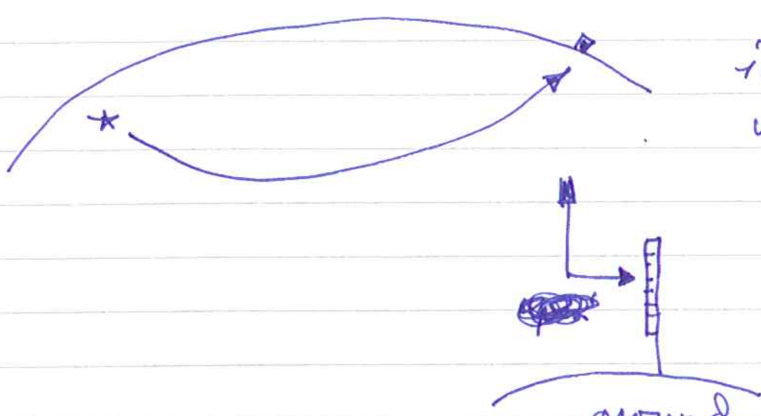
GEO 225 Week #5 Lecture #2

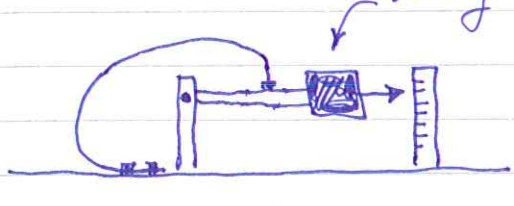
Seismometry: how are the signals from distant 'quakes recorded?



ideal seismometer would be a skyhook – measure ground displacement

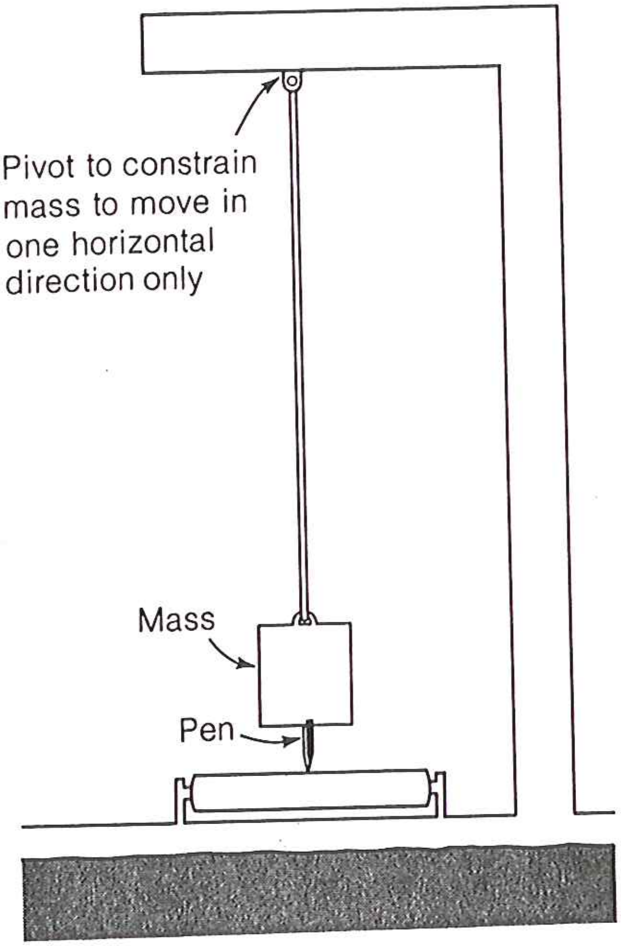
Compromise is to loosely attach the "pointer" to a spring

The modern Streckeisen STS-1 uses a leaf spring

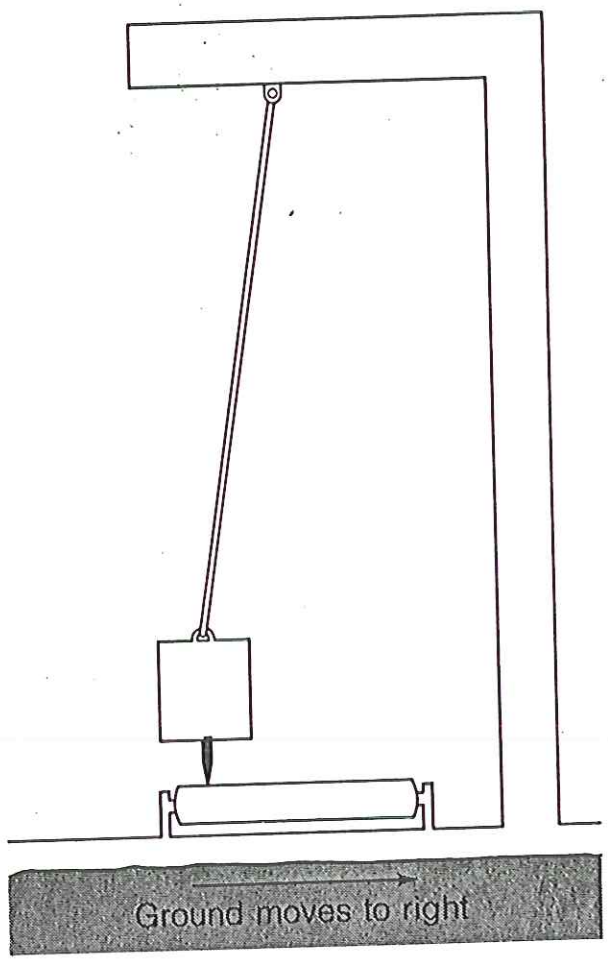


The "pointer" & "scale" is actually a feedback loop which keeps the relative motion zero.

Seismometers are very sensitive
Can detect and measure displacements of 10^{-10} m $= 10^{-4}$ μm ≈ atomic dimensions.



not a great picture should show ground moving to the right



The principal limitation is not instrument sensitivity but ground noise

<u>microseismic noise</u> : main source H_2O pressure fluctuations on seafloor ; also wind blowing trees , etc.

Ground noise vs frequency at 3 sites.

~~RPN on Easter Island is noisiest~~

Dominant period <u>6 seconds</u>. Much lower at longer periods but only very large 'quakes excite long-period waves.

<u>Noise</u> in 1–10 s period range :

RPN : 10^{-5} m = 10 μm noisy site

PFO : 10^{-7} m = $\frac{1}{10}$ μm <u>quiet</u> site

Typical <u>signal</u> sizes are as follows

~~M~~	~~wave type~~	~~displacement (μm)~~
~~7~~	~~20 s surface wave at 3000 km~~	~~100 μm~~
~~7~~	~~1 s P wave at 3000 km~~	~~10 μm~~
~~3.5~~	~~1 s S wave at 100 km~~	~~10 μm~~

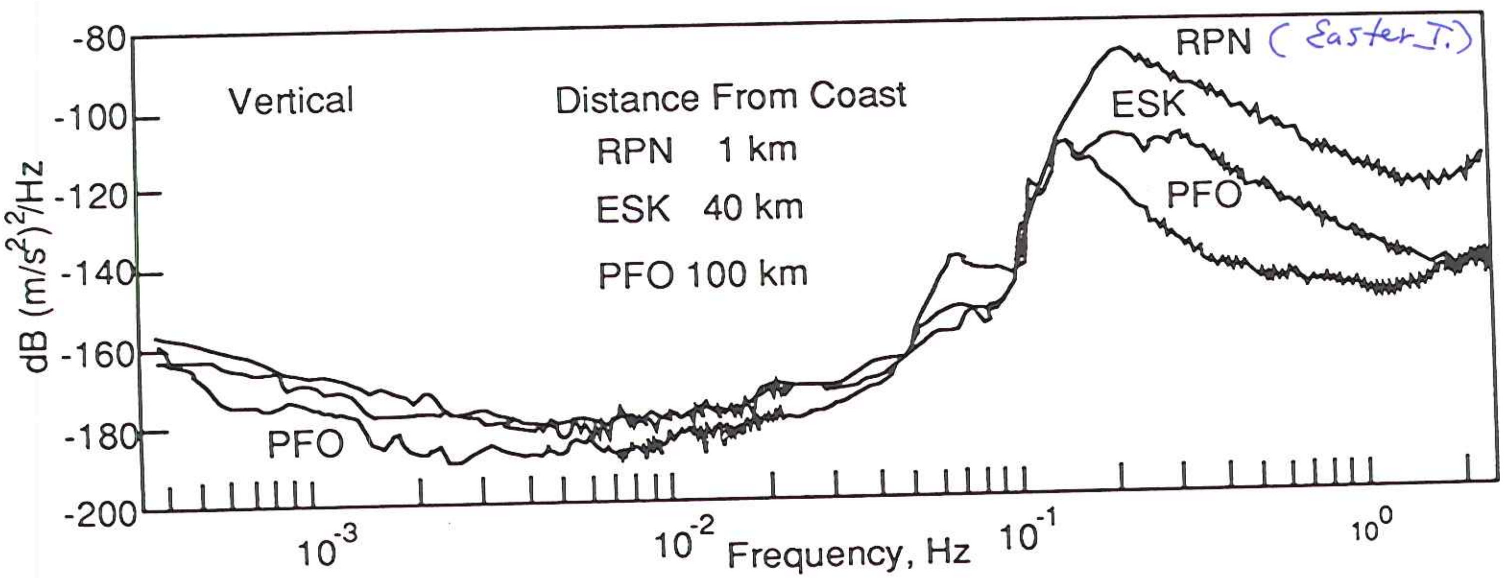


FIGURE 5.3 Power spectra of average background-noise ground acceleration recorded on vertical-motion accelerometers. Note the peak in noise near 0.2 Hz at all stations and the systematic decrease in noise with distance from the coast. Figure 5.14 shows the station locations. The units of dB (decibels) are in terms of $10 \log_{10}$ (acceleration power). Thus, 20 dB corresponds to a factor of 10 variation in ground acceleration. (From Hedlin *et al.*, 1988.)

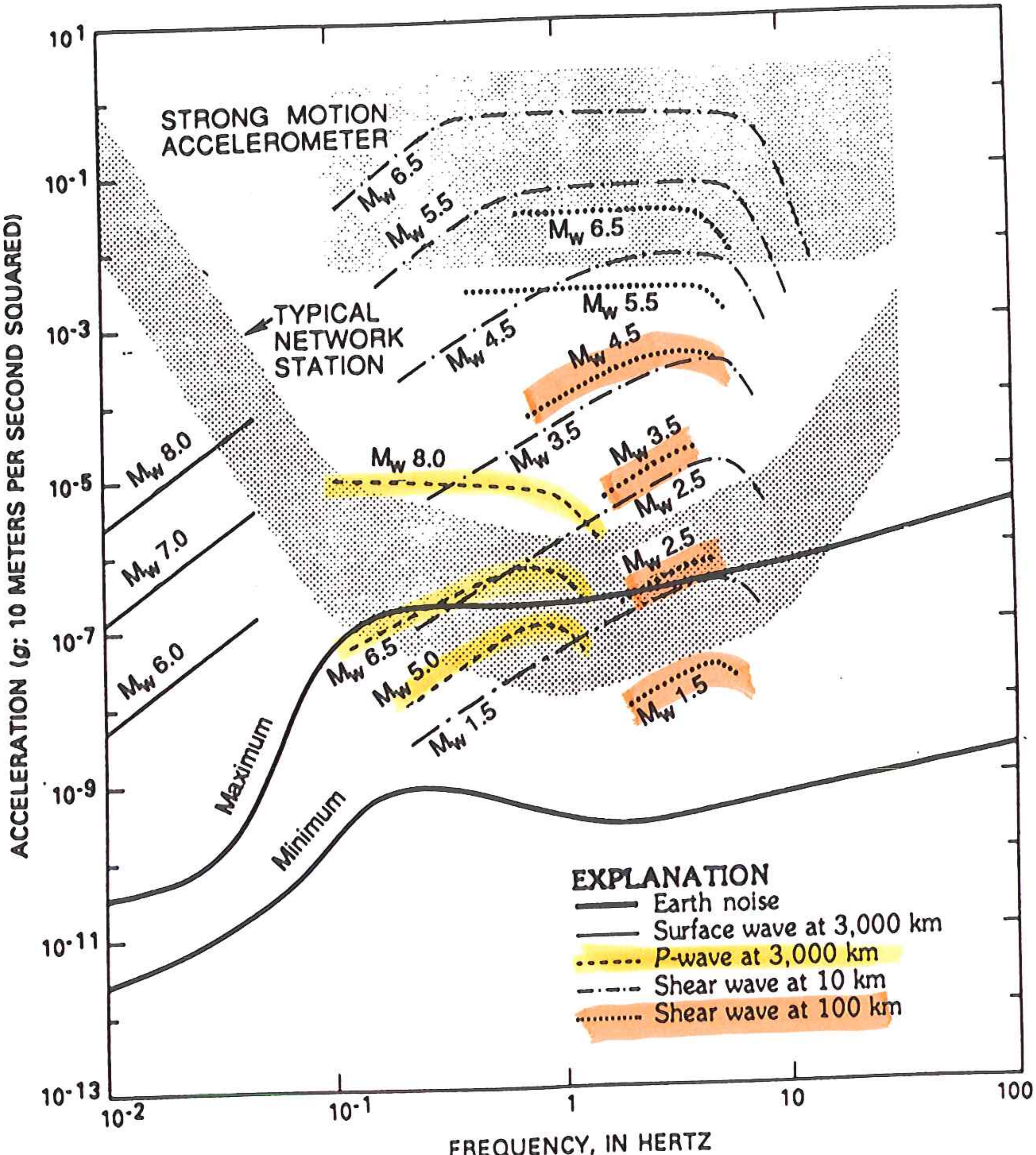


FIGURE 5.22 Comparison of accelerometer and regional-network recording capabilities relative to average noise levels and ground accelerations caused by earthquakes of various sizes at three distances. (From Heaton *et al.*, 1989.)

P wave at 3000 km distance (across US) ← easy to detect M=5 at a moderately quiet site

S wave at 100 km regional networks

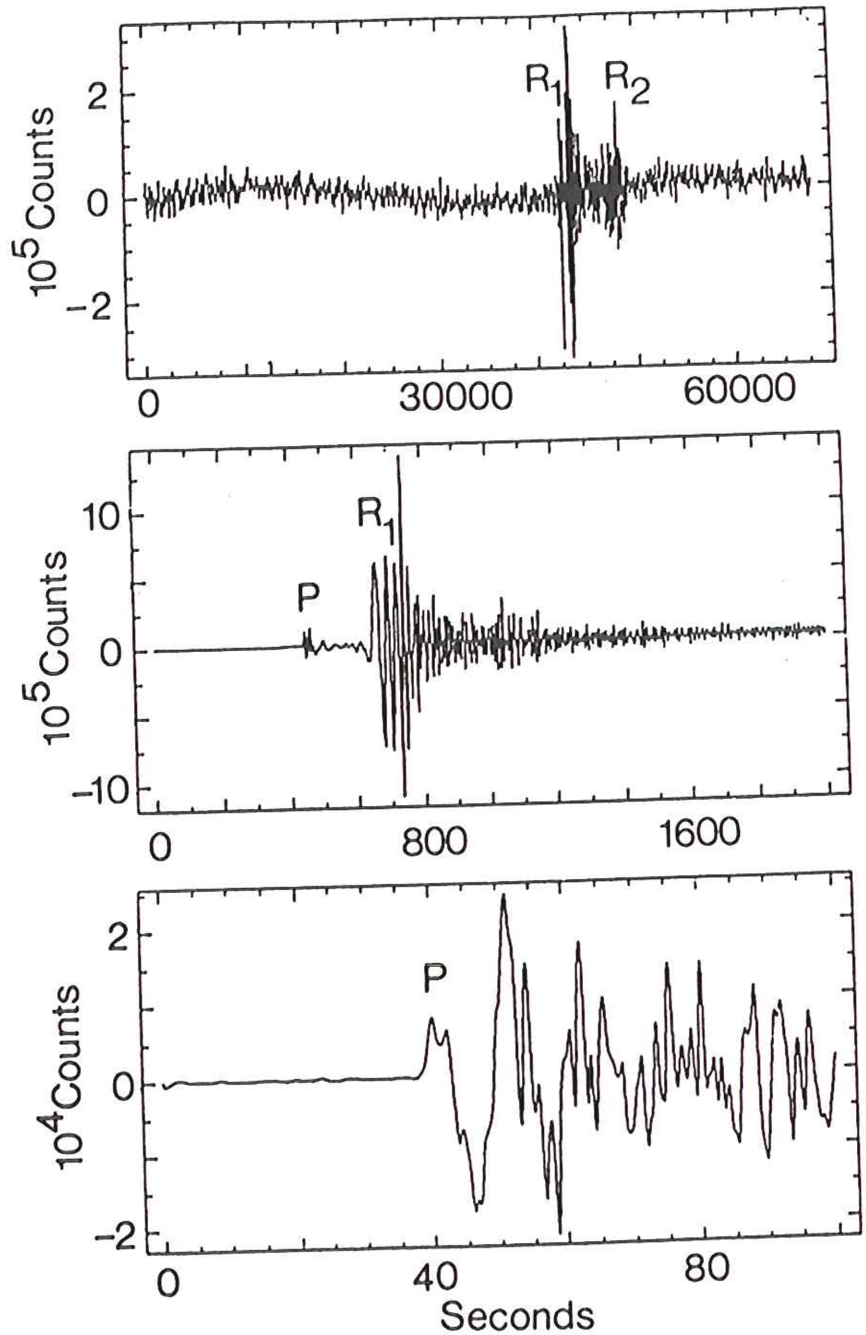


FIGURE 1.6 Broadband vertical-component recording of the 1989 Loma Prieta earthquake at station ANMO (Albuquerque, New Mexico). The top panel is 20 h in duration (the earthquake is the rider on the long-period signal); tidal effects dominate. The middle panel is for a 30-min interval, and the bottom panel is for a 100-s interval.

magnitude	wave type	distance (km)	displ (μm)
7	surface	3000	100
5	surface	3000	1
7	P	3000	10
5	P	3000	1 μm
5	S	100	1000 μm = 1 mm
3	S	10	1 μm

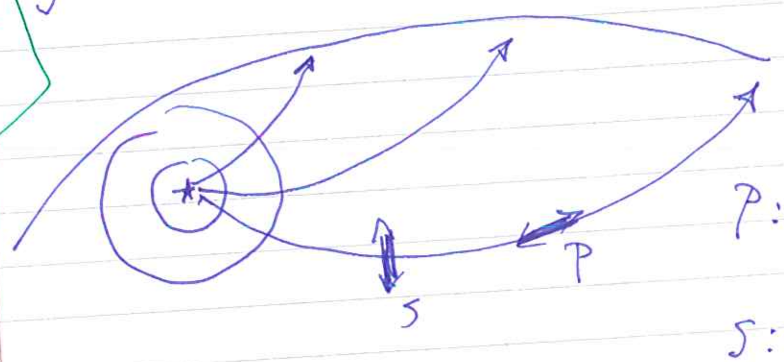
Surface wave from a M = 5 quake can be analyzed at global stations.

Regional or local networks are needed to record M ≤ 5.

How are earthquake locations determined.

Similar to determining the proximity of a lightning bolt by noting the time interval between the flash and the sound ($c_{air} = 340$ m/sec

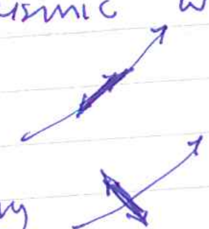
DIFFERENCE: in lightning case, since $c_{light} \gg c_{sound}$, we know the origin time



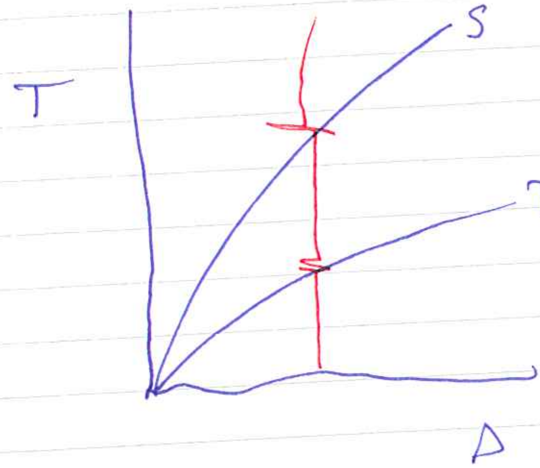
Two types of seismic waves

P: primary

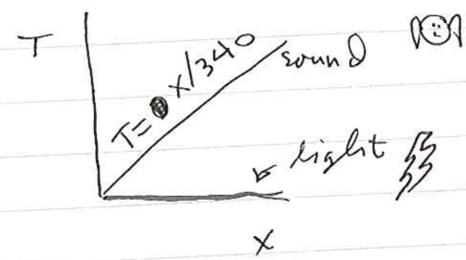
S: secondary



We know T versus Δ for these waves



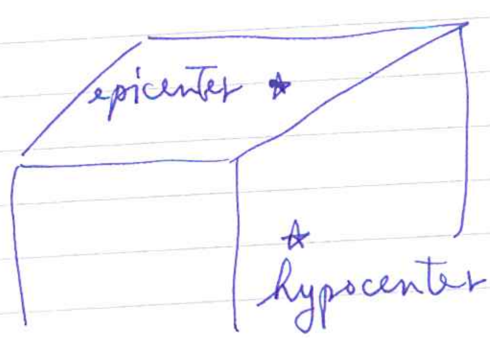
$T_S - T_P$ gives distance Δ to 'quake



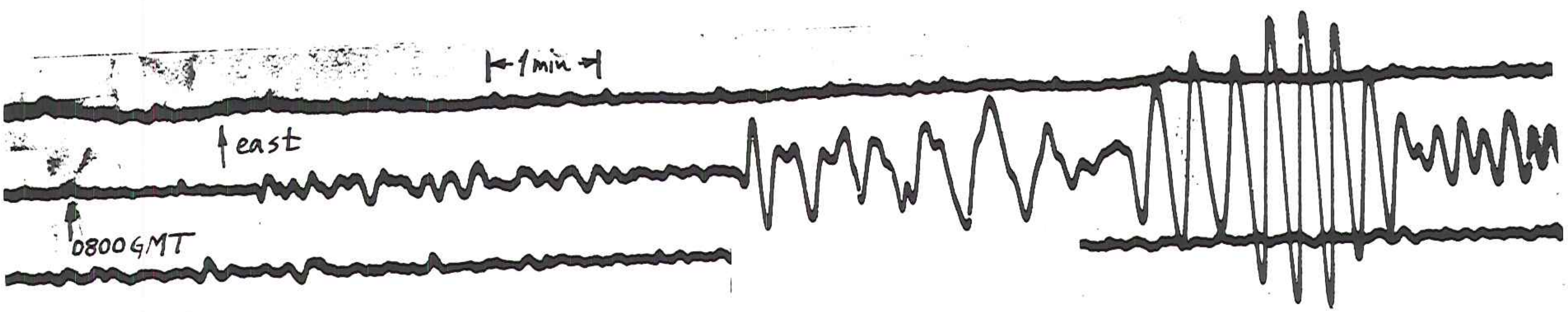
Example: recording from CHG in Thailand S−P ≈ 4½ min ⇒ Δ ≈ 24°

Stations HKC and DAR are situated at distances of ~10° and 30° respectively.

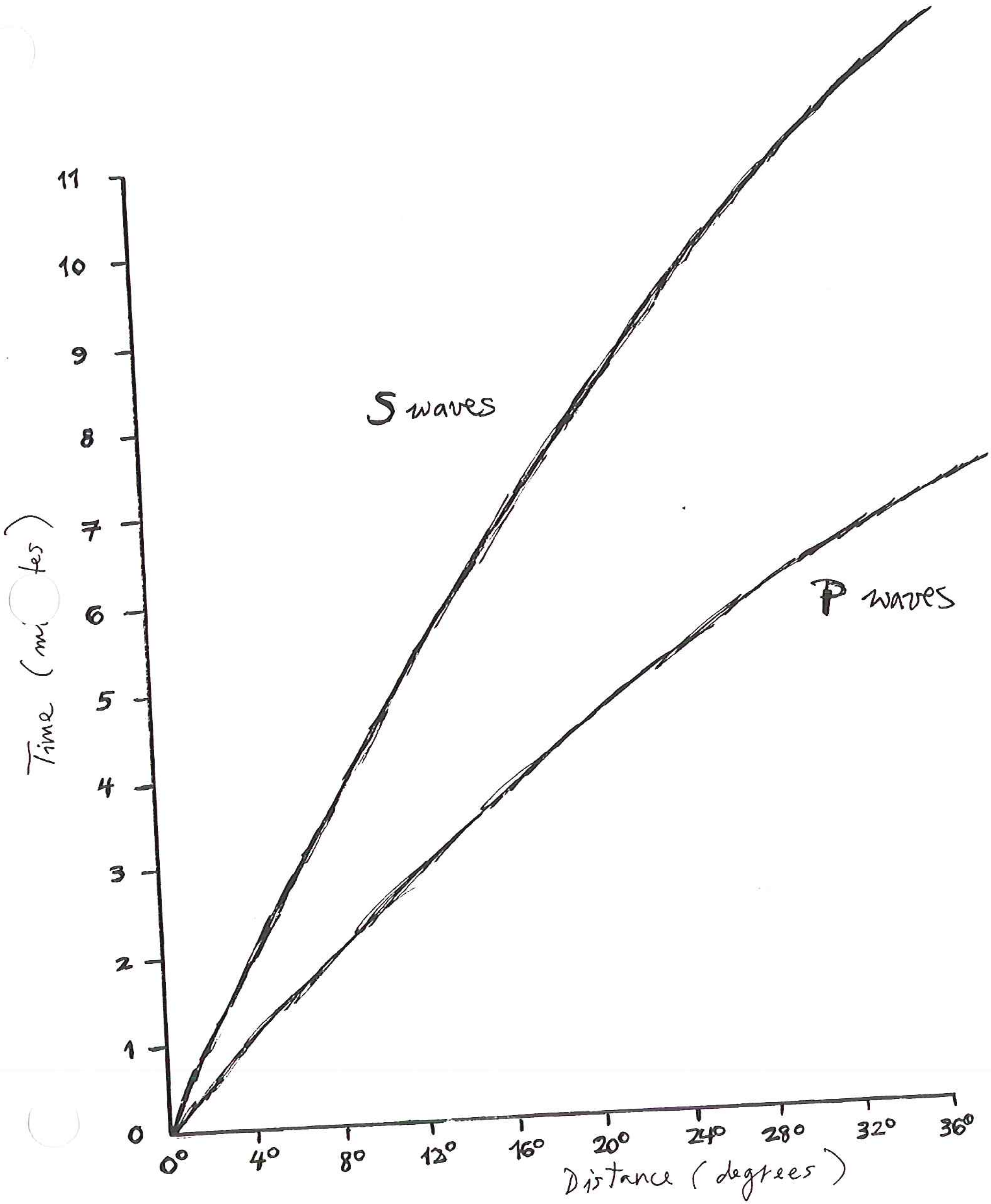
Only three stations are needed to determine the epicenter: note that the HKC and DAR small circles intersect twice.



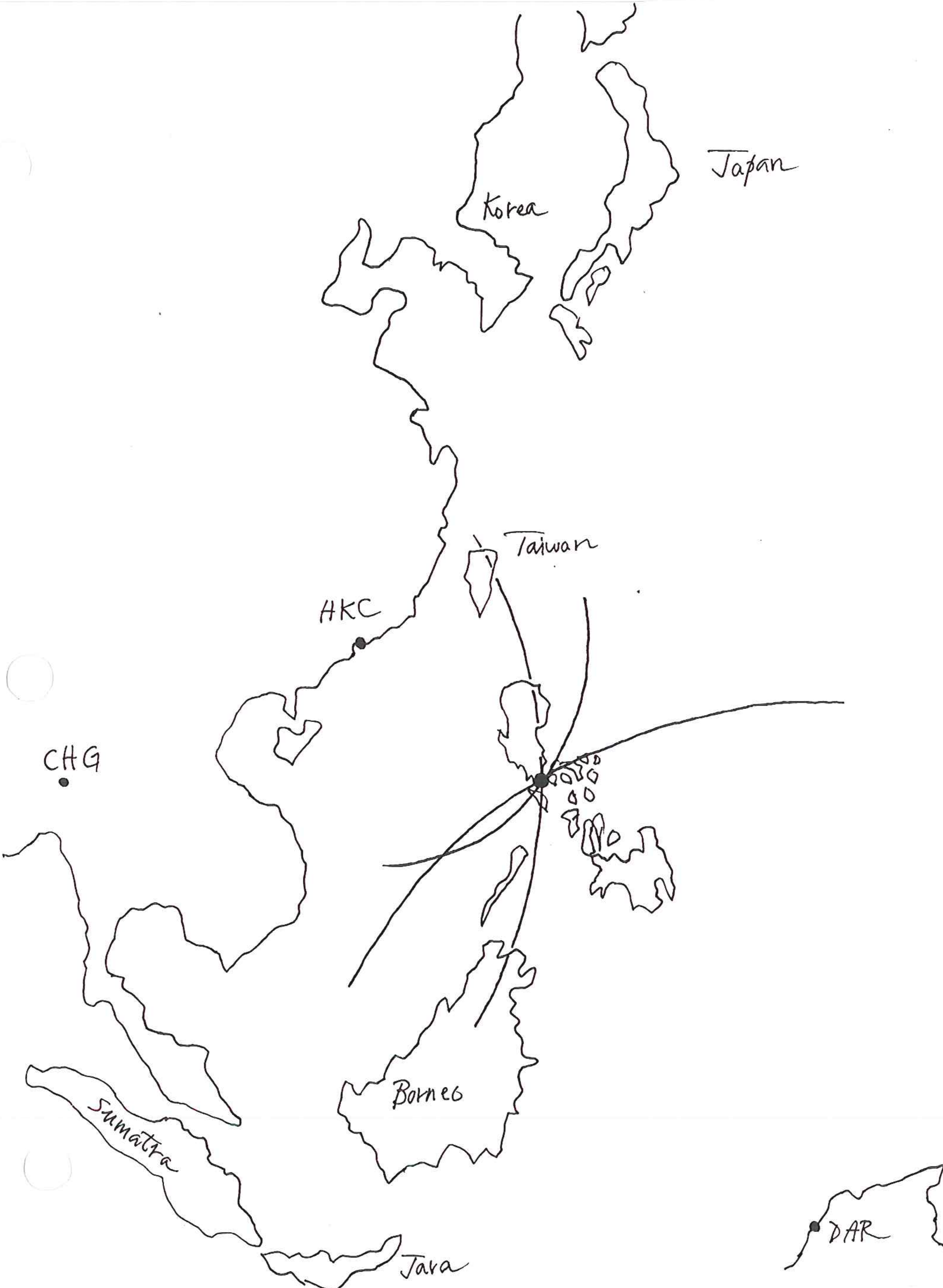
In practice this 'quake location is done by a number of agencies routinely & automatically (using as many stations as possible) by computer.

