AD-A113 119 FUGRO NATIONAL INC LONG BEACH CA F/G 8/11

ACTIVE FAULTS AND EARTHQUAKE HAZARDS IN THE FY 79 VERIFICATION --ETC(U)

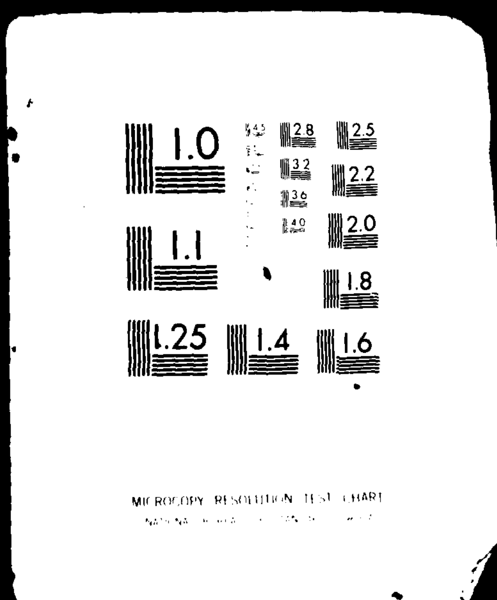
MAR 80 F04704-80-C-0006

UNCLASSIFIED FN-TR-36 NL

1 OF 2

1 OF 2

AD A113119



FN-TR-36

PHOTOGRAPH THIS SHEET

AD-A113 119

DTIC ACCESSION NUMBER

LEVEL: II

INVENTORY: 1

FN-TR-36

DOCUMENT IDENTIFICATION

This document has been approved for public release and sale; its distribution is unlimited.

DISTRIBUTION STATEMENT

ACCESSION FOR		
NTIS	GRA&I	X
DTIC	TAB	☐
UNANNOUNCED		☐
JUSTIFICATION		
BY		
DISTRIBUTION /		
AVAILABILITY CODES		
DIST	AVAIL AND/OR SPECIAL	
A		

DISTRIBUTION STAMP

COPY INSPECTED 2

DTIC ELECTE APR 0 7 1982 L

DATE ACCESSIONED

DATE RECEIVED IN DTIC

PHOTOGRAPH THIS SHEET AND RETURN TO DTIC-DDA-2

DTIC FORM OCT 79 70A

DOCUMENT PROCESSING SHEET

CONSULTING ENGINEERS AND GEOLOGISTS

FN-TR-36

INTERIM REPORT ON ACTIVE FAULTS AND EARTHQUAKE HAZARDS IN THE FY 79 VERIFICATION SITES - NEVADA-UTAH SITING REGION

Prepared for:

U.S. Department of the Air Force
Ballistic Missile Office (BMO)
Norton Air Force Base, California 9[illegible]

Prepared by:

Fugro National, Inc.
3777 Long Beach Boulevard
Long Beach, California 90807

26 March 1980

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: FN TR 36	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): Interim Report on Active Faults & Earthquake Hazards in FY 79 Verification Sites - NV-UT Siting Region	5. TYPE OF REPORT & PERIOD COVERED: Final
	6. PERFORMING ORG. REPORT NUMBER: FN TR 36
7. AUTHOR(s): Fugro National Inc	8. CONTRACT OR GRANT NUMBER(s): F04704-80-C-0006
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Ertec Western Inc. (formerly Fugro National) P.O. Box 7765 Long Beach Ca 90807	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 64312 F
11. CONTROLLING OFFICE NAME AND ADDRESS: U.S. Department of the Air Force Space and Missile Systems Organization Norton AFB Ca 92409 (SAMSO)	12. REPORT DATE: 26 Mar 80
	13. NUMBER OF PAGES: 72
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

Distribution Unlimited

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Seismicity, Quaternary faults, ~~[illegible]~~ ~~[illegible]~~
faults, earthquake

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Investigation in this report identifies areas in which hazardous ground rupture due to fault movement - Review is Holocene & late Quaternary faults in area of verification sites of Utah and Nevada. Most verification sites have north-south oriented faults.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

TABLE OF CONTENTS

TABLE OF CONTENTS (cont.)

LIST OF FIGURES

LIST OF DRAWINGS

1.0 PROJECT DESCRIPTION AND SUMMARY

1.1 PURPOSE OF INVESTIGATION

The Nevada-Utah siting region, although not among the most seismically active areas in the western United States, is nonetheless situated in a geologic province characterized by large historic earthquakes and active faults. The most significant potential earthquake hazards for the MX system are fault ruptures beneath hardened facilities, and strong ground shaking which could interrupt operations. Additionally, system operations may be affected by ground ruptures beneath the designated transportation and communications networks.

The investigation described in this report identifies those areas of the FY 79 Verification sites in which there is a hazard of ground rupture or strong ground shaking because of fault movement. These studies represent the first phase of a two-phased investigation. During the first phase, available data on active faulting and seismicity have been reviewed. In the second phase, the faults identified during the first phase will be field checked and a preliminary assessment will be made of the potential for seismic shaking. Before beginning the second phase, Fugro National proposes to meet with the Ballistic Missile Office (BMO) to discuss the seismic-shaking and fault-rupture criteria to be applied to the MX system. Such criteria will provide guidance for the remainder of the study.

1.2 SCOPE OF INVESTIGATION

Fugro National's investigation of active-fault and earthquake hazards has to date consisted of a literature study aimed at: 1) characterizing the seismicity of the Nevada-Utah siting region, and 2) delineating active or potentially active faults in the FY 79 Verification sites. These sites include the following: Dugway, Whirlwind, Tule, Snake, Hamlin, Spring, Cave, Muleshoe, Dry Lake, Delamar, Pahroc, White River, Coal, Garden, Tikaboo, Railroad, Ralston, and Big Smoky.

In reviewing the seismicity, we have utilized our in-house files, U.S. Geological Survey files, and catalogues compiled by the University of Nevada and the University of Utah. The result is a comprehensive study of known earthquakes which has allowed us to analyze, in detail, the seismicity characteristics of the region. The results of this review are presented in Section 2.0, and discussed in Section 4.0.

Faults in the vicinity of the FY 79 Verification sites showing the characteristics of being active or potentially active have been identified from the geological literature and from data in our in-house files. The initial emphasis of this effort has been on the identification of faults which show evidence of offsetting Quaternary deposits. We have analyzed the color aerial photography (1:25,000 scale) of the Verification sites in detail to identify other active or potentially active faults.

The results of the fault identification studies are presented in Section 3.0, and discussed in Section 4.0.

1.3 SUMMARY OF RESULTS

Our review indicates that there are Holocene (<12,000 year old) and late Quaternary (<700,000 year old) faults in and near the majority of the FY 79 Verification sites. Generally, these faults are oriented north-south, parallel to the regional topographic grain, but there are significant cross trends.

The regional seismicity shows that the siting region has a low level of seismicity during historic time compared to other portions of Nevada and Utah. The siting region is flanked by two zones having higher levels of seismic activity. One of these zones (the Dixie Valley-Fairview Peak zone) possesses many of the same geologic characteristics and the same tectonic style that the siting region does. These similarities suggest that the earthquake hazards of the Dixie Valley-Fairview Peak zone may be applicable to the siting region as well.

In consideration of these recognized earthquake- and fault-rupture hazards there is a need to develop mitigative criteria to be applied to the MX system.

2.0 SEISMICITY

2.1 REGIONAL OVERVIEW

The generalized distribution of earthquake activity in and around the Nevada-Utah siting region during historic time is well known and generally occurs in areas which show geologic evidence of active faulting and tectonism. Two zones of seismicity, the Intermountain Seismic Belt and the Dixie Valley-Fairview Peak zone, have been the major centers of historic earthquake occurrence in the region. The Intermountain Seismic Belt was originally described (Smith and Sbar, 1974) as a zone of pronounced earthquake activity, some 120 miles (190 kilometers) wide, extending northward from Arizona through Utah, eastern Idaho and western Wyoming, and ending in northwestern Montana. The Intermountain Seismic Belt is sometimes considered to include a lesser zone of seismicity extending southwestward from south-central Utah across southern Nevada (the Southern Nevada Transverse Zone). The Dixie Valley-Fairview Peak seismicity zone lies immediately to the west of the Nevada-Utah siting region and consists of a north-south alignment of earthquake activity in western Nevada. In addition to these two major zones of seismicity, occasional small earthquakes, or swarms of small earthquakes, have occurred throughout the siting region.

The above regional description is adequate for estimating earthquake hazards in a general way, but a more detailed analysis is needed to carefully assess the hazards of strong ground shaking and fault [illegible]ure [illegible]n the Verification sites. Unfortunately, the existing seismological data are of only marginal utility for this task. This situation exists because 1) the area has been only sparsely inhabited resulting in incomplete reporting of activity, 2) the duration of seismological observations has been brief, and 3) instruments to measure seismicity have been placed primarily to study the seismic zones just outside of the siting region.

2.2 DATA BASE AND SOURCES

2.2.1 General Discussion

The most comprehensive catalog of seismologic data for the siting region is maintained by the U. S. Geological Survey (USGS). This same catalog was formerly maintained by the U. S. Coast and Geodetic Survey (USCGS) and the National Oceanic and Atmospheric Administration (NOAA). The USGS compiles earthquake epicenters reported by many different institutions and also determines the locations of larger shocks (about magnitude 4 and above) independently using data from seismographs in the region. Seismographic networks for the study of local (small) earthquakes are operated by the U. S. Geological Survey for the area around the Nevada Test Site (NTS), the University of Utah for much of the Intermountain Seismic Belt, and the University of Nevada at Reno for the northern part of Nevada.

In the following discussions and on the accompanying drawings, the data from each of these sources is kept separate because each data source represents different levels of detection capability, areal coverage, and duration of observations.

Combining the data into a single display would tend to be misleading.

Great variation exists in the accuracy to which the epicenters have been determined. Earthquakes which occurred before seismographs were available were normally assigned the location where the strongest shaking was felt. From about 1925 until the early 1960's, locations of larger earthquakes could be based on instrumental data from seismograph stations around the region. Earthquake locations determined during these years are uncertain by at least 0.1 to 0.25 degrees (6 to 18 miles or 10 to 30 kilometers). Since about 1963, improved networks have resulted in more accurate locations, and the local seismograph networks recently installed have reduced location uncertainties to only a few miles for earthquakes occurring within the networks. Locations for earthquakes outside the networks remain less certain and vary in accuracy according to the earthquake's location and size.

2.2.2 U. S. Geological Survey (USGS/NOAA)

The USGS/NOAA data set is the only one with relatively uniform coverage across the entire region of the candidate sites, at least for earthquakes of magnitude about 4 and larger (Drawing 2-1). Probably all shocks of magnitude 4 and larger which have occurred since the mid-1930's are shown. Many smaller earthquakes are also shown, but the record of smaller earthquakes is known to be incomplete, particularly in the central-northern portion of the region. The data include earthquakes from 1873 through 1978, but only a few earthquakes are known for dates prior to the early 1930's when seismograph stations began to locate earthquakes, magnitude 4 and larger, in the region.

2.2.3 U. S. Geological Survey (USGS/NTS)

A local seismographic network in the vicinity of the Nevada Test Site is operated by the U. S. Geological Survey as part of a program to qualify a site for storage of high-level radioactive wastes. The network was installed to monitor local seismicity after compilation and review of prior seismicity data (Rogers et al., 1976) and a preliminary assessment of the seismic hazard (Rogers et al., 1977). Data from the network (Drawing 2-2) have been supplied by Rogers (personal communication) for the period from August 1978 through September 1979; subsequent data are still being processed. Coverage by this network extends over only the southernmost part of the Nevada-Utah siting region, to about 37° 45'N; all seismograph stations are south of 38°N.

2.2.4 University of Utah (UTAH)

The Utah seismographic network has the majority of its stations in northern Utah along the Intermountain Seismic Belt, although several seismograph stations are sited along the belt in south-western Utah. None of the stations is west of about 113°W. This data set (Drawing 2-3) applies exclusively to areas in Utah and near the Nevada-Utah border.

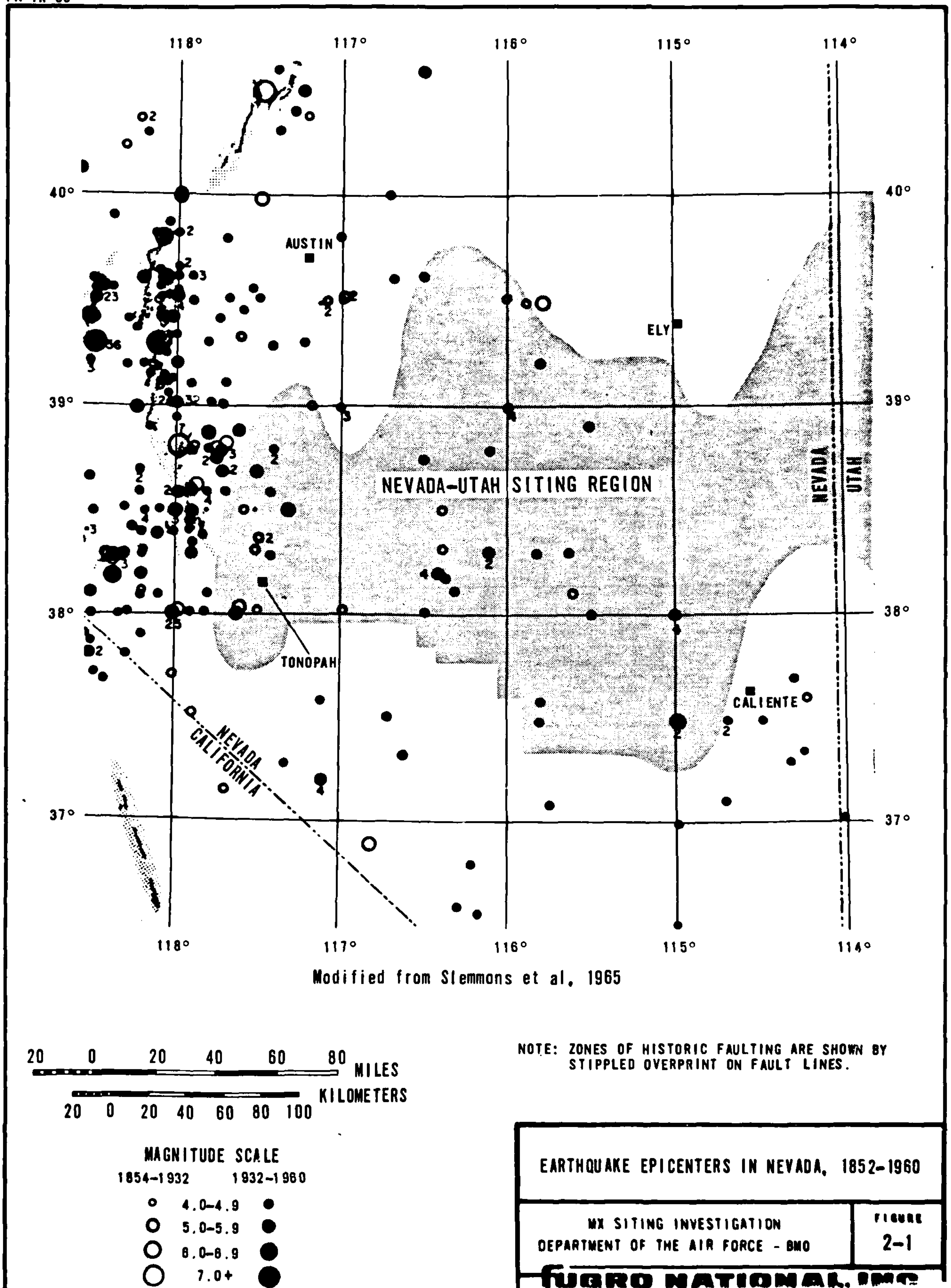
Early Mormon settlement in Utah has led to a number of historical reports of earthquakes (also included in the UTAH data set) felt along the Intermountain Seismic Belt. For earthquakes prior to the 1930's, locations are assigned according to the felt reports. Until 1962, many smaller earthquakes were felt only locally and their epicenters have considerable uncertainty. Larger earthquakes during this period were registered at regional seismographic stations, and epicenters were determined to within 6 to 18 miles (10 to 30 kilometers). After 1962, local stations began to contribute enough data that accuracy of epicenter determinations was considerably improved; locations are correct within 3 to 6 miles (5 to 10 kilometers) in most cases (Arabasz et al., 1979).

2.2.5 University of Nevada at Reno (RENO)

Seismograph stations of the RENO network provide coverage primarily for western and northern Nevada. Supplementary data from other networks are used to help locate earthquakes south of about 38°N. Data are available for 1970 through February 1978 (Drawing 2-4); subsequent data have not been released. The University of Nevada at Reno has also compiled extensive seismicity catalogs for historical earthquakes and early instrumental earthquakes in Nevada (Slemmons et al., 1965); these data are shown in Figure 2-1.

2.3 PRE-INSTRUMENTAL SEISMICITY

Epicenters for earthquakes prior to 1932 are shown on the USGS/NOAA and UTAH maps (Drawings 2-1 and 2-3) as solid circles and in Figure 2-1 as open circles. Because the region was thinly populated, not many earthquakes have been reported for the early years. Early earthquakes are known to have occurred in central



EARTHQUAKE EPICENTERS IN NEVADA, 1852-1960

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - BMO

FIGURE 2-1

FUGRO NATIONAL, INC.

26 MAR 80

Utah from accounts by Mormon pioneers after 1847, and in western Nevada from mining camp newspapers after about 1850.

Moderate earthquakes have been felt with some regularity along the Intermountain Seismic Belt. The earliest recorded earthquakes date from 1853 south of Provo. The largest of these, on 14 November 1901, had an estimated magnitude of 7.1 and occurred slightly east of the area covered by the maps. Several other early earthquakes with magnitudes of about 6.5 have occurred along the Intermountain Seismic Belt in Utah. Two of these were in the area studied here: November 17, 1902, north of St. George, Utah, M = 6.3 (estimated); and, August 16, 1966, near the southern end of the Utah-Nevada border (instrumentally located), M = 6.1. The historically reported earthquakes in Utah have locations that are fully consistent with the instrumentally observed distribution of recent seismicity.

Other pre-instrumental earthquakes recorded for the siting region are mostly in the Dixie Valley-Fairview Peak zone. These earthquakes are shown as circles in Figure 2-1. The shock estimated to be the largest in the region occurred during preinstrumental time: the October 2, 1915, Pleasant Valley earthquake south of Winnemucca, M = 7.5 (USGS/NOAA) or M = 7-3/4 (Coffman and Von Hake, 1973).

The Utah local seismographic network became operative in 1962. For the period between about 1932 and 1962, epicenters of moderate earthquakes were determined from regional seismograph recordings with the uncertainties described above, and smaller earthquakes were located by felt reports. Epicenters for this period are shown by open circles over the X's on the UTAH map (Drawing 2-3).

A pertinent question remains concerning the pre-instrumental time period: could a large earthquake have occurred in the siting region during historic time and be unreported? Although the non-Indian population in the region was sparsely distributed, the occurrence of a large unreported earthquake (magnitude 7 or more) in the region after the mid-1800's seems unlikely because distinctive long-period shaking probably would have been reported at distant locations.

There are Indian accounts of an 1845 or 1852 major earthquake in western Nevada (Ryall, 1977). Indian accounts of any earlier, large earthquakes are not reported, but such accounts might not have been relayed to white settlers except as a comparison if a current shock had been felt. For example, after the Owens Valley, California, earthquake of 1872, M = 8+, Indians told of a comparable shock about 100 years earlier (Townley and Allen, 1939). This reasoning suggests that there have been no large earthquakes in the Nevada-Utah siting area since about 1840. However, geologic evidence of relatively young fault scarps shows that late Quaternary or possibly Holocene (the last few thousand years) earthquakes have occurred.

The possibilities for smaller, unreported shocks, say magnitude 6, are much more uncertain. A detailed study of the changes in regional demography through time would be necessary to draw conclusions about magnitude-6 shocks.

2.4 DISCUSSION OF REGIONAL SEISMICITY

Instrumentally determined epicenters comprise most of the seismicity data on the USGS/NOAA, USGS/NTS, UTAH, and RENO maps (Drawings 2-1 to 2-4). As described above, these maps from different data sources reflect various time periods, detection capabilities, areal coverages, and location accuracies. Some individual earthquakes may be assigned slightly different epicenters by different agencies, but the data sources are complementary and mutually consistent in their representation of the region's seismicity. Features of the seismicity distribution are discussed in the following sections.

2.4.1 Dixie Valley-Fairview Peak Seismicity Zone

This zone of concentrated seismic activity lies along the western edge of the area shown on the maps. No widely used name has been given to this zone. Slemmons et al. (1965) used "118° Meridian Seismic Zone". The name used in this discussion arises from the most recent, large earthquakes along the zone in 1954.

The zone is significant to the siting region, not so much because of strong ground motion from earthquakes centered in it, but because it has geologic characteristics and tectonic style similar to those present within the Nevada-Utah siting region, suggesting a possibility that similar seismicity might occur at other places closer to the sites.

The zone extends from the vicinity of Winnemucca in north-central Nevada, south-southwest to about the 118°W meridian and then south to Owens Valley in California. The portions of this zone that are in Nevada show many similarities in geology and recent fault features when compared to areas of the Verification sites. The zone is one of the most active in the western United States, having been the locale for the following Nevada earthquakes (USGS/NOAA magnitudes):

- 1903, near Wonder (39.5°N, 118.1°W), unknown magnitude, at least 5 miles (8 kilometers) of surface rupture.
- October 2, 1915, Pleasant Valley earthquake (40.5°N, 117.5°W) near Winnemucca, magnitude 7.5, 36 miles (58 kilometers) of surface rupture in four major breaks.
- December 21, 1932, Cedar Mountain earthquake (38.80°N, 117.98°W) magnitude 7.2, 38 miles (61 kilometers) of surface ruptures.
- January 30, 1934, Excelsior Mountain earthquake (38.28°N, 118.37°W), magnitude 6.3, some surface faulting (less than a mile).
- July 6, 1954, Rainbow Mountain earthquakes (39.42°N, 118.53°W) near Fallon, magnitude 6.8, a second earthquake of equal magnitude but slightly less intensity occurred August 24, about 20 miles (32 kilometers) of discontinous surface rupture.
- December 16, 1954, Dixie Valley-Fairview Peak earthquake (39.3°N, 118.2°W) magnitude 7.2; an aftershock of magnitude 7.1 occurred 4 minutes later; Coffman and Von Hake (1973) list the magnitudes as 7.1 and 6.9, 55 miles (88 kilometers) of surface faulting.
- March 23, 1959, Dixie Valley (39.60°N, 118.07°W), magnitude 6.3.

Recent activity, 1970 through 1978, in this zone is displayed on Drawing 2-4, which shows many small earthquakes recorded by the University of Nevada local seismographic network. Generally, the current seismicity is consistent with the longer term distribution shown on the USGS/NOAA map (Drawing 2-1). No earthquakes with magnitudes as large as 5 were recorded in the zone during the 1970-78 time period. Several tight clusters of epicenters demonstrate the capability of the local network to yield accurate locations, and thus better correlation to geologic features.

Mining camps and newspapers in the region date from the early 1850's. Several historic earthquakes were reported felt in this area from 1868 onwards, however the largest are estimated at about magnitude 5.5 (Slemmons et al., 1965). Thus, there is a period of about 50 years, 1850 to 1900, during which earthquakes were reported, but no large earthquakes were recorded in the Nevada portion of the zone. From 1903 to 1959, there were three main shocks of magnitude 7 or greater, and three or possibly four more above magnitude 6.3. No shocks greater than 5.3 have occurred in the Nevada part of the zone for nearly 20 years.

These observations suggest that the rate of seismic activity in the Dixie Valley-Fairview Peak zone is very irregular, at least on the time scale of the past 130 years. Because other areas in the Great Basin have expressions of young faulting similar to that of the Dixie Valley-Fairview Peak zone, these other areas may have similar seismic potential, but currently may be in a relatively quiescent phase. Wallace (1977) concluded that Great Basin faults, including particularly those similar to the 1915 Pleasant Valley rupture, have recurrence periods on the order of thousands of years. Ryall (1977) proposed cycles of seismic activity, on the order of thousands of years, which have foreshock activity of one or two decades, then a mainshock, and aftershocks for as much as a century.

The possibility exists that other areas having young faults within the siting region could become seismically active, or even be active now at the level of microearthquakes. More detailed seismographic information, particularly from networks monitoring microearthquake activity, could help identify such zones and possibly provide data precursory to large earthquakes. Return periods on the order of thousands of years may not present a significant hazard for a single fault system, but the large areal extent of the siting region, and the many fault systems included, increase the potential that at least one system could become active in the next several decades.

2.4.2 Intermountain Seismic Belt

This broad, extensive zone of seismicity lies east and southeast of most of the siting area. The zone is as much as 120 miles (190 kilometers) wide, and extends from north-central Arizona through Utah, eastern Idaho and western Wyoming, to end in northwestern Montana (Smith and Sbar, 1974). A branching zone of seismicity, called the "Southern Nevada Transverse Zone" by Slemmons et al. (1965), extends southwestward from south-central Utah across southern Nevada, and is considered here to be part of the Intermountain Seismic Belt. Only a portion of the zone cuts across the southeastern corner of the area shown on the seismicity maps (Drawings 2-1 to 2-4).

Small and moderate earthquakes have been felt often since the Mormon pioneers entered the area in 1847. Within the siting region, the largest shocks have been:

- December 5, 1887, Kanab, Utah (37.05°N, 112.52°W), magnitude estimated as 5.7.
- November 17, 1902, Pine Valley, Utah (37.39°N, 113,52°W), magnitude estimated as 6.3.
- July 21, 1959, near Kanab, Utah (37°N, 112.5°W), magnitude 5.7.
- August 16, 1966, Clover Mountain, Nevada (37.46°N, 114.15° W), magnitude 6.1 (USGS/NOAA) or 5.6 (UTAH; Coffman and Von Hake, 1973).

Larger shocks have occurred in other parts of the Intermountain Seismic Belt: a magnitude 7.1 (estimated) in 1901 near Richfield, Utah (38.75°N, 112.10°W), and magnitude 7.1 in 1959 at Hebgen Lake, Montana, and several magnitude 6 shocks.

2.4.3 Nevada Test Site

The dense clusters of epicenters in the vicinity of 36.8°N to 37.4°N and 115.8°W to 116.5°W on the USGS/NOAA map (Drawing 2-1) delineate the Nevada Test Site, the locus of numerous nuclear blasts. These blasts are pertinent to the evaluation of seismic hazard because they have triggered significant earthquakes on nearby fault zones showing the area to be in a state of natural stress from tectonic forces.

Smith et al. (1969) concluded from strain measurements of the BENHAM explosion of December 19, 1968 [1.1 megaton at about

4600 feet (1400 meters) depth, earthquake magnitude of 6.0] that the explosion could significantly affect local earthquake occurrences out to distances of about 9 miles (15 kilometers). Analysis of seismic wave spectra by Aki et al. (1969) strongly suggested that the BENHAM explosion triggered an earthquake about 3 seconds after the blast. Displacements up to 18 inches (46 centimeters) vertically and 6 inches (15 centimeters) laterally on previously recognized faults were mapped by Bucknam (1969) following this event; fractures were observed as much as 3.5 miles (5.6 kilometers) from the explosion. Further, extensive seismological literature has discussed blast triggering of earthquakes and measurements of tectonic prestress near NTS.

These observations are significant because they demonstrate clearly that tectonic forces are active in a part of the Great Basin that showed evidence of young faulting but previously had only very low levels of seismicity. These conditions are analagous to those in the Nevada-Utah siting region and suggest that a large explosion within 3 to 6 miles (5 to 10 kilometers) of a fault could trigger an earthquake and accompanying ground rupture on that fault.

2.4.4 Verification Site Region

The Nevada-Utah siting region has experienced only infrequent earthquakes of magnitude 4 and larger for at least the past 50 years. For smaller shocks, the frequency and distribution of seismicity is less certain because seismographic networks in the region have not been designed to study small shocks in the area of the sites. Some small earthquakes have been registered for the area, but their epicenters often have uncertainties of 6 to 9 miles (10 to 15 kilometers) or more. In general, the distribution of epicenters shows that the area is currently experiencing a low level of earthquake activity, but reliable correlations to recognized geologic structures are lacking. A few features of the local seismicity emphasize these views.

There is a cluster of eight epicenters northwest of 39°N, 114°W on the USGS/NOAA map (Drawing 2-1). This area is in the Snake Range north of the Spring and Hamlin Verification sites. There were 18 events between December 1963 and December 1964; some have duplicate epicenters and some have undetermined magnitudes. The largest shock is assigned a magnitude of 4.0. The epicenters suggest a north-south alignment, but only weakly. Although this area is somewhat outside the UTAH seismographic network, using the local and regional seismograph stations gives an improved location capability, as shown on the UTAH map (Drawing 2-3). UTAH reports 20 events in the same time period and an additional shock six months later, magnitudes from 2.0 to 3.9, and epicenter uncertainties of about 6 to 9 miles (10 to 15 kilometers). The UTAH map indicates a distinct cluster at the southern end of the trend and a clear linear alignment northward, but epicenter locations are too uncertain for reliable correlation to geologic features.

There is a tenuous alignment of epicenters northwest of 39°N, 114°W on the UTAH map (Drawing 2-3), and the USGS/NOAA map (Drawing 2-1) shows only a loose cluster. The UTAH data also show many more events in the area southwest of 40°N, 113°W than are shown on the USGS/NOAA map. No alignments are apparent here, though. Otherwise, the UTAH data contribute mostly to a description of the Intermountain Seismic Belt.

The RENO data (Drawing 2-4) from the University of Nevada (1970-1978) show a more or less random distribution of epicenters over the western portion of the siting region. One exception is a cluster of epicenters near Eureka, Nevada (39.5°N, 116°W) that is not apparent on the USGS/NOAA map. RENO coverage does not extend to the eastern Verification sites, but the data does include events of small magnitudes. These data suggest that appreciable seismicity does occur in the region at the level of micro-earthquakes.

The USGS/NTS data (1978-1979; Drawing 2-2) show that this local network has resolved a distinct cluster of epicenters near the southern end of Delamar Valley (37.2°N, 115°W). The USGS/NOAA data for the local area include many earlier events, but do not show any clusters or trends.

In summary, the combined data from the four data sources indicate widespread, low-level seismic activity in the siting region. This seismicity is less than that of the nearby Intermountain Seismic Belt and the Dixie Valley-Fairview Peak zone. A few seismically active areas can be identified because of nearby local seismograph networks. Other active areas would probably be delineated if additional seismograph stations were operated in the siting region.

2.4.5 Earthquake Recurrence Relationships

Recurrence relations express the rate of seismicity as a function of earthquake magnitude: Log N = a + bM, where a and b are constants characteristic of a region and N is the number of earthquakes of magnitude M. For interval curves, N_I includes all earthquakes in some range $\pm \Delta M$ about M; for cumulative curves, N_C includes all earthquakes of magnitude M and larger. The constant a depends on the level of seismic activity, and the constant b reflects the ratio of larger shocks to smaller shocks.

A review of the regional seismicity data strongly indicates that the current seismicity should not be taken as the sole basis for describing the statistics of earthquake occurrence in the siting area. Detection of earthquakes in the area has not been uniform for smaller shocks even during the past decade. Also, geologic studies suggest that our observations represent only a small part of the time for faulting sequences to occur in the area. Several approaches for estimating the recurrence relationship are possible, but each has unsatisfactory aspects. However, design engineers must have some basis on which to proceed. The choice will necessarily depend to some extent upon the design philosophy and the projected useful life of the facilities.

In one instance, the gross statistics of the region may be used with the implicit assumption that the seismicity zones can move around as a function of time so that all of the Great Basin areas are similar in the long term. Ryall and Van-Wormer (1979) have applied the statistics of western Nevada [Log N_C = 6.48 - 0.19M for 38 years and an area of 33,600 miles^2 (84,000 km^2)] to a larger area of the Great Basin to predict that the rate of occurrence of major earthquakes, $M \geq 7.2$, is about 1.0×10^{-4}/ year/1000 km^2 (386 miles^2). The corresponding recurrence curve then becomes Log N_C = 2.55 - 0.91M for N events/year/1000 km^2. These authors also consider a 1970-1974 data set which includes smaller earthquakes and leads to a rate for major earthquakes of 1.4×10^{-4}/year/1000 km ^{2} and Log N_C = 1.76 - 0.78M. However, the seismicity distribution in the past 130 years has not been completely random: all of the major Nevada events have been in Dixie Valley-Fairview Peak zone.

Ryall and VanWormer (1979) have also used purely geologic data from studies of fault scarp morphology (Wallace, 1977) over an area of 6800 miles^2 (17,000 km^2) in north-central Nevada. Wallace considered that his study area was representative of Holocene faulting in the Great Basin. These fault studies lead to an estimate of occurrence of major earthquakes at the rate of 0.34×10^{-4}/year/1000 km^2. No recurrence relation is implied unless a value for the constant b is assumed.

A third approach is to base a recurrence relation as much as possible on the seismicity data for the siting region. Clearly, small earthquakes have been under-reported in the data, and the time period of observation is too short for large shocks to have occurred. However, the record of shocks of magnitude about 4 to 5 may be fairly complete since about 1962. If a reasonable value is assumed for the constant b (which does not vary greatly between different areas or levels of seismicity), then the rate of events in the range 4 to 4.9 can be used to define an interval recurrence curve. For the area of about 27,200 miles^2 (68,000 km^2) around the siting region, the USGS/NOAA data have 24 events of magnitude 4.0 to 4.9 for the period 1942 through 1978; 18 of these are from 1960 onward. Using 18 events of magnitude 4.5 $\pm$ 0.5 for 19 years gives an interval recurrence curve of Log N_I = 2.2 - 0.9M (events/year/400 miles^2), where M includes a range of 1 unit of magnitude. For magnitude 7 and larger (summing intervals centered on 7.5, 8.5, etc.), the rate of occurrence is 0.3 x 10^{-4} events/year/400 miles^2. However, 19 years should not be considered as a good statistical base for geologic processes which operate over a much longer time period.

The various rate estimates can be used to calculate return periods for a large earthquake somewhere in the 27,200 miles^2 (68,000 km^2) area of the siting regtion. The two rates based on regional statistics give return periods of about 100 and 150 years for M $\geq$ 7.2 shocks. Wallace's (1977) geologic data give a return period of about 430 years for major ruptures. The local statistics of the siting areas give return periods of about 500 years for $M \geq 7$ shocks and 700 years for $M \geq 7.2$ shocks.

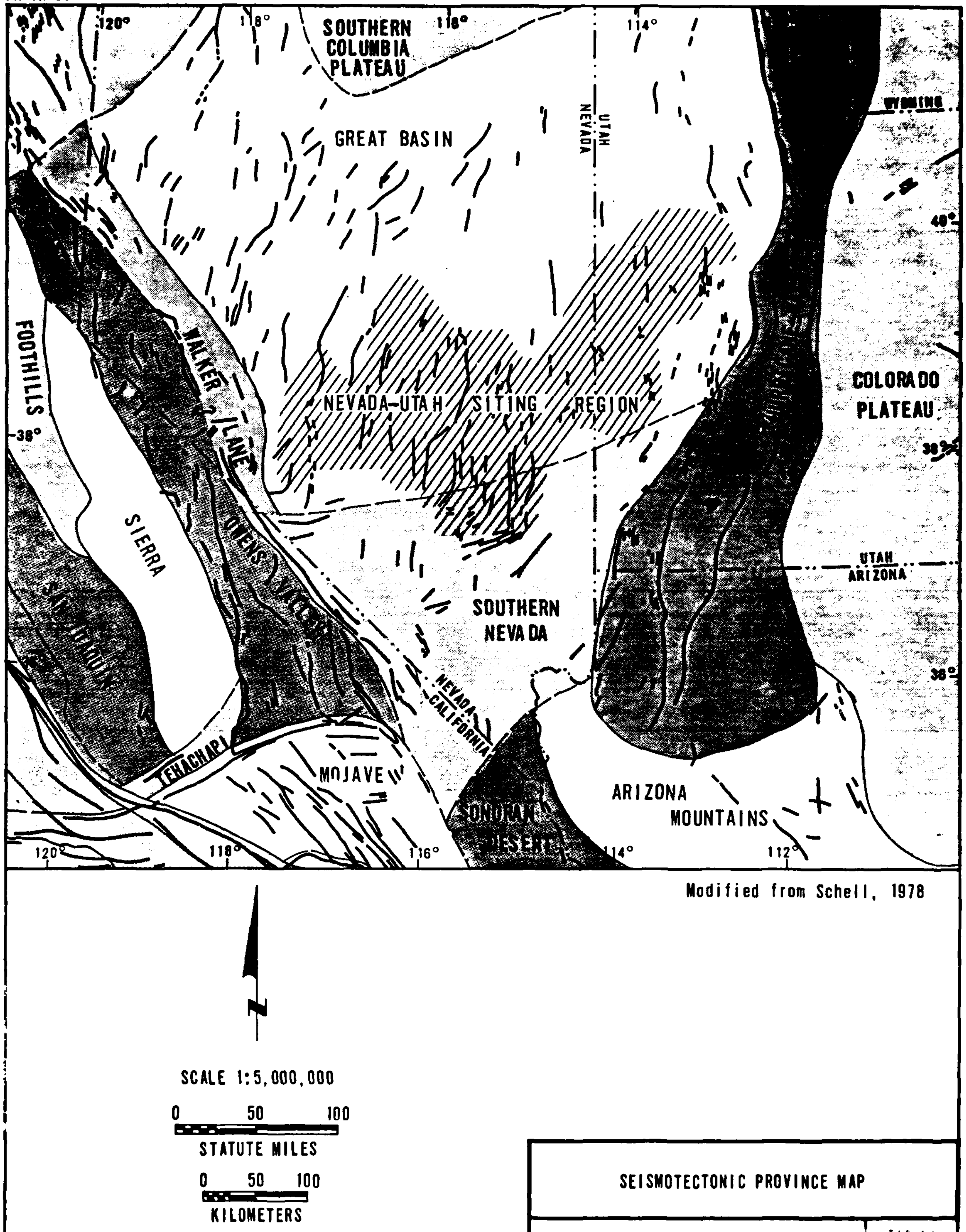
3.0 QUATERNARY FAULTS

3.1 REGIONAL OVERVIEW

3.1.1 Regional Tectonic Setting

The valleys comprising the FY 79 Verification sites are within a large geologic province, the Basin and Range, which extends from Oregon and Idaho to central Mexico. The Basin and Range province is characterized by a block-faulted terrain of mountain ranges (horsts) and alluviated basins (grabens). The basins and ranges are separated from each other by high-angle, down-to-basin, normal faults. During its early history, the entire Basin and Range area was subjected to several regional tectonic events (for example, Nevadan Orogeny, Cordilleran Orogeny, and/or the Laramide Orogeny). However, not until the late Tertiary did the present basins and ranges begin to form. The age of origin for individual basins and ranges varies somewhat throughout the province but they appear not to have developed to any great extent before about 10 million years ago (Stewart, 1978).

The Nevada-western Utah portion of this large province (herein called the Great Basin seismotectonic province; Figure 3-1) can be distinguished from the rest of the Basin and Range on the basis of its physiography, fault trends, earthquake frequency and distribution, and several geophysical characteristics (Schell and Hileman, 1979). The eastern boundary of the Great Basin province is along the Intermountain Seismic Belt (ISB) which roughly corresponds with the Hurricane-Wasatch province (Figure



Modified from Schell, 1978

SEISMOTECTONIC PROVINCE MAP	
MX SITING INVESTIGATION DEPARTMENT OF THE AIR FORCE - BMO	3-1

FUGRO NATIONAL, INC.

26 MAR 80

3-1). The western boundary of the Great Basin is marked by the Walker Lane structural lineament, which forms the mutual boundary with the Owens Valley province to the southwest. The Southern Nevada Transverse Zone (a branch of the ISB) forms the southern limit, and the Southern Columbia Plateau forms the northern limit (Figure 3-1). The northern boundary is not significant to this study because of its great distance from the siting region. The eastern boundary has been discussed in Section 2.4.2. The other two boundaries have seismicity and tectonic features which are near or within several of the Verification sites.

The boundary between the Great Basin and Owens Valley is a zone of late Quaternary, right-lateral shear faults extending from the northwestern corner of Nevada near Pyramid Lake to near the southern terminus of Big Smoky Valley. Although the role of this shear zone (Walker Lane) in Basin and Range tectonics is not clear, its presence is well documented and it has been studied extensively.

A less well known zone of shearing deformation and seismicity (Southern Nevada Transverse Zone) extends across the southern tip of Nevada. This zone includes the Pahranagat Shear Zone, described by Tschanz and Pampeyan (1970), which extends from the southern end of Delamar Valley to the northern end of Desert Valley. The northeast-southwest trending Pahranagat shear zone is subparallel to similar faults such as the Kane Springs fault (in Kane Springs Valley) and to Cane Springs and Rock Valley faults (near Frenchman Flat at the southern end of the Nevada Test Site), but cannot be connected directly to these faults using present data. The Southern Nevada zone abuts the Furnace Creek-Death Valley zone, which, like the Walker Lane zone, is a zone of right lateral shearing.

The tectonic significance of the Walker Lane, and Southern Nevada structural zones and their interrelationships are still not fully understood. They appear to be corridors of distinctive tectonics which are not typical of the Basin and Range. These zones form the southwestern and southern boundaries of the Great Basin seismotectonic province (Schell, 1978; Schell and Hileman, 1979).

The significance of the Great Basin as a distinct seismotectonic province is that the commonality of tectonic features and seismicity within the province enables general statements to be made about the tectonics and seismic hazard in the whole province, including areas that are perhaps not as well known as others. It should be noted that there are no known geologic, tectonic or geophysical characteristics which allow separation of the Dixie Valley-Fairview Peak seismicity zone from the rest of the province.

3.1.2 General Characteristics and Distribution of Faults

In the Great Basin seismotectonic province, most young faults have a vertical component of displacement and often form conspicuous steps in the alluvium or colluvium at or near the base of the ranges. These fault scarps are assumed to be the result of rapid offsets during earthquakes rather than slow tectonic creep because of their stepped nature and because there are no known examples of fault creep within the Great Basin (Wallace, 1977). Typical of Great Basin faulting, most of the faults mapped during this study are down-to-basin normal faults. Although many short segments trend northeasterly and lie within the alluvium of the basins well away from the mountains, the major trends are more northerly and form mountain-block bounding faults.

East-west trending faults and compressional faults occur within the rocks of the mountain blocks but these generally show no signs of Quaternary movement. These faults clearly were formed during earlier tectonic episodes such as the Cordilleran and/or Laramide Orogeny.

Some faults within the mountain blocks exhibit northerly trends, normal displacements, and youthful-looking scarps. These faults are probably active or potentially active, but they are not within the FY 79 Verification sites and were not closely examined unless they appeared to represent potential earthquake hazards to Verification site areas.

3.2 DATA BASE AND METHODS

3.2.1 Data Base

To date, the fault hazard study has consisted of two parts: a literature search-review and an aerial-photograph analysis. The faults shown on Drawing 3-1 are taken from these two data bases.

The literature study included a computer search for data on faults in Nevada and Utah using the GEOREF system. The initial printout was screened and pertinent references were obtained from libraries at Fugro, Los Angeles area universities, the University of Nevada, the University of Utah, and the Colorado School of Mines.

The aerial-photograph analysis was done on color stereo photographs at a scale of 1:25,000. Faults were plotted on plastic overlays attached to the photos. These faults were transferred to a 1:500,000 scale map (Drawing 3-1). The 1:500,000 scale is a convenient scale for overview studies of this type because it depicts fault trends and the interrelationships of these trends throughout the entire area. Detailed large-scale maps (1:62,500) will be prepared prior to field examination of the aerial photograph features (during the second phase of this study).

3.2.2 Compilation and Plotting of Faults

The faults shown on Drawing 3-1 are generalized from published maps (for example, Kleinhampl and Ziony, 1967; Tschanz and Pampeyan, 1970; Hose and Blake, 1976; Stewart and Carlson, 1978; Howard, 1978; Howard et al., 1978, and Anderson and Miller, 1979) and from aerial photographs. The accuracy and reliability of the map varies from place to place due to the variety of scales of the source maps and aerial photographs.

The primary emphasis of the aerial-photograph analysis was directed at the FY 79 Verification site areas and the adjacent mountains. This emphasis resulted in a greater density of faults and less generalization in these areas than in other areas. White Pine County has not been examined in detail, either in this study or in previous Quaternary geologic studies and thus may have unrecognized Quaternary faults which do not show on Drawing 3-1. The barren area along the Nevada-Utah border (38°N to 40°N), on the other hand, was examined on aerial photographs but appears to have few young faults.

Some areas outside of the study area appear to have longer, more continuous faults but these faults were taken from published regional-scale maps, such as that by Stewart and Carlson (1978), which are significantly generalized. In reality, the faults are probably no more continuous than the Dry Lake, Railroad, and White Pine Valley features documented during this study. These major basin-bounding faults are really systems of fairly discontinuous fault breaks, with much of their traces partly obscured by erosion or deposition, which are part of the mountain-bounding master fault systems as shown on Drawing 3-1.

An important point concerns faults which might be present in the central portions of the valleys in fine-grained alluvial fans and playa deposits. If displacement on such faults is small, scarps may not be preserved for more than a few hundred or a few thousand years. Therefore, if their recurrence intervals are on the order of several thousand years (Wallace, 1977), they may not survive as long as scarps in coarse-grained fans at higher elevations, and may not be recognized by aerial-photograph analysis or reconnaissance field geologic inspection.

The faults on Drawing 3-1 were generalized with respect to age, location, and continuity as appropriate for a map scale of 1:500,000. As a result of this generalization, the lines shown on the map should be considered as depicting the general area of the faults rather than the fault traces themselves. For example, a series of short, semi-parallel, closely spaced discontinuous faults will have been shown as a continuous fault if, in the judgement of the analyst, they are part of the same master fault system. Also, when a fault scarp appears to have different ages along various portions of its trace, it is assigned the age of the youngest segment on the premise that the youngest rupture is most indicative of the fault's potential for future ruptures.

3.3 AGES OF FAULTS

The faults shown on Drawing 3-1 are divided into three age groups: Holocene, late Quaternary, and Indeterminate. These ages are based primarily on the age of the sediments which the faults displace. Thus, two factors must be understood; 1) that the true ages of these sediments are poorly known and are based primarily on relative geomorphic relationships, and 2) that the age assigned represents a maximum because the faults may be considerably younger than the sedimentary deposits they displace.

Holocene faults are those which displace Holocene features such as young alluvial fans, playa deposits, recent stream alluvium, and Holocene/Pleistocene shorelines. A key horizon for establishing these relative ages is the shoreline left by the highest level of the latest Pleistocene-Holocene glacial lakes. Major lakes, Lake Bonneville in northwestern Utah and Lake Lahontan in northwestern Nevada, covered large areas in late Pleistocene and Holocene time. The exact dates of the lake's highstands are disputed but most estimates fall between 10,000 and 15,000 years ago (Wallace, 1977; Bucknam and Anderson, 1979). During the same time interval, numerous other isolated lakes existed in many of the valleys in the Nevada-Utah region (Tschanz and Pampeyan, 1970). We have assumed that the highest shorelines from these features are all about the same age and, in agreement with Wallace (1977), that this age is about 12,000 years. We use these shoreline features as an index time line; features and sediments postdating the time line are referred to as Holocene and those predating it are Pleistocene or older.

Late Quaternary faults are those younger than 700,000 years (the approximate age of the Brunhes-Matuyama magnetic reversal). These faults cut intermediate-age alluvial fans or late Quaternary volcanic rocks. They are most likely considerably younger than 700,000 years (probably less than 200,000) because they have well developed scarps in the poorly ind -ated alluvial fan materials. Scarps in this type of material would probably be completely eroded within 200,000 years. Only in competent rocks, such as lava flows or heavily calcified alluvium would scarps last 700,000 years.

