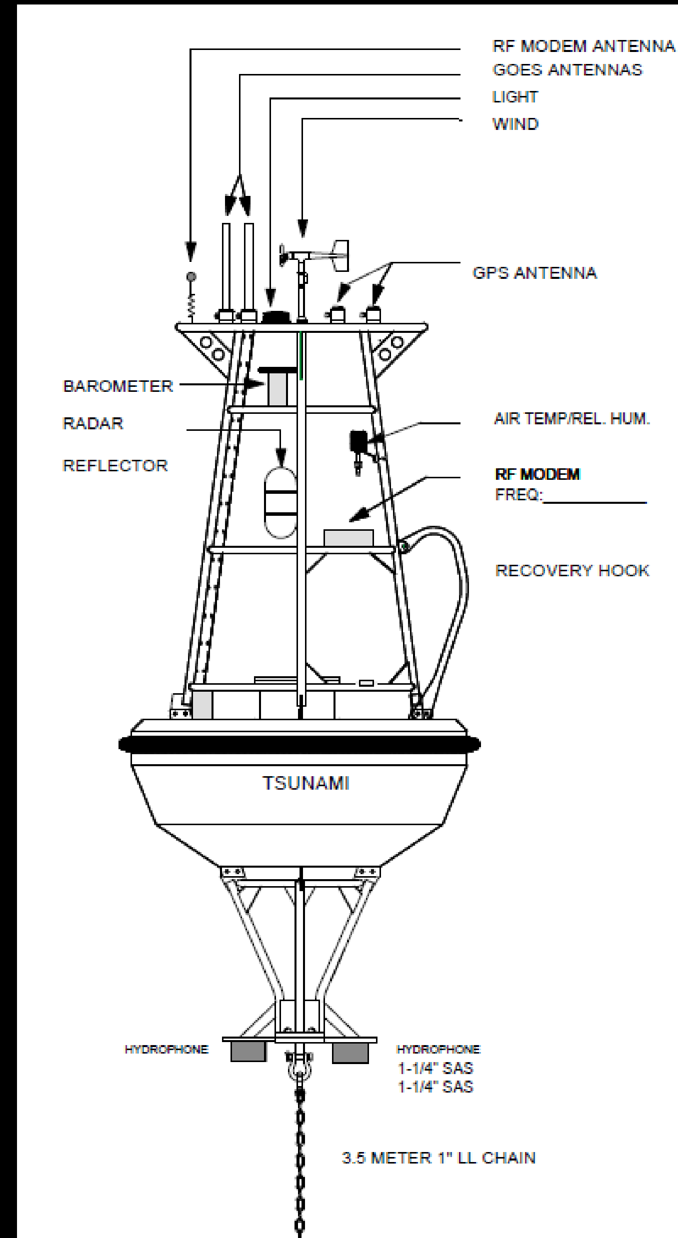


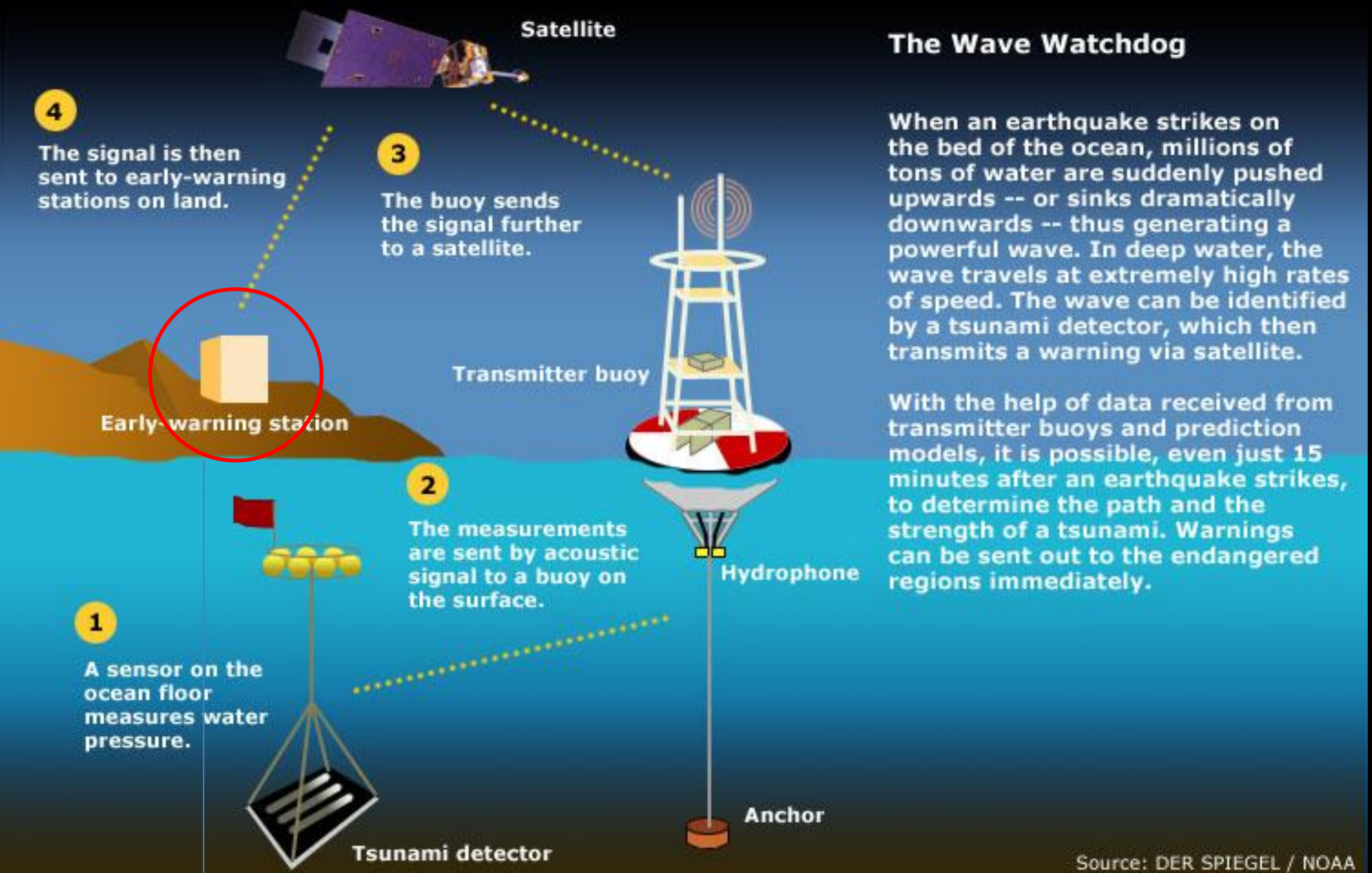
TSUNAMI WARNING SYSTEM CURRENTLY IN OPERATION IN PACIFIC AND INDIAN OCEANS