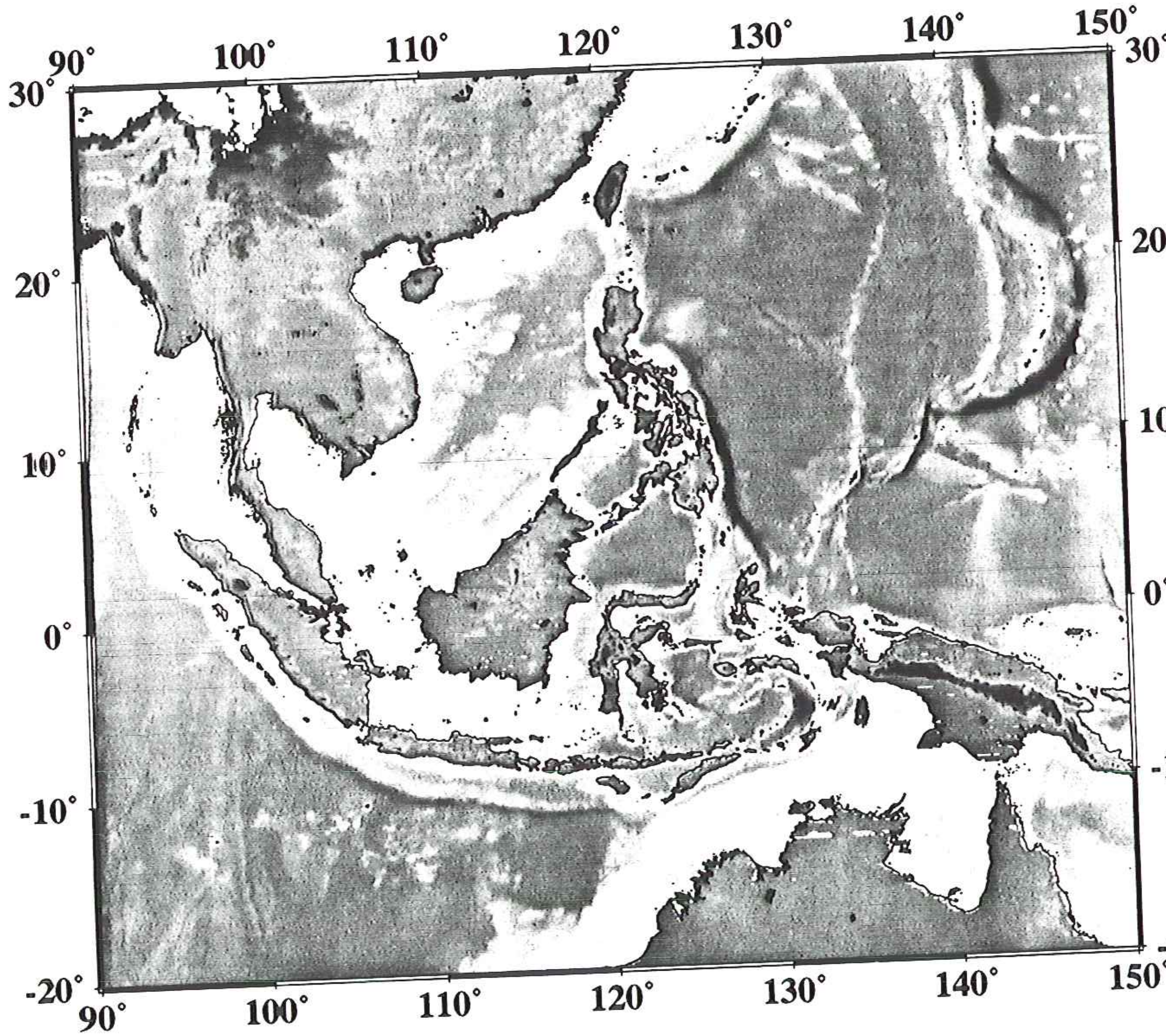


Station CHG
Chiengmai, Thailand



S waves
P waves
Time (minutes)
Distance (degrees)
0
1
2
3
4
5
6
7
8
9
10
11
0°
40
80
120
160
200
240
280
320
360


Japan
Korea
Taiwan
HKC
CHG
Borneo
Sumatra
Java
DAR

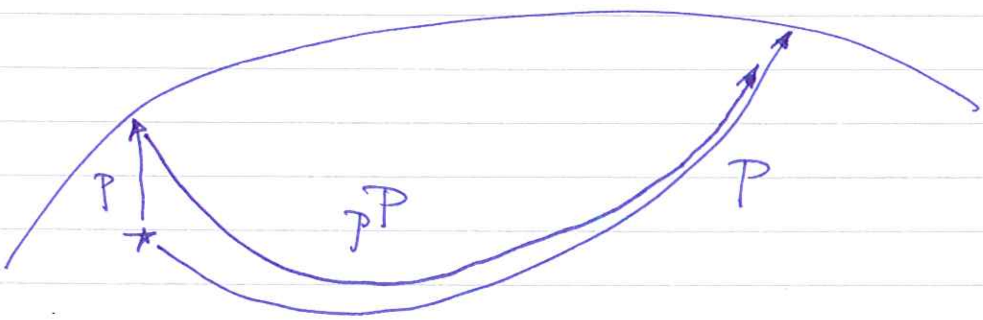

90°
100°
110°
120°
130°
140°
150°
30°
20°
10°
0°
-10°
-20°

Example: Center for Monitoring Research

Prototype for a UN-run CTBT monitoring center to be located in a more neutral host country (Vienna)

How is earthquake depth determined?

Best constrained depths make use of the pP phase



Most of the raypath is very similar

$$pP-P \text{ time} \approx \frac{2 \times \text{depth}}{P \text{ velocity}} = \frac{2h}{\alpha}$$

T_{pP-P} is measured and compared to the observed dependence upon h and Δ (primarily sensitive to former)

For shallow-focus events pP and P come in very close together — synthetic seismogram modelling — example Shudofsky.

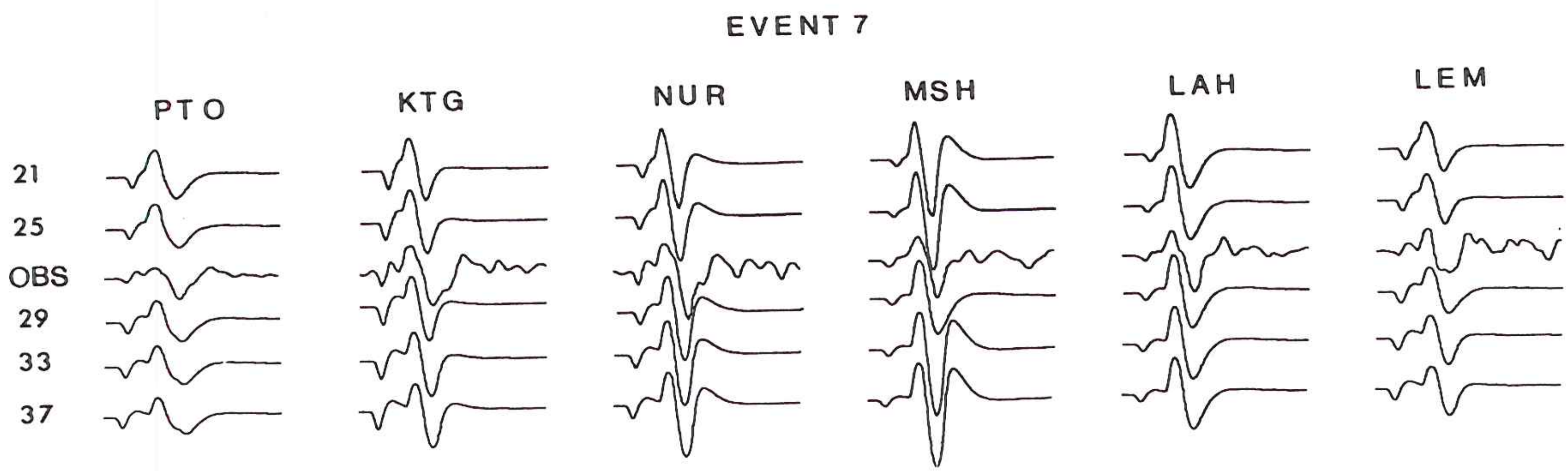


Fig. 13. Variation of the synthetic waveforms with focal depth for Event 7 and comparison with observed signals.

USGS

Earthquake Hazards Banner

Latest Quake Info

Real-time Earthquake Maps
- California - Nevada
- United States
- World

Real-time Shaking Maps

Real-time Seismogram Displays

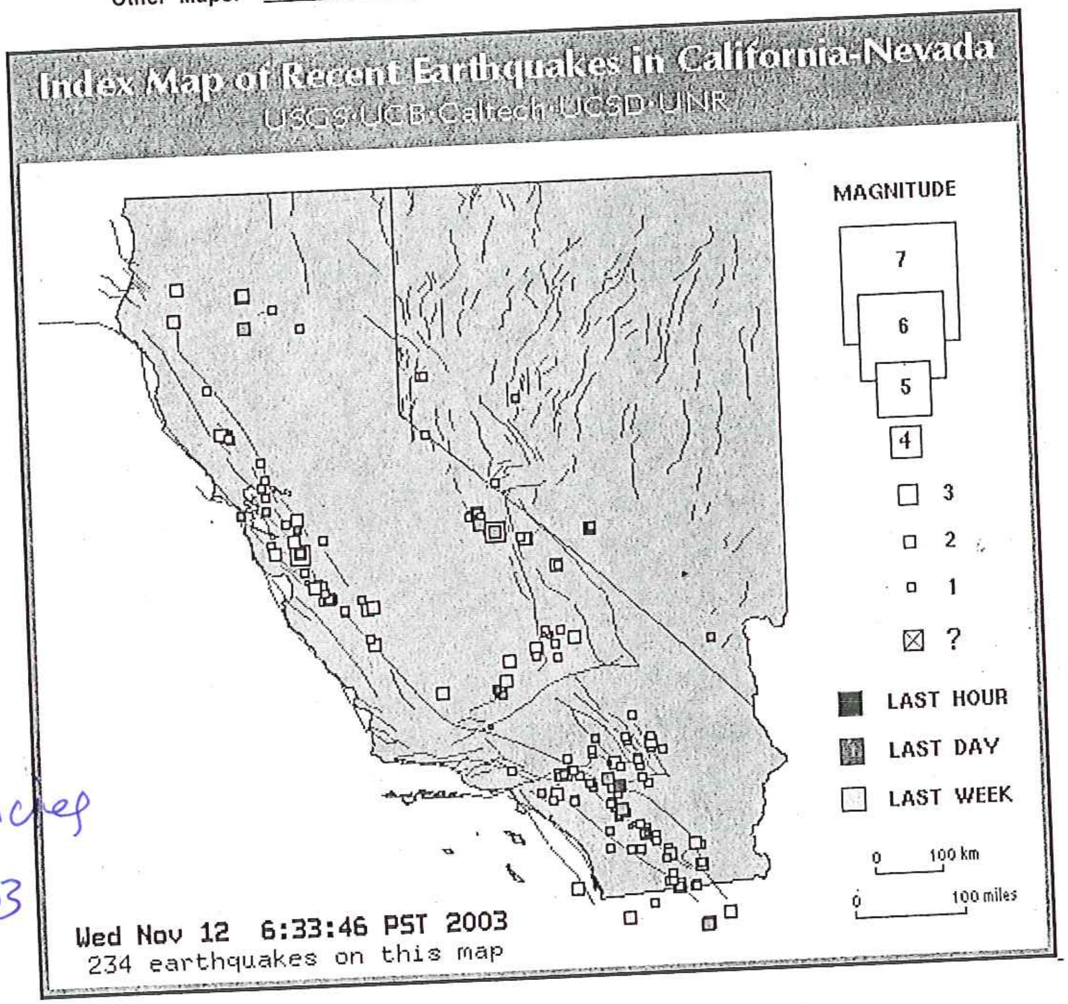
Earthquake Network Reports and Updates

Recent and Significant Past Earthquakes

USGS Earthquake News Releases

recent quake transparencies Fall 2003

Other Maps: Recent earthquakes with fault and topographic information



Click on an earthquake on the map above to zoom in.

Did you feel it? - Report an Earthquake
ShakeMaps - Southern CA || Northern CA
Special maps - Long Valley || Los Angeles || San Francisco || Parkfield

- Try to **reload this page** if you do not have the most current map.
- Maps are updated within 5 minutes of an earthquake and once an hour.
- Magnitude = ? for new earthquakes until a magnitude is determined (4-5 minutes).
- Brown lines indicate faults.

Big earthquake list (with map) || All earthquake list (with map)
Lists of M > 3 earthquakes and of all earthquakes appearing on the above map.

About Real-time Earthquake Maps
Frequently Asked Questions, Data Sources, Credits and Disclaimer, Glossary, Other Sites that Host these Maps.

Old version of maps without sidebar

Animation showing earthquakes over last 7 days (This link takes you offsite.)

USGS
Earthquake Hazards Program

Earthquake Activity

Current Earthquakes

- USA
- World

NEIC Current Earthquake Information

ShakeMaps

Seismogram Displays

Past & Historical Earthquakes

Earthquake Notification E-mail

Earthquake Lists

- M > 1.0
- M > 3.0

Regional Websites and Other Eq Maps

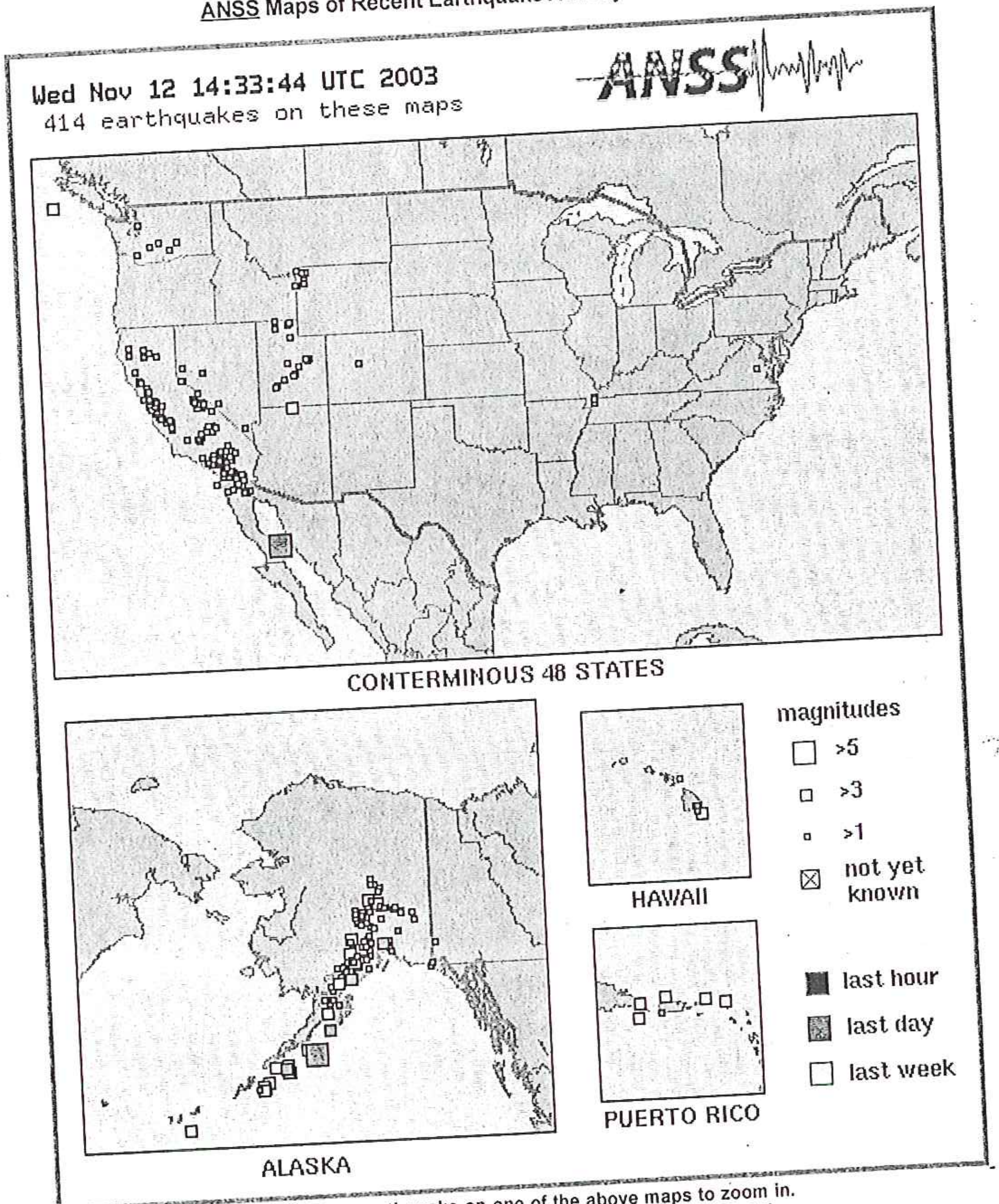
- Alaska
- California/Nevada
- Central & Southeast
- Hawaii
- Guam
- Northeast
- Northwest
- Puerto Rico
- Utah & Yellowstone

Data Sources

FAQ about these maps

Network Contacts

ANSS Maps of Recent Earthquake Activity in the USA



Click on an earthquake on one of the above maps to zoom in.
Click here or on UTC date-time above maps for list of local times.

M>3 earthquake list (with map) || M>1 earthquake list (with map)

Did you feel it? - Report an Earthquake || View ShakeMaps

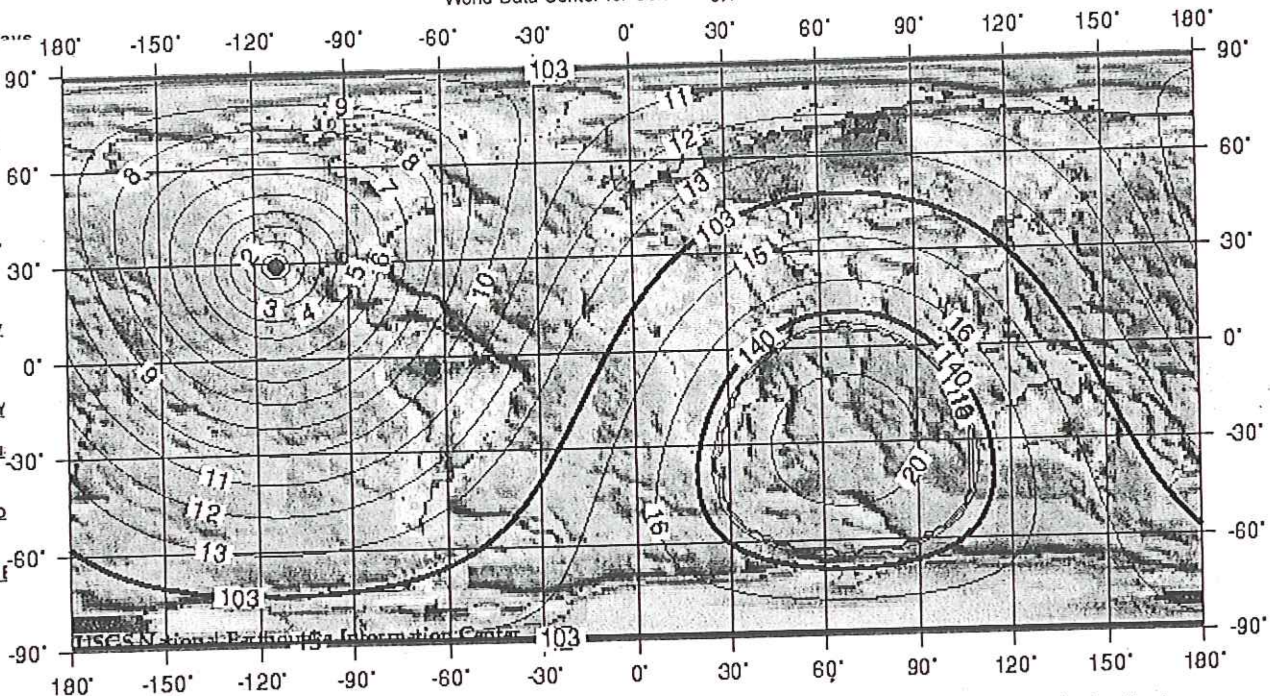
To convert UTC to local time see this list or this table.
Maps show events with M >= 1.0 recorded in the last 7 days.
Try to reload this page if you do not have the most current map.
Maps are updated whenever a new earthquake has been located and once an hour.
Magnitude = ? for new earthquakes until a magnitude is determined (4-5 minutes).

FAQ about Earthquakes | Earthquake Preparedness

The USGS Earthquake Hazards Program (EHP) of the U.S. Geological Survey (USGS) is part of the National Earthquake Hazards Reduction Program (NEHRP)

Magnitude 5.5 GULF OF CALIFORNIA
2003 November 12 04:54:58 UTC

Preliminary Earthquake Report
U.S. Geological Survey, National Earthquake Information Center
World Data Center for Seismology, Denver



This map shows the predicted (theoretical) travel times, in minutes, of the compressional (P) wave from the earthquake location to points around the globe. The travel times are computed using the spherically-symmetric IASP91 reference earth velocity model. The heavy black lines shown are the approximate distances to the P-wave shadow zone (103 to 140 degrees).

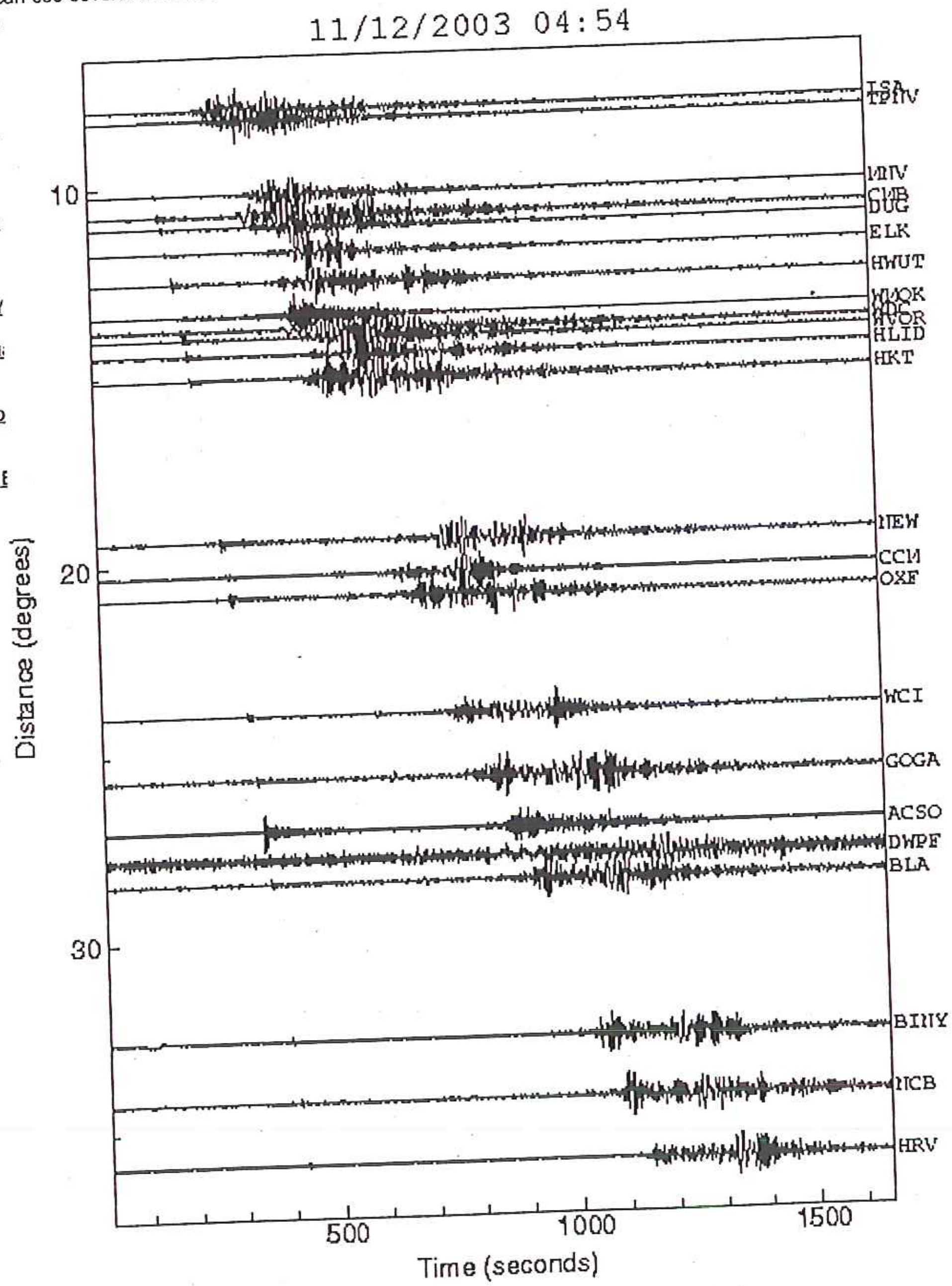
Philadephia, Pennsylvania	32.88	6:34.1	5:01:32.1	P
Ottawa, Canada	33.59	6:40.2	5:01:38.2	P
New York, New York	33.86	6:42.6	5:01:40.6	P
Boston, Massachusetts	36.25	7:03.1	5:02:01.1	P
Bangor, Maine	38.26	7:20.2	5:02:18.2	P
Anchorage, Alaska	40.29	7:37.1	5:02:35.1	P
Honolulu, Hawaii	40.98	7:42.9	5:02:40.9	P
San Juan, Puerto Rico	44.04	8:07.8	5:03:05.8	P
Lima, Peru	53.78	9:22.5	5:04:20.5	P
Bergen, Norway	77.72	11:57.0	5:06:55.0	P
London, England	80.55	12:12.5	5:07:10.5	P
Tokyo, Japan	85.92	12:40.2	5:07:38.2	P
Moscow, Russia	91.89	13:08.4	5:08:06.4	P
Rome, Italy	93.38	13:15.3	5:08:13.3	P
Agana, Guam	93.82	13:17.3	5:08:15.3	P
Wellington, New Zealand	96.61	13:30.0	5:08:28.0	P
Beijing, China	97.31	13:33.1	5:08:31.1	P
Palmer Station, Antarctica	103.27	13:59.6	5:08:57.6	Pdiff
Brisbane, Australia	105.94	14:11.4	5:09:09.4	Pdiff
Kathmandu, Nepal	120.82	15:17.5	5:10:15.5	Pdiff
Nairobi, Kenya	140.20	16:43.5	5:11:41.5	Pdiff

Magnitude 5.5 GULF OF CALIFORNIA
2003 November 12 04:54:58 UTC

Preliminary Earthquake Report

U.S. Geological Survey, National Earthquake Information Center
World Data Center for Seismology, Denver

The record section below shows seismograms recorded on seismographic stations spanning the contiguous United States. The seismograms are plotted as a function of distance with stations close to the earthquake at the top and more distant stations plotted at the bottom. Zero time corresponds to the origin time of the earthquake. The station name is plotted to the right. For large earthquakes, you can see several seismic arrivals that travel different paths through the earth. Each trace is normalized to its maximum amplitude.



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Earthquake Lists

M > 2.5
M > 5

Region Maps

Africa
Asia
Australia
Europe
North America
North Pole
South America
South Pacific
South Pole

Hemisphere Maps

West
East
North
South

Other Maps

Guam
Hawaii
World-Mercator

NEIC Maps (with events color coded by depth)

Data Sources

FAQ about these maps

Network Contacts

Magnitude Greater Than 2.5 Earthquakes From Around the World

This list contains all earthquakes with magnitude greater than 2.5 catalogued in the last week (168 hours). Magnitudes 5 and above are in bold font. Magnitudes 6 and above are in red. (Some early events may be obscured by later ones on the maps.)