The Indeterminate category was established for well developed fault scarps which do not intersect young Quaternary deposits along their traces. Because young deposits are not present along the fault traces, their age can only be approximated as Quaternary (herein considered as less than about 1.8 million years) These faults were identified on the basis of 1) well preserved fault scarps, 2) location along bedrock/alluvium contacts, 3) orientation (compatible with typical, late-stage, Great Basin fault trends), and 4) structural connections to other faults of late Quaternary age. Consideration of these faults as "hazards" is dictated by the 1915 Pleasant Valley earthquake (7.6 magnitude) which like many of the Indeterminate faults, had long segments of its rupture directly at the bedrock/alluvium contact.

All of the faults on Drawing 3-1 are believed to represent an earthquake hazard based on the premise that earthquakes are most likely to occur along faults which have evidence of past displacement within Quaternary time. In addition, there may be faults within the bedrock blocks which have moved in late Quaternary time but which are unrecognized because they lack overlying young alluvial cover, have short lengths, or have small displacements. This is exemplified by the 6.3 magnitude Excelsior Mountain earthquake (Section 2.4.1) which resulted in about a 4500 feet (1370 meter) long scarp in bedrock and fissures within playa deposits of two adjacent valleys. The effects of this earthquake probably could not be recognized today by aerial photograph analysis, less than 50 years after the event.

3.4 FAULTS IN THE FY 79 VERIFICATION SITES

The following sections discuss the faults identifed during this study in each of the FY 79 Verification sites. The order of discussion has no significance and is merely an east to west progression.

3.4.1 Dugway Verification Site

The Dugway Verification site lies east of the Dugway, Thomas, and Drum mountains. There are three areas of young fault offsets in the site: a group of faults south of Topaz Mountain which are of Indeterminate age, one scarp west of Keg Mountain of late Quaternary age, and a series of semiparallel Holocene and Indeterminate age scarps east of the Drum Mountains.

The features east of the Drum Mountains are of particular concern because they form a broad zone of tectonic deformation extending into the contiguous Whirlwind site to the south, a distance of about 20 miles (32 kilometers) (see discussion in Section 3.4.2). The zone cannot be associated with any major mapped structural feature, and thus probably is associated with a major basin-bounding fault along the western side of the Sevier Desert. These features have received some attention during previous fault and seismic hazards studies in Utah (Bucknam and Anderson, 1979), but to date remain somewhat of an enigma in that they are not typical Great Basin faults. The features appear to be approximately the same age; many of them look like dessication cracks, and others appear like erosional effects. That they are adjacent to relatively recent volcanic features has also been noted. Because the features are not typical of Great Basin faults, they need further examination.

3.4.2 Whirlwind Verification Site

The Whirlwind Verification site lies predominantly between the House Range and Sevier Lake, with an extension northward along the eastern side of the Little Drum Mountains. The portion along the eastern side of the Little Drum mountains is contiguous with the Dugway site. The only fault-related features noted on aerial photographs lie within the northern portion of the Whirlwind site along the eastern side of the House Range in Swasey Bottom and along the eastern side of the Little Drum and Drum mountains.

The features in Swasey Bottom appear to be older features related to faulting at the bedrock/alluvium contact. No other features were noted in this portion of Whirlwind site, and gravity studies here (Fugro National, 1980), found no significant gravity anomalies.

The features of most concern are those on the eastern side of the Drum Mountains (see Section 3.4.1). These features extend into the Whirlwind site from the Dugway site. They are a branching series of scarps and cracks which transect both dessication features and young Lake Bonneville shorelines, and thus are Holocene in age. The traces are generally confined to alluvium, but in a few cases appear to involve bedrock outcrops. Their sense of displacement varies, with both the upslope and the downslope blocks being relatively uplifted. Several of the major features appear to be tilt blocks with the western edge of the block being uplifted relative to the eastern edge of the block. Vertical separations range from about 2 to 24 feet (0.7 to 7.3 meters) (Bucknam and Anderson, 1979).

3.4.3 Tule Verification Site

The Tule Verification site is an irregular, elongate series of interconnected valleys east of the Confusion Range and west of the Fish Springs and House ranges.

A Holocene fault scarp displaces young Lake Bonneville shorelines just west of Swasey Peak (central House Range). This feature is about 9.5 miles (15.3 kilometers) long and cuts across recessional shorelines from the playa to the mountains, indicating that it is much younger than 12,000 years. The scarp does not appear to be related to any mapped bedrock features. Thus, it is probably related to a basin-bounding fault which is inferred to lie along the base of the House Range.

At the northern end of Tule site, west of the Fish Springs Range, faults cut young shorelines and thus are also Holocene.

At the southern end of Tule site some faint scarps cut older shorelines and trend toward bedrock faults at the northern end of the Wah Wah Mountains. These features appear to be older than those in northern Tule site, and thus are classified as late Quaternary and Indeterminate in age.

The prevalence of well-developed, multiple, Lake Bonneville shorelines in this Verification site should be noted here because of the difficulty in distinguishing between them and the fault scarps. This is important because other faults may go undetected, giving a false impression of low tectonic activity.

3.4.4 Snake Verification Site

The Snake site comprises several smaller interconnected valleys surrounding the Burbank Hills and Tunnel Spring Mountains at the southern end of Snake Valley. The largest portion of the Snake site is known as the Ferguson Desert, which lies northeast of the Burbank Hills-Tunnel Spring Mountains block and southwest of the Confusion Range.

Quaternary faults were mapped in only three localities: along the northern edge of the Tunnel Spring Mountains; between the Snake Range and the northern tip of the Burbank Hills, near the town of Garrison; and in the central area of Snake Valley northwest of the Conger Range.

The Tunnel Spring Mountain feature is a minor break which does not align with any major bedrock ruptures.

The Garrison features are a series of cracks which have an orientation similar to short bedrock faults in the Burbank Hills. These features are similar to the Drum Mountain scarps but are recognized primarily by a contrast in density of vegetation. A few of the features appear to have vertical displacements. Final decision as to whether these features are true faults, earthquake-related cracks due to settlement, or dessication cracks must await field inspection, but tentatively they are regarded as tectonic features.

The northernmost feature in the middle of Snake Valley is similar to those found near Garrison. The scarp is quite far from the mountain block and does not appear to be related to any bedrock features. A final decision as to the true nature of the feature must await field checking.

In summary, there are a few isolated "tectonic" features, but in general the Snake site appears to be relatively free from late Quaternary faulting.

3.4.5 Hamlin Verification Site

The Hamlin Verification site lies south of the Snake Range and is bounded on the west by the Limestone Hills and Spring Valley. On the east, the Hamlin site is bounded by the Mountain Home Range.

Quaternary faults were not observed on the aerial photographs. Because of the linear mountain front along the Mountain Home Range, published maps (for example, Heinze, 1965, and Howard, 1978) show a concealed fault below the alluvium along the base of the range. Gravity studies (Fugro National, 1980) show that, in the northern portion of the site, the major basin-bounding fault lies farther out in the valley and, with its western counterpart forms a distinct graben, up to 10,000 feet (3000 meters) deep. This graben is not connected to grabens underlying southern Hamlin Valley or Snake Valley to the north. The major basin-bounding fault on the western side of the Hamlin site, defined by gravity, extends directly toward a bedrock fault, but there is no evidence of a direct connection or Quaternary movement along either of the faults.

3.4.6 Spring Verification Site

Spring Verification site lies between the Schell Creek and Fortification ranges on the west and the Snake Range and Limestone Hills on the east.

Several short, late-Quaternary scarps occur along the edges of the Spring site but do not appear to bear any relationship to major regional tectonic features. Although these small features indicate that tectonism has occurred quite recently, the tectonism seems to have been relatively mild compared to that in the Verification sites to the southwest.

3.4.7 Cave Verification Site

The Cave Site is bounded by the Schell Creek Range on the east and the Egan Range on the west. No major fault-related features were found within the Cave Site. In the southern part of the valley very distinct tonal contrasts lie on-trend with a fault extending through the Schell Creek Range from the adjacent Muleshoe Verification site. The features in the valley could be old shorelines, dessication cracks, or eroded fault scarps. They are on the fan surfaces near the playa, where they might be subjected to long-term saturation and lacustrine activity, and thus if they are fault scarps may be younger than they appear on photos.

Some fracture-like features in the northern part of the Cave Site are near sinkholes and may be related to karst activity as well as faulting.

3.4.8 Muleshoe Verification Site

Muleshoe Verification site is the northern portion of the long linear Muleshoe-Dry Lake-Delamar Valley graben. The Muleshoe site is bounded by the Fairview Range on the east and the Schell Creek Range on the west. No prominent Holocene or late Quaternary faults were recognized in the area. A few short scarps occur along the eastern flank of the Schell Creek Range at the southwestern border of the Verification site. These features lie at the northeastern end of the Coyote Wash fault, but appear to transect that fault, indicating that the Coyote Wash fault is inactive and that there may be a potentially active basin-bounding fault along the Schell Creek Range.

A north-south trending fault extends from the Muleshoe Verification site through the Schell Creek Range in the vicinity of Sidehill Pass and into Cave Valley. This fault looks young, but it was not possible to document displacement of late Quaternary deposits; thus this feature is assigned an Indeterminate age.

Another obvious north-south trending fault displaces Paleozoic rocks along the western edge of the Fairview Range. The feature forms a distict bedrock/alluvium contact but does not appear to displace the alluvium, thus it must be considered Indeterminate until a field check can be made. Farther south, directly on trend, are some other, young-looking bedrock faults. Together these scarps form an alignment about 15 miles (24 kilometers) long.

In summary, even though there are no major Holocene or late Quaternary fault scarps in the Muleshoe Verification site, several significant features may prove to be young faults upon detailed field analysis and, if related to each other, may form faults of sufficient magnitude to be significant in the seismic hazard analysis.

3.4.9 Dry Lake Verification Site

The Dry Lake Verification site lies between the North Pahroc Range on the west and the Bristol-Highland-Chief and Delamar mountains on the east. The Dry Lake site is contiguous with the Muleshoe site on the north and the Delamar site on the south.

The most obvious fault feature of the Dry Lake site is the Dry Lake Fault scarp which cuts alluvial fans along the eastern side of the valley. This feature consists of a nearly continuous, down-to-basin, linear escarpment with several splays and a paralleling, down-slope scarp with opposite displacement. The two parallel scarps form a graben which is similar to features formed during the 1954 Dixie Valley earthquake (magnitude 7.2). Such grabens are commonly found on the down-thrown block of normal faults (trench-type or graben fault-trace scarp of Slemmons, 1977) and are a result of downdropping or subsidence of the center block to take up the space left by the crustal extension. Some of these features which occurred during the Dixie Valley event were attributed to slumping and liquefaction (Krinitzsky, 1974). The Dry Lake scarp extends nearly uninterrupted, except for removal by stream erosion where it crosses active channels, for about 28 miles (45 kilometers). Discontinuous, more-widely spaced scarps lying on trend along the mountain front in Delamar Valley may be part of the same rupture, giving a total length of about 50 miles (80 kilometers).

The Dry Lake scarp is one of the most prominent features noted in this study. Like many of the long scarps, at certain localities, it seems to exhibit characteristics of a shoreline. However, the trace crosses elevation contours in an erratic manner which a shoreline would not. Continuing studies should include a field examination to determine the origin. If the scarp height, generally in excess of 15 feet (4.5 meters), is the result of one single fault displacement, it would indicate an earthquake with a magnitude on the order of 8. Determination of whether this scarp is the result of one earthquake or more than one is important, not only for the Dry Lake site, but also for the contiguous Muleshoe, Delamar, and Pahroc sites, and perhaps for other nearby sites. This determination can probably be made by comparative geomorphic analysis of dissection, crest rounding, scarp-slope angle, etc., along the surface trace. If the feature is the result of multiple events, it would provide perhaps the best opportunity in this part of the Great Basin to determine recurrence intervals. Such a determination could be compared to other features, both in the study area and in northwestern Nevada, and could provide a framework for seismic hazard analysis for the whole study area.

Two sets of discontinous Holocene features extend for distances of about 6 miles (10 kilometers) and 3 miles (5 kilometers) down the west-central portion of the valley, and there are also a few short late-Quaternary scarps along the base of the North Pahroc Range.

In addition to the Dry Lake fault on the eastern side of the Verification site, there are several features along the western side and within the mountains that should be studied further. The major features are the White River and Pahroc faults in the Pahroc Mountains. These faults are in proximity to or border, several other Verification sites (see also Sections 3.4.10 and 3.4.11). The White River and Pahroc faults and associated features (Pahroc Mountain zone) form a zone of intense tectonic deformation which may be related to the Pahranagat Shear Zone and other deformational features in the Southern Nevada Transverse Zone. The Pahroc Mountain zone of deformation is about 75 miles (120 kilometers) long and 10 miles (16 kilometers) wide. A zone of such magnitude may have substantial impact on seismic hazard analyses if it is active. Furthermore, the relationship of the Pahroc Mountain zone to the Pahranagat Shear Zone is of interest because the zones appear to intersect. As discussed in Section 3.1, the Pahranagat Shear Zone may be part of a much larger structural zone of regional tectonic significance. If this structural zone is an active tectonic element, it may significantly alter established Basin and Range tectonic models.

Gravity data (Fugro National, 1980) indicate fairly symmetrical, steeply dipping, basin-bounding faults on both sides of Dry Lake Valley. The graben between these boundary faults has a maximum depth on the order of 10,000 feet (3000 meters).

3.4.10 Delamar Verification Site

Delamar Verification site is contiguous with Dry Lake site to the north and both are within the same tectonic regime. Delamar Valley lies between the Delamar Mountains on the east and the South Pahroc Range to the west.

The western edge of the Verification site is bounded by the Pahroc fault, a major north-south trending fault which extends from the Buckhorn fault of the northeast-striking Pahranagat Shear Zone on the south, along the eastern side of the South Pahroc Range, and into the bedrock of the North Pahroc Range. Several short segments along this trend indicate that the Pahroc fault has been active in Holocene and Late Quaternary time.

The Dry Lake fault (Section 3.4.9) extends into Delamar Valley along the western flank of the Delamar Mountains. The fault bifurcates just inside the Delamar Site, with one splay trending along the mountain front toward other scarps farther south and the other toward Holocene features in the center of the valley. The western splay also aligns with short scarps along an outlying ridge of the South Pahroc Range. This pattern appears to form an active zone of right-stepping, en echelon fault segments.

The southern end of Delamar Valley is bounded by the Buckhorn and Maynard Lake faults of the Pahranagat Shear Zone. These faults have 3 and 4.5 miles (4.8 and 7.2 kilometers) of left-lateral separation respectively, since emplacement of the Hiko Tuff about 17 to 19 million years ago (Tschanz and Pampeyan, 1970). The Pahranagat Shear Zone was not studied in detail, so its present age status is Indeterminate. Similarly oriented Late Quaternary scarps in adjacent areas indicate that the zone of shearing may be much more extensive than previously thought. The abundance of earthquakes in this area suggests that crustal movements are presently occurring, but whether this movement is lateral displacement or typical Great Basin normal faulting is not known.

3.4.11 Pahroc Verification Site

The Pahroc Verification site is a small valley between the Hiko Range on the west and the South Pahroc Range on the east. According to published fault maps and aerial photographs, the mountain block on the east is one of the most intensely faulted ranges in the study area. Several of the long north-south trending faults in the South Pahroc Range are suspected of having had Quaternary movement because they display well developed bedrock scarps. These scarps parallel quite closely the north-south trending Pahroc fault (the major fault along the eastern side of the South Pahroc Range) which does have indications of Quaternary movements. Also, along the western side of the Hiko Range in Pahranagat Valley are some very recent-appearing fault scarps. In the northern part of Pahroc Valley, a cluster of short, Holocene and late Quaternary fault scarps trend northeasterly and align with similar trending bedrock faults in the North Pahroc Range. These northeast-southwest-trending faults form an alignment parallel to the late Quaternary (possibly Holocene) Pahranagat Shear Zone south of the South Pahroc Range.

In summary, although the central portion of the Verification site does not have late Quaternary faults, it is surrounded by several active and potentially active, major faults.

3.4.12 White River Verification Site

The White River Verification site occupies the eastern and western edges of White River Valley. The western White River site is bounded by the Horse and Grant ranges on the west and the White River flood plain on the east. On the eastern side of the White River, the site is bounded by the Egan Range.

The major fault feature in the White River site is the Egan fault which is near the bedrock/alluvium contact at the base of the Egan Range. The fault scarp is continuous for a distance of about 24 miles (39 kilometers) except where it has been eroded by streams. The fault is unusual in that it parallels the topography remarkably well over major portions of its length and has a secondary scarp downslope which parallels the major scarp. The two scarps form a graben that winds around the base of the mountains through the alluvial fans. Although some portions of this scarp are certainly due to faulting, as indicated by the issuance of springs from the base of the scarp, portions of the feature may represent an ancient shoreline. If an ancient lake did exist here, then the basin-bounding fault scarp may have been eroded and the fault may be located considerably farther to the west. The limited width of suitable siting area along the margins of the central valley in this Verification site makes it imperative that this fault be examined in more detail prior to siting of facilities.

A group of cracks occurs in the center of the White River Valley and in part of the western White River Verification site. Many of these features could be dessication cracks because they have little or no relief. In a few cases, the cracks do appear to be faults and they occur only adjacent to the Egan fault. Their proximity to the Egan fault might indicate that these features are of tectonic origin, and if not faults, they are perhaps liquefaction features.

Near the northern portion of the western White River site, numerous short fault segments cutting late Quaternary alluvium form a zone of faults about 13 miles (21 kilometers) long. Some of these faults continue into bedrock and others skirt the edge of the bedrock hills.

3.4.13 Coal Verification Site

Coal Valley Verification site lies between the Golden Gate Range on the west and the Seaman Range on the east. As noted in the Garden Valley discussion below, the Golden Gate Range is bounded by a few very short late Quaternary faults but no major late Quaternary bounding fault is known. The western flank of Seaman

Range also does not appear to have any major, late Quaternary fault activity. However, there are two features of concern.

Published geologic maps (Tschanz and Pampeyan, 1970; Stewart and Carlson, 1978; Howard, 1978) show a 13-mile-long (21 kilometers) fault extending from near Seaman Wash along the eastern edge of the central playa, and a southwesterly trending splay cutting across the playa. As shown on these maps, these features would be of Holocene age, but aerial photo analysis suggests that major portions of this feature are shoreline features. Portions of the remaining segments appear to have been altered by aeolian processes. Shoreline scarps and fault scarps are sometimes difficult to distinguish and this feature may be a fault forming the eastern shoreline of the playa. The scarps are the most prominent mid-valley scarps (as opposed to valley-marginal scarps) in the study area, and as such can provide a framework for determining the frequency and mechanism for this type of faulting. It is important to determine how much of the mapped fault is a true fault.

The other fault of interest in the Coal Verification site extends from Pahranagat Valley, through the Pahranagat and Seaman Ranges into the southern end of Coal Valley. Only short segments of this fault can be documented as being of late Quaternary age because most of the rocks through which the fault passes are Paleozoic in age. However, the presence of late Quaternary rupture at both ends of the feature and the easily recognized bedrock ruptures suggest that the fault is young and continuous for at least 7 miles (11 kilometers). Its alignment with the eastern edge of the playa may also indicate that it is continuous with the mapped feature discussed in the preceding paragraph. If this is true, the total length of this feature is about 30 miles (48 kilometers), and it transects the valley longitudinally, nearly down the middle.

3.4.14 Garden Verification Site

Garden Verification site is bounded by the Worthington, Quinn Canyon, and Grant ranges on the west. This western boundary has numerous, short, late Quaternary and possibly Holocene faults which form discontinuous breaks very near the foot of the mountains. The faults extend southward along both sides of the Worthington Range. The scarps on the western flank of the Worthington Range are aligned with the Penoyer fault and if the features are related, the length of the fault system is more than twice that suggested by published maps suggesting that it represents a significant fault and earthquake hazard. The total length of this system of scarps is more than 50 miles (80 kilometers). The relationships between these newly mapped scarps and the published fault trace should be verified.

The eastern side of the Garden Verification site is bounded by the Golden Gate Range, a narrow block which separates Garden Valley from Coal Valley. This mountain block contains several short faults which can be documented as late Quaternary in age in only a few cases.

3.4.15 Tikaboo Verification Site

The Tikaboo Verification site lies at the northern end of Tikaboo Valley between the Pahranagat Range on the east and the Groom Range-Jumbled Hills on the west.

Tikaboo Valley has only a few, short, late Quaternary faults near the southern boundary of the Verification site and along the edge of the Jumbled Hills. These features do not appear to align with any major, mapped faults, and therefore presently are not considered to represent a major hazard.

3.4.16 Railroad Verification Site

The Railroad Verification site comprises the southern end of Railroad Valley. Railroad Valley is bounded by the Pancake and Reveille ranges on the west and the Quinn Canyon, Grant, and White Pine ranges on the east. Both the western and the eastern moutain blocks are tilted down to the east, giving Railroad Valley an asymmetrical cross-section, with the deepest alluvial fill and maximum total fault displacement on the east. The mountain front along the Grant Range rises 4000 to 5000 feet (1200 to 1500 meters) above the valley floor in less than 4 miles (6 kilometers) horizontal distance. Geophysical investigations by Dolly (1978) indicate that the valley has 6000 feet (1800 meters) of late Tertiary and Quaternary basin fill and a maximum total alluvial thickness of about 15,000 feet (4500 meters). These great thicknesses of young sediments indicate a high rate of relative uplift/downdropping along the bounding faults on the eastern side of the valley.

The Railroad Verification site is bounded on both sides by well-developed fault scarps that cut late Quaternary sedimentary deposits and appear relatively young. Some minor features are as young as Holocene. The fault on the eastern side of the site is fairly continuous for more than 40 miles (64 kilometers) and has additional discontinuous segments on both its northern and southern ends which yield a total length of about 70 miles (112 kilometers). The highest scarps are north of the Verification site. This feature may consist of two separate segments, one of which extends through the mountain block toward the Penoyer fault to the south. These relationships should be studied by continued aerial photograph analysis in conjunction with detailed field verification. The Railroad Valley fault appears to be one of the major faults in Nevada, and thus a recurrence interval determination would add greatly to the understanding of the fault/earthquake hazard in the eastern Great Basin.

The presence of some short, Holocene-age fault segments in the central valley region, in conjunction with geophysical data, suggest that active faulting may occur in the valley center as well as along the bedrock-alluvium contact.

The southern Pancake Range, which bounds the western side of the valley, is the locus of some of the youngest volcanic rocks in Nevada, and exhibits well developed cinder cones of probable Holocene age (French and others, 1979). Interbedded basalt flows contain features suggesting an upper mantle origin (Scott and Trask, 1971), which in turn implies that a major crustal break underlies the volcanics and that it has been active in Holocene or late Quaternary time. As is commonly the case, the fault along which the volcanics were extruded is not visible on the surface because the volcanics cover it. Volcanic bombs are found on the ground surface up to 20 miles (32 kilometers) from the nearest young cone and could signify a potential hazard if another eruption should occur during the life of the MX system.

The western side of the valley also has had significant young fault displacements. Displacements on both margins of an asymmetrical valley such as Railroad are unusual. These features should be investigated to determine the nature and style of deformation, and the magnitude and frequency of movement.

3.4.17 Ralston Verification Site

The Ralston Verification site is bounded by the San Antonio Mountains on the west and the Monitor Range on the east. There is no evidence of Quaternary faults in Ralston Valley on aerial photographs. There are a few Indeterminate faults in the mountains to the west. The nearest major Quaternary fault is on the eastern side of the Monitor Range, more than 15 miles (24 kilometers) to the northeast.

3.4.18 Big Smoky Verification Site

The Big Smoky Verification site lies at the southern end of Big Smoky Valley south of the Toiyabe and Toquima ranges. Big Smoky Valley bifurcates at its southern end; one branch extends on trend, south-southwesterly between the Monte Cristo/Cedar

Mountain block and the Weepah Hills. The other branch trends more southerly between the Weepah Hills and the San Antonio Mountains.

The Big Smoky site has numerous Holocene and Late Quaternary fault scarps. The major feature is the basin-bounding fault, which trends into the area along the eastern side of the Toiyabe Range. This feature is very near the bedrock/alluvium contact for a distance of about 55 miles (88 kilometers), and extends into the alluvium of the site for about another 14 miles (22 kilometers). A series of late Quaternary scarps with this same trend occurs along the western flank of the Weepah Hills. Another series of late Quaternary scarps with a more northerly trend lies along the western edge of the San Antonio Mountains.

Several other short scarps are scattered about the Big Smoky site and, in conjunction with the major features, indicate that this area has undergone repeated late Quaternary tectonic activity. Evidence of the significance of this continuing tectonic activity was provided by the magnitude 7.2 Cedar Mountain earthquake which occurred near here in 1932 (Section 2.4.1).

The Big Smoky site occupies a key position in Great Basin/Basin and Range tectonics. The faults in the valley extend across or truncate the Walker Lane Shear Zone. The change of fault trends at the southern extremities of the Verification site may offer a clue regarding the relationship of this graben to the shear zone.

4.0 DISCUSSION

4.1 FAULT-RUPTURE HAZARD

Tectonic analysis suggests that the Great Basin seismotectonic province has been under its present extensional regime for about 10 million years and that the fault activity has been predominantly along the flanks of the mountains or high up on the alluvial apron near the base of the mountains. This style of faulting is typical throughout most of the province. The Dixie Valley-Fairview Peak Seismic Zone in western Nevada, which today is among the most seismically active areas in the western United States, is geologically and geophysically similar to other ranges and basins in the Great Basin province.

There appear to be cycles of seismic activity, with the western Nevada area presently being more active than the rest of the province (Ryall, 1977). Similarly, Wallace (1977) observed that fault ruptures cluster in both time and space, and that a range front may experience several movements within a few thousand years and then remain quiescent for several thousands of years. Apparently, seismic hazard analyses in the Great Basin cannot rely too heavily on the concept that the most dangerous faults are those with recent ruptures.

As discussed in Section 3, the dominant mode of faulting in the Great Basin seismotectonic province is down-to-basin normal faulting. There are numerous arguments about the underlying cause of these faults, but these arguments are not of importance to this study. What may be important, however, is the question of whether the major faults occur predominantly near the base of the mountain blocks or farther out toward the centers of the basins. Geologic and geophysical evidence indicates that the most active faults (those with repeated large displacements) are near the basin-mountain juncture, although some exceptions do occur (notably the 1934 Hansel Valley, Utah earthquake with a magnitude of 6.6). The existence and nature of subsurface faults in the center of the basins can only be studied through geophysical studies (gravity) or trenching. No large faults in central valley locations have been identified from aerial photograph or literature analysis. In some cases, faults may "cross over" from the western side of one valley to the eastern side of a contiguous valley, but this apparently occurs only at the ends of the valleys and is compatible with block fault mechanics.

In summary, it is our opinion that the greatest hazard of fault rupture is near the base of the mountains or high up on the alluvial fans near the bedrock-alluvium contact, and that not only Holocene but also late Quaternary faults represent a hazard.

The detailed scale and high resolution of the aerial photographs used for this study enabled a more detailed analysis of faults than was hitherto possible. Thus, several previously mapped late Quaternary faults have been tentatively discounted, and numerous previously unmapped Quaternary faults have been identified. Quaternary faults are so numerous that every Verification site except Ralston and Hamlin was found to have some. Some sites such as Tule, Snake, and Tikaboo have only a few scattered minor surface faults.

The Verification sites with the highest potential for fault activity appear to be:

Dugway
Whirlwind
Dry Lake
Delamar
Pahroc
White River
Coal
Garden
Railroad
Big Smoky

The major faults in these areas are:

Drum Mountain faults	(Dugway and Whirlwind)
Dry Lake Valley fault	(Dry Lake and Delamar)
Pahroc fault	(Pahroc, Delamar, and Dry Lake)
Egan fault	(White River)
Penoyer and Freiberg faults	(Garden)
Golden Gate fault	(Coal)
Railroad Valley fault	(Railroad)
Big Smoky Valley fault	(Big Smoky)

These faults appear very similar in style and length to fault scarps formed during the 1915 Pleasant Valley earthquake (M = 7.6) and the 1954 Dixie Valley-Fairview Peak earthquakes (M = 7.2 and 7.1) and thus are tentatively considered to be capable of generating similar sized earthquakes. However, the probability of a major earthquake on one of these faults during the life of the MX system is believed to be low but a detailed evaluation is yet to be made. The long interval (several thousand years) since the occurrence of the last rupture on these features may not indicate a lower level of risk because the faults may have accumulated enough strain over that long interval to be ready for release of that strain with an earthquake and fault rupture.

4.2 RELATION BETWEEN FAULTING AND SEISMICITY AND ITS SIGNIFICANCE TO SEISMIC-HAZARD ANALYSES

Within the siting region area, no earthquakes are known to have been associated with surface rupture during the time of the historic record. Some earthquakes have occurred that were large enough to have been accompanied by small amounts of surface rupture that would be unnoticed without prompt field study. The occasional clustering and crude alignment of earthquakes suggests that the seismicity is not completely random.

A regional comparison of the earthquake distribution with geologic and geophysical data shows major zones of earthquakes are near major faults. The best examples are the Owens Valley Zone, the Hurricane-Wasatch Zone (Intermountain Seismic Belt) and the Dixie Valley-Fairview Peak zone. The Owens Valley Zone is a zone of intense Holocene-late Quaternary faulting and volcanic activity. This zone has been the site of a great earthquake in historic times and presently has a relatively high level of seismicity.

The Intermountain Seismic Belt (ISB), (Drawings 2-1, 2-3, and 3-1) coincides with a belt of closely spaced young faults along the western edge of the Colorado Plateau. This correlation between earthquakes and faulting resulted in establishment of the Hurricane-Wasatch Seismotectonic Zone.

The southwestern branch of the ISB, commonly referred to as the Southern Nevada Transverse Zone (SNTZ), does not seem to be represented by a greater density of late Quaternary faults. At least three hypotheses are suggested; 1) that late Quaternary faults have not yet been completely recognized, 2) that seismicity has just recently begun (say within the last few hundred or thousand years), or 3) that the earthquakes are much deeper than elsewhere in the Great Basin and do not result in surface rupture. The presence of deeper hypocenters is not supported by geologic, geophysical, or seismologic data. A new seismic regime can be neither verified nor discounted. Some interesting features of the SNTZ which may ultimately shed some light on the problem are:

1. The SNTZ has an abundance of northeast-southwest trending faults, some with documented lateral displacement.

2. The intersection of the SNTZ with the ISB in Utah is the largest and most continuously active volcanic field in the Basin and Range area.

3. The SNTZ forms the northern edge of an area which has a definite lack of Tertiary and Quaternary volcanic rocks.

4. The zone correlates with a distinct gravity anomaly.

The above features and correlations are not well understood. Presently the zone is considered by some to be an area of fundamentally different tectonics from the remainder of the Basin and Range (Slemmons, 1967; Anderson, 1978; Schell, 1978).

Another zone of concentrated seismic activity, the Dixie Valley-Fairview Peak Zone (DVFPZ), has had several large earthquakes, accompanied by surface rupture, in this century. Most of these surface ruptures are shown near the western edge of Drawing 3-1.

A comparison of the nature and density of faulting in the DVFPZ with other areas on the map (where detailed studies have been done) shows that the DVFPZ is not unique. For example, the area including Railroad, Garden, Coal, Pahroc, Dry Lake, Delamar, and White River valleys shows similar density, style, and lengths of faulting, but generally lacks historic earthquakes. Apparently, the Railroad, Garden, Coal, Pahroc, Dry Lake, Delamar, and White River region became seismically inactive only recently. This observation is in agreement with the concept that the seismicity in the Great Basin seismotectonic zone is cyclic, with an area experiencing earthquakes and faulting for a short period (say a hundred or a few hundred years) then becoming inactive for a few thousand years (perhaps 5,000 to 10,000 years or more).

As previously noted, this concept is supported by the studies of Ryall (1977) which suggest a cyclical seismicity and by Wallace (1977) who suggested recurrence intervals for Great Basin faults on the order of a few thousand years.

The evidence seems to indicate that the Nevada-Utah siting area (Great Basin seismotectonic province), cannot be viewed with the same concepts of seismic hazard as are used elsewhere (such as in California). The data seem to indicate that faults which have not moved in Holocene time still have a potential for large earthquakes and fault rupture. If large earthquakes occur only every few hundred years, it would take many thousands of years before every active fault or potentially active fault experiences one.

4.3 DEVELOPING FAULT AND EARTHQUAKE CRITERIA FOR THE MX SYSTEM

4.3.1 General

As evidenced by the preceding discussions, faulting and earthquake hazards must be considered in the Nevada-Utah siting region. As a result, there is a need for mitigative criteria in the siting of the MX system. This section provides general concepts useful in the formulation of such criteria. Although we recognize the need for avoidance and mitigation, we are not sufficiently well versed in the details of the MX system design to recommend exact criteria at this time. As will be discussed below, the criteria should be predicated on the performance needs of the system.

The formulation of fault and earthquake criteria generally involves three questions: 1) which faults are to be considered significant to the facility because of their potential for earthquakes and ground rupture; 2) how far from one of these significant faults should the facility (or its components) be located to be "safe"; and 3) should the facility be designed for the greatest level of earthquake shaking that could possibly occur, or only for a level of shaking that has some specified probability to occur during the design lifetime.

Examples of criteria which respond to each of these questions are discussed in the following sections. These criteria have been used in siting such diverse facilities such as nuclear power plants, dams, liquified natural gas terminals, schools, and private homes. None of these criteria, however, is directly applicable to MX-system siting, because the MX system is unique in several respects:

1. The system covers a large area so that hazards which normally have low probabilities of occurrence at any one site may have larger probabilities of occurring somewhere in the system during its lifetime;

2. Fulfillment of the system's function is partly assured by redundancy so that fault rupture in one valley may not impair the strike capabilities of missiles in other valleys; and

3. The consequences of structural failure in an earthquake may not threaten human safety to the extent envisioned for certain other facilities.

4.3.2 Determination of Significant Faults

The determination of which faults should be considered as potential sources of earthquakes and ground rupture is generally based on some sort of age criterion applied to observations of the most recent movement. A fault that has not moved within a certain time period is considered either to be inactive or to have such a long recurrence period that the likelihood of its reactivation is acceptably low. If a fault is found to be inactive, it is not considered further in determining design earthquake or fault rupture hazard.

The ages used in defining significant faults varies from application to application. The U.S. Nuclear Regulatory Commission uses criteria of one movement in 35,000 years or more than one movement in 500,000 years to define capable (active) faults. The California Division of Mines and Geology, in evaluating sites for schools and hospitals, considers faults to be active if they have moved during the Holocene (about the last 11,000 years). The U.S. Bureau of Reclamation, in examining dam sites, informally classes faults as active if they have moved in the past 100,000 years. The California Public Utilities Commission is using a 140,000-year criterion in siting liquified natural gas terminals.

Every definition of "active" fault deals implicitly with the likelihood that the fault will move again within a given time frame. The eventual application of a definition dictates the degree of conservatism invoked, and the age criterion is one manifestation of this conservatism. In selecting an age criterion for active faults, the level of conservatism has not been defined but probably will be influenced by economic cost-risk choices, system performance needs, and the exposure of personnel or inhabitants to risk. This situation contrasts with the examples given above (that all have significat population risk), and might lead to selection of a lower, less conservative age criterion. However, in the Nevada-Utah siting region, the geologic and seismologic data indicate that fault activity is cyclical and that centers of activity shift from place to place within the Great Basin. In this context, all of the late Quaternary faults should be considered active since all of them may be prone to movement in the current tectonic regime. Based on this consideration alone, we suggest that all faults with evidence of movement within the last 700,000 years (late Quaternary) should be considered potential hazards.

4.3.3 Setbacks from Faults and Fault Crossings

The appropriate distance that a structure should be located away from a fault is actually a dual consideration involving: 1) the effects of surface rupture, and 2) the effects of earthquake vibration. Other "lifeline" facilities such as roads, utilities and hardwire communications are obligated to cross faults in at least some places.

Again, there is considerable variation in practice. The U.S. Nuclear Regulatory Commission Regulatory Guide 4.7 discourages placing a nuclear plant near a "capable" (active, as used here) fault; a setback of 5 miles or more is suggested. This "set-back" is used because of assumptions that it is not presently feasible to design a plant to withstand ground rupture beneath or through its foundation and recognizes our limited ability in many areas to locate all of a fault's traces and splays, and to predict the width of its rupture. In contrast, the State of California applies a minimum 50-foot setback from active faults for siting houses, schools, and hospitals. The California Public Utilities Commission requires a fault-specific setback (based on the fault's rupture characteristics) for the safety-critical components (storage tanks and fire control system) of liquified natural gas terminals, but permits other portions, such as transfer piping, to cross active faults. The Trans-Alaska pipeline was designed to withstand 10 feet of offset at buried crossings of active faults. Thus there is considerable variation in setbacks from active faults, ranging from wide avoidance to no avoidance depending on the nature of the facility.

In establishing a setback criterion for the MX system, several aspects of the system function need to be kept in mind. First, a fault rupture will impair only a small portion of the system at any one time. One might argue that the functional impairment to the system as a whole will be small, temporary, and have a low probability of occurrence so that setbacks are not needed. Looking at the problem from a cost-risk standpoint, however, it may prove appropriate to place expensive or critical structures, such as shelters and command/control facilities, away from rupture hazards. Again, the probability of rupture, the effect of damage and the cost of repair will dictate the criteria adoped.

Secondly, certain portions of the system will be less resistant to vibration than others, and setbacks should be determined accordingly. Accelerations at frequencies of engineering interest decay very slowly with distance from a fault rupture. Strong ground motion could extend one or two valleys in either direction from a fault rupture. Thus, for a normally engineered, earthquake resistant, structure, there is very little difference whether the distance from the fault is 2 miles or 6 miles. However, high frequency accelerations decrease more rapidly with increasing distance from a causative fault, and placement of a structure can be critical if the structure houses electronic equipment which is susceptible to damage by high frequency vibration. In such cases, cost-risk should again be a guiding factor.

Finally, some considerations should be given to the Designated Transportation Network (DTN) and the ground communication system. Generally, the cost in dollars and time to repair fault breaks in the DTN appear to be low enough that there is little need to establish strict criteria for roads. Other lifeline systems may need more strict siting because of the experience at Nevada Test Site where test blasts activated rupture on several faults. Because geologic and seismologic evidence suggest that the faults in the Nevada-Utah siting region are under stress, there is a possibility that blasts in a massive nuclear attack might trigger fault ruptures that would threaten communication systems at a critical time.

As indicated above, the need for setbacks from faults (particularly large setbacks) and fault crossing criteria are not well defined. A single set of criteria probably should not be uniformly applied to all system components and the criteria should be based on component design, purpose and the consequences of the components failure.

4.3.4 Determination of Design Earthquakes

Two basic types of seismic hazard analyses are commonly used in the determination of design earthquakes and ground motions: deterministic analysis and probabilistic analysis. The deterministic procedure bases the criteria for the seismic design of a facility on the largest credible ground motion at the site of the facility. This method is utilized in design of critical facilities where human safety or facility failure is a crucial consideration, such as in the design of large dams or nuclear power plants. A probabilistic analysis is sometimes applied in situations where the failure of a facility is mainly an economic risk. A probabilistic analysis determines the likelihood that various levels of strong ground motion will be exceeded within a given period of time, and these probabilities are used for cost-risk analyses to select criteria for the most economic design.

Parameters needed for a probabilistic analysis include recurrence curves describing the rate of seismicity, and attenuation relations to account for distance effects. Some probabilistic analyses use an arbitrary area such as that defined by a 200-mile radius circle centered on the site under investigation. Others use a province approach: only those earthquakes occurring within a seismotectonic province are used to calculate the recurrence curve for that province, and the major earthquakes from outside the province are considered only if they might have a significant impact on the site (accelerations $\geq$ 0.1 g). Thus, probabilistic analyses require that the earthquake history be known and must incorporate some form of seismotectonic model.

In the deterministic approach, the most important parameter is the maximum level of shaking that could reasonably be expected to affect the site without regard to time; this shaking is called the Maximum Credible Earthquake (MCE). The MCE is based on the largest earthquake to occur within historic time, unless geologic evidence dictates that larger shocks should be used. Geologic evidence generally consists of field evidence of late Quaternary surface ruptures. Using empirical relations between fault length and earthquake magnitude, or fault displacement and earthquake magnitude, these ancient surface ruptures can be used to postulate the largest earthquake. Attenuation relations can then predict the maximum ground motion at the site (MCE).

In both the probabilistic approach and the deterministic approach, the ultimate product is a design earthquake which predicts the maximum levels of ground motion at the site. Some agencies use both approaches and have dual design earthquakes: Safe Shutdown Earthquake and Operating Basis Earthquake in NRC criteria; Ductility Level and Strength Level earthquakes in American Petroleum Institute guidelines. A dual approach, with structures whose continuing function is imperative (such as the operational base) designed to accommodate an MCE, and less critical structures (such as the shelters) designed for a probabilistically determined event, may have merit for the MX system.

5.0 CONCLUSIONS AND AREAS OF CONTINUING STUDY

The results to date of the active fault and earthquake study are as follows:

1. The following FY 79 Verification sites contain, or are close to late Quaternary faults or fault systems of considerable length:

   Dugway
   Whirlwind
   Dry Lake
   Delamar
   Pahroc
   White River
   Coal
   Garden
   Big Smoky
   Railroad

2. The spatial distribution of known historic seismicity shows that the current seismicity of the regions immediately to the east, west, and south of the siting region is greater than in the Nevada-Utah siting region proper. The low level of known historic seismicity in the siting region is in part a result of the lack of instrumentation in that area. Although no major earthquakes have occurred in that area in historic time, numerous smaller earthquakes have probably escaped detection. Consequently, a subregional seismograph network to bolster the existing detection capability should be considered.

3. Tectonic interpretations, combined with observations of current seismicity, indicate that the siting region is currently tectonically and seismically active, although at a low level. This pattern could change, with local areas becoming more active; the most likely candidates for increased activity would be those faults which show evidence of late Quaternary activity.

4. Siting criteria should be developed for active fault and earthquake hazards.

Because of the number of factors to be evaluated in order to develop seismic design criteria, it is recommended that personnel of Fugro National meet with the BMO. The purpose of the meeting will be to develop guidelines which can be used to complete the next phase of the study.

During the next phase of this study, the following tasks will be completed:

1. The office evaluations of faulting and fault activity will be verified in the field (currently being done);

2. A seismotectonic model of the siting region will be developed which takes into account all of the potential earthquake sources recognized during the first phase of the study; and

3. An assessment will be made of the potential for seismic shaking in selected valleys. The methodology for this task may be either deterministic or probabilistic, depending on the criteria established in our meeting with Ballistic Missile Office.

BIBLIOGRAPHY

Aki, K., Reasenberg, P., DeFazio, T., and Tsai, Y. 1969, Near-field and far-field seismic evidences for triggering of an earthquake by the Benham explosion: Bull. Seismol. Soc. Am., v. 59, p. 2197-2207.

Anderson, L. W., and Miller, D. G., 1979, Quaternary fault map of Utah: Fugro National, Inc. and Utah Geological and Mineralogic Surv.

Anderson, R. E., 1978, Quaternary tectonics along the Intermountain Seismic Belt south of Provo, Utah: Brigham Young Univ. Geol. Studies, v. 25, p. 1-10.

Arabasz, W. J., Smith, R. B., Richins, W. D., 1979, Earthquake studies in Utah 1850-1978: Salt Lake City, Univ. of Utah.

Bucknam, R. C., 1969, Geologic effects of the BENHAM underground nuclear explosion, Nevada Test Site: Bull. Seismol. Soc. Am., v. 59, p. 2209-2220.

Bucknam, R. C., and Anderson, R. E., 1979, Estimation of fault-scarp ages from a scarp-height-slope-angle relationship: Geology, v. 7, p 11-14.

Coffman, J. L., and Von Hake, C. A., 1973, Earthquake history of the United States: U.S. Dept. Commerce Publication 41-1, 208 p.

Dolly, E. D., 1979, Geological techniques utilized in Trap Spring field discovery, Railroad Valley, Nye County, Nevada, in Newman, G. W., and Goode, H. D., eds., Basin and Range symposium and Great Basin field conference: Rocky Mountain Assoc. of Geologists, p. 455-468.

French, D. E., and Freeman, K. J., 1979, Tertiary volcanic stratigraphy and reservoir characteristics of the Trap Spring field, Nye County, Nevada, in Newman, G. W., and Goode, H. D., eds., Basin and Range symposium and Great Basin field conference: Rocky Mountain Assoc. of Geologists, p. 487-502.

Fugro National, Inc., 1980, MX siting investigation gravity survey - Dry Lake Valley, Nevada: Unpubl. rept. to U.S. Dept. Air Force, FN-TR-33-DL.

___________, 1980, MX siting investigation gravity survey - Hamlin Valley, Nevada: Unpubl. rept. to U.S. Dept. Air Force, FN-TR-33-HV.

Fugro National, Inc., 1980, MX siting investigation gravity survey - Hamlin Valley, Nevada: Unpubl. rept. to U.S. Dept. Air Force, FN-TR-33-HV.

___________, 1980, MX siting investigation gravity survey - Whirlwind Valley, Utah: Unpubl. rept. to U.S. Dept. Air Force, FN-TR-33-WW.

Heintze, L., 1963, Geologic map of southwestern Utah: Dept. Geol. Brigham Young Univ.

Hose, R. K., and Blake, M. C., Jr., 1976, Geology and mineral resources of White Pine County, Nevada: Nevada Bur. Mines and Geology Bull. 85, p. 1-32.

Howard, E. L., 1978, Geologic map of the eastern Great Basin, Nevada and Utah: Denver, Terrascan Inc.

Howard, K. A., Aaron, J. M., et al, 1978, Preliminary map of young faults in the United States as a guide to possible fault activity: U.S. Geol. Surv. Map MF-916.

Kleinhampl, F. J., and Ziony, J. I., 1967, Preliminary geologic map of northern Nye County, Nevada: U.S. Geol. Survey Open-File map.

Krinitsky, E. L., 1974, State-of-the-art for assessing earthquake hazards in the United States; report 2, fault assessment in earthquake engineering: Vicksburg, U.S. Army Engineer Waterways Experiment Station, Misc. Paper 5-73-1.

Rogers, A. M., 1977, A preliminary assessment of the seismic hazard of the Nevada test site region: Bull. Seismol. Soc. Am., v. 67, p. 1587-1606.

___________, 1979, Personal communication.

Rogers, A. M., Perkins, D. M., and McKeown, F. A., 1976, A catalog of seismicity within 400 km of the Nevada Test Site: U.S. Geol. Survey Open-File Rept. 76-832.

Ryall, A., 1977, Earthquake hazard in the Nevada region: Bull. Seismol. Soc. Am., v. 67, p. 517-532.

Ryall, A., Slemmons, D. B., and Gedney, L. D., 1966, Seismicity, tectonism, and surface faulting in the western United States during historic time: Bull. Seismol. Soc. Am., v. 56, p. 1705-1135.

Ryall, A., and VanWormer, J. D., 1979, Seismic zoning in the western Great Basin: in press.

Schell, B. A., 1978, Seismotectonic microzoning fo. . thquake risk reduction, in Proc. Second Int. Conf. on Microzonation, p. 571-585.

Schell, B. A., and Hileman, J. A., 1979, Seismotectonic zones of the southwestern United States and northern Mexico: Geol. Soc. Am., Abst. with Programs, v. 11, no. 7, p. 511.

Scott, D. H., and Trask, N. J., 1971, Geology of the Lunar Crater volcanic field, Nye County, Nevada: U.S. Geol. Surv. Prof. Paper 599-I, 22 p.

Slemmons, D. B. 1967, Pliocene and Quaternary crustal movements of the Basin-and-Range province, U.S.A.: Osaka City Univ. Jour. of Geoscience, v. 10, p. 91-103.

Slemmons, D. B., Jones, A. E., and Gimlett, J. I., 1965, Catalog of Nevada earthquakes 1852-1960: Bull. Seismol. Soc. Am., v. 55, p. 519-565.

Smith, R. B., and Sbar, M. L., 1974, Contemporary tectonics and seismicity of the western United States with emphasis on the Intermountain Seismic Belt: Geol. Soc. Am. Bull., v. 85, p. 1205-1218.

