

## GEOL 106 Earthquake Country

### Activity 7: Tsunami

**Materials:** Marigram recorded in San Diego, May 23, 1960.  
Tsunami Travel-Time Graph To San Diego.  
Answer sheet

Source of information: Lander, James F., Patricia A. Lockridge and Michael J. Kozuch, **Tsunamis Affecting the West Coast of the United States 1806 - 1992**, NGDC Key to Geophysical Record Documentation No. 29, National Geophysical Data Center, Boulder, Colo., 1993, 242 p.

#### **Distant Source Tsunamis**

A distant-source tsunami is caused by an earthquake or other tsunami source 1000 km (about 2 hours travel-time) or farther from a particular coastal region of interest. Distant-source tsunamis are almost always the result of large subduction zone earthquakes. These earthquakes deform a large region of the sea floor, producing a series of waves which may travel across an entire ocean. The great 1960 Chilean earthquake ( $M_w = 9.5$ ) produced a series of waves which devastated Hilo, Hawaii about 18 hours after the earthquake and coastal communities in Japan nearly 24 hours afterwards. It also damaged a number of communities along the California coast, including Crescent City.

#### **Features of the Distant-Source Tsunami:**

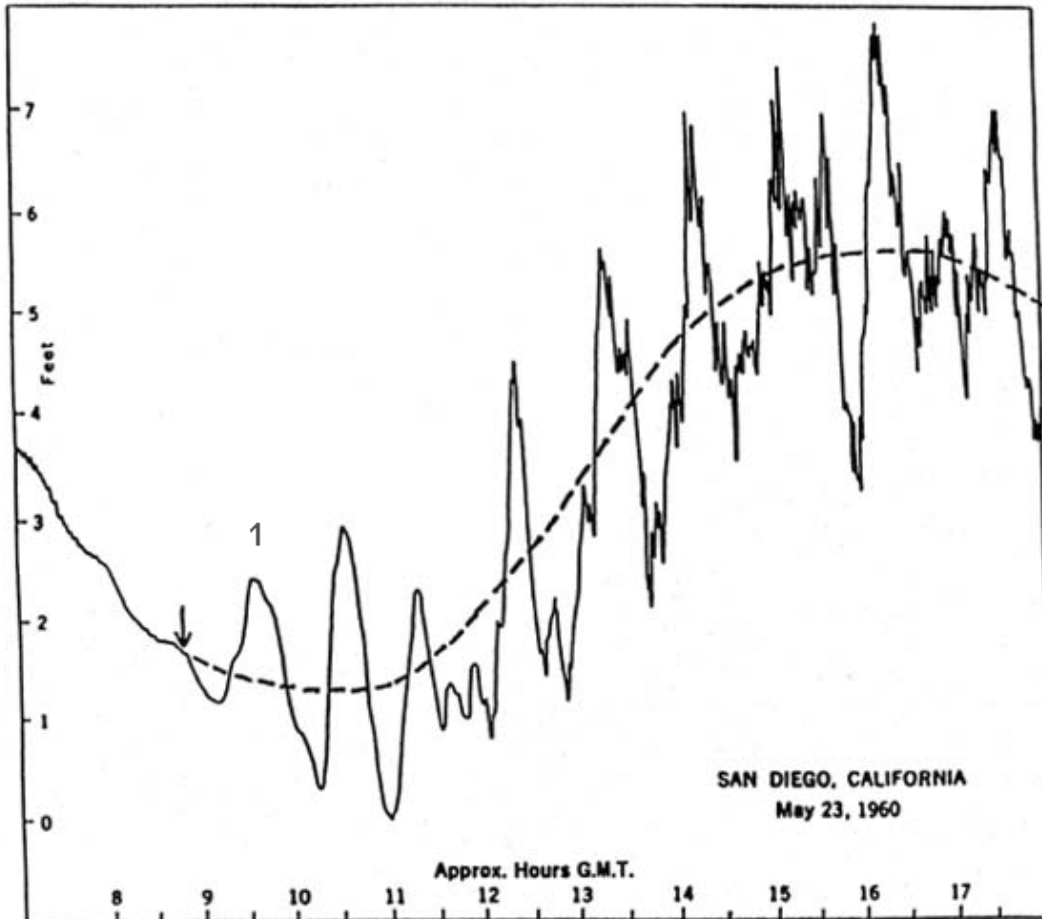
- Waves arrive at a coastline without warning. The earthquake source is too far away to feel.
- Waves may either arrive as a draw-down (initial lowering or negative wave) or an increase in the water height (positive wave).
- There is always a series of waves which are typically many minutes apart. The interval between successive waves is not constant. The first wave is rarely the largest in the sequence.
- Tsunami warning systems are designed to issue warnings so that orderly evacuations of vulnerable coastal areas can be made before the first wave arrives.
- An earthquake which generates a significant distant-source tsunami almost always produces a major local tsunami along coastlines close to the source.