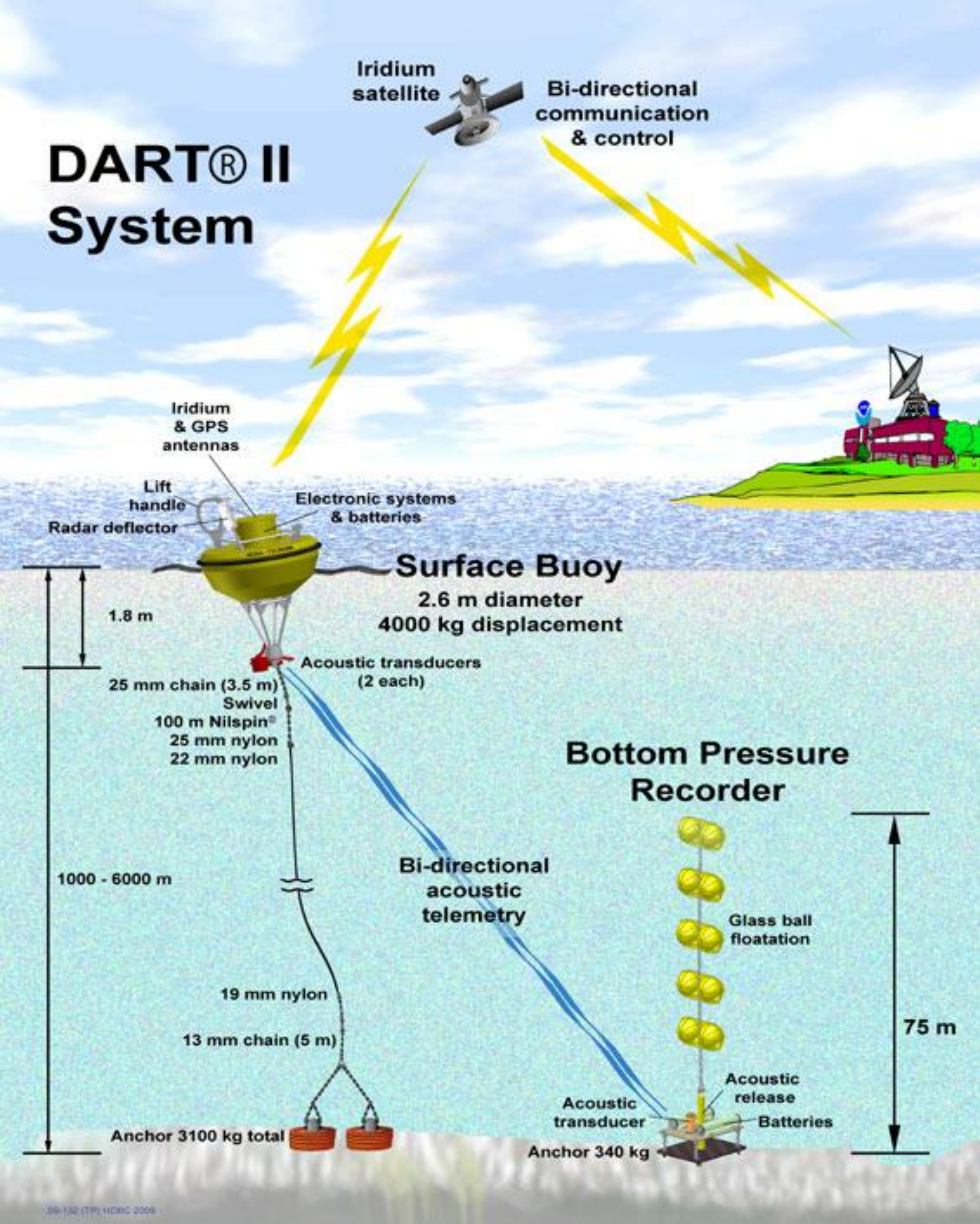
Posted on: Tuesday, April 3, 2007

New buoys give Isles added protection against tsunamis

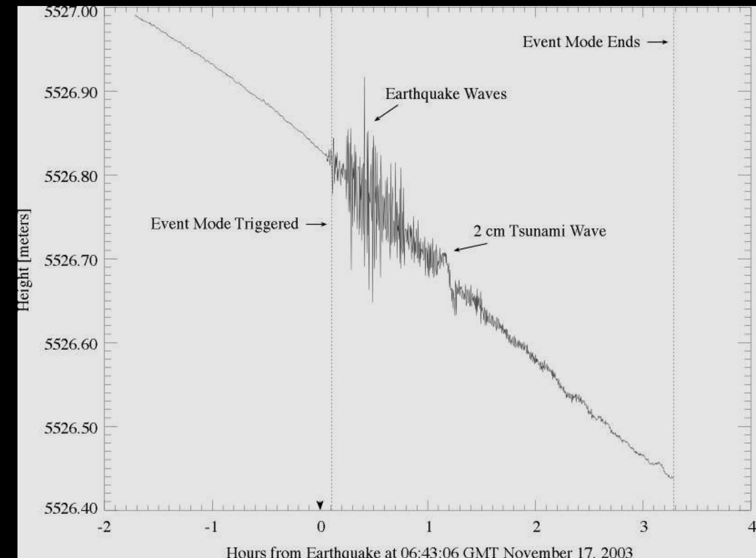