Smith, S. W., Archambeau, C. B., and Gile, W., (1969), Transient and residual strains from large underground explosions: Bull. Seismol. Soc. Am., v. 59, p. 2185-2196.

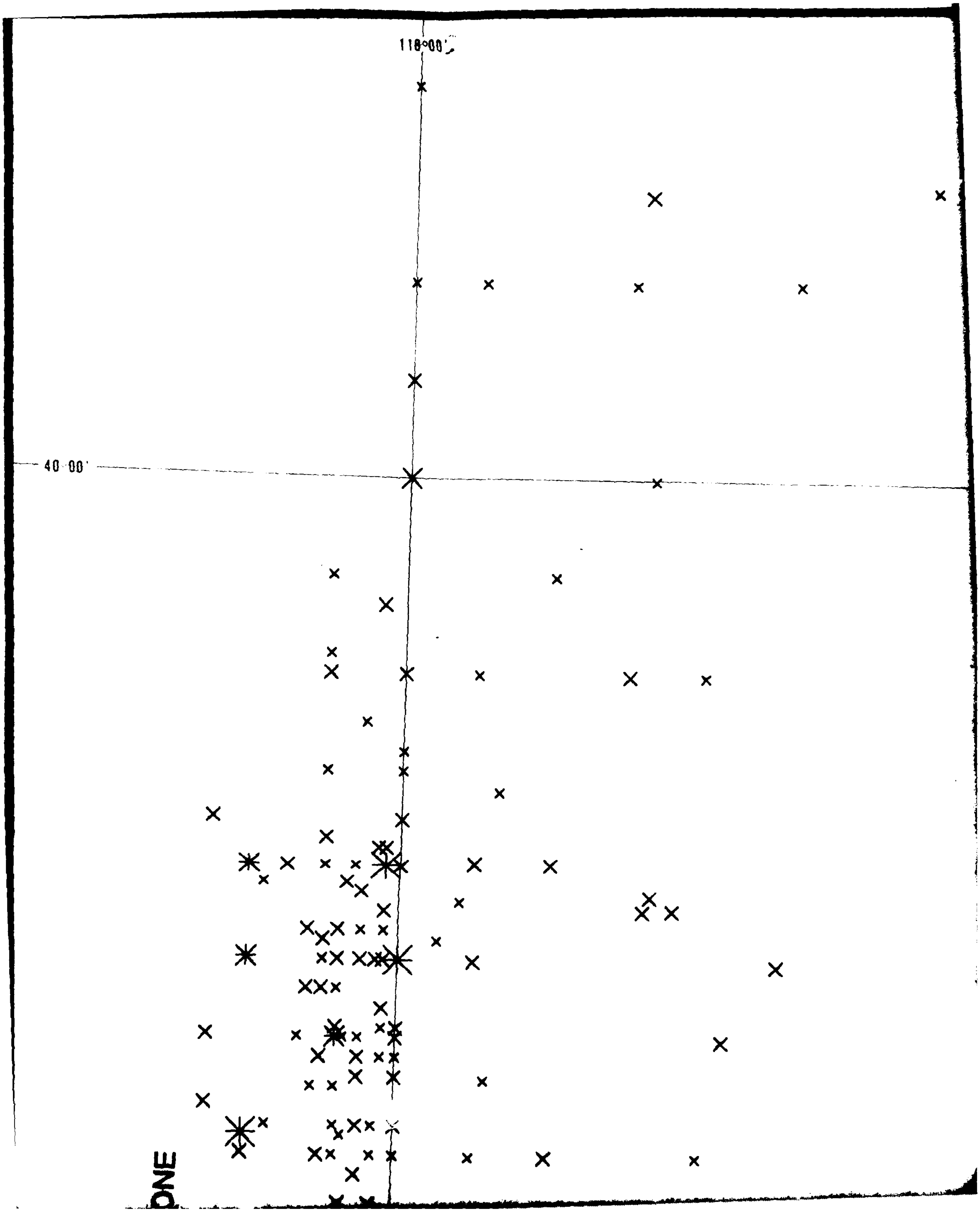
Stewart, J. H., 1978, Basin-range structure in western North America: a review in, Smith, R. B., and Eaton, G. P., eds., Cenozoic tectonics and regional geophysics of the western cordillera: Geol. Soc. Am. Mem. 152, p. 1-32.

Stewart, J. H., and Carlson, J. E., 1978, Geologic map of Nevada U.S. Geol. Survey and Nev. Bur. Mines and Geol.

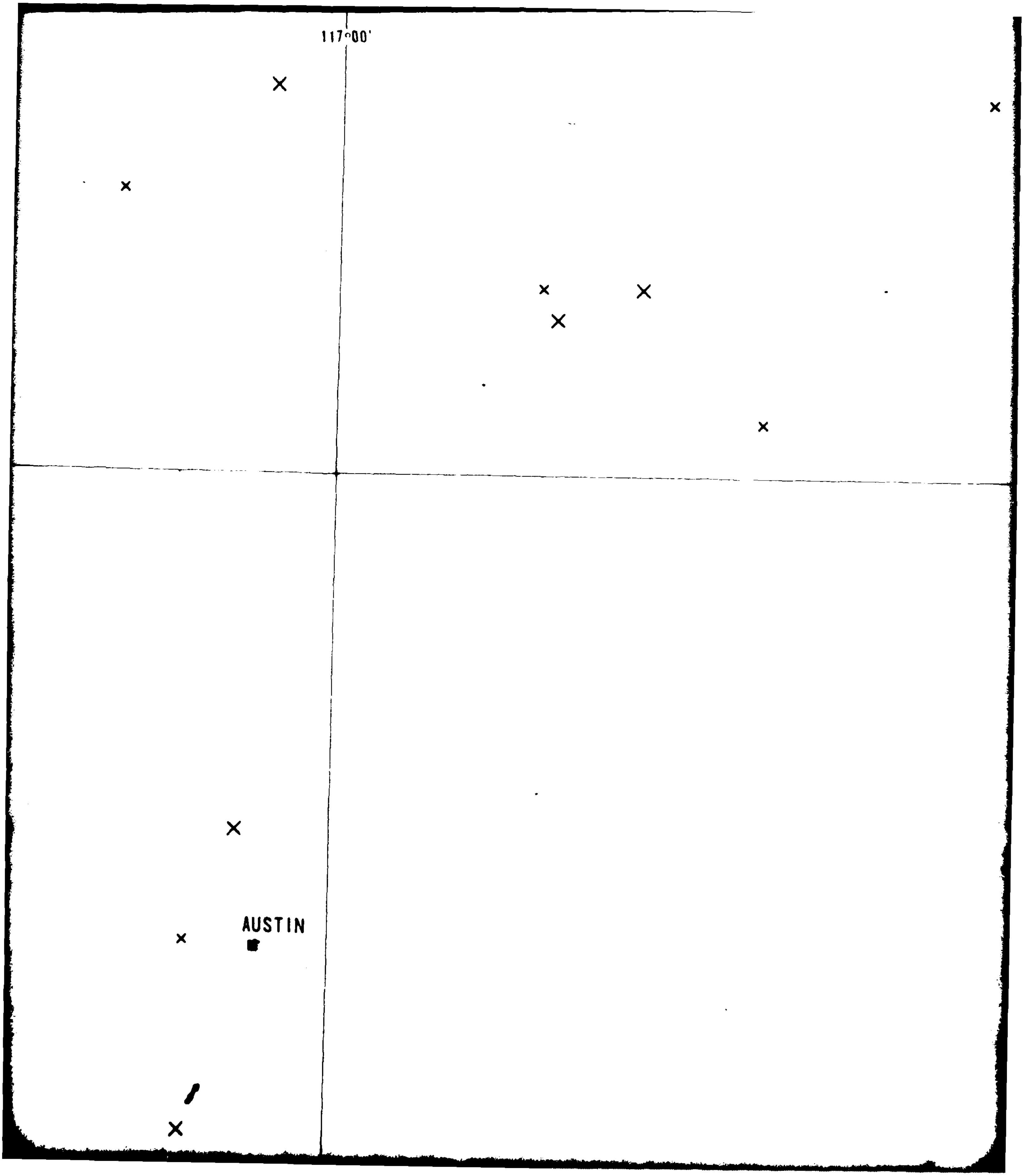
Townley, S. D., and Allen, M. W., 1939, Descriptive catalog of earthquakes of the Pacific Coast of the United States 1769-1928: Bull. Seismol. Soc. Am., v. 29, p. 1-297.

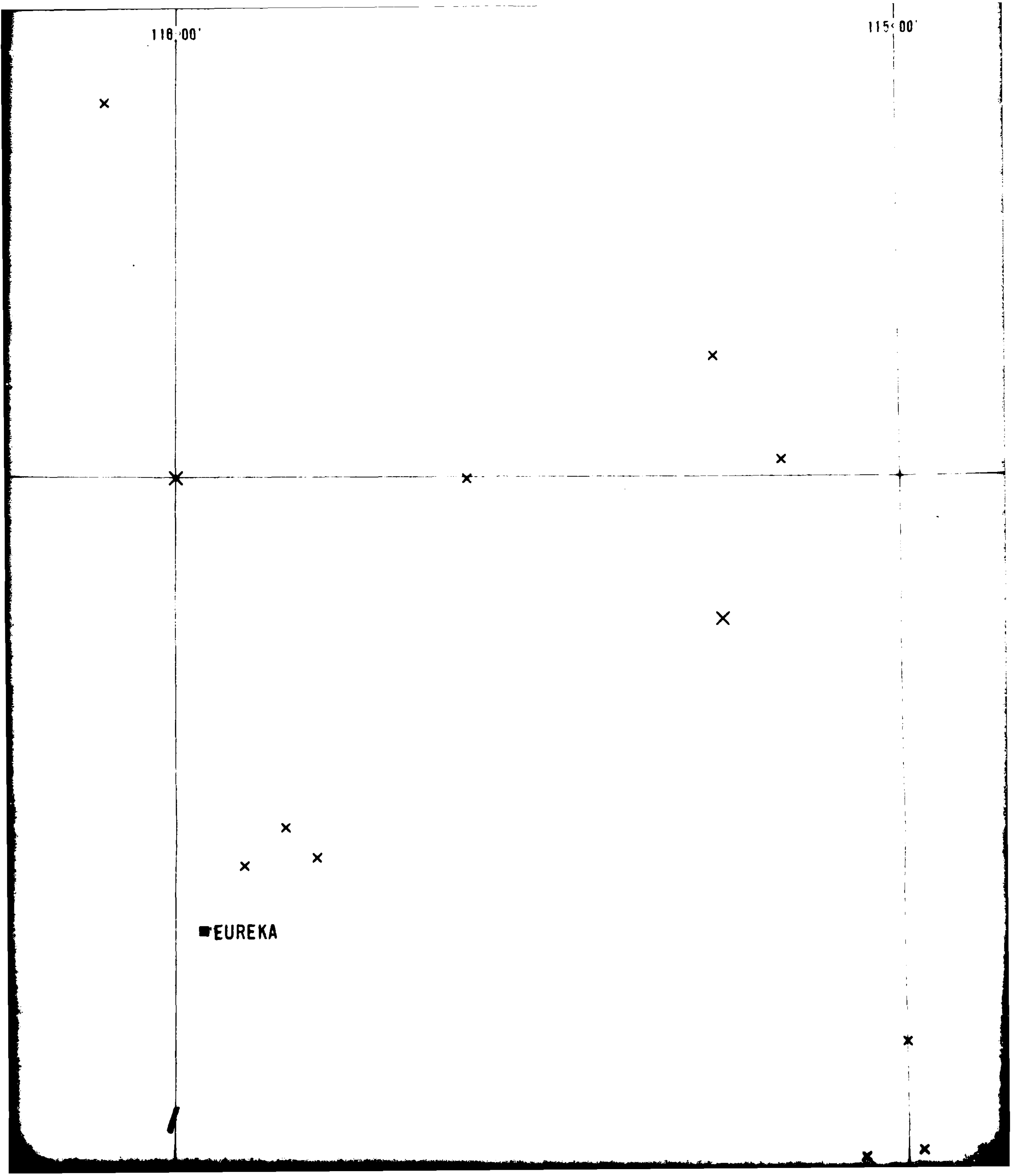
Tschanz, C. M., and Pampeyan, E. H., 1970, Geology and mineral deposits of Lincoln County, Nevada: Nevada Bur. Mines Bull. 73, 187 p.

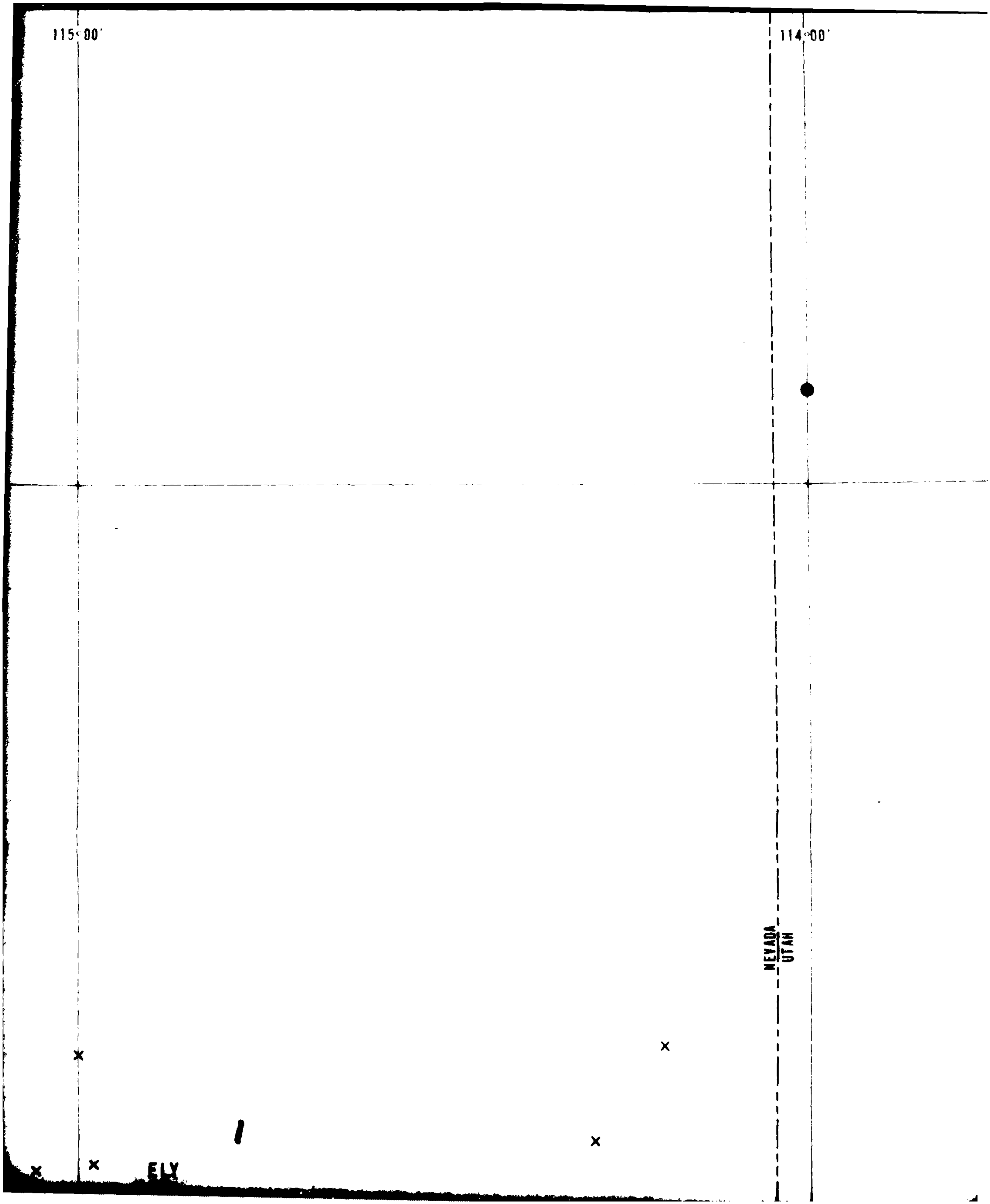
Wallace, R. E., 1977, Profiles and ages of young fault scarps, north-central Nevada: Geol. Soc. Am. Bull., v. 88, p. 1267-1281.

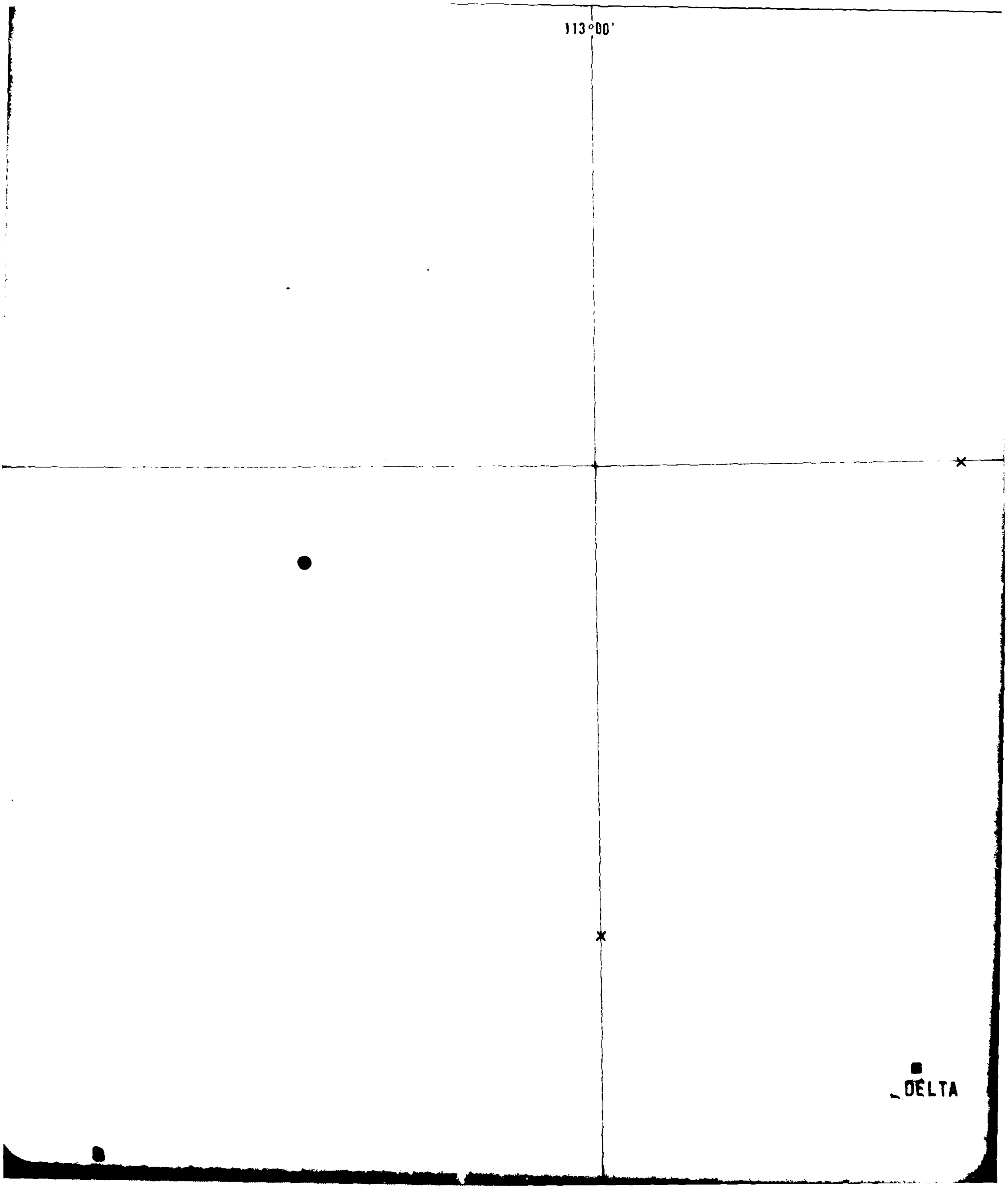


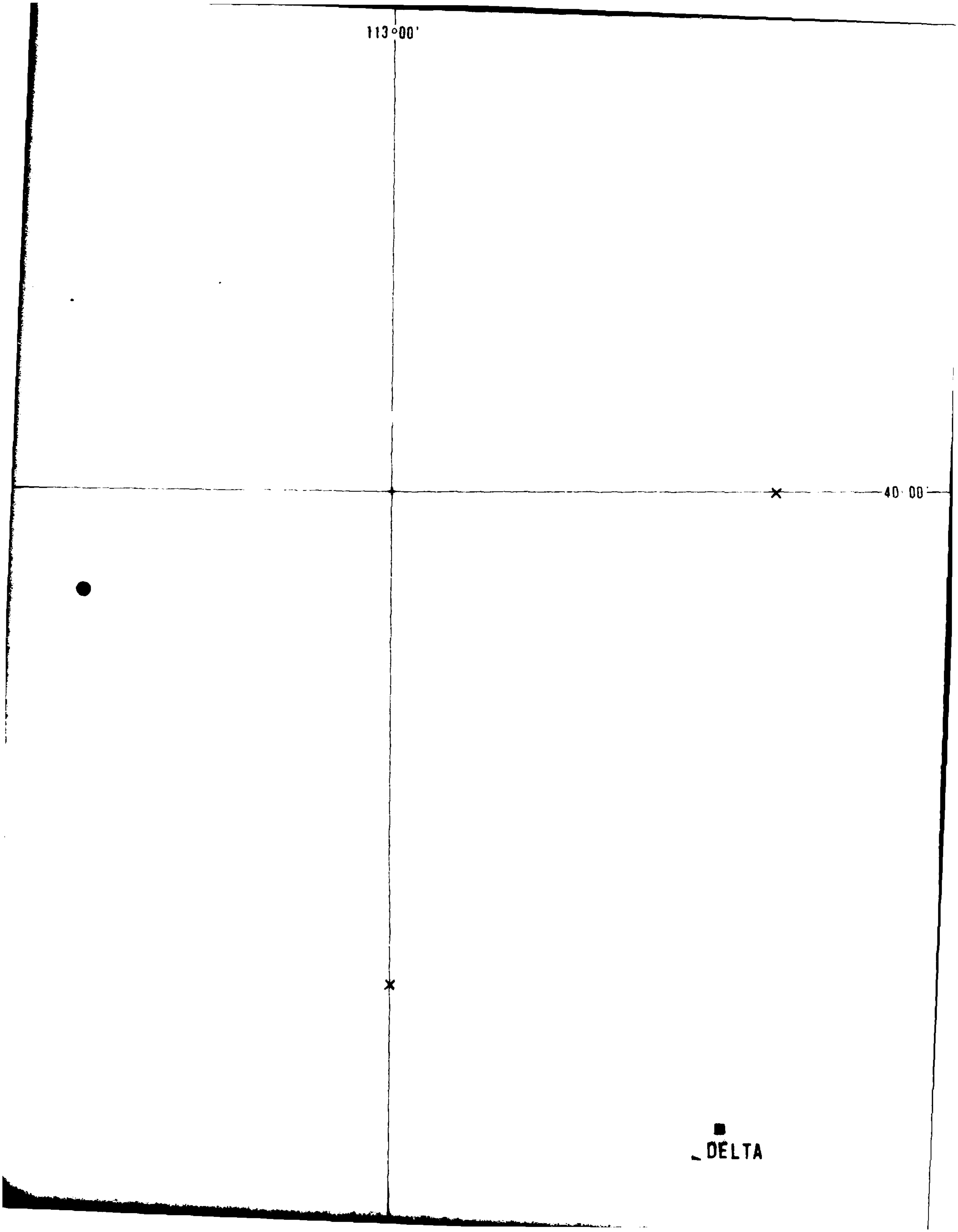
118°00'
40°00'
ONE

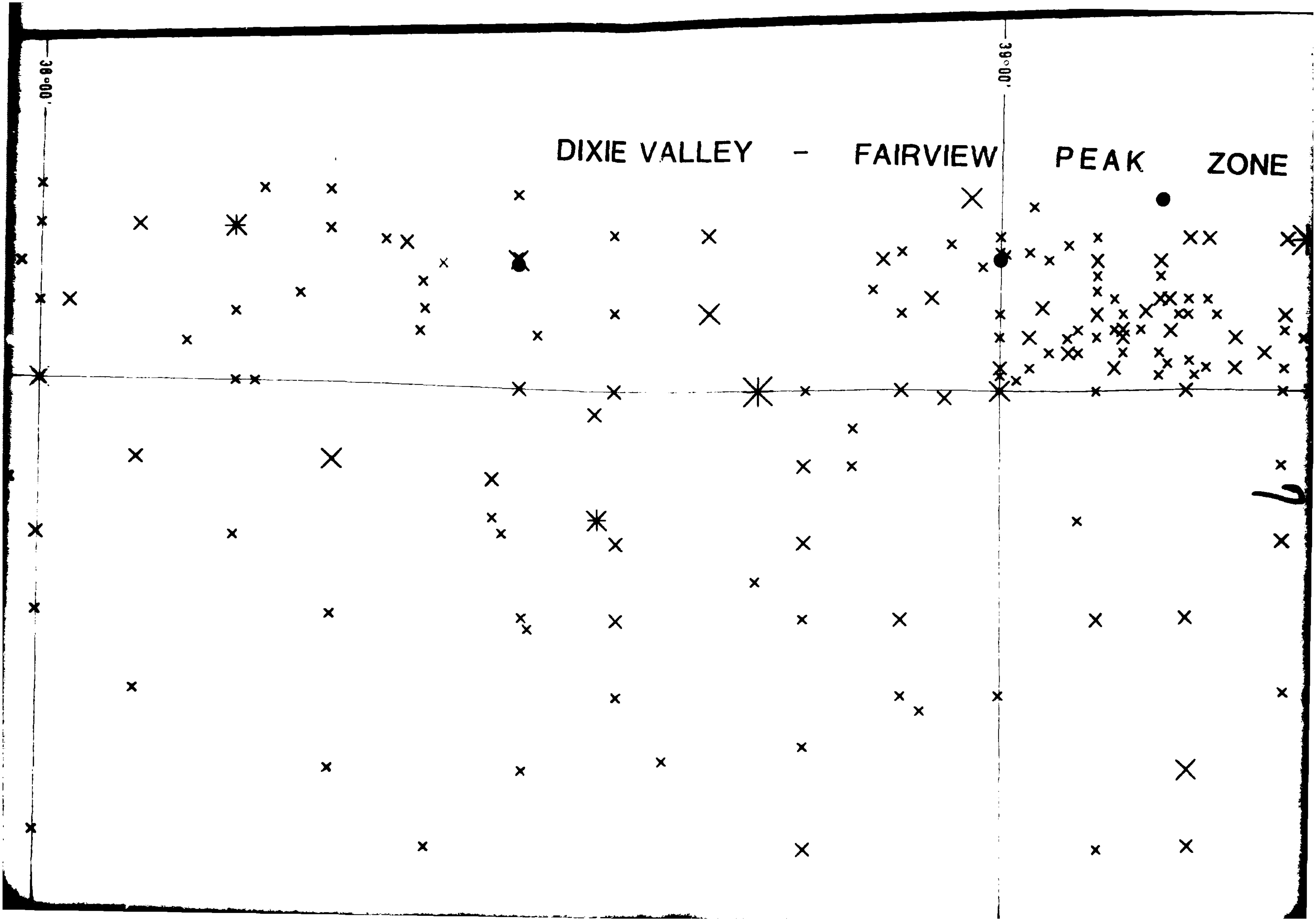

117°00'
AUSTIN


116°00'
115°00'
EUREKA

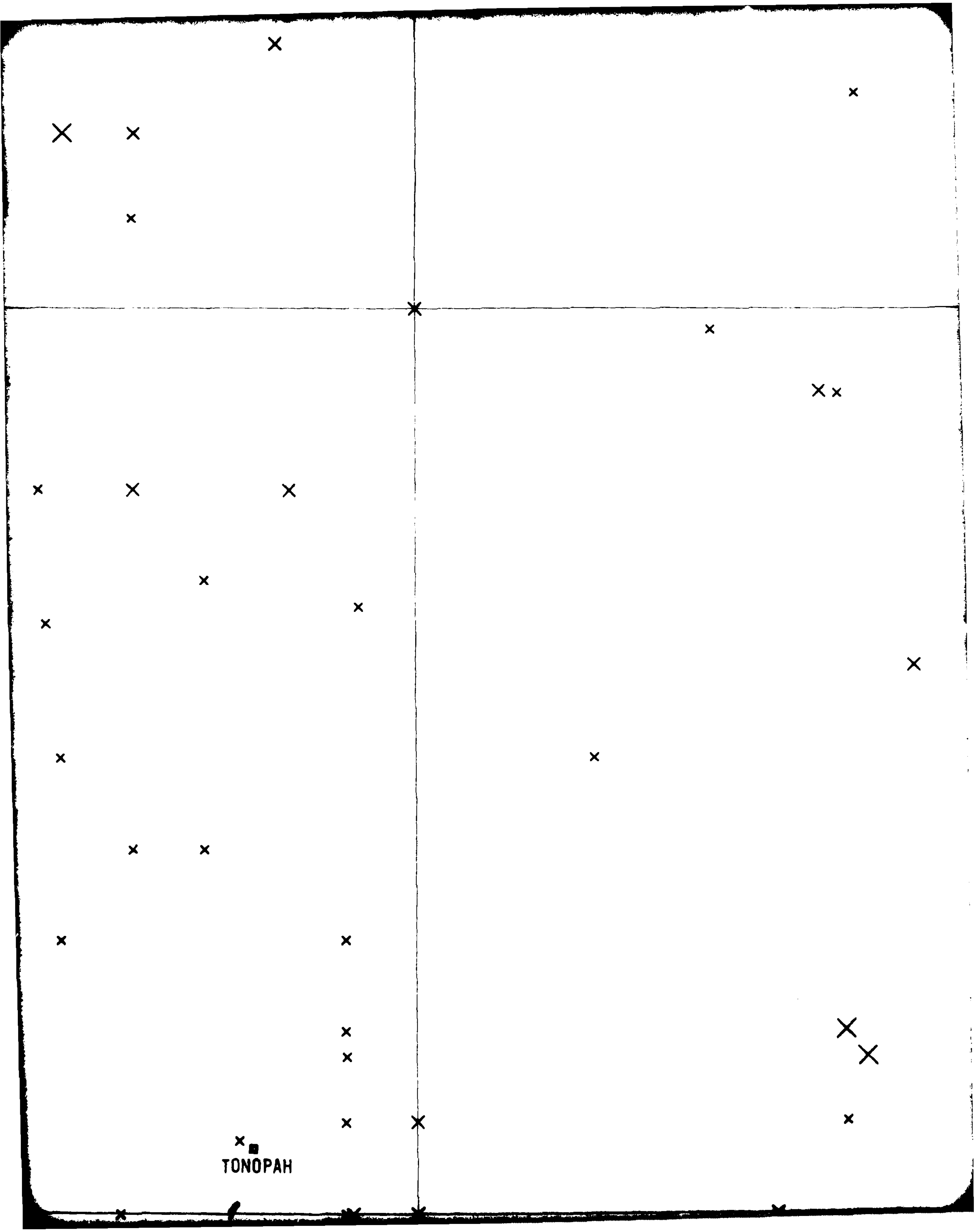

115°00'
114°00'
NEVADA
UTAH
ELY

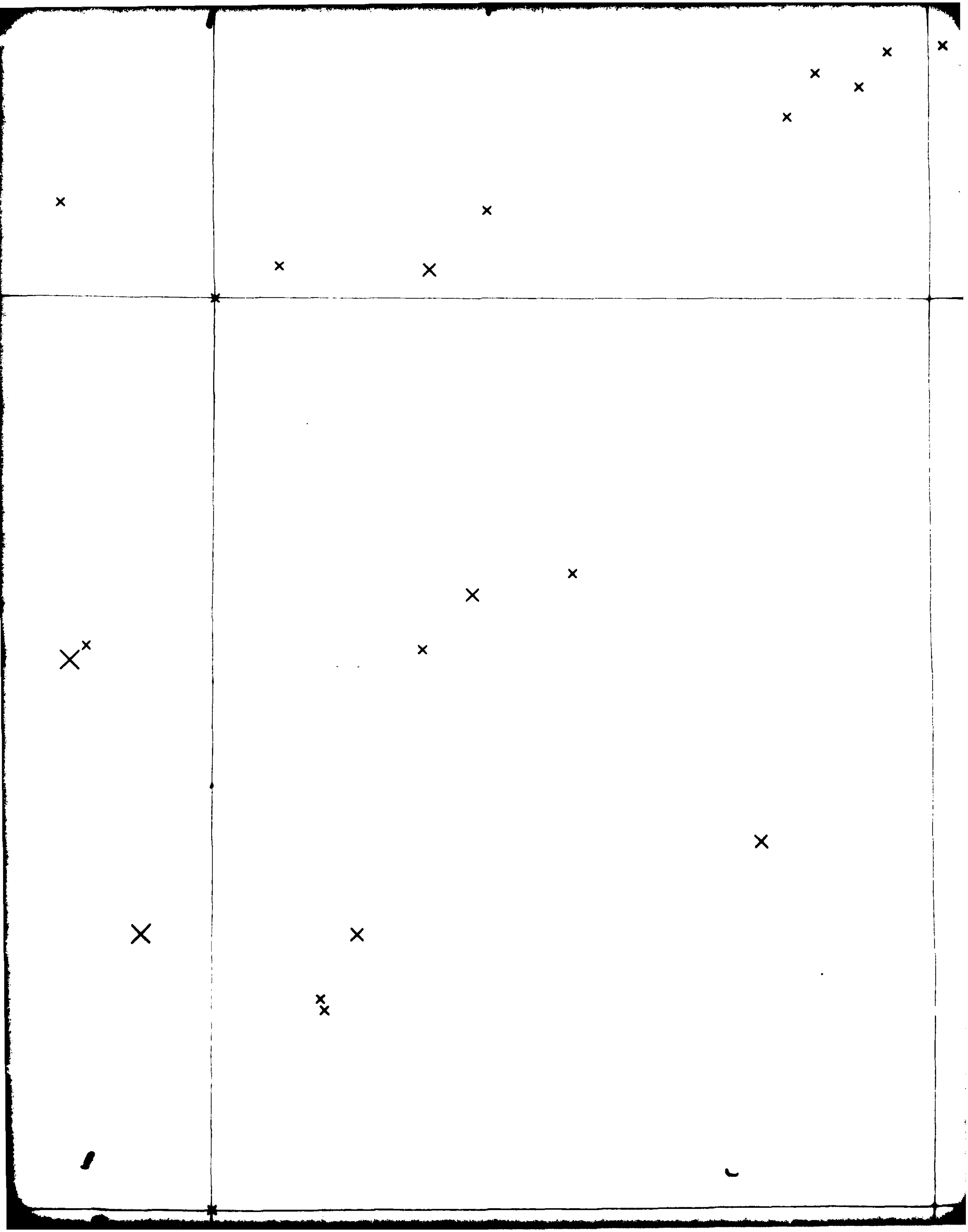

113°00'
DELTA

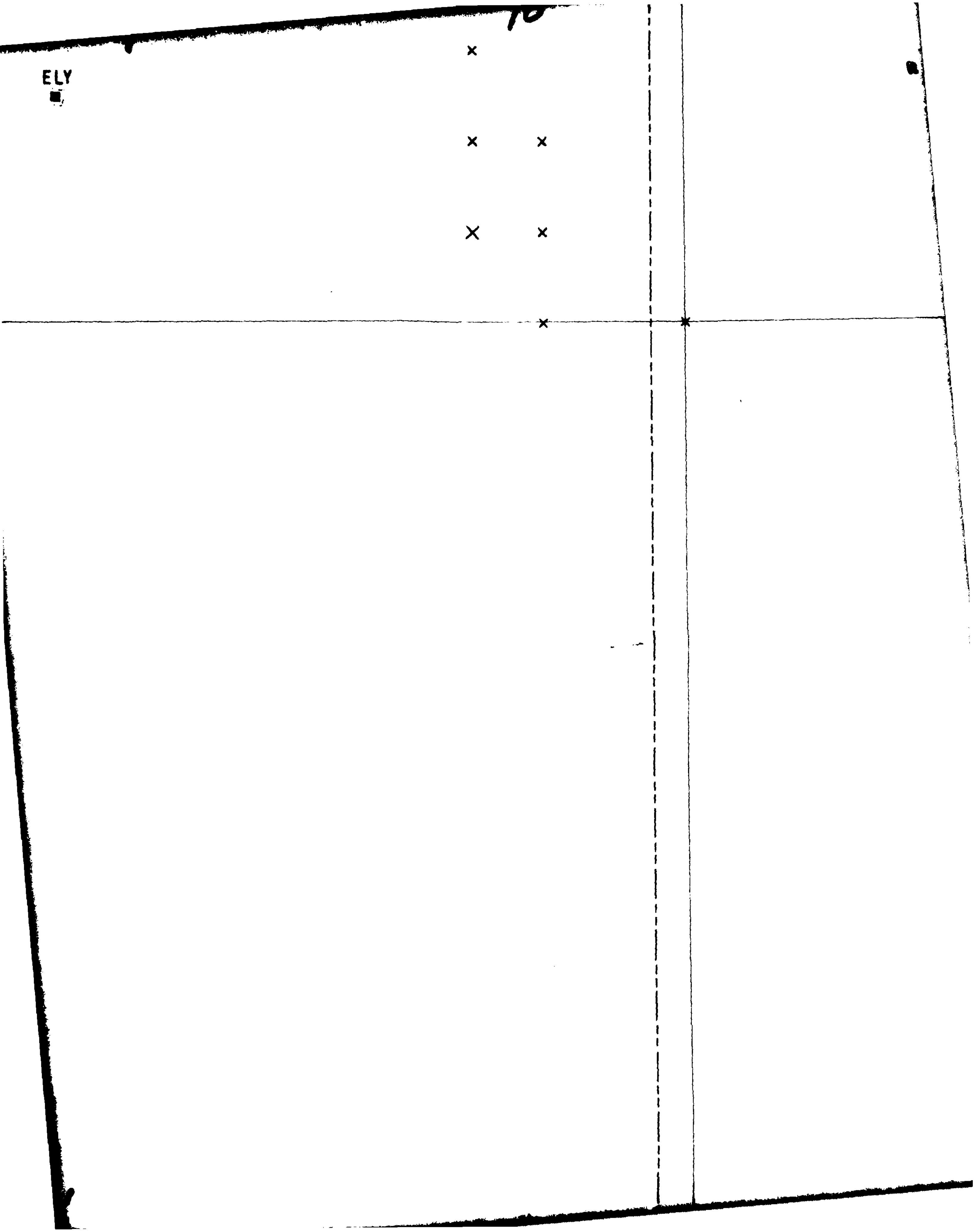

113°00'
40°00'
DELTA

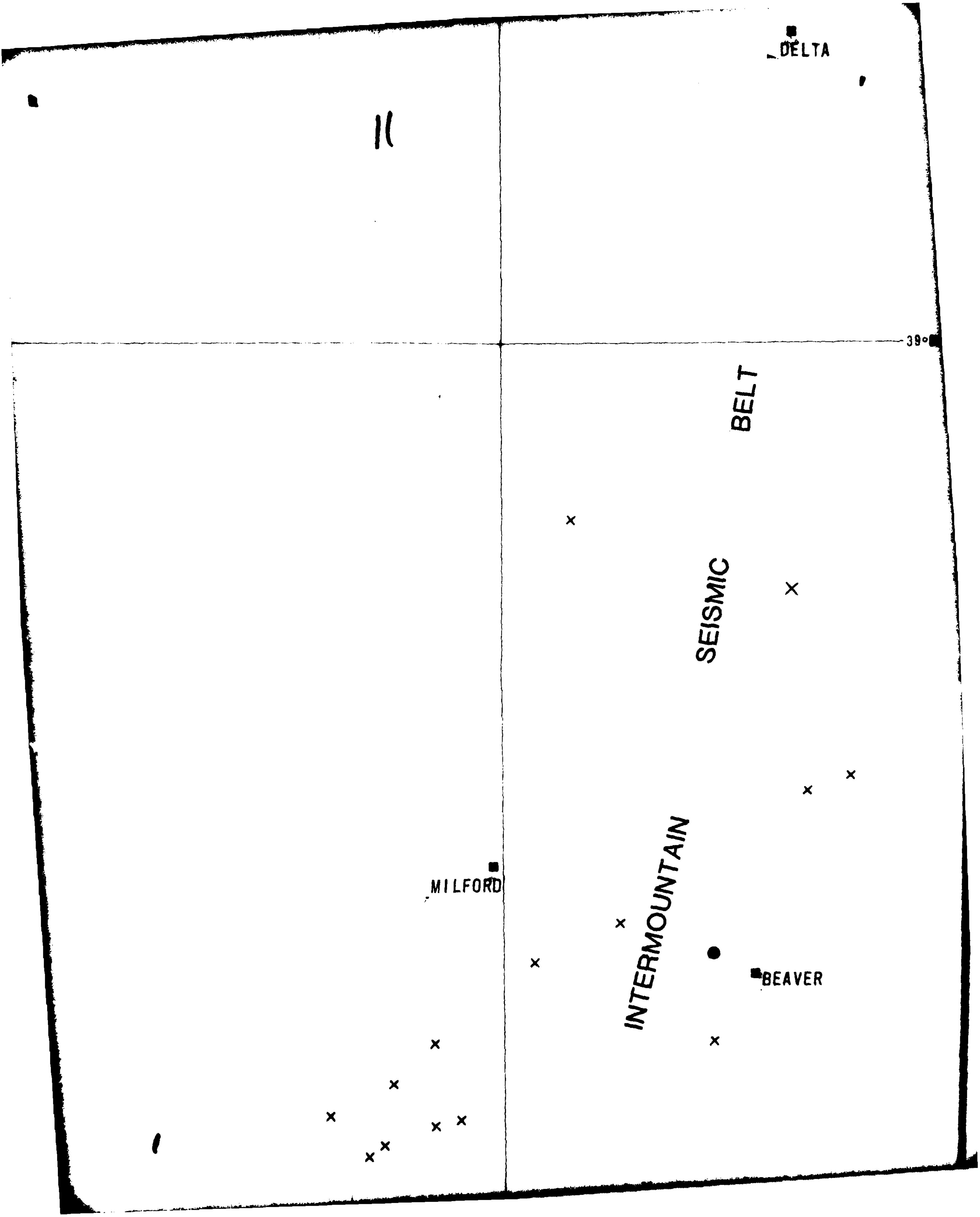


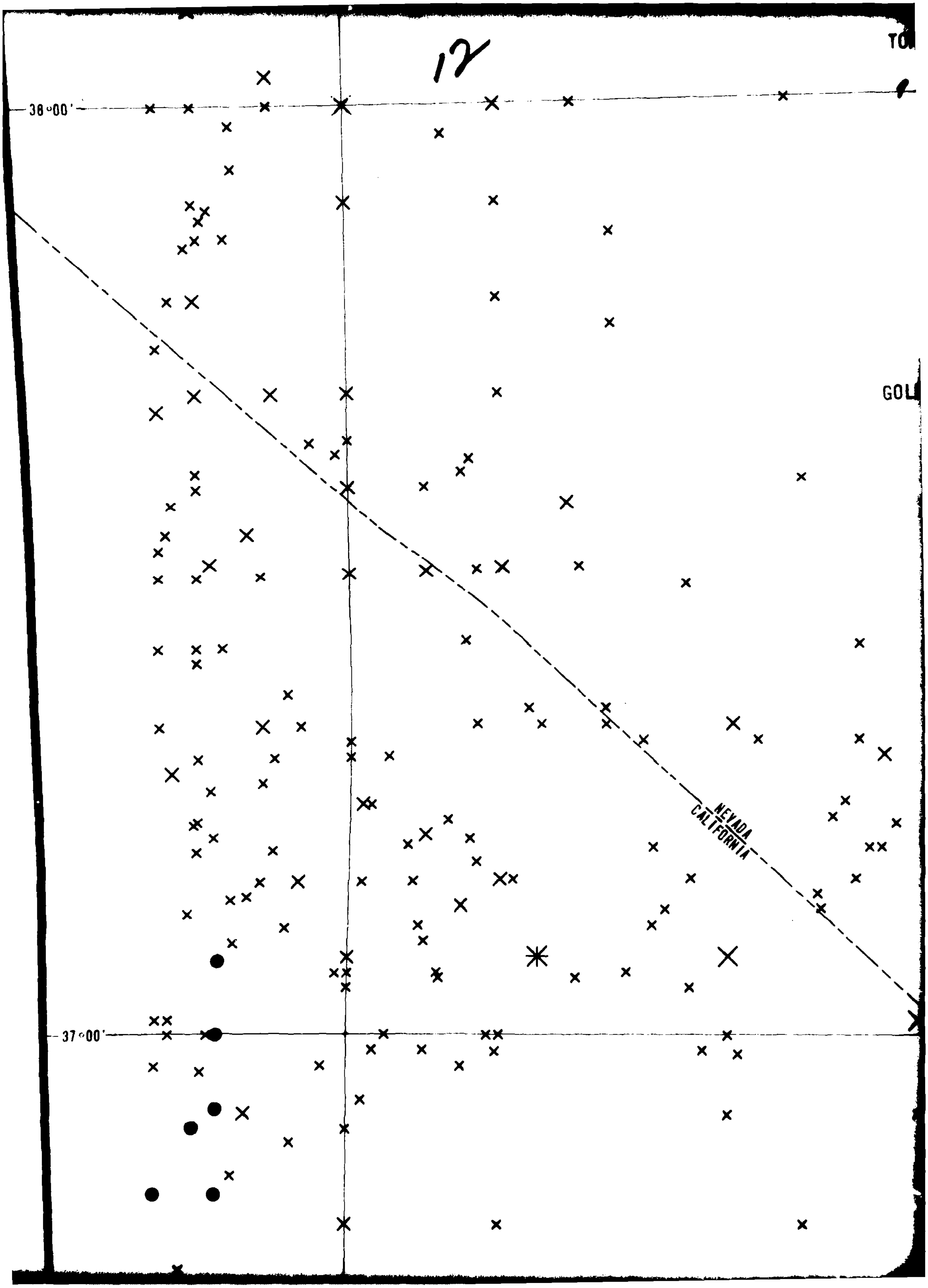
DIXIE VALLEY - FAIRVIEW PEAK ZONE
38°00'
39°00'

