Department of Energy
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John W. Bartlett, Director, Civilian Radioactive Waste Management,
HQ (RW-1) FORS

ACTION PLAN TO ASSESS SEISMIC HAZARD AT YUCCA MOUNTAIN ON A PRIORITY BASIS

References: (1) Memo, Bartlett to Gertz, dtd 7/6/92
(2) Ltr, Gertz to Bartlett, dtd 8/6/92

In response to your memorandum referenced above, the Yucca Mountain Site Characterization Project Office has prepared a seismic action plan (enclosure) to accelerate seismic studies at Yucca Mountain, Nevada. The plan consists of four major components: (1) an accelerated technical program; (2) an evaluation of the seismic hazard aspects of site suitability; (3) a study of seismic vulnerabilities of a potential underground repository at Yucca Mountain; and (4) preparation of topical reports to support resolution of this issue with the U.S. Nuclear Regulatory Commission (NRC). The enclosed plan differs somewhat from the one described in outline in my letter of August 6, 1992. The differences reflect an evolution in our thinking on how to address the issues raised in your original correspondence.

The technical program described in the Site Characterization Plan and related study plans will be accelerated by moving forward into fiscal year (FY) 1993, those activities that can be carried out in parallel. Follow-on activities will be initiated as these early activities near completion. The activity plans are also being examined to consolidate or revise activities as appropriate. Data from the Little Skull Mountain earthquake sequence will be incorporated into studies within the current technical program.

The effect of seismic hazards on the suitability of the Yucca Mountain site for a potential repository will be evaluated. Discussions presented in the Early Site Suitability Evaluation will be reconsidered in light of new data and interpretations arising from the accelerated technical program. This evaluation and subsequent report are scheduled for FY 1994.

The seismic vulnerability study will assess the consequences of various levels of seismic hazard on the potential repository at Yucca Mountain. This study will respond to repeated comments from the Nuclear Waste Technical Review Board that suitability must be evaluated not just in terms of the ground motion and fault displacement that could occur at the site, but also in terms of their consequences. This study and subsequent report are scheduled for FY 1994.

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Issue resolution will address seismic hazard concerns raised by the NRC to increase confidence that results produced by the seismic hazard program will be appropriate and sufficient. The issue resolution process will produce two topical reports. The first, to be completed in FY 1993, will cover methodology for seismic hazard assessment. The second, scheduled for FY 1996, will represent the culmination of the accelerated seismic program. The latter will address site suitability and seismic design basis issues.

Funding required for the accelerated program is shown by fiscal year. The costs of the accelerated program include those for support activities such as environmental permits and surveys, and trenching along known fault traces.

If you have any questions concerning this action plan, please contact me at (702) 794-7920. We look forward to implementing the action plan upon your authorization.

for Margaret Blanchard
Carl P. Gertz
Project Manager

RSED:AVG-5014

Enclosure:
Action Plan to Assess Seismic
Hazard at Yucca Mountain on
a Priority Basis

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ACTION PLAN TO ASSESS SEISMIC HAZARD AT YUCCA MOUNTAIN ON A PRIORITY BASIS

1. INTRODUCTION

The magnitude 5.6 earthquake beneath Little Skull Mountain on June 29, 1992 heightened public awareness of seismic hazards in the vicinity of the potential repository at the Yucca Mountain site. The mainshock and its aftershocks also provided a wealth of data that can be used to reduce uncertainties in assessing seismic hazard for this region (Appendix 1). Given the increased public concern, and the opportunity offered by the new data set, Dr. John Bartlett requested that the Yucca Mountain Project Office (YMPO) develop an Action Plan to accelerate seismic hazard studies at Yucca Mountain. This document represents YMPO's response to Dr. Bartlett's request.

2. OBJECTIVE

The objective of this Action Plan is to produce a series of reports that culminates in a Topical Report providing an assessment of seismic hazard at Yucca Mountain. This objective will be accomplished by reviewing and accelerating the current seismic hazards program. Progress will be measured by a series of interim reports that describe the results of major activities as they are completed. These reports will include:

• Technical Assessment: ESF Seismic Design	Dec 1992
• Topical Report: Seismic Hazard Methodology	Apr 1993
• Final Quaternary Fault Map of the Yucca Mountain Area	Apr 1993
• Quaternary Faulting in Midway Valley	Nov 1993
• Update on Site Suitability: Seismic Hazard Considerations	May 1994
• Seismic Vulnerability of a Potential Underground Repository at Yucca Mountain	Jun 1994
• Effects of Local Site Geology on Seismic Ground Motion	Sep 1994
• Preliminary Deterministic Seismic Hazards Assessment of Yucca Mountain	Dec 1994
• Final Determination of Ground Motion from Controlling Seismic Events	Sep 1995
• Probabilistic Seismic Hazard Analysis of Yucca Mountain	Dec 1995
• Topical Report: Seismic Hazard and Seismic Design Basis for Yucca Mountain	Jun 1996

The Action Plan also describes funding, resources and support activities that must be provided to implement the plan successfully.

ENCLOSURE

3. SUMMARY OF BASELINE PLAN TO ASSESS SEISMIC HAZARD

The current program to assess seismic hazards in the vicinity of Yucca Mountain is contained in the Site Characterization Plan and related Study Plans. Sources of future earthquake activity are to be identified through studies of Quaternary faults, an evaluation of contemporary and historical seismicity, and development of tectonic models for the region. Rates of future activity will be inferred from geologic evidence of past movement and from analysis of the earthquake catalog. Earthquake magnitudes will also be estimated on the basis of paleoseismic studies and historically documented events within the Basin and Range and elsewhere. Ground motion levels from future earthquakes will be assessed using both regional data appropriate for the Yucca Mountain area and site specific data. Probabilistic and deterministic methods will be employed to evaluate the hazard at the site and develop a seismic design basis. Table 3-1 lists the activities related to seismic hazard assessment.

The program to assess seismic hazards at Yucca Mountain is already underway. Nineteen studies are active. They include: Evaluation of Quaternary Activity on Faults at or within 100 km of the Site (17.4.3.1, 17.4.4.1, 17.4.6.1, 17.4.6.2, 17.4.2.1, 17.4.2.2), Monitoring Current Seismicity (17.4.1.2), Evaluating Tectonic Processes and Tectonic Stability at the Site (17.4.12.1), Surface Fracture Network Studies (4.2.2.2), and Borehole Evaluation of Faults and Fractures (4.2.2.3).

TABLE 3-1
Studies Related to Seismic Hazard Assessment

Tectonic Data Collection	
8.3.1.17.4.2	Midway Valley - Surface Facility
8.3.1.17.4.3	Quaternary Faulting Within 100 km of Yucca Mountain
8.3.1.17.4.4	Quaternary Faulting within NE-Trending Fault Zones
8.3.1.17.4.5	Detachment Faults
8.3.1.17.4.6	Faulting at the Site
8.3.1.17.4.7	Subsurface Geometry of Faults
8.3.1.17.4.8	Stress Fields within the Site
8.3.1.17.4.9	Tectonic Geomorphology
8.3.1.17.4.10	Geodetic Leveling
8.3.1.17.4.11	Regional Lateral Crustal Movement
Seismic Hazards Interpretation and Modeling	
8.3.1.17.3.1.1	Identify Relevant Earthquake Sources
8.3.1.17.3.1.2	Deterministic Seismic Hazard Analyses
8.3.1.17.3.3	Ground Motion from Regional Earthquakes
8.3.1.17.3.4	Site Effects on Ground Motion
8.3.1.17.3.5	Ground Motion from Controlling Events
8.3.1.17.3.6	Probabilistic Seismic Hazard
8.3.1.17.3.12	Tectonic Model and Synthesis
Critical Geologic Supporting Studies	
8.3.1.4.2.1.2	Surface-Based Geophysics
8.3.1.4.2.2.1	Geologic Mapping North and West of Yucca Mountain
8.3.1.4.2.2.2	Surface Fracture Studies
8.3.1.4.2.2.3	Borehole Evaluation of Faults
8.3.1.8.5.2.3	Heat Flow at Yucca Mountain
8.3.1.8.3.2.5	Effects of Faulting on Water Table Elevation
8.3.1.5.1.4.2	Surficial Deposits Map of Yucca Mountain
Operation of Seismic Monitoring Network	
8.3.1.17.4.1	Historical and Current Seismicity

4. ACCELERATED PROGRAM TO ASSESS SEISMIC HAZARDS

The program to assess seismic hazards at Yucca Mountain will be accelerated on four fronts. First, elements of the current technical program that can be carried out in parallel will be moved forward in time. Data collected from the June 29th earthquake will be incorporated into the assessment of hazard, particularly in understanding ground motion at the site. Second, the suitability of the site with respect to seismic ground motion and fault displacement will be evaluated. Third, a seismic vulnerability study will be carried out for the potential underground repository. Fourth, resolution of issues of concern to the NRC will be pursued to increase confidence that the proposed design basis will be appropriate and acceptable. The major components of these four elements are discussed below. A detailed schedule for the accelerated seismic hazards program is being developed.