#### **Marigrams:**

Look at the marigram on the following page. Answer questions 1-10 on the answer sheet.

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# Marigram for San Diego, California



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A marigram shows the height of the ocean surface at a particular coastal site. When the line moves up it means the water level is higher, the line moving down means a lower water level. The gentle background curvature is caused by the tides (shown by the dashed line); the sharper peaks show the tsunami waves. The time is listed in G.M.T. (Greenwich Mean Time). This is the same as UTC. The marigram begins at 07:00:00 on 5/23/60.

- 1. What time (G.M.T.) did low tide occur?**
- 2. Look at the first tsunami wave arrival. It is marked by the arrow. It arrives at about 08:50:00. Was this wave positive (a rise in the water level) or negative (a draw-down in the water level)?**

The amplitude of a tsunami wave is defined in the same way as a seismic wave. It is the height from the median position to either the largest positive (crest) or negative (trough). In this case, the median position is the tide as shown by the dashed line. You can use the scale on the ordinate (y) axis to determine the amplitude of the tsunami at any time. For example, the first positive wave (labeled by a "1"), has an amplitude of about 1 foot. This first peak arrives at about 09:40:00. The absolute height of the water when this wave arrives is 2.4 feet.

- 3. Look at the positive wave crests. What time (G. M.T.) did the largest amplitude positive tsunami wave occur? Estimate the time to the nearest 5 minutes.**
- 4. What was the amplitude (in feet) of the highest positive tsunami wave on this record?**

Tsunamis are sometimes called tidal waves because they often appear on shore as a rapidly rising tide. The tides have nothing to do with the generation of a tsunami; however, the background tidal height can affect the tsunami's potential to do damage.

- 5. What is the absolute height of the highest water on this marigram? (taking into account both the tide and the tsunami height).**
- 6. Suppose the largest waves had occurred at low, rather than high tide. Describe what the difference in effect might be.**

Tsunamis always consist of a series of waves. The wave activity may continue for a number of hours. On this record, tsunami waves with amplitude of a foot or more continue for nine hours! The first wave is rarely the largest.

- 7. How many tsunami wave crests with amplitudes of more than 1 foot are shown on this record?**
- 8. What is the average amount of time between successive 1 foot or larger wave crests? Assume the tsunami waves continue to arrive over a period of 9 hours. Round off your answer to the nearest 1/4 hour.**

The peak height of the water is only one factor that contributes to the damage a tsunami may cause. Just as important is the speed of the water. Look at the wave around 14:00 hours.

- 9. What is the range (total water level fluctuation from trough to peak) from the trough a little before 14:00 hours to the peak a little after?**
- 10. How much time did it take for the water to go from this trough to the peak?**

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The time it takes tides to go from low to high tide is 6 hours. The currents produced, particularly in bays and inlets, can be quite significant as the tide comes in and goes out. The range in water height from troughs to peaks produced by tsunamis may be as large or larger than the normal tidal fluctuation. But the time for the water to rise or drain is much shorter! Imagine the current velocities at Crescent City in 1964 when water levels fluctuated more than 20 feet in about an hour's time.