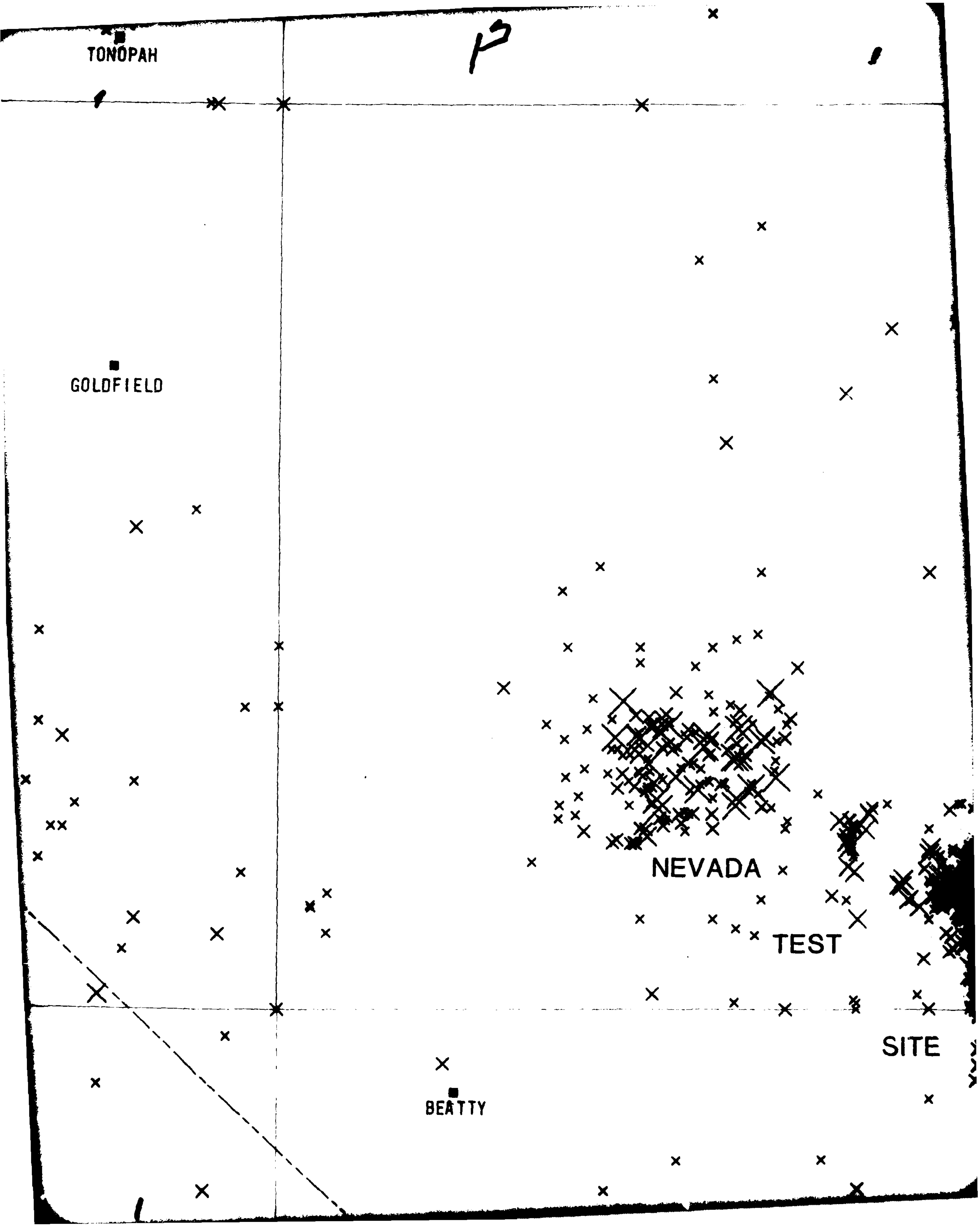

TONOPAH

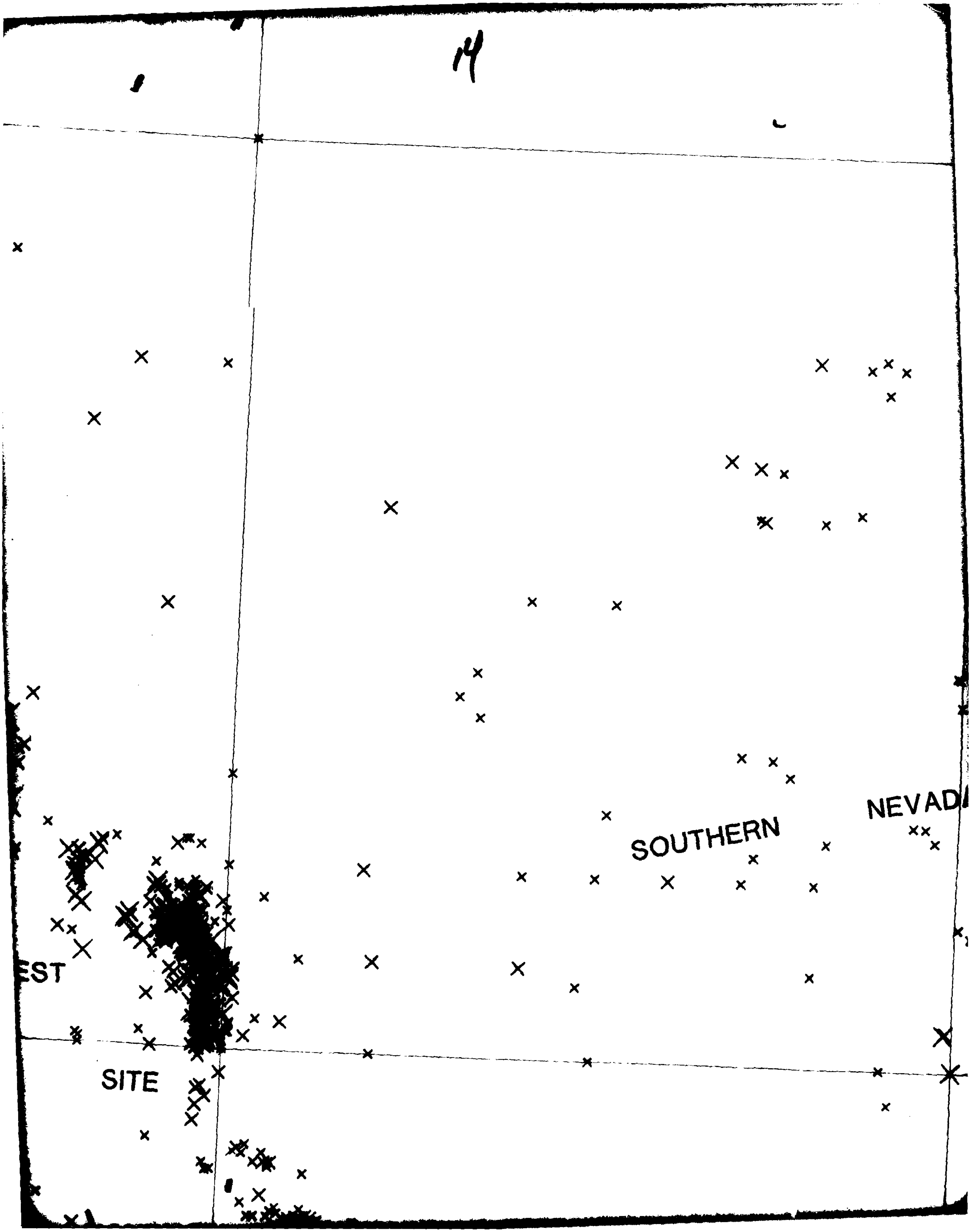



ELY


DELTA
39°
BELT
SEISMIC
INTERMOUNTAIN
MILFORD
BEAVER

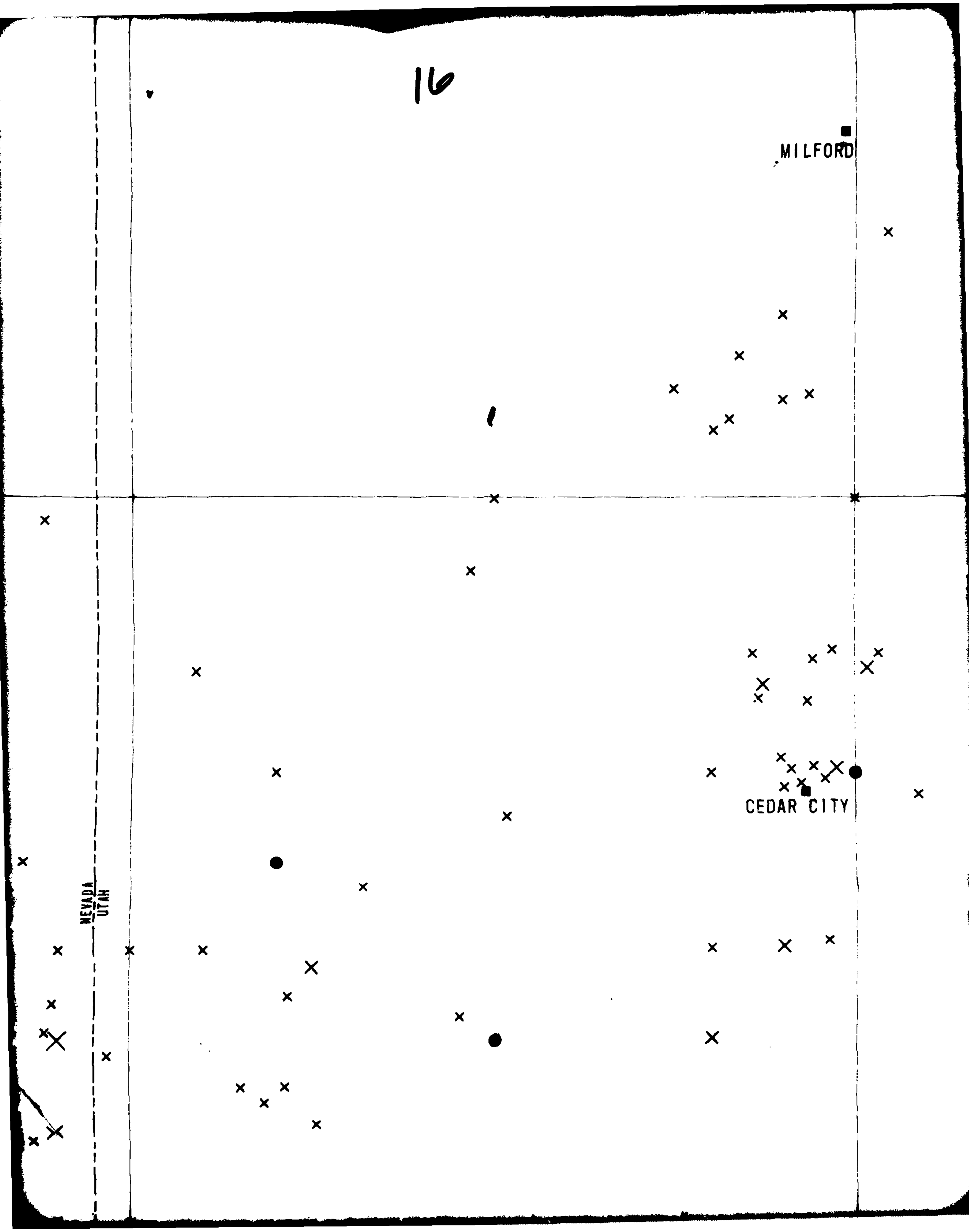

12
38°00'
37°00'
NEVADA
CALIFORNIA
TO
GOL

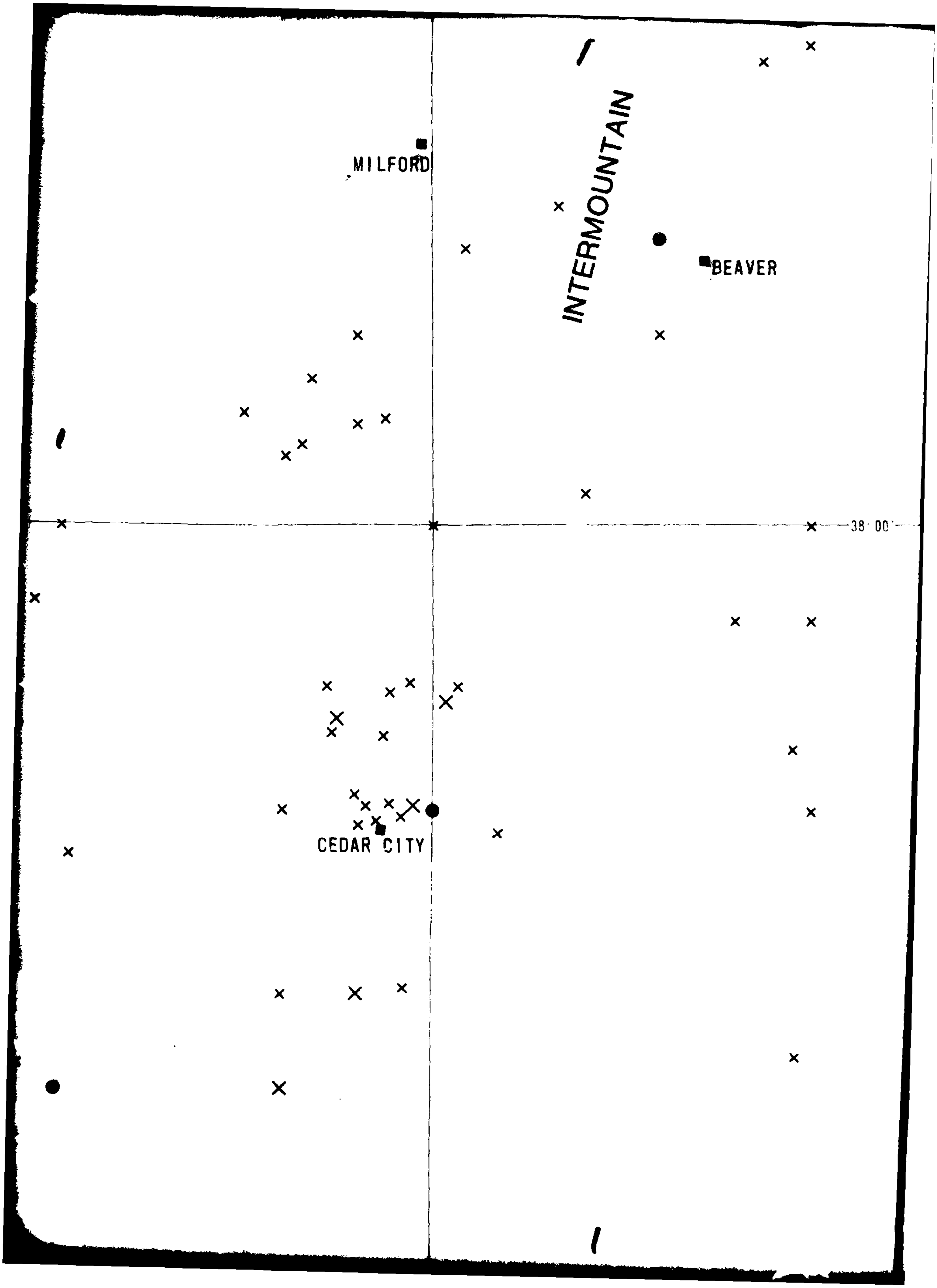

TONOPAH
GOLDFIELD
NEVADA
TEST
SITE
BEATTY

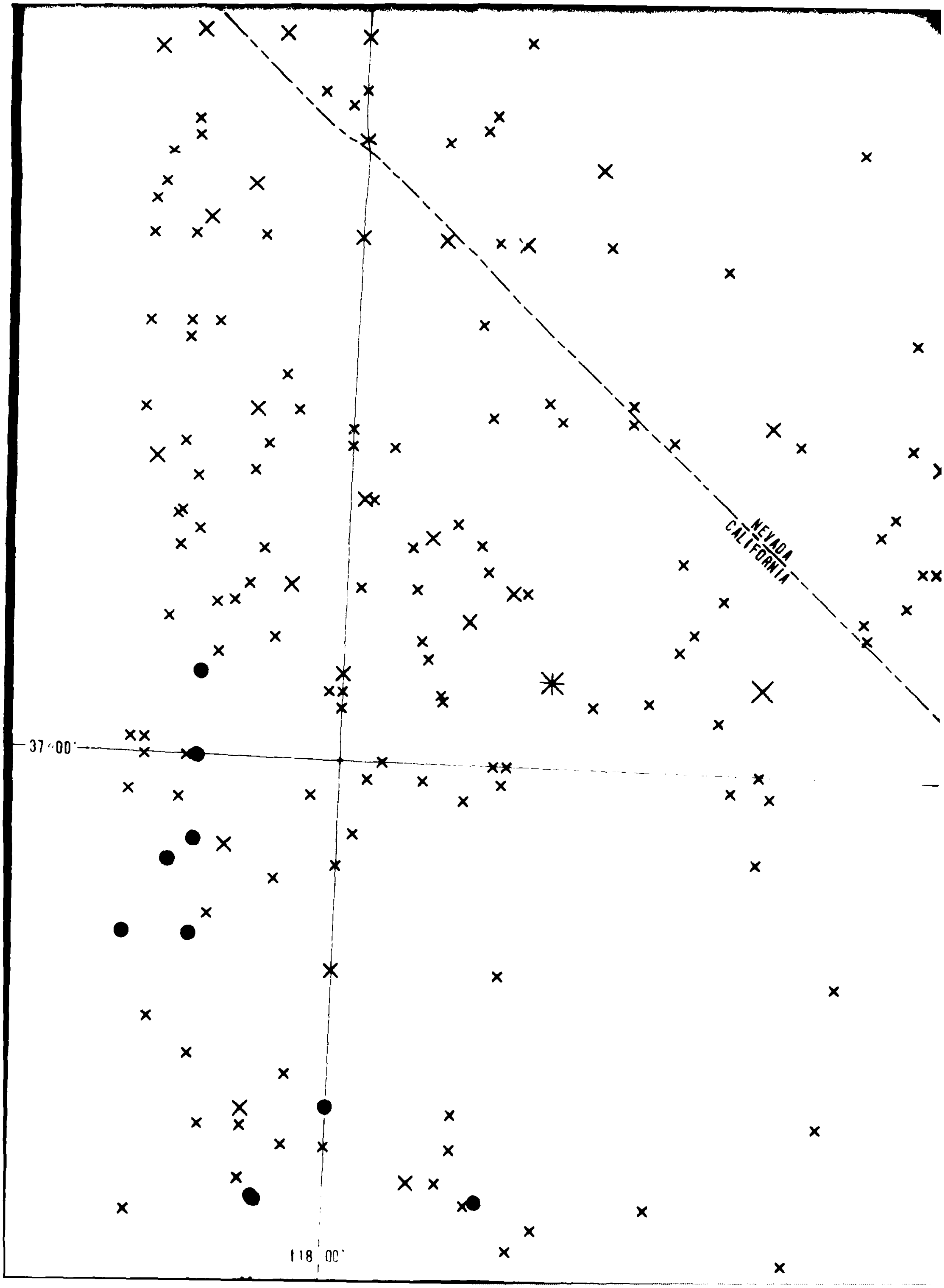


14
SOUTHERN
NEVAD
EST
SITE

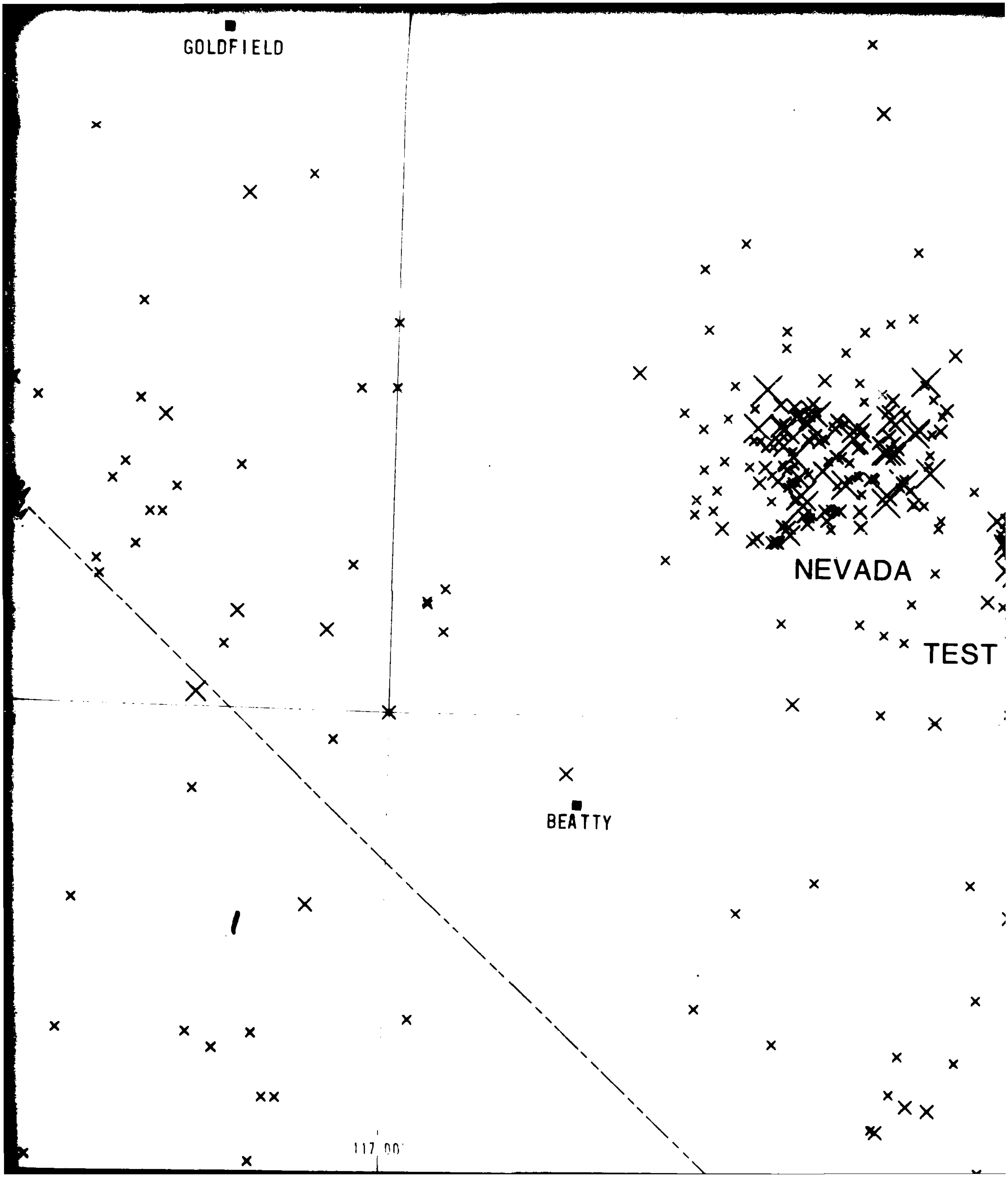
16




MILFORD
INTERMOUNTAIN
BEAVER
38°00'
CEDAR CITY



NEVADA
CALIFORNIA
37°00'
118°00'


GOLDFIELD
NEVADA
TEST
BEATTY
117 00'

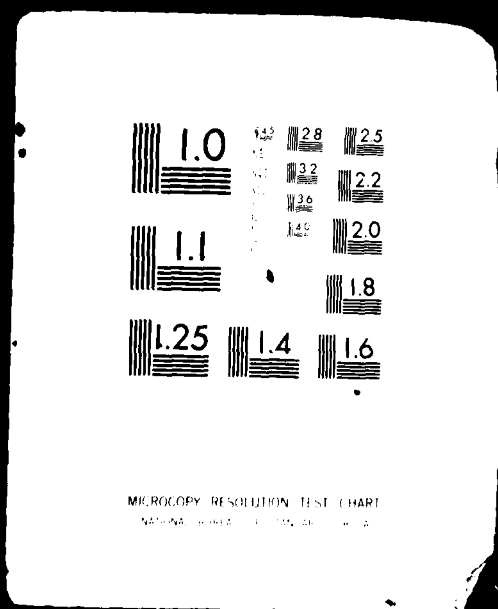
AD-A113 119 FUGRO NATIONAL INC LONG BEACH CA F/G 8/11
ACTIVE FAULTS AND EARTHQUAKE HAZARDS IN THE FY 79 VERIFICATION --ETC(U)
MAR 80 F04704-80-C-0006
UNCLASSIFIED FN-TR-36 NL

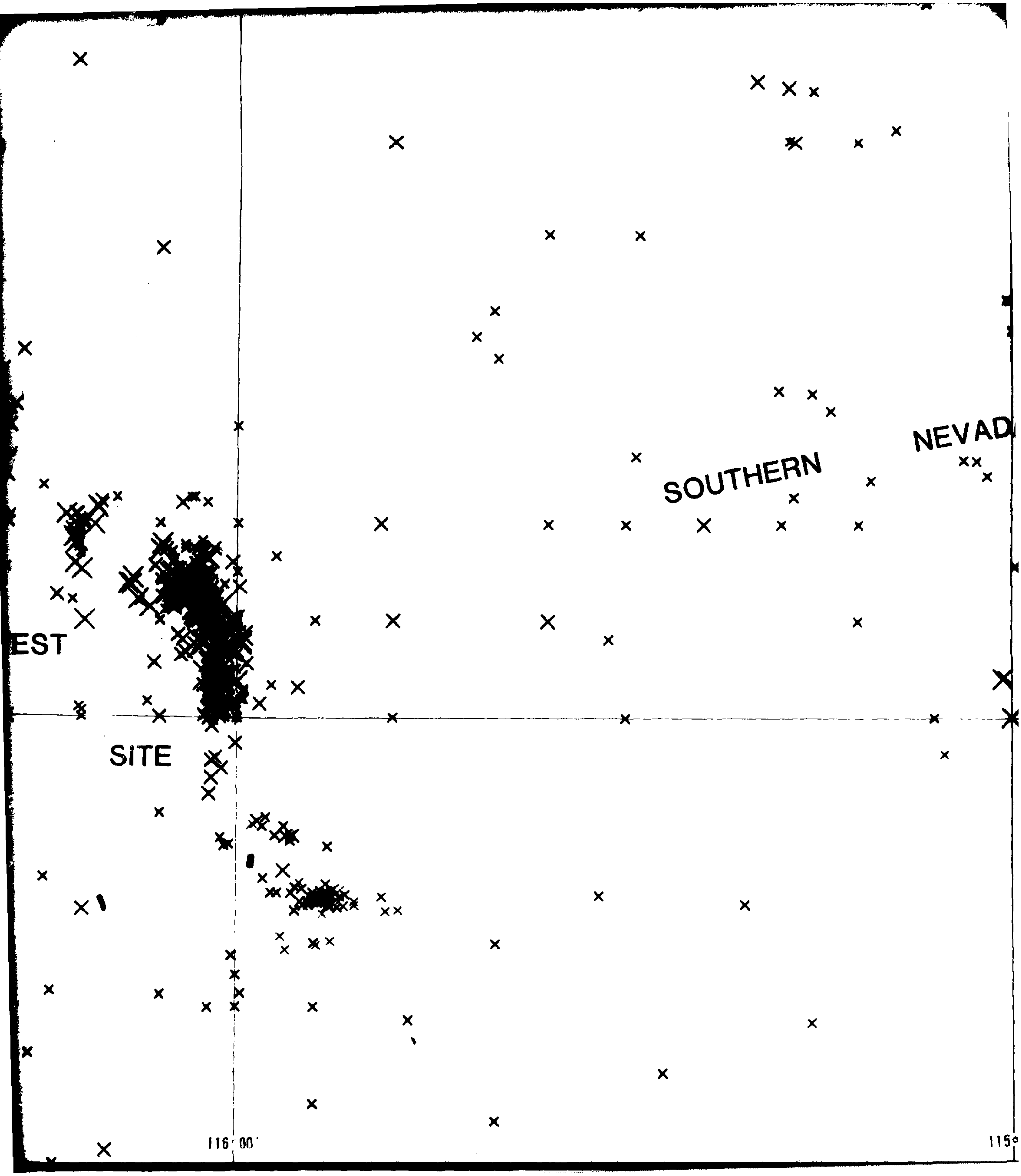
2 OF 2

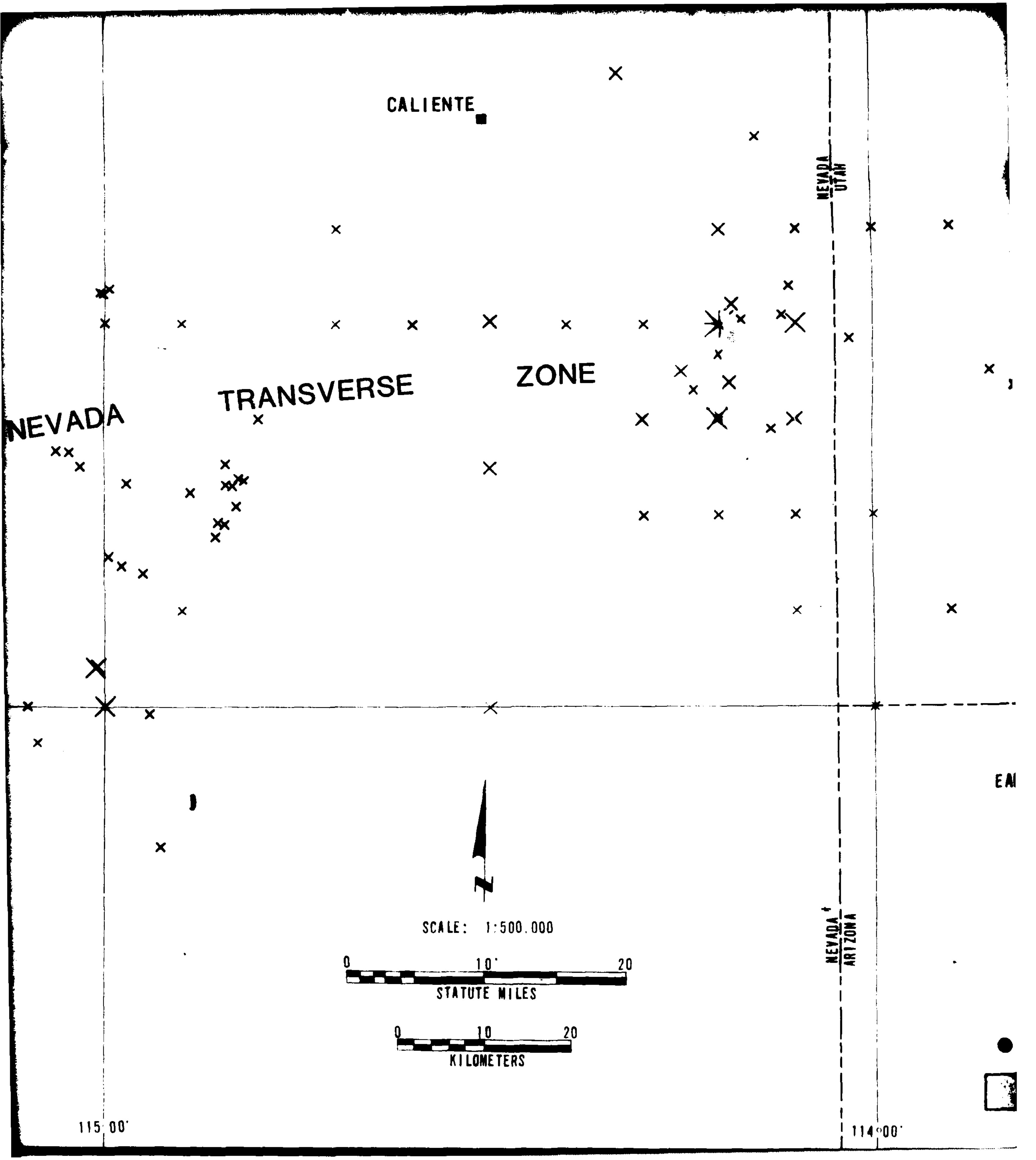
END
DATE
FILMED
5-82
DTIC

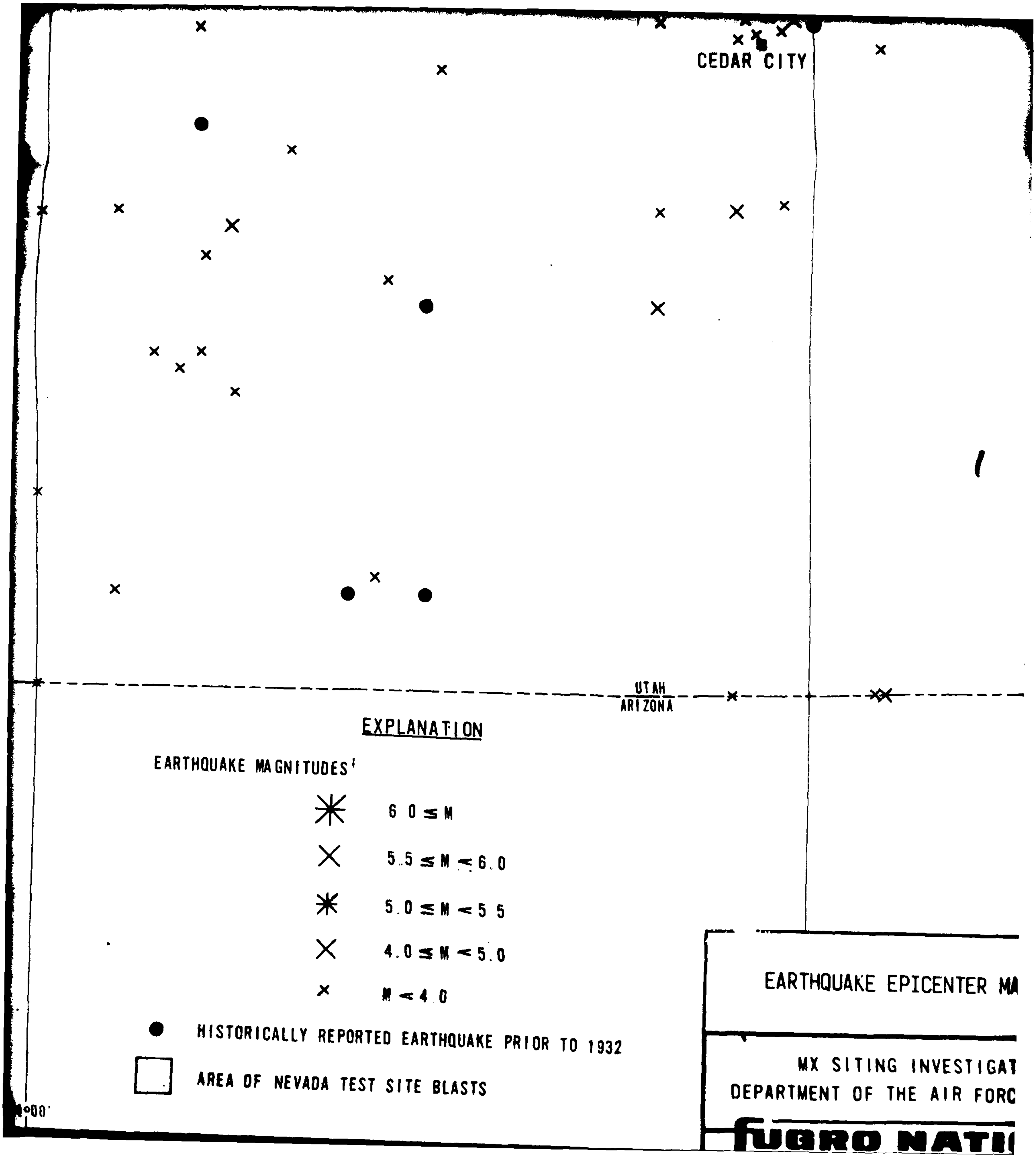
2 OF 2

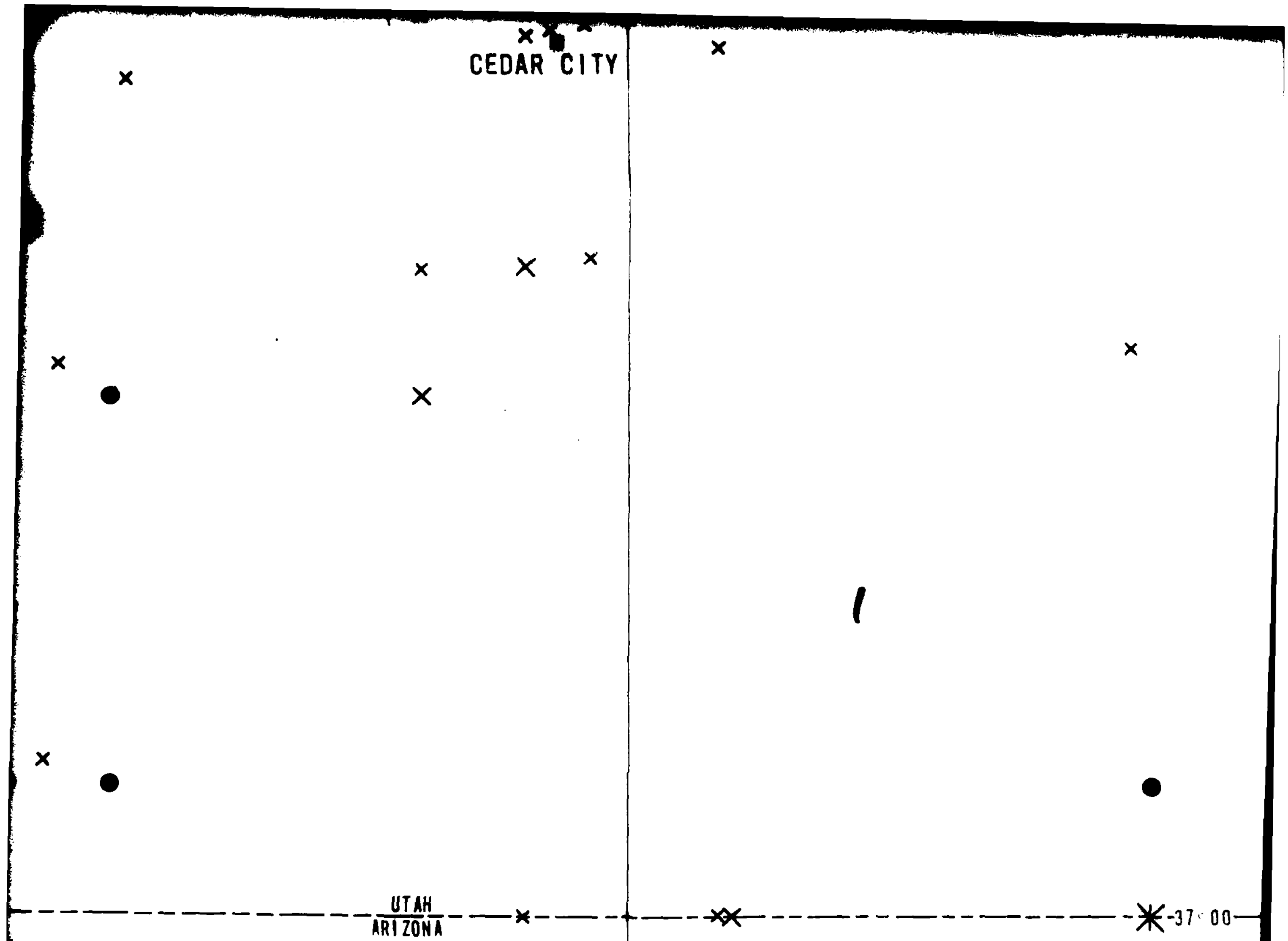
AD
A113119




EST
SITE
SOUTHERN
NEVAD
116°00'
115°


CALIENTE
NEVADA
UTAH
NEVADA
TRANSVERSE
ZONE
SCALE: 1:500,000
0
10
20
STATUTE MILES
0
10
20
KILOMETERS
NEVADA
ARIZONA
115°00'
114°00'


CEDAR CITY
UTAH
ARIZONA
EXPLANATION
EARTHQUAKE MAGNITUDES[1]
6 0 ≤ M
5.5 ≤ M < 6.0
5.0 ≤ M < 5 5
4.0 ≤ M < 5.0
M < 4 0
HISTORICALLY REPORTED EARTHQUAKE PRIOR TO 1932
AREA OF NEVADA TEST SITE BLASTS
EARTHQUAKE EPICENTER MA
MX SITING INVESTIGAT
DEPARTMENT OF THE AIR FORC
FUGRO NATI



EXPLANATION

6.0 ≤ M

5.5 ≤ M < 6.0

5.0 ≤ M < 5.5

4.0 ≤ M < 5.0

M < 4.0

ORTED EARTHQUAKE PRIOR TO 1932

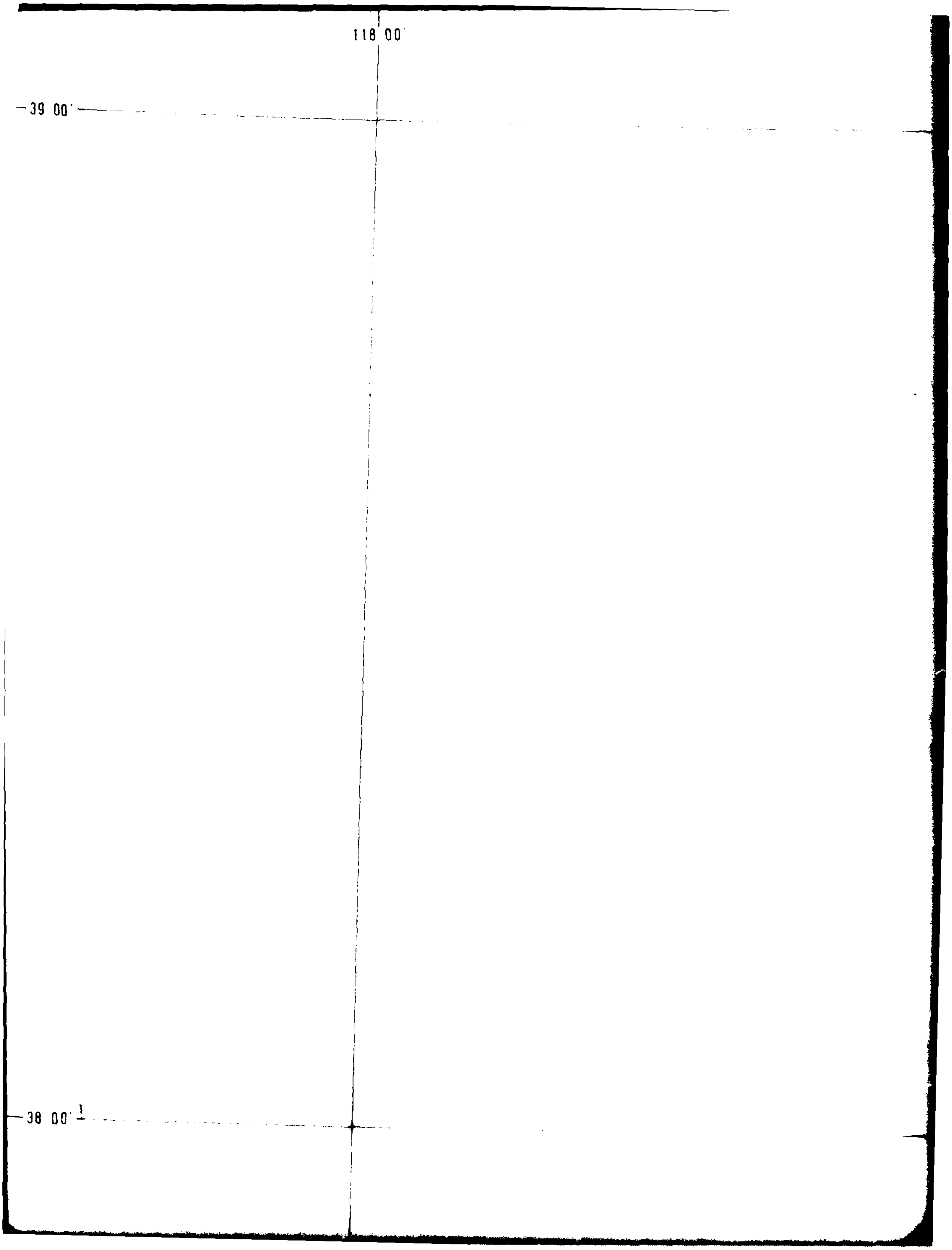
EST SITE BLASTS

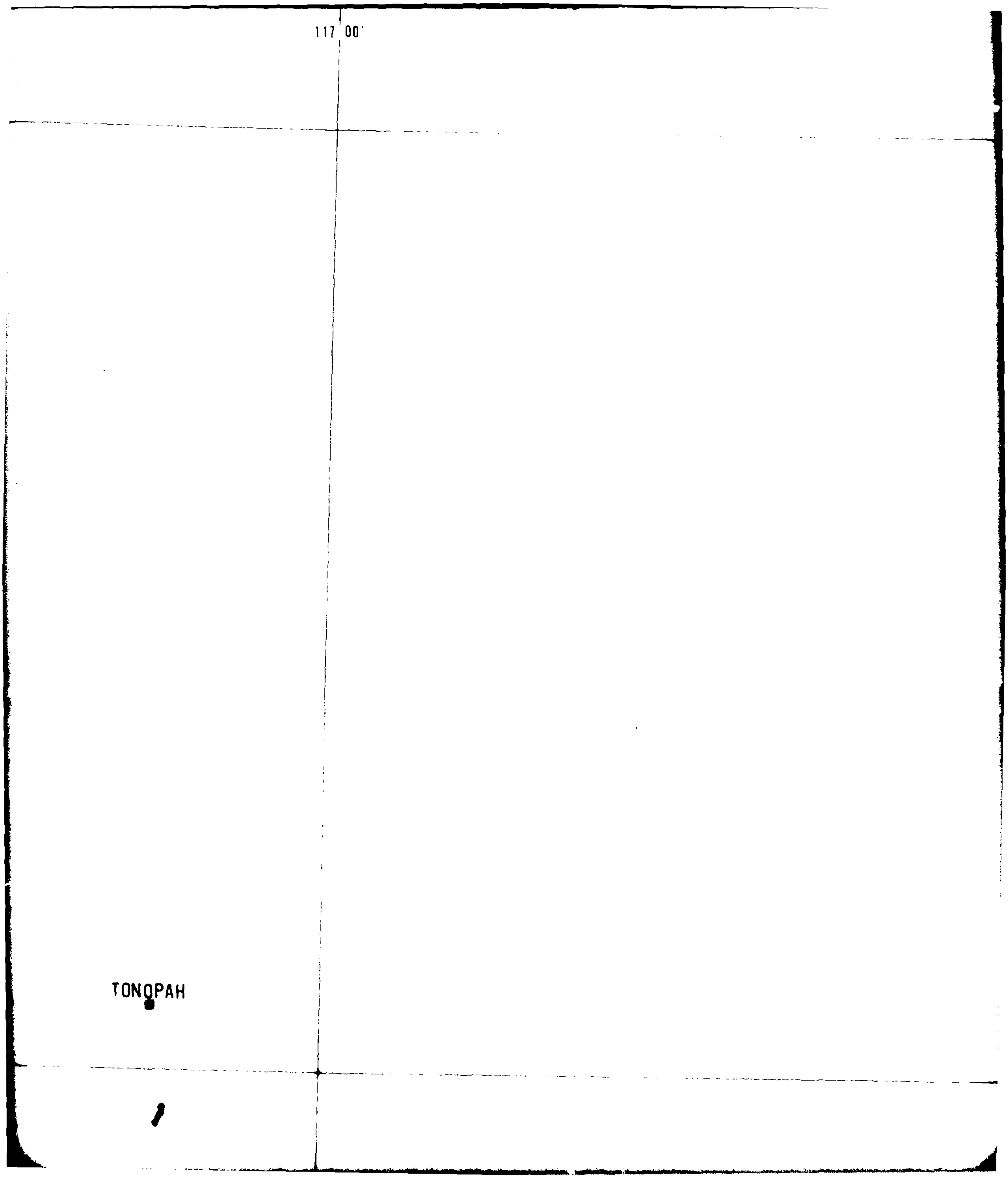
EARTHQUAKE EPICENTER MAP USGS/NOAA DATA

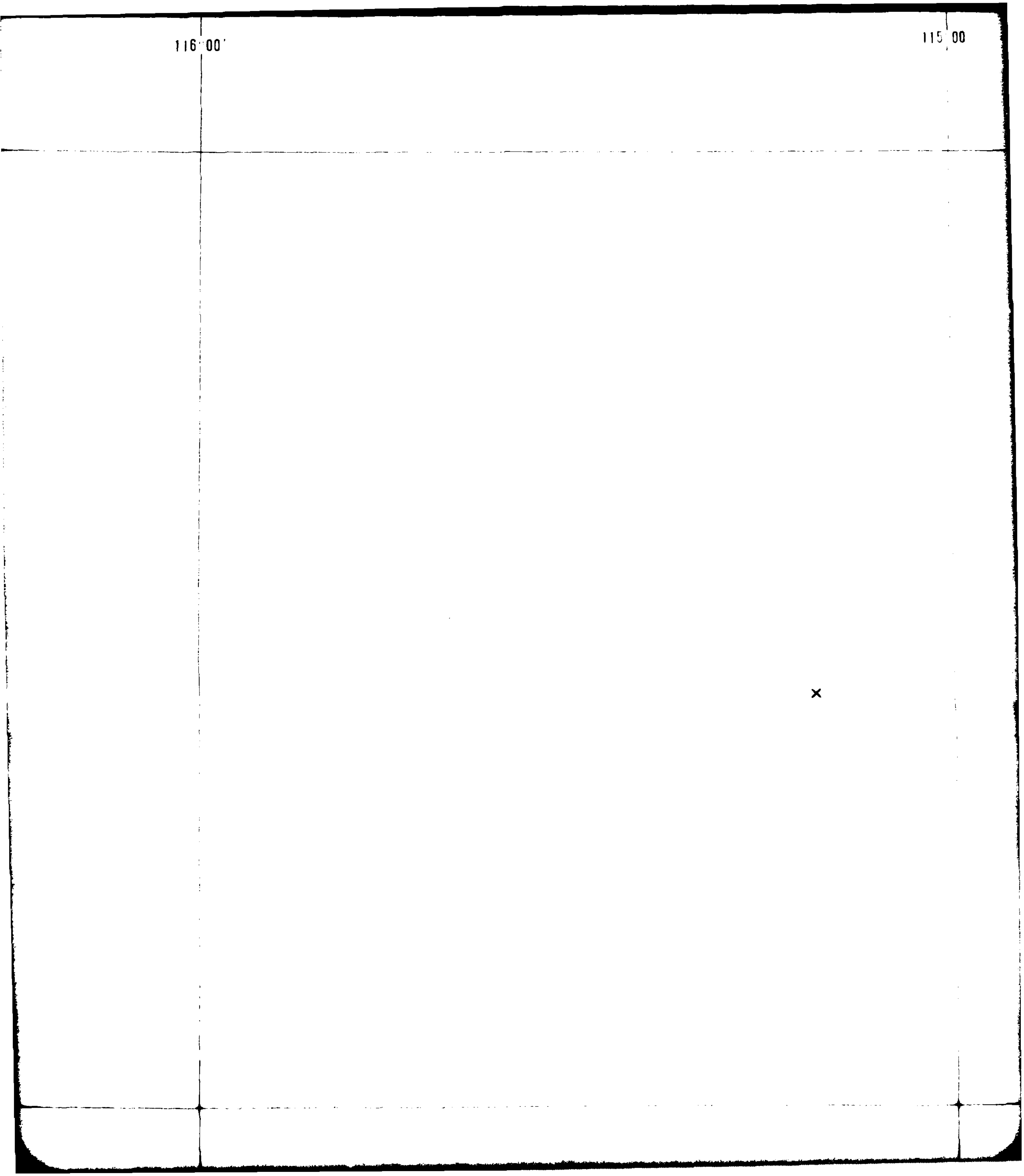
MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - BMO

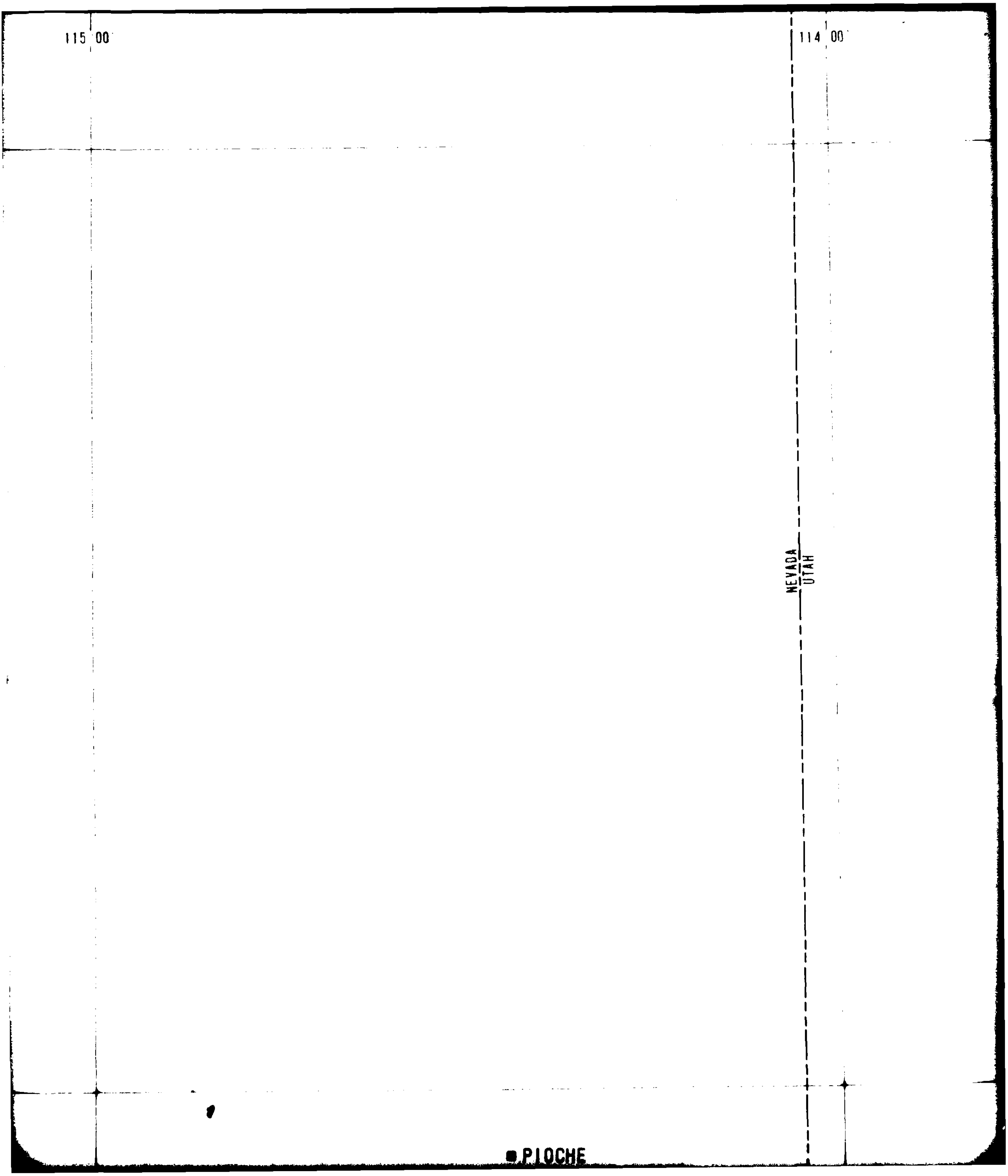
DRAWING
2-1

FUGRO NATIONAL, INC.