4.1 Accelerated Technical Program

The technical program to assess seismic hazards at Yucca Mountain consists of a series of studies and activities described in the Site Characterization Plan. Some of these activities are not dependent on each other; others depend on the completion of predecessor activities. The accelerated program moves all non-dependent activities forward to FY93. Dependent activities will be initiated as predecessors are completed.

Technical activities that will be accelerated in the coming fiscal year include:

(1) The seismic hazards program will be accelerated to begin in FY93 instead of FY94. Study plans for ground motion models from regional earthquakes (8.3.1.17.3.3) and probabilistic seismic hazards (8.3.1.17.3.6) will be written by early in FY93. The study of relevant earthquake sources (8.3.1.17.3.1) will be revised to begin a deterministic seismic hazard analysis of Yucca Mountain in FY93. The study of local site effects on ground motion (8.3.1.17.3.4) will be accelerated and will use the new seismic data collected from the June 29 earthquake. Conclusions regarding site effects, therefore, will be available at least one year earlier than originally planned.

(2) Data collection of the paleoseismic histories of faults will be accelerated. Emphasis will be placed on faults that are likely to make a significant contribution to ground motion hazard at the site.

(3) Data collection on faults and potential faulting in the surface facilities area will be completed by October 1993.

(4) The study plan for tectonic models and synthesis will be submitted in early FY93, six months ahead of the current schedule. Work will initially be directed towards how the proposed alternative tectonic models will affect seismic hazard assessment.

(5) The planned deep seismic refraction/reflection line across Crater Flat and Yucca Mountain will be extended across Forty Mile Wash to locate faults not apparent at the surface, and to examine the subsurface geometry of known Quaternary faults.

(6) Collection of data related to the present state of stress (8.3.1.17.4.8) and strain (8.3.1.17.4.11) in the Yucca Mountain area will be accelerated to begin in FY93 instead of FY94. Both activities will be completed by FY95 instead of FY97.

(7) A team of experts in seismic hazard assessment will be formed by the USGS in FY93 to analyze the present geologic and tectonic data base, as well as to provide recommendations on the appropriate ground-motion assessment models to be used at Yucca Mountain. This increase in manpower will not only speed final issue resolution, but will increase confidence levels for interim products.

We emphasize that supportive elements of the accelerated plan must also be accelerated. Priority will be placed on obtaining environmental permits and performing pre-activity environmental surveys. Contractor support for surveying and construction activities will also be provided. Assistance may also be required from DOE-HQ in requesting NRC to expedite review of study plans or Topical Reports.

4.2 Evaluation of Seismic Hazards and Site Suitability

An understanding of seismic hazards contributes to the evaluation of whether Yucca Mountain is a suitable site for a potential repository. In Report of Early Site Suitability Evaluation of the Potential Repository Site at Yucca Mountain, Nevada, a higher-level finding was reached for the Disqualifying Condition related to preclosure tectonics. For the Qualifying Condition, however, only a lower-level suitability finding (Level 3) could be reached. To obtain a higher-level finding, it was felt that more site specific data were needed to evaluate the ability to design surface facilities using reasonably available technology.

With the completion of trenching studies in Midway Valley in October 1993, it will be appropriate to re-examine this Qualifying Condition. A Working Group will be convened to review available data and decide if a higher-level finding is supported. This finding will be described in a report. The report will then be subjected to a Technical Assessment or a Peer Review. The goal is to complete the report in May 1994.

4.3 Seismic Vulnerability Study of the Potential Underground Repository

The suitability of the Yucca Mountain site from a seismic viewpoint should be evaluated not solely on the basis of the ground motion or fault displacement levels that might be experienced, but also on the basis of their consequences of these events. Thus, the vulnerability of the potential repository to seismic hazards, and the implications for worker safety and radiological release to the environment, need to be evaluated. This point has been repeatedly emphasized by the Nuclear Waste Technical Review Board.

In recognition of the importance of seismic vulnerability studies, DOE carried out in 1988 a Preliminary Seismic Design Cost-Benefit Assessment of the Tuff Repository Waste-Handling Facilities (SAND88-1600). This report examined the combined costs of design, licensing, construction and the consequences of failure as a function of different seismic design levels. As part of the accelerated seismic program, a similar study will be made for the potential underground repository.

The vulnerability of the repository will be assessed in terms of consequences for different levels of expected ground motion. The costs of those consequences will then be evaluated to determine whether they are significant, and how they vary as a function of ground motion level. If warranted, the seismic hazards program will be adjusted to place emphasis on those studies that provide insight into effects with significant consequences. This activity will begin in mid-FY93 with a completion goal of June 1994.

4.4 Seismic Hazards Issue Resolution with the NRC

A Seismic Hazards Issue Resolution Working Group has been established to resolve an appropriate methodology for determining a seismic design basis at Yucca Mountain. A plan to carry out this task was developed for DOE on July 23, 1992. As a result of the directive to assess seismic hazards on a priority basis, the issue resolution schedule has been revised so that a DOE Topical Report on an appropriate methodology to assess seismic hazards can be transmitted to the NRC by April 1, 1993. While both the DOE and the NRC staff agree that deterministic and probabilistic approaches are needed, the emphasis and details of the methods still require discussion.

To try to resolve the methodology issue, the Working Group will review Guidelines on Dynamic Analysis and Design Considerations for High-Level Nuclear Waste Repositories being prepared by the American Society of Civil Engineers (ASCE), Design and Evaluation Guidelines for Department of Energy Facilities Subjected to Natural Phenomena Hazards (UCRL-15910), any pertinent Staff Technical Positions (STP) issued by the NRC staff, and the approach contained in the Site Characterization Plan. The Working Group will then identify the most appropriate methodology based on the strengths and weaknesses of the reviewed material. The recommended approach may differ in some respects from the one presented in the Site Characterization Plan. The recommendation defining activities and approaches needed to assess seismic hazard at Yucca Mountain will be described in a Topical Report. The report will serve as a basis for discussion and negotiation with the NRC staff to reach a resolution on this issue.

An accelerated schedule to resolve the issue of an appropriate methodology for seismic hazards assessment at Yucca Mountain calls for resolution of the issue by the end of fiscal year 1993. The Topical Report will be completed in March 1993 and submitted to the NRC. Revisions to Study Plans to reflect any changes from the current approach can begin in October 1993. Any changes in the planned program will be reported in Semi-Annual Progress Reports. This aggressive schedule is necessary to increase the likelihood that the work carried out will be acceptable in a licensing proceeding.

A follow-on Topical Report summarizing the results of the deterministic and probabilistic seismic hazard assessments for Yucca Mountain is also included as part of the accelerated program. This report will describe the findings of the accelerated program with respect to a seismic design basis for the potential repository. It will draw from the interim reports to support its conclusions. It will represent the culmination of the accelerated seismic hazards program. Work on this Topical Report will begin in January 1996; it is scheduled for completion in June 1996.

5. REQUIRED RESOURCES, FUNDS AND SUPPORT

Resources to carry out the accelerated seismic program are summarized in Table 5-1. The primary effect of acceleration is to shift costs from out years into more immediate years. There also are some new costs associated with hiring and training personnel to staff the accelerated activities. Such costs would not be incurred if the activities were carried out in series over a longer period of time. Estimates of the cost for this support are included in Table 5-1.

TABLE 5-1
COST SUMMARY (000'S) FOR ACCELERATED SEISMIC PROGRAM

	FY93	FY94	FY95	FY96
Technical Program				
Seismic/Tectonic Activities	3808	5395	4325	3035
Other Geologic Activities Supporting Seismic Hazards Assessment	1765	2025	1240	1200
Permitting and Field Support Activities	650	450	100	---
Site Suitability Evaluation	---	500	---	---
Seismic Vulnerability Study	400	400	---	---
Issue Resolution				
Topical Report: Methodology	500	---	---	---
Topical Report: Seismic Hazard Assessment	---	---	---	800
TOTAL COST	7123	8770	5665	5035

APPENDIX 1
SUMMARY OF FINDINGS ON THE LITTLE SKULL MOUNTAIN EARTHQUAKE OF JUNE 29, 1992.