#### **Tsunami Travel Time Maps (NOAA):**

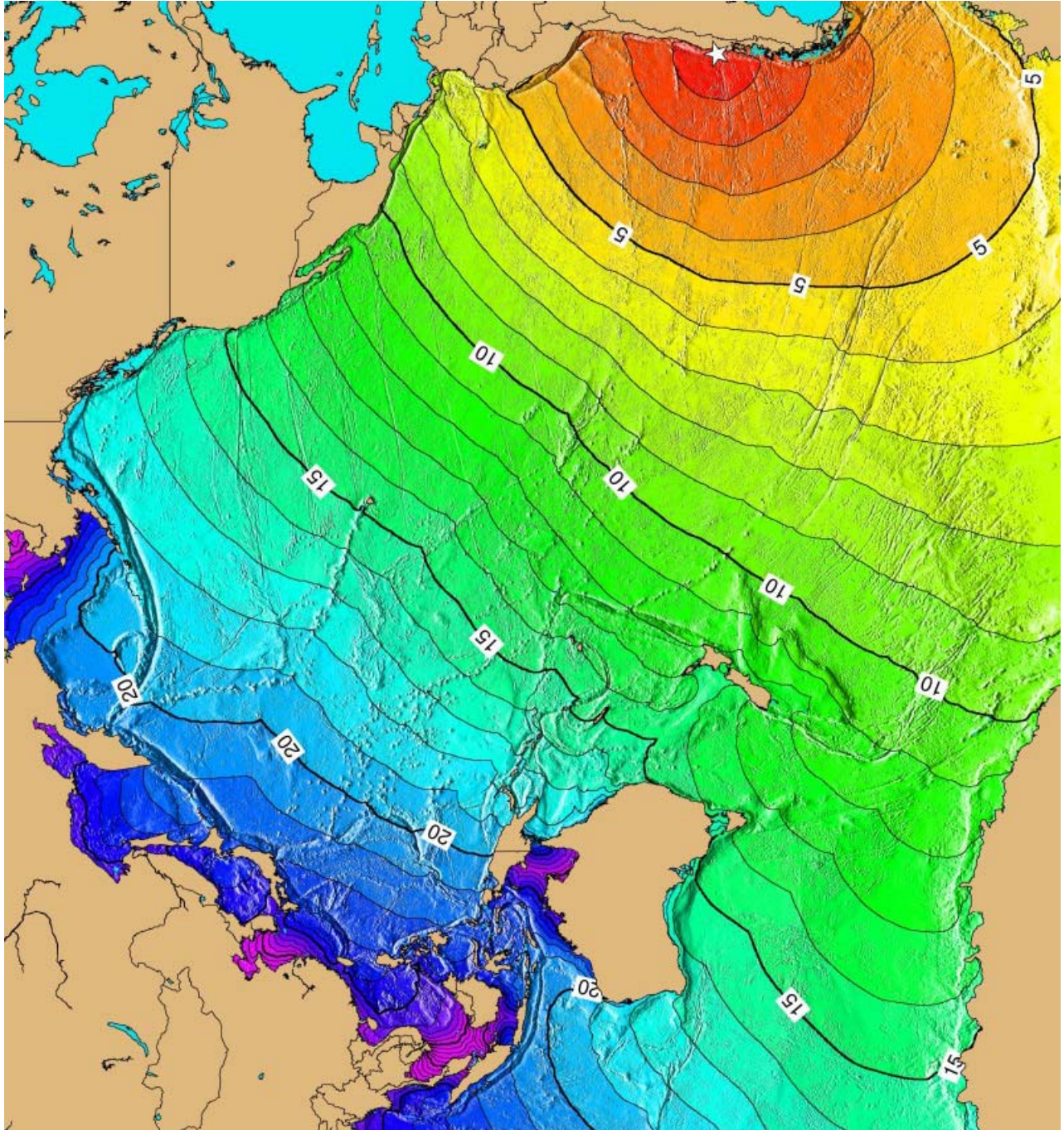
Look at the Tsunami Travel-Time Map To San Diego (colored world map). This shows the expected travel time to anywhere in the Pacific basin. The epicenter of earthquake which generated the marigram you used in the questions above was located in southern Chile where the star is marked. This was historically the largest recorded earthquake, with a moment magnitude calculated as  $M = 9.5$