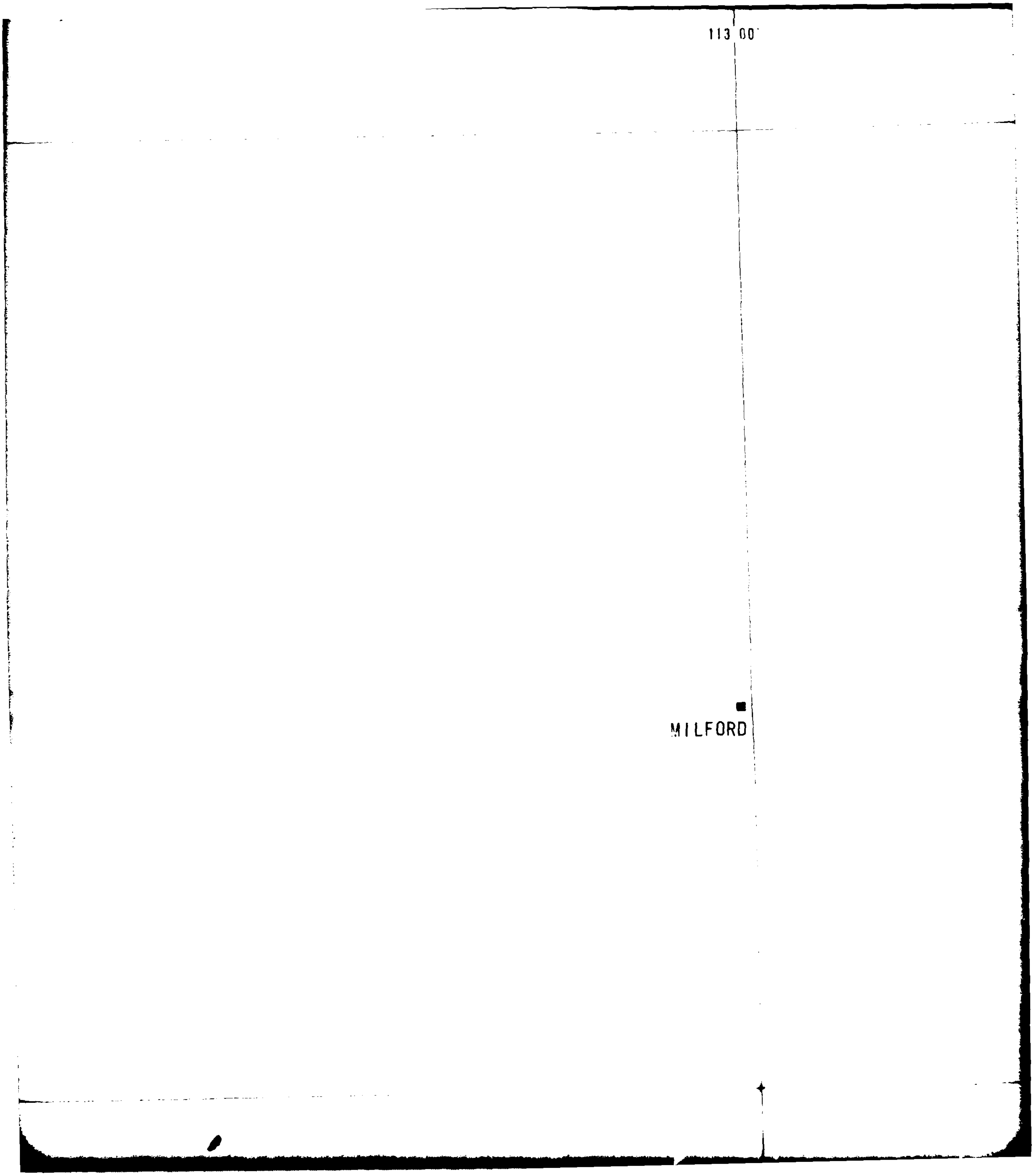

118 00'
39 00'
38 00'

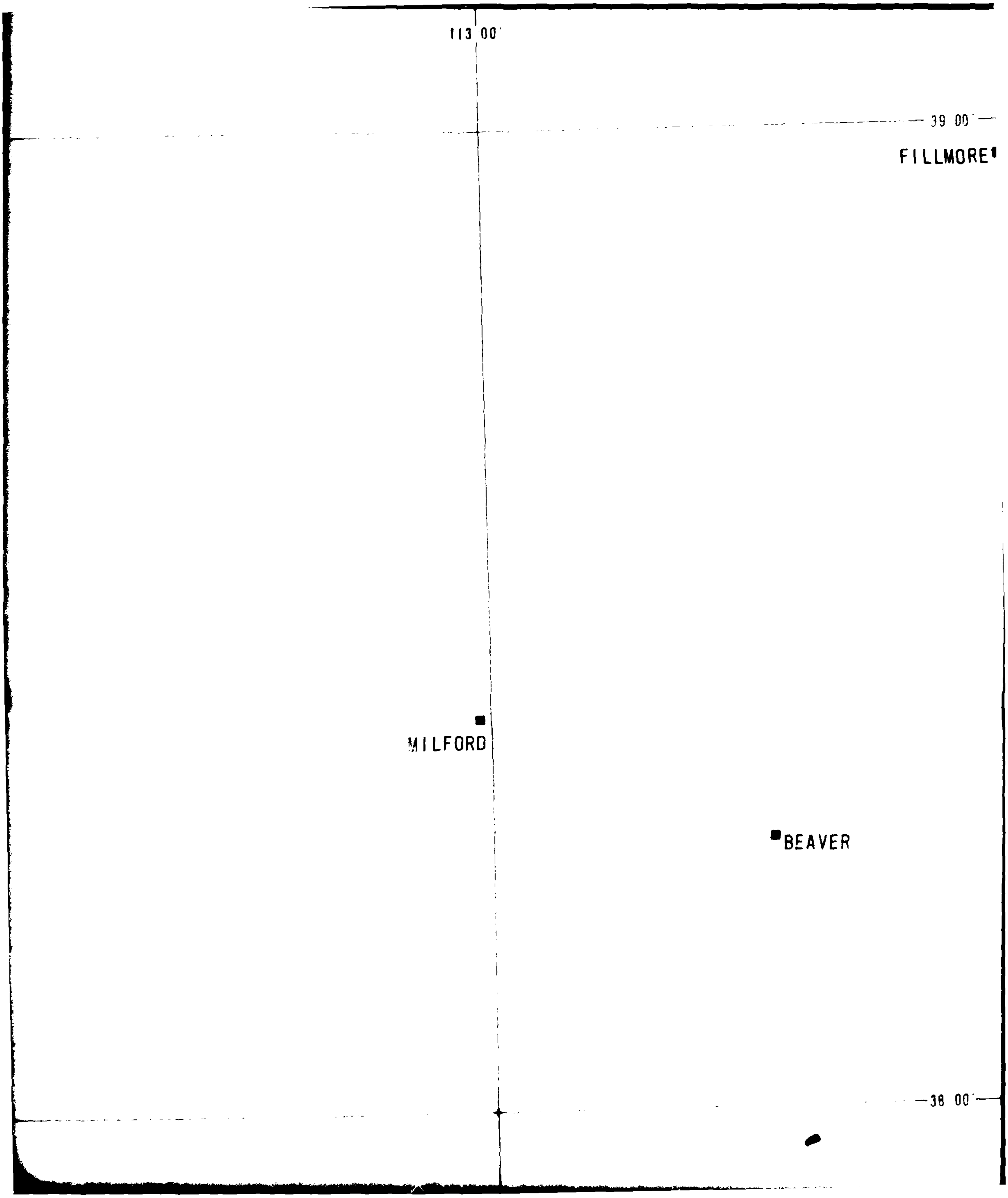

117 00'
TONOPAH

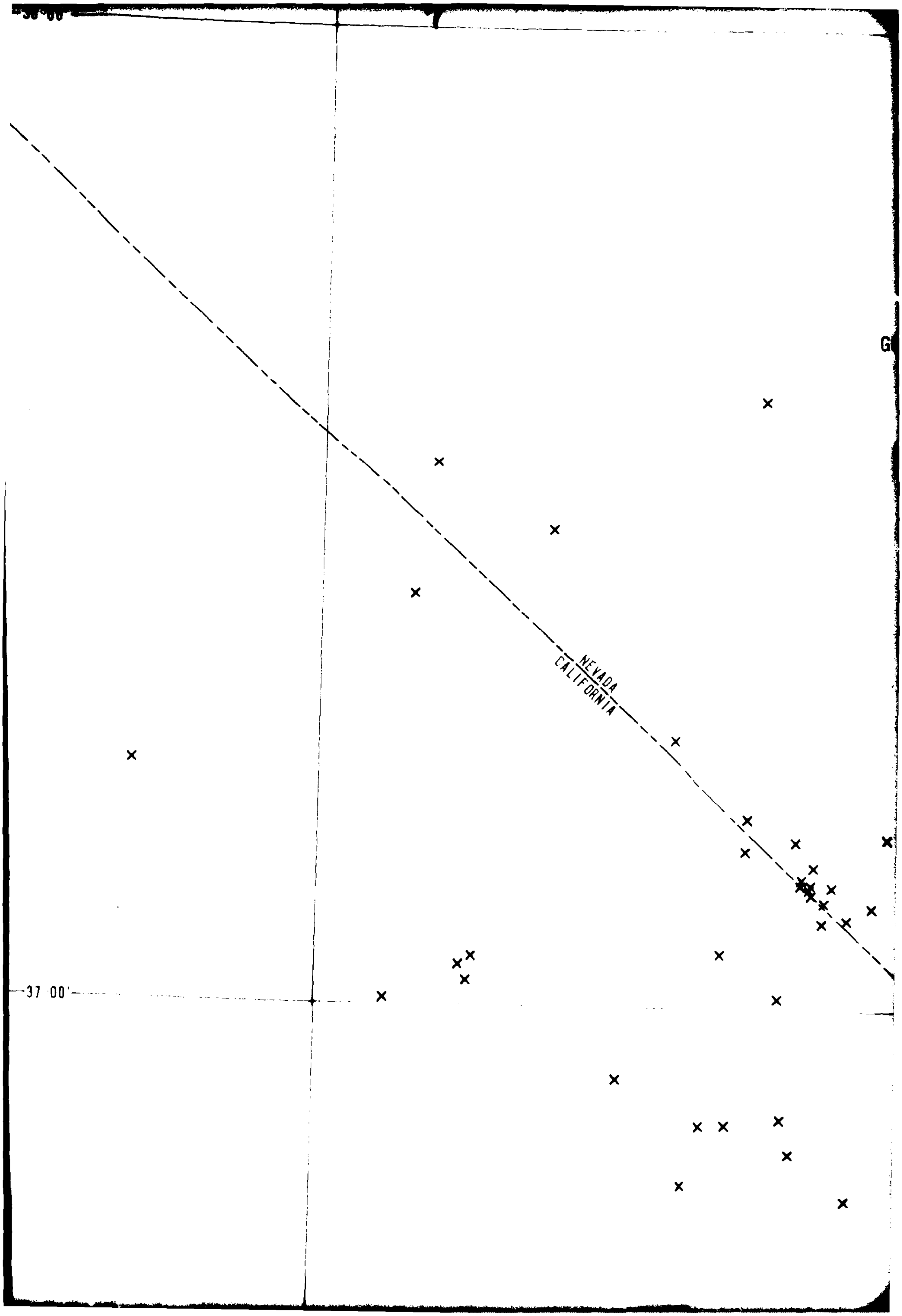

116°00'
115°00'

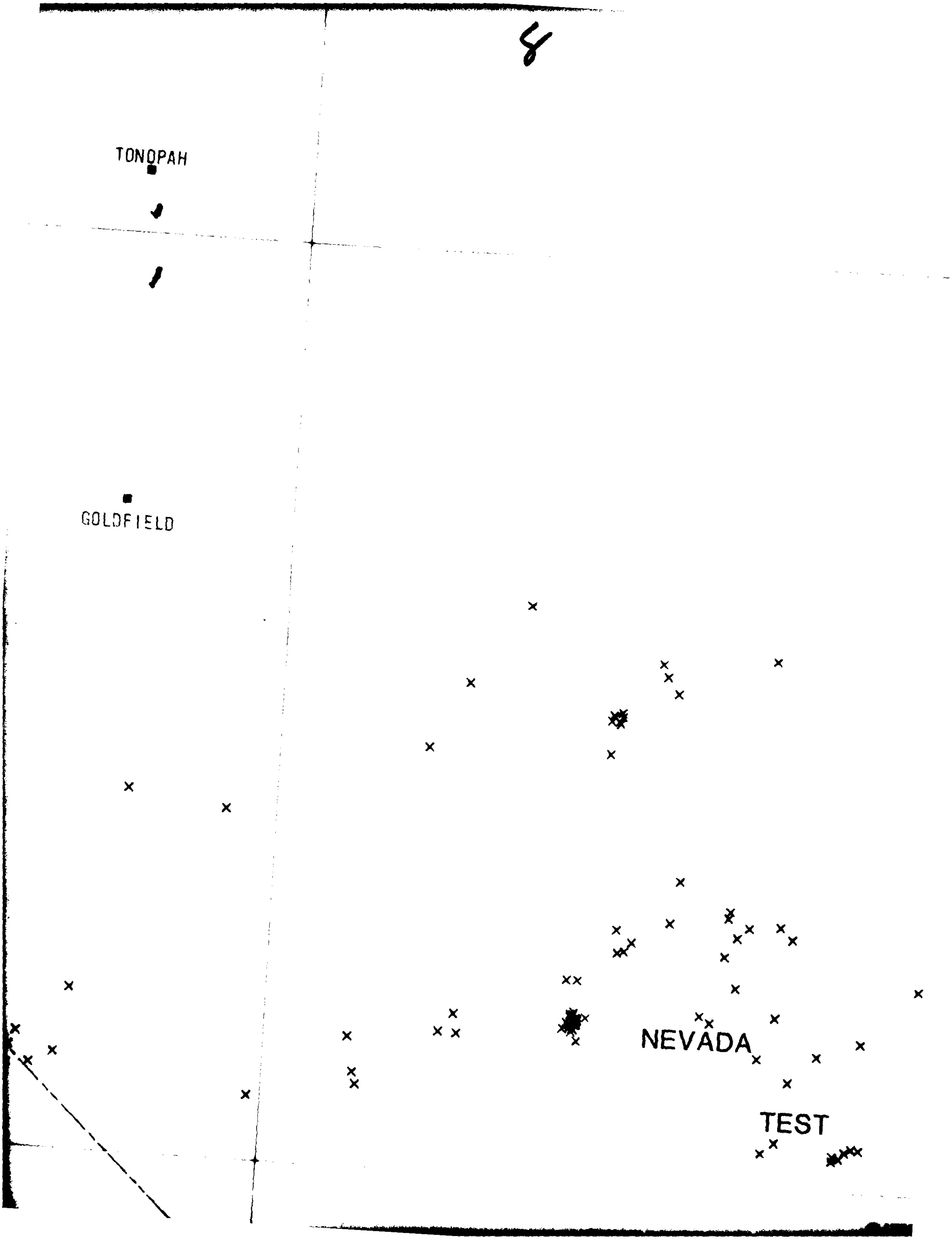


115 00
114 00
NEVADA
UTAH
PIOCHE

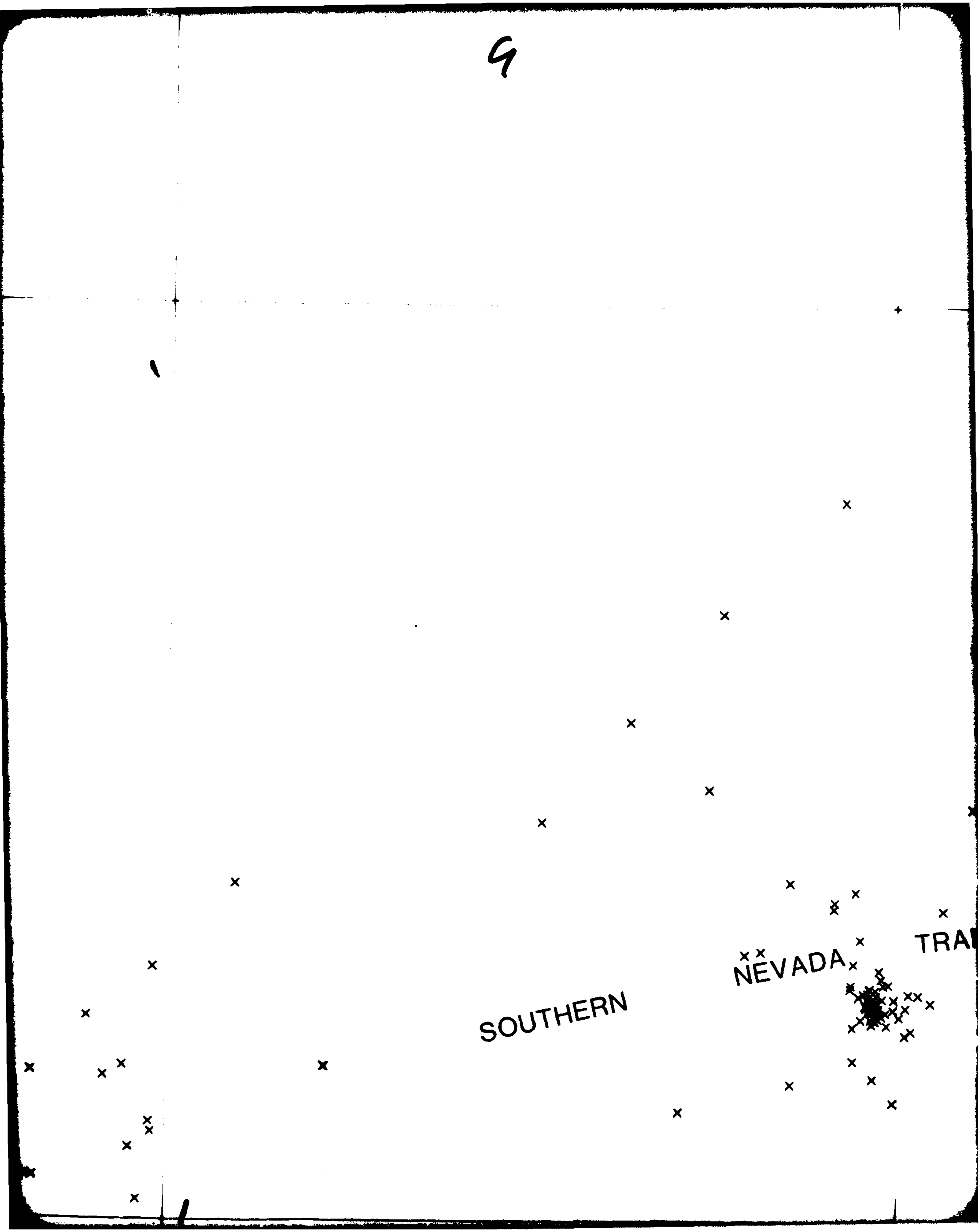

113 00'
MILFORD

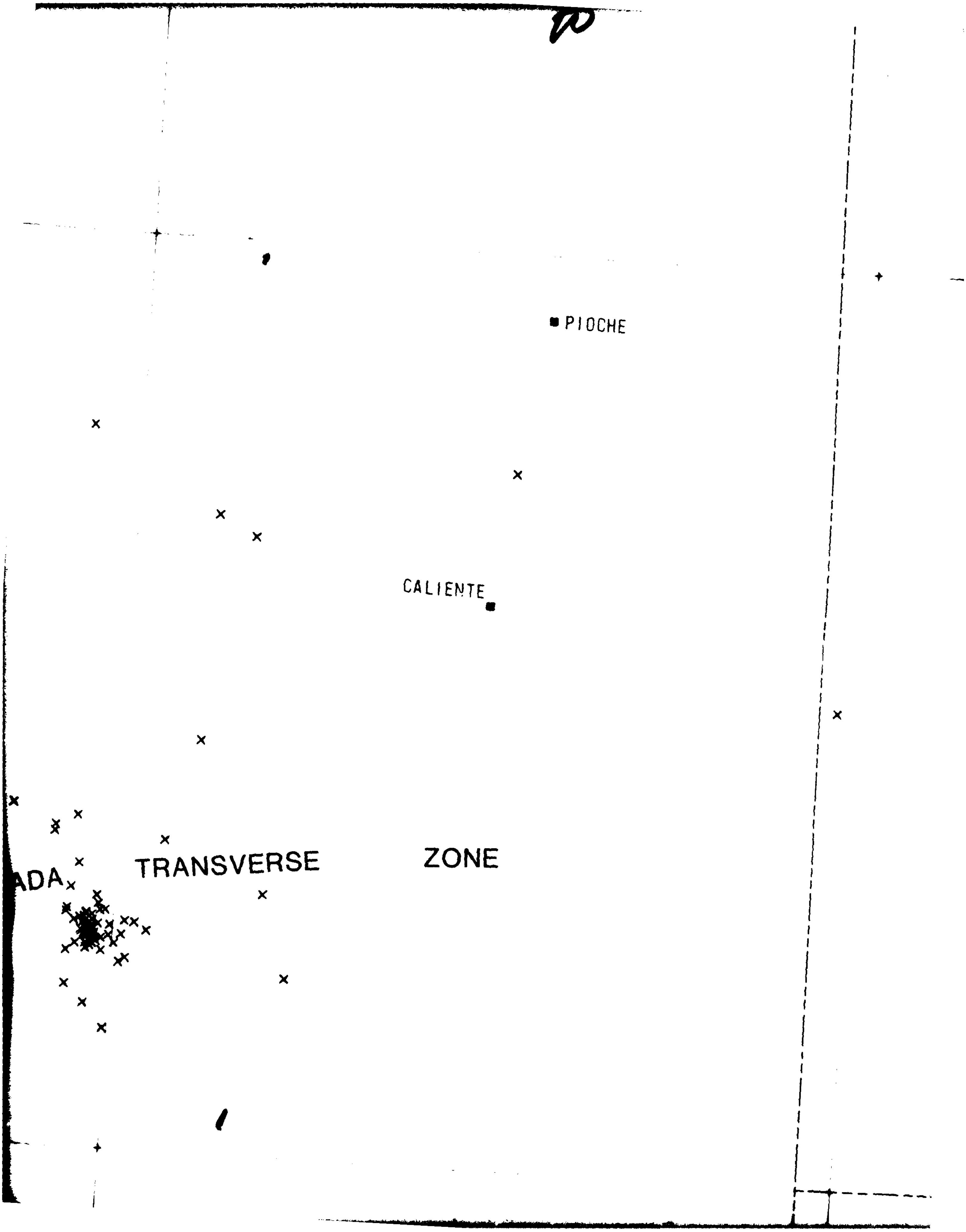

113 00'
39 00'
FILLMORE
MILFORD
BEAVER
38 00'

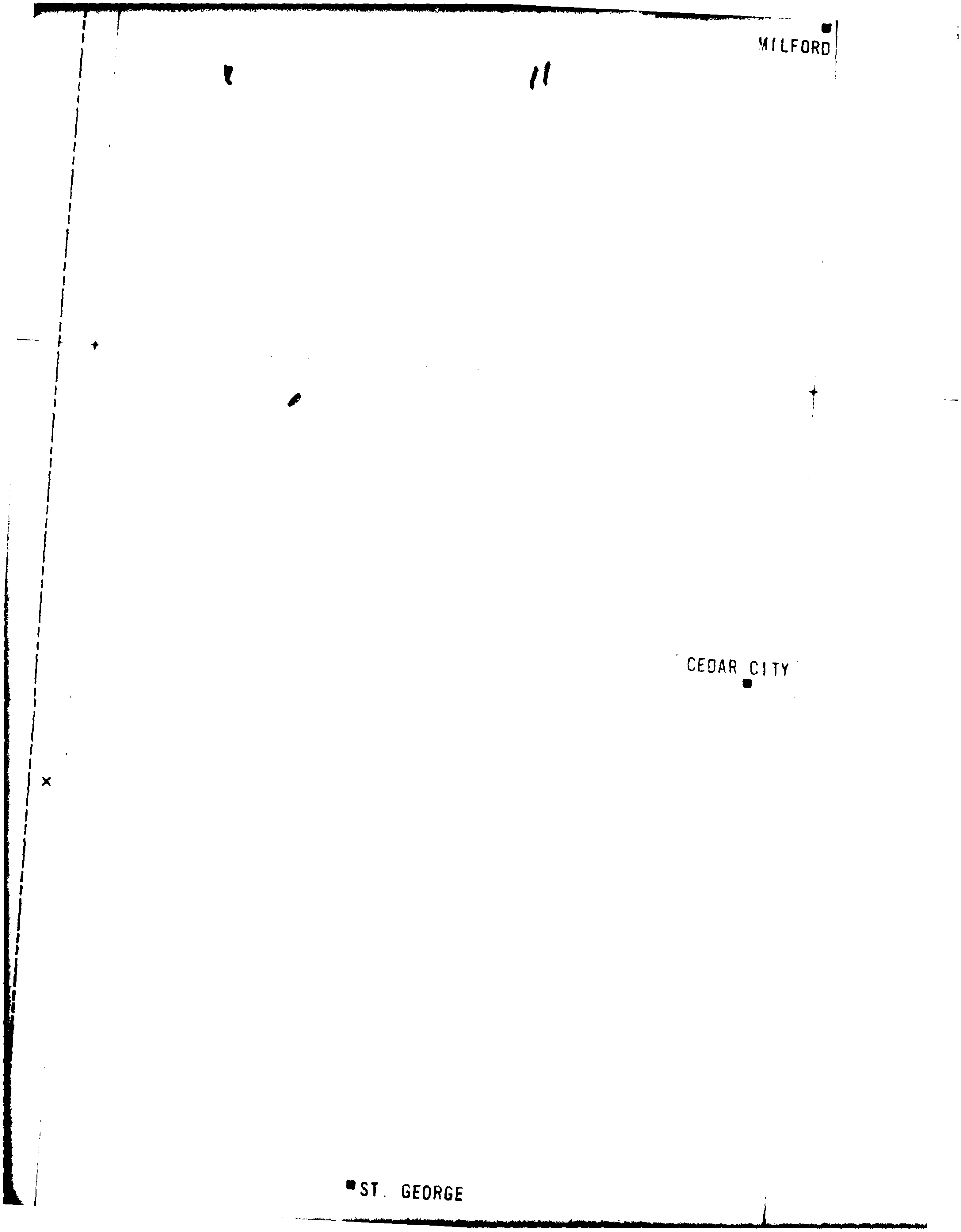

NEVADA
CALIFORNIA
37°00'

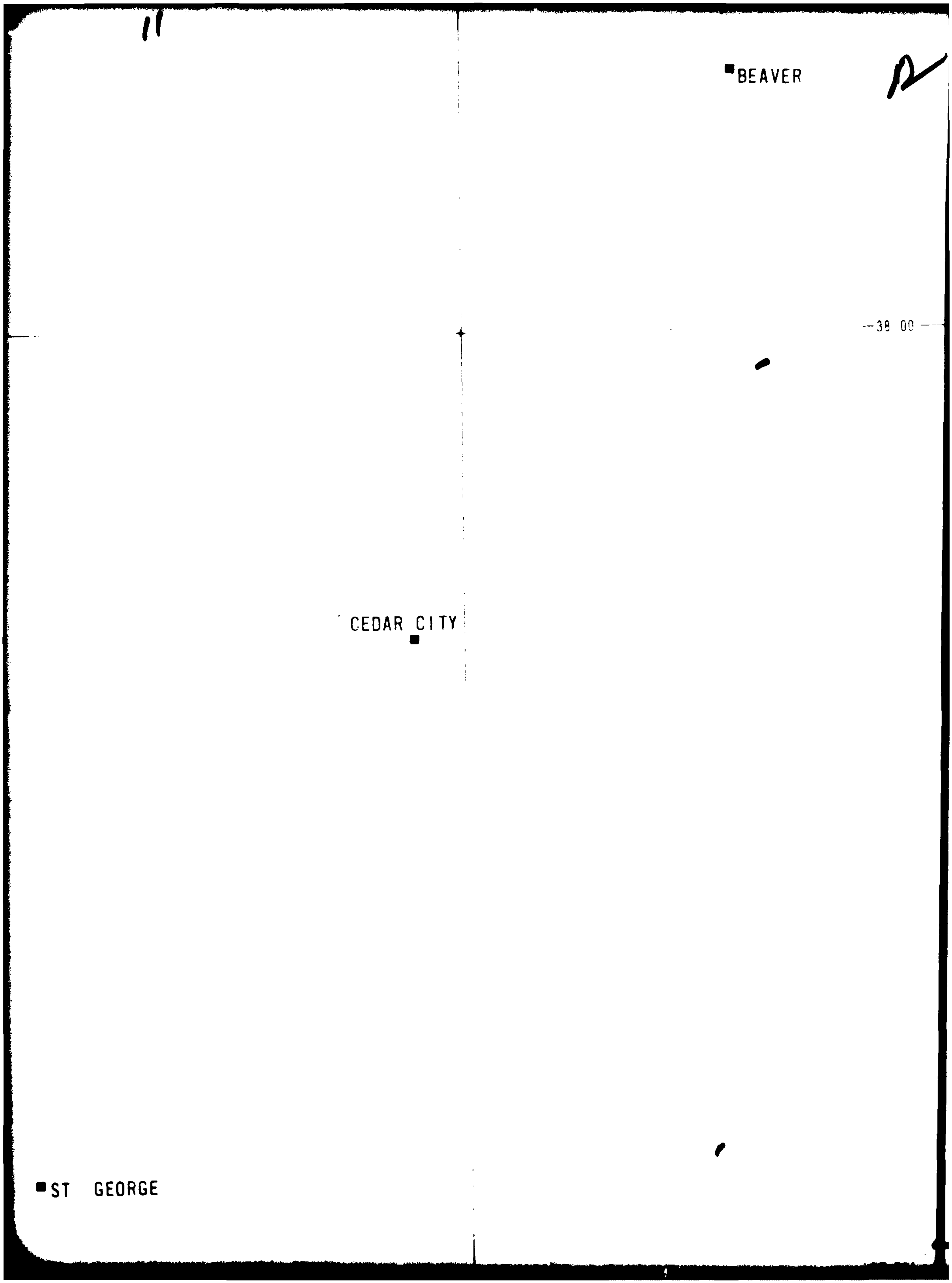

8
TONOPAH
GOLDFIELD
NEVADA
TEST

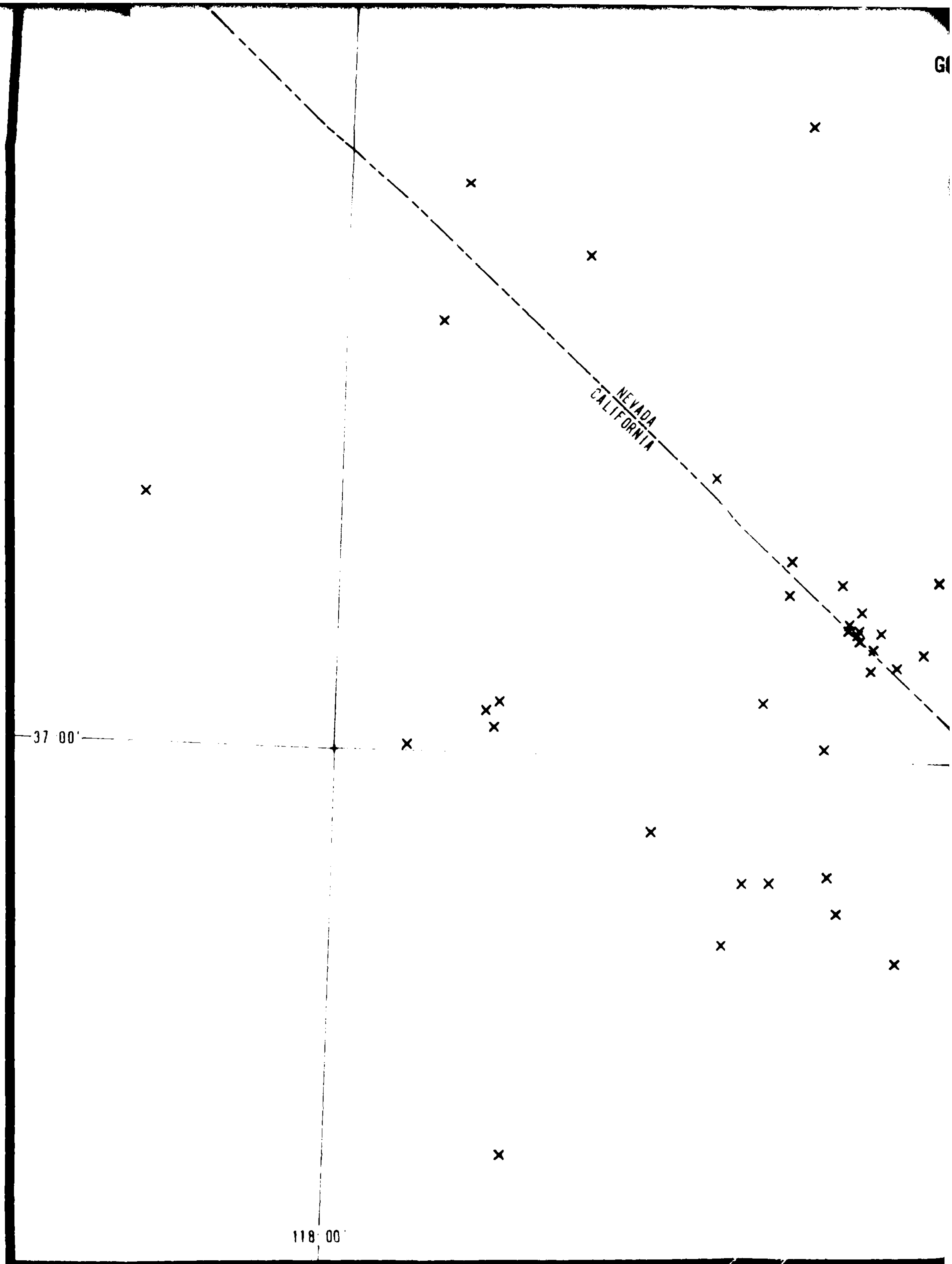
9




PIOCHE
CALIENTE
ADA
TRANSVERSE
ZONE

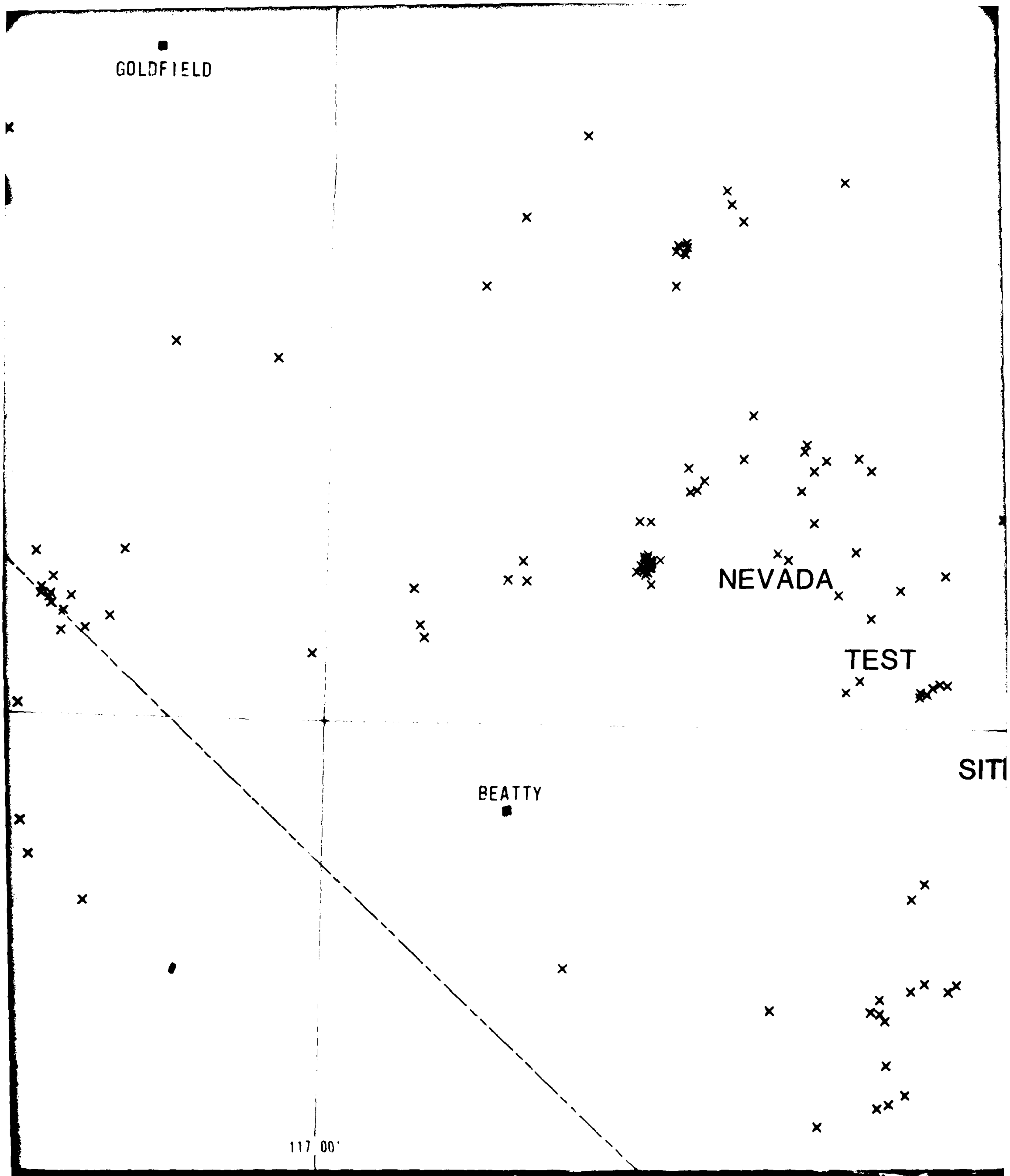

MILFORD
CEDAR CITY
ST. GEORGE

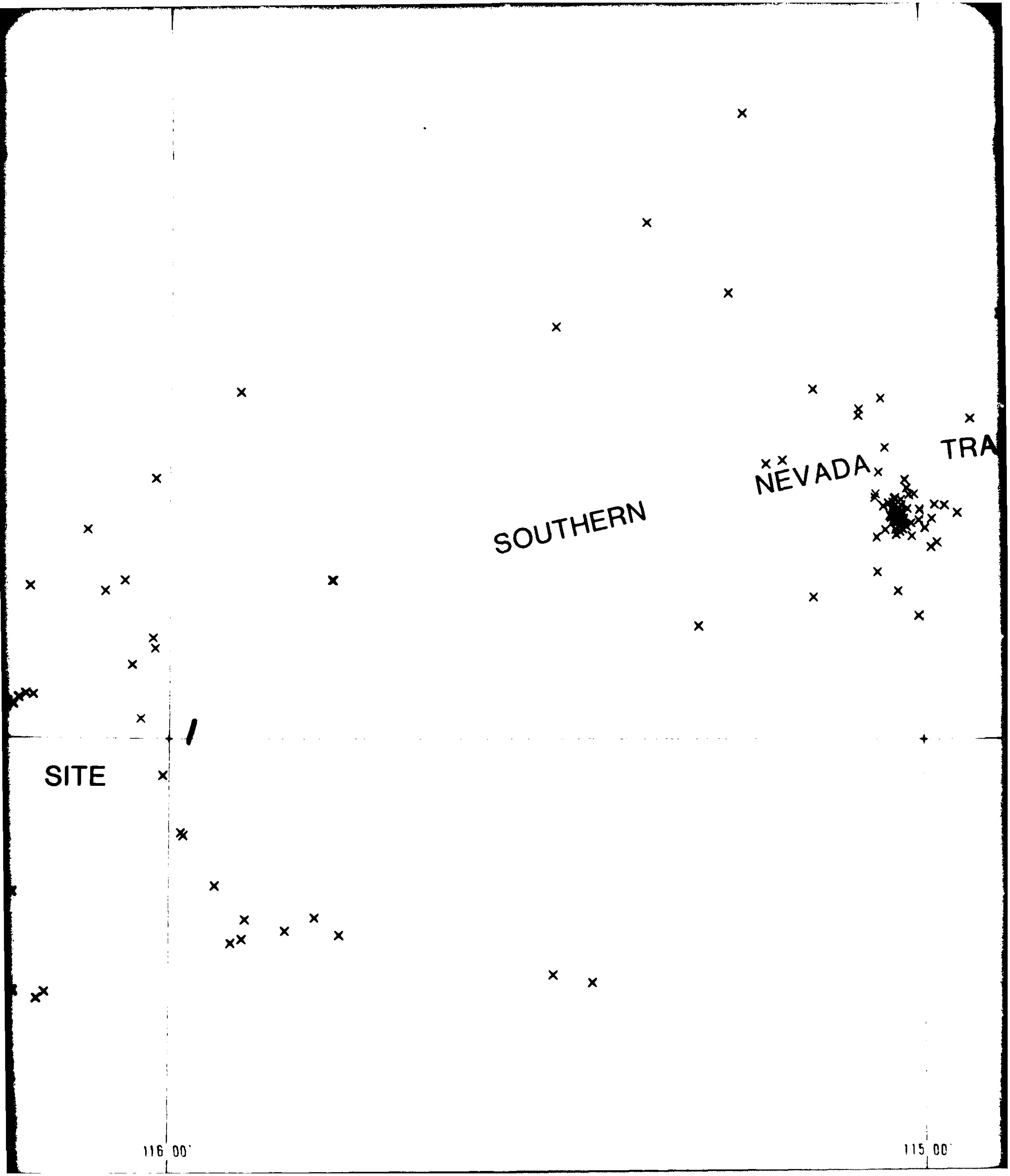

BEAVER
38 00
CEDAR CITY
ST GEORGE



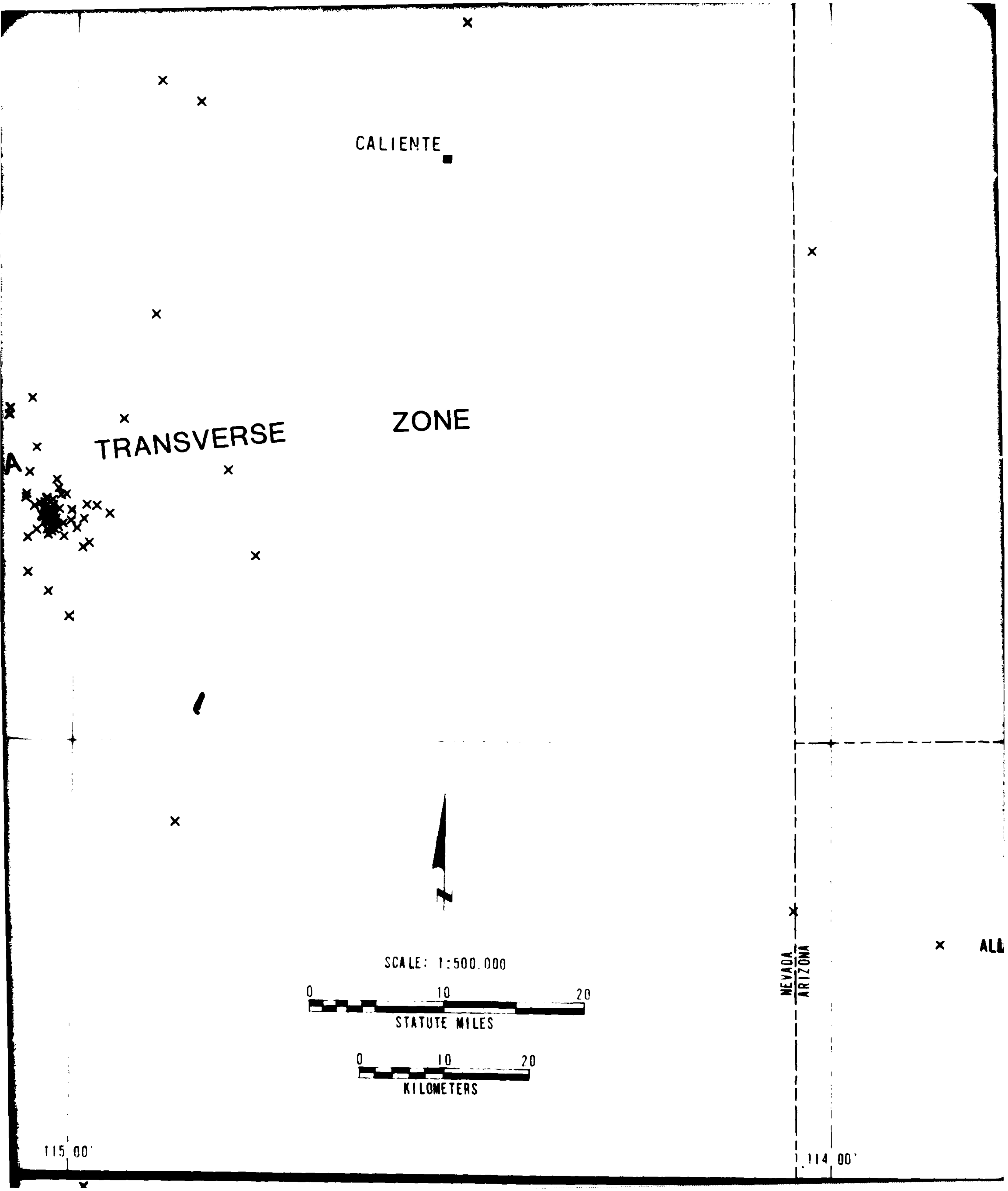
26 MAR 80

13


GOLDFIELD
NEVADA
TEST
SIT
BEATTY
117 00'