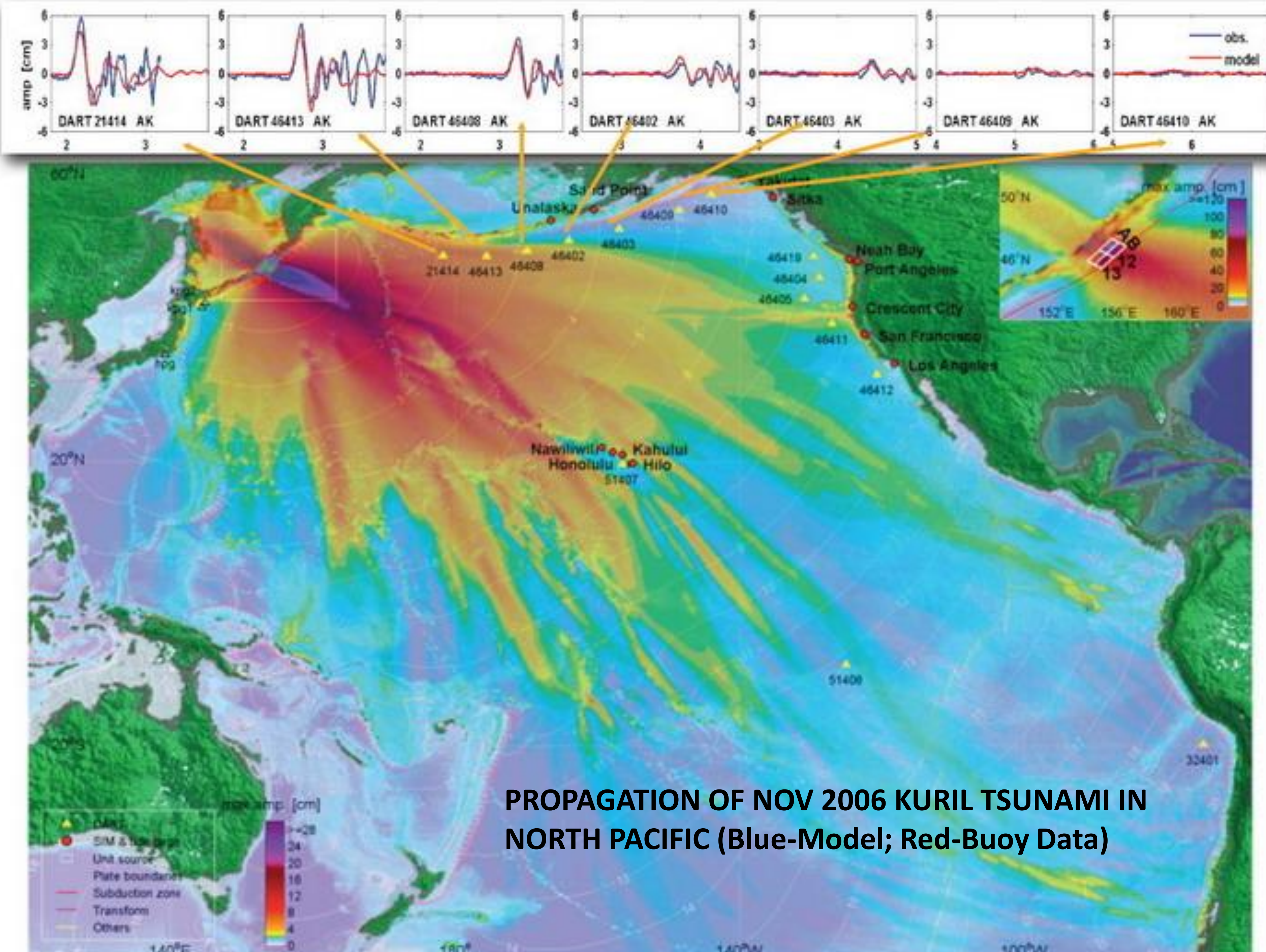
RELAYING THE WARNING TO THREATENED POPULATION - e.g., SIRENS, MOBILE PHONE MESSAGES, RADIO BROADCAST