THE LITTLE SKULL MOUNTAIN EARTHQUAKE OF JUNE 29, 1992

University of Nevada, Reno, Seismological Laboratory,
Reno, Nevada

U.S. Geological Survey, Branch of Geological Risk Assessment,
Golden, Colorado

OVERVIEW

The Little Skull Mountain Earthquake of June 29, 1992, M = 5.6, is the largest recorded earthquake within the boundaries of the Nevada Test site (several large underground explosions have had larger body wave magnitudes). Although M = 5-6 earthquakes are common in Nevada and could occur almost anywhere, because the earthquake is near the proposed national high level nuclear waste repository at Yucca Mountain (Fig. 1) it is of particular importance and interest. Aftershock recording equipment was installed around the epicenter within a couple of days by the USGS, Branch of Geological Risk Assessment, Golden, and University of Nevada, Reno, Seismological Lab. Thousands of aftershocks have been recorded and are providing a wealth of data for outlining the fault plane of the fault (or faults) which slipped. Also being carried out are studies of source physics (e.g., stress drop and complexity), rock attenuation, and effects of near surface geology on ground motion (e.g., at the Yucca Mountain Field Operations Center, FOC).

Several aspects of the earthquake occurrence are unique. The time of the earthquake was apparently in part determined by the occurrence of the M = 7.4 Landers earthquake, which triggered a considerable amount of activity throughout the western U.S. The Little Skull Mountain earthquake caused considerable damage to the Field Operations Center for the Yucca Mountain project, --the first earthquake known to have caused significant damage on NTS. The earthquake occurred within the relatively dense Southern Great Basin Seismic Network operated by the USGS (now in the process of transfer to the University of Nevada, Reno). A very sensitive 4-station micro-earthquake array was in operation near the proposed repository site and continued to operate through both the Landers and Little Skull Mountain earthquakes (and up to the present). This array provides important information on the microseismicity in the immediately vicinity of the proposed repository, but also gives a continuous record of the activity at Little Skull Mountain before and after the Landers and Little Skull Mountain earthquakes.

Finally, the earthquake provided an important opportunity to study rockfalls caused by earthquakes. The earthquake dislodged numerous large boulders from the crest of Little Skull Mountain, and further study of these boulders, and others possibly dislodged by earlier earthquakes, may provide important data on seismicity in the region, and on the erosional effects of earthquake shaking. Some constraints may be placed on the ground motion expected at Yucca Mountain based on the ground acceleration that would be necessary to topple precarious rocks observed near the proposed repository site.

1. BACKGROUND SEISMICITY AND TECTONIC SETTING.

The region near Little Skull Mountain has been one of low level seismicity since the installation of the Southern Great Basin Seismic Network (Fig. 2). Based on this, a moderate sized earthquake in the region was not unexpected. Earthquakes with magnitudes greater than 5 have occurred in many parts of Nevada (Figs. 3 and 4), and, given a longer record of seismicity, they undoubtedly would be observed in most regions of Nevada. The tectonic region near Little Skull Mountain is part of the Walker Lane Province at the western edge of the Basin and

Range, and has a mixture of North tending normal faults, and NW and NE striking strike slip faults.

2. DESCRIPTION OF THE MAIN EVENT.

The origin time of the main event was June 29, 1992, at 10:14:22 GMT. The preliminary location is 36°43.1'N, 116°16.35W, at a depth of 13 km below sea level (Figs. 5 and 6). The preliminary magnitude is 5.6. These values are subject to small changes once data analysis is complete.

3. PRELIMINARY AFTERSHOCK LOCATIONS AND INTERPRETATION.

A number of portable instruments were installed in the region of Little Skull Mountain beginning about 1 day after the earthquake. These instruments will provide accurate locations for hundreds of aftershocks, and are expected to outline the fault which ruptured. Preliminary results indicate a northeast trending zone dipping to the southeast (Figs. 5 and 6). The aftershocks suggest the rupture began at a depth of about 13 km below sea level and ruptured upward, northwest, in roughly the direction of the Yucca Mountain Field Operations Center (FOC), reaching a depth of about 5 km. This may in part have contributed to the damage at the FOC. If this turns out to be the correct fault plane, it does not appear to be correlated with any mapped surface faults, a situation typical for earthquakes of this magnitude in the Basin and Range.

4. FAULT PLANE SOLUTION FOR THE MAIN EVENT AND SOME AFTERSHOCKS.

The preliminary fault plane solution based on short period data indicates a northeast striking normal fault dipping either to the SE or NW (Fig. 7). The preliminary moment tensor solution based on longer period waves is consistent with this (Fig. 8). The aftershock data suggests the SE dipping plane is the fault plane. Aftershock fault plane solutions indicate both normal faulting, similar to the main event, and strike slip faulting. This suggests a complex stress release pattern.

5. EVIDENCE FOR TRIGGERING BY THE LANDERS EARTHQUAKE.

As mentioned above the area near Little Skull Mountain was an area of low level seismicity. In February 1992 there was a sequence of small events (largest magnitude 2.4) at Little Skull Mountain, and it would be logical to associate these with premonitory activity, or foreshocks, of the June 29 event.

Nevertheless there is strong evidence that seismic waves from the Landers, California ($M = 7.4$) earthquake determined the actual time of the Little Skull Mountain Earthquake sequence, along with numerous other sequences in the western U.S. (Big Bear Lake, CA; Geysers, CA; Lassen, CA; Shasta, CA; Mammoth, CA; Fish Lake Valley, NV; Mina, NV; Smith Valley, NV; Death Valley, CA). Foreshocks of the Little Skull Mountain earthquake began appearing on the University of Nevada Seismological Laboratory (UNRSL) microearthquake array at Yucca Mountain within a couple of hours of the Landers earthquake (they may have started sooner but were hidden in the large amplitude waves of aftershocks of the Landers earthquake). The foreshock sequence then increased in frequency and size up until the time of the Little Skull Mountain earthquake about one day later. The evidence does not rule out the possibility that the Little Skull Mountain earthquake would have occurred more or less at the same time even if the Landers earthquake had not occurred, but does constitute strong circumstantial evidence that the Landers earthquake controlled the timing of the Little Skull Mountain Earthquake.

6. LACK OF TRIGGERED MICRO-EARTHQUAKE ACTIVITY IN THE IMMEDIATE VICINITY OF THE PROPOSED REPOSITORY SITE AT YUCCA MOUNTAIN.

The region within about 20 km of the proposed repository boundary is a region of very low seismicity as determined from the Southern Great Basin Seismic Network operated by the USGS for the last 20 years. Furthermore, the microearthquake level (down to magnitudes less than zero), is also very low. The University of Nevada Seismological Laboratory (UNRSL) has operated a sensitive micro-earthquake network near the proposed repository site for over a year (Fig. 10) and found no microearthquake activity in the immediate vicinity of the proposed repository. Neither the Landers earthquake nor the Little Skull Mountain earthquake triggered any apparent microearthquake activity on faults in the immediate vicinity of the repository within the first 6 days (later data has not yet been reviewed). No microearthquakes have yet been observed from nuclear explosions occurring during operation of the microearthquake array, but a more careful study needs to be made. Microearthquake activity might indicate fault instability or high stress level. Lack of triggered microearthquake activity by either the Landers and Little Skull Mountain earthquake, or nuclear explosions, suggests that faults in the neighborhood of the repository (e.g., the Ghost Dance fault and the Solitario Canyon faults) are not as unstable as faults in regions for which activity was triggered.

7. ROCKFALLS AT LITTLE SKULL MOUNTAIN, AND PRECARIOUS ROCKS AT YUCCA MOUNTAIN.

The Little Skull Mountain earthquake dislodged numerous large boulders along the crest of Little Skull Mountain (Figs. 11, 12, 13). This was to be expected as a consequence of the high ground accelerations likely in the immediate vicinity of the earthquake (probably of the order of .4 g--no strong motion instruments were in operation there at the time to confirm this).

Near the proposed repository site in Solitario Canyon a large number of precariously balanced rocks have been documented (Figs. 14-16). A technique is being developed to use such rocks to place upper limits on the ground motion for the last several thousand years. This technique involves quantitative estimates of the acceleration needed to topple the boulders, along with quantitative estimates of the time the rocks have been standing, based on the thickness of rock varnish which has developed. Although the technique requires further quantification, it does suggest that the region of Solitario Canyon near the proposed repository site has not been subjected to large ground accelerations (greater than about 0.2 g) in the last few thousand years. The Little Skull Mountain earthquake may have generated accelerations of the order of .05 g to .15 g at some sites of precarious rocks. Thus it would constitute important data if any of the rocks had been toppled. At present, about 2/3 of the precarious rock sites have been visited, and none have been found to have been toppled. The other sites will be visited in the near future.

If one or more of the rocks with very thick rock varnish had been toppled, it might suggest that accelerations of the intensity produced by the Little Skull Mountain earthquake are rare at the proposed repository site. On the other hand if none of the rocks has been toppled, ground accelerations of the level produced by the Little Skull Mountain earthquake may have occurred at the proposed repository site a number of times in the past, and a quantitative study of the stability of the precarious rocks will be required to establish the likely upper bound for ground accelerations experience by the site over the last few thousand years. Based on numerous studies of rockfalls in other earthquakes, it is not likely that the upper limit on acceleration will be more than a few tenths of g. No precarious rocks of the type found in Solitario Canyon have been observed in any of the regions of strong shaking around historical earthquakes in Nevada and California.