**11. How long (round off to the nearest 1/2 hour) did it take the first tsunami wave to travel from the epicentral region of the Chilean earthquake to San Diego?**

**12. The distance between the epicenter of the Chilean earthquake and San Diego is about 5900 miles. What is the average velocity of the first wave on the San Diego record? (hint, velocity is measured in units of distance traveled divided by elapsed time to get m.p.h)**

The tsunami waves produced by the 1960 Chilean earthquake did cause damage in San Diego. Approximately 165 feet of dock were destroyed, a bridge was damaged, a barge sank and 8 boat slips were destroyed. Property losses were estimated at over \$16,500. A crowd gathered on Shelter Island in San Diego Bay to watch the waves. Police were needed to break up a traffic jam and dispel spectators.

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**Table 7-2.** Recorded tide gauge heights.

Gauge Location	Distance (km)	Wave Height cm (peak - trough)	Initial Motion	Travel Time hr:min	*
Arica, Chile	415	257	rise	0:35	1
Callao, Peru	609	80	rise	1:34	1
Antofagasta, Chile	856	90	rise	1:02	1
Valparaiso, Chile	1,886	60	rise	2:27	1
Talcahuano, Chile	2,283	250	rise	3:41	1
Santa Cruz, Galapagos Is.	2,523	90	rise	3:59	1
Easter Is., Chile	3,905	35	?	5:41	2
Cabo San Lucas, Mexico	5,960	25	?	8:56	2
La Jolla, CA	7,170	10	?	11:19	2
Los Angeles, CA	7,304	10	?	11:36	2
San Francisco, CA	7,887	7	?	12:51	2
Crescent City, CA	8,280	40	?	13:13	2
Hilo, HI	9,770	70	rise	13:27	1
Chatham Is., NZ	9,781	55	?	14:05	2
Sitka, AK	9,929	5	?	16:02	2
Apia, Western Samoa	10,450	25	?	14:49	1
Kodiak, AK	10,890	8	?	16:59	2
Sand Point, AK	11,298	24	?	17:08	2
Nukualofa, Tonga	11,489	20	?	15:07	1
Midway Is., USA	12,188	15	?	16:27	2
Adak, AK	12,317	20	?	17:27	2
Kwajalein, Marshall Is.	13,347	10	?	18:00	2
Wake Is.	13,679	10	?	18:11	2
Omaezaki, Honshu, Japan	16,259	25	?	21:39	2
Naha, Okinawa, Japan	17,565	10	?	23:05	2

\* 1.) travel time measured from recorded arrivals  
2.) travel time estimated from algorithm; source:<http://wcatwc.gov/06-23-01.htm>

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Last Name, First Name \_\_\_\_\_ Date: \_\_\_\_\_

**1960 Chile Tsunami and San Diego, California**

1. Time (GMT) of low tide: \_\_\_\_\_

2. First wave positive or negative? \_\_\_\_\_

3. Time (GMT) of the largest positive tsunami wave: \_\_\_\_\_

4. The amplitude (in feet) of the highest tsunami wave: \_\_\_\_\_

5. The absolute height of the highest water: \_\_\_\_\_

6. Difference in effects between largest tsunami waves arriving at high or low tide?

7. Number of tsunami crests of amplitudes of more than 1 foot? \_\_\_\_\_

8. Average time between successive crests: \_\_\_\_\_

9. Total range in feet between trough and peak at 14:00 hours: \_\_\_\_\_

10. Total time (to nearest 1/4 hour) between low and high water: \_\_\_\_\_

11. Time for first tsunami wave to travel to San Diego: \_\_\_\_\_

12. Average speed (distance/time) of the first tsunami wave: \_\_\_\_\_

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### Tsunami Times, Basin Depth, Wave Height

Using the equation for shallow water waves ( $C = \sqrt{gd}$ ), calculate the following water wave speeds for the following depths. This yields the speed in m/sec. Multiply by 1.94 to get the speed in knots.