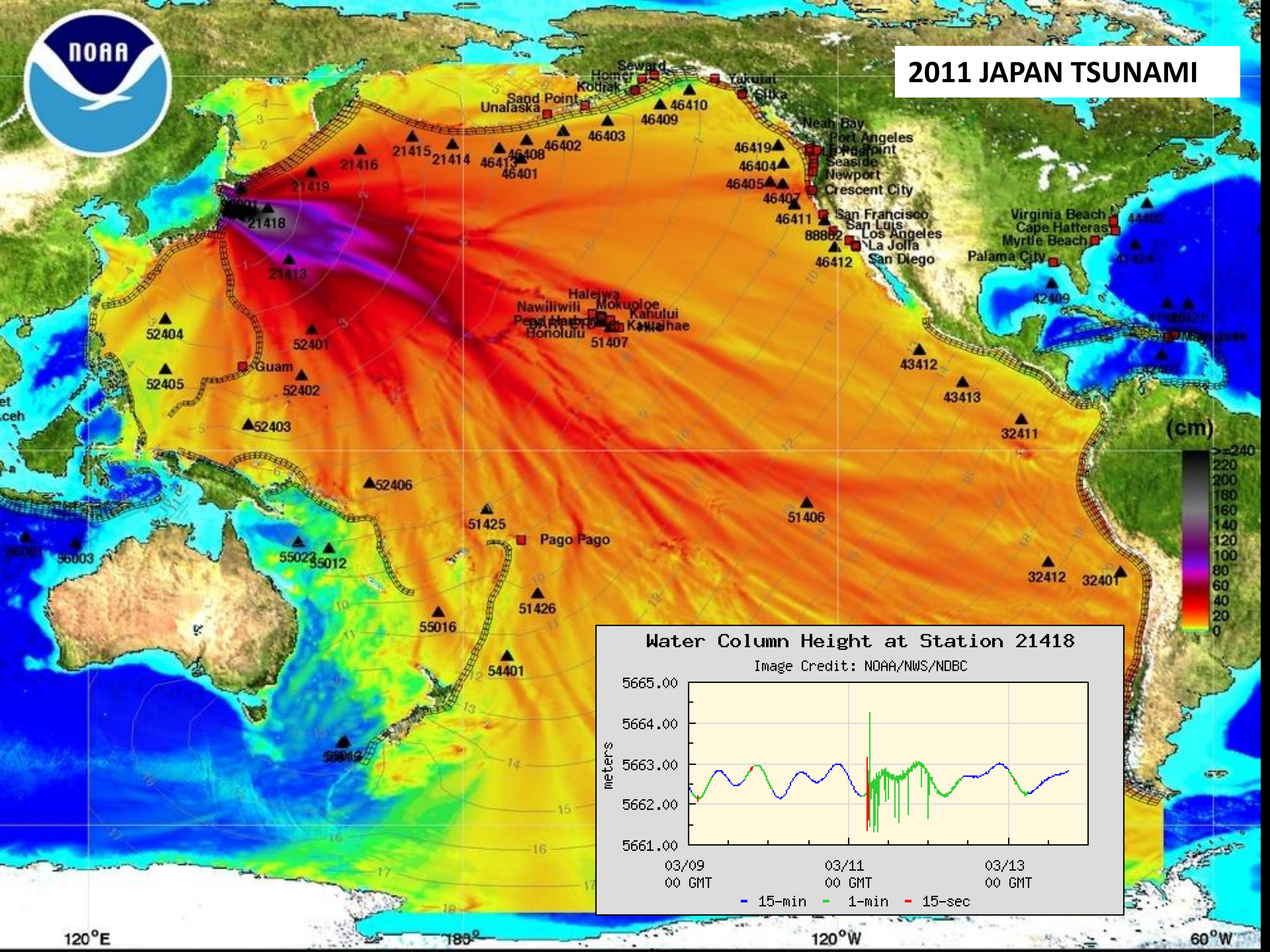
DART II SYSTEM



- DART II SYSTEM IN PLACE
- 39 BUOYS DEPLOYED WORLDWIDE
- TYPICAL TRACE OF OCEAN BOTTOM PRESSURE RECORDER MEASURES UNUSUAL OCEAN SURFACE ELEVATION INCREASE AND INTERPRETS TSUNAMI BY COMPLEX DETECTION ALGORITHM
- WARNING ISSUED



PROPAGATION OF NOV 2006 KURIL TSUNAMI IN NORTH PACIFIC (Blue-Model; Red-Buoy Data)


2011 JAPAN TSUNAMI
NOAA
Seward
Homer
Kodiak
Yakutat
Sitka
Sand Point
Unalaska
46410
46409
46403
46402
46408
46413
46401
21414
21415
21416
21419
21418
21413
Neah Bay
Port Angeles
Seaside
Newport
Crescent City
46419
46404
46405
46407
46411
San Francisco
San Luis
Los Angeles
La Jolla
San Diego
46412
Virginia Beach
Cape Hatteras
Myrtle Beach
Palama City
42409
Haleiwa
Nawiliwili
Mokuoloe
Kahului
Honolulu
51407
52404
52401
Guam
52405
52402
52403
43412
43413
32411
52406
51425
51406
Pago Pago
55023
55012
56003
51426
55016
54401
32412
32401
(cm)
>=240
220
200
180
160
140
120
100
80
60
40
20
0
Water Column Height at Station 21418
Image Credit: NOAA/NWS/NDBC
meters
5665.00
5664.00
5663.00
5662.00
5661.00
03/09 00 GMT
03/11 00 GMT
03/13 00 GMT
15-min
1-min
15-sec
120°E
180°
120°W
60°W

The McGraw-Hill Companies/John A. Karachewski, photographer

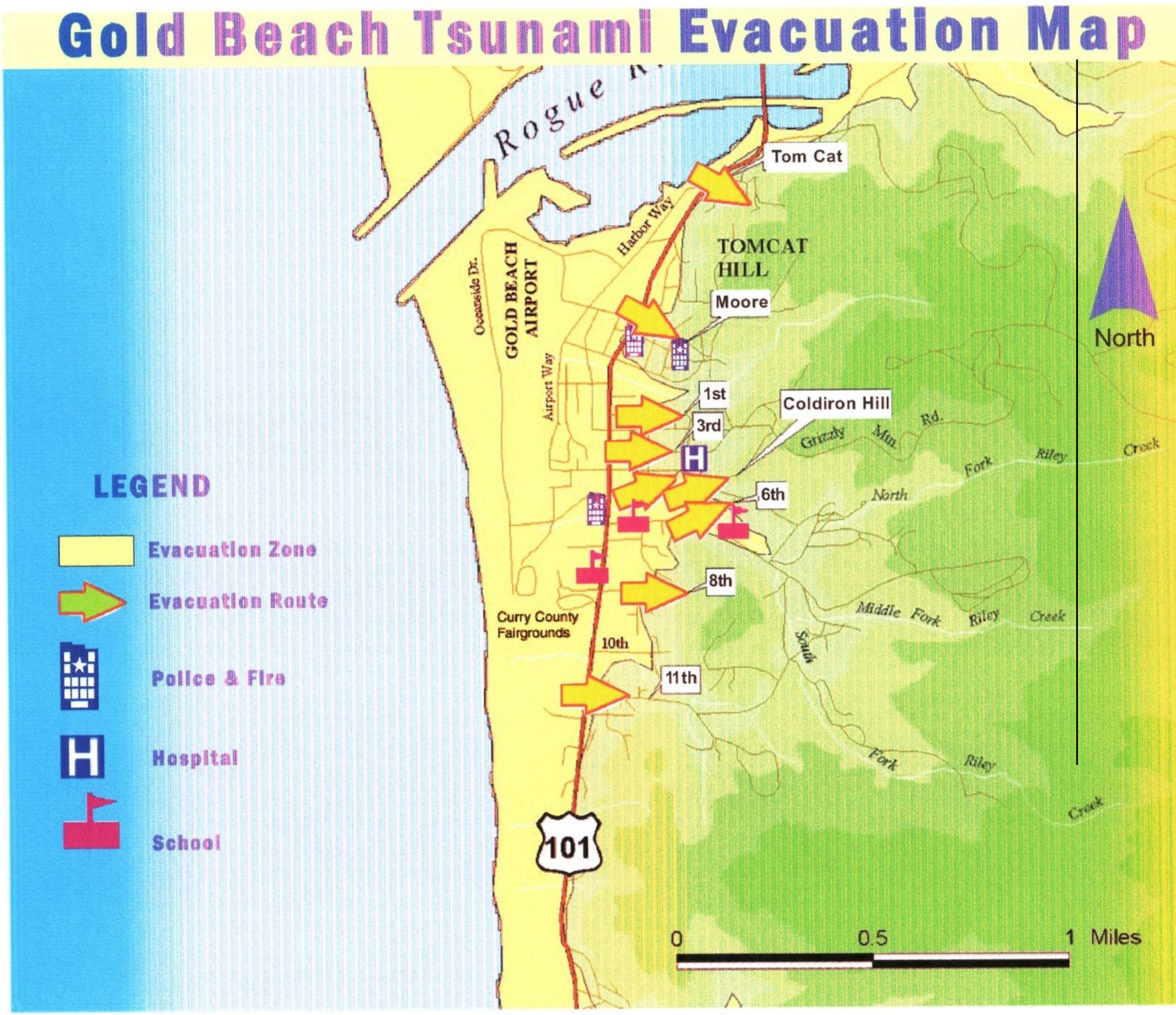
IF YOU FEEL THE GROUND SHAKE, MOVE QUICKLY TO HIGHER GROUND AND SAFETY! DO NOT WAIT FOR AN OFFICIAL WARNING!

