Chapter J

Seismicity in the Southern Great Basin, 1868–1992

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Contents

Figures

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Tables

[For table of abbreviations and conversions, click here]

Abstract

Yucca Mountain, Nevada, is located in the southern part of the Great Basin of the western United States. Historically, this region has been the site of several major earthquakes, and seismic hazard analysis is therefore a key characterization task in the overall study of Yucca Mountain as a potential repository for high-level radioactive waste. Although the length of the historical earthquake record is short (decades) compared to the anticipated repository life (tens of thousands of years), the study of past and current seismicity, in conjunction with other geologic studies, is considered to be a fair indicator of future seismicity. This report focuses on the seismicity in the southern part of the Great Basin, within approximately 200 kilometers of Yucca Mountain and since the year 1868.

The seismicity of the southern Great Basin can be described as moderate. Since 1868, fewer than 10 known earthquakes having a magnitude of 5.5 or greater have occurred within approximately 150 kilometers of Yucca Mountain. Only one of these, the Little Skull Mountain earthquake in 1992, occurred within the time frame of the current seismic network of 62 stations in the southern Great Basin. This network, operating since 1978, is composed of mostly vertical instruments with a passband of 1 to 20 hertz. Approximately 1,000 events are recorded in a normal year, but in 1992 more than 5,000 events were recorded and located primarily owing to the aftershocks of the Little Skull Mountain earthquake. The recurrence curve derived from the current seismic network data predicts a recurrence rate for magnitude 6 earthquakes of approximately one per 150 years in the southern Great Basin. Microearthquake data recorded by a small array of high-frequency instruments near Yucca Mountain confirm a very low seismicity rate at that particular location. No events of magnitude greater than 2.0 are known within 10 kilometers of the proposed surface facilities for the potential radioactive-waste repository.

The seismic activity in the southern Great Basin since 1978 has been irregular in space and time. Several areas of more intense activity show up in an examination of the instrumental earthquake catalog. Some of this type of activity is related to underground nuclear testing and should be discounted as not representative of the natural seismicity of the area. Focal mechanisms determined for many of the larger events show a mixture of normal and strike-slip mechanisms, characteristic of the Great Basin as a whole. Events with predominantly strike slip motion show compression axes whose average trend is approximately N. 45° E.

Overview of Seismicity in the Southern Great Basin

The record of earthquakes in the southern Great Basin (SGB) can be roughly divided into four periods: (1) 1868–1932, a period of only felt earthquake reports or very sparse station coverage; (2) 1932–1968, a period when the California Institute of Technology and University of California-Berkeley located events; (3) 1968–1978, a period when several instrumentation programs were initiated or sponsored by the Department of Defense around the Nevada Test Site (NTS) in relation to underground nuclear testing; and (4) 1978–1992, a period of a modern network of short-period instruments installed primarily to monitor seismic activity in the Yucca Mountain region. Each successive period has been marked by a lowering of the seismic threshold (magnitude at which 90 percent of earthquakes are detected) within the SGB and consequently an increase in the number of reported events. Figure 1 illustrates this progressive lowering of threshold; we emphasize that the values shown here are only rough estimates.

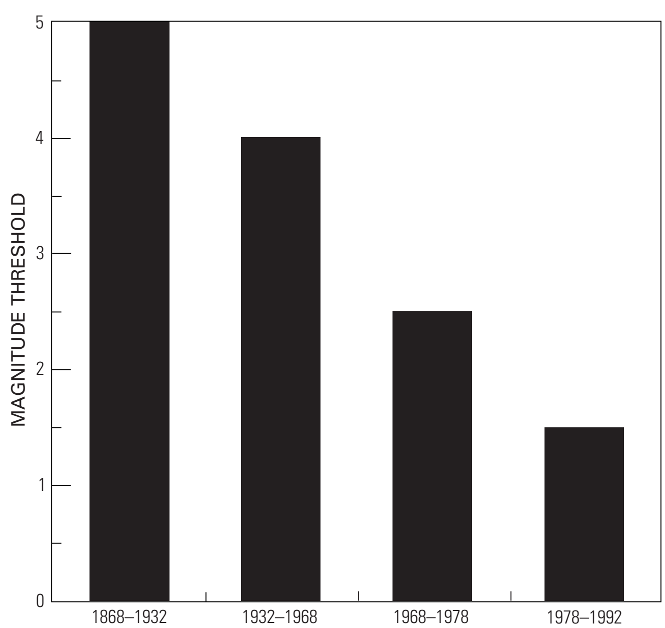

Figure 1. Estimated seismic threshold for earthquakes in southern Great Basin during historical reporting time.