8. DATA GENERATED FOR ENGINEERING STUDIES BASED ON GROUND MOTION.

One of the major efforts outlined in the Site Characterization Plan for the proposed nuclear waste repository is study of the effects of local site geology on ground motion from earthquakes. Aftershocks of the Little Skull Mountain earthquake are providing a wealth of data to advance these studies. For example, over ten 3 component digital records have been obtained from the $M = 4.4$ aftershock of July 4, including an important record from the Field Operations Center building damaged by the main event (e.g. Fig 17). Hundreds of records from smaller events are being recorded at a variety of sites, (e.g., hard rock, underground tunnels, deep alluvial fill, ridge crests, canyons, and the site of the proposed surface facilities). Once these data are analyzed, we will be able to much better determine ground motions expected at surface facilities and underground.

Figure Captions

Figure 1	Schematic Map of Little Skull Mountain Aftershock Region Relative to Proposed Nuclear Waste Repository Site.
Figure 2	Seismicity Near the Nevada Test Site.
Figure 3	Nevada Region Earthquakes, M=5.0 to 5.9.
Figure 4	Nevada Region Earthquakes, M=>6.0.
Figure 5	Little Skull Mountain, Main Shock and Aftershocks, Map View.
Figure 6	Little Skull Mountain, Main Shock and Aftershocks. Section plot for A-A' of Fig. 5.
Figure 7	Fault Plane Solution for Little Skull Mountain Main Event from Local, Short Period Instruments.
Figure 8	Fault Plane Solution for Little Skull Mountain Main Event, Based on Long Period Teleseismic Waves (Harvard Moment Tensor Solution).
Figure 9	Events in Nevada Triggered by Landers, Calif., Earthquake of June 28, 1992, M=7.4.
Figure 10	Map of University of Nevada, Reno, Yucca Mountain Microearthquake Array.
Figures 11, 12, 13	Boulders Dislodged Along Crest of Little Skull Mountain by June 29th Earthquake.
Figures 14-16	Precarious Rocks on Yucca Mountain Left Standing after Little Skull Mountain Earthquake.
Figure 17	Examples of Digital Recordings of M=4.4 Little Skull Mountain Aftershock.

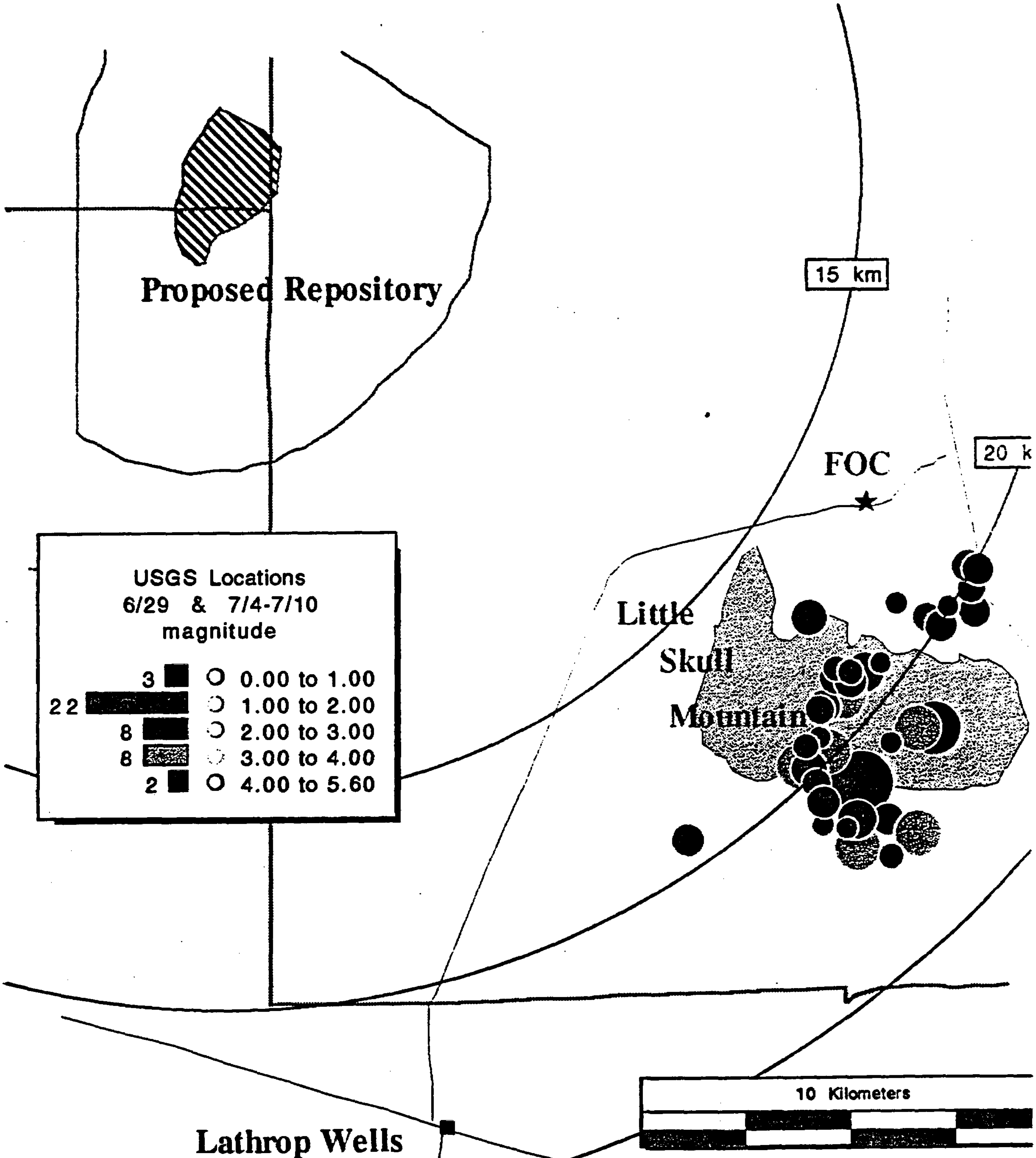

Figure 1: Schematic Map of Little Skull Mountain Aftershock Region Relative to Proposed Nuclear Waste Repository Site.