TSUNAMI EVACUATION ROUTE

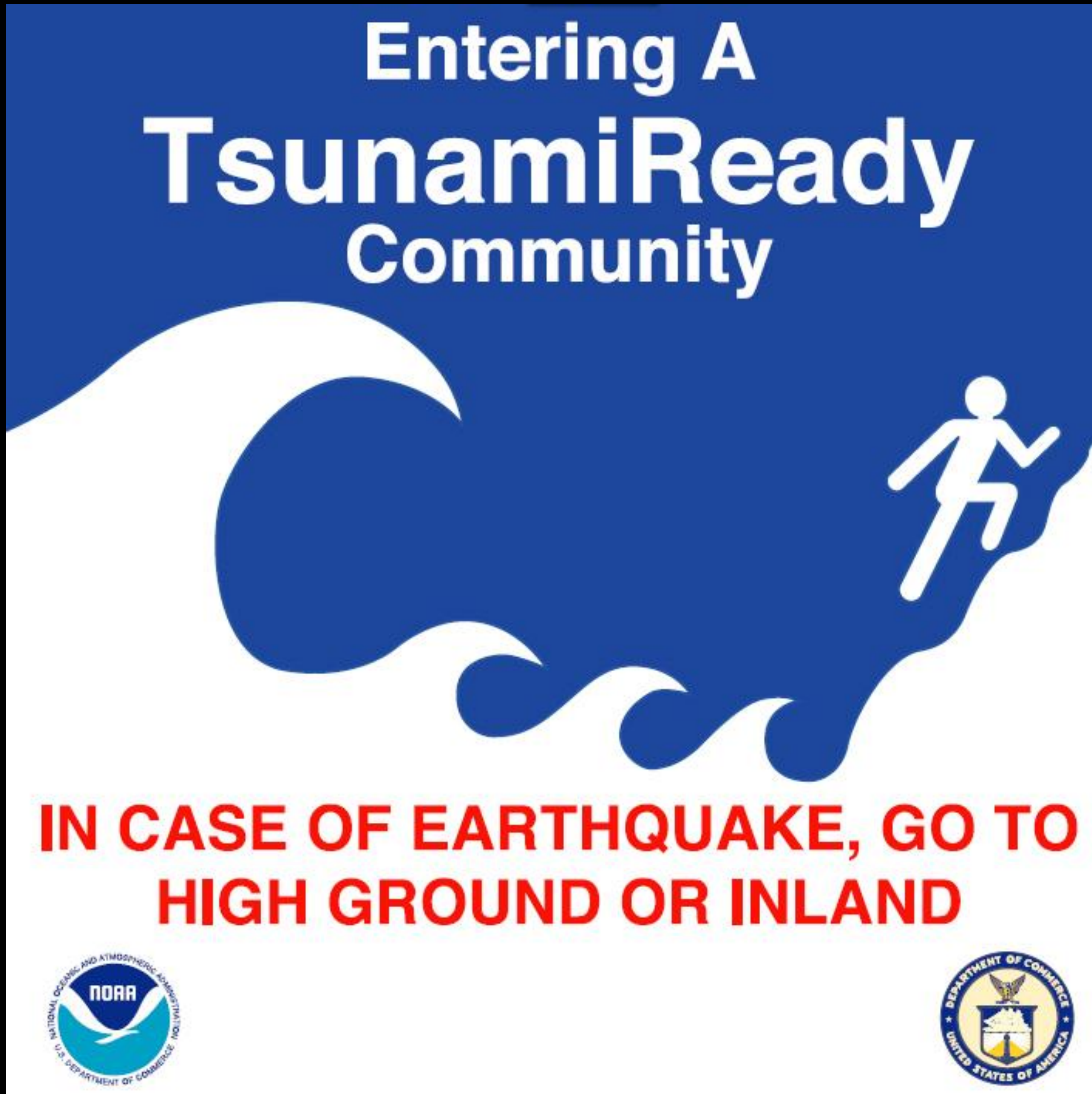
NOTICE

The evacuation zone on this map was developed by the Oregon Department of Geology and Mineral Industries in consultation with local officials. It is intended to represent a worst-case scenario for a tsunami caused by an undersea earthquake near the Oregon coast. Evacuation routes were developed by local officials and reviewed by the Oregon Department of Emergency Management.