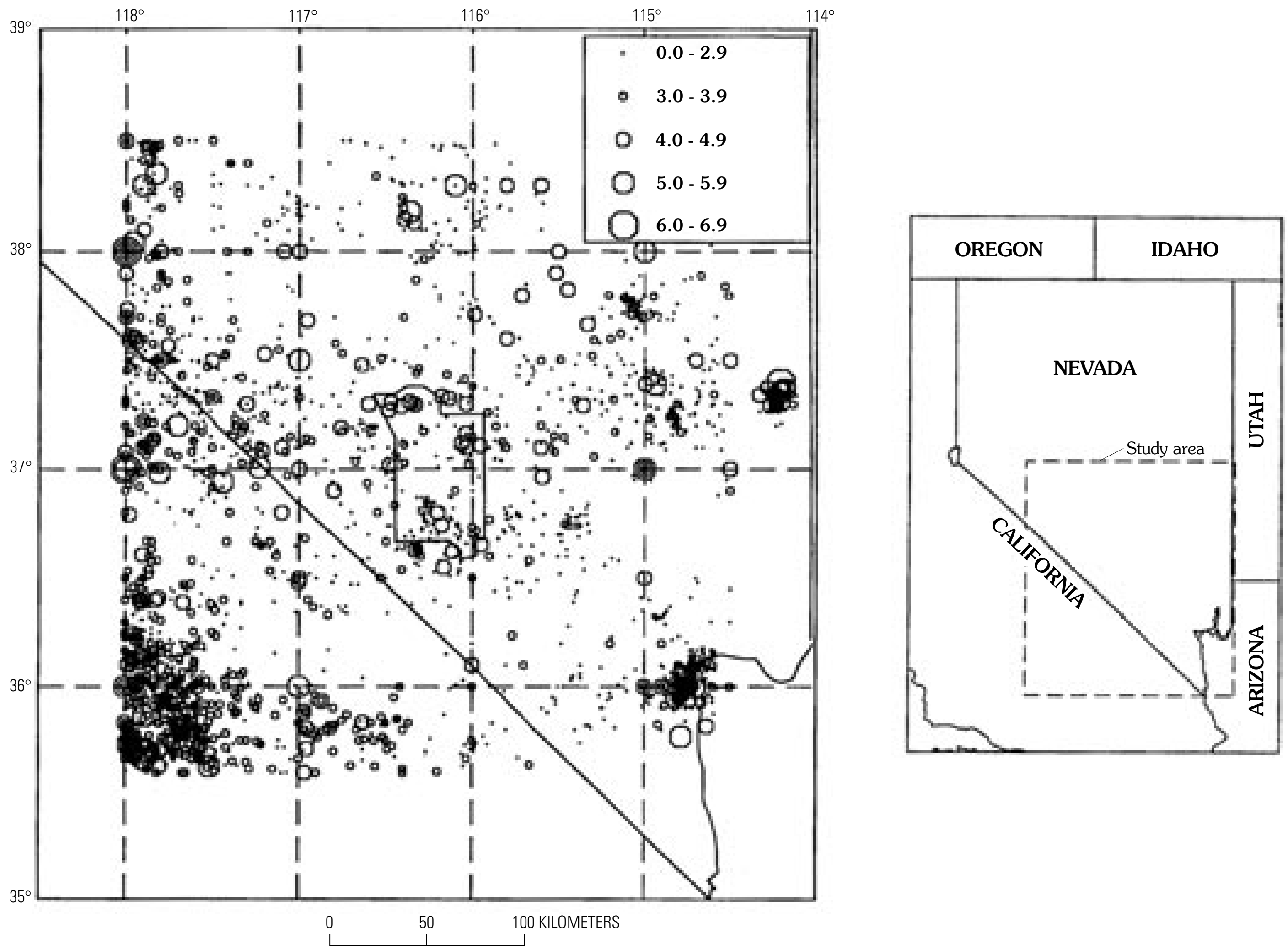

Figure 2. Map showing epicenters of southern Great Basin earthquakes (1868–1978) in the Meremonte and Rogers (1987) historical catalog. Outline of Nevada Test Site in center of large-scale map.

The historical catalog of events in the SGB is taken from the report of Meremonte and Rogers (1987) for the period 1868–1978. The events are plotted in figure 2. The quality of the event locations varies widely, and making reliable tectonic interpretations on the basis of this catalog is difficult. Some of the seismicity apparent on the NTS is related to the underground nuclear testing since approximately 1956 (McKeown, 1975), whereas some of the activity apparent in southeast Nevada near Lake Mead is known to be associated with the filling of that reservoir (Carder, 1945).

In the latter part of 1978, a network of seismic stations utilizing short-period instruments was established by the U.S. Geological Survey; it is referred to as the Southern Great Basin Seismic Network (SGBSN). This network was fixed at 55 stations until 1992, when it was expanded to 62 stations (fig. 3), owing to the important Little Skull Mountain earthquake. The network covers a radius of approximately 150 km around Yucca Mountain. The station density around Yucca Mountain itself is significantly greater than that in the outer parts of the network, and the threshold is less than magnitude 1.0 (Gomberg, 1991). The events located using this network from August 1978 through the end of 1992 are shown in figure 4 (Rogers and others, 1987; Harmsen and Rogers, 1987; Harmsen and Bufe, 1991; Harmsen, 1991, 1992, 1993; D.H. von Seggern, University of Nevada-Reno, written commun., 1993). The seismicity in the northern and eastern parts of the NTS is artificially inflated with events induced by underground nuclear tests.

Significant Earthquakes in the Southern Great Basin

Only nine of the earthquakes in the historical and modern catalogs exceeded 5.5 in magnitude (M) (table 1 and fig. 5). The locations and magnitudes of earthquakes in 1949 and earlier are quite uncertain and are indicated with question marks in the table. Note that only three of the nine are within 100 km of

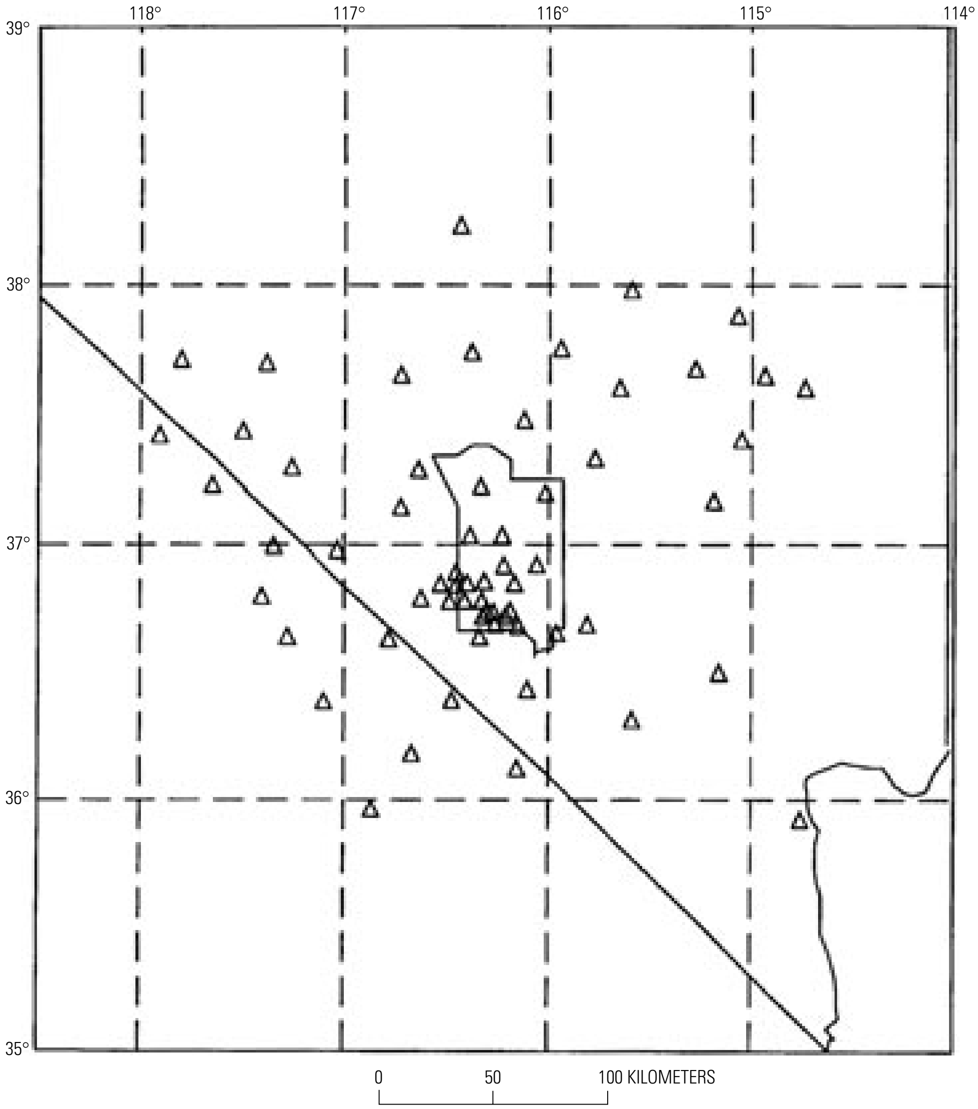

Figure 3. Seismic network stations (triangles) operating in the southern Great Basin 1978–1992. Outline of Nevada Test Site in center of map.

Yucca Mountain, and that these three are all less than 6.0 in magnitude. Table 1 shows the maximum Modified Mercalli ground-motion intensity reported in any location for each earthquake, but the largest Modified Mercalli (MMI) intensity occurring at Yucca Mountain in historical time is probably MMI 6 associated with the 1992 Little Skull Mountain earthquake.

Characteristics of Recent, Well-Recorded Seismicity in the Southern Great Basin

The most reliable data on seismicity in the SGB are those obtained during the period 1978–1992. Events recorded during that period are reasonably well located; epicentral errors are generally less than 1 km, and depth errors are generally on the order of 1–2 km within the more densely instrumented parts of the network. The larger events are probably much better located than the smaller ones. Magnitudes of the majority of these events are based on local magnitude (M_L) calculations, with some magnitudes (approximately 20 percent) based on coda durations.