SOUTHERN
NEVADA
TRA
SITE
116 00'
115 00'


CALIENTE
TRANSVERSE
ZONE
A
SCALE: 1:500,000
0
10
20
STATUTE MILES
0
10
20
KILOMETERS
NEVADA
ARIZONA
115 00'
114 00'

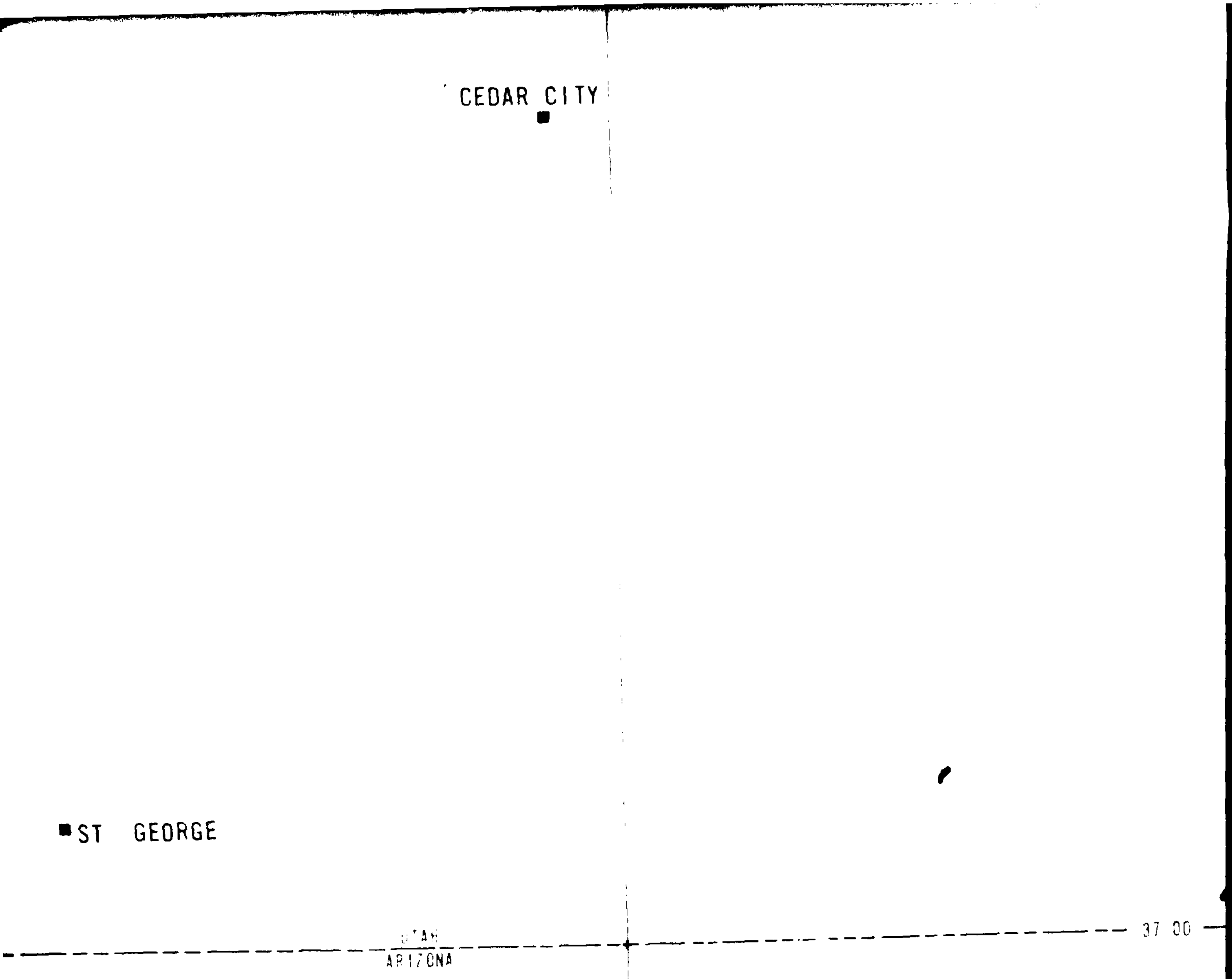
EXPLANATION

* ALL EARTHQUAKES SHOWN ARE LESS THAN MAGNITUDE 4.0

EARTHQUAKE EPICENTER MAP US

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE -

FUGRO NATION



EXPLANATION

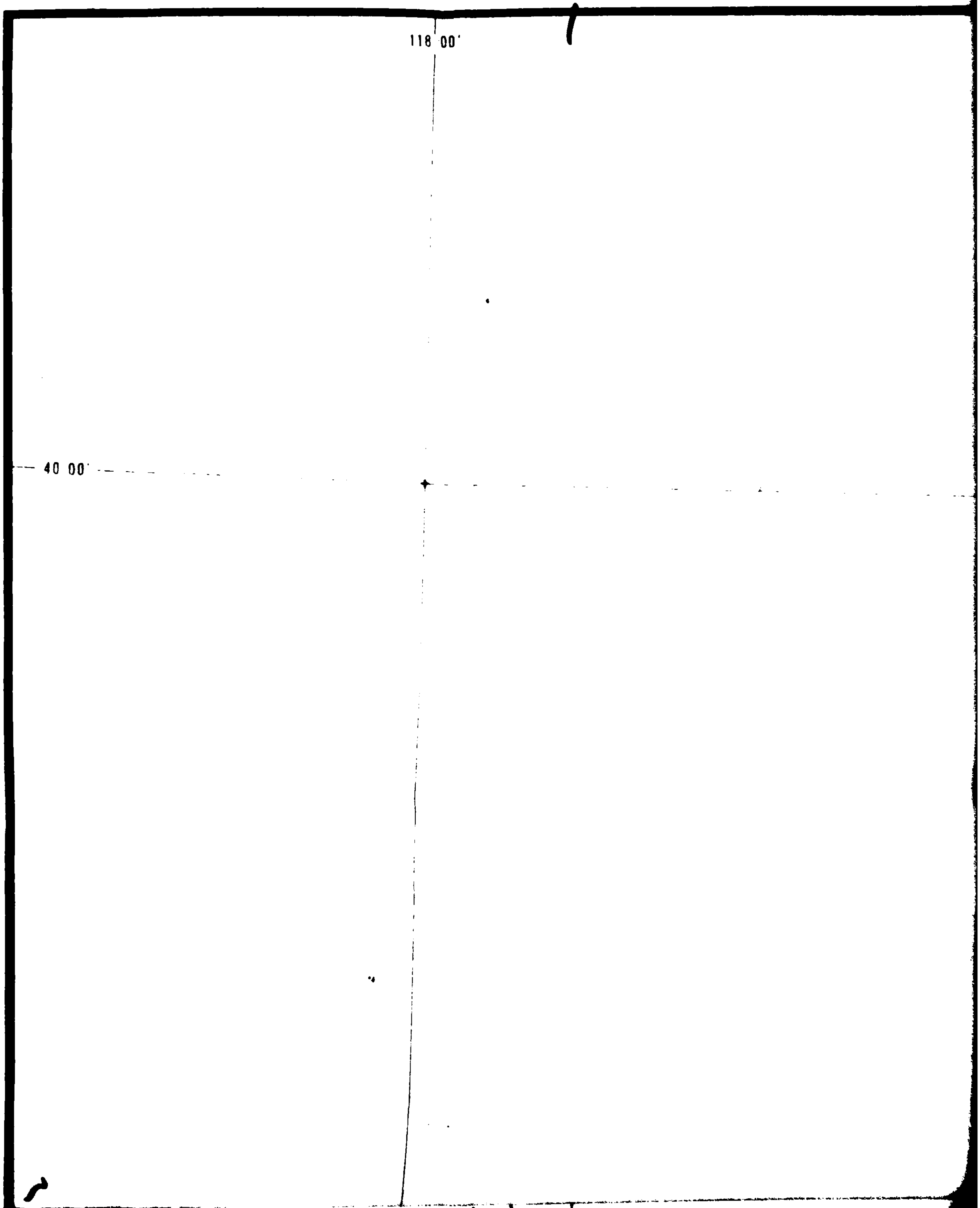
SHOWN ARE LESS THAN MAGNITUDE 4.0

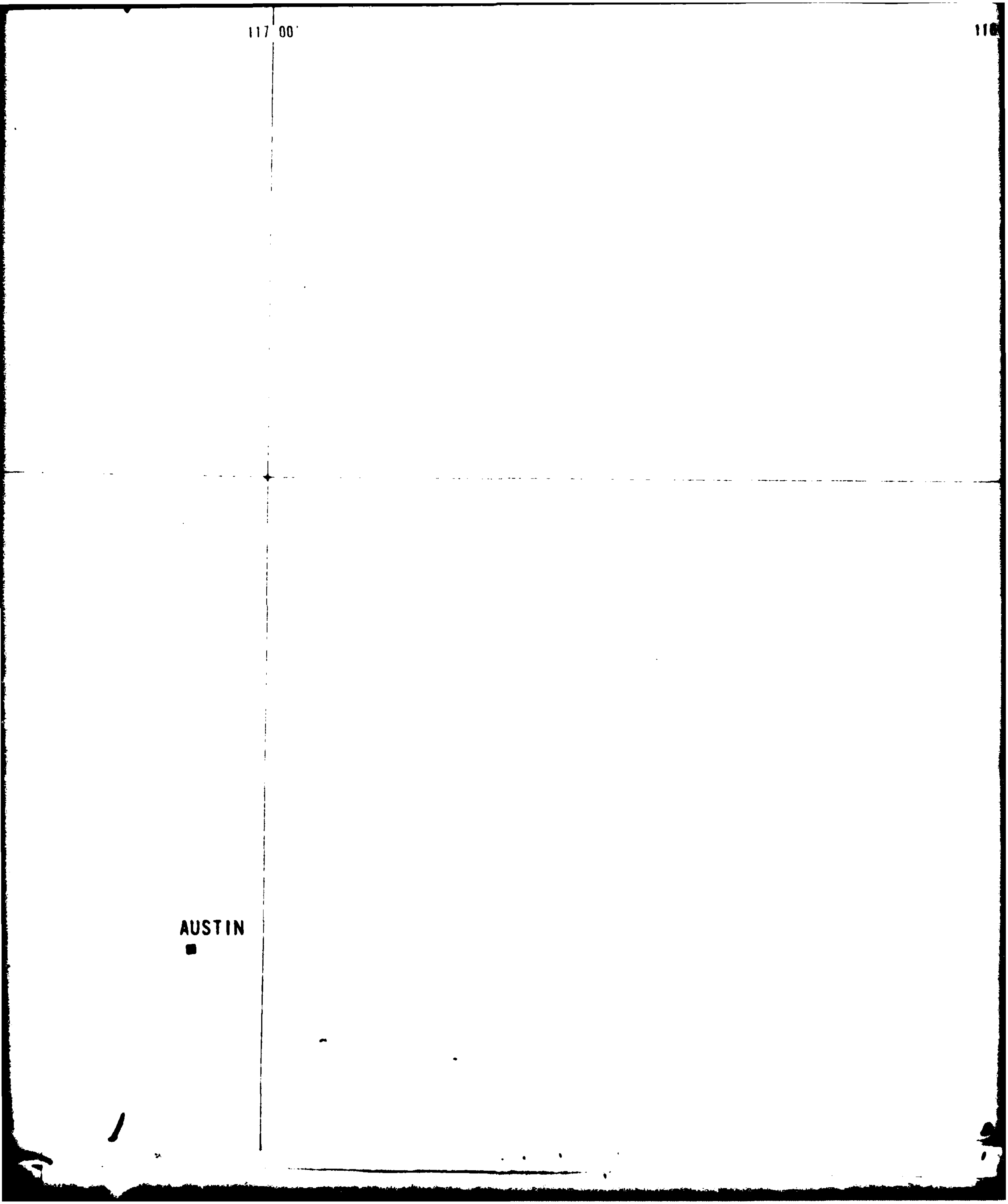
EARTHQUAKE EPICENTER MAP USGS/NTS DATA

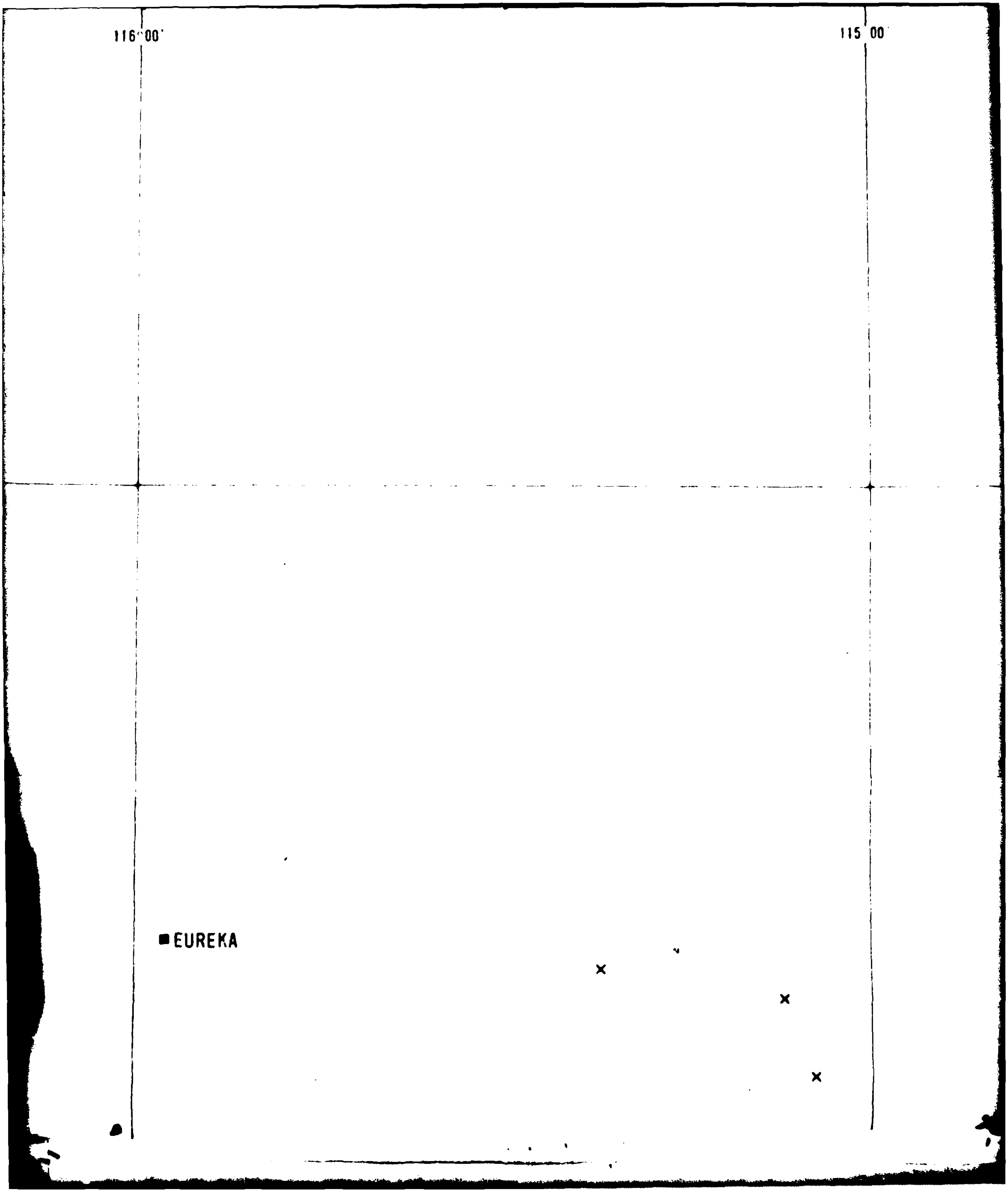
MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - BMO

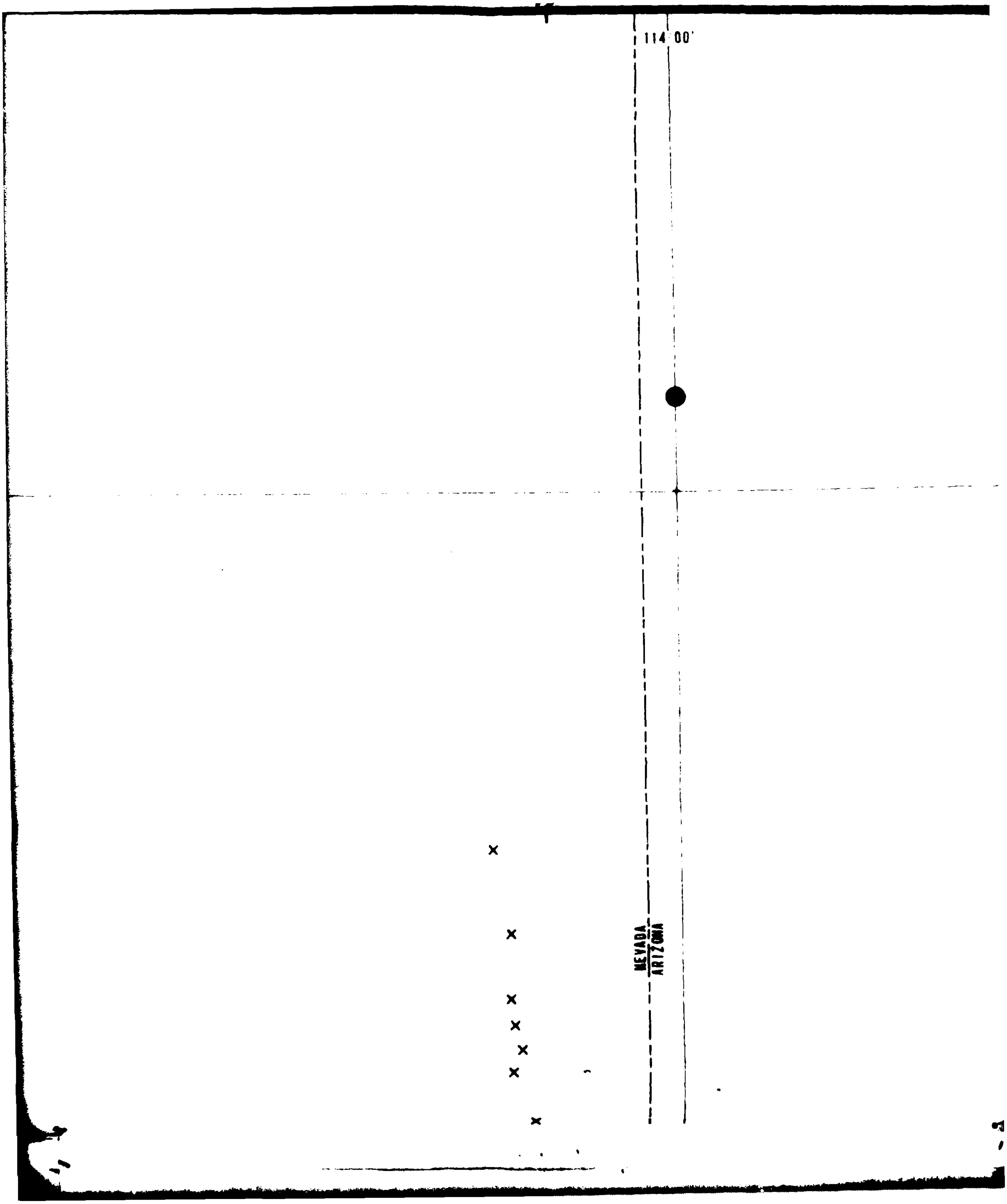
DRAWING 2-2

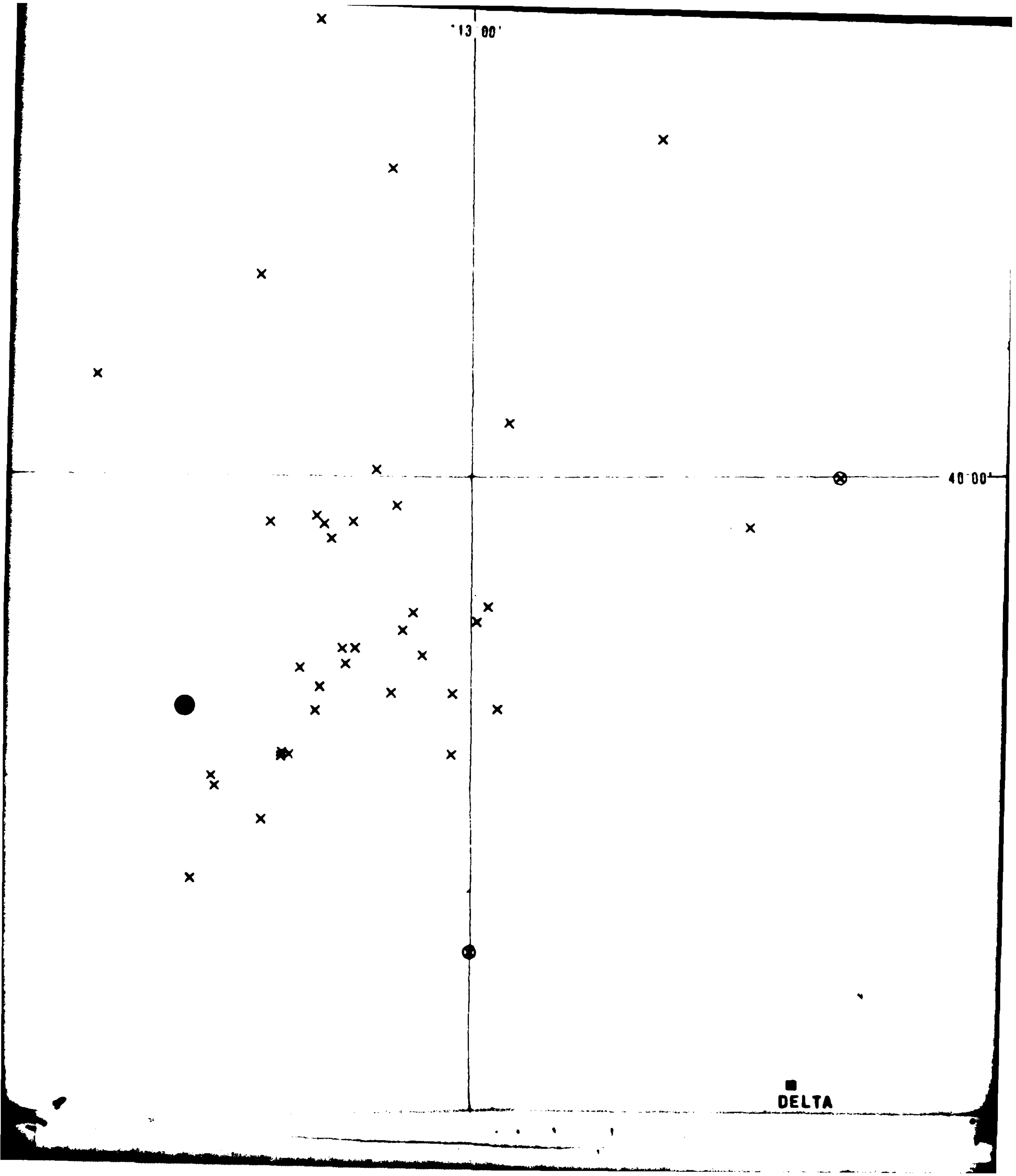
FUGRO NATIONAL, INC.


118 00'
40 00'

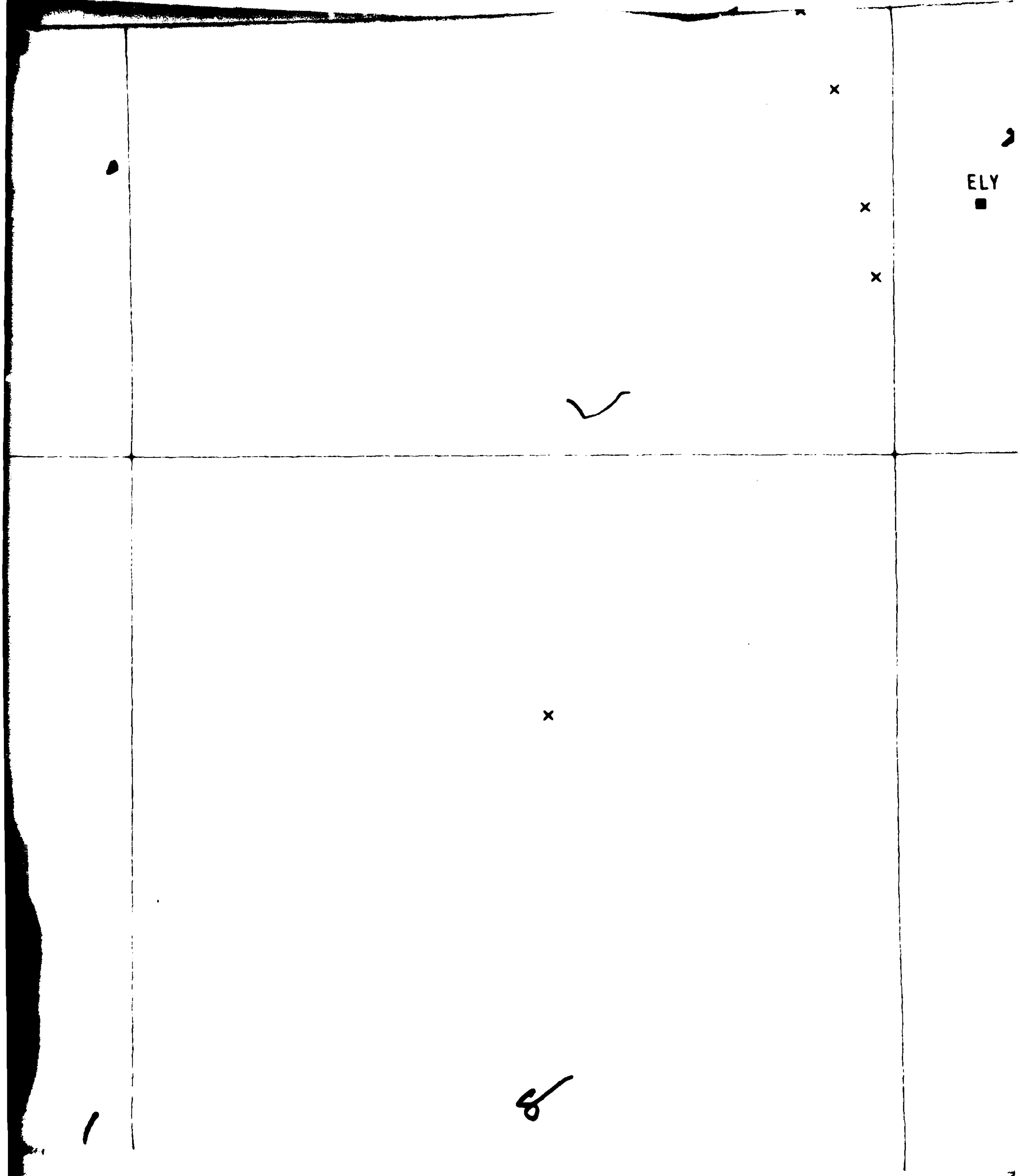

117°00'
AUSTIN

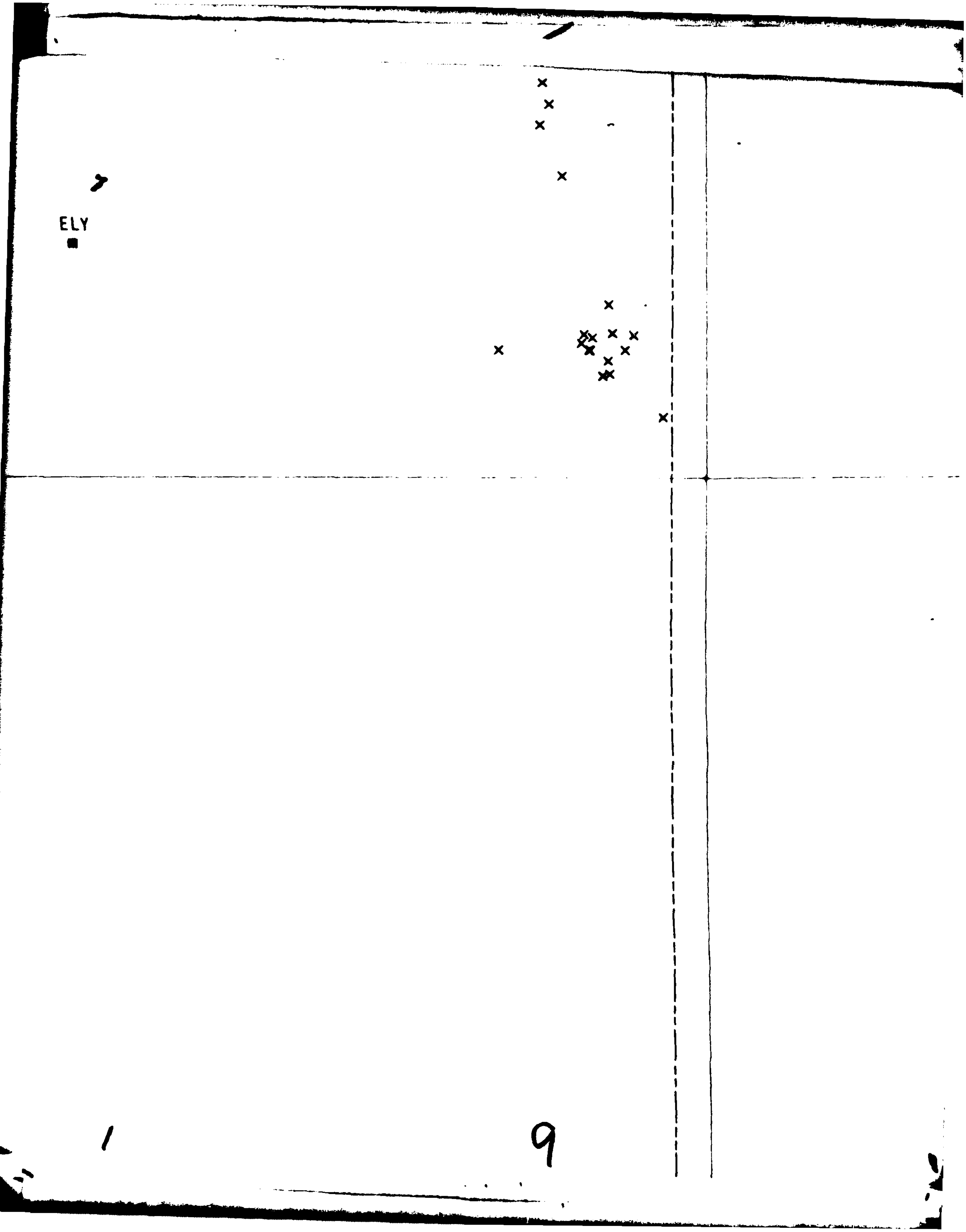

116°00'
115°00'
EUREKA

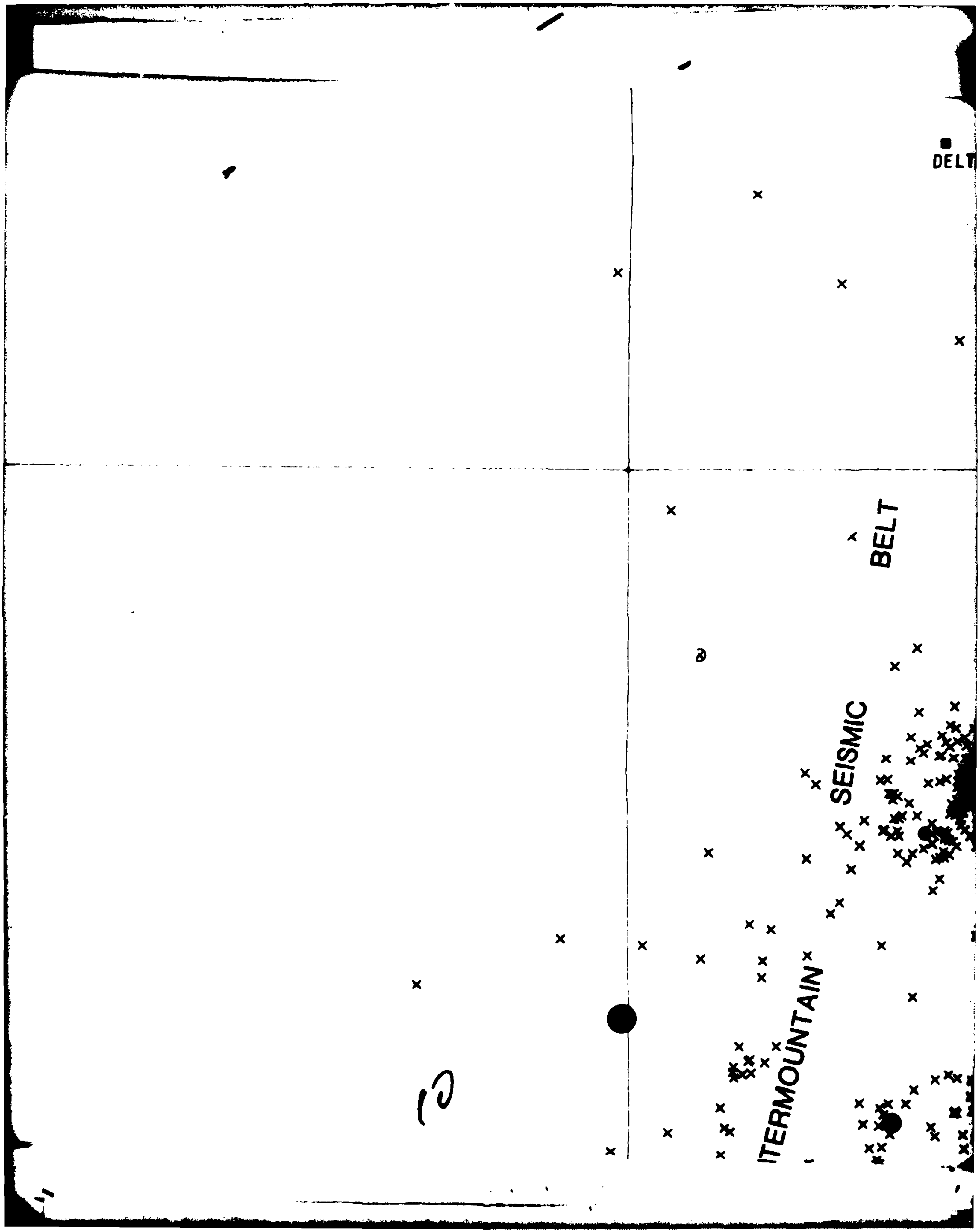

114°00'
NEVADA
ARIZONA

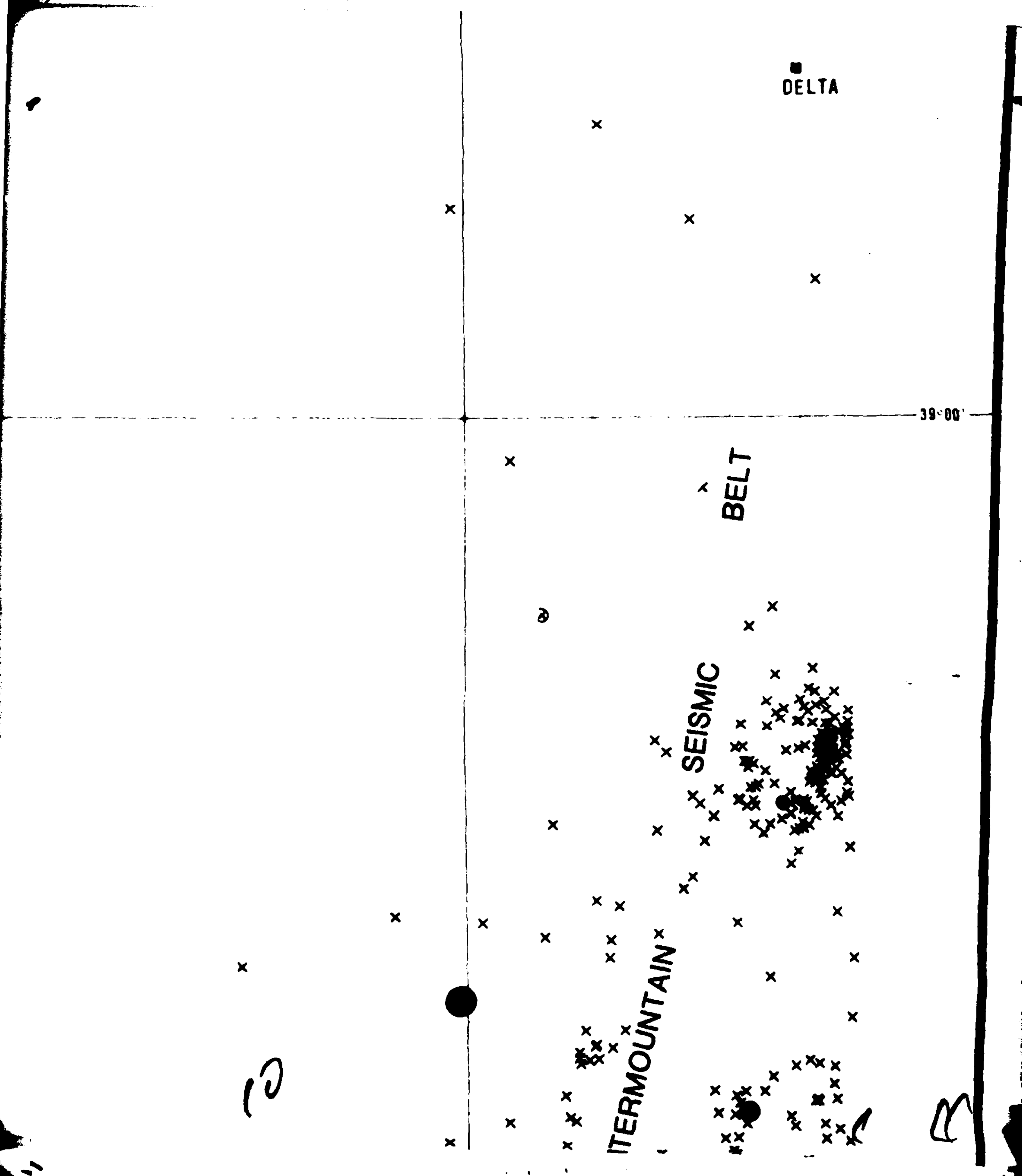

13 00'
40 00'
DELTA

39 00'