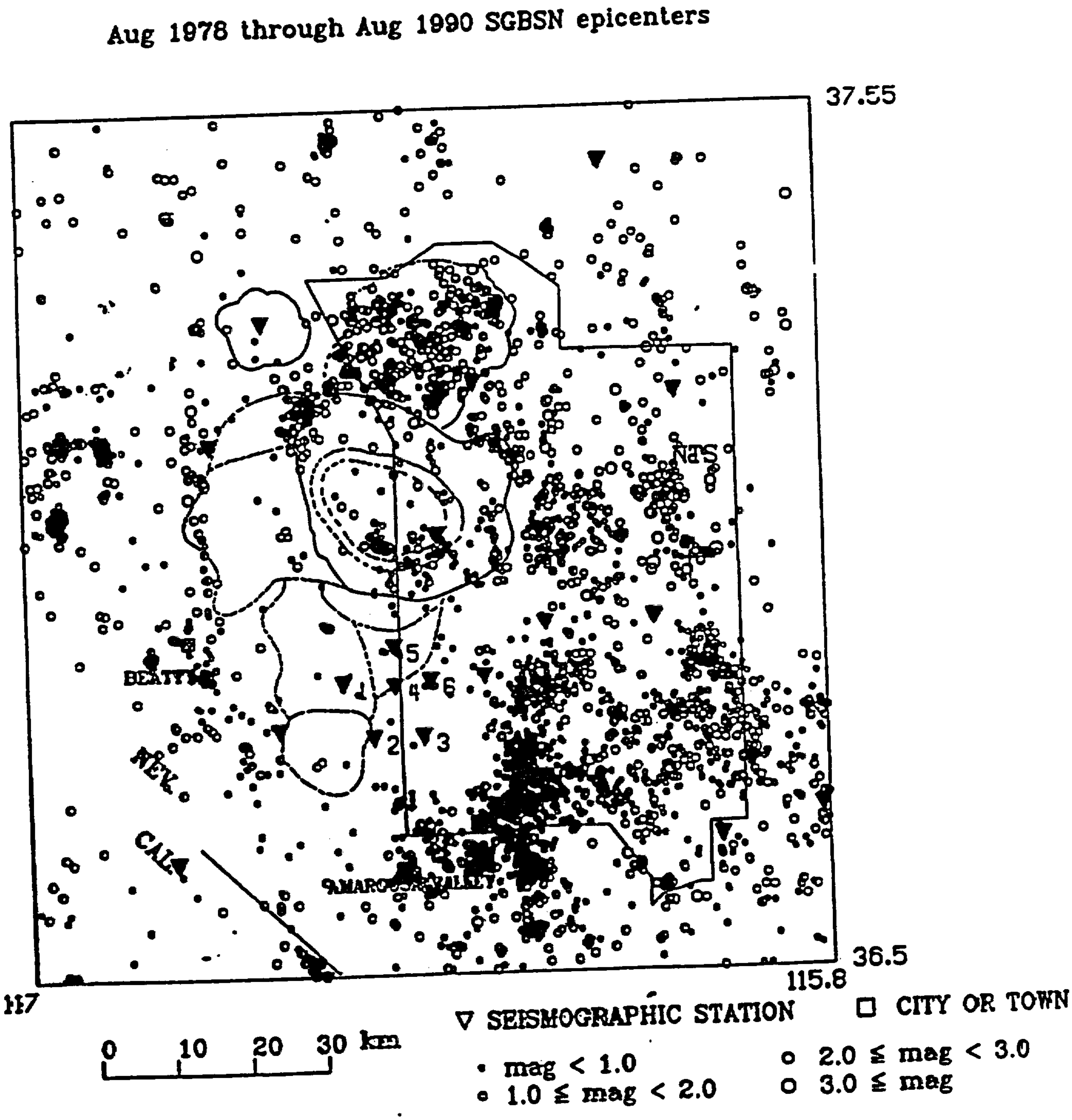

Figure 2: Seismicity Near the Nevada Test Site.

Nevada Earthquakes

Magnitudes 5.0 to 5.9

255 epicenters determined by The University of Nevada Seismological Laboratory, Reno, and the U.S. Geological Survey, Golden, Colorado. Includes regional and historical events.

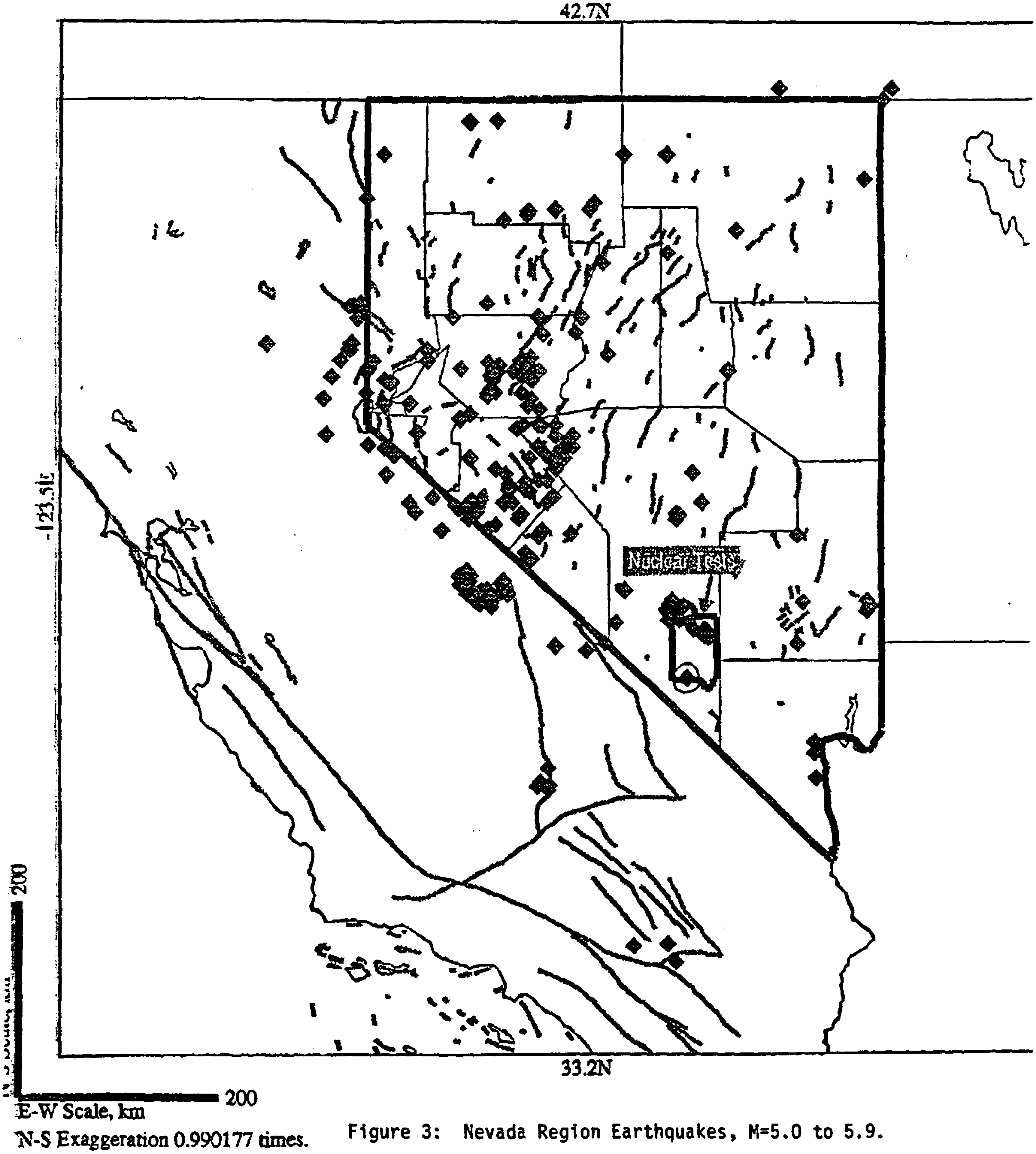

Figure 3: Nevada Region Earthquakes, M=5.0 to 5.9.

Nevada Earthquakes

Magnitudes 6.0 and Greater

48 epicenters determined by The University of Nevada Seismological Laboratory, Reno, and the U.S. Geological Survey, Golden, Colorado. Includes regional and historical events.

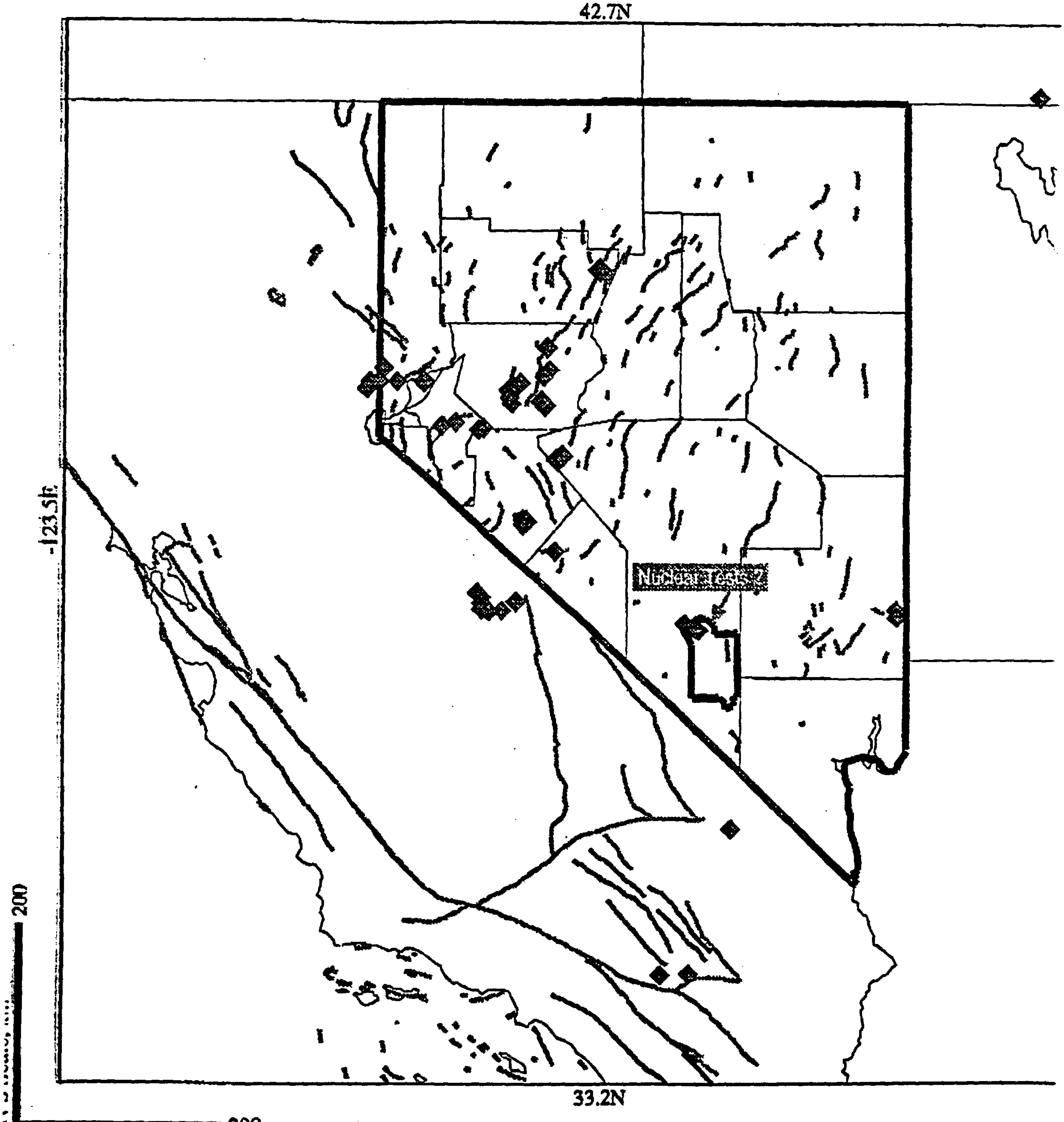

Figure 4: Nevada Region Earthquakes, M=>6.0.