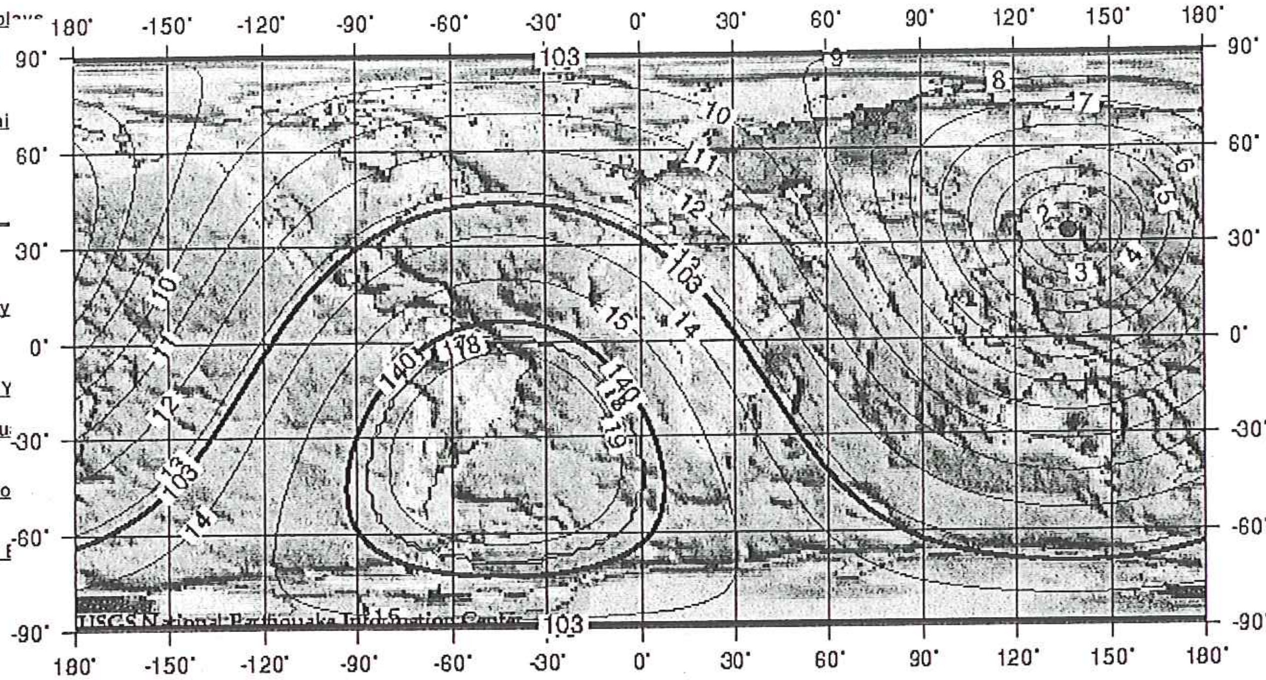
The most recent earthquakes are at the top of the list. Times are in Coordinated Universal Time (UTC). Click on the word "map" to see a ten-degree tall map displaying the earthquake. Click on an event's "DATE" to get additional text information.

Update time = Wed Nov 12 14:21:32 UTC 2003

	MAG	DATE y/m/d	UTC-TIME h:m:s	LAT deg	LON deg	DEPTH km	region
map	3.3	2003/11/12	13:03:23	61.484	-147.905	25.0	SOUTHERN ALASKA
MAP	**5.4**	**2003/11/12**	**10:05:59**	**55.248**	**-157.730**	**200.0**	**ALASKA PENINSULA**
map	3.3	2003/11/12	09:27:40	54.422	-161.772	15.0	ALASKA PENINSULA
MAP	**6.4**	**2003/11/12**	**08:26:46**	**33.631**	**137.020**	**391.1**	**NEAR THE SOUTH COAST OF HONSHU, JAPAN**
map	2.7	2003/11/12	06:04:51	19.094	-155.191	21.1	HAWAII
MAP	**5.5**	**2003/11/12**	**04:54:59**	**29.115**	**-113.135**	**10.0**	**GULF OF CALIFORNIA**
map	3.2	2003/11/12	03:03:10	59.431	-152.262	80.0	SOUTHERN ALASKA
map	2.6	2003/11/12	02:35:18	63.519	-146.974	1.0	CENTRAL ALASKA
map	2.7	2003/11/12	02:26:07	63.194	-151.329	5.0	CENTRAL ALASKA
map	2.8	2003/11/12	02:12:24	34.097	-116.955	4.8	SOUTHERN CALIFORNIA
MAP	**5.5**	**2003/11/12**	**01:54:25**	**-39.965**	**-74.764**	**31.6**	**OFF THE COAST OF CENTRAL CHILE**
MAP	**5.9**	**2003/11/12**	**00:29:46**	**1.654**	**126.443**	**33.0**	**MOLUCCA SEA**
map	2.7	2003/11/11	23:36:44	59.919	-152.894	100.0	SOUTHERN ALASKA
map	2.6	2003/11/11	21:05:07	61.008	-146.595	1.0	SOUTHERN ALASKA
MAP	**6.1**	**2003/11/11**	**18:48:26**	**22.336**	**143.287**	**112.6**	**VOLCANO ISLANDS, JAPAN REGION**
map	4.7	2003/11/11	16:51:56	15.039	-93.778	33.0	OFFSHORE CHIAPAS, MEXICO
map	2.6	2003/11/11	16:35:24	53.330	-165.589	1.0	FOX ISLANDS, ALEUTIAN ISLANDS, ALASKA
MAP	**6.0**	**2003/11/11**	**15:40:37**	**-31.729**	**-179.582**	**619.0**	**KERMADEC ISLANDS REGION**
MAP	**6.0**	**2003/11/11**	**15:39:34**	**-30.632**	**-179.298**	**33.0**	**KERMADEC ISLANDS REGION**
map	3.3	2003/11/11	15:36:14	56.620	-155.639	40.0	ALASKA PENINSULA
map	4.1	2003/11/11	14:32:06	54.303	-161.592	5.0	ALASKA PENINSULA
MAP	**5.9**	**2003/11/11**	**13:44:53**	**-30.528**	**-179.044**	**33.0**	**KERMADEC ISLANDS REGION**
map	3.2	2003/11/11	13:00:56	60.388	-151.821	60.0	KENAI PENINSULA, ALASKA
map	3.9	2003/11/11	12:47:06	54.296	-161.401	1.0	ALASKA PENINSULA
map	3.9	2003/11/11	12:13:09	53.305	-165.102	20.0	FOX ISLANDS, ALEUTIAN ISLANDS, ALASKA
map	3.0	2003/11/11	11:04:26	60.980	-152.370	120.0	SOUTHERN ALASKA
map	2.9	2003/11/11	10:23:26	37.303	-118.140	10.8	CENTRAL CALIFORNIA
map	2.5	2003/11/11	07:16:09	63.049	-150.551	120.0	CENTRAL ALASKA
map	3.5	2003/11/11	02:07:53	37.412	-118.603	11.3	CENTRAL CALIFORNIA
map	2.8	2003/11/11	01:47:01	59.221	-152.737	45.0	SOUTHERN ALASKA
map	2.9	2003/11/11	00:45:46	61.265	-146.880	20.0	SOUTHERN ALASKA
map	2.7	2003/11/10	22:04:08	46.418	-120.137	0.0	WASHINGTON
map	3.2	2003/11/10	21:03:23	59.238	-154.010	140.0	SOUTHERN ALASKA
map	4.6	2003/11/10	19:55:09	49.965	87.571	10.0	RUSSIA-KAZAKHSTAN-XINJIANG BORDER REGION
map	2.8	2003/11/10	15:46:41	40.642	-122.422	14.9	NORTHERN CALIFORNIA
map	2.6	2003/11/10	15:46:17	58.292	-155.237	5.0	ALASKA PENINSULA
map	3.4	2003/11/10	15:44:36	57.558	-155.972	10.0	ALASKA PENINSULA
MAP	**5.0**	**2003/11/10**	**14:45:55**	**41.022**	**67.940**	**33.0**	**EASTERN UZBEKISTAN**
map	2.5	2003/11/10	13:41:21	40.626	-122.433	20.7	NORTHERN CALIFORNIA
map	4.5	2003/11/10	13:08:12	53.517	-165.217	23.0	FOX ISLANDS, ALEUTIAN ISLANDS, ALASKA
map	2.8	2003/11/10	12:07:26	36.758	-121.458	7.3	CENTRAL CALIFORNIA
map	4.8	2003/11/10	12:04:54	14.250	-92.163	33.0	NEAR THE COAST OF GUATEMALA
map	2.6	2003/11/10	10:01:56	36.614	-121.220	6.5	CENTRAL CALIFORNIA
map	3.5	2003/11/10	06:45:43	63.819	-148.453	105.1	CENTRAL ALASKA
map	2.6	2003/11/10	05:40:50	63.521	-147.086	10.0	CENTRAL ALASKA
map	2.8	2003/11/10	03:15:35	60.000	-149.800	40.0	KENAI PENINSULA, ALASKA
map	4.8	2003/11/10	02:32:44	45.818	142.469	320.4	HOKKAIDO, JAPAN REGION
map	3.9	2003/11/09	21:11:18	18.754	-64.471	34.5	VIRGIN ISLANDS
MAP	**6.6**	**2003/11/09**	**19:52:35**	**-0.617**	**-19.280**	**10.0**	**CENTRAL MID-ATLANTIC RIDGE**
MAP	**5.8**	**2003/11/09**	**19:23:28**	**1.583**	**127.336**	**125.4**	**HALMAHERA, INDONESIA**
map	4.8	2003/11/09	17:40:16	14.411	-93.060	33.0	OFFSHORE CHIAPAS, MEXICO
map	2.6	2003/11/09	15:29:40	20.918	-156.198	6.3	HAWAII
map	2.7	2003/11/09	15:11:32	65.250	-149.119	10.0	NORTHERN ALASKA
map	2.6	2003/11/09	14:51:19	59.552	-153.554	160.0	SOUTHERN ALASKA
map	4.0	2003/11/09	14:05:43	53.370	-164.876	1.0	UNIMAK ISLAND REGION, ALASKA
map	2.7	2003/11/09	11:04:23	38.708	-119.722	3.6	NORTHERN CALIFORNIA
map	4.6	2003/11/09	08:36:20	52.865	160.503	69.6	OFF THE EAST COAST OF KAMCHATKA, RUSSIA
map	2.7	2003/11/09	07:06:13	62.944	-151.318	120.0	CENTRAL ALASKA
map	2.7	2003/11/09	00:20:27	62.996	-151.100	140.0	CENTRAL ALASKA
map	2.6	2003/11/09	00:09:46	32.148	-115.435	7.0	BAJA CALIFORNIA, MEXICO
map	4.3	2003/11/08	20:38:53	10.668	-73.430	33.0	NORTHERN COLOMBIA
map	4.7	2003/11/08	18:23:59	53.702	-164.490	30.0	UNIMAK ISLAND REGION, ALASKA
map	2.6	2003/11/08	18:22:08	40.338	-123.508	33.2	NORTHERN CALIFORNIA
map	3.9	2003/11/08	17:26:24	61.786	-152.009	160.0	SOUTHERN ALASKA
map	2.5	2003/11/08	14:37:05	58.135	-155.404	5.0	ALASKA PENINSULA

Magnitude 6.4 NEAR S. COAST OF HONSHU, JAPAN
2003 November 12 08:26:46 UTC

Preliminary Earthquake Report
U.S. Geological Survey, National Earthquake Information Center
World Data Center for Seismology, Denver



This map shows the predicted (theoretical) travel times, in minutes, of the compressional (P) wave from the earthquake location to points around the globe. The travel times are computed using the spherically-symmetric IASP91 reference earth velocity model. The heavy black lines shown are the approximate distances to the P-wave shadow zone (103 to 140 degrees).

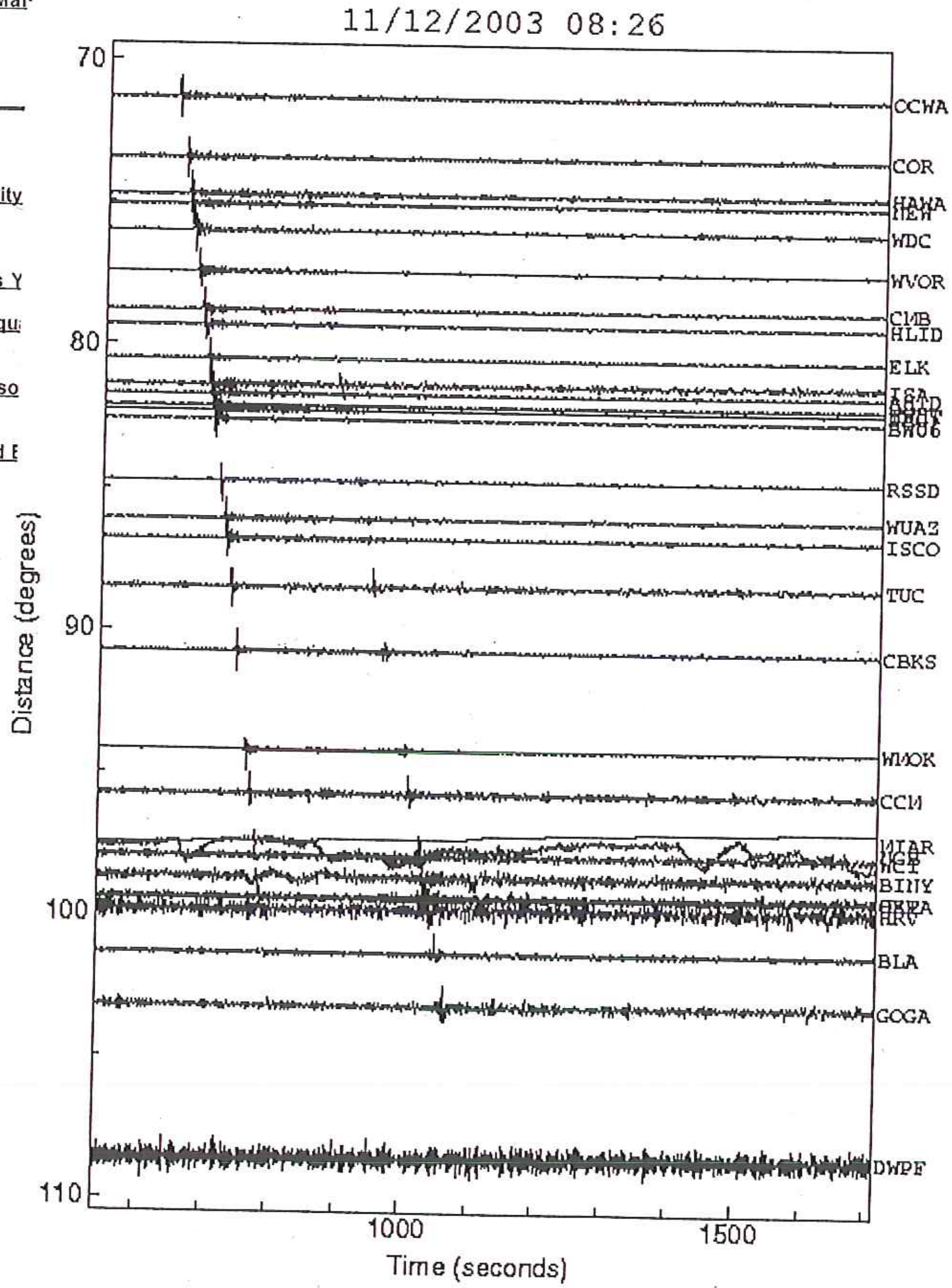
Golden, Colorado	87.07	12:02.4	8:38:48.4	P
London, England	87.27	12:03.4	8:38:49.4	P
Duluth, Minnesota	88.56	12:09.4	8:38:55.4	P
Rome, Italy	89.23	12:12.5	8:38:58.5	P
Albuquerque, New Mexico	89.33	12:13.0	8:38:59.0	P
Wichita, Kansas	92.83	12:29.1	8:39:15.1	P
St. Louis, Missouri	95.76	12:42.4	8:39:28.4	P
Ottawa, Canada	95.92	12:43.1	8:39:29.1	P
Bangor, Maine	98.51	12:54.6	8:39:40.6	Pdiff
Nairobi, Kenya	99.19	12:57.7	8:39:43.7	Pdiff
Boston, Massachusetts	100.14	13:01.9	8:39:47.9	Pdiff
Knoxville, Tennessee	100.34	13:02.8	8:39:48.8	Pdiff
New York, New York	100.69	13:04.3	8:39:50.3	Pdiff
Philadephia, Pennsylvania	100.98	13:05.6	8:39:51.6	Pdiff
Washington, D.C.	101.24	13:06.7	8:39:52.7	Pdiff
Brownsville, Texas	101.35	13:07.2	8:39:53.2	Pdiff
Mexico City, Mexico	104.84	13:22.7	8:40:08.7	Pdiff
Miami, Florida	111.16	13:50.8	8:40:36.8	Pdiff
San Juan, Puerto Rico	123.67	14:46.3	8:41:32.3	Pdiff
Lima, Peru	142.26	16:08.8	8:42:54.8	Pdiff
Palmer Station, Antarctica	143.70	16:15.2	8:43:01.2	Pdiff

Magnitude 6.4 NEAR S. COAST OF HONSHU, JAPAN
2003 November 12 08:26:46 UTC

Preliminary Earthquake Report

U.S. Geological Survey, National Earthquake Information Center
World Data Center for Seismology, Denver

The record section below shows seismograms recorded on seismographic stations spanning the contiguous United States. The seismograms are plotted as a function of distance with stations close to the earthquake at the top and more distant stations plotted at the bottom. Zero time corresponds to the origin time of the earthquake. The station name is plotted to the right. For large earthquakes, you can see several seismic arrivals that travel different paths through the earth. Each trace is normalized to its maximum amplitude.



USGS
Earthquake Hazards Program

st Quakes

Earthquake AcWorldwide Earthquake Activity in the Last Seven Days

2004
transparancy

Version en Español

Current EarthquakeYou may need to reload this page for the latest list.

USA
World

Current Time: Wed, 10 Nov 2004 17:41:46 UTC

Updated as of Wed Nov 10 14:25:10 UTC 2004.

ShakeMaps
Seismogram Displays
Past & Historical Earthquakes
Earthquake E-Mail Notification
Earthquake Activity in the Last 8 - 30 Days
Large/Significant Earthquakes This Year
Significant Earthquake Posters
Fast Moment Tensor Solutions
Latest Energy and Broadband Solutions

DATE-(UTC)-TIME yyyy/mm/dd hh:mm:ss	Latitude degrees	Longitude degrees	Depth km	Magnitude	Comments
2004/11/09 23:58:26	11.10S	163.66E	26.2	6.9	SOLOMON ISLANDS
2004/11/09 22:14:37	11.58N	140.69E	52.7	5.5	STATE OF YAP, MICRONESIA
2004/11/09 18:43:08	37.38N	138.78E	10.0	5.3	NEAR WEST COAST OF HONSHU, JAPAN
2004/11/09 07:40:09	43.72N	147.76E	42.0	4.7	KURIL ISLANDS
2004/11/09 07:23:40	43.69N	127.23W	10.0	4.2	OFF COAST OF OREGON
2004/11/09 06:44:04	35.03N	116.91W	4.3	3.7	SOUTHERN CALIFORNIA
2004/11/08 21:56:51	34.05N	117.26W	12.2	2.7	GREATER LOS ANGELES AREA, CALIFORNIA
2004/11/08 21:04:22	19.31N	155.76W	10.7	3.7	ISLAND OF HAWAII, HAWAII
2004/11/08 20:01:22	14.34N	146.90E	10.0	5.1	ROTA REGION, N. MARIANA ISLANDS
2004/11/08 19:38:11	24.01N	122.56E	30.0	5.3	TAIWAN REGION
2004/11/08 19:16:03	37.21N	138.88E	39.2	4.8	NEAR THE WEST COAST OF HONSHU, JAPAN
2004/11/08 18:34:55	42.94N	145.42E	37.5	4.5	HOKKAIDO, JAPAN REGION
2004/11/08 16:33:10	23.95N	122.58E	30.0	4.8	TAIWAN REGION
2004/11/08 15:55:01	24.06N	122.55E	29.0	6.3	TAIWAN REGION
2004/11/08 15:07:25	33.71N	138.40E	13.1	5.6	IZU ISLANDS, JAPAN REGION
2004/11/08 06:21:11	63.08N	151.43W	9.0	4.9	CENTRAL ALASKA
2004/11/08 02:32:17	37.32N	138.98E	10.0	5.0	NEAR WEST COAST OF HONSHU, JAPAN
2004/11/08 02:27:10	37.25N	138.91E	10.0	5.0	NEAR WEST COAST OF HONSHU, JAPAN
2004/11/08 02:15:58	37.38N	138.84E	10.0	5.5	NEAR WEST COAST OF HONSHU, JAPAN
2004/11/08 00:40:58	18.79N	119.94E	36.2	4.8	PHILIPPINE ISLANDS REGION
2004/11/07 23:11:10	28.59N	143.28E	39.7	4.6	BONIN ISLANDS, JAPAN REGION
2004/11/07 19:23:59	46.84N	121.76W	1.6	3.2	MOUNT RAINIER AREA, WASHINGTON
2004/11/07 11:20:22	32.67N	87.98W	4.8	4.2	ALABAMA
2004/11/07 06:54:59	38.24N	108.92W	0.6	4.1	COLORADO
2004/11/07 02:41:41	55.52S	29.10W	39.8	5.8	SOUTH SANDWICH ISLANDS REGION
2004/11/07 02:16:08	36.90S	177.25E	211.0		OFF EAST COAST OF THE NORTH ISLAND, N.Z.
2004/11/07 02:02:26	47.95N	144.41E	476.2	6.2	SEA OF OKHOTSK
2004/11/06 23:59:36	38.72S	175.39E	215.0		NORTH ISLAND OF NEW ZEALAND
2004/11/06 23:42:30	28.72N	51.22E	45.0	3.9	SOUTHERN IRAN
2004/11/06 23:19:52	28.99N	51.32E	75.9	4.4	SOUTHERN IRAN
2004/11/06 22:20:43	2.58N	128.23E	69.9	5.2	HALMAHERA, INDONESIA
2004/11/06 21:48:01	59.44N	151.48W	45.0	3.3	KENAI PENINSULA, ALASKA
2004/11/06 20:58:07	36.24N	70.06E	128.1	4.4	HINDU KUSH REGION, AFGHANISTAN
2004/11/06 20:46:53	26.21N	66.63E	17.8	4.7	PAKISTAN
2004/11/06 20:46:02	35.18S	178.31E	193.0		OFF EAST COAST OF THE NORTH ISLAND, N.Z.
2004/11/06 18:09:00	28.52N	53.80E	35.0	4.1	SOUTHERN IRAN
2004/11/06 17:07:01	42.74N	145.97E	7.9	4.6	HOKKAIDO, JAPAN REGION
2004/11/06 15:28:48	41.33S	85.65W	10.0	4.8	WEST CHILE RISE
2004/11/06 14:28:17	16.64S	173.54W	15.0	4.8	TONGA
2004/11/06 13:05:11	37.25N	138.94E	10.2	4.6	NEAR WEST COAST OF HONSHU, JAPAN
2004/11/06 12:16:19	28.72N	143.21E	40.0	4.3	BONIN ISLANDS, JAPAN REGION
2004/11/06 11:19:03	18.31N	67.57W	81.6	2.7	MONA PASSAGE
2004/11/06 09:25:56	37.05N	138.80E	10.0	4.3	NEAR THE WEST COAST OF HONSHU, JAPAN
2004/11/06 08:46:02	27.61N	139.75E	475.2	4.6	BONIN ISLANDS, JAPAN REGION
2004/11/06 07:58:48	14.39N	146.80E	41.6	4.4	ROTA REGION, NORTHERN MARIANA ISLANDS
2004/11/06 07:04:38	24.29S	179.85W	492.6	4.4	SOUTH OF THE FIJI ISLANDS
2004/11/06 06:33:46	38.02S	176.37E	179.0		NORTH ISLAND OF NEW ZEALAND

Link to USGS home page

Magnitude 6.9 - SOLOMON ISLANDS
2004 November 9 23:58:26 UTC

Preliminary Earthquake Report

U.S. Geological Survey, National Earthquake Information Center
World Data Center for Seismology, Denver

A strong earthquake occurred at 23:58:26 (UTC) on Tuesday, November 9, 2004. The magnitude 6.9 event has been located in the SOLOMON ISLANDS. (This event has been reviewed by a seismologist.)

Magnitude	6.9
Date-Time	Tuesday, November 9, 2004 at 23:58:26 (UTC) = Coordinated Universal Time Wednesday, November 10, 2004 at 10:58:26 AM = local time at epicenter Time of Earthquake in other Time Zones
Location	11.101°S, 163.664°E
Depth	26.2 km (16.3 miles) set by location program
Region	SOLOMON ISLANDS
Distances	200 km (125 miles) ESE of Kira Kira, San Cristobal, Solomon Isl. 240 km (150 miles) W of Lata, Santa Cruz Islands, Solomon Isl. 445 km (275 miles) ESE of HONIARA, Guadalcanal, Solomon Islands 2130 km (1320 miles) NNE of BRISBANE, Queensland, Australia
Location Uncertainty	horizontal +/- 7.7 km (4.8 miles); depth fixed by location program
Parameters	Nst=140, Nph=140, Dmin=>999 km, Rmss=0.83 sec, Gp=101°, M-type=teleseismic moment magnitude (Mw), Version=7
Source	USGS NEIC (WDCS-D)
Event ID	usqqcg

Location Maps:
10-degree
NEIC Maps

Did you feel it?
Report shaking and damage at your location. You can also view a map displaying accumulated data from your report and others.


NEIC Moment Tensor Solution

Historical Moment Tensor Solutions


Seismic Hazard Map

Historical Seismicity

Theoretical P-Wave Travel Times

Phase Data

News Release

Archive of newsworthy events

Tsunami Information

- West Coast & Alaska Tsunami Warning Center
  - Latest Tsunami Bulletin
- Pacific Tsunami Warning Center
  - Latest Tsunami Bulletin

The earthquake locations and magnitudes cited in these bulletins are very preliminary, and may disagree with the more accuate USGS locations and magnitudes computed using more extensive data sets.

Printer friendly version

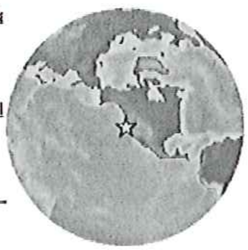
For more information, go to http://neic.usgs.gov/ || Contacts

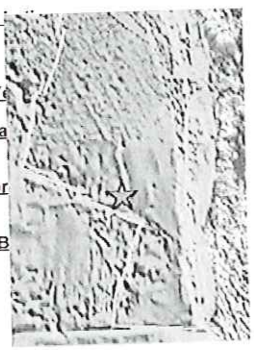
Back to: World map | USA map

The official magnitude for this earthquake is indicated at the top of this page. This was the best available estimate of the earthquake's size, at the time that this page was created. Other magnitudes associated with web pages linked from here are those determined at various times following the earthquake with different types of seismic data. Although, given the data used, they are legitimate estimates of magnitude, they are not considered the official magnitude.

The USGS Earthquake Hazards Program (EHP) of the U.S. Geological Survey (USGS) is part of the National Earthquake Hazards Reduction Program (NEHRP)

USGS
Earthquake Hazards Program





Magnitude 4.2 OFF COAST OF OREGON
Tuesday, November 09, 2004 at 07:23:40 UTC

Preliminary Earthquake Report
U.S. Geological Survey, National Earthquake Information Center
World Data Center for Seismology, Denver

Version en Español

Magnitude	4.2
Date-Time	**Tuesday, November 09, 2004 at 07:23:40 (UTC)** - Coordinated Universal Time Monday, November 08, 2004 at 11:23:40 PM local time at epicenter Time of Earthquake in other Time Zones
Location	43.69N 127.23W
Depth	10.0 kilometers
Region	OFF COAST OF OREGON
Reference	245 km (155 miles) W of **Coos Bay**, Oregon 275 km (170 miles) WSW of **Newport**, Oregon 300 km (190 miles) NW of **Brookings**, Oregon 365 km (225 miles) WSW of **SALEM**, Oregon
Location Quality	Error estimate: horizontal +/- 14.3 km; depth fixed by location program
Location Quality Parameters	Nst=23, Nph=23, Dmin=330.0 km, Rmss=0.79 sec, Erho=14.3 km, Erzz=0 km, Gp=210.3 degrees
Source	USGS NEIC (WDCS-D)

Location Maps

Did You Feel It?
Report shaking and damage at your location.

Historical Seismicity

Theoretical P-Wave Travel Times

Historical Moment Tensor Solutions

Phase (Arrival Time) Data

Seismic Hazard Map

Earthquakes: Frequently Asked Questions

Printer Friendly Version

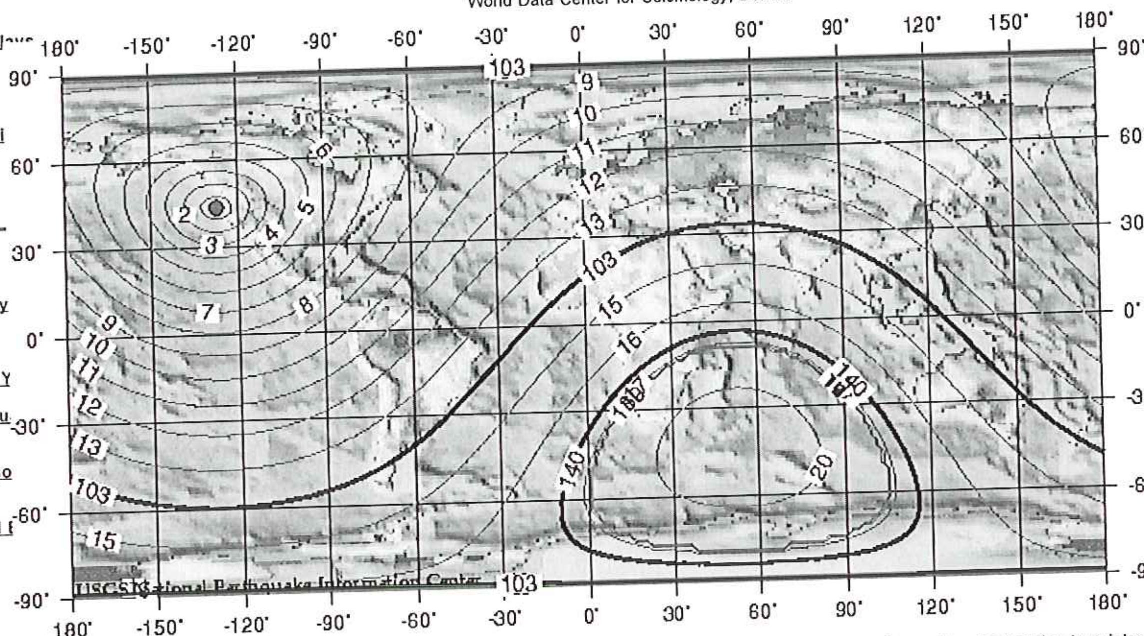
NB: The official magnitude for this earthquake is indicated at the top of this page. This was the best available estimate of the earthquake's size, at the time that this page was created. Other magnitudes associated with web pages linked from here are those determined at various times following the earthquake with different types of seismic data. Although, given the data used, they are legitimate estimates of magnitude they are not considered the official magnitude.