8,000m: \_\_\_\_\_ m/sec = \_\_\_\_\_ knots; 4,000m: \_\_\_\_\_ m/sec = \_\_\_\_\_ knots,

200m: \_\_\_\_\_ m/sec = \_\_\_\_\_ knots; 100m: \_\_\_\_\_ m/sec = \_\_\_\_\_ knots; 10m: \_\_\_\_\_ m/sec \_\_\_\_\_ knots

A magnitude 8.2 earthquake occurred of the southern coast of Peru (16.2° S, 73.4° W) on June 23, 2001 at 2033 GMT. The earthquake generated a tsunami that was recorded on tide gauges around the Pacific basin. Using six of these tidal records calculate the arrival time, travel speed, average depth of travel, wave height, and damage hindcast for each site.

**Site: ARICA, CHILE** [18.4667°S, 70.3333°W; distance from epicenter: 412 km]

Arrival After Quake = \_\_\_\_\_ (hours)

Avg. Travel Speed \_\_\_\_\_ (km/hr). Shallow-water Calculation, Avg Depth of Travel = \_\_\_\_\_ (m)

Wave Height (cm) = \_\_\_\_\_ Expect Damage? Why or why not?

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**SITE: ANTAFOGASTA, CHILE** [23.65°S, 70.4°W; distance from epicenter: 856 km]

Arrival After Quake = \_\_\_\_\_ (hours)

Avg. Travel Speed \_\_\_\_\_ (km/hr). Shallow-water Calculation, Avg Depth of Travel = \_\_\_\_\_ (m)

Why was the speed faster to this location?

Wave Height (cm) = \_\_\_\_\_ Expect Damage? Why or why not?

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**SITE: CALLAO, PERU** [12.05°S, 77.15°W; distance from epicenter: 609 km]

Arrival After Quake = \_\_\_\_\_ (hours)

Avg. Travel Speed \_\_\_\_\_ (km/hr). Shallow-water Calculation, Avg Depth of Travel = \_\_\_\_\_ (m)

Wave Height (cm) = \_\_\_\_\_ Expect Damage? Why or why not?

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**SITE: VALPARAISO, CHILE** [33.0333°S, 71.6333°W; distance from epicenter: 1,886 km]

Arrival After Quake = \_\_\_\_\_ (hours)

Avg. Travel Speed \_\_\_\_\_ (km/hr). Shallow-water Calculation, Avg Depth of Travel = \_\_\_\_\_ (m)

Wave Height (cm) = \_\_\_\_\_ Expect Damage? Why or why not?

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**SITE: SANTA CRUX, GALAPAGOS ISLANDS** [00.75°S, 90.3167°W; distance from epicenter: 2,531 km]

Arrival After Quake = \_\_\_\_\_ (hours)

Avg. Travel Speed \_\_\_\_\_ (km/hr). Shallow-water Calculation, Avg Depth of Travel = \_\_\_\_\_ (m)

Wave Height (cm) = \_\_\_\_\_ Expect Damage? Why or why not?

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**SITE: SAND POINT, ALASKA** [55.3366°N, 160.4933°E; distance from epicenter: 11,298 km]

Arrival After Quake = \_\_\_\_\_ (hours)

Avg. Travel Speed \_\_\_\_\_ (km/hr). Shallow-water Calculation, Avg Depth of Travel = \_\_\_\_\_ (m)

Wave Height (cm) = \_\_\_\_\_ Expect Damage? Why or why not?

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