The recurrence curve for all the 1978–1992 events in the catalog is shown in figure 6. This curve, when extrapolated on a constant-slope basis, predicts a M 6 earthquake every 150 years in the SGB and a M 7 earthquake approximately every 1,000 years in the SGB. This curve also shows that the seismic threshold (point of 90 percent detection) is approximately M 1.3 for the network as a whole. Gomberg (1991) has shown how this threshold varies across the SGB owing to the station distribution. Most importantly, the threshold is considerably lower (by perhaps one magnitude unit) in the immediate vicinity of Yucca Mountain because of the denser station coverage there.

The distribution of reported depths for SGB earthquakes in the period of 1978–1992 is shown in figure 7. Many events are reported at zero depth, indicating that the location algorithm placed them above the surface; they are consequently constrained to zero while final latitudes and longitudes are

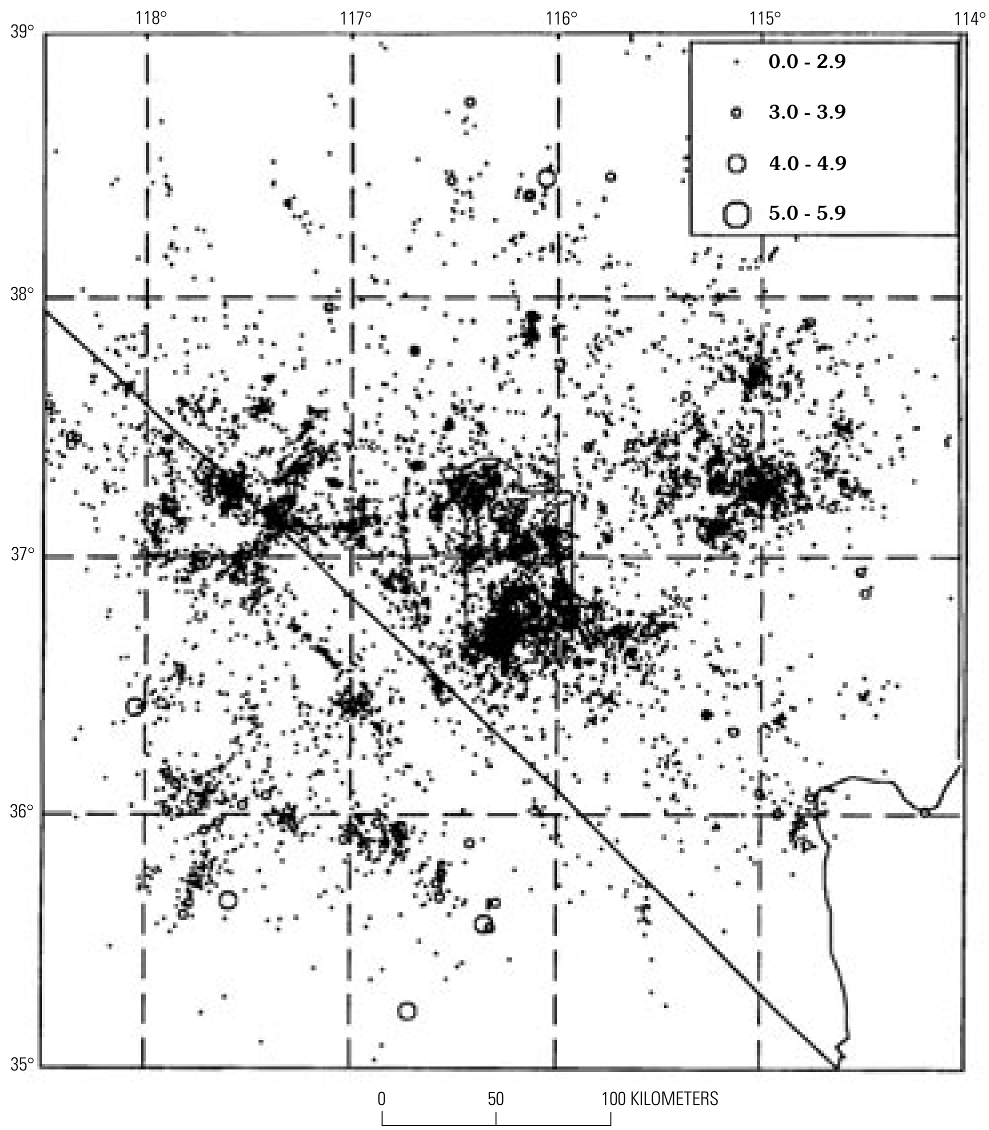

Figure 4. Epicenters of earthquakes in southern Great Basin 1978–1992 catalogs. Outline of Nevada Test Site in center of map.

obtained. Most of the depths greater than 15 km are unreliable, and events for which this occurs are generally on the fringes of the reporting area.

Since 1978, focal mechanisms have been derived for 120 earthquakes in the SGB, exclusive of the Little Skull Mountain area, by the analysis of *P*-wave first motions. The pressure (P) and tension (T) axes of these focal mechanisms can be examined for regional trends. The directions of the P and T axes are shown separately in figure 8. In these plots, the length of the arrow has been determined by the cosine of the dip angle of the axis; thus, a mechanism with a horizontal P or T axis will project the longest arrow. Pressure axes are generally oriented NE.-SW. whereas tension axes are generally NW.-SE. This agrees with the regional stress field inferred for southern Nevada from earlier events (Gawthrop and Carr, 1988), from seismicity studies (Meremonte and Rogers, 1987), and with the results of Smith, Brune, and others (this volume) and Harmsen (1994) for earthquakes of the Little Skull Mountain sequence. A composite focal mechanism plot of the data of figure 8 is shown in figure 9. This clearly shows the grouping of the P axes and T axes.

Seismicity Near Yucca Mountain

The seismicity near Yucca Mountain is of importance for seismic hazard assessment. Therefore, an area of 10-km radius around the north portal of the Exploratory Studies Facility (ESF) (lat 36.8725° N., long 116.4281° W.) was examined for seismic activity. Again, the data are divided into two time periods, 1968–1978 and 1978–1992.

The catalog of Meremonte and Rogers (1987) lists only four events within 10 km of Yucca Mountain (as measured from the ESF location), as listed in table 2. These events preceded the SGBSN and, as discussed previously, the locations