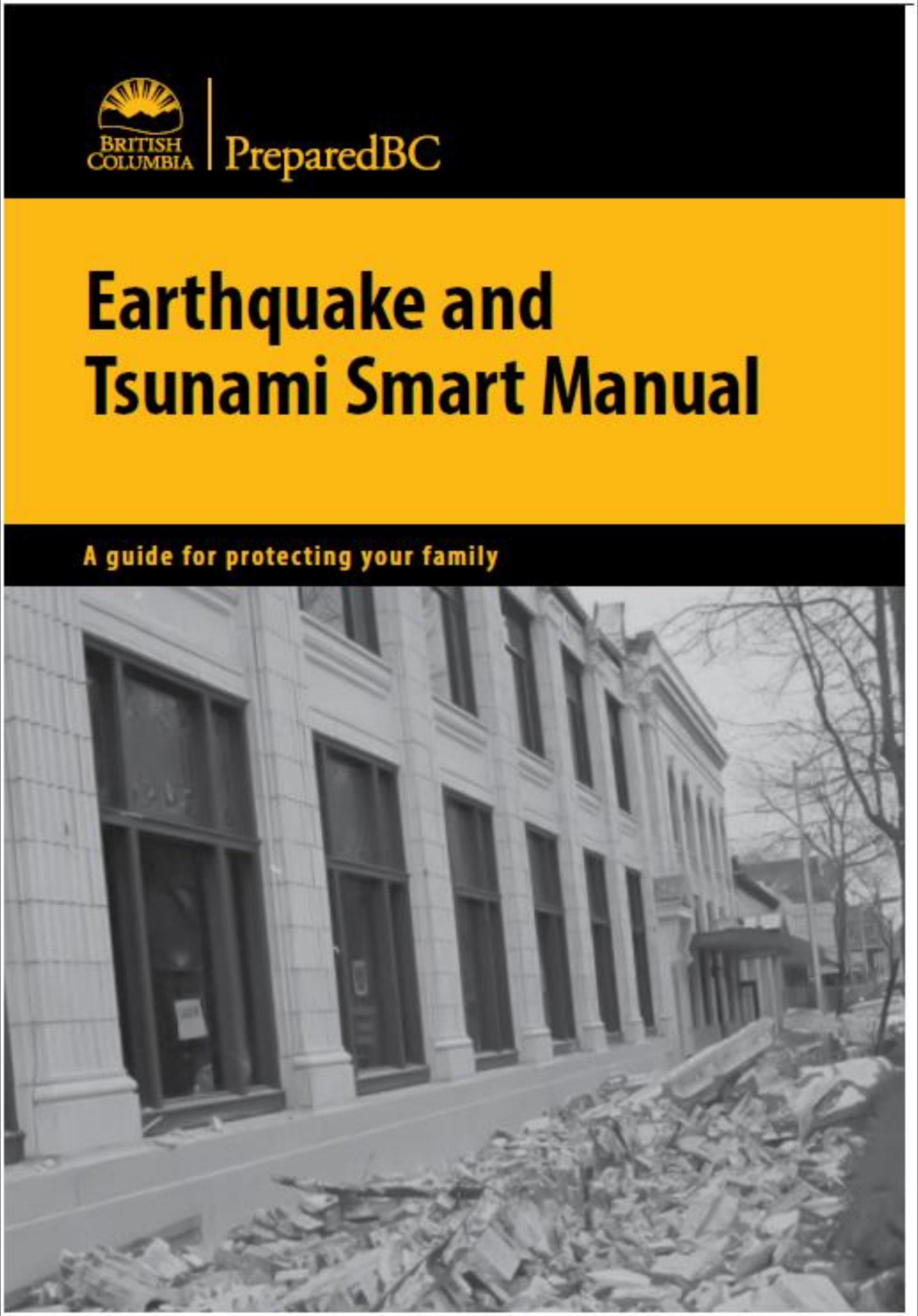
The Oregon Department of Geology and Mineral Industries is publishing this brochure because the information furthers the mission of the Department. The map is intended for emergency response and should not be used for site-specific planning.



COASTAL COMMUNITIES HAVE TSUNAMI EVACUATION PLANS


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

20 metres in
20 minutes



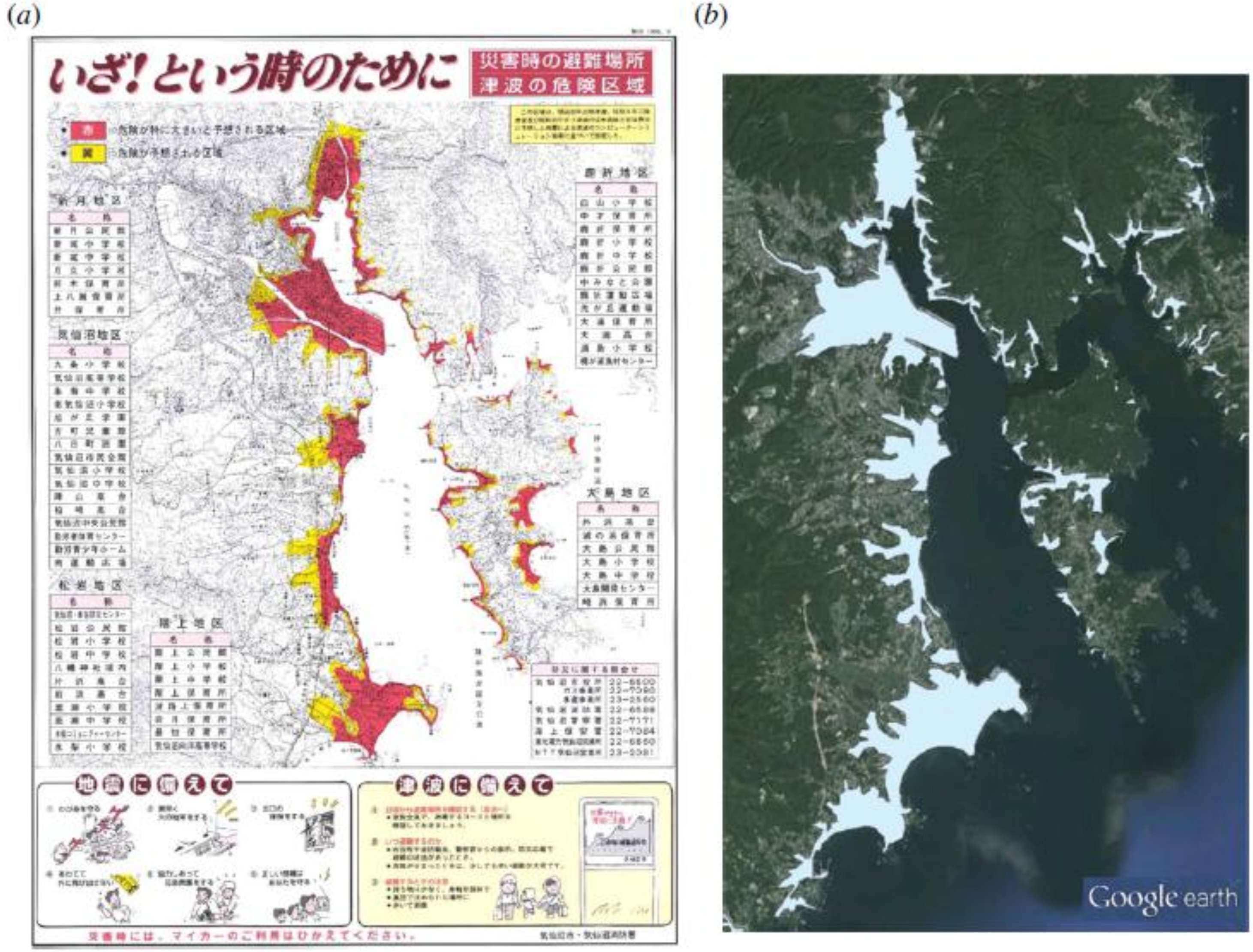


Figure 1. (*a*) Tsunami hazard map published for Kesennuma city, Miyagi prefecture. The map was delivered to every household before the 2011 event to announce the tsunami inundation zone in past events, list of evacuation facilities, and brief instructions for earthquake and tsunami preparedness. (*b*) The map of tsunami inundation extent in the 2011 event (www.gsi.go.jp). The tsunami caused 1280 dead or missing even in this well-prepared community.