ELY

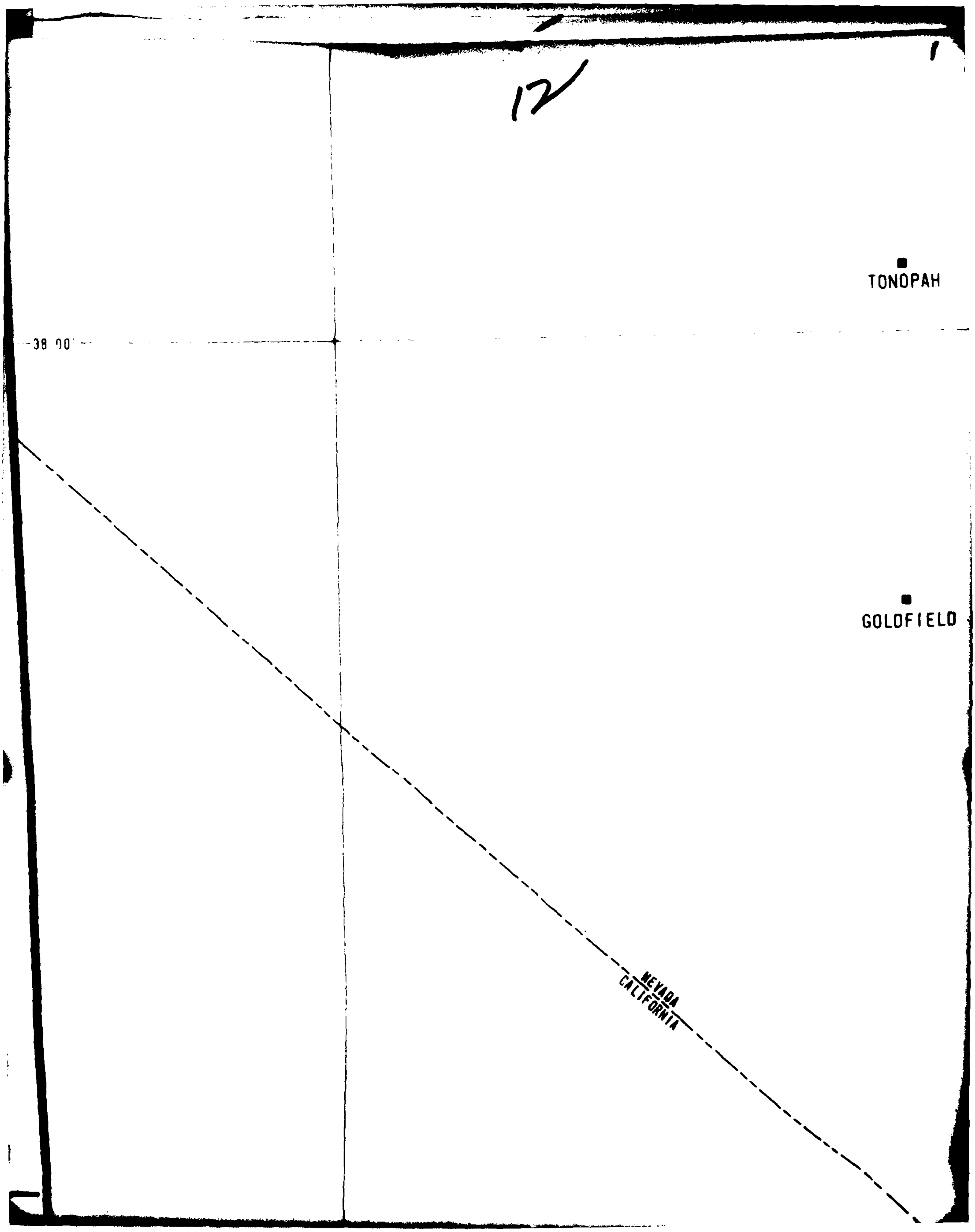

ELY
1
9

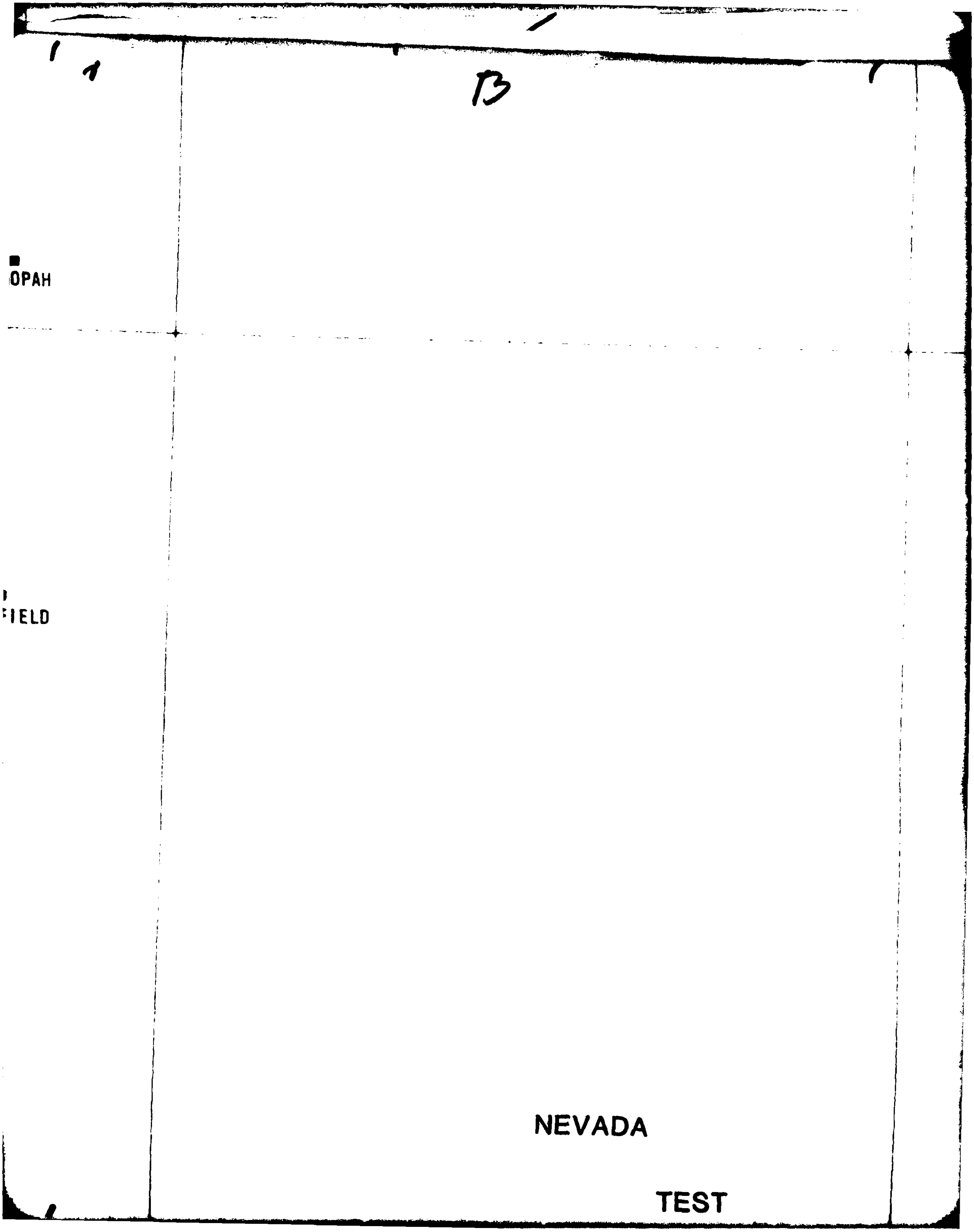

DELT
ITERMOUNTAIN
SEISMIC
BELT



DELTA
39°00'
BELT
SEISMIC
ITERMOUNTAIN

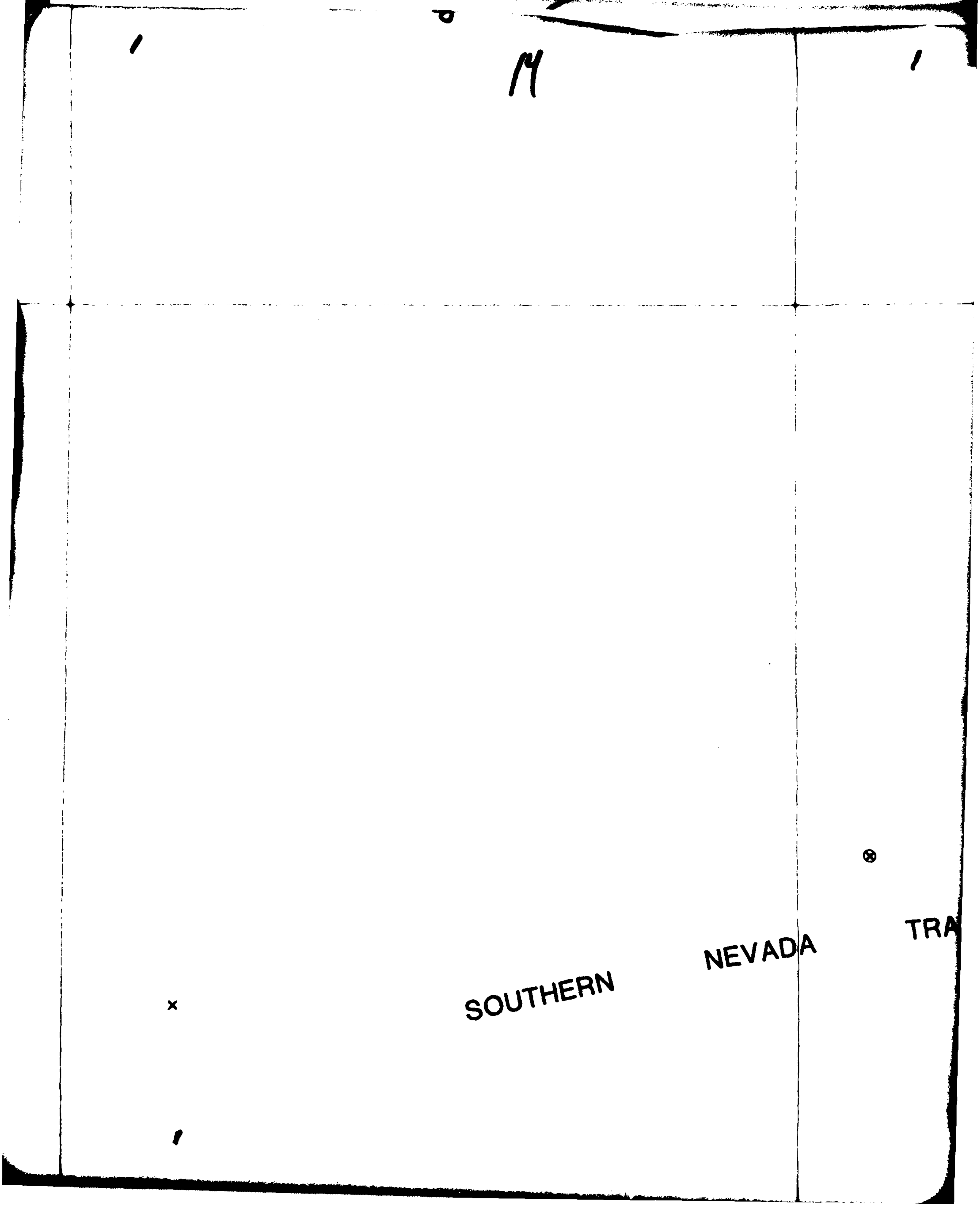
12

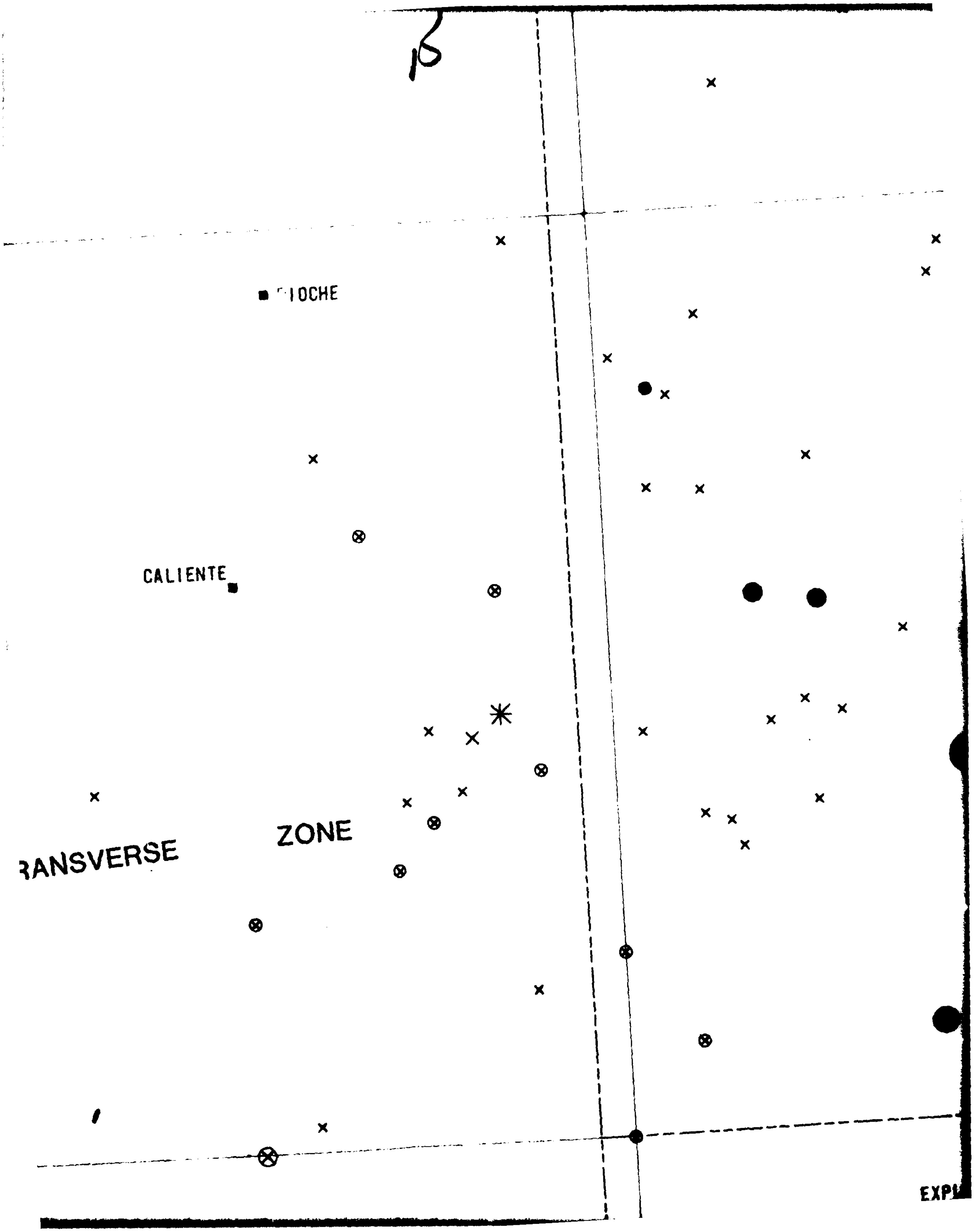




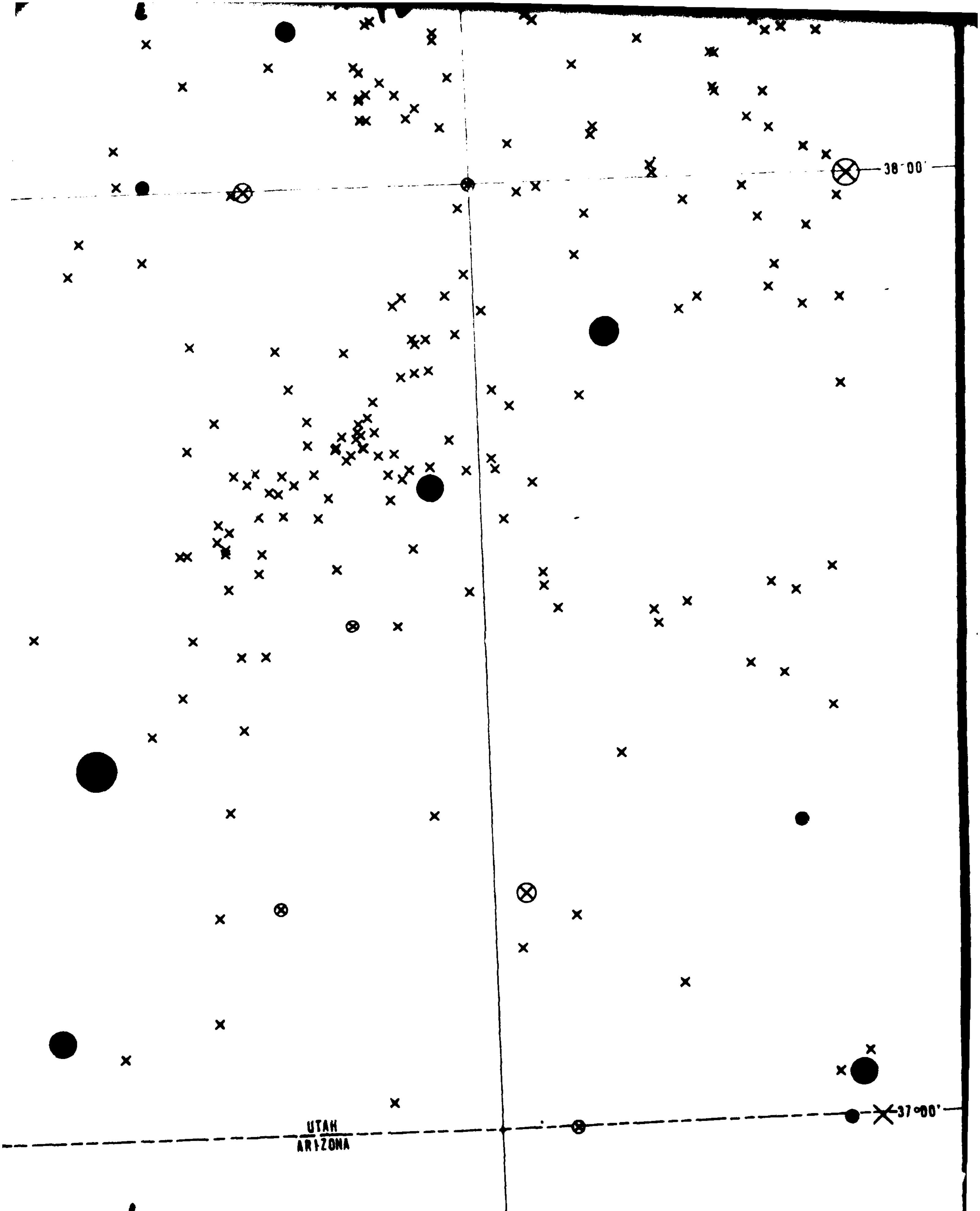
OPAH
FIELD
NEVADA
TEST

14

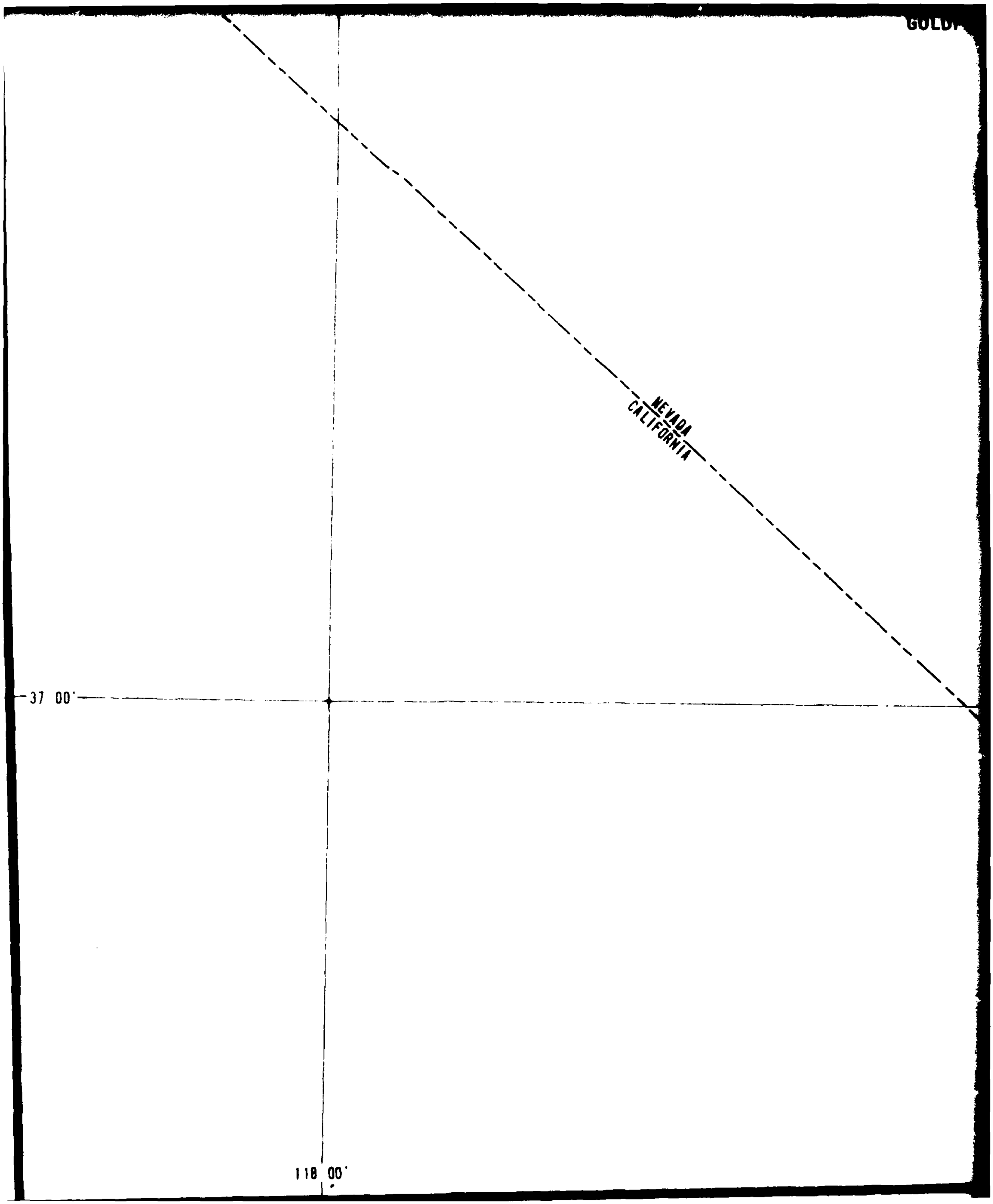


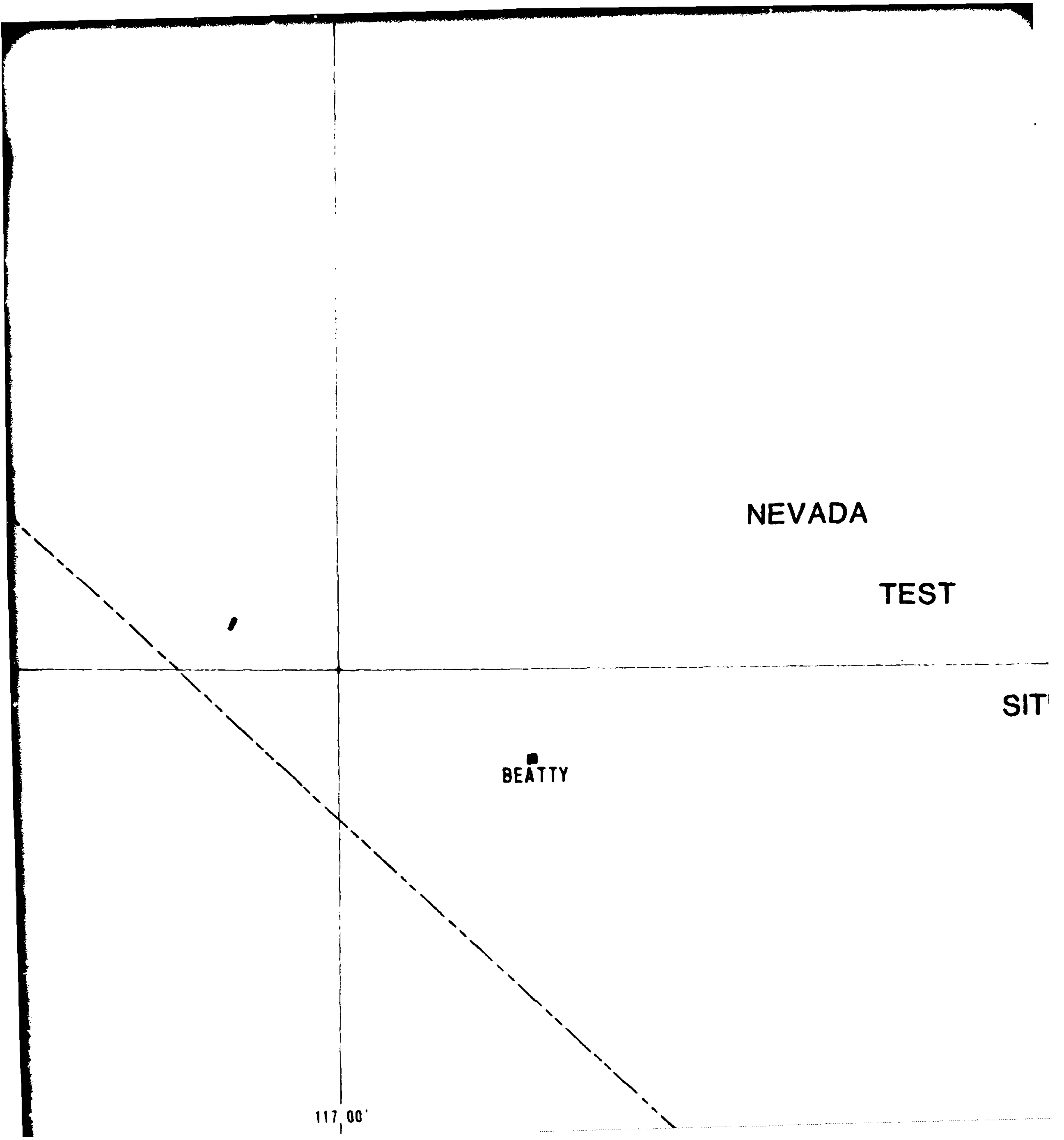


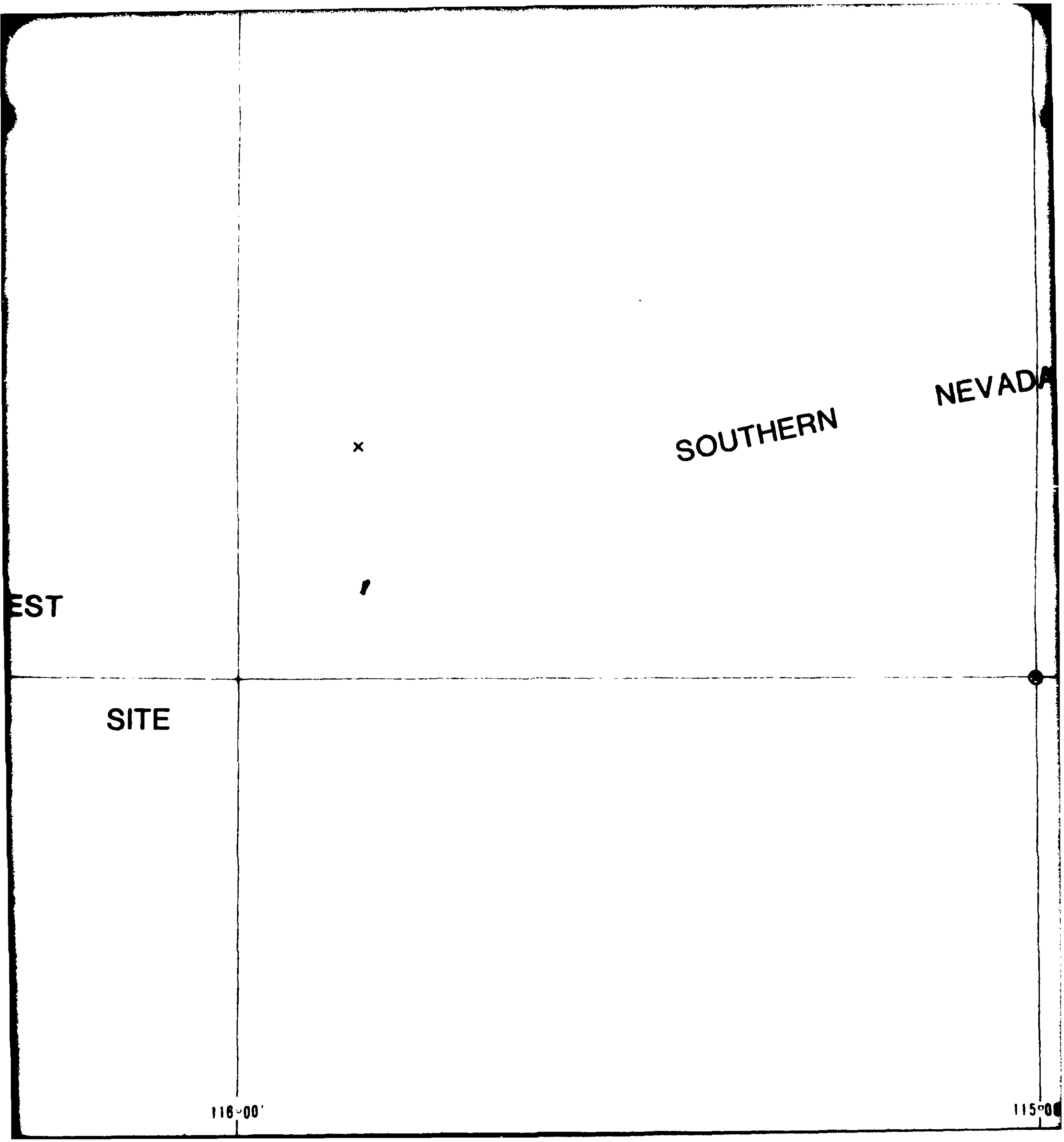
IOCHE
CALIENTE
ZONE
RANSVERSE
EXP



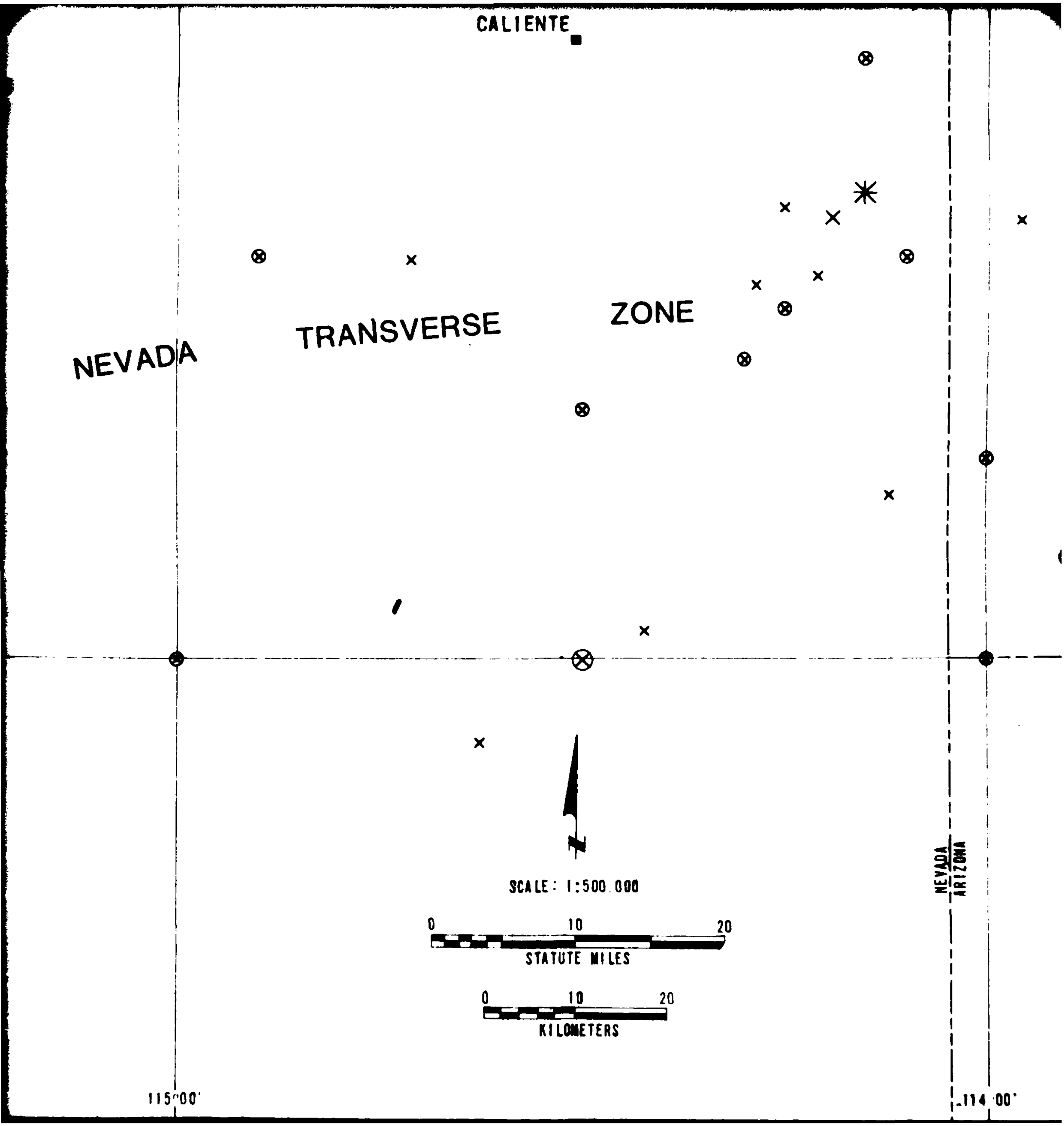
EXPLANATION

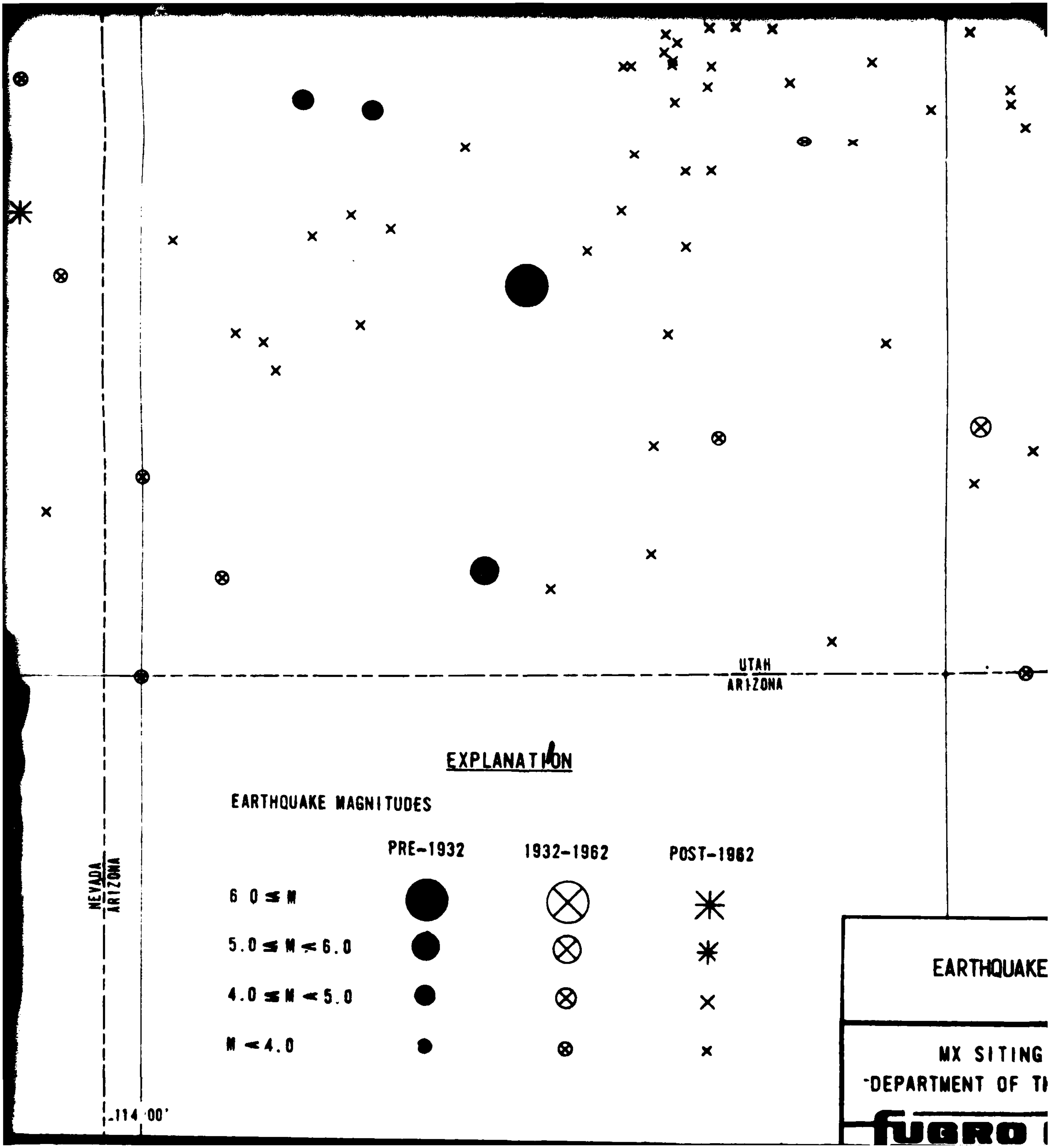

NEVADA
CALIFORNIA
37 00'
118 00'


NEVADA
TEST
SIT
BEATTY
117 00'

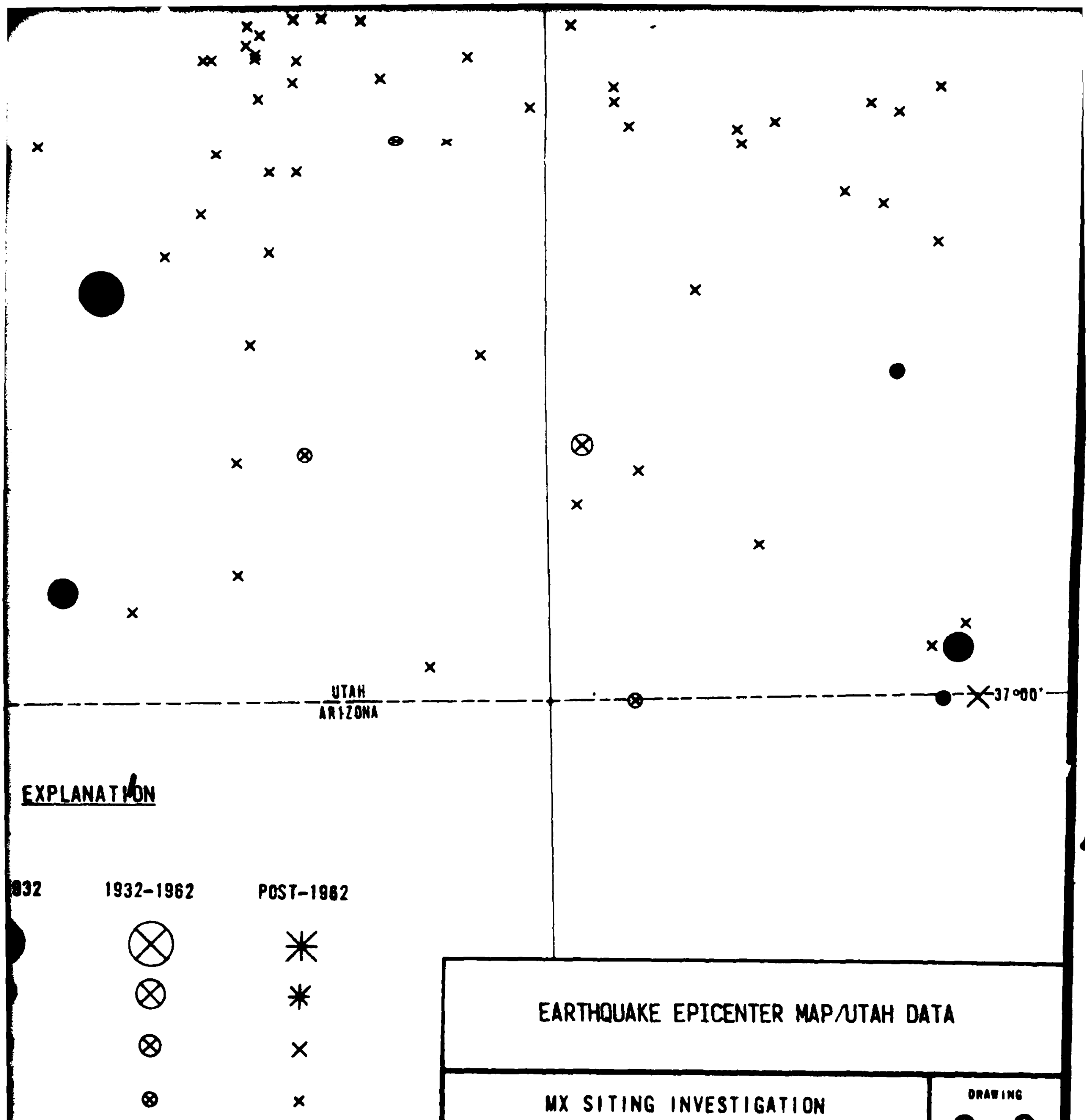


SOUTHERN
NEVADA
EST
SITE
116°00'
115°0


CALIENTE
NEVADA TRANSVERSE ZONE
N
SCALE: 1:500,000
0 10 20
STATUTE MILES
0 10 20
KILOMETERS
NEVADA
ARIZONA
115°00'
114°00'



UTAH
ARIZONA
NEVADA
ARIZONA
114°00'
EXPLANATION
EARTHQUAKE MAGNITUDES
PRE-1932
1932-1962
POST-1962
6.0 ≤ M
5.0 ≤ M < 6.0
4.0 ≤ M < 5.0
M < 4.0
EARTHQUAKE
MX SITING
DEPARTMENT OF TH

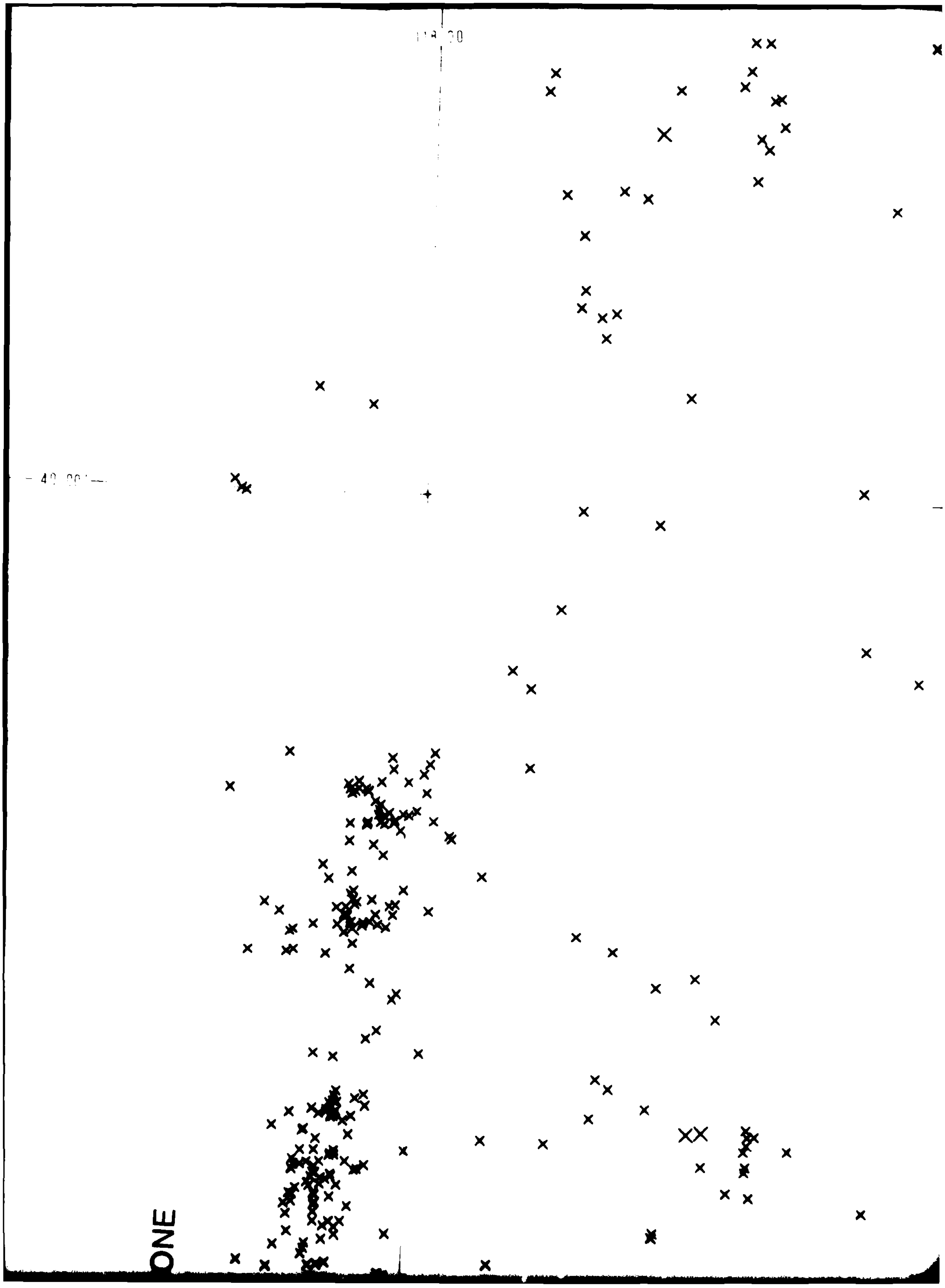


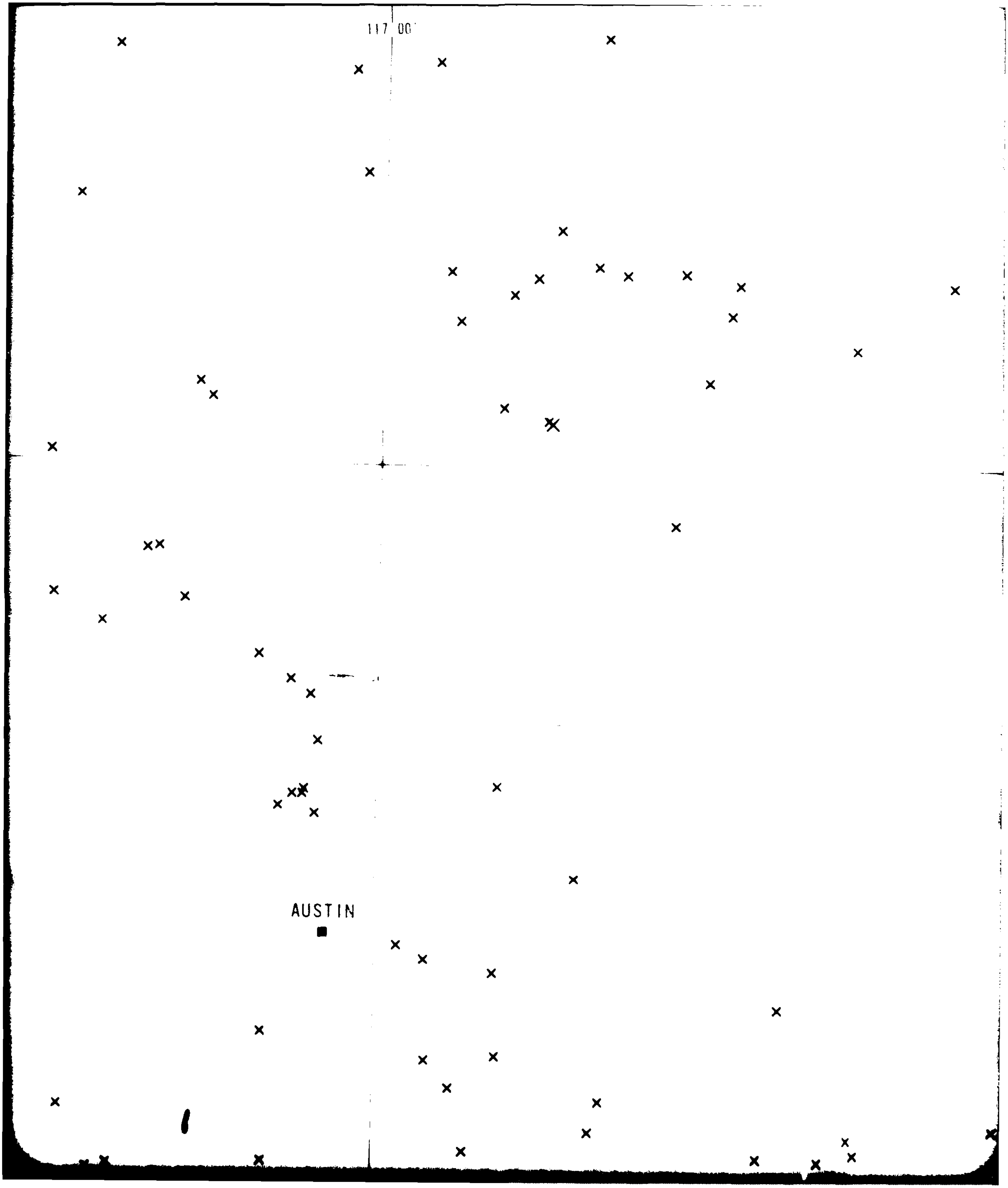
EARTHQUAKE EPICENTER MAP/UTAH DATA

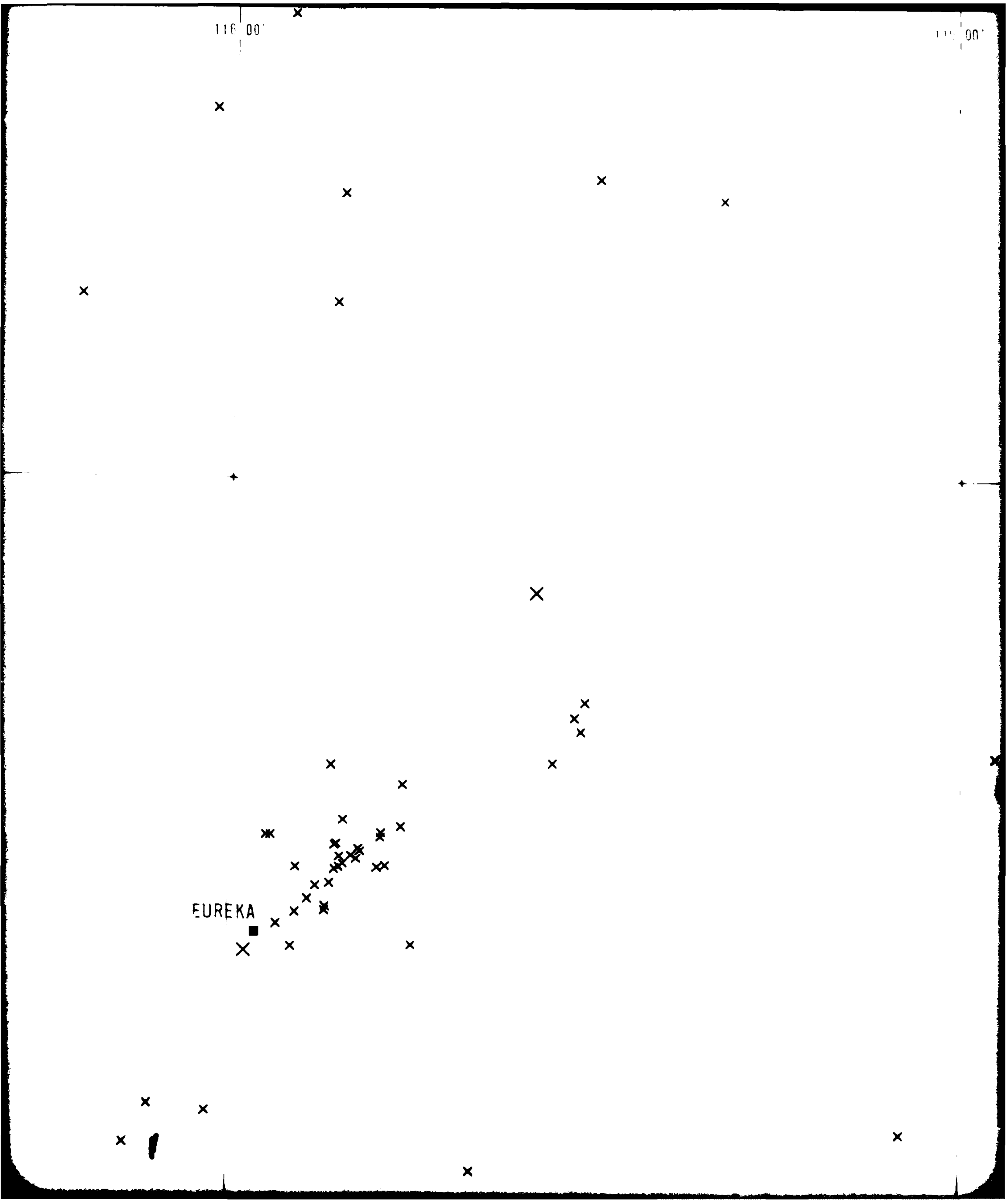
MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - BMO

DRAWING
2-3

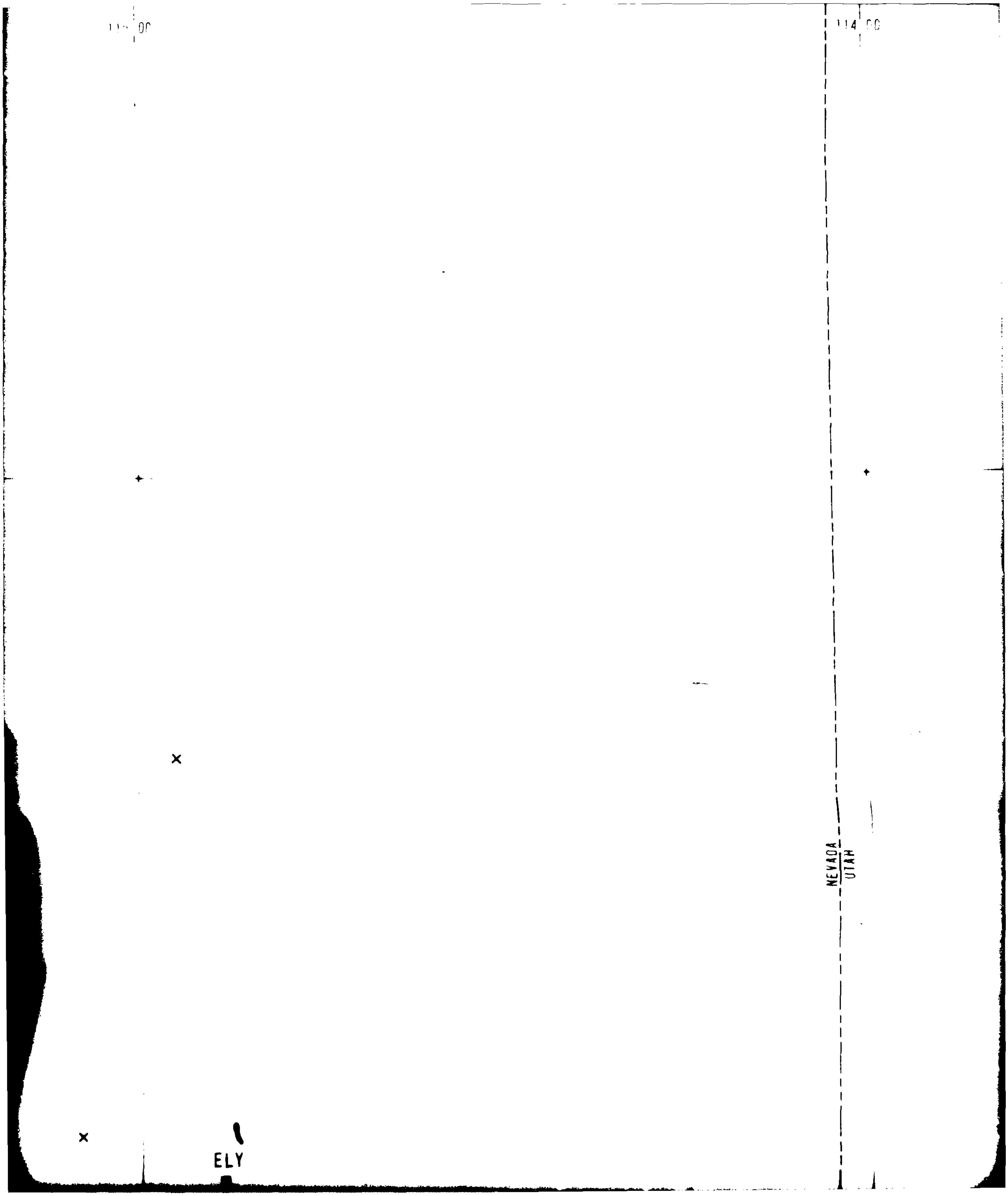
FUGRO NATIONAL, INC.