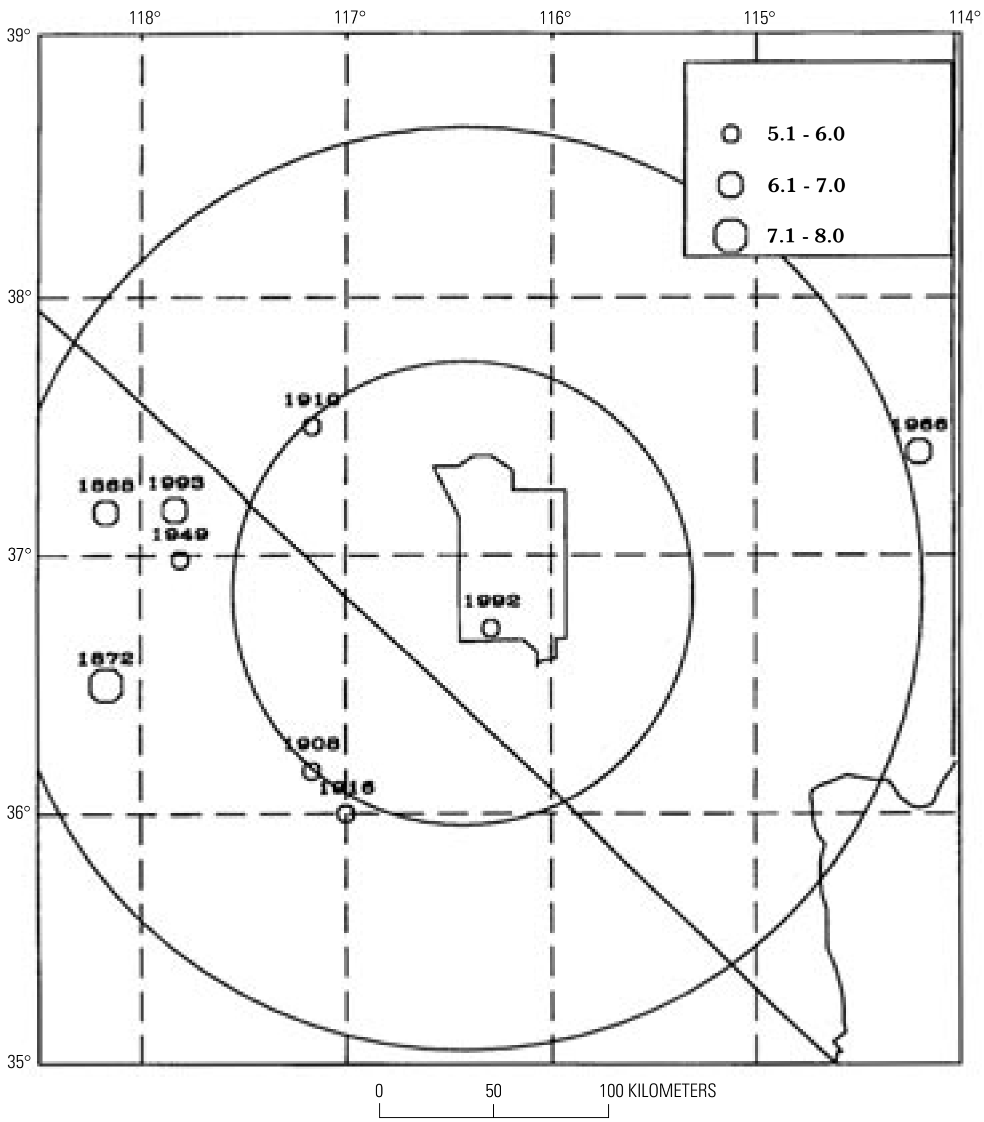

Figure 5. Epicenters of significant earthquakes in southern Great Basin since 1868. Radii of 100 and 200 km from Yucca Mountain are shown. Outline of Nevada Test Site in center of map.

are not reliable. The last three events have no magnitude given and are presumed to be small. Figure 10 shows the reported location of the October 1, 1948 earthquake whose location was originally shown as being very near the potential repository. The closest locating station at Tinemeha, Calif., approximately 160 km to the west, had variable and unreliable timing on this date. Figure 11 shows that the Pn (base of crust) and Pg (middle of crust) waveforms of this event (October 1, 1948) at Tinemeha are identical to those of the events at 11:25 GMT on August 29, 1948, and at 01:11 GMT on August 30, 1948, and very similar to that of the M 5.6 Little Skull Mountain mainshock at 10:14 GMT on August 16, 1992 (Tinemeha was running at low gain at the time of the mainshock). The largest of the 1948 events, on August 30, M 4.0, is most likely the best located. Its location is south of Little Skull Mountain, more than 35 km from Yucca Mountain; and Pg-Pn time and its waveform are the same as the other 1948 events (fig. 11). Nuclear tests at Rainier Mesa in the northern part of the NTS gave a nearly zero Pg-Pn time and those in Yucca Flat about 1.0 second Pg-Pn time at Tinemeha. These timing data, with a correction for depth, confirm that the October 1, 1948, event was at least 20 km southeast of Yucca Mountain. A conclusion that all the 1948 events recorded were actually located near Little Skull Mountain, or farther southeast in Rock Valley, appears reasonable. This conclusion is also supported by the fact that all three 1948 events occurred so close in time.

Figure 12 shows the seismicity within the 10 km radius around Yucca Mountain from the 1978–1992 SGBSN catalog. This data set contains 29 events, none with M > 1.2. Locations for this time period are more reliable than those for events in the historical catalog. However, because the events are so small, their locations are subject to large uncertainties owing to the possible misinterpretation of seismograms. Reexamination of these small events (S. Gross, University of Colorado, written commun., 1995) indicates that roughly one-third of them are located outside the 10-km radius or are not actual earthquakes (being sonics or other noise). Therefore, the count of 29 is an upper limit.

Table 1. Significant earthquakes in southern Great Basin since 1868.

[?, location, depth, or magnitude uncertain]

Origin time				Latitude (N.)		Longitude (W.)		Depth	M[2]	MMI[3]	Geographic location
Yr	Mo	Day	Hr/min/s[1]	Deg	Min	Deg	Min	(km)			
1868	09	04	16:00:00.00	37	10.00?	118	10.00?	?	6.3?	8	Independence, Calif.
1872	03	26	02:30:00.00	36	30.00?	118	10.00?	?	8.0?	9	Owens Valley, Calif.
1908	11	04	08:37:00.00	36	10.00?	117	10.00?	?	5.7?	?	Death Valley, Calif.
1910	11	07	17:20:00.00	37	30.00?	117	10.00?	?	5.7?	8	Goldfield, Nev.
1916	11	10	09:11:00.00	36	00.00?	117	00.00?	?	5.5?	6	Death Valley, Calif.
1949	02	11	21:05:23.00	36	58.98	117	48.30	?	5.5?	6	Eureka Valley, Calif.
1966	09	22	18:57:34.00	37	24.00	114	12.00	7.00	6.1	6	Caliente, Nev.
1992	06	29	10:14:22.00	36	43.02	116	17.58	10.00	5.6	8	L. Skull Mtn., Nev.
1993	05	17	23:20:50.00	37	10.56	117	49.92	9.00	6.1	5	Eureka Valley, Calif.

[1]Universal Time.
[2]Magnitude.
[3]Modified Mercalli Intensity.