THE GREAT WALL OF JAPAN UNDER CONSTRUCTION – TSUNAMI DEFENCE STRUCTURE WILL PREVENT TSUNAMI INUNDATION (7.8 m HIGH)

THE GREAT WALL OF JAPAN UNDER CONSTRUCTION AT RIKUZENTAKATA – TSUNAMI DEFENCE STRUCTURE WILL PREVENT TSUNAMI INUNDATION (7.8 m HIGH)

Tsunami-proof 'Great Wall of Japan' divides villagers

Government wants to build 440 walls along coastline, but some residents believe a concrete fortress is not the answer

Seawalls are controversial. They look hideous and the evidence for their effectiveness is flimsy. True, Fudai, a village sheltering behind a giant concrete shield, escaped unscathed in 2011. But in the city of Kamaishi a $1.6 billion breakwater, listed in the "Guinness Book of Records" as the world's largest, crumbled on impact. Nearly 90% of existing seawalls along the northeast coast suffered a similar fate. Critics say they even resulted in greater damage being caused elsewhere. "There is simply no guarantee that seawalls will stop every single tsunami," says Nobuo Shuto, an engineer at Tohoku University.

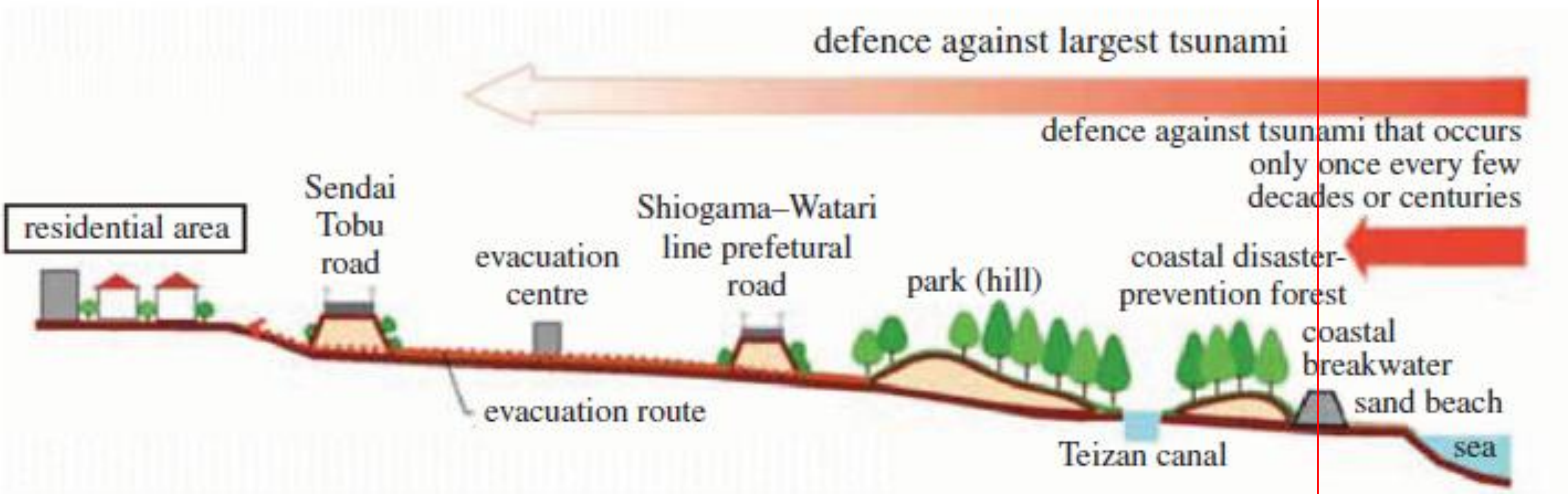


Figure 4. Conceptual image of tsunami-prevention facilities in Sendai city [49]. The seawall was designed for Level 1 tsunami (the height equivalent to the historical tsunami heights in the past 150 years and storm surge heights in the past 50 years). The other measures secure multiple protection. (Online version in colour.)