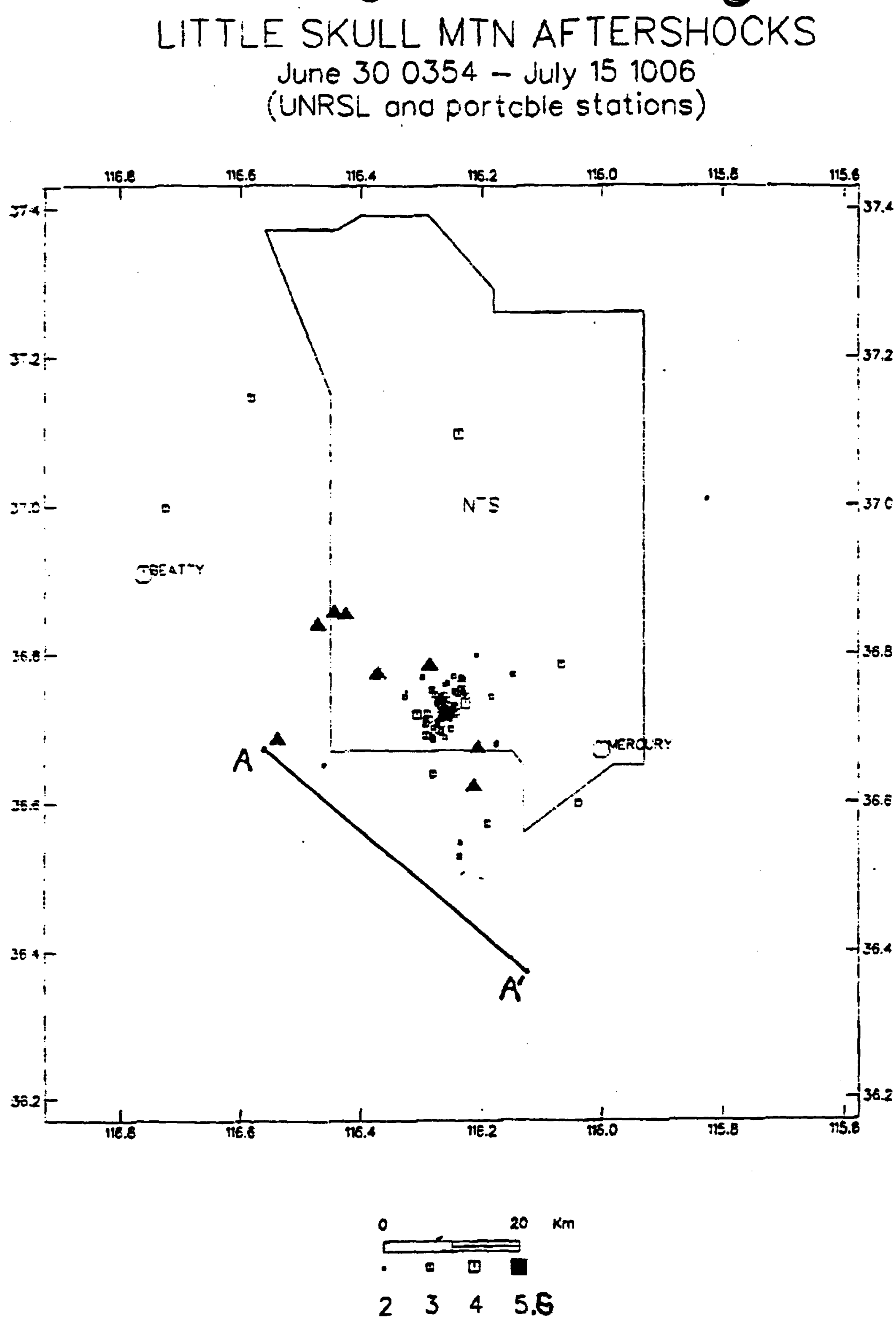

Figure 5: Little Skull Mountain, Main Shock and Aftershocks, Map View.

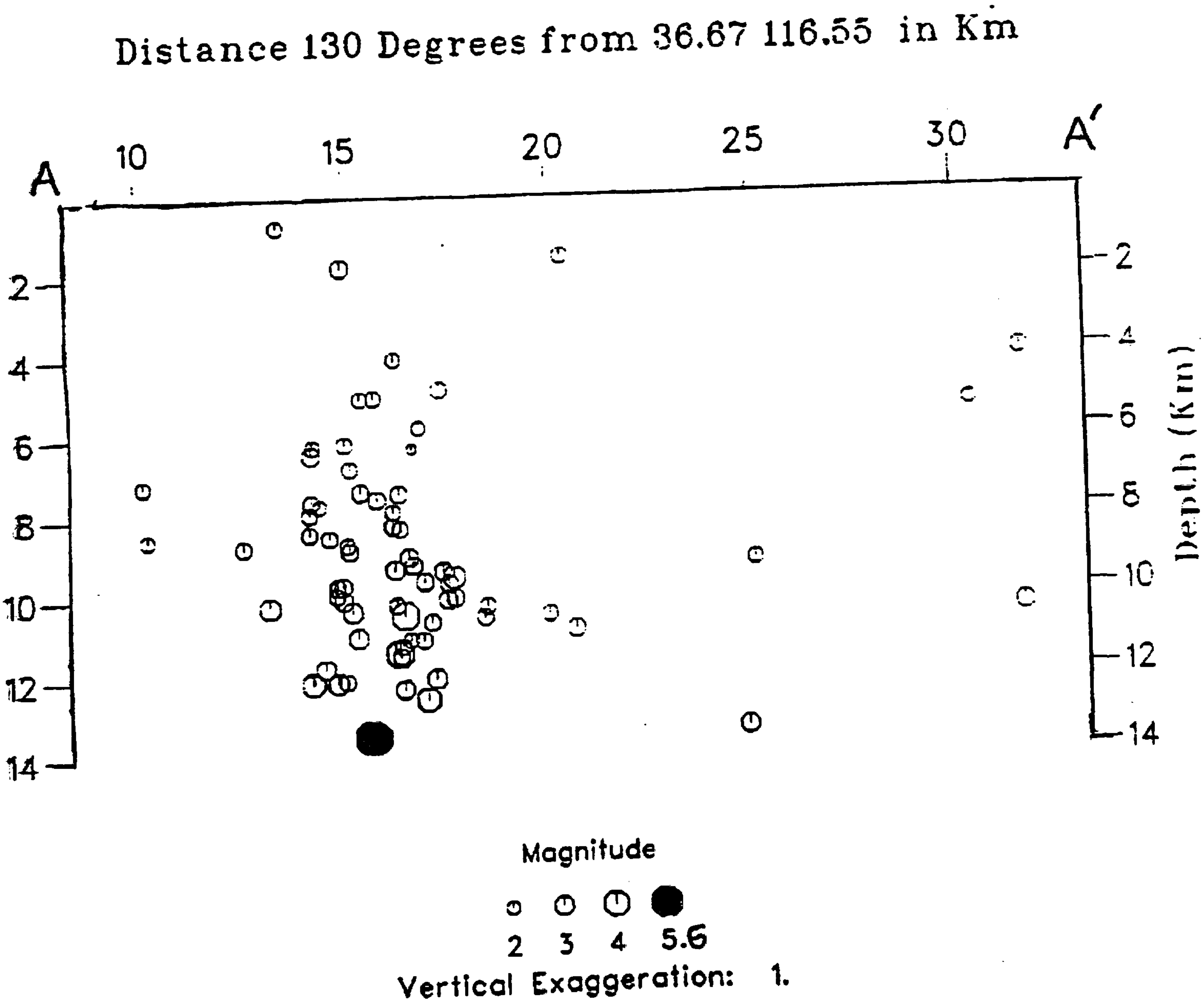

Figure 6: Little Skull Mountain, Main Shock and Aftershocks. Section plot for A-A' of Figure 5.