The region name is an automatically generated name from the Flinn-Engdahl (F-E) seismic and geographical regionalization scheme. The boundaries of these regions are defined at one-degree intervals and therefore differ from irregular political boundaries. More->

USGS
Earthquake Hazards Program

Magnitude 4.2 OFF COAST OF OREGON
Tuesday, November 09, 2004 at 07:23:40 UTC

Preliminary Earthquake Report
U.S. Geological Survey, National Earthquake Information Center
World Data Center for Seismology, Denver



This map shows the predicted (theoretical) travel times, in minutes, of the compressional (P) wave from the earthquake location to points around the globe. The travel times are computed using the spherically-symmetric IASP91 reference earth velocity model. The heavy black lines shown are the approximate distances to the P-wave shadow zone (103 to 140 degrees).

USGS
Earthquake Hazards Program

est Quakes

HOME | ABOUT US | EQ GLOSSARY | FOR TEACHERS | PRODUCTS & SERVICES | DID YOU FEEL IT? | FAQ | SEARCH

Earthquake Activity

Current Earthquakes

- USA
- World

NEIC Current Earthquake Information

ShakeMaps

Seismogram Displays

Past & Historical Earthquakes

Earthquake Notification E-mail

Earthquake Lists

- M > 1.0
- M > 3.0

Regional Websites and Other Eq Maps

- Alaska
- California/Nevada
- Central & Southeast
- Hawaii
- Guam
- Northeast
- Northwest
- Puerto Rico
- Utah & Yellowstone

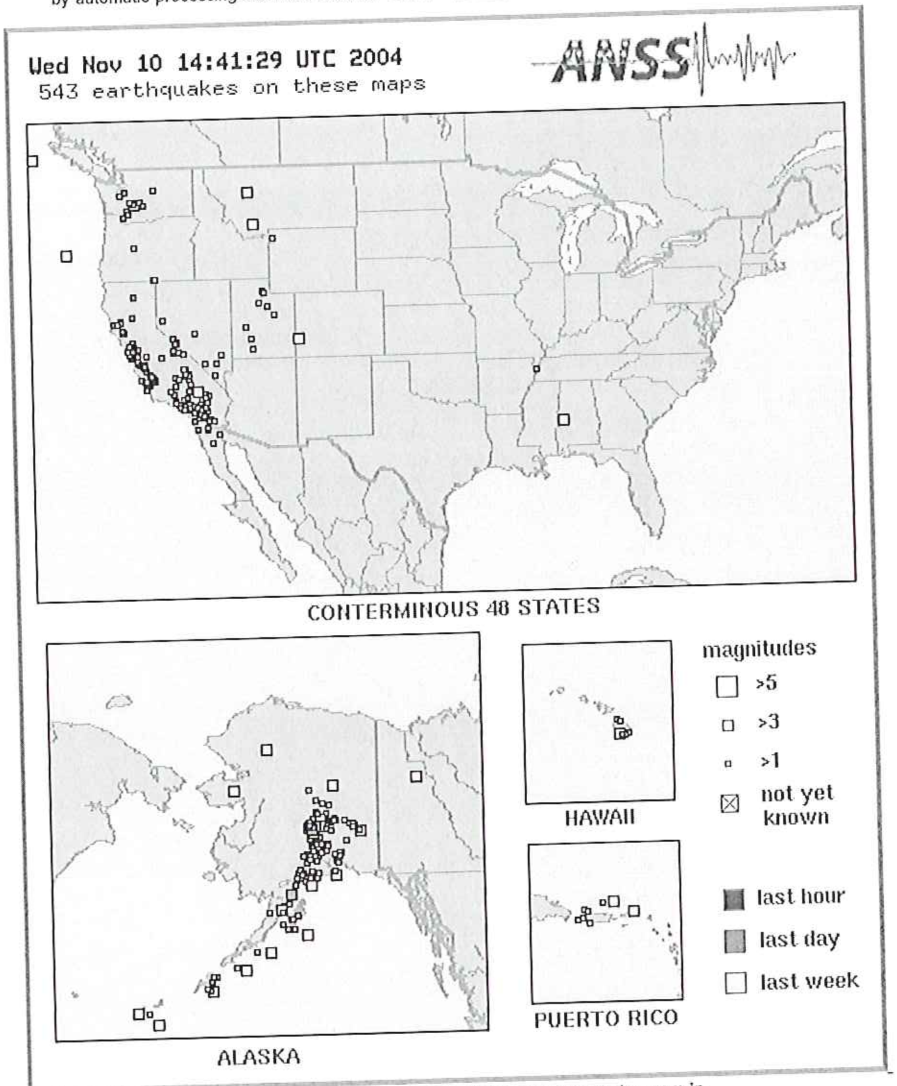
Data Sources

FAQ about these maps

Network Contacts

Recent Earthquake Activity in the USA

NOTE: - These maps do not currently show Mount St. Helens events. The events are occurring so frequently that they cannot be accurately located by automatic processing software. See, for example, PNSN Webicorder displays for 9/24 and 10/1.



Click on an earthquake on one of the above maps to zoom in.
Click here or on UTC date-time above maps for list of local times.

M>3 earthquake list (with map) || M>1 earthquake list (with map)

Did you feel it? - Report an Earthquake || View ShakeMaps

To convert UTC to local time see this list or this table.
Maps show events with M >= 1.0 recorded in the last 7 days.
Try to reload this page if you do not have the most current map.
Maps are updated whenever a new earthquake has been located and once an hour.
Magnitude = ? for new earthquakes until a magnitude is determined (4-5 minutes).

FAQ about Earthquakes | Earthquake Preparedness

The USGS Earthquake Hazards Program (EHP) of the U.S. Geological Survey (USGS) is part of the National Earthquake Hazards Reduction Program (NEHRP) led by the Federal Emergency Management Agency (FEMA).

Latest Quake Info

Real-time Earthquake Maps
- **California - Nevada**
- United States
- World

Real-time Shaking Maps

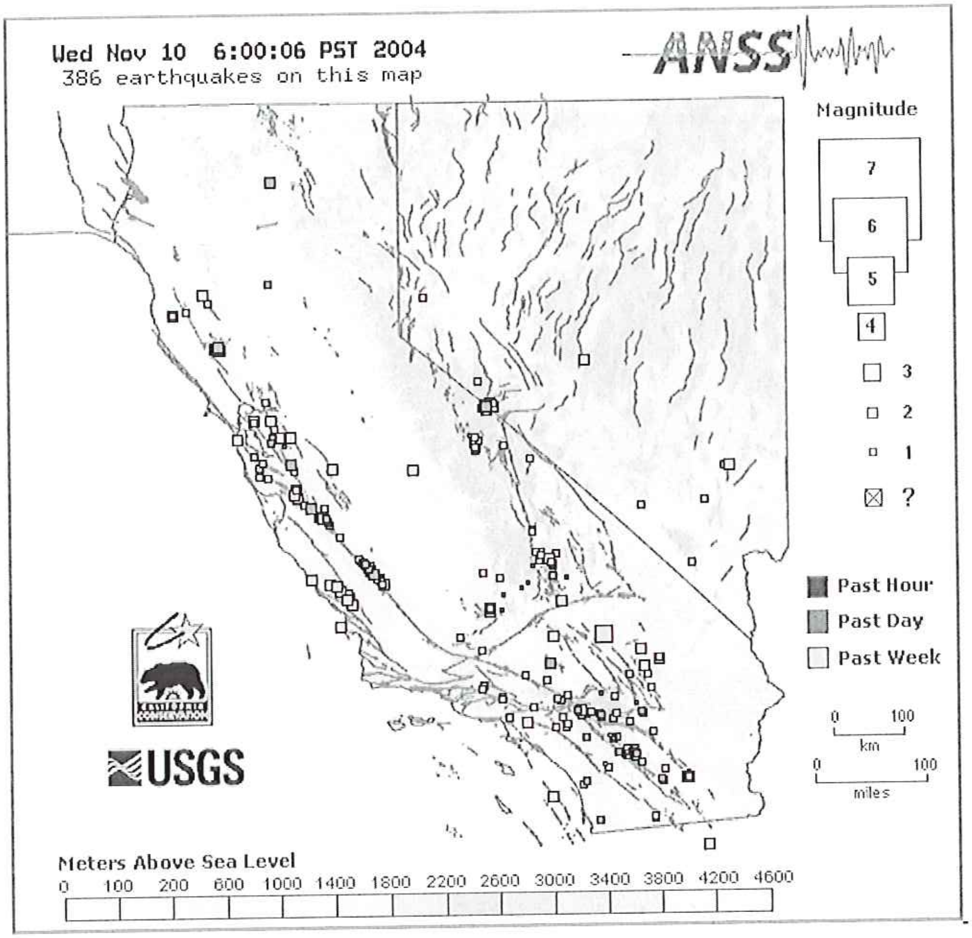
Real-time Seismogram Displays

Earthquake Network Reports and Updates

Recent and Significant Past Earthquakes

USGS Earthquake News Releases

Maps of Recent Earthquake Activity in California-Nevada



Instructions
- **Click on the map to zoom in.**
- Maps are updated within 5 minutes of an earthquake and once an hour. Try to **reload this page** if you do not have the most current map.

Options and other maps
- List of earthquakes on this map
- List of earthquakes PLUS map
- Alphabetical index of CA-NV faults
- Map showing recency of fault movement in CA
- Faster loading map without topography and fault names
- Remove earthquakes from this map

Information
- Red lines are known faults.
- Magnitude = ? for new earthquakes until a magnitude is determined (takes 4-5 minutes).
- About Real-time Earthquake Maps
  Frequently Asked Questions, Data Sources, Credits and Disclaimer, Glossary, Other Sites that Host these Maps.

Did you feel it?
Report an Earthquake

ShakeMaps
Southern CA || Northern CA

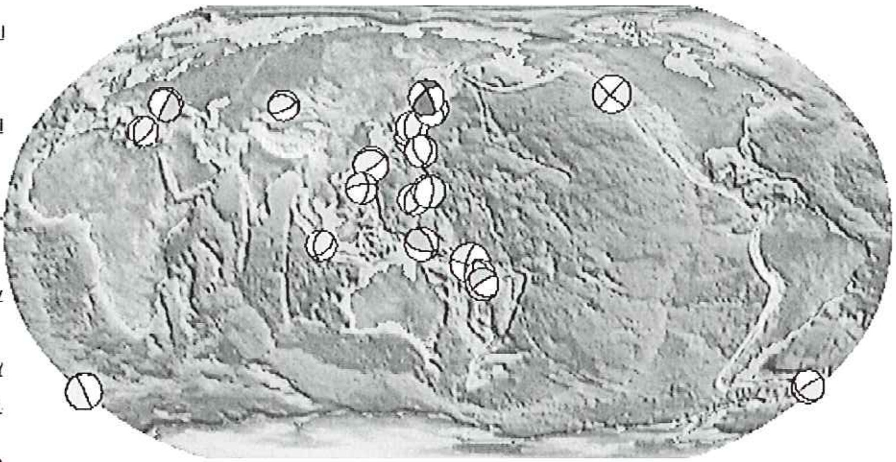
U.S. Geological Survey, Earthquake Hazards Program
URL http://quake.wr.usgs.gov/recenteqs/latestfault.htm
Contact:webmaster@ehznorth.wr.usgs.gov
Last modification: 19 October 2004

USGS
Earthquake Hazards Program

Current USGS Fast Moment Tensor Solutions

Current Earthquake 04/11/02 10:02:13.16 VANCOUVER ISLAND, CANADA REGION MW 6.'

USGS Fast Moment Tensor Solutions



- 04/11/09 23:58:23.70 SOLOMON ISLANDS MW 6.9
- 04/11/09 22:14:37.27 STATE OF YAP, MICRONESIA MW 5.5
- 04/11/08 15:55:03.54 TAIWAN REGION MW 6.2
- 04/11/08 15:07:25.10 IZU ISLANDS, JAPAN REGION MW 5.5
- 04/11/08 02:15:59.03 NEAR WEST COAST OF HONSHU, JAPANMW 5.5
- 04/11/07 02:41:41.11 SOUTH SANDWICH ISLANDS REGION MW 5.8
- 04/11/07 02:02:26.35 SEA OF OKHOTSK MW 6.2
- 04/11/05 17:31:33.21 VANUATU MW 5.7
- 04/11/05 05:18:34.64 NEW GUINEA, PAPUA NEW GUINEA MW 6.0
- 04/11/04 14:03:11.60 KURIL ISLANDS MW 5.9
- 04/11/04 06:22:39.11 CRETE, GREECE MW 5.3
- 04/11/03 08:31:49.50 ROTA REGION, N. MARIANA ISLANDS MW 5.9
- 04/11/02 10:02:13.16 VANCOUVER ISLAND, CANADA REGION MW 6.7
- 04/11/02 08:46:00.66 BONIN ISLANDS, JAPAN REGION MW 5.7
- 04/10/30 13:26:55.57 VANUATU MW 5.6
- 04/10/29 19:28:59.38 LUZON, PHILIPPINES MW 5.5
- 04/10/28 08:32:06.74 SOUTHERN SUMATRA, INDONESIA MW 5.4
- 04/10/27 20:34:36.96 ROMANIA MW 5.9
- 04/10/27 09:23:38.89 KAZAKHSTAN-XINJIANG BORDER REG. MW 5.3
- 04/10/26 22:53:07.86 SOUTH SANDWICH ISLANDS REGION MW 6.4

Source Parameter Search

Previous Fast Moment Tensor Solutions

NEIC E-MAIL Notification Services

Description of Fast Moment Process

For more information, contact Stuart Sipkin sipkin@usgs.gov

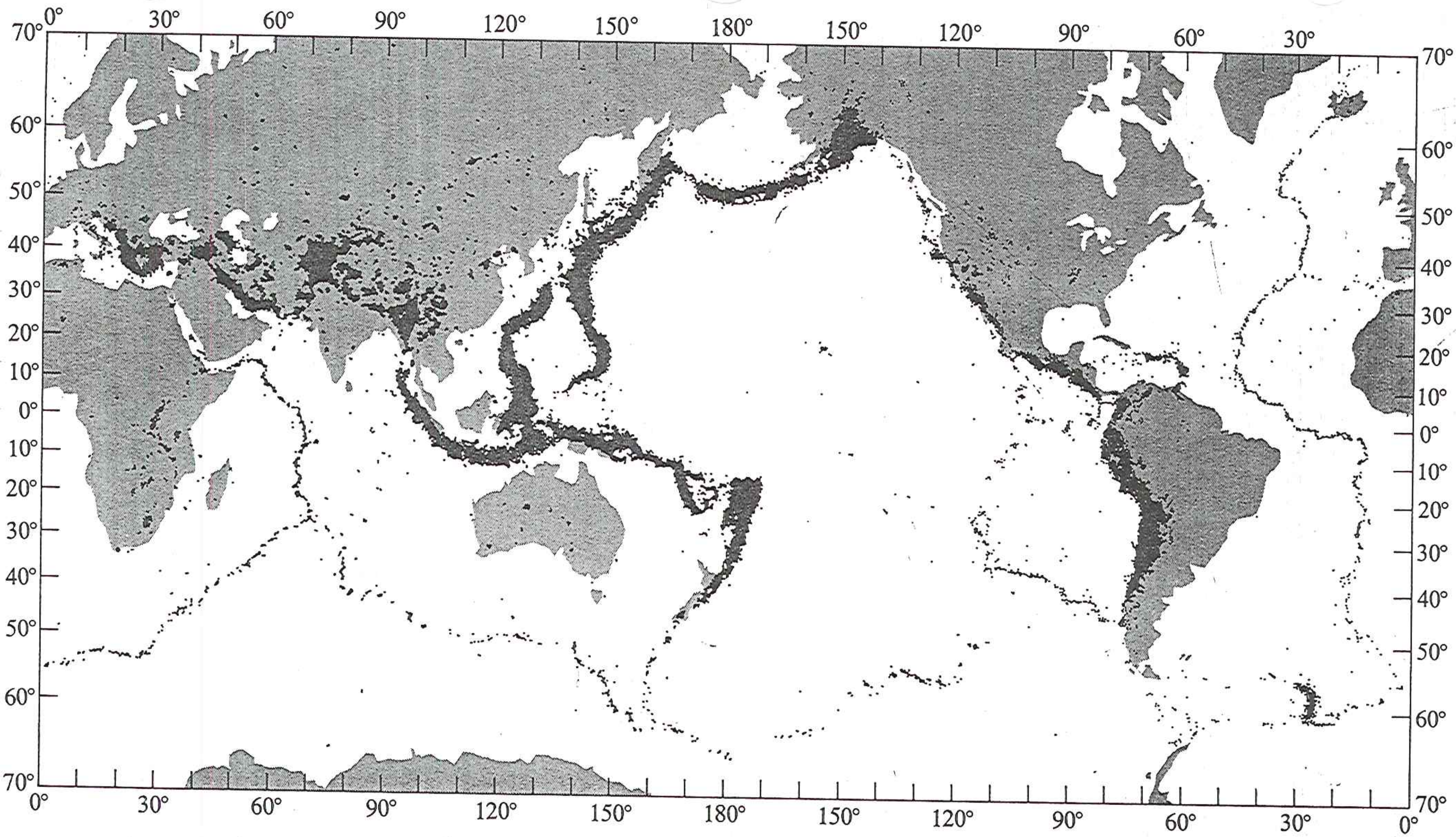
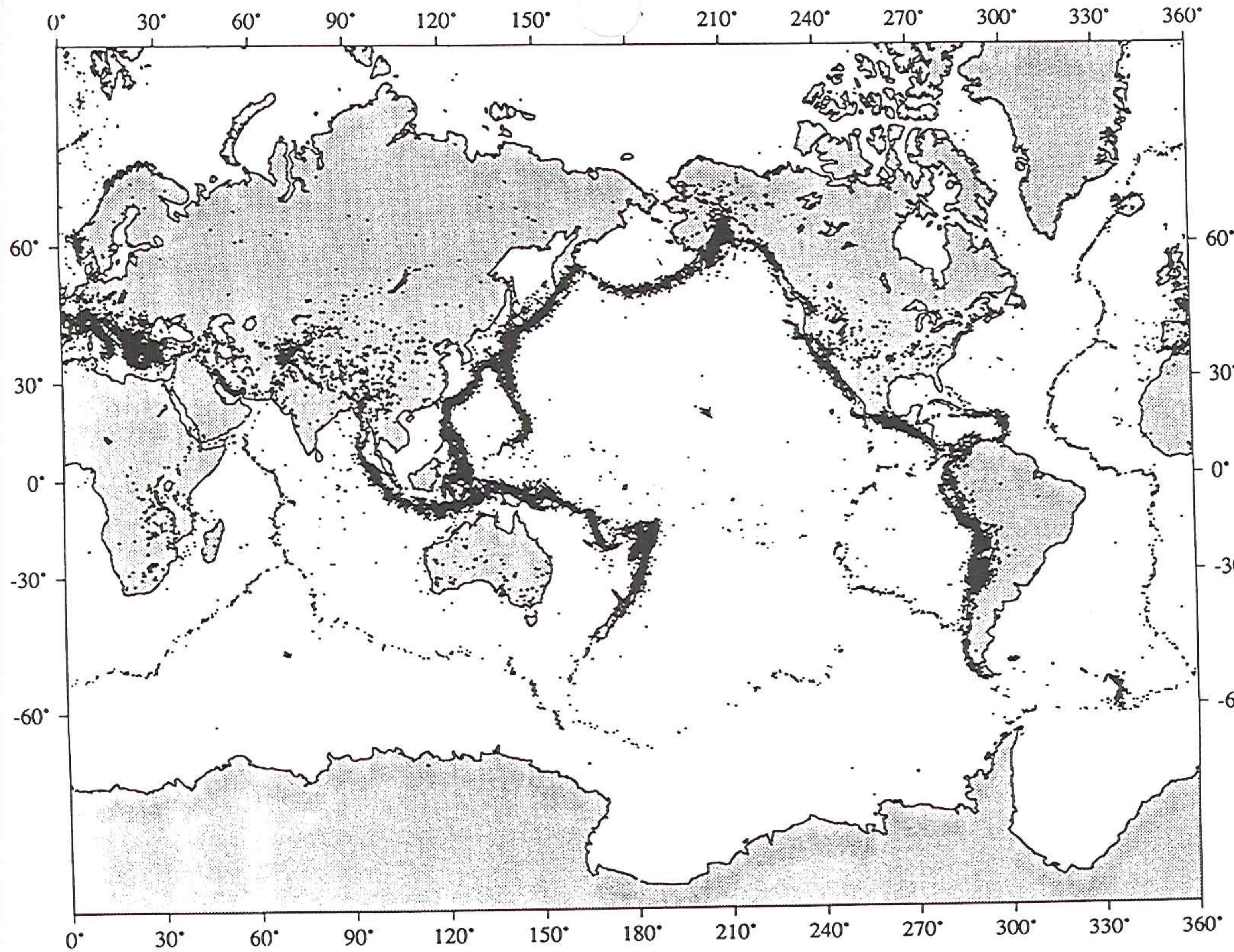


Figure 3.1 Epicenters for earthquakes of magnitude greater than 4.5, in the period 1963–1977. [Map computer plotted by Peter W. Sloss of NGSDC.]


0°
30°
60°
90°
120°
150°
180°
210°
240°
270°
300°
330°
360°
60°
30°
0°
-30°
-60°

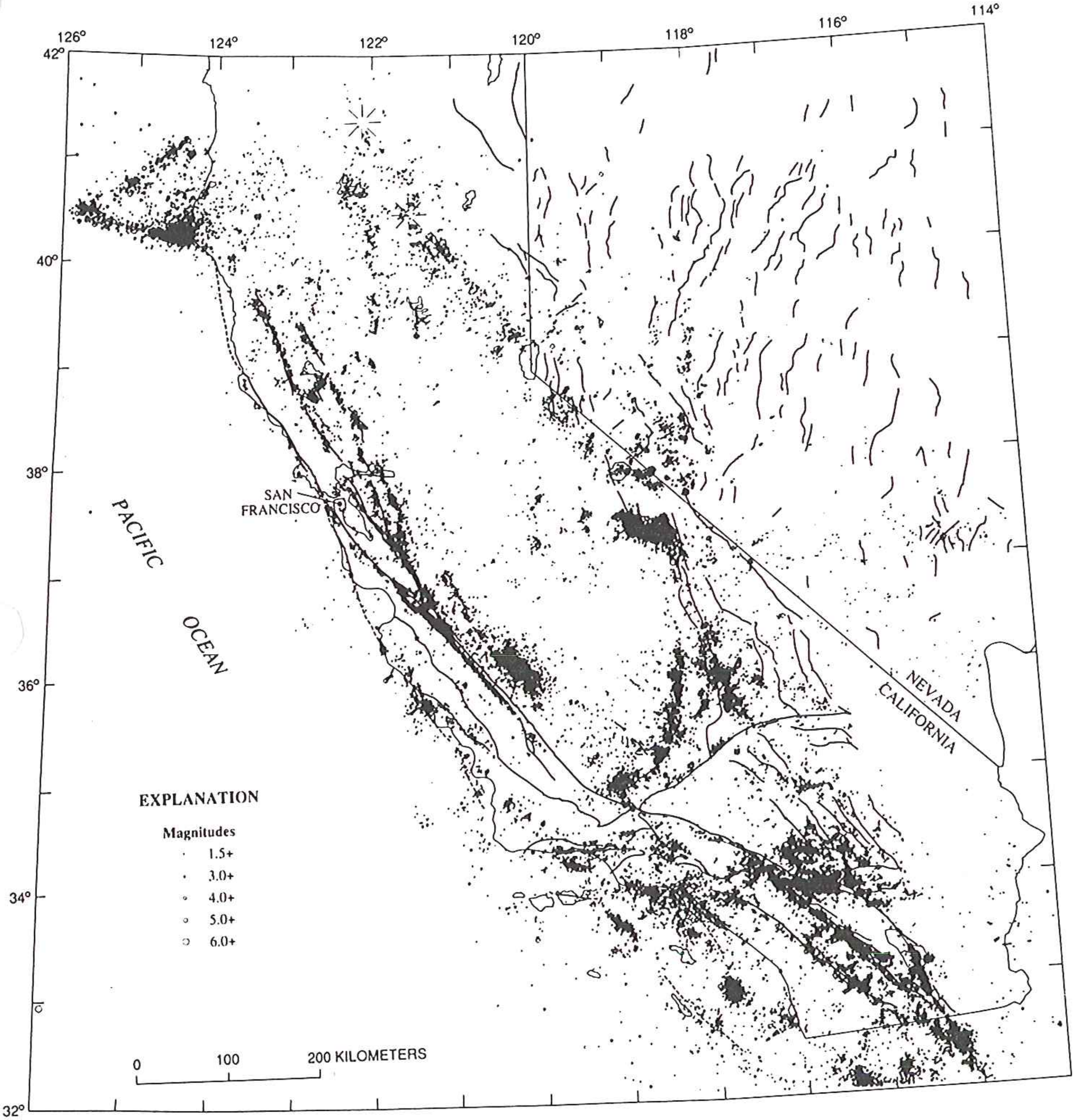


Figure 2.7 Earthquake epicenters in central California for magnitudes greater than 1.5 from 1972 through 1983. [Courtesy of USGS.]

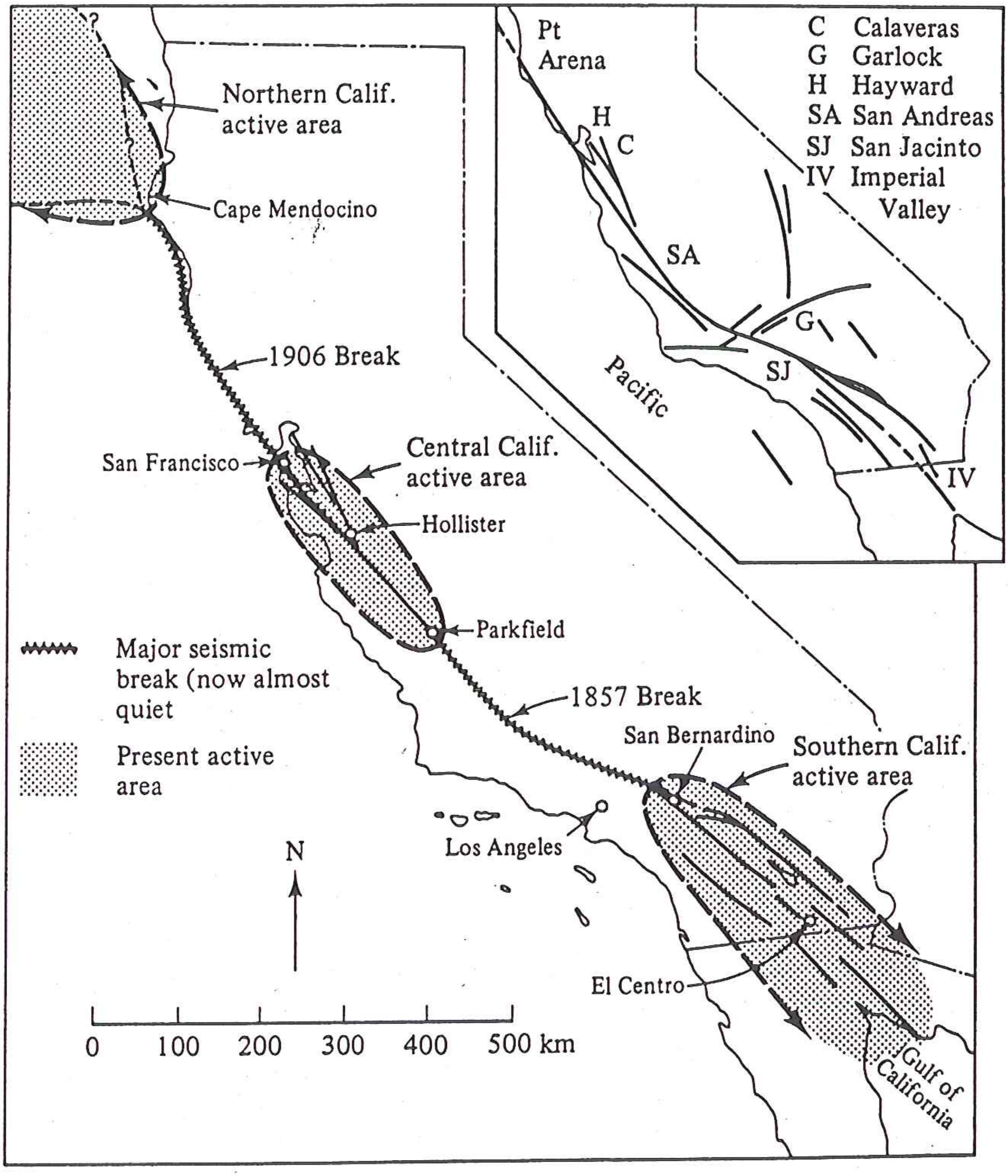


Fig. 7.1. Areas of contrasting seismic behaviour along the San Andreas fault zone in California. (After Allen, 1968.)