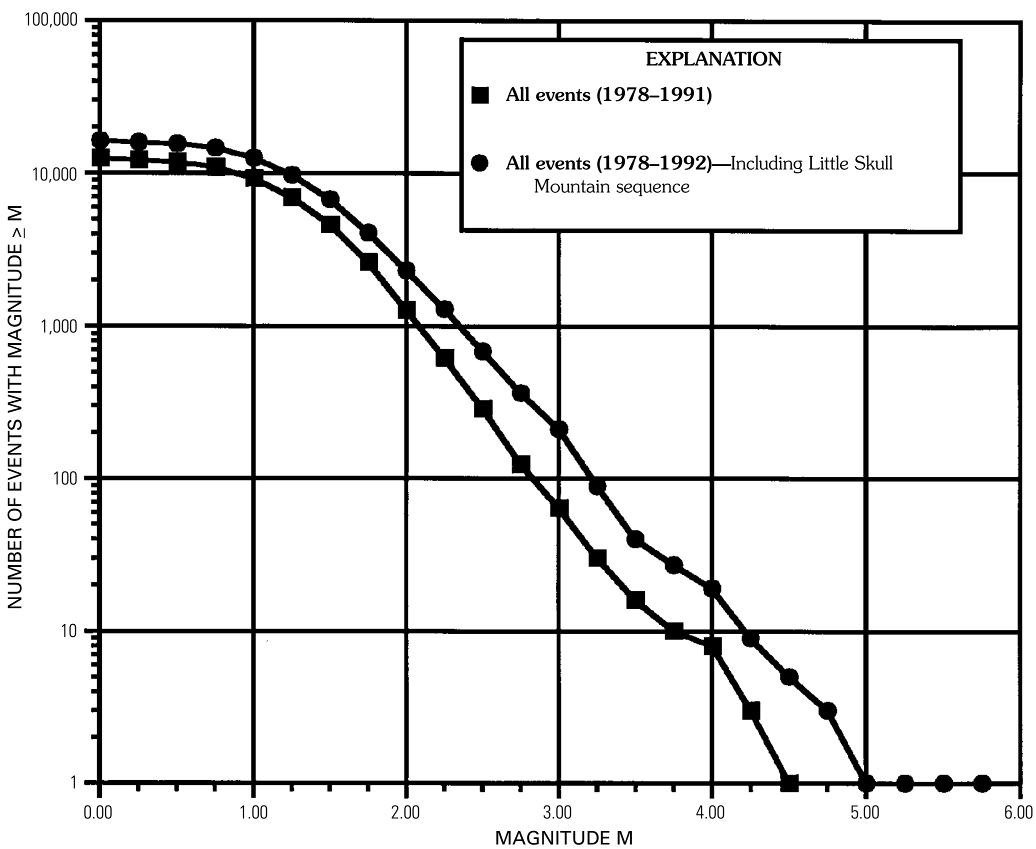

Figure 6. Recurrence curve for seismicity of southern Great Basin for 1978–1992.

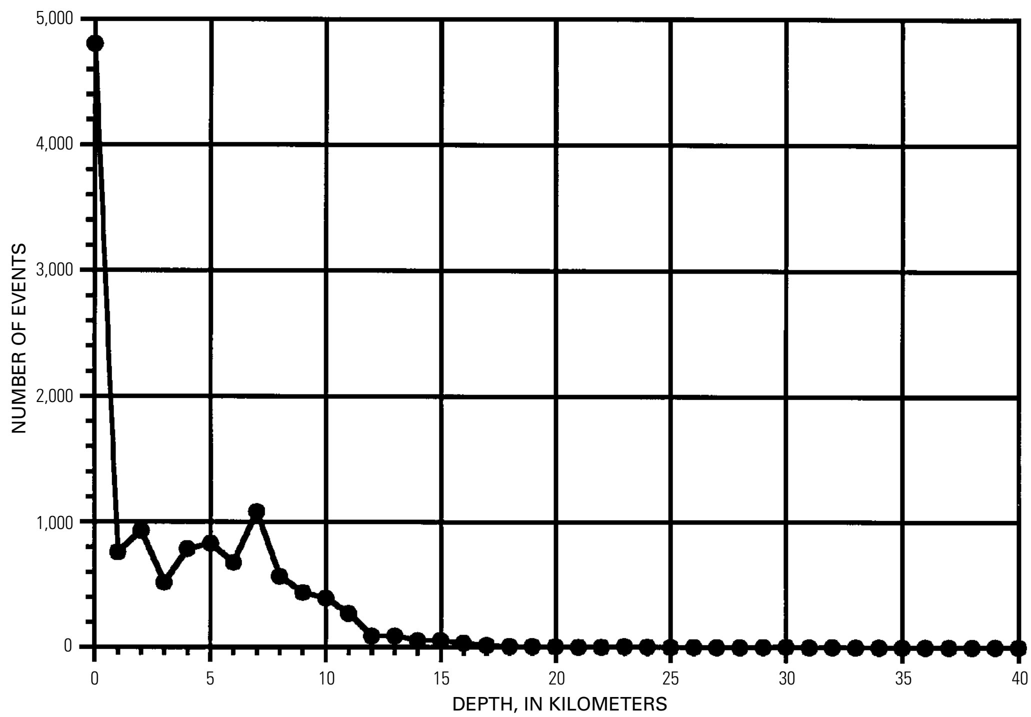

Figure 7. Depth distribution of earthquakes in southern Great Basin 1978–1992.

A comparison of the seismicity rate at Yucca Mountain with that of the SGB as a whole can be made using the recurrence curves of the earthquakes plotted in figures 4 and 12. An adjustment for different areas in each figure can be made by multiplying the number of events in the SGB by $10^2/150^2$, the ratio of the areas, in order to make that number appropriate to an equivalent 10-km radius. The recurrence curves are then plotted together in figure 13. Downward arrows on the Yucca Mountain curve indicate its “upper limit” nature. Although an accurate assessment is difficult, the observed seismicity rate in the immediate vicinity of the potential repository appears to be several times less than that of the average, similar-size, area in the SGB. Taken as a whole, the southern Great Basin has many areas that show similarly low seismicity rates; however, they can be broken by a significant earthquake, as in the Little Skull Mountain area on June 29, 1992. Further confirmation of the low seismicity rate at Yucca Mountain has been made in the microearthquake study of Brune and others (1992). They reported that only one event of M > –1 was recorded in 25 days of quiet recording time. This observation extrapolates to a microseismicity rate at M > –1 of 219 events per 15 years within approximately the 10-km-radius circle around Yucca Mountain. This point is plotted in figure 13 to compare with the extrapolated Yucca Mountain recurrence rate. We stress that this value is uncertain because it is based on only one event. The actual curve determined from the SGBSN data would, if extrapolated to M –1, fall at or below approximately this point.

Conclusions

The seismicity of the southern Great Basin is moderate, and an estimated recurrence interval of an M 6 event is roughly 150 years. The seismicity is geographically distributed in clusters of high activity with zones of relatively low activity between. The region in the immediate vicinity of the potential repository had been a zone of very low activity for at least 15 years prior to the 1992 Little Skull Mountain earthquake and probably as far back as at least the 1930’s when instrumental monitoring began for this area. Focal mechanisms of events recorded since 1978 reflect the regional tectonic stress, with tension oriented in a NW.-SE. direction.