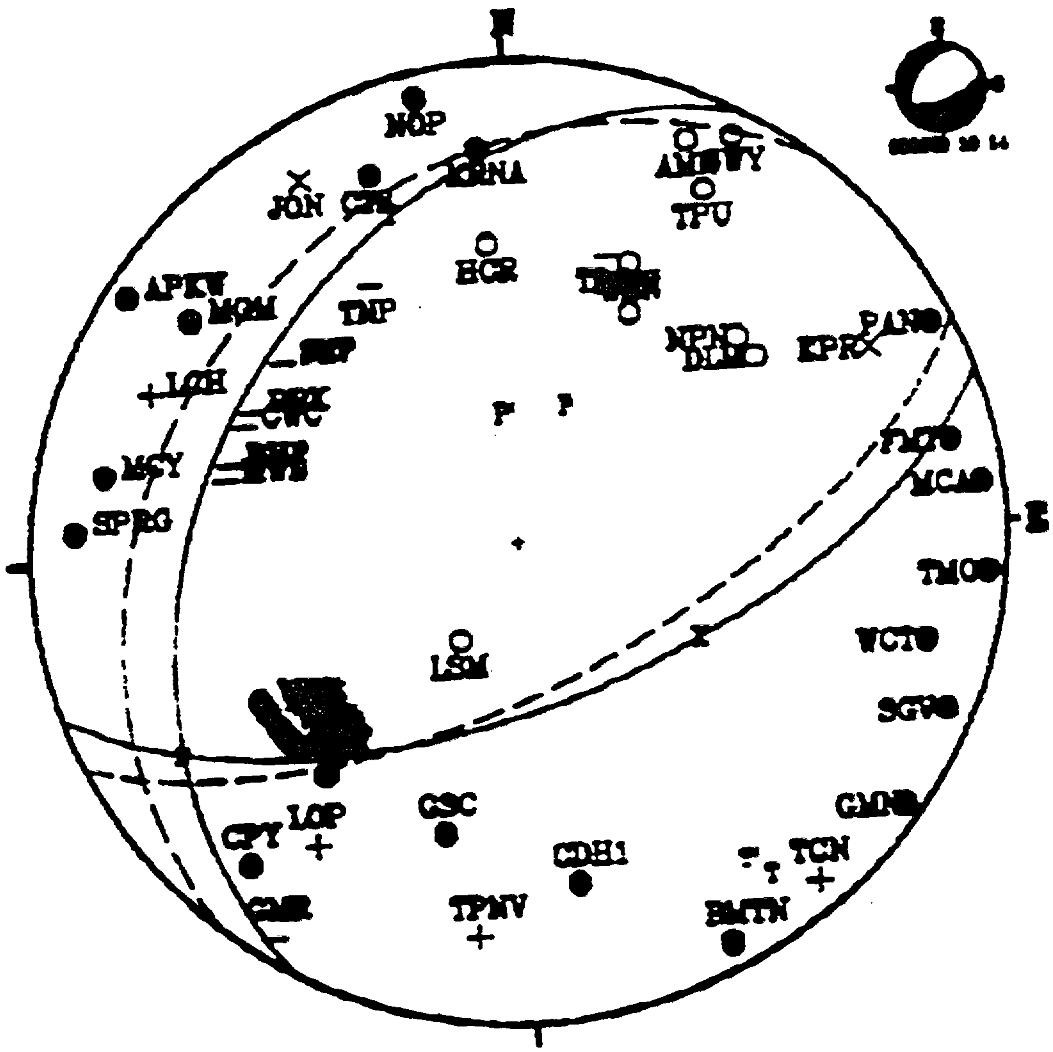

Figure 7: Fault Plane Solution for Little Skull Mountain Main Event from Local, Short Period Instruments.

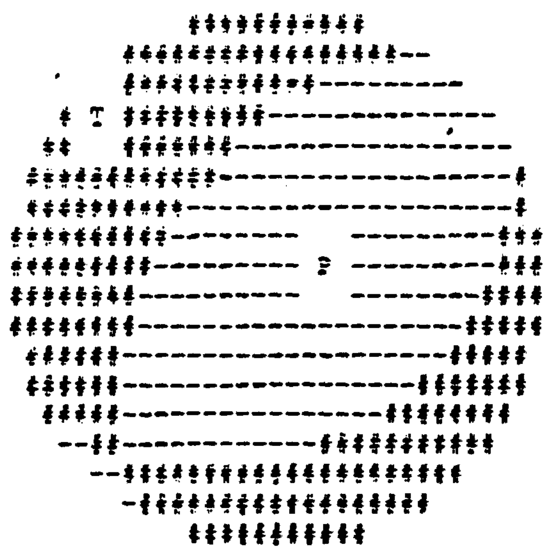

Figure 8: Fault Plane Solution for Little Skull Mountain Main Event, Based on Long Period Teleseismic Waves (Harvard Moment Tensor Solution).

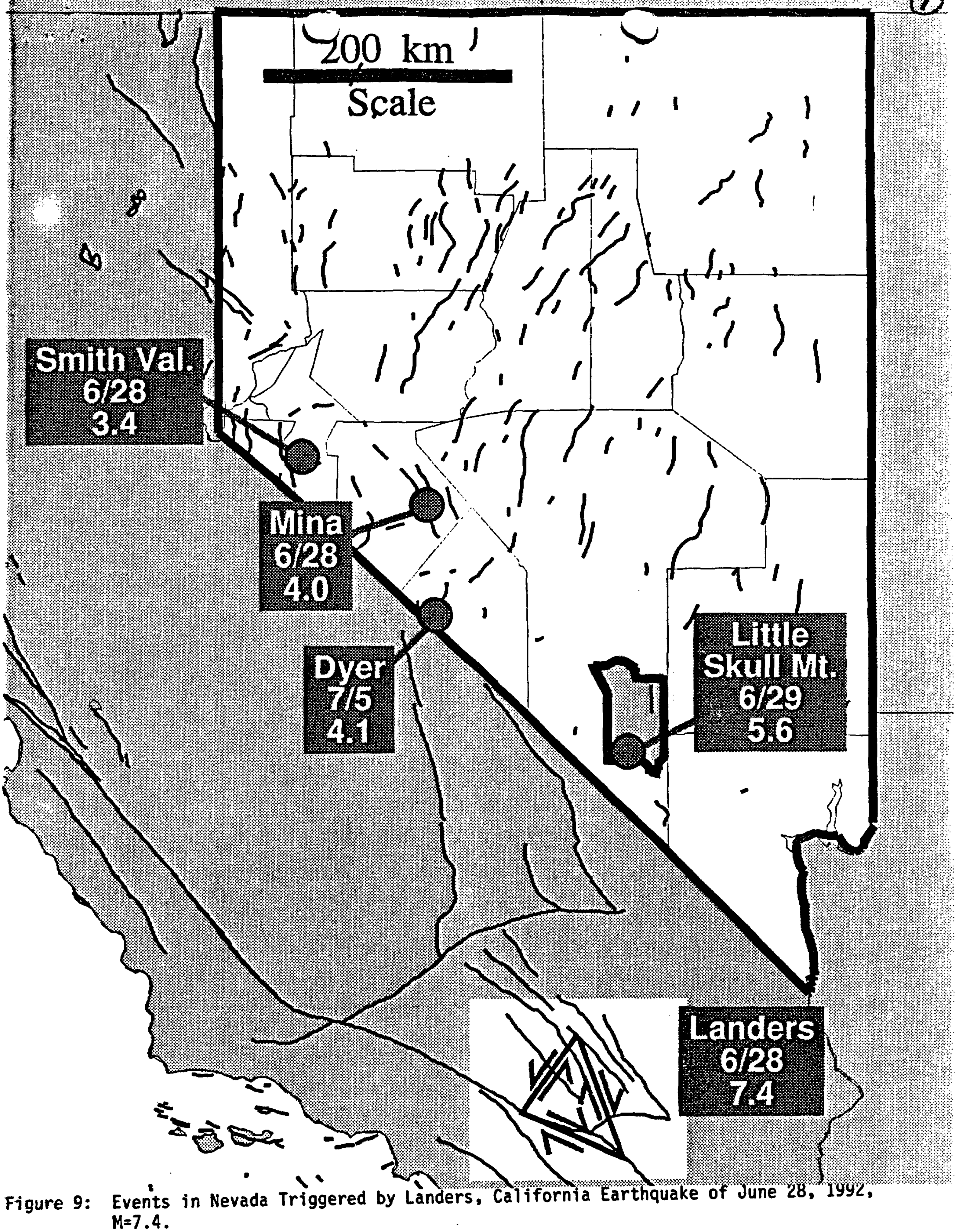

Figure 9: Events in Nevada Triggered by Landers, California Earthquake of June 28, 1992, M=7.4.