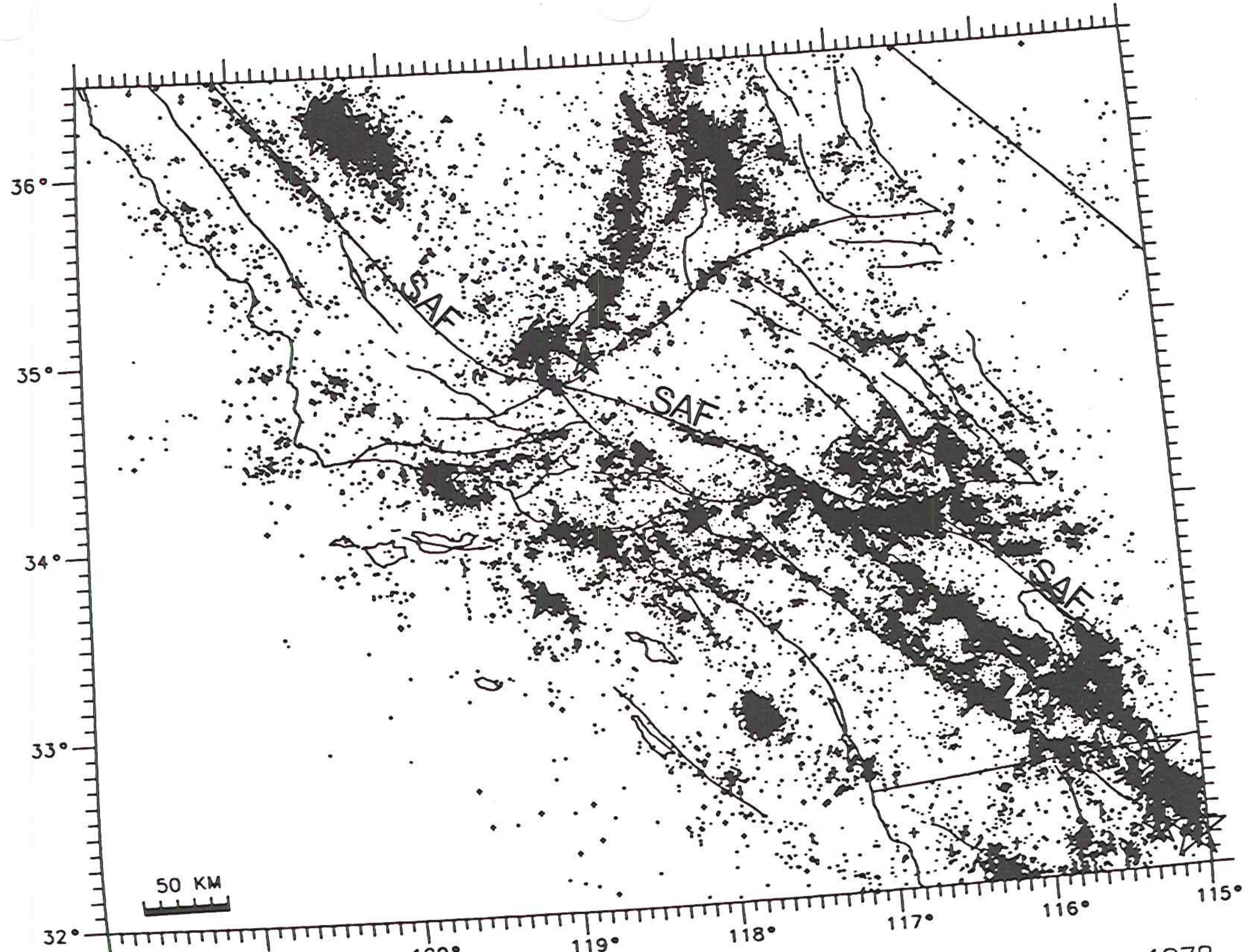


FIGURE 1.12 A map of earthquake locations in Southern California for the years 1978–1988. Most of the events are very small, and a dense network of seismometers is deployed in the region to locate all of the earthquakes accurately. The traces of known active faults observed at the surface are superimposed for comparison (as well as the borders of California), with the San Andreas fault labeled SAF. (Courtesy of Tom Heaton.)

Point Reyes — lab exercise

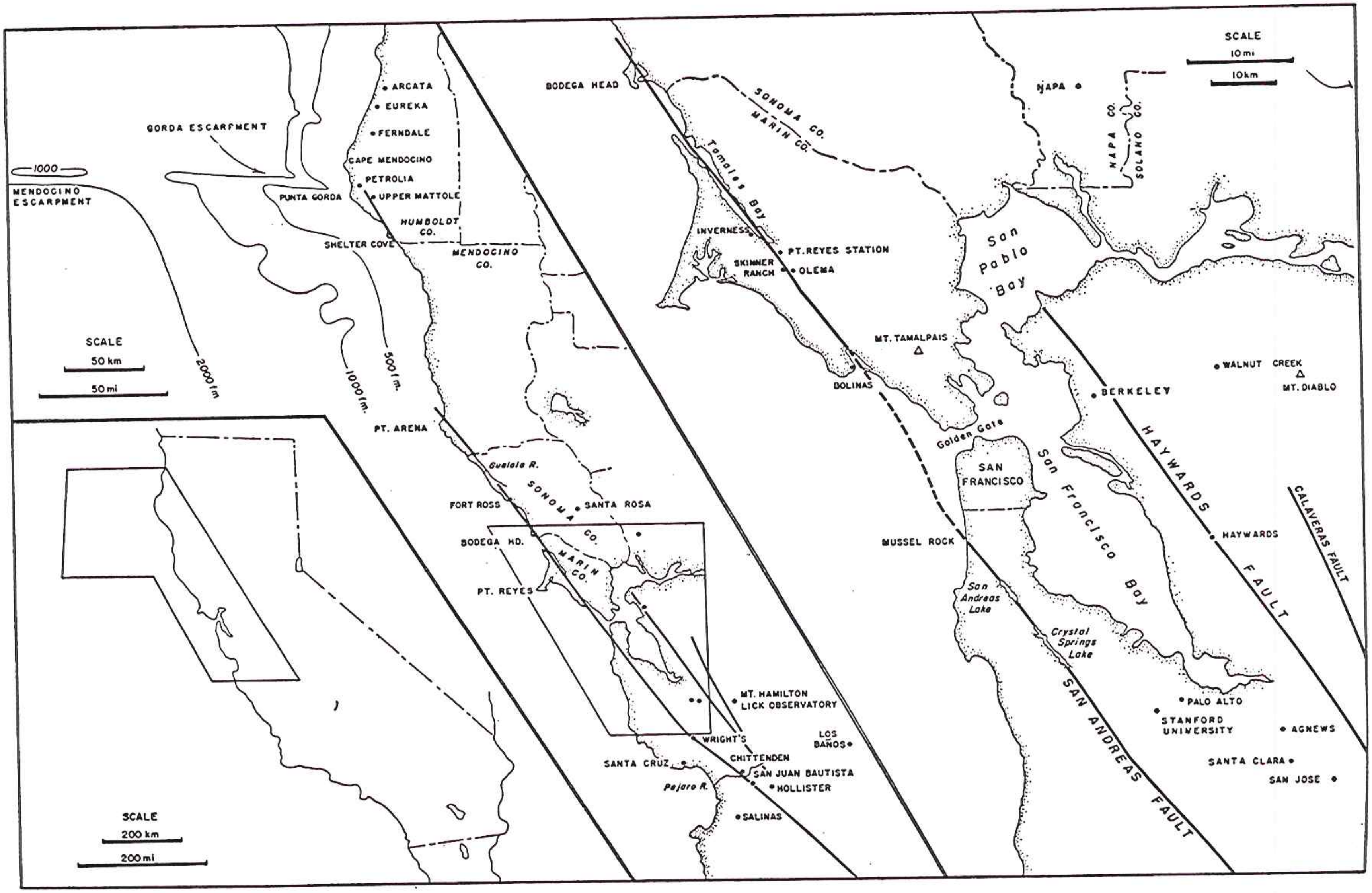
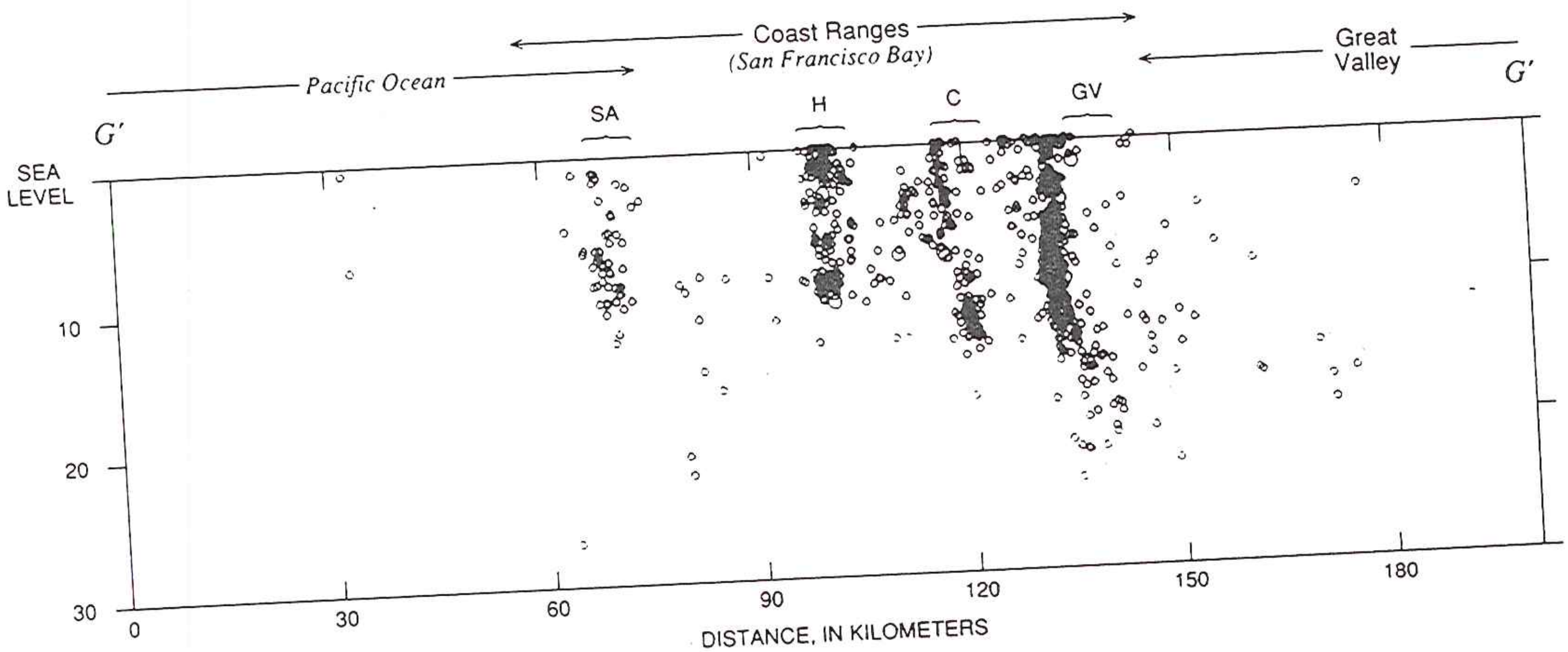


FIGURE 28-5 *Earthquake of 1906, location map.*

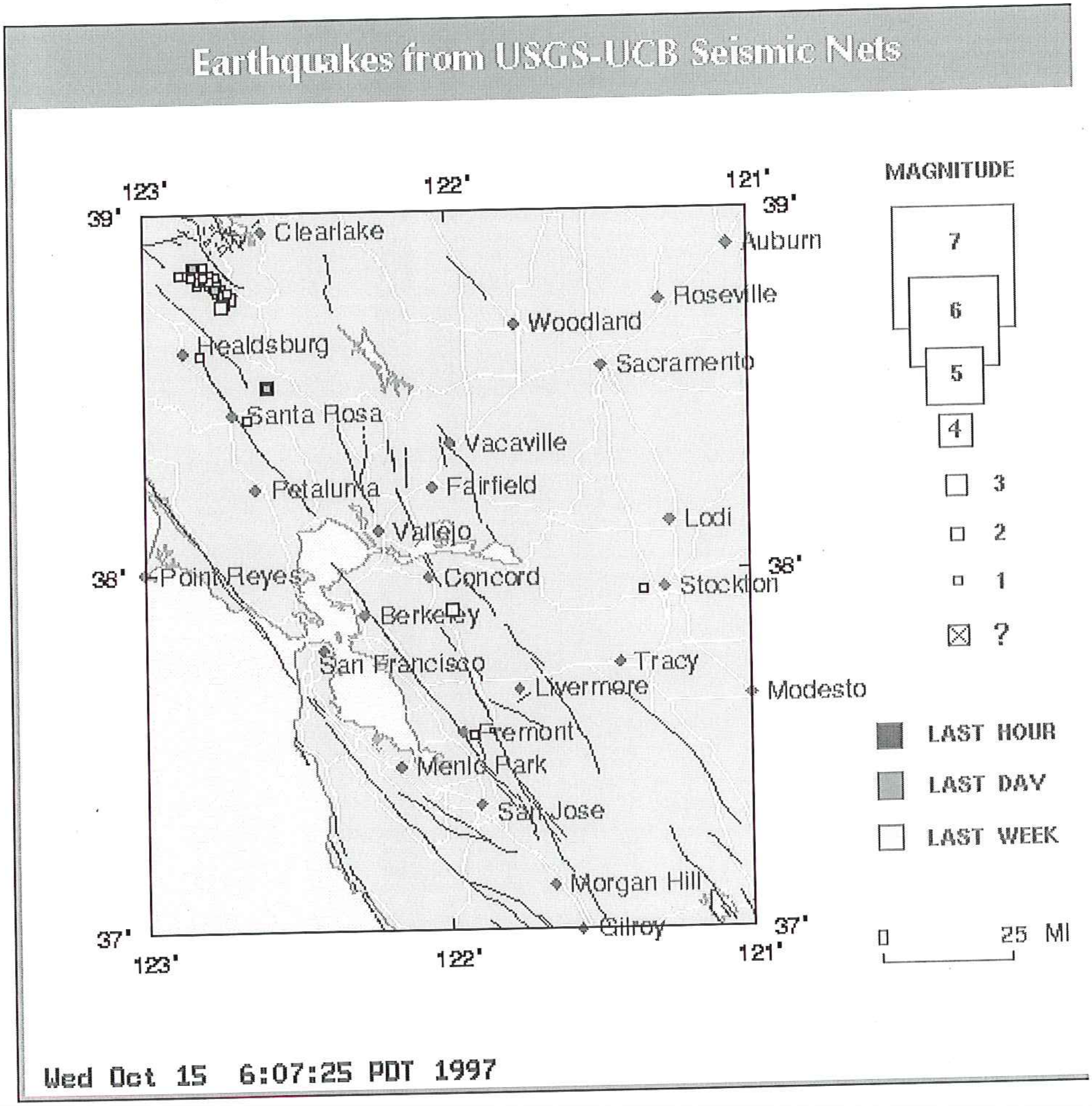


A transverse depth section across the San Andreas Fault in the California Coast Range. The distribution of small earthquakes clearly delineates the several active strike-slip faults that define the Pacific-North American plate boundary. The abrupt termination of the seismogenic zone shows a pronounced discontinuity in the mechanical behavior from brittle to ductile. SA: San Andreas Fault; H: Hayward Fault; C: Calaveras Fault; GV: Greenville Fault. *From D. Hill, J. Eaton, and L. Jones (1990), The San Andreas Fault System, USGS Professional Paper 1515, R.E. Wallace, Editor, pp. 115–152.*

http://quake.wr.usgs.gov

Recent Earthquakes in California and Nevada

San Francisco Special Map

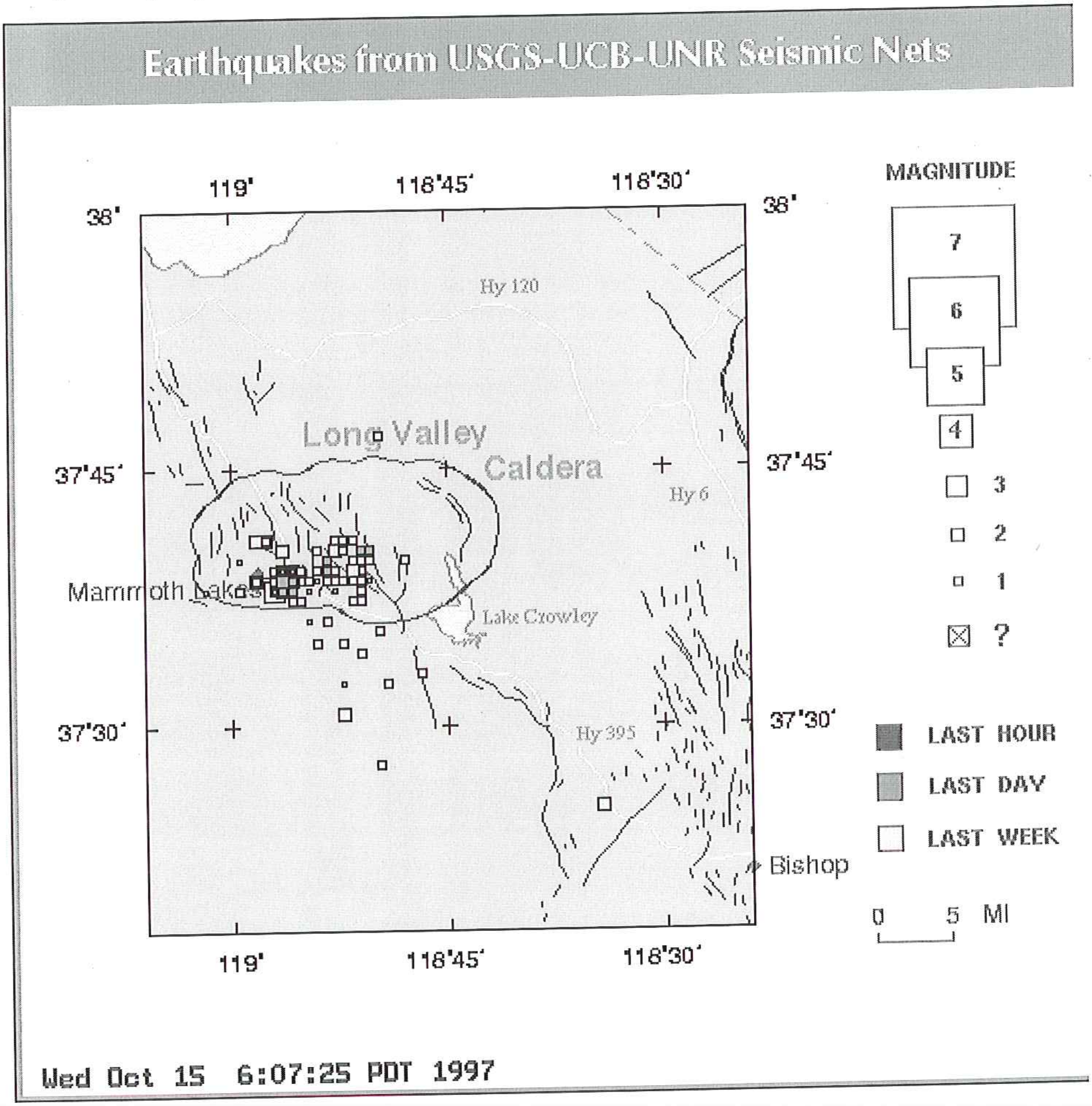


- Click on an earthquake on the above map for more information...
- Click here to go to index map || big earthquake list || all earthquakes list
- Special maps: Long Valley || Los Angeles || San Francisco

http://quake.wr.usgs.gov

Recent Earthquakes in California and Nevada

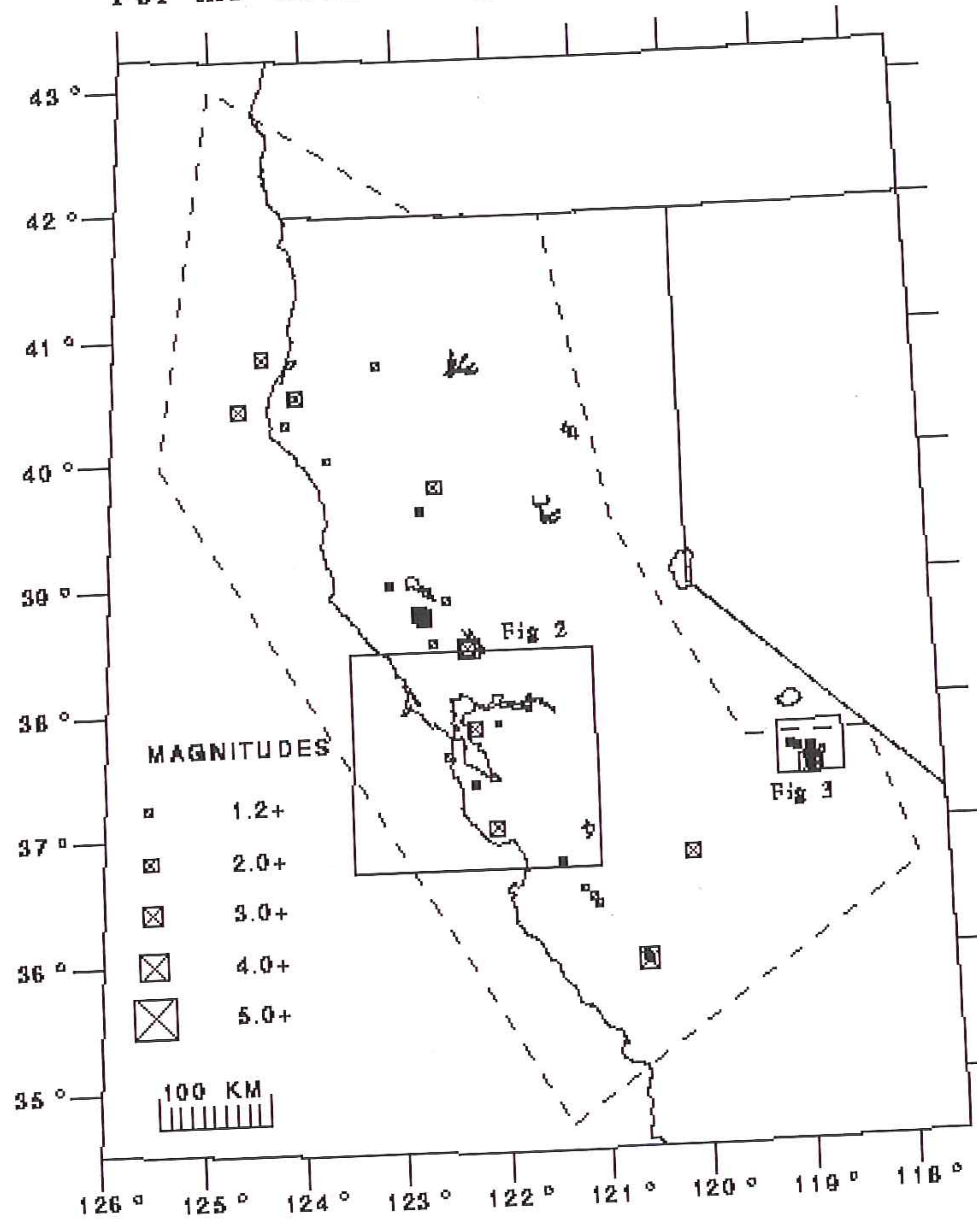
Long Valley Special Map



- Click on an earthquake on the above map for more information...
- Click here to go to index map || big earthquake list || all earthquakes list
- Special maps: Long Valley || Los Angeles || San Francisco