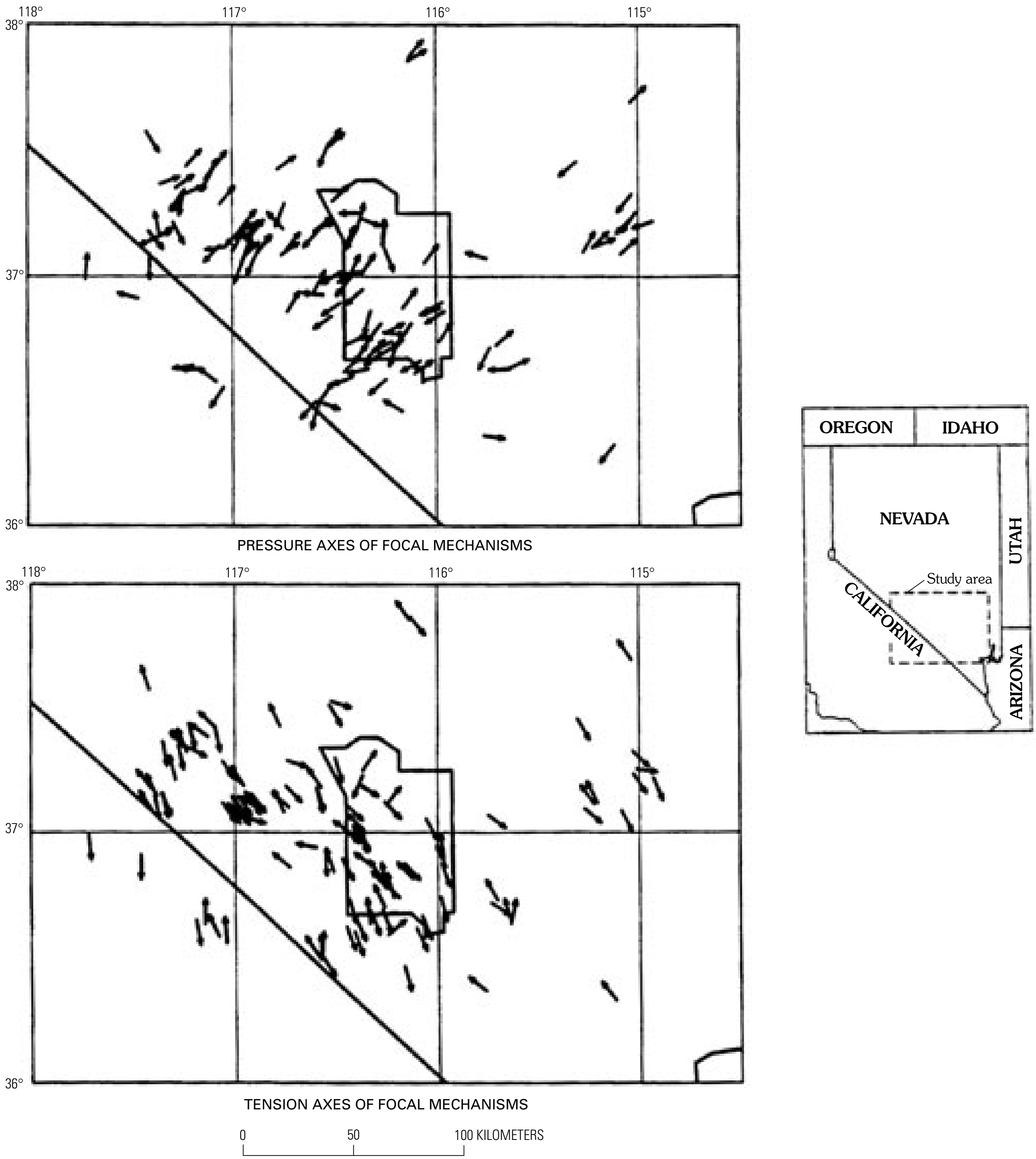

Figure 8. Orientations of pressure and tension axes for 1978–1992 events whose focal mechanisms were determined from first motions. Outline of Nevada Test Site in center of large maps.

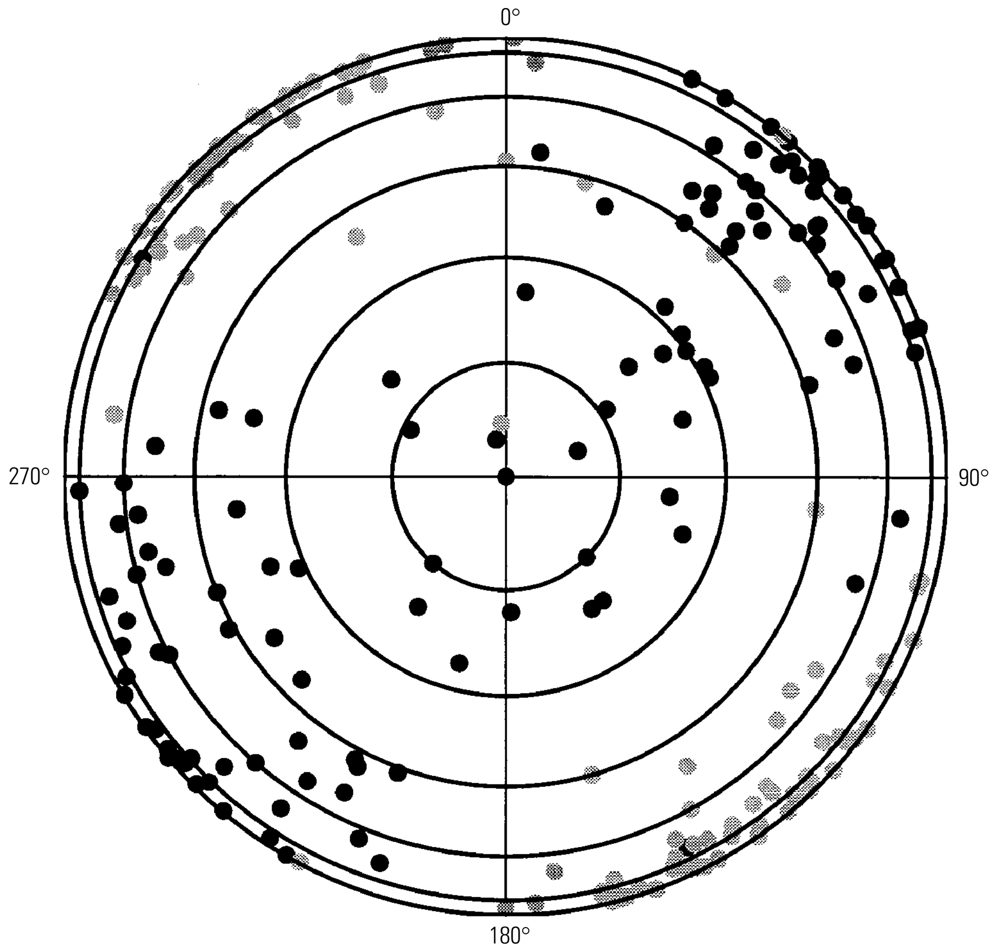

Figure 9. Projections of pressure and tension axes onto focal sphere for 1978–1992 events whose focal mechanisms were determined from first motions. Black dots, intersection of pressure axes; gray dots, intersection of tension axes. Concentric circles represent every 15° of dip angle from vertical, with outside edge being horizontal.

Table 2. Earthquakes within 10 kilometers of Yucca Mountain in the historical catalog of Meremonte and Rogers, 1987.

Origin time				Latitude (N.)		Longitude (W.)		Depth (km)	Magnitude
Yr	Mo	Day	Hr/min/s[1]	deg	min	deg	min		
1948	10	01	01:11:21.00	36	49.98	116	27.00	6.0	3.6
1972	09	26	17:15:59.11	36	54.00	116	24.60	5.0	0.0
1973	02	18	01:18:06.84	36	52.20	116	19.20	5.7	0.0
1973	04	19	10:24:36.39	36	55.20	116	30.00	0.0	0.0

[1]Universal time.