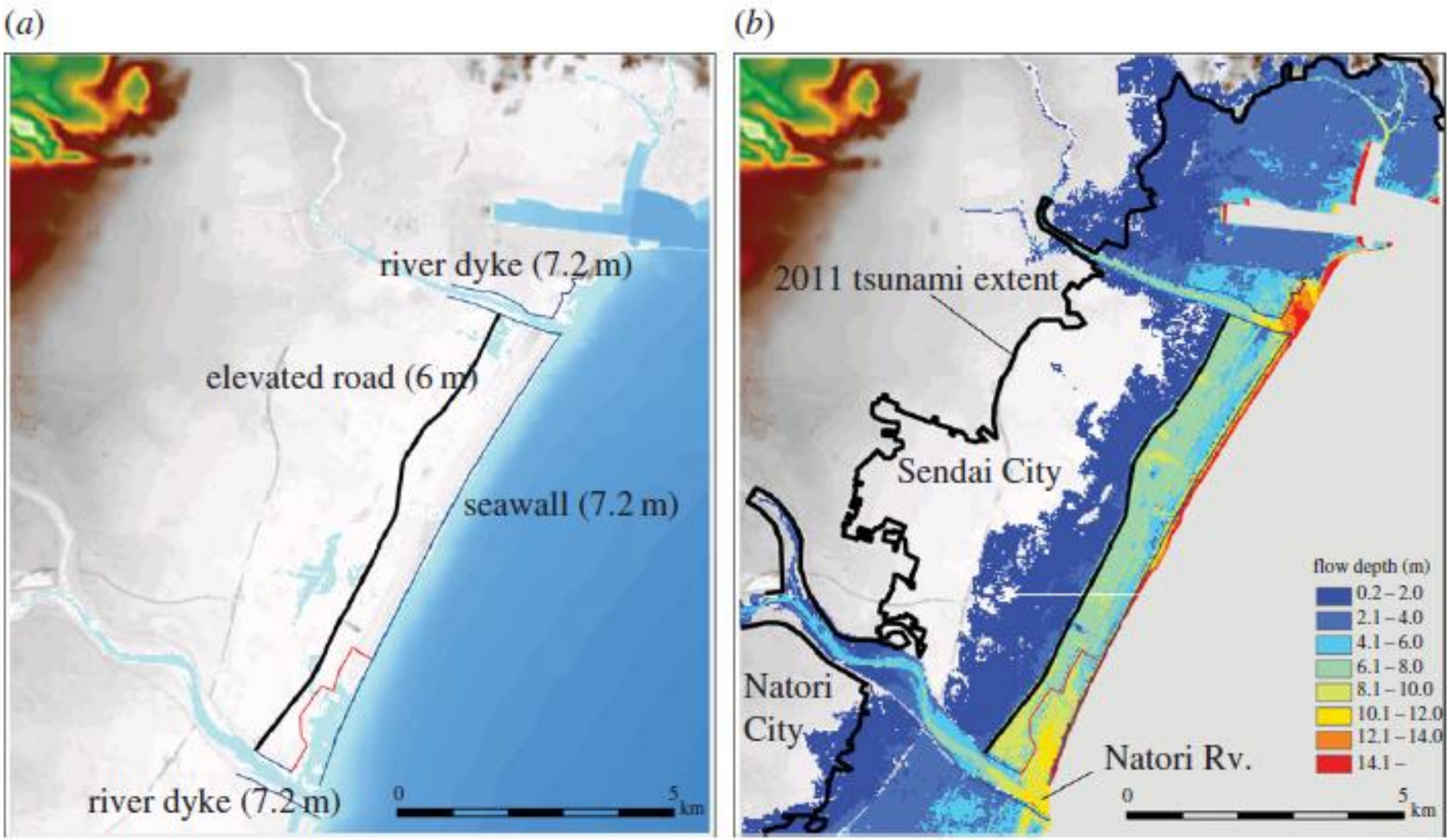
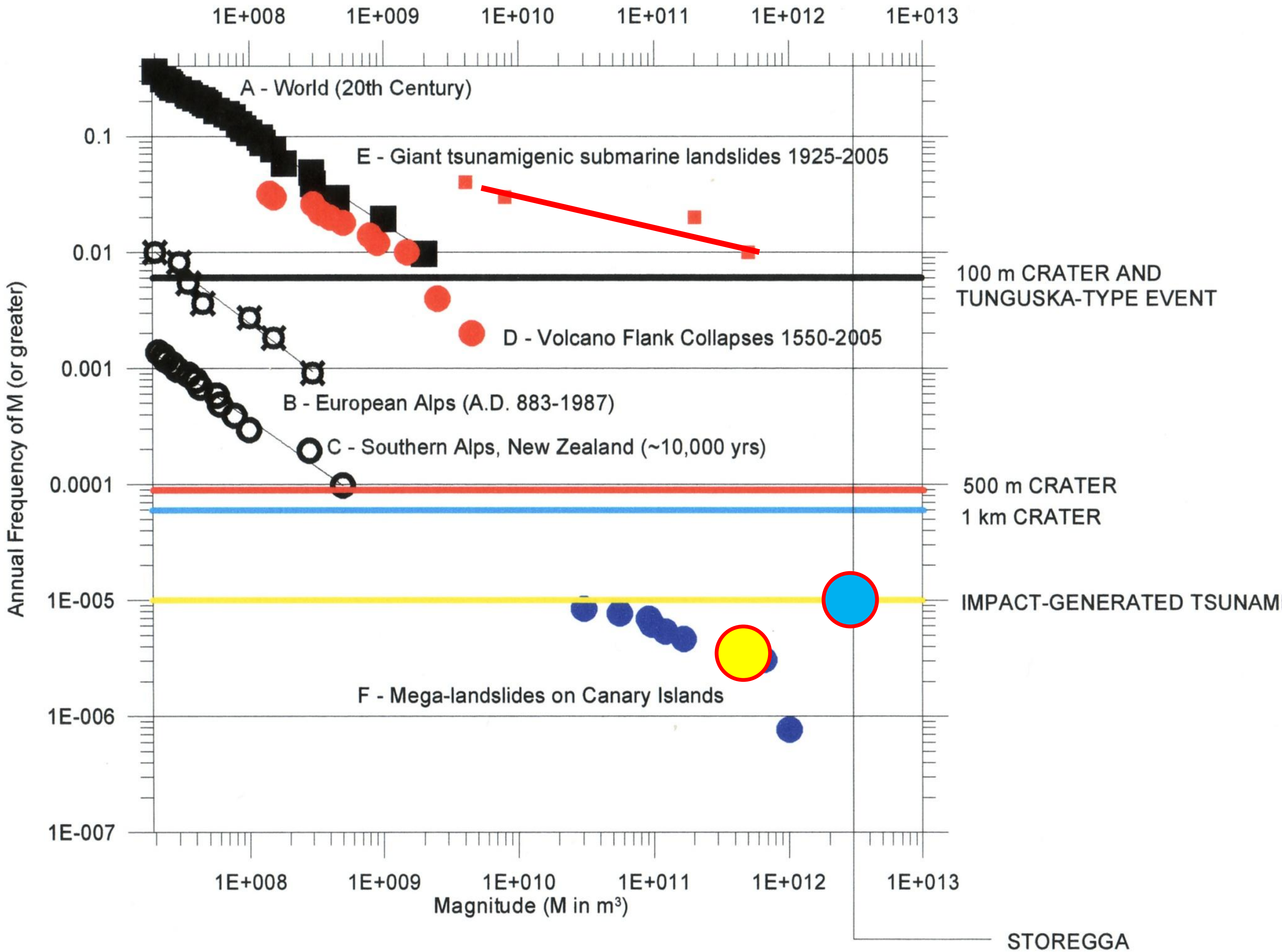


Figure 5. (*a*) Setting of tsunami prevention facilities in Sendai city reconstruction plan [49]. (*b*) Result of tsunami numerical modelling to evaluate the effect of the proposed reconstruction plan in Sendai city (maximum flow depth).



1E+008
1E+009
1E+010
1E+011
1E+012
1E+013
A - World (20th Century)
E - Giant tsunamigenic submarine landslides 1925-2005
0.1
0.01
0.001
0.0001
1E-005
1E-006
1E-007
100 m CRATER AND
TUNGUSKA-TYPE EVENT
D - Volcano Flank Collapses 1550-2005
B - European Alps (A.D. 883-1987)
C - Southern Alps, New Zealand (~10,000 yrs)
500 m CRATER
1 km CRATER
IMPACT-GENERATED TSUNAMI
F - Mega-landslides on Canary Islands
Annual Frequency of M (or greater)
Magnitude (M in m³)
STOREGGA