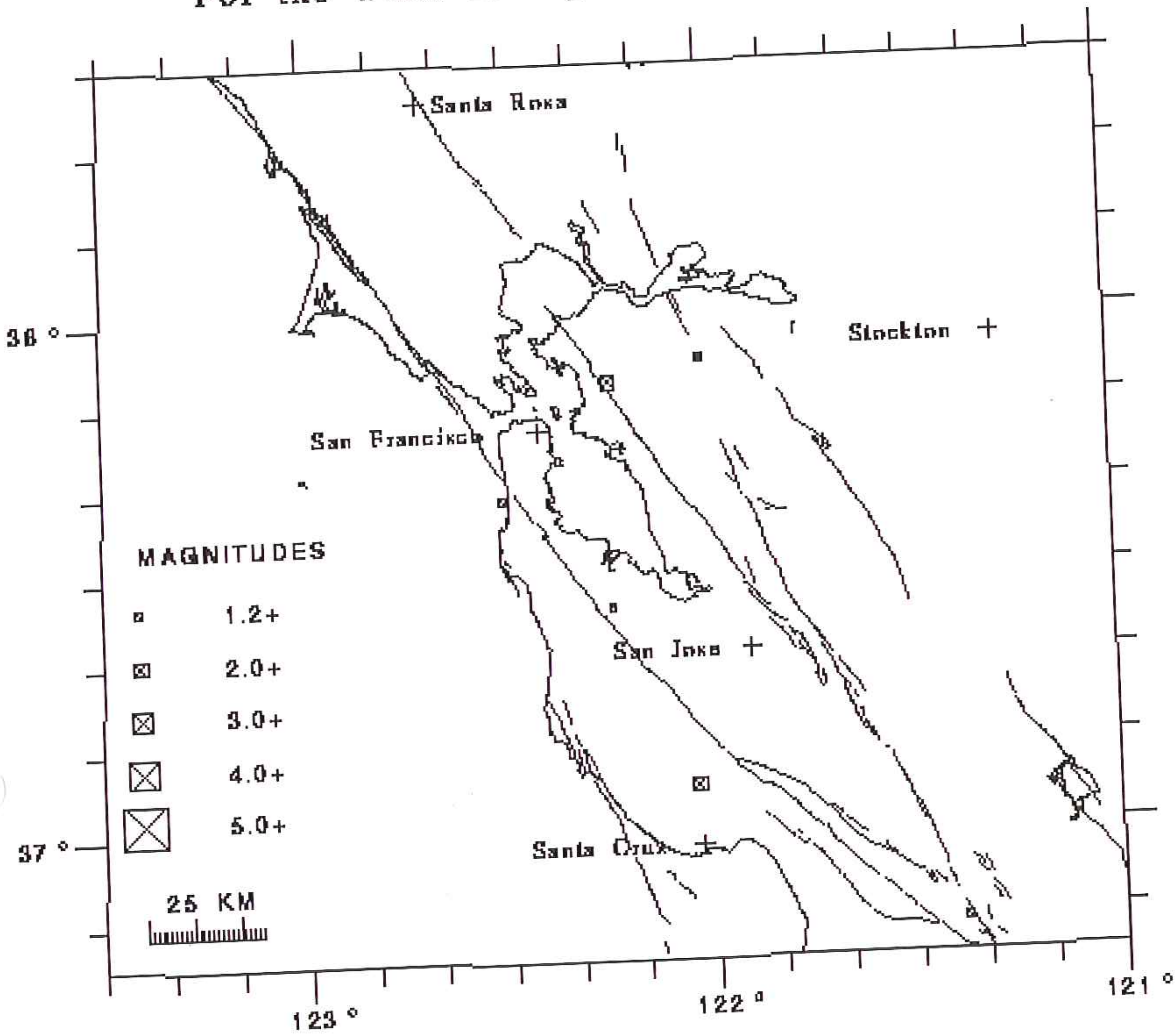
http://quake.wr.usgs.gov

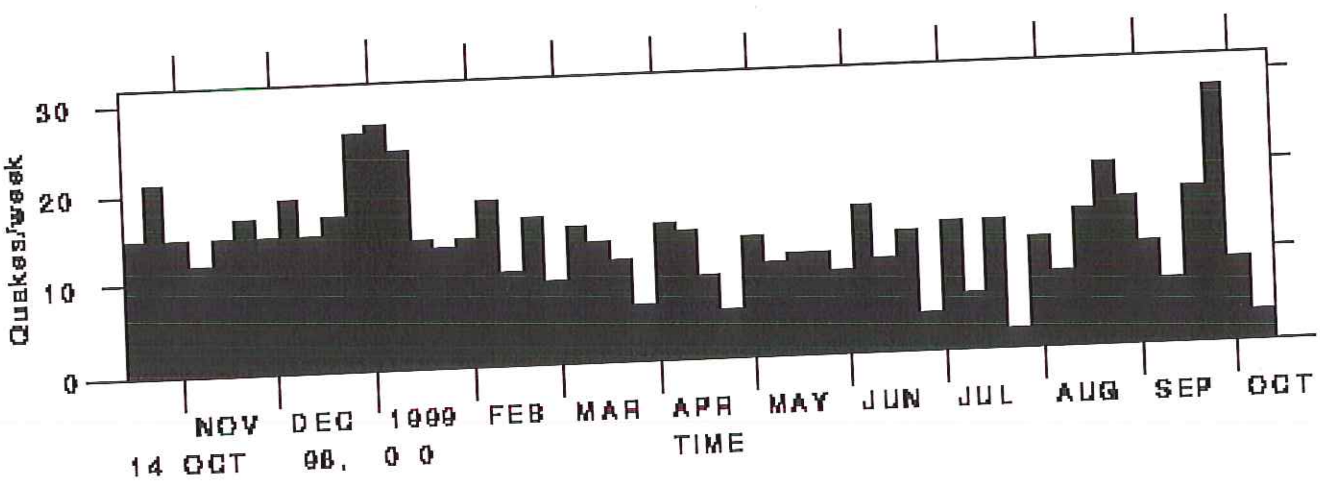
For the week ending Oct 14, 1999



6 quakes M = 1-2

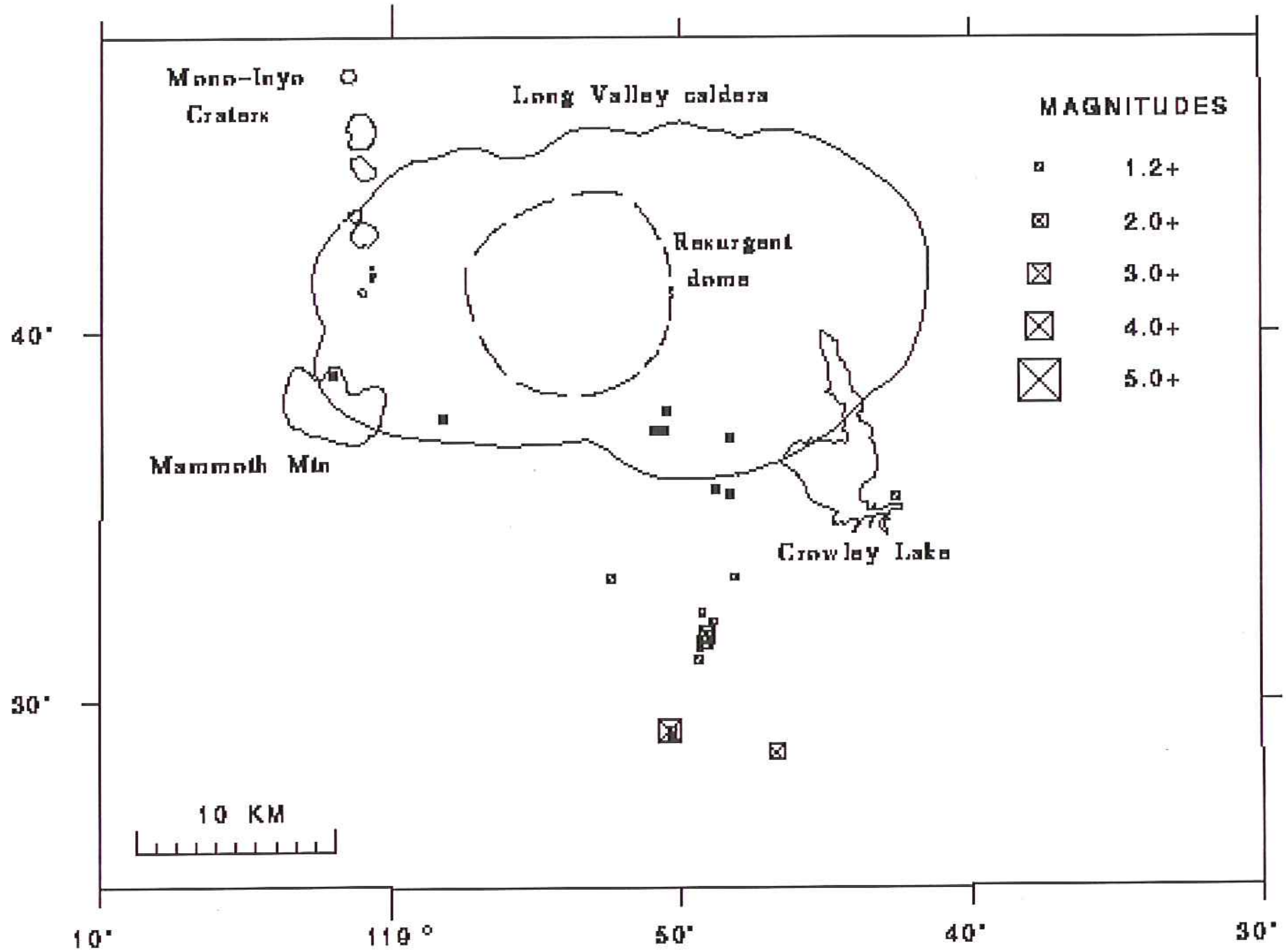
For the week ending Oct 14, 1999

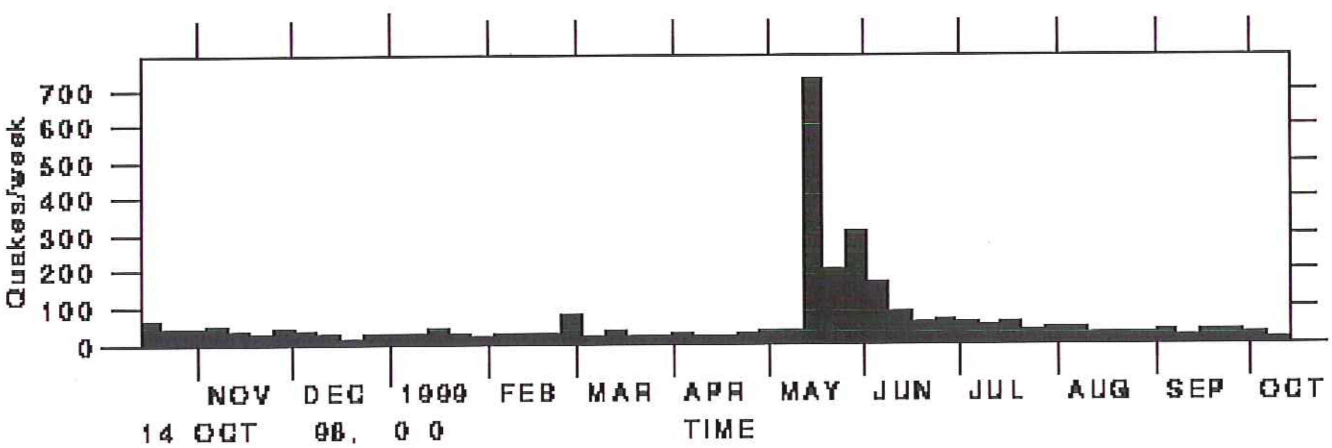




22 quakes

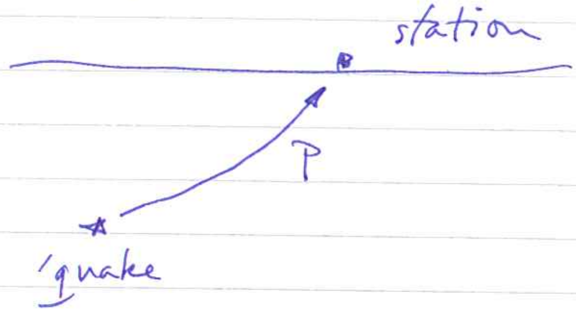
For the week ending Oct 14, 1999





Many 'quakes are located today using only P waves recorded at as many stations as possible.

Regional networks (such as that in California) can be right on top of quakes — measure h directly.



About 90% of 'quakes are shallow ($h \leq 50-100$ km) and occur along plate boundaries; in fact this was one of first important pieces of evidence in favor of plate tectonics in early 1960's.

Many plate boundaries, particularly in continental regions, are complicated in detail, with more than one fault, e.g. Hayward, Calaveras, etc. in N. California.

There are also intraplate events in the US

(1) Nevada seismic belt
(2) Wasatch belt in Utah

There are far fewer quakes in the eastern US.
But by making use of historical accounts in newspapers as well as seismic data we have been able to determine the distribution.

Most active area in Eastern US is along ~~Mississippi~~ Mississippi River between St. Louis & Memphis — site of New Madrid quakes (3 events M > 8) in 1811 and 1812.

These events caused a major change in course of Mississippi and formed Reelfoot Lake (30 km long, 10 km wide, 2 – 4 m deep) in Tennessee by subsidence.

Felt as far away as NYC — rang church bells in Boston

Another large historic quake is 1886 Charleston, S.C. — possibly largest in historical record in the US.

Also a linear belt of quakes in southern Quebec and northern NYC.
These get up occasionally to M = 5 — strong enough to be felt (barely) in Princeton.

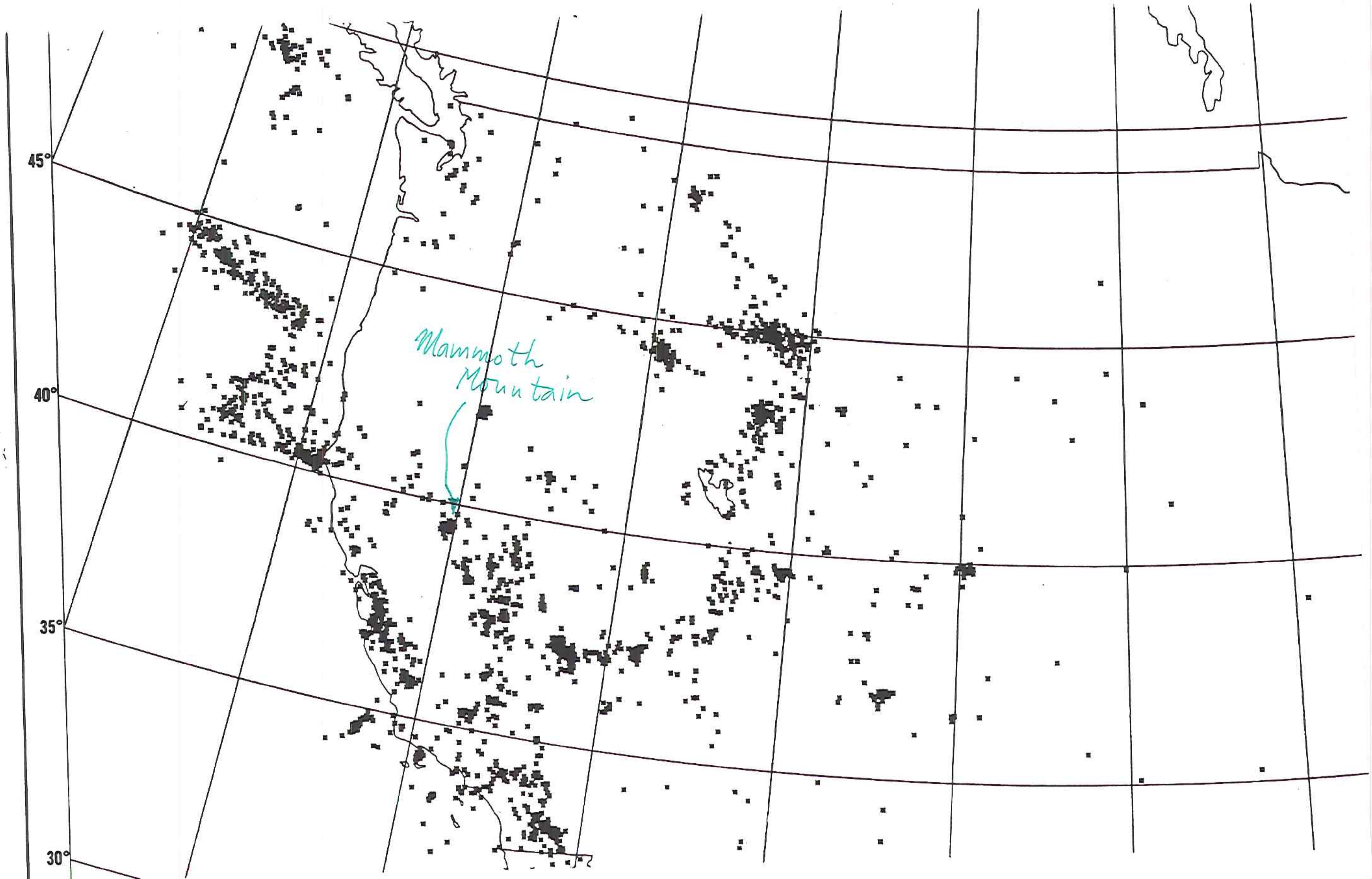

45°
40°
35°
30°
Mammoth Mountain

Figure 9–11. Topography of the Basin and Range Province, western United States, part of a shaded-relief image prepared by Thelin and Pike (1991) by digitizing elevation values at intervals of 805 m and illuminating the resulting digital elevation model from the west-northwest, 25° above the horizon. North is approximately toward the top of page. Vertical exaggeration 2×. Black area at upper right is Great Salt Lake; flat area farther north is Snake River Plain (cf. Fig. 9–12). Basin and Range Province extends from Wasatch fault, east of Great Salt Lake, to eastern front of Sierra Nevada (lower left corner). Albers Equal-Area Conic Projection.

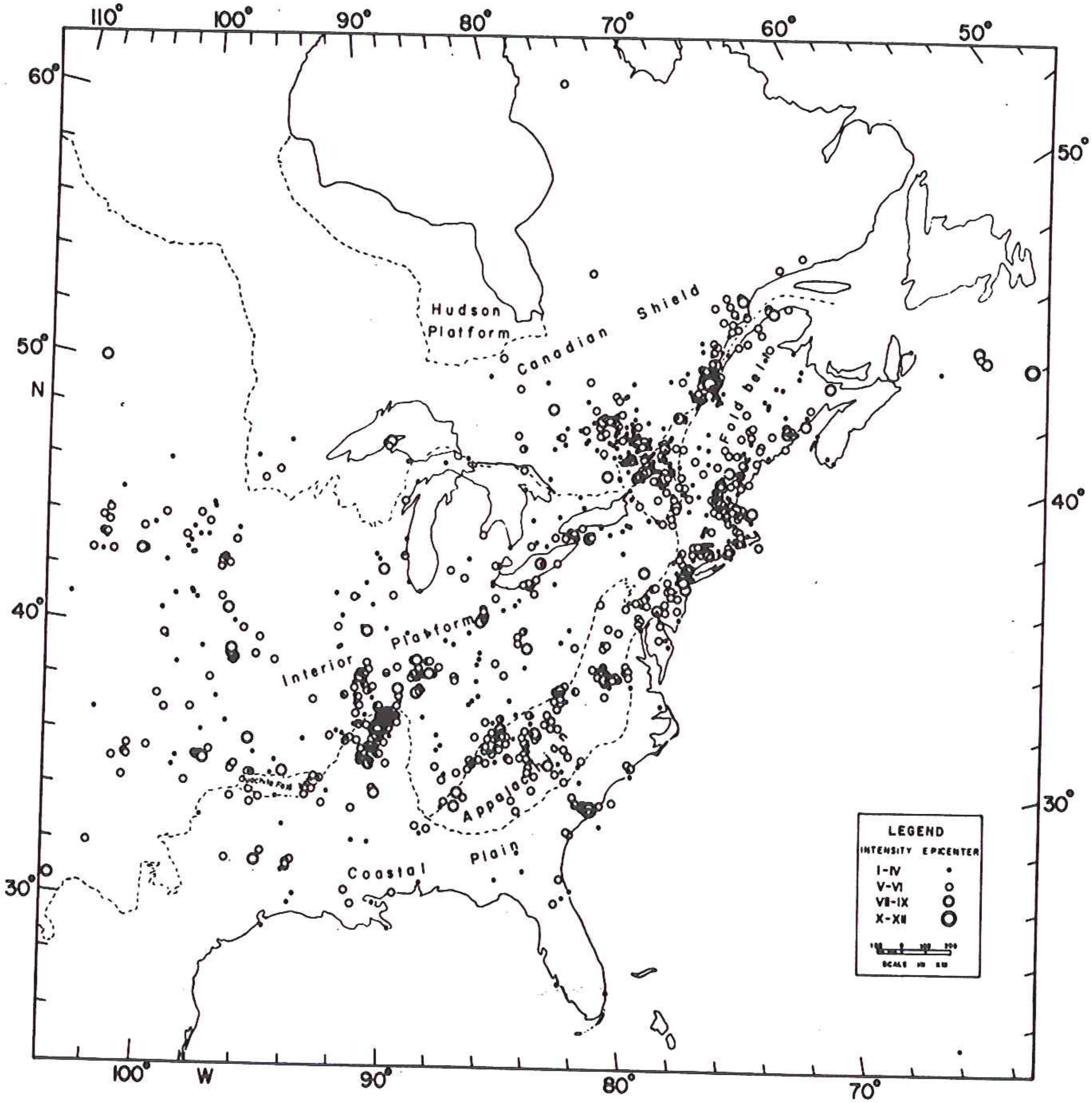


Fig. 14. Distribution of reported earthquakes in eastern North America, 1534–1971, from historical and instrumental data [after *York and Oliver,* 1976]. Note activity along the Appalachian fold belt, the northwest trending zone in New England and southern Quebec, and the northwesterly trend in South Carolina.

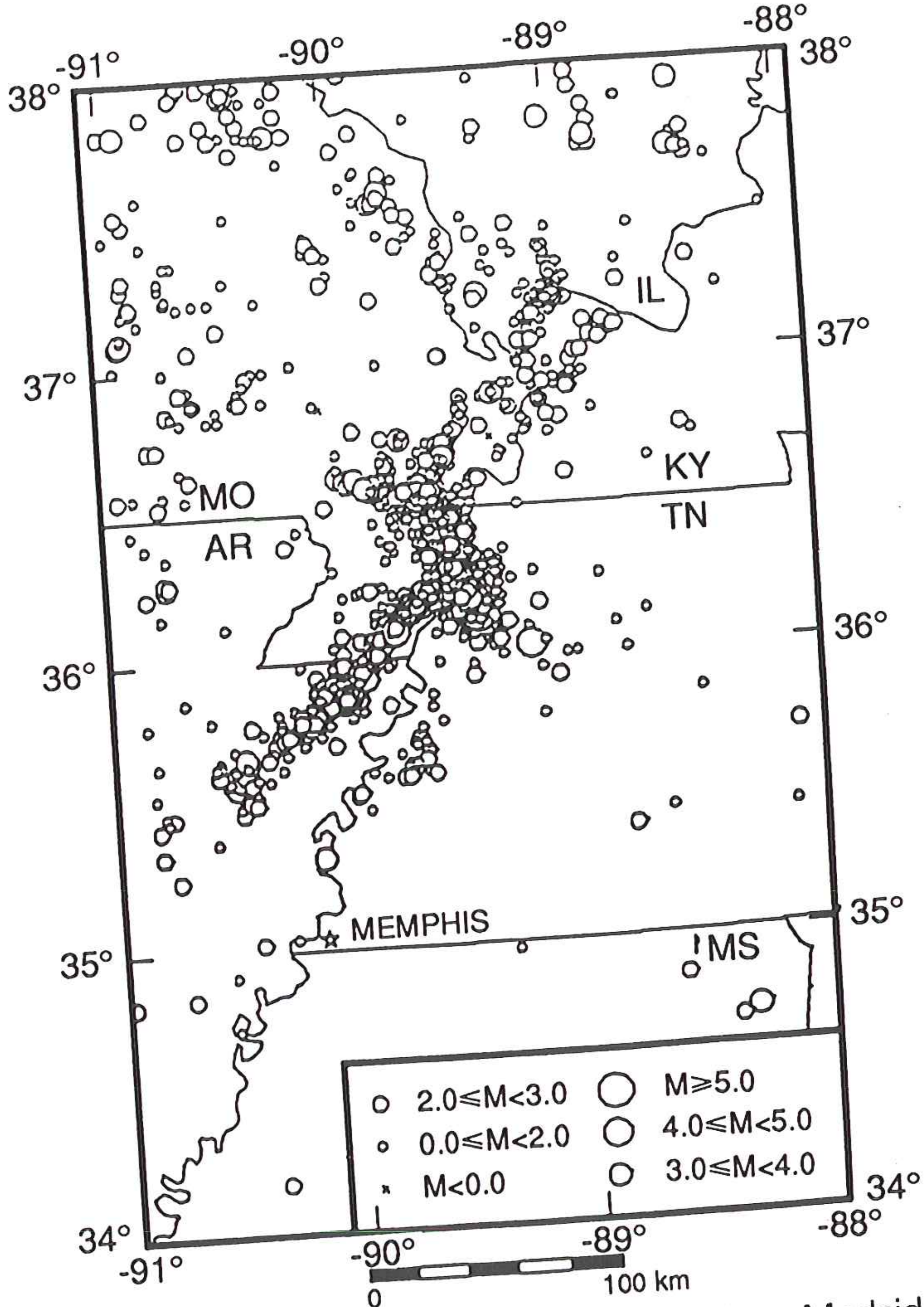


FIGURE 11.42 Seismicity in the New Madrid seismic zone. (Courtesy of R. Herrmann.)

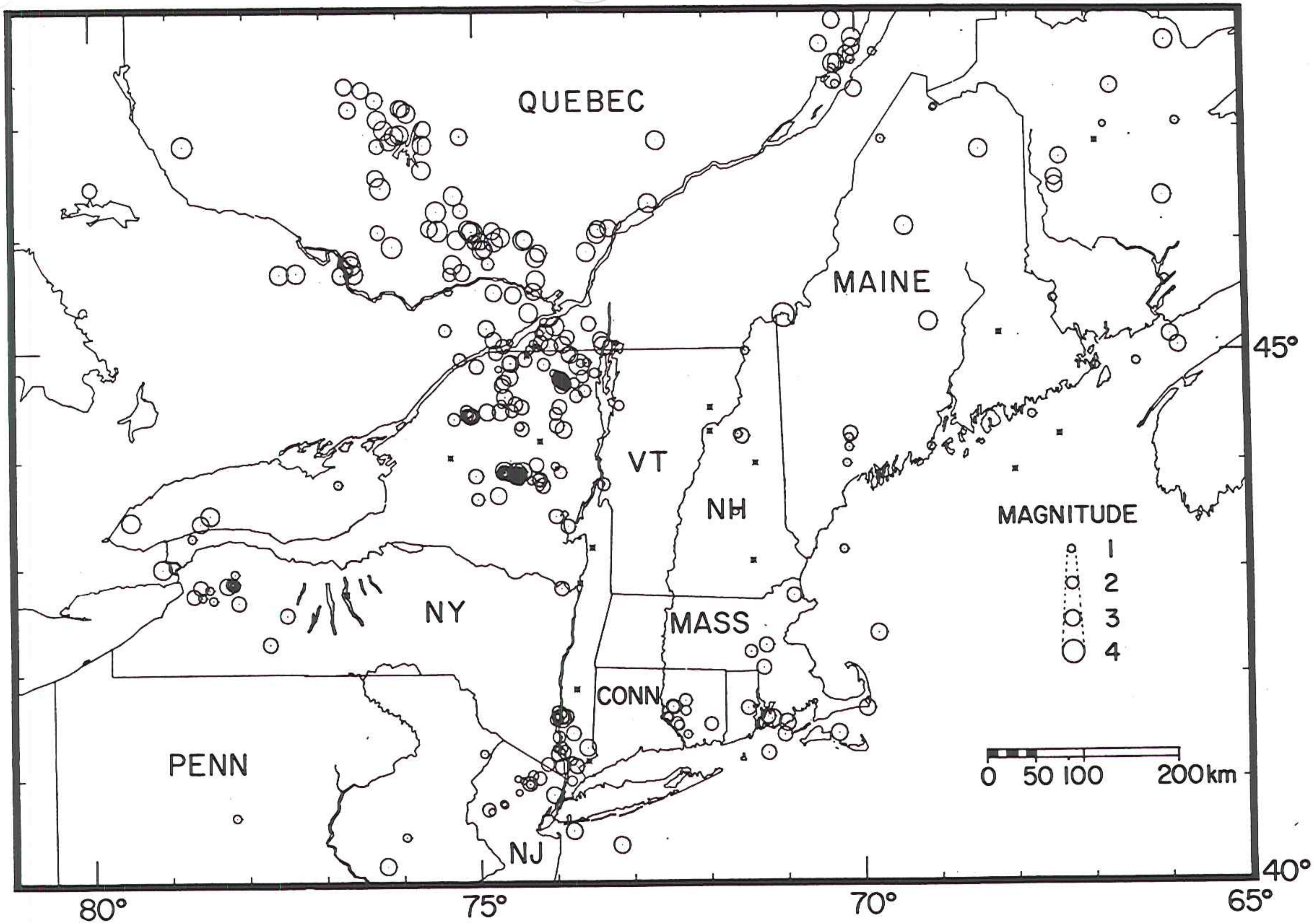


Fig. 17. Epicenters of earthquakes (1970–1977) in northeastern North America located by various networks in the area. For New York State and adjacent areas the coverage is probably complete for magnitudes of >2; for New England the coverage is poorer. Note the northeast alignment of earthquakes in northern New Jersey and southern New York. Asterisks denote unidentified events [after *Aggarwal and Sykes*, 1978].

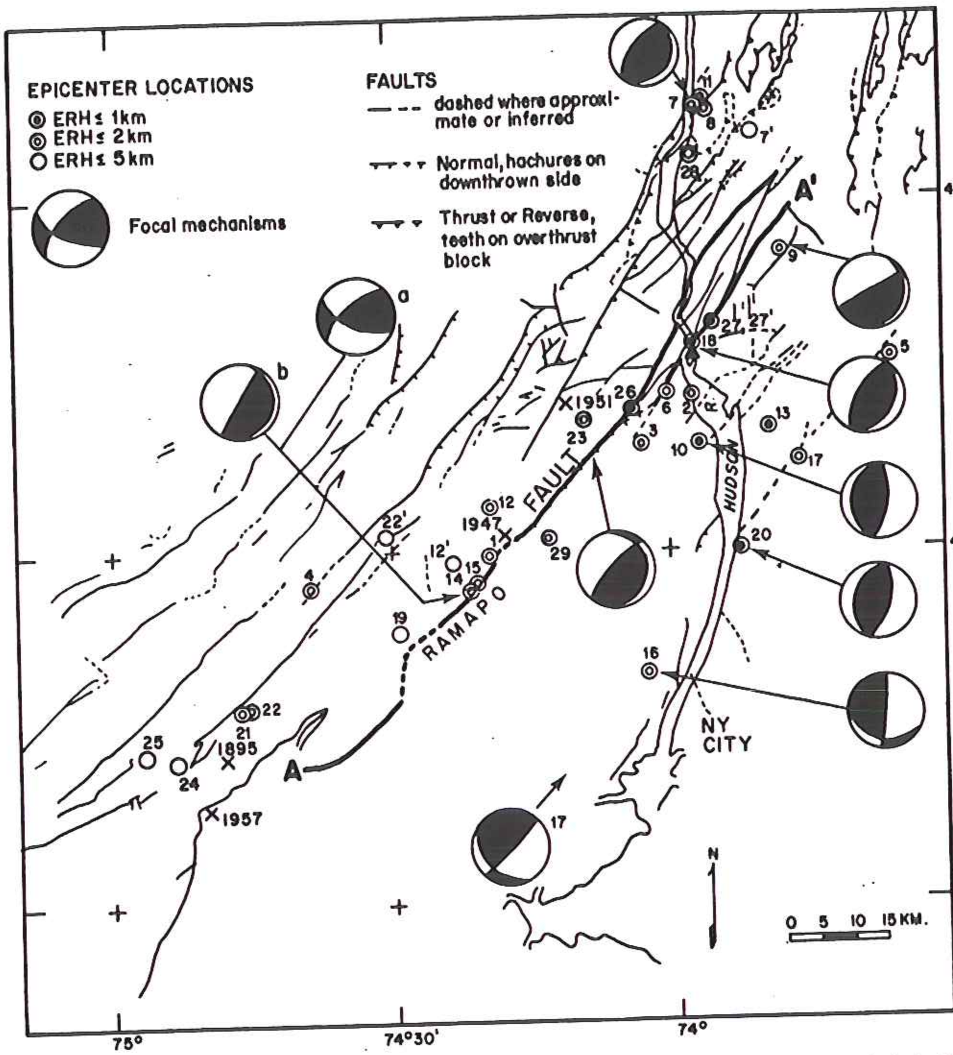
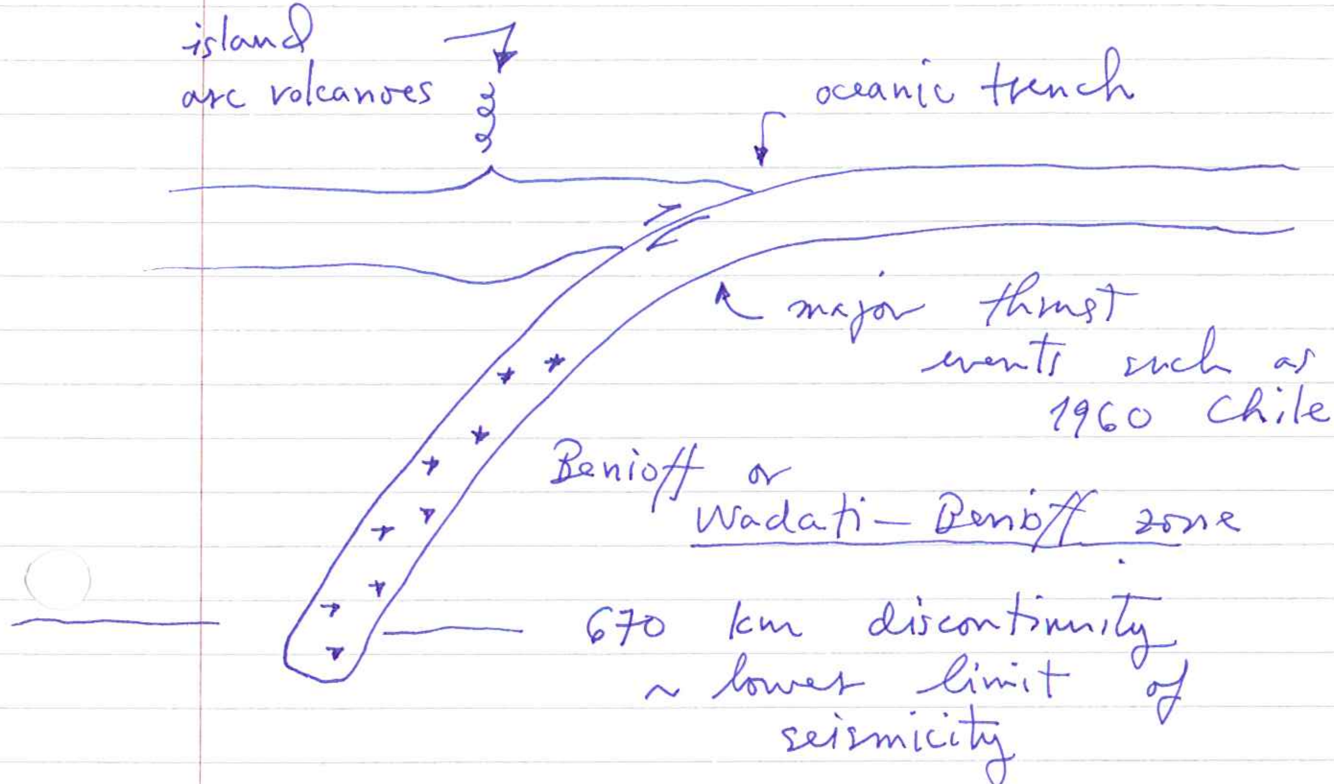


Fig. 22. Fault map of southeastern New York and northern New Jersey showing epicenters (circles) of instrumentally located earthquakes from 1962 to 1977, after *Aggarwal and Sykes* [1978]. Indicated uncertainties (ERH) in epicentral locations represent approximately 2 standard deviations. Focal mechanism solutions (FMS) are upper hemisphere plots; dark area represents the compressional quadrant. Note that for event 14 there are two possible FMS; the data, however, are more consistent with solution b than with solution a. The Ramapo fault and two of its major branches (A-A′) are shown by heavy lines. Crosses denote locations for older events near the Ramapo fault. Triangle shows location of nuclear power reactors.