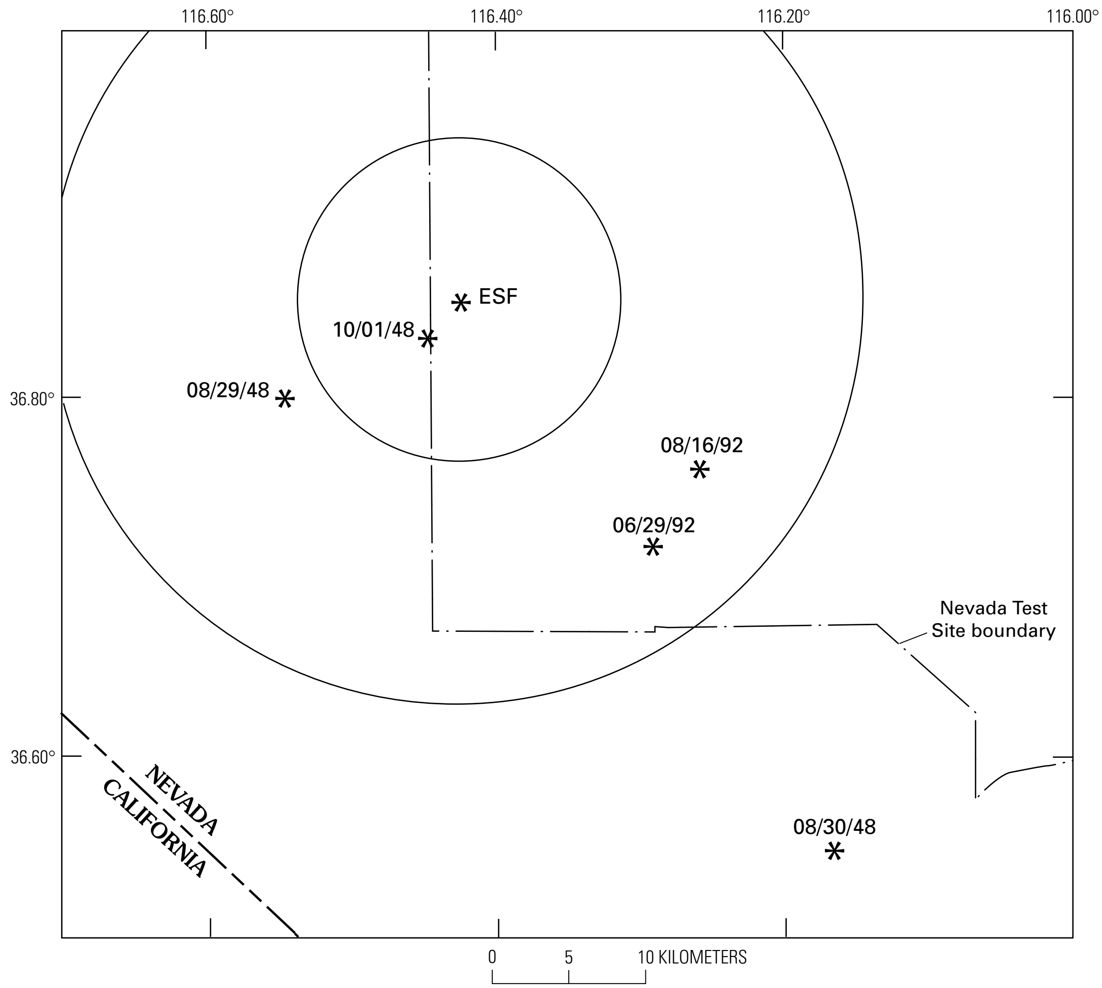

Figure 10. Earthquakes used in studying location problems for pre-1978 events near Yucca Mountain.

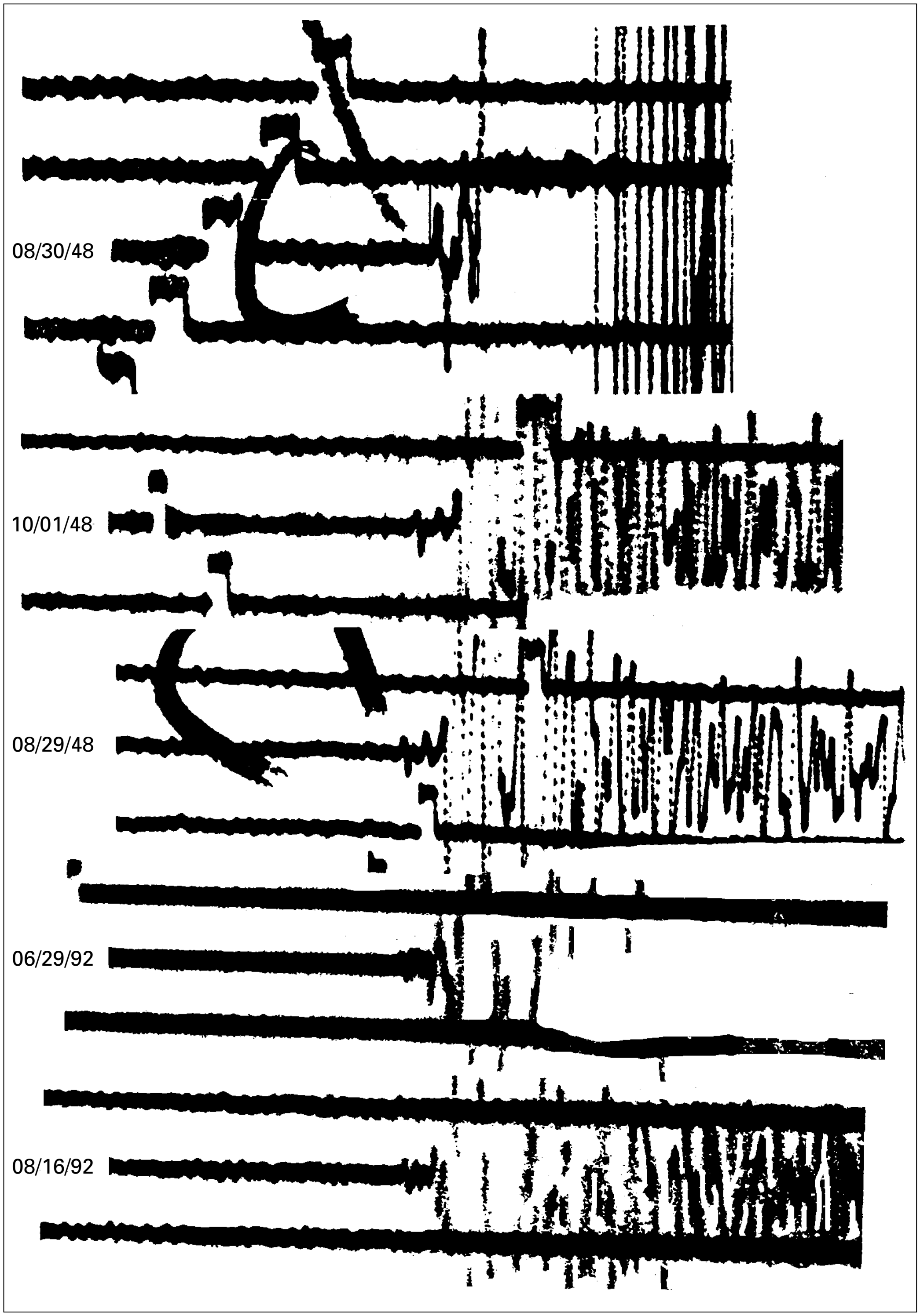

Figure 11. From top to bottom, Pn and Pg arrivals at station TIN (Tinemeha) from three earthquakes near Yucca Mountain in 1948, Little Skull Mountain mainshock of June 29, 1992, and one of its aftershocks of August 16, 1992.