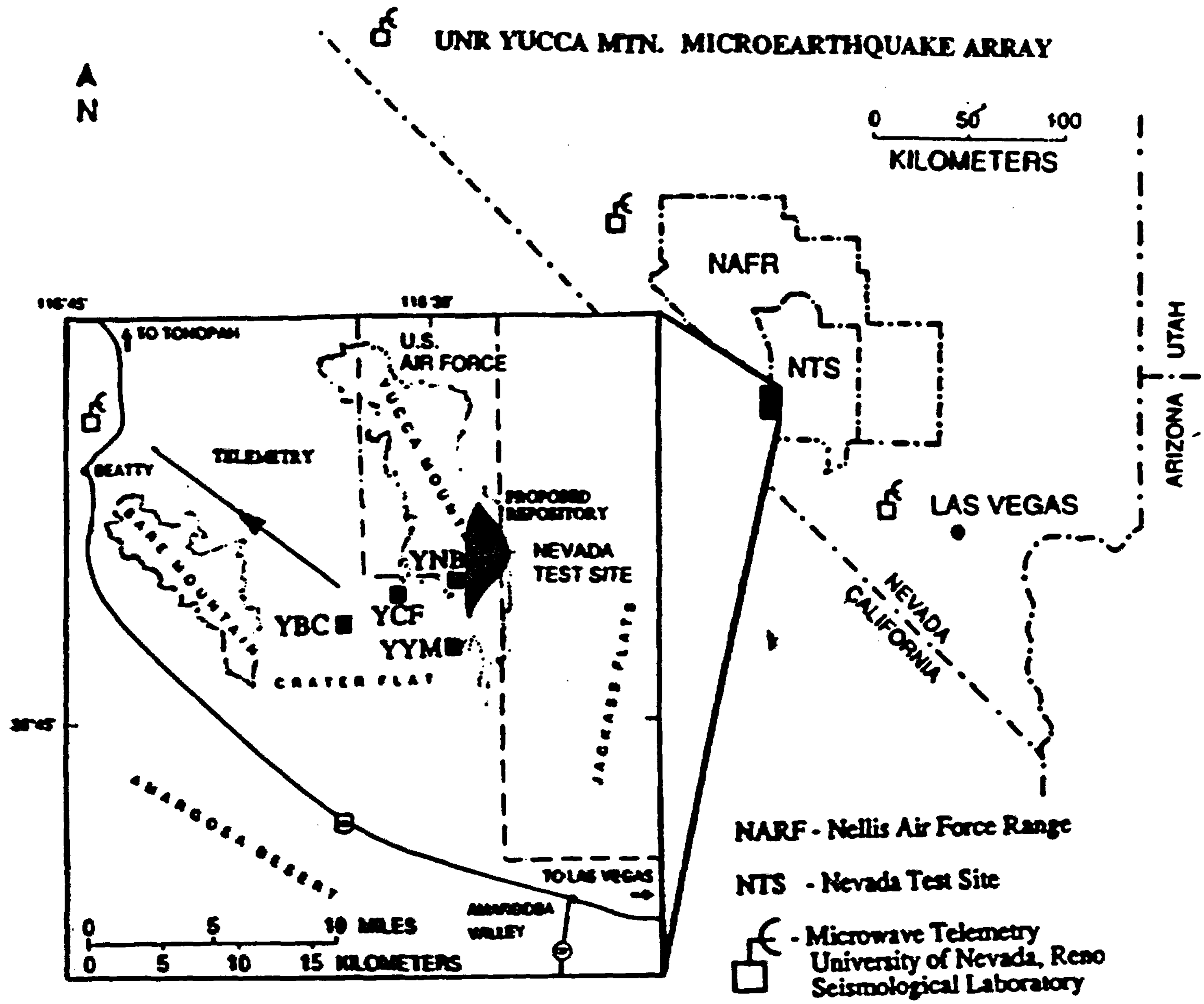

Figure 10: Map of University of Nevada, Reno, Yucca Mountain Microearthquake Array.

Figure 11: Boulders Dislodged Along Crest of Little Skull Mountain by June 29th Earthquake.

Figure 12: Boulders Dislodged Along Crest of Little Skull Mountain by June 29th Earthquake.

Figure 13: Boulders Dislodged Along Crest of Little Skull Mountain by June 29th Earthquake.

Figure 14: Precarious Rocks on Yucca Mountain Left Standing after Little Skull Mountain Earthquake.

Figure 15: Precarious Rocks on Yucca Mountain Left Standing after Little Skull Mountain Earthquake.

Figure 16: Precarious Rocks on Yucca Mountain Left Standing after Little Skull Mountain Earthquake.

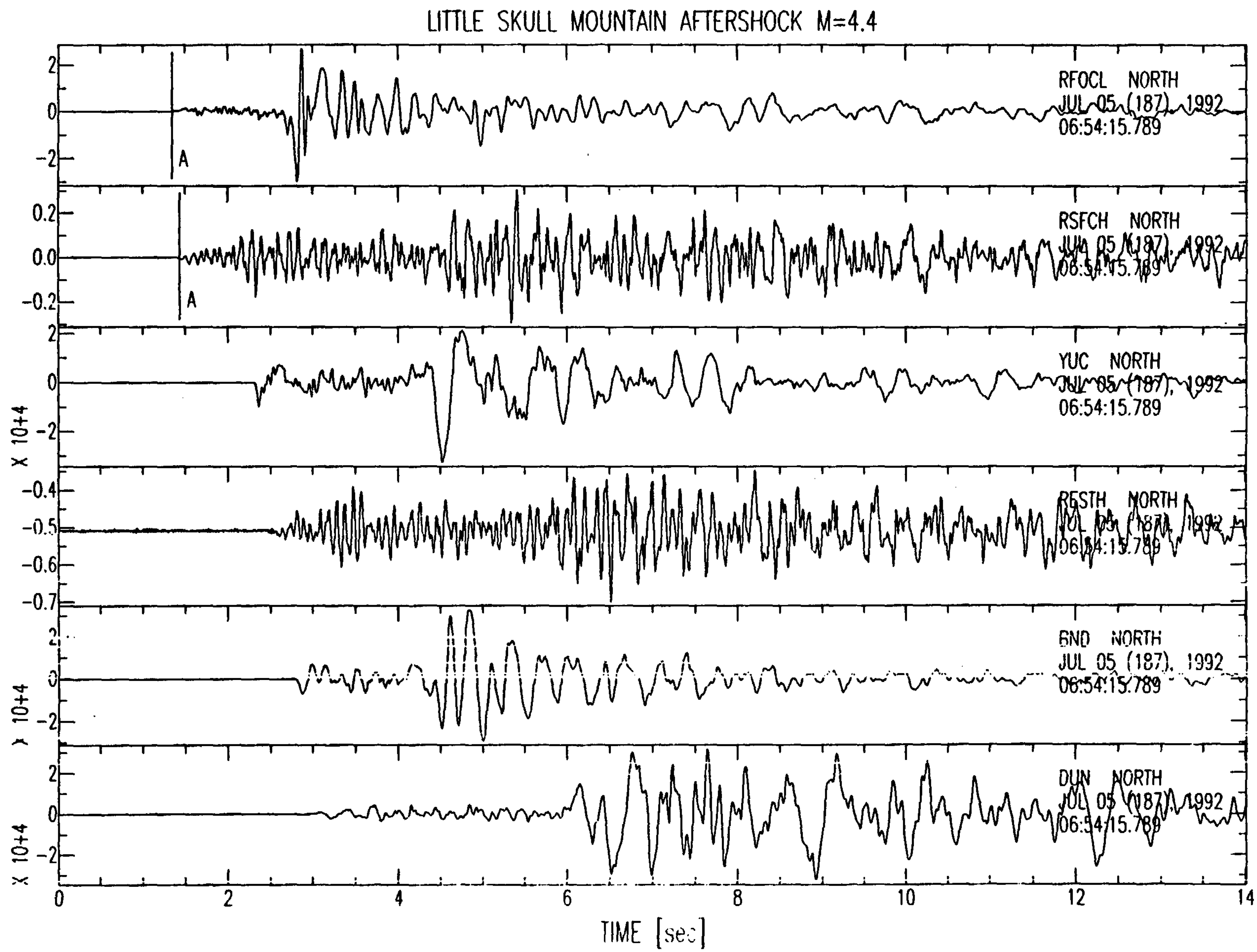

Figure 17: Examples of Digital Recordings of M=4.4 Little Skull Mountain Aftershock.