Finally, yes, there are earthquakes in New Jersey, mostly in northern NJ on Ramapo Fault (site of Indian Point Nuclear Power Plant)

Deep-focus 'quakes: associated with subduction zones, where old oceanic lithosphere gets so heavy that it sinks



Example — Tonga-Kermadec arc in South Pacific

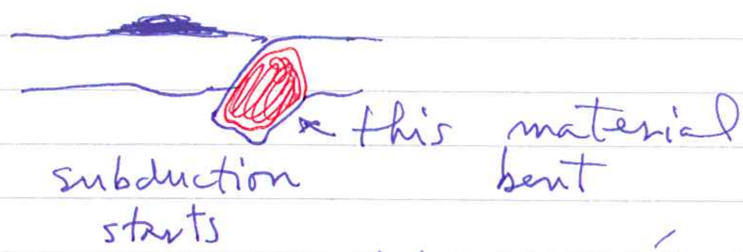
Show several maps & cross-sections
Note contortions in the slab

Not known whether the slab penetrates the 670 km discontinuity — an active research question being addressed by seismic tomographers and thermal modellers

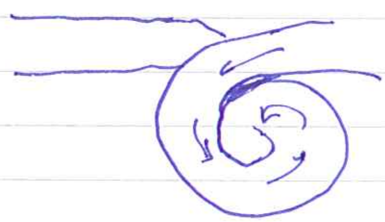
An interesting phenomenon which can only be revealed by careful location studies using dense regional networks.

Double Wadati–Benioff zone between 50 – 200 km depth

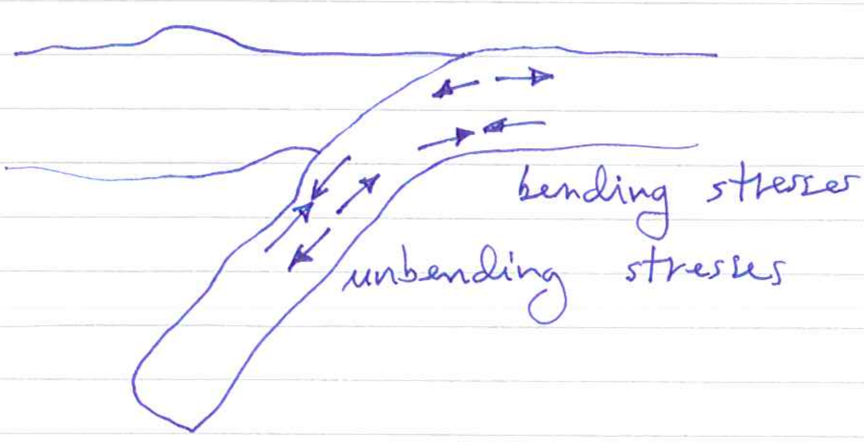
Proposed unbending mechanism:



slabs aren't curled



...so they must be unbent between 50 – 200 km



The largest deep-focus earthquake in recorded history:

June 9, 1994 Bolivia

$h = 600$ km

$M = 8.3$

$M_0 = 4 \cdot 10^{21}$ Nm (recall 1906 SF was $4 \cdot 10^{20}$ Nm — ten times smaller)

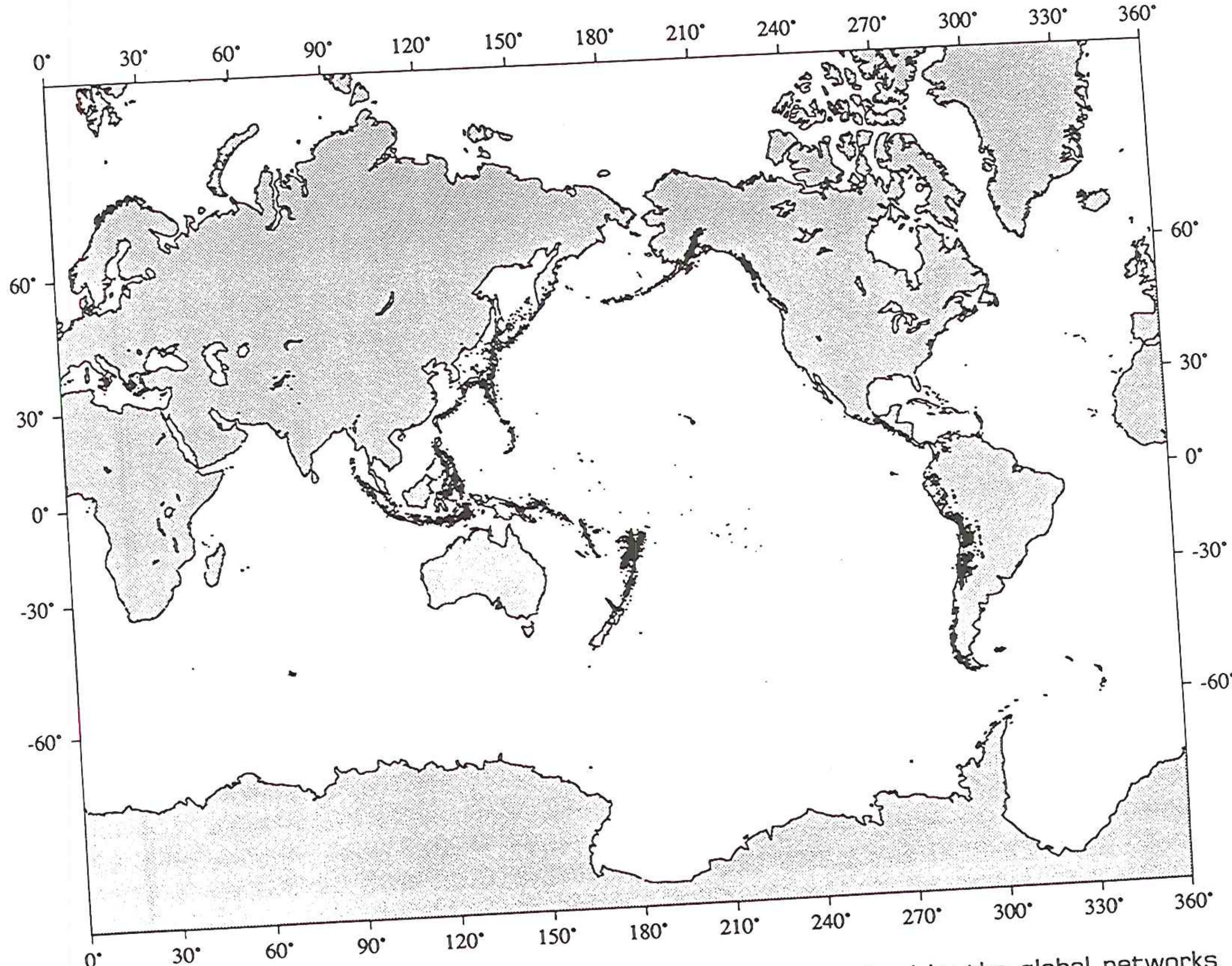
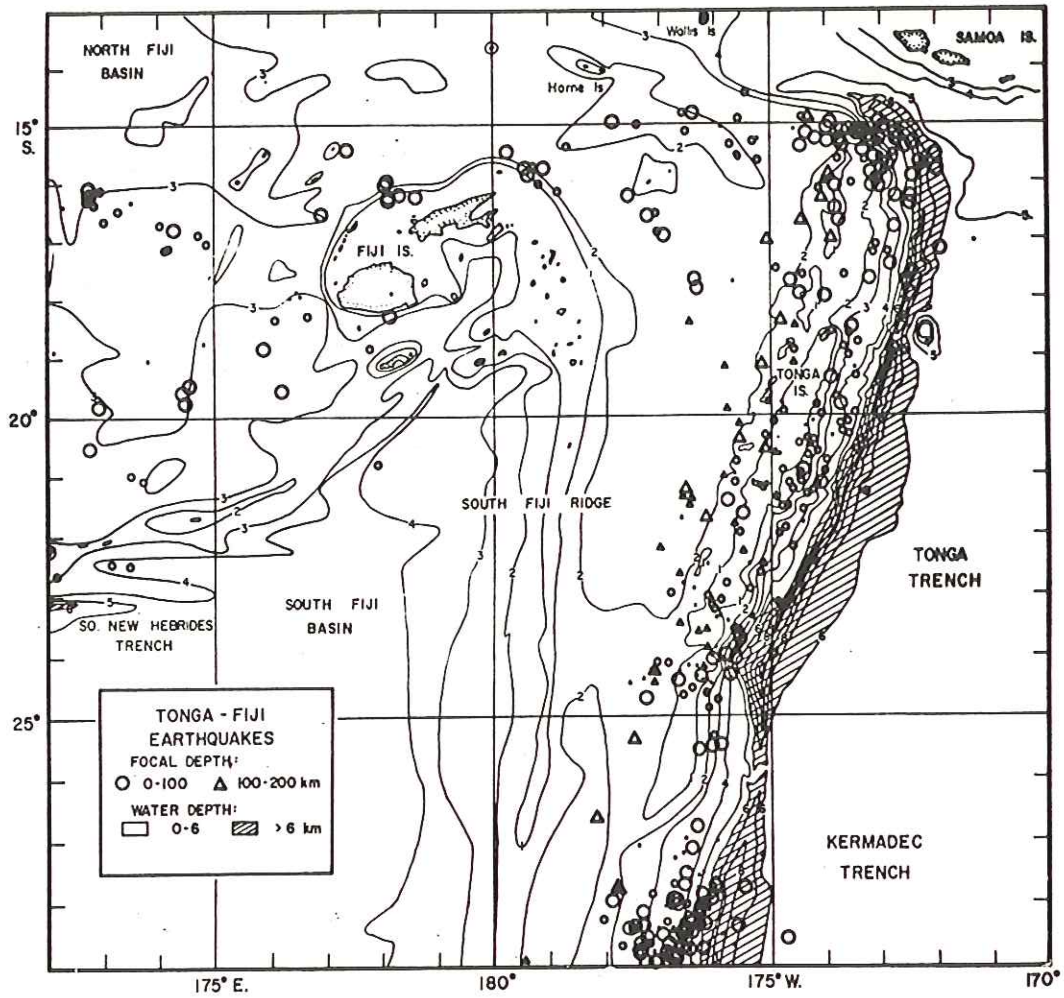
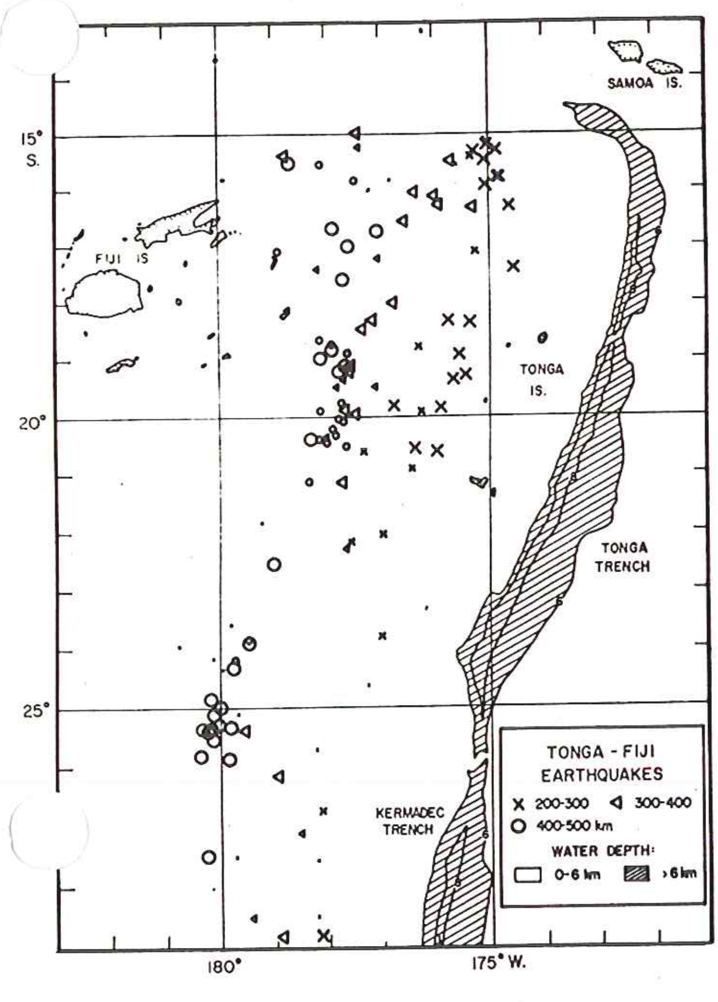
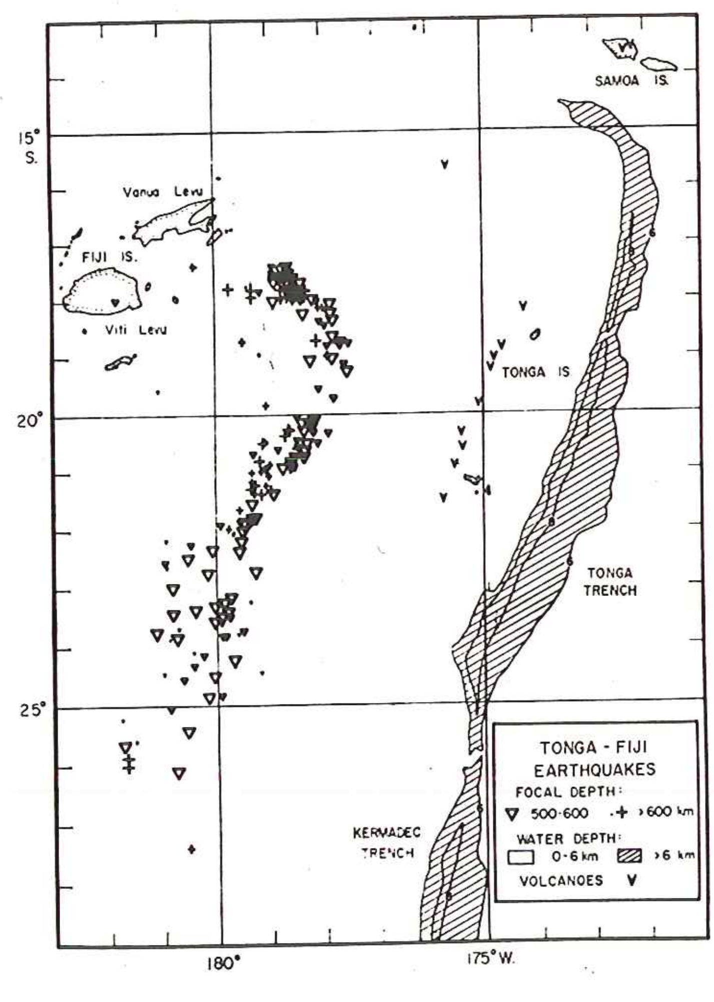


FIGURE 1.11 Maps of the distribution of earthquakes determined by the global networks for the years 1970 to 1990. At the top, the source location for events less than 100 km ... at the bottom, events with depths from 100 to 700 km are shown.


NORTH FIJI BASIN
Wallis Is
SAMOA IS.
Horne Is
FIJI IS.
TONGA IS.
SOUTH FIJI RIDGE
TONGA TRENCH
SOUTH FIJI BASIN
SO. NEW HEBRIDES TRENCH
KERMADEC TRENCH
TONGA - FIJI EARTHQUAKES
FOCAL DEPTH:
0-100
100-200 km
WATER DEPTH:
0-6
>6 km
15° S.
20°
25°
175° E.
180°
175° W.
170°


SAMOA IS.
FIJI IS
TONGA IS.
TONGA TRENCH
KERMADEC TRENCH
TONGA - FIJI EARTHQUAKES
200-300
300-400
400-500 km
WATER DEPTH:
0-6 km
>6 km
15° S.
20°
25°
180°
175° W.


SAMOA IS.
Vanua Levu
FIJI IS.
Viti Levu
TONGA IS
TONGA TRENCH
KERMADEC TRENCH
TONGA - FIJI EARTHQUAKES
FOCAL DEPTH:
500-600
>600 km
WATER DEPTH:
0-6 km
>6 km
VOLCANOES
15° S.
20°
25°
180°
175° W.

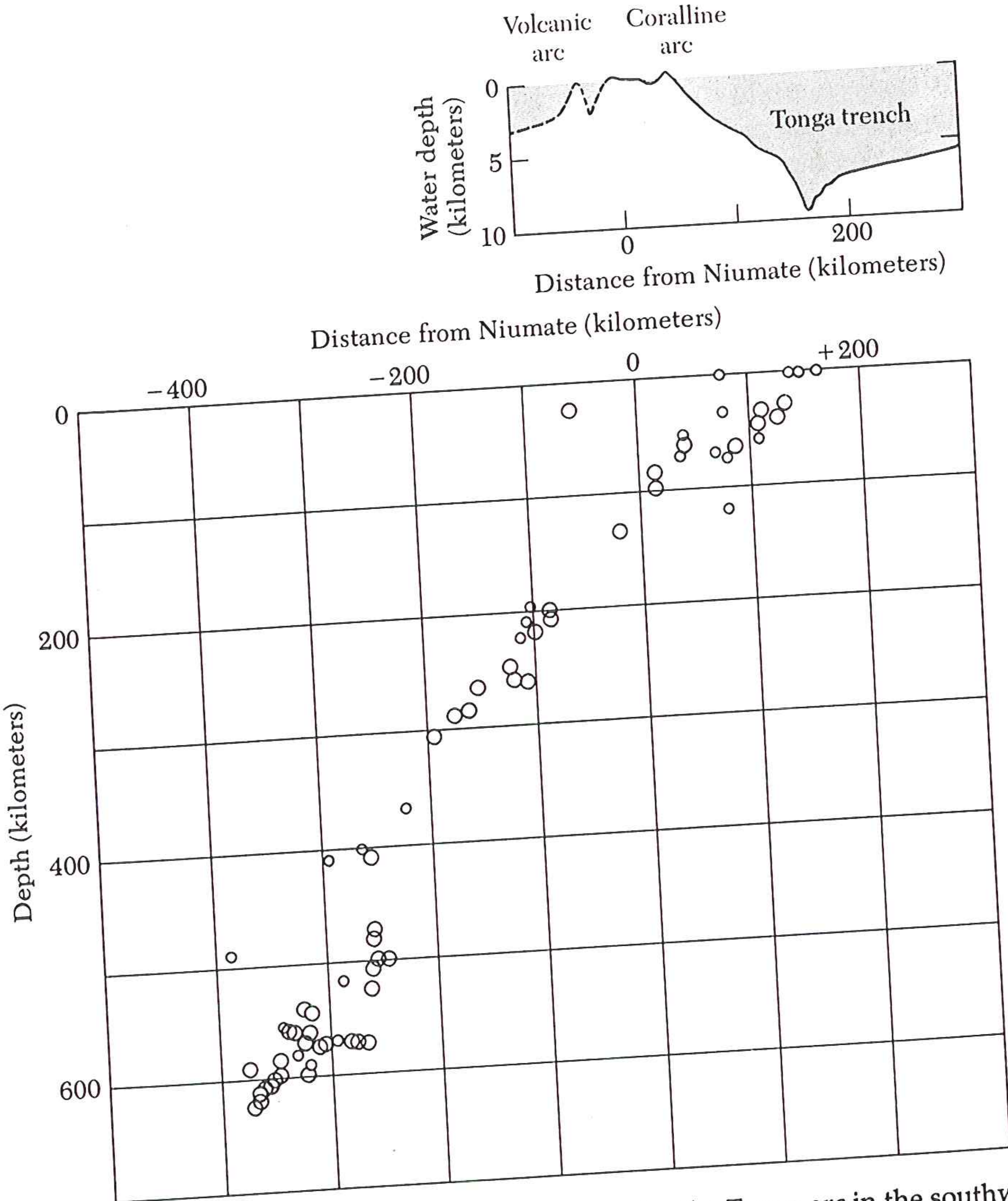


Figure 2.4 Foci of earthquakes in 1965 occurring under the Tonga arc in the southwest Pacific. The vertical section shows that most earthquake centers cluster along a narrow zone starting under the trench and dipping under it at an angle of about 45° to depths of more than 600 kilometers. [Courtesy of B. Isacks, J. Oliver, L. R. Sykes, and *J. Geophys. Res.*]

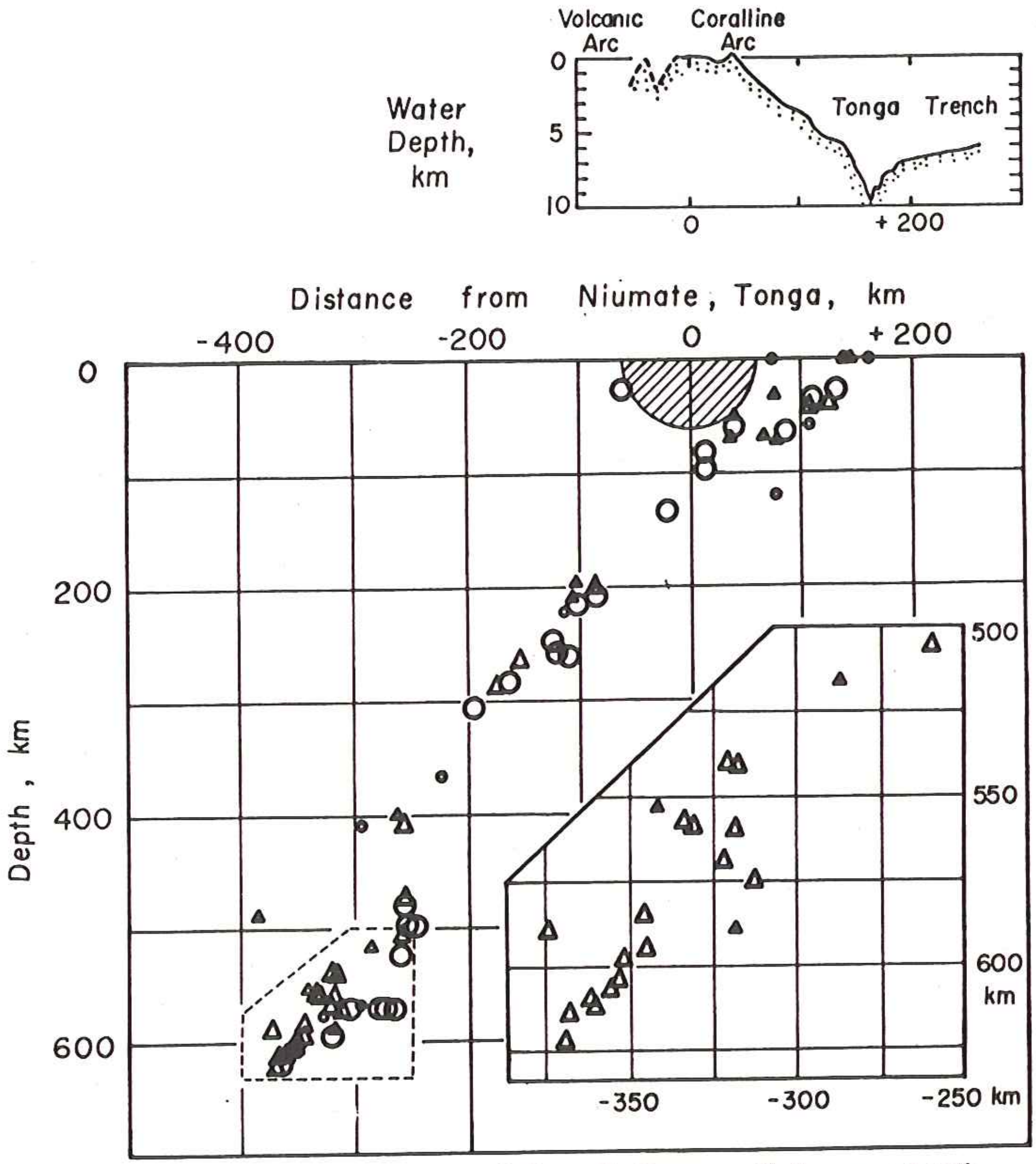
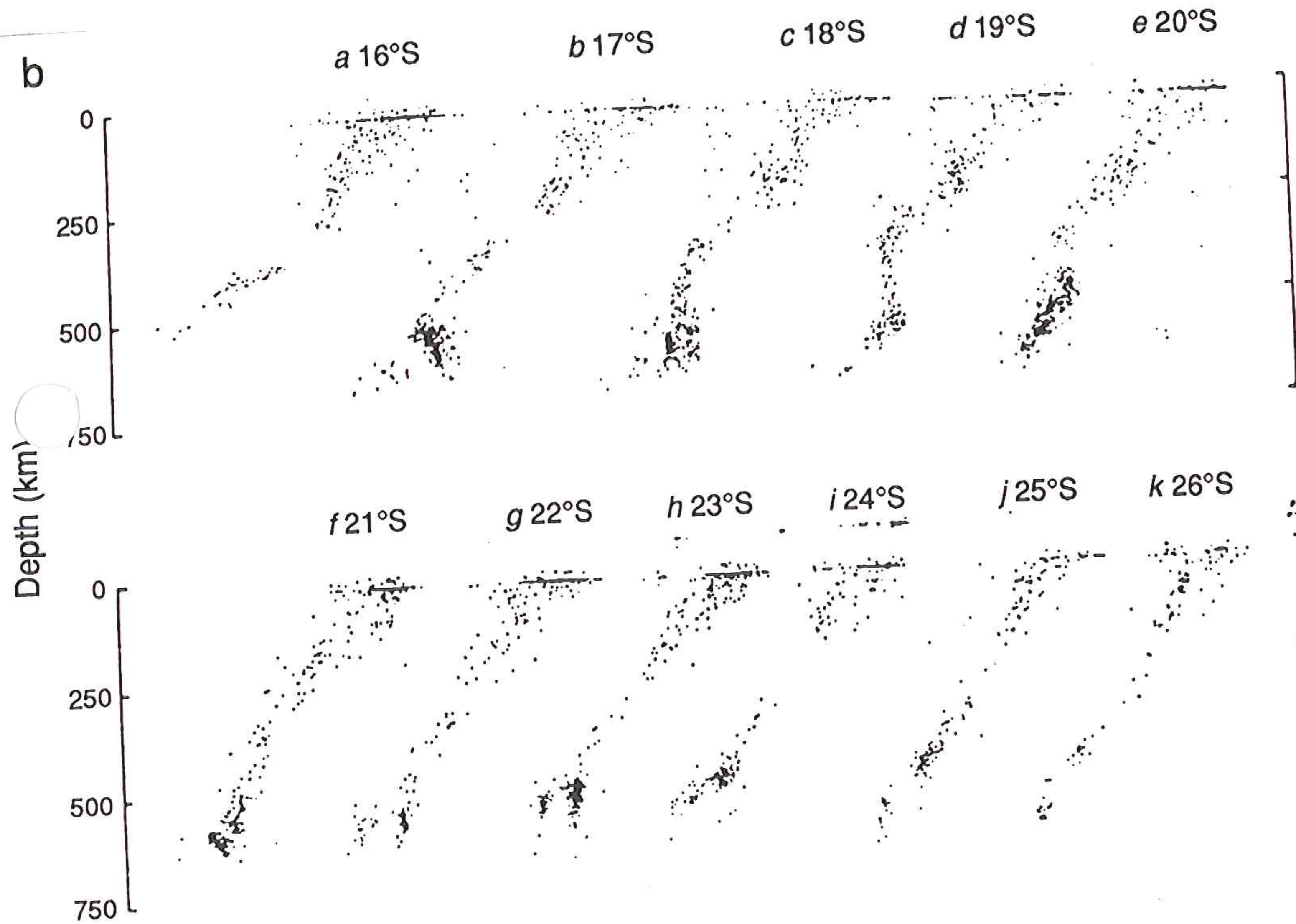
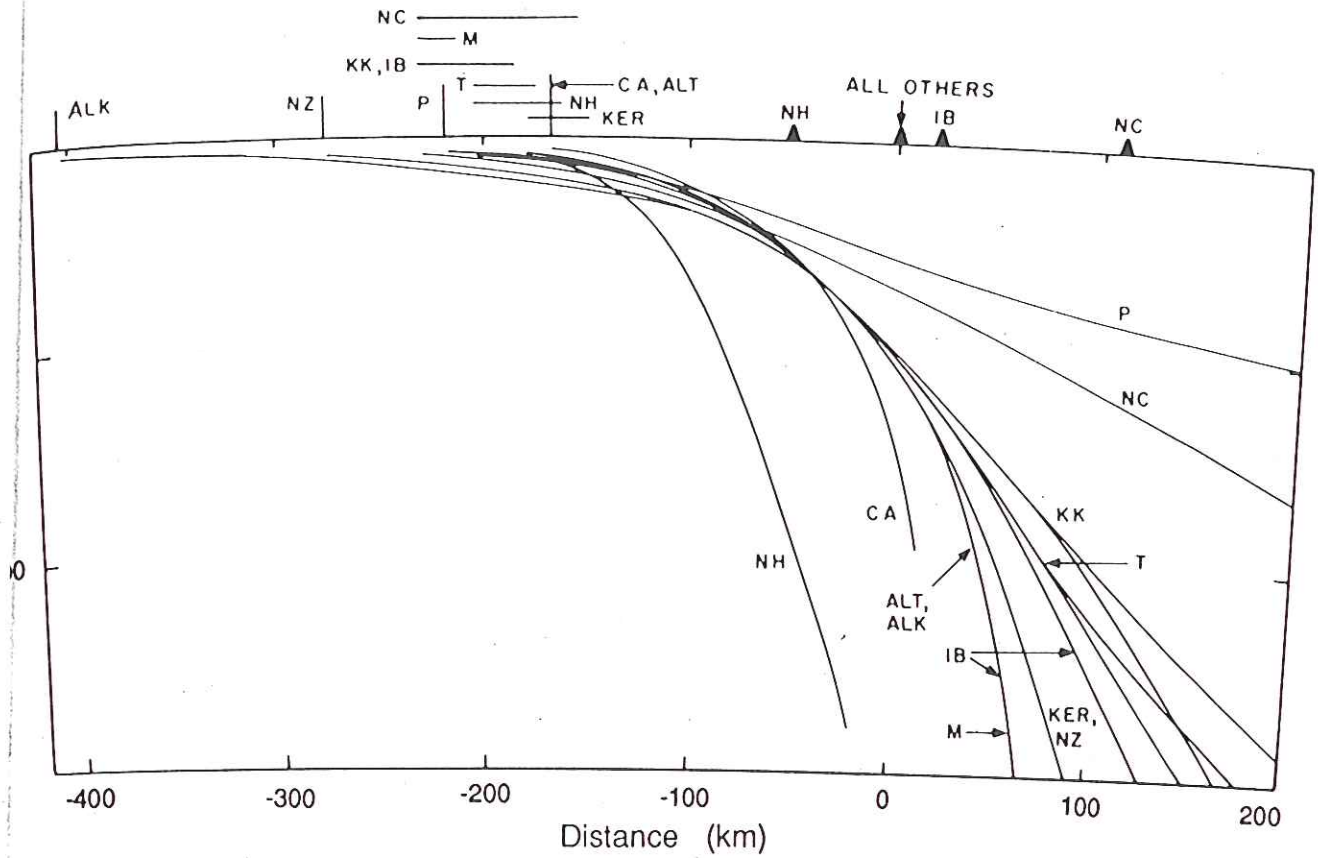
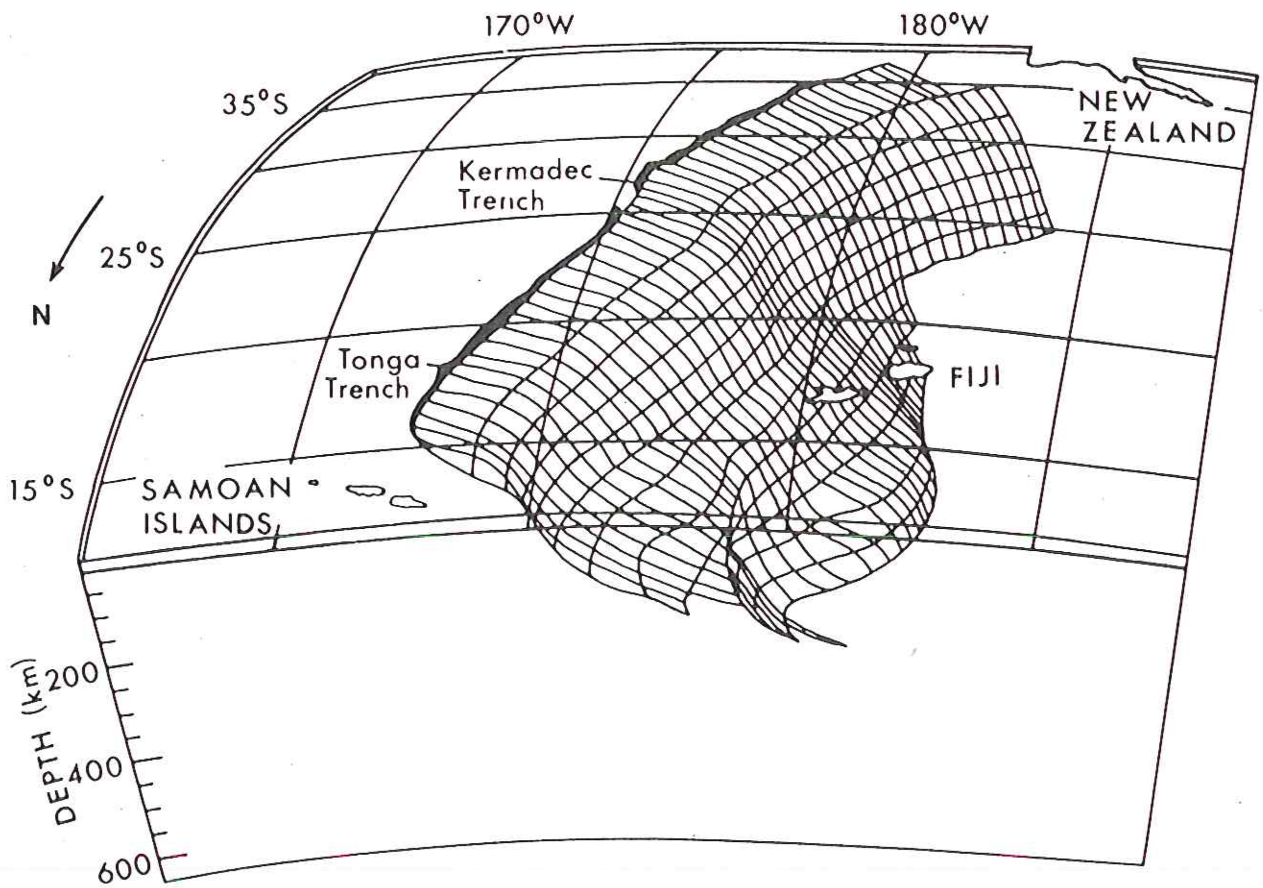