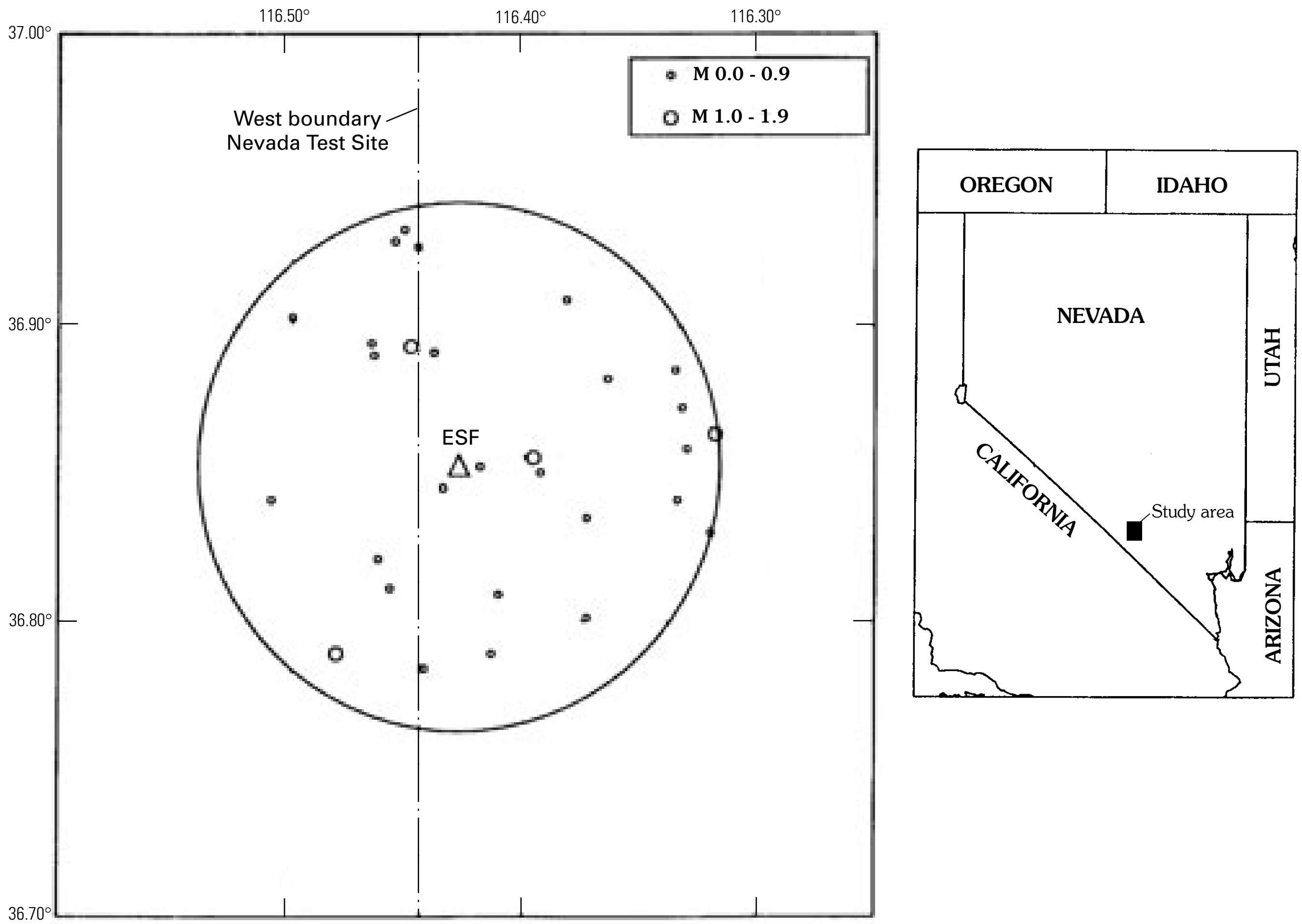

Figure 12. Epicenters of earthquakes in the Southern Great Basin Seismic Network 1978–1992 catalogs within 10 km of north portal of Exploratory Studies Facility (ESF) at Yucca Mountain.

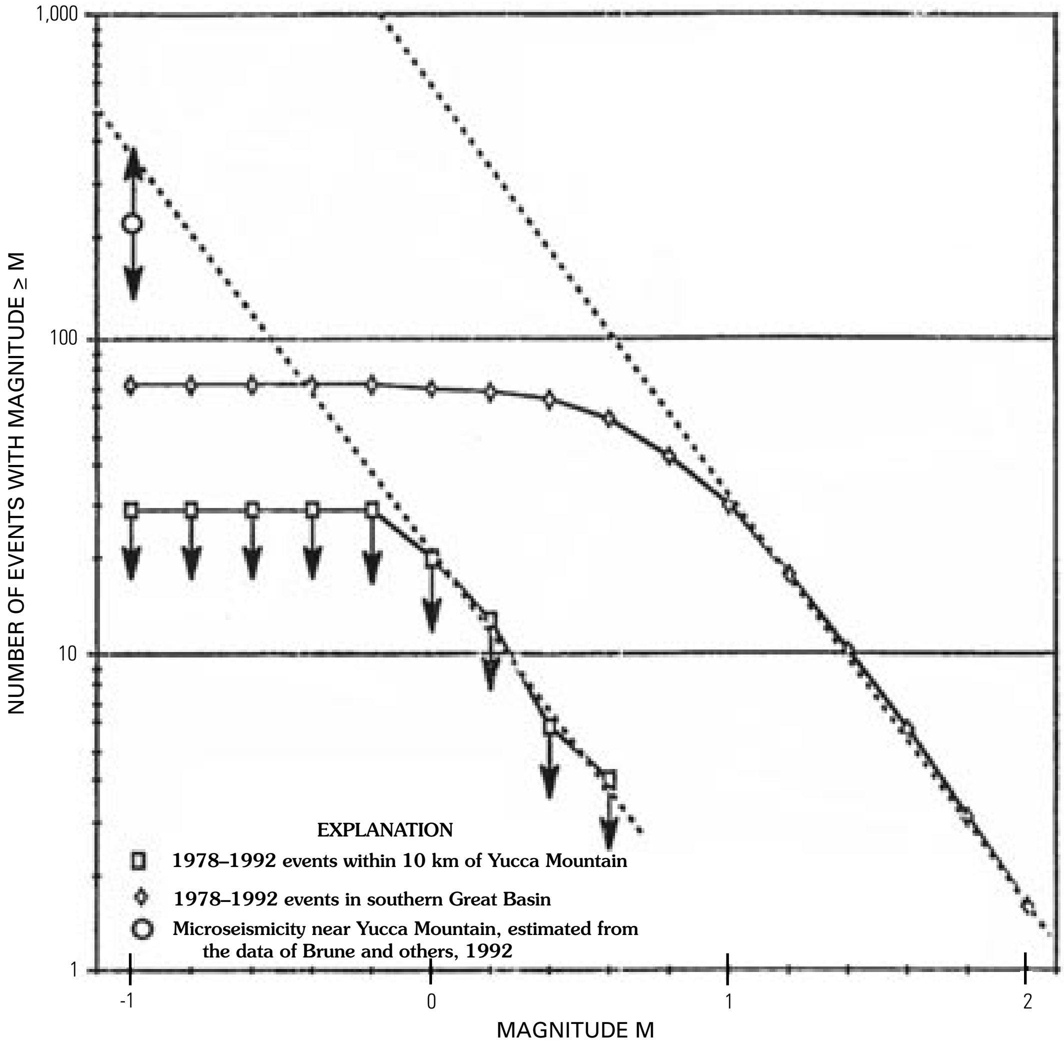

Figure 13. Recurrence curves for earthquakes of figure 12 and for earthquakes of figure 4 after adjustment to a 10-km-radius circle. Arrows on lower curve indicate that it is an upper bound. Diagonal dotted lines are visual fits to the curves above the complete detection thresholds.

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