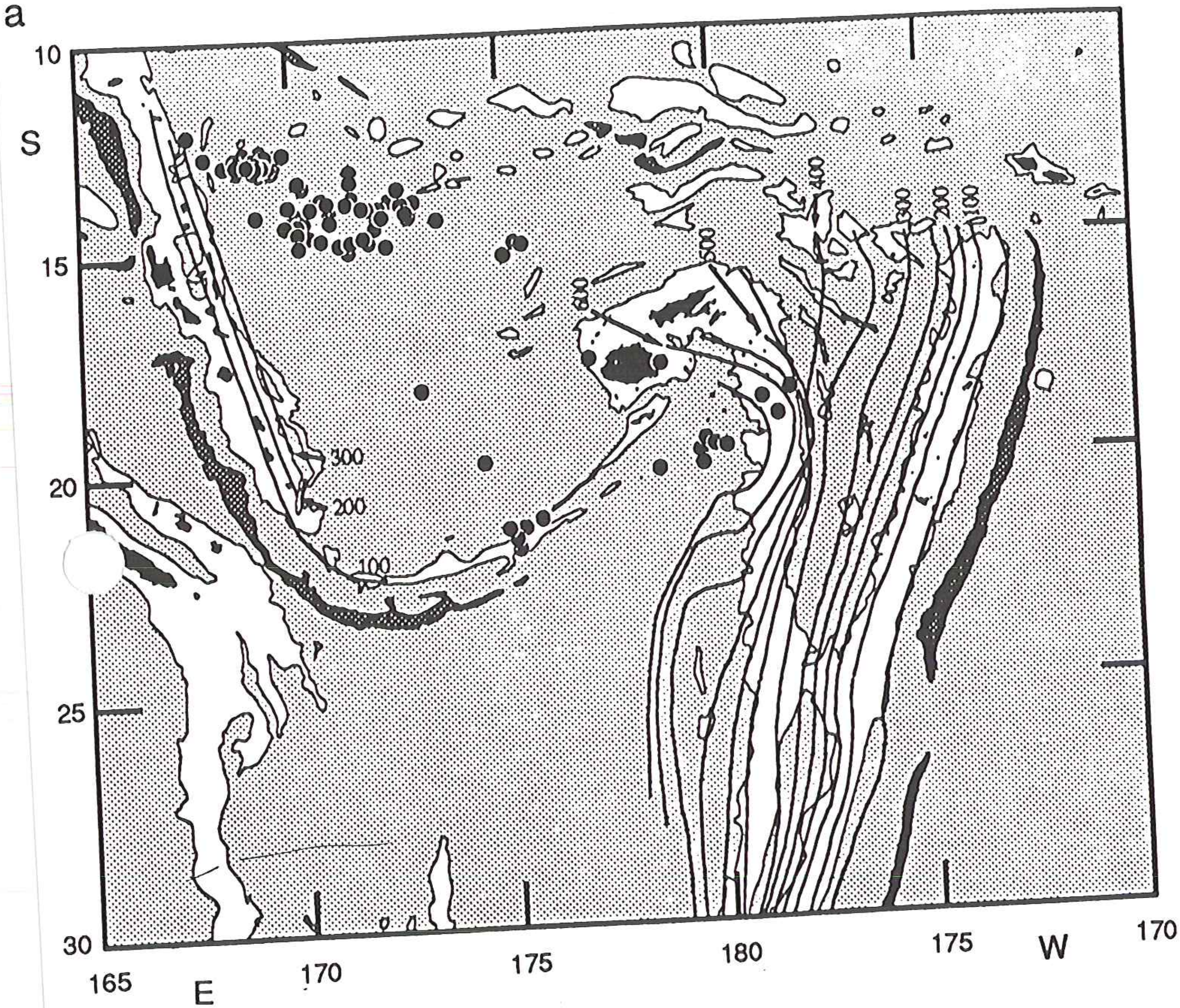
Fig. 9. Vertical section oriented perpendicular to the Tonga arc. Circles represent earthquakes projected from within 0 to 150 km north of the section; triangles correspond to events projected from within 0 to 150 km south of the section. All shocks occurred during 1965 while the Lamont network of stations in Tonga and Fiji was in operation. Locations are based on data from these stations and from more distant stations. No microearthquakes from a sample of 750 events originated from within the hatched region near the station at Niumate, Tonga (i.e., for *S-P* times less than 6.5 sec). A vertical exaggeration of about 13:1 was used for the insert showing the topography [after *Raitt et al.*, 1955]; the horizontal and vertical scales are equal in the cross section depicting earthquake locations. Lower insert shows enlargement of southern half of section for depths between 500 and 625 km. Note small thickness (less than ~20 km) of seismic zone for wide range of depths.


b
a 16°S
b 17°S
c 18°S
d 19°S
e 20°S
f 21°S
g 22°S
h 23°S
i 24°S
j 25°S
k 26°S
Depth (km)
0
250
500
750





looking to the S
from the N


a
10
S
15
20
25
30
165
E
170
175
180
175
W
170
300
200
100
400
500
600
300
200
100

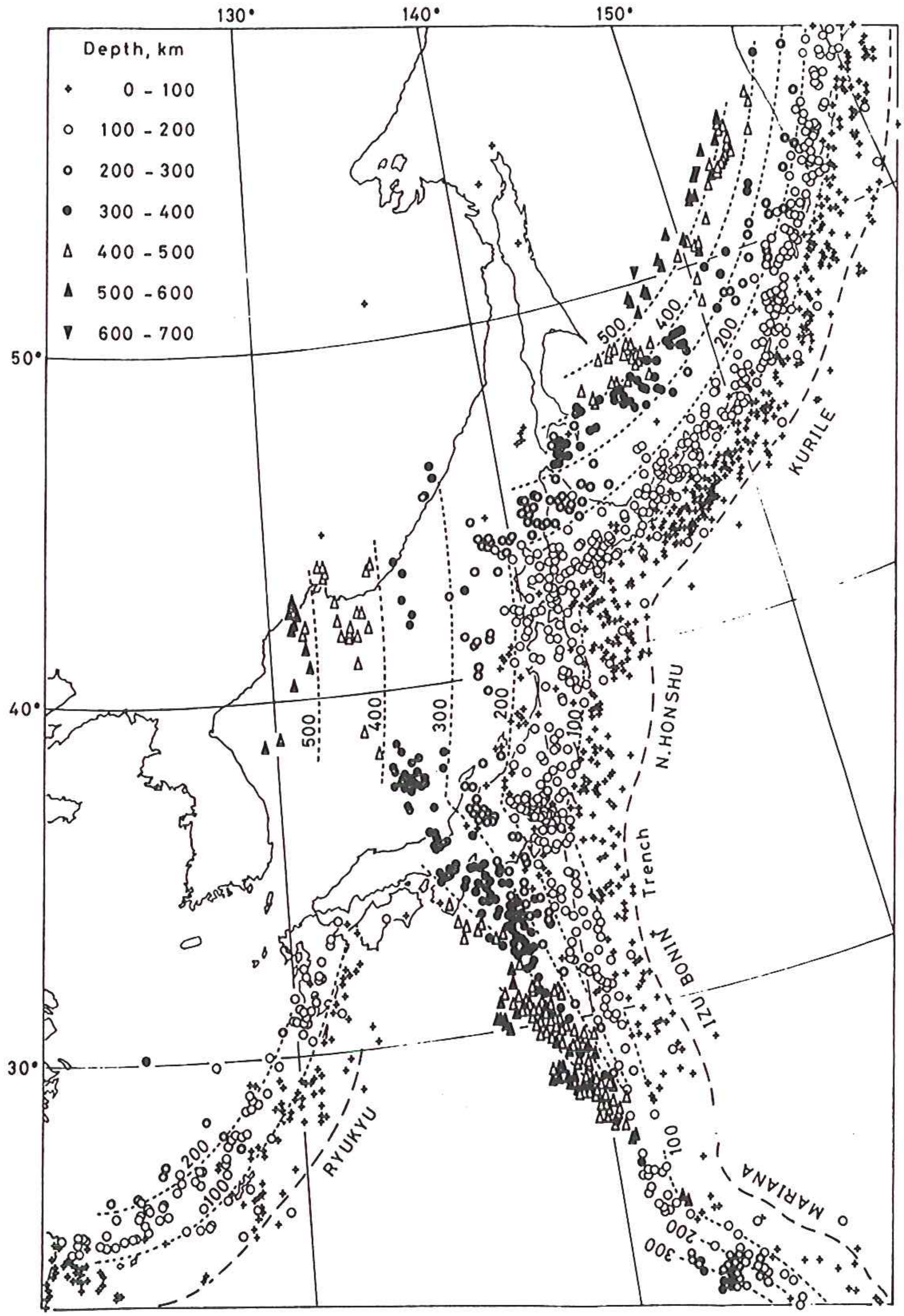


Figure 4.15 The pattern of earthquake foci down the Wadati-Benioff zones of Japan and neighbouring arcs. Reproduced, by permission, from a redrawing by Sasatani (1989) of an original plot by T. Utsu. Several dipping planes of foci intersect in this area, indicating complicated plate geometry.

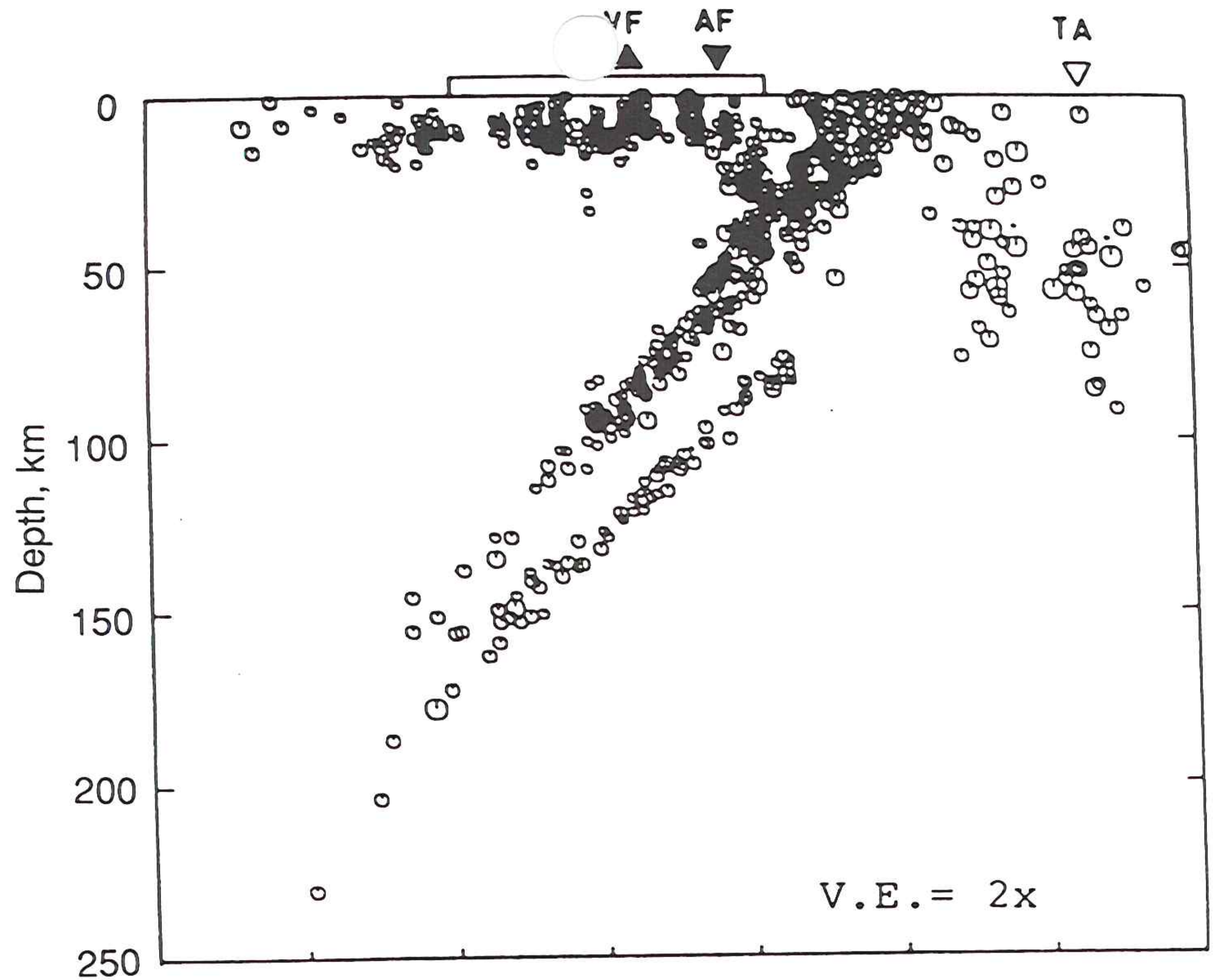


FIGURE 11.24 Double Wadati–Benioff zone in northeast Japan. (After Hasegawa *et al.*, 1978.)

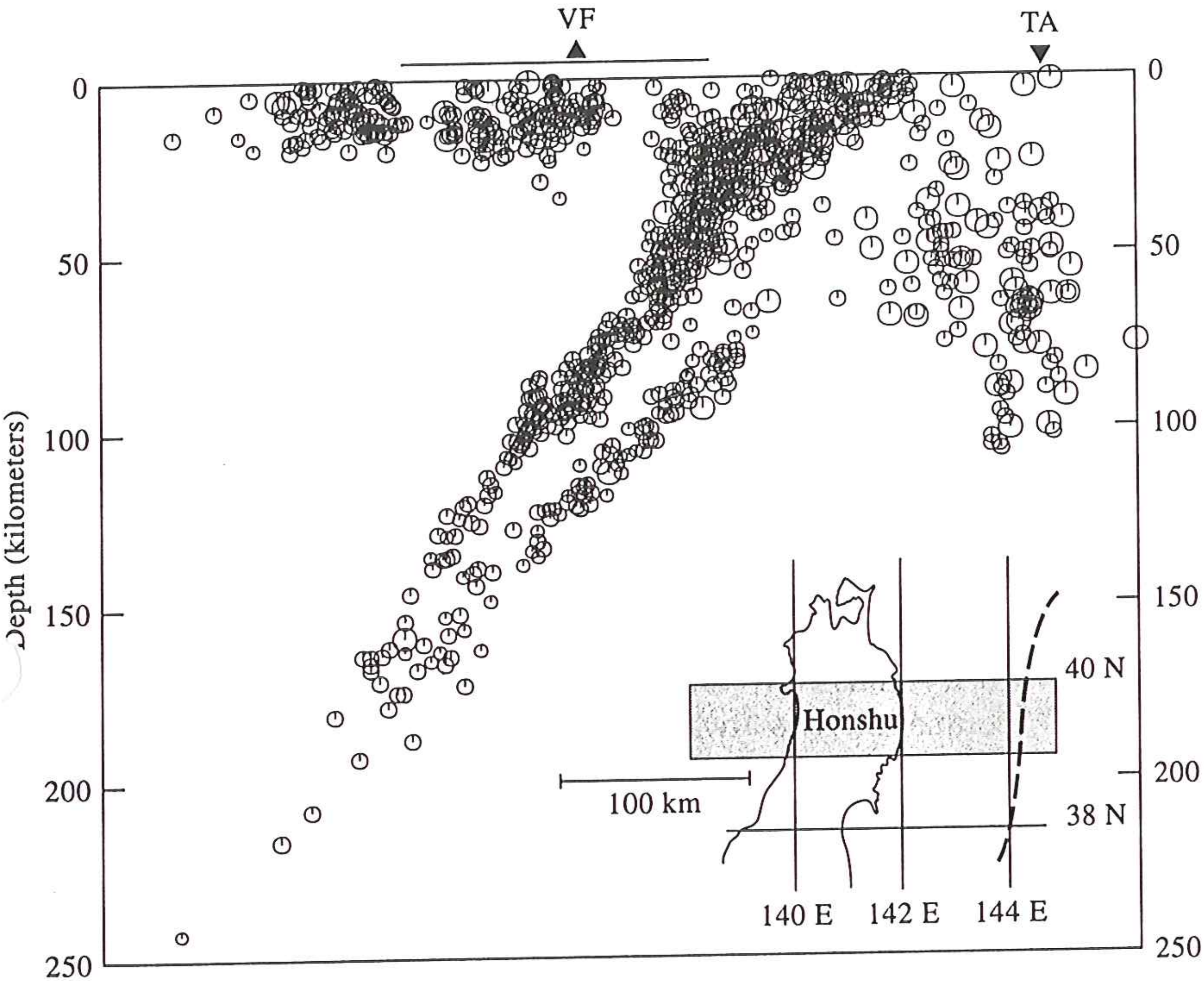
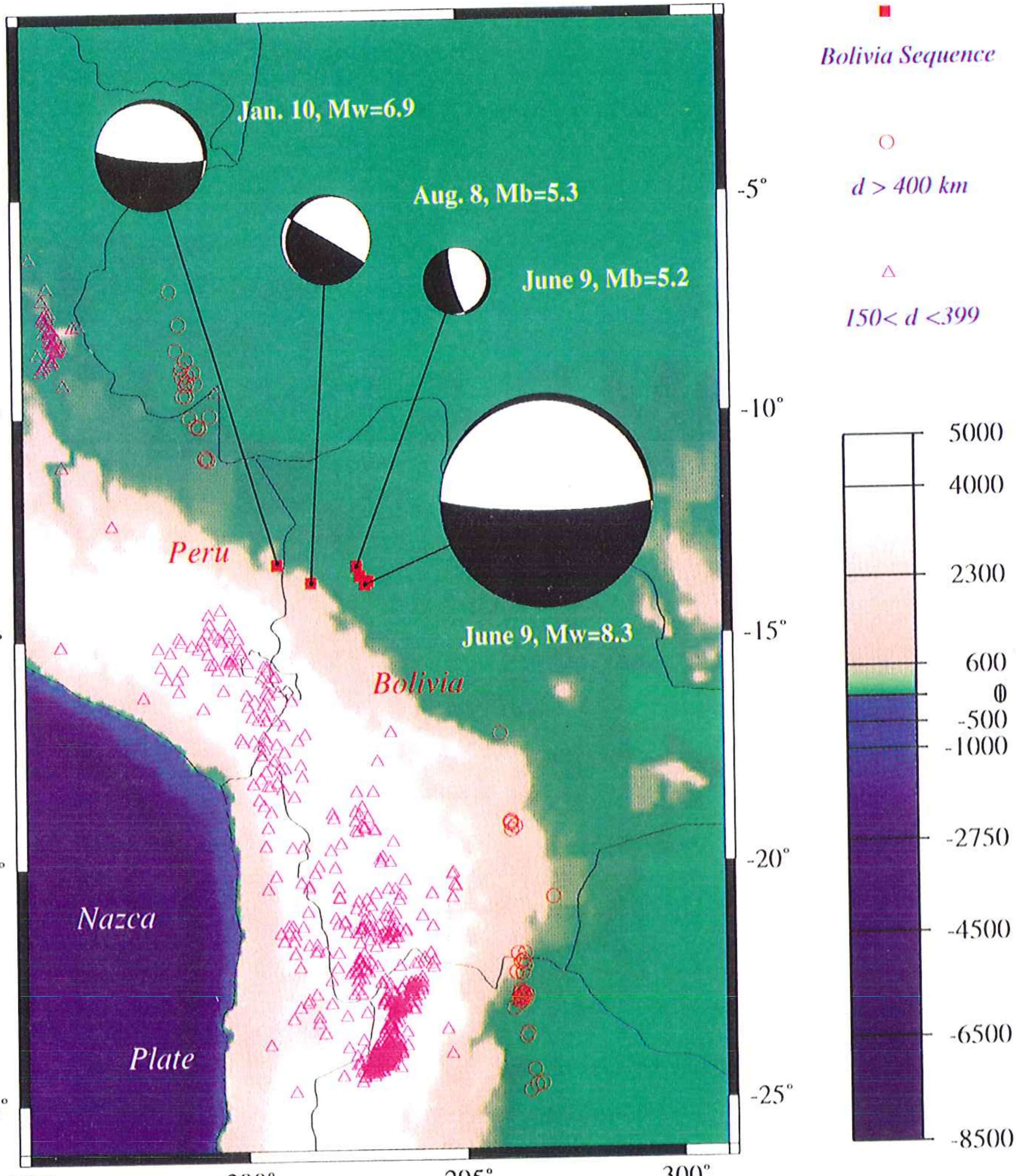
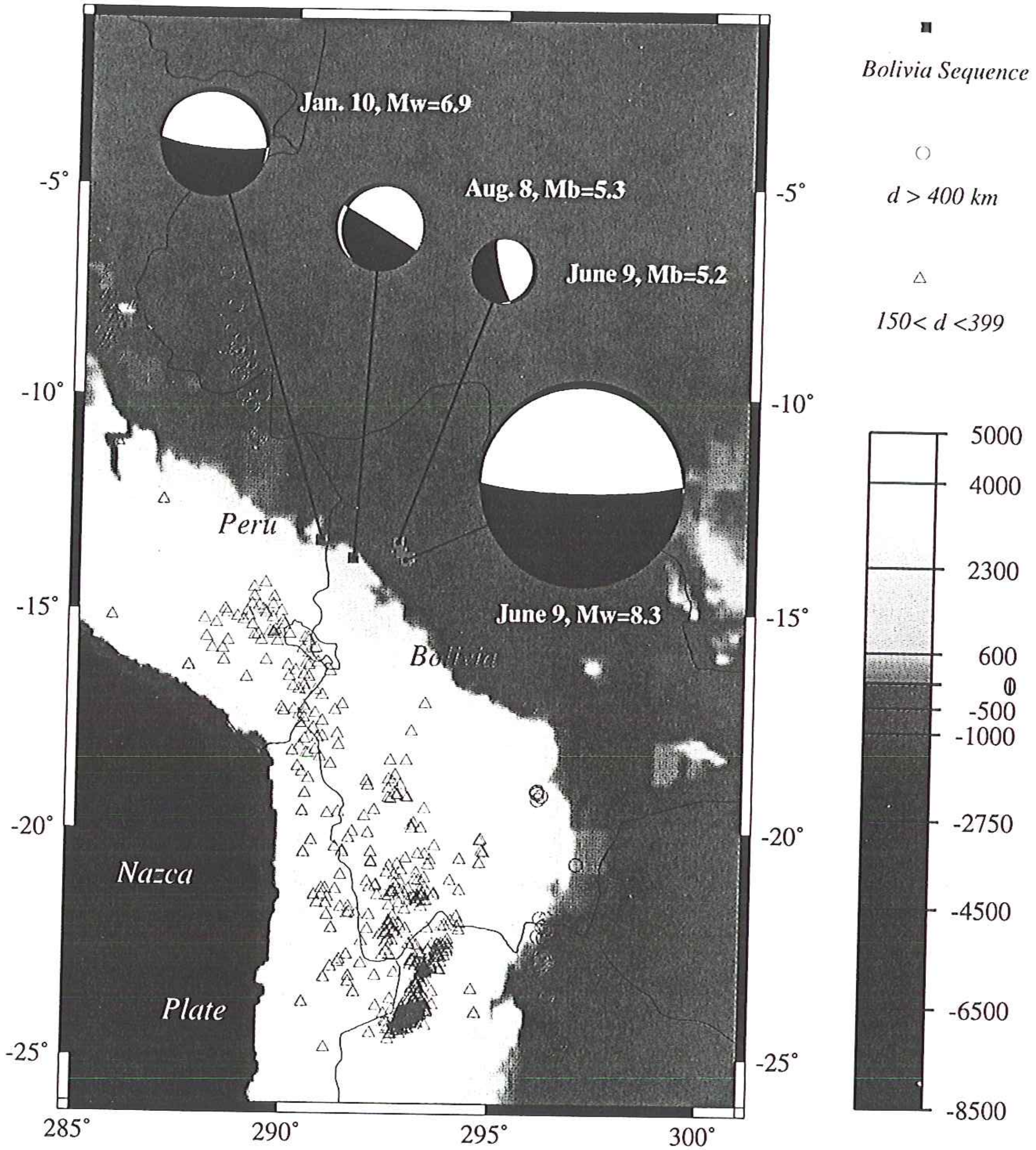


Figure 4.5 Foci of earthquakes recorded in 1975 and 1976 by a network of sensitive seismographs in Honshu, Japan. VF is the volcanic front; TA is the Japan Trench axis. The foci are drawn as a side elevation with depth in kilometers. The Wadati-Benioff zone can be clearly seen dipping from the Japan Trench just west of TA toward the west. The deepest focus is at about 240 kilometers. The striking feature of the Wadati-Benioff zone is the two distinct lines of foci about 20 kilometers apart. The seismicity plot also shows shallow earthquakes under Honshu within the crust as well as scattered earthquakes down to depth of 100 kilometers to the east of the Japan Trench under the marker TA. [Courtesy A. Hasegawa, M. Umino, and A. Takagi, 1978.]



Jan. 10, Mw=6.9
Aug. 8, Mb=5.3
June 9, Mb=5.2
June 9, Mw=8.3
Peru
Bolivia
Nazca
Plate
-5°
-10°
-15°
-20°
-25°
285°
290°
295°
300°
Bolivia Sequence
d > 400 km
150< d <399
5000
4000
2300
600
0
-500
-1000
-2750
-4500
-6500
-8500



Focal Mechanisms of Bolivian Sequence, 1994