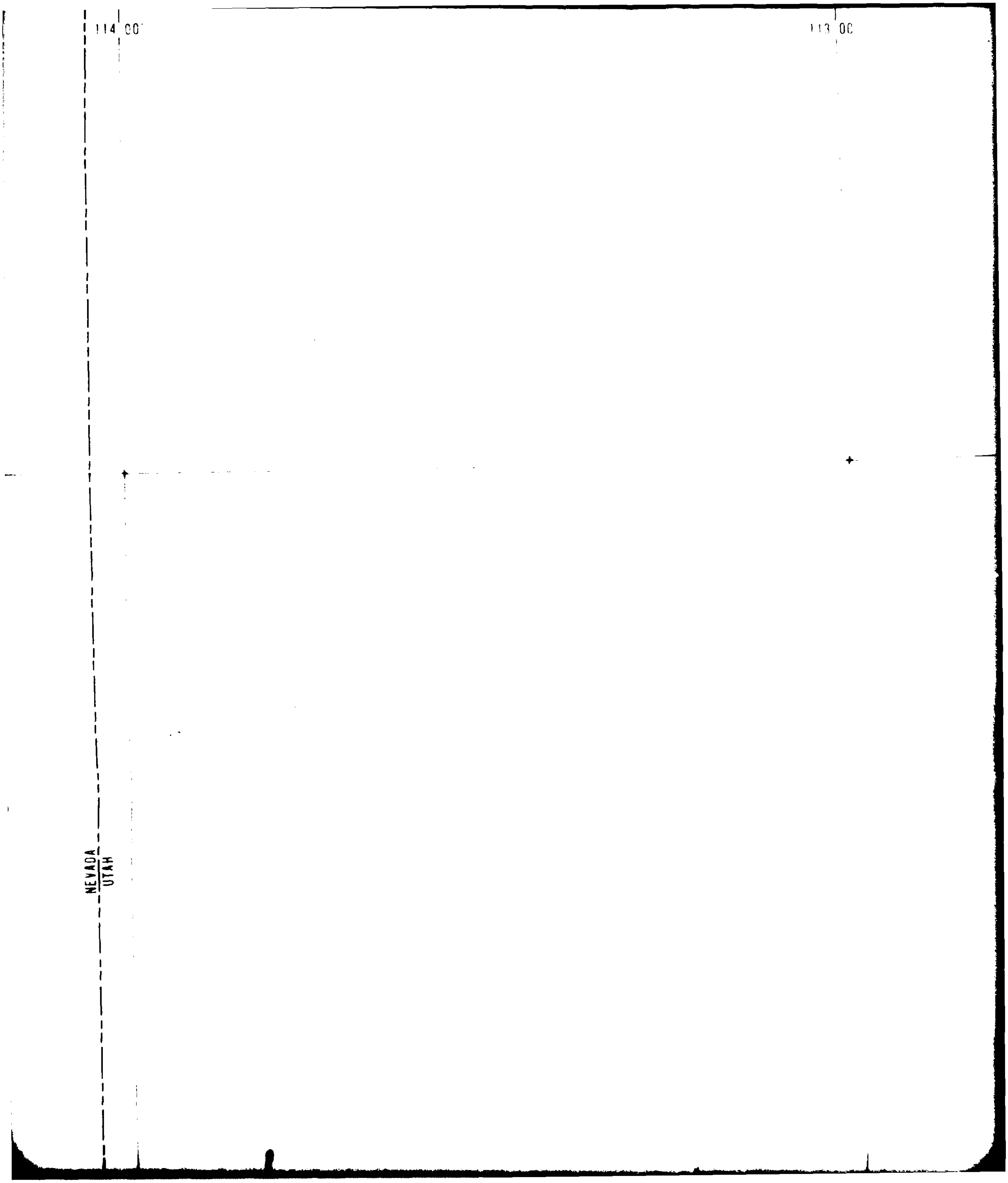

ONE

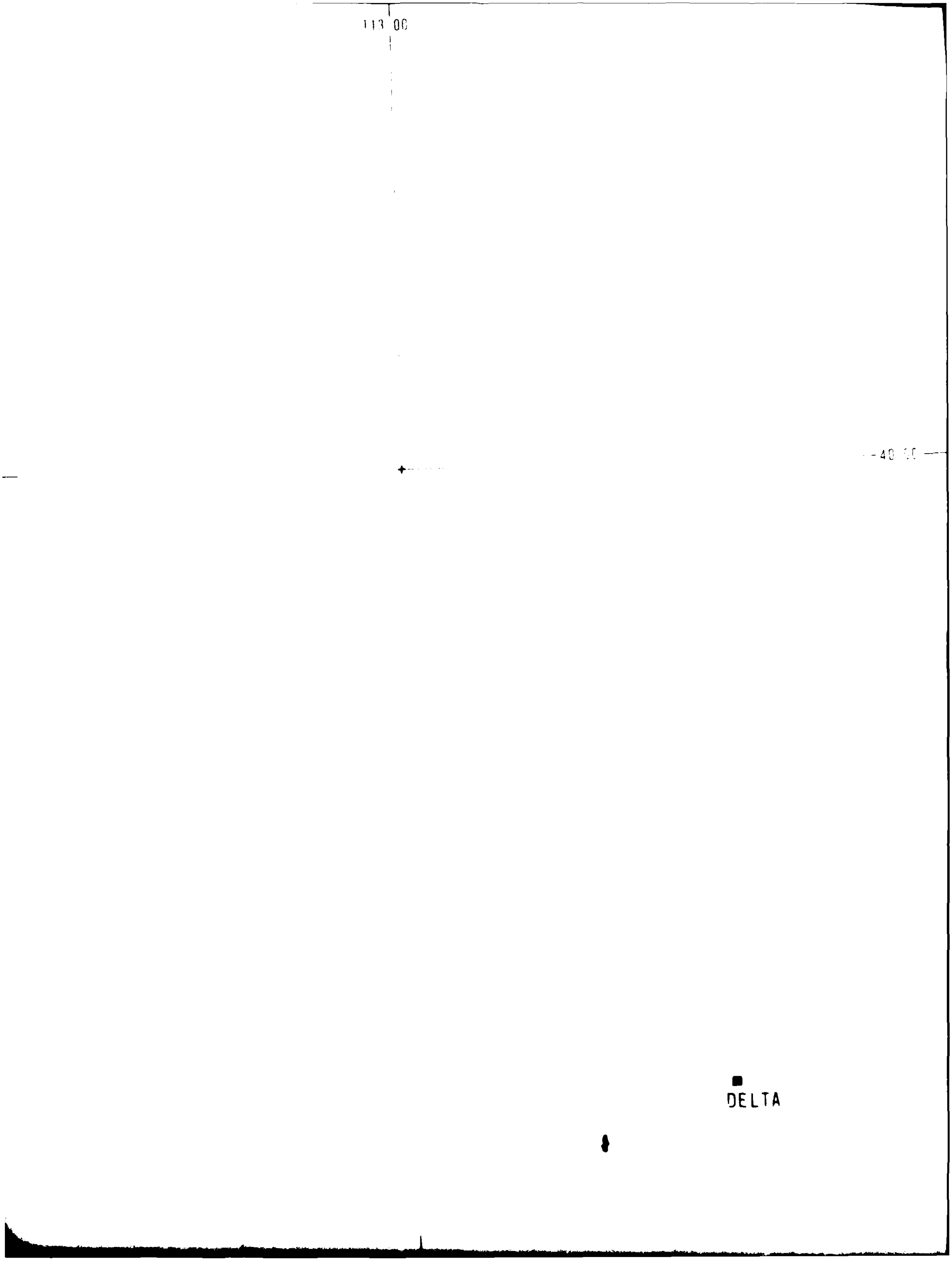

117°00'
AUSTIN

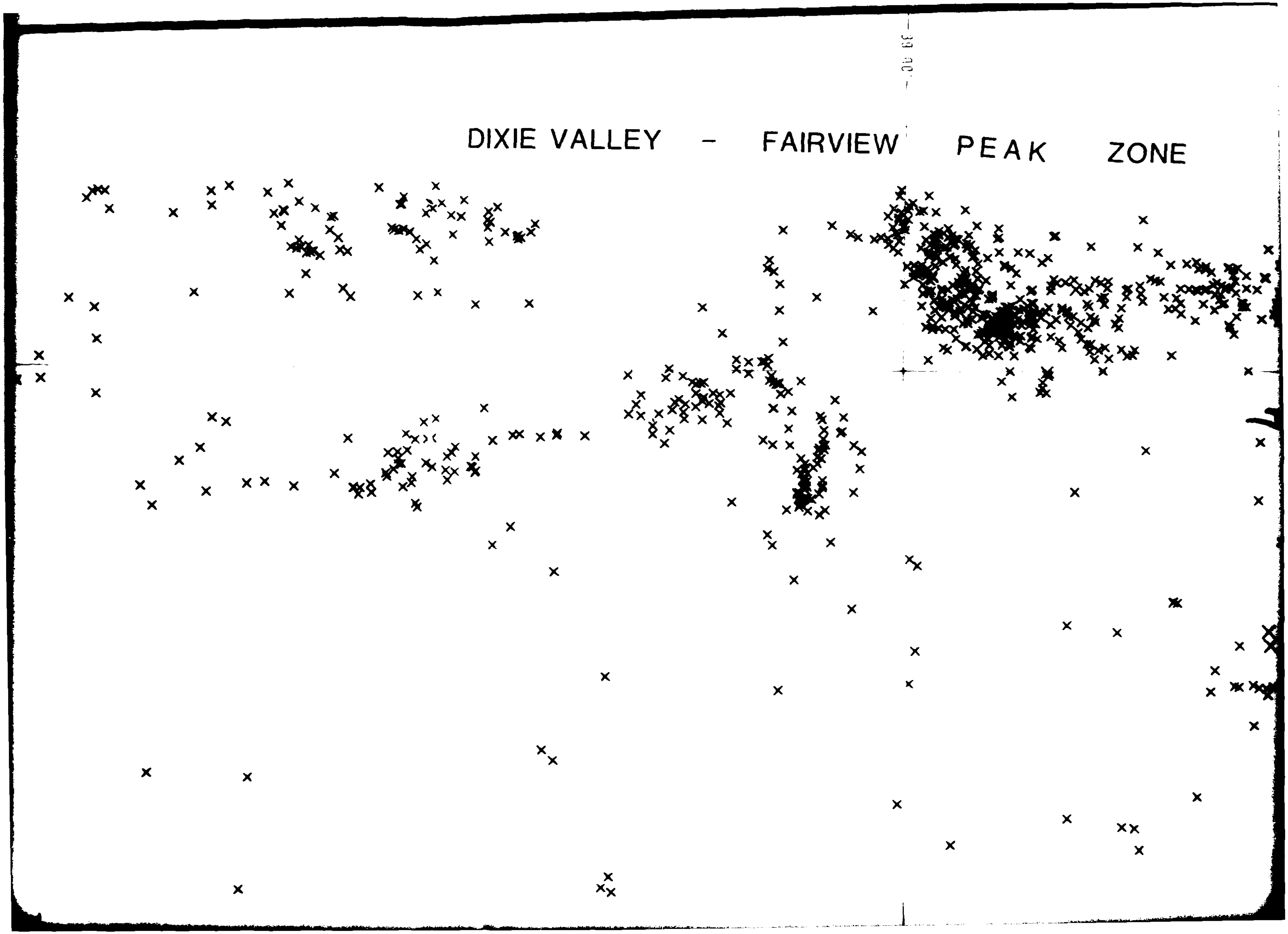


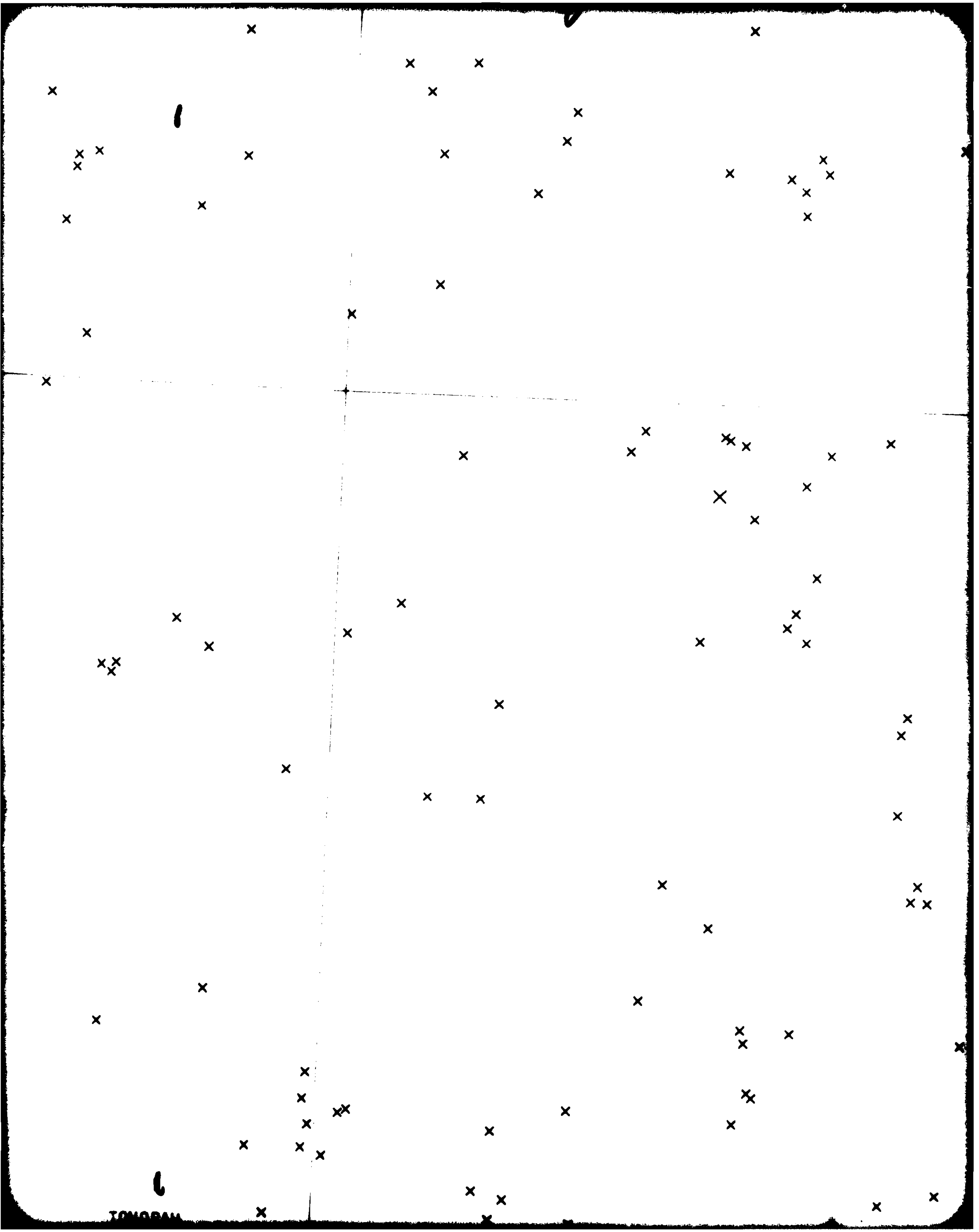
116 00'
EUREKA

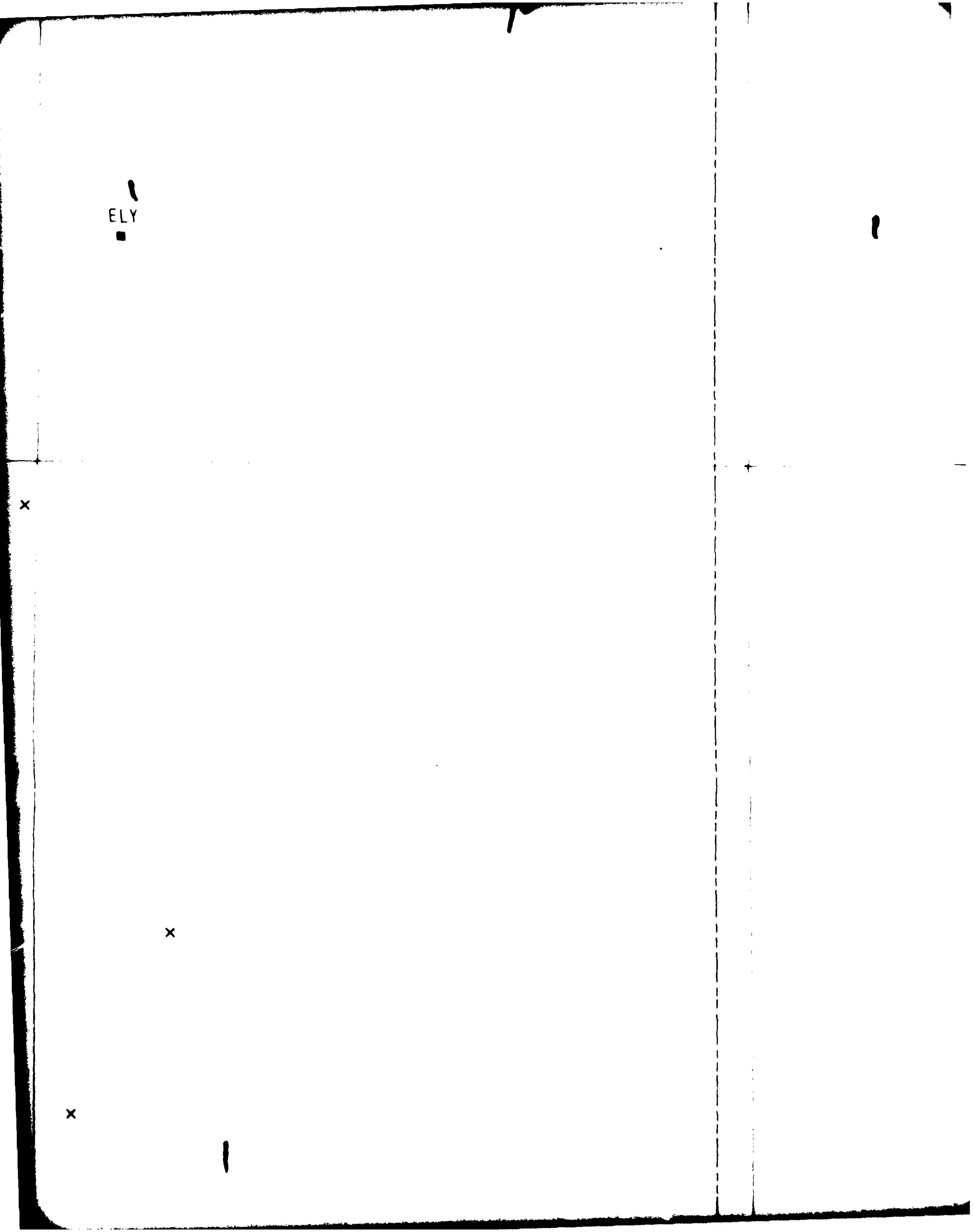

114 00
NEVADA
UTAH
ELY

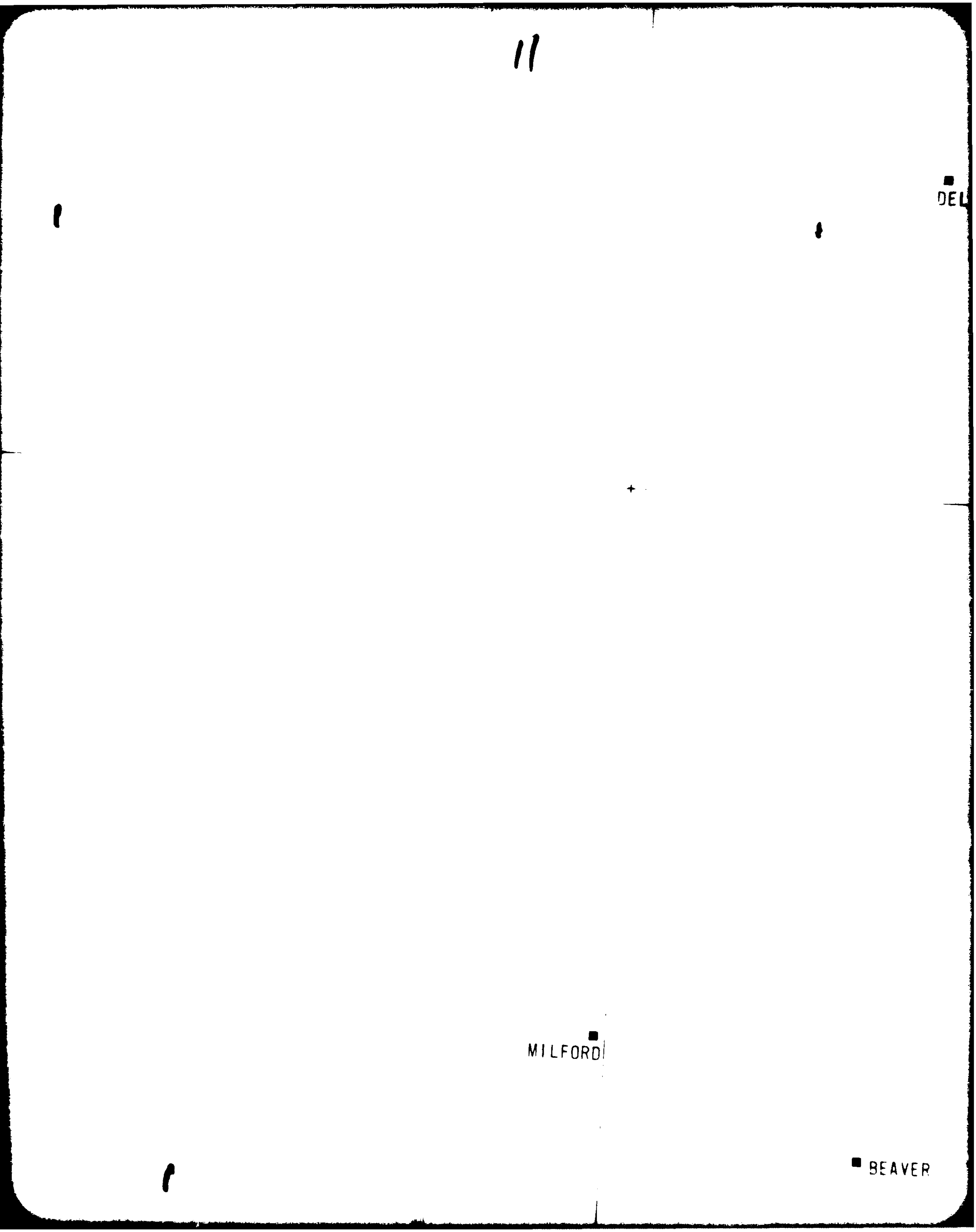

114 00'
113 00
NEVADA
UTAH

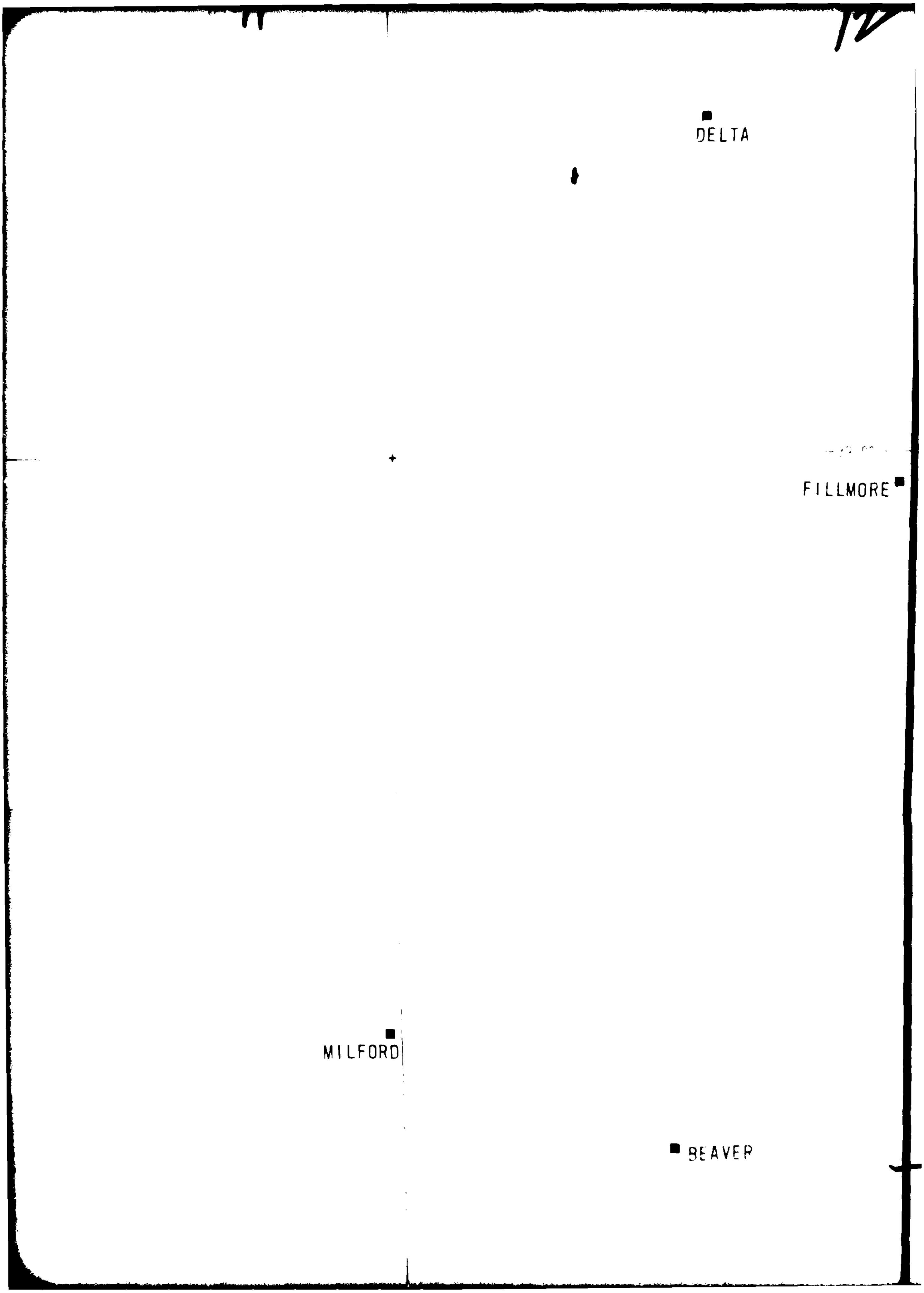

113 00
40 00
DELTA

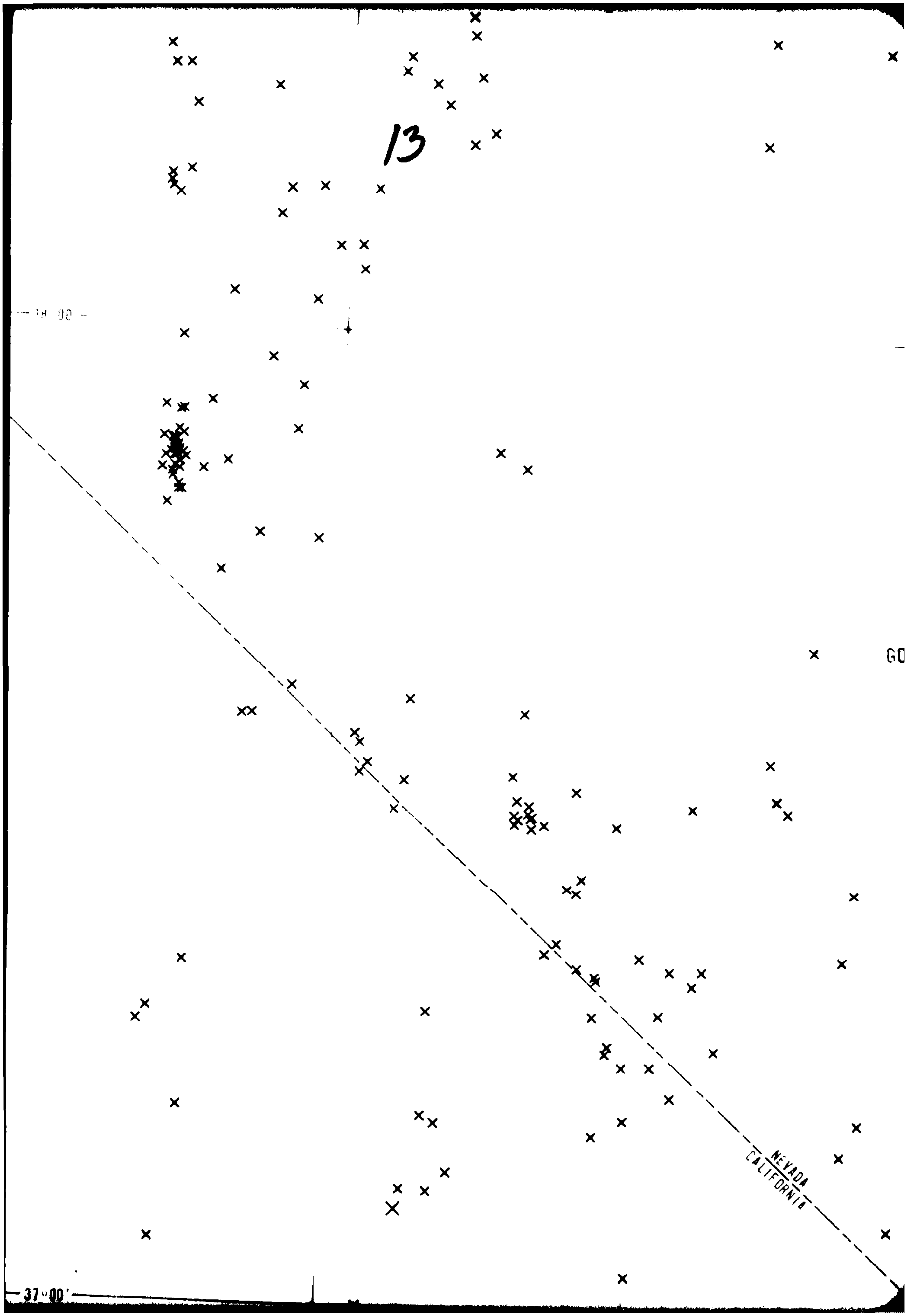

39 00'
DIXIE VALLEY - FAIRVIEW PEAK ZONE

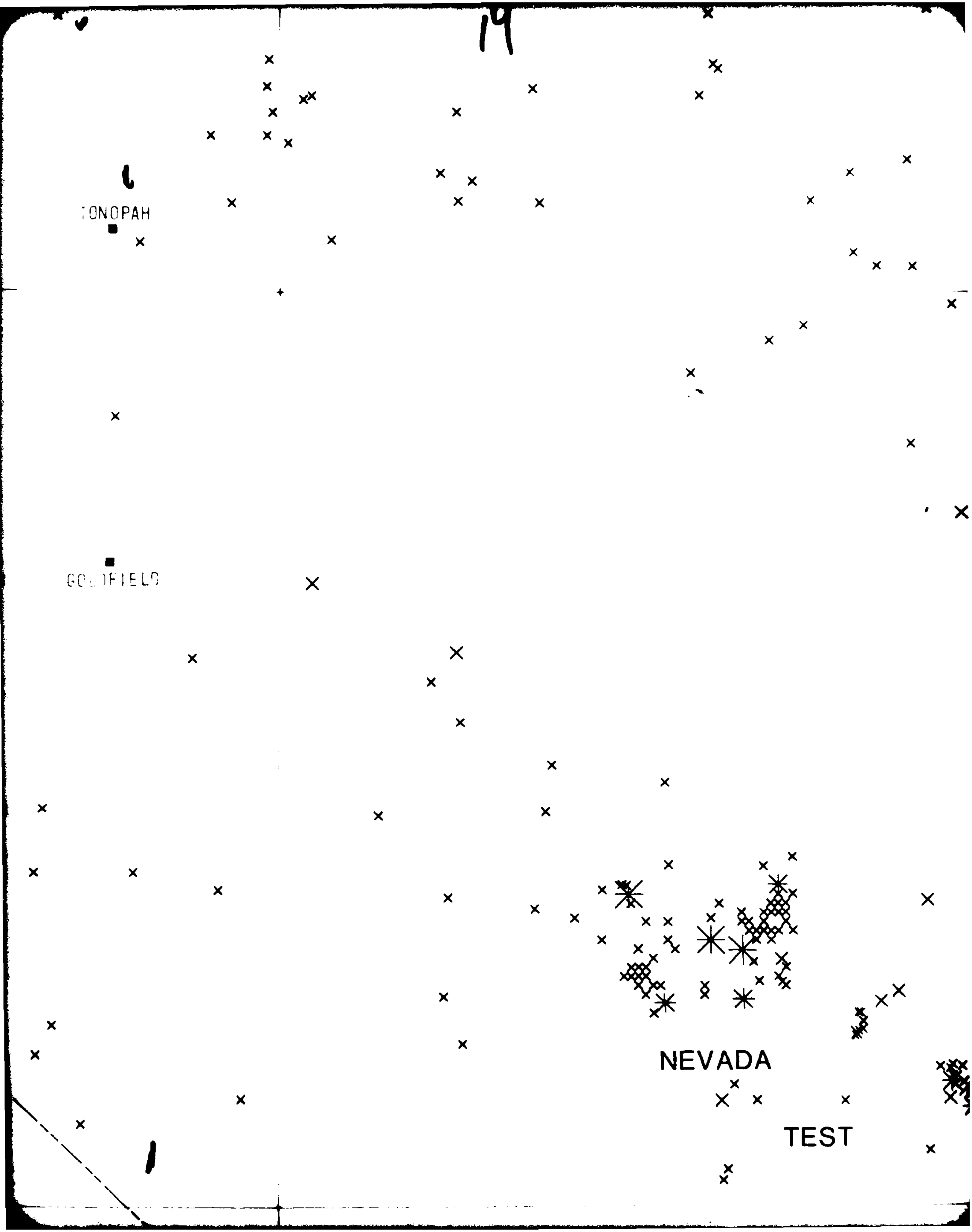


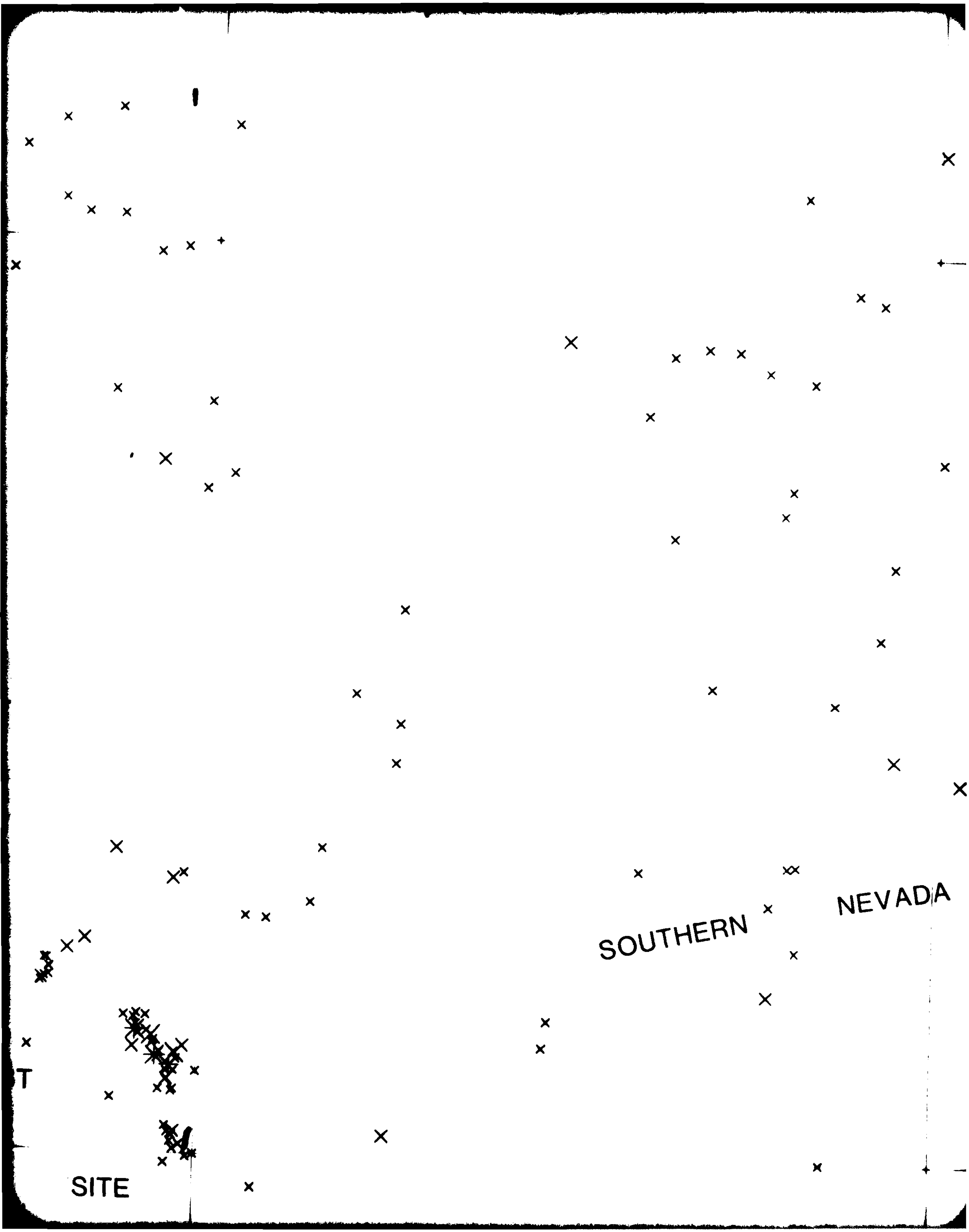

ELY

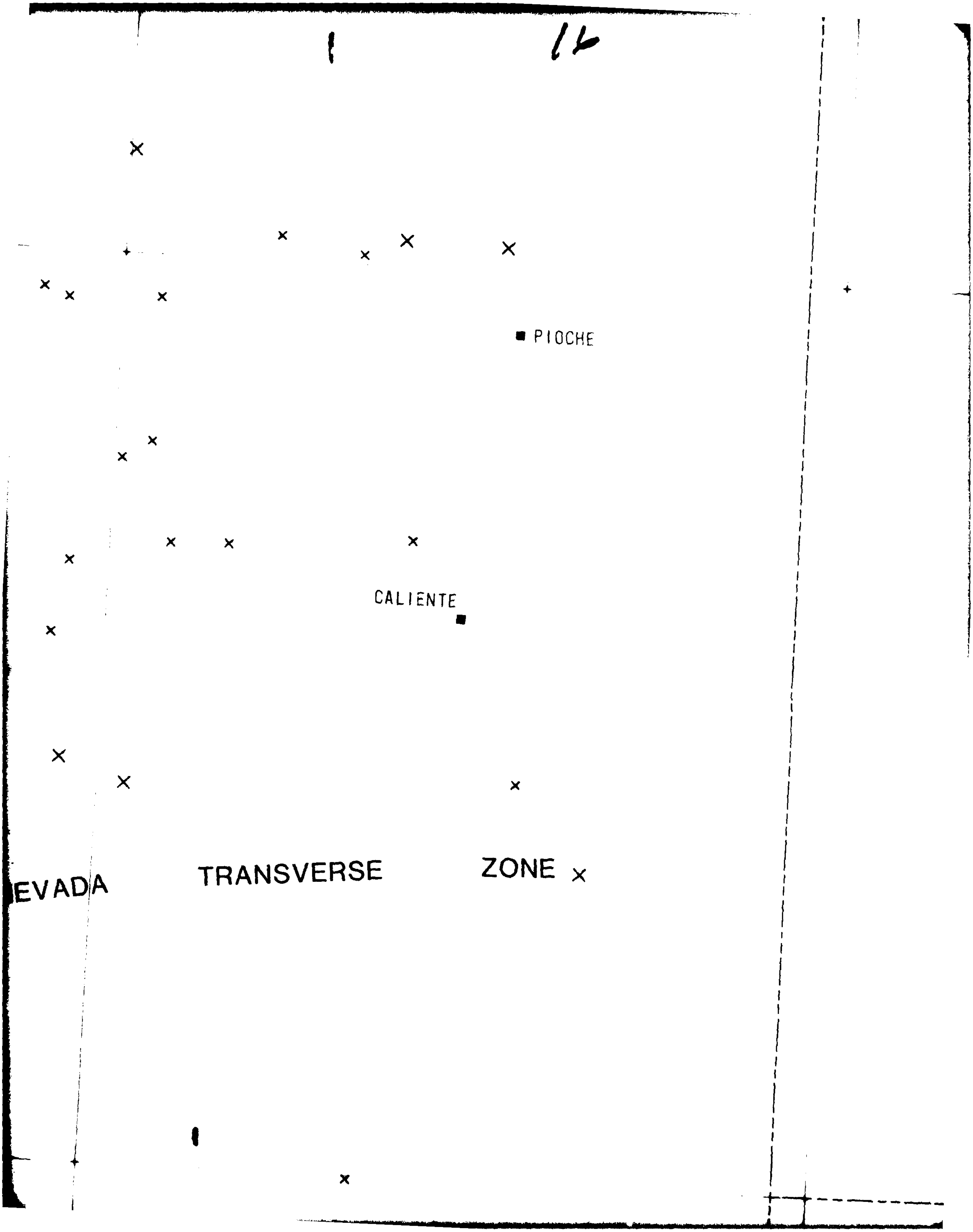

DEL
MILFORD
BEAVER

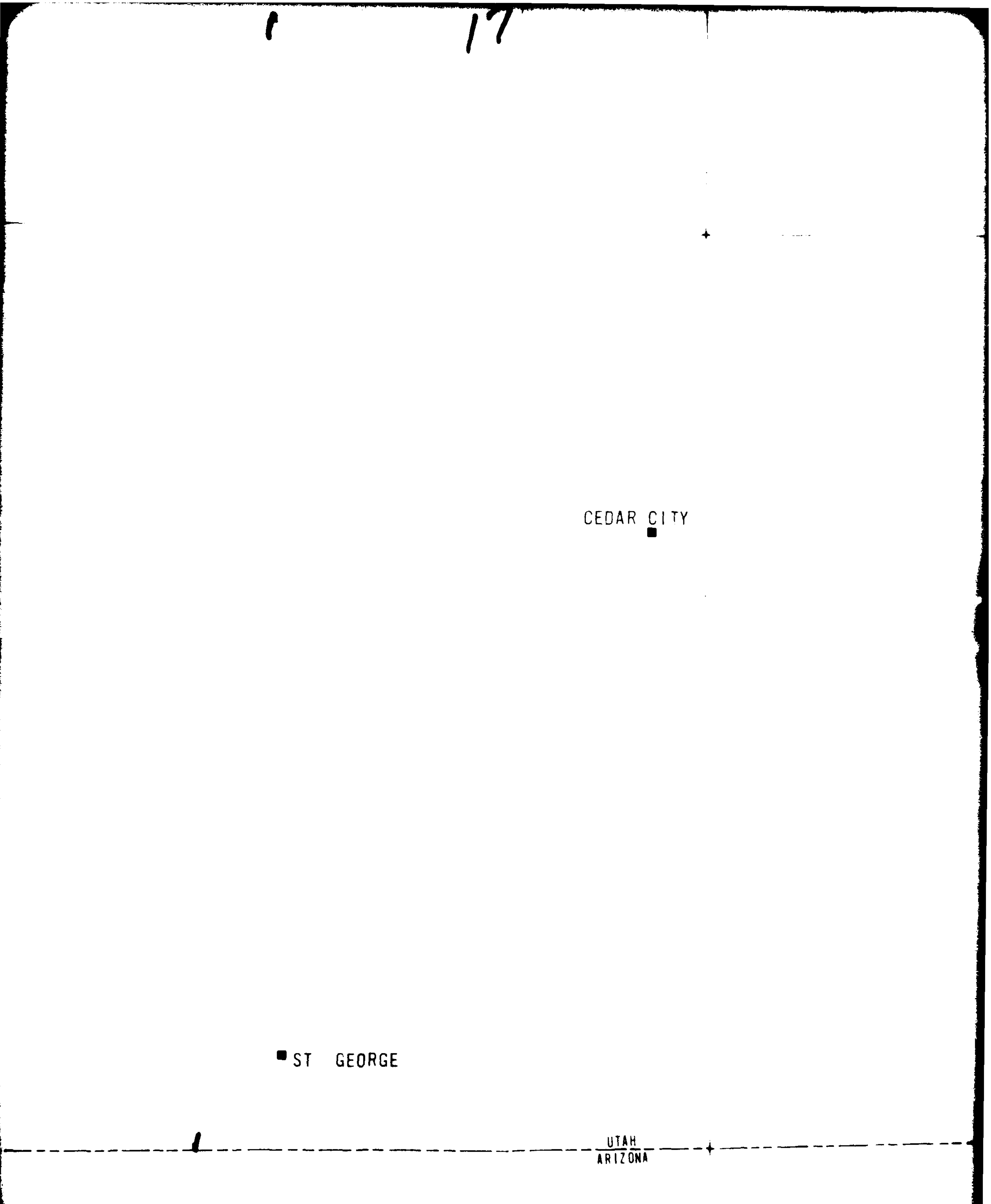

DELTA
FILLMORE
MILFORD
BEAVER


13
38°00'
GO
NEVADA
CALIFORNIA
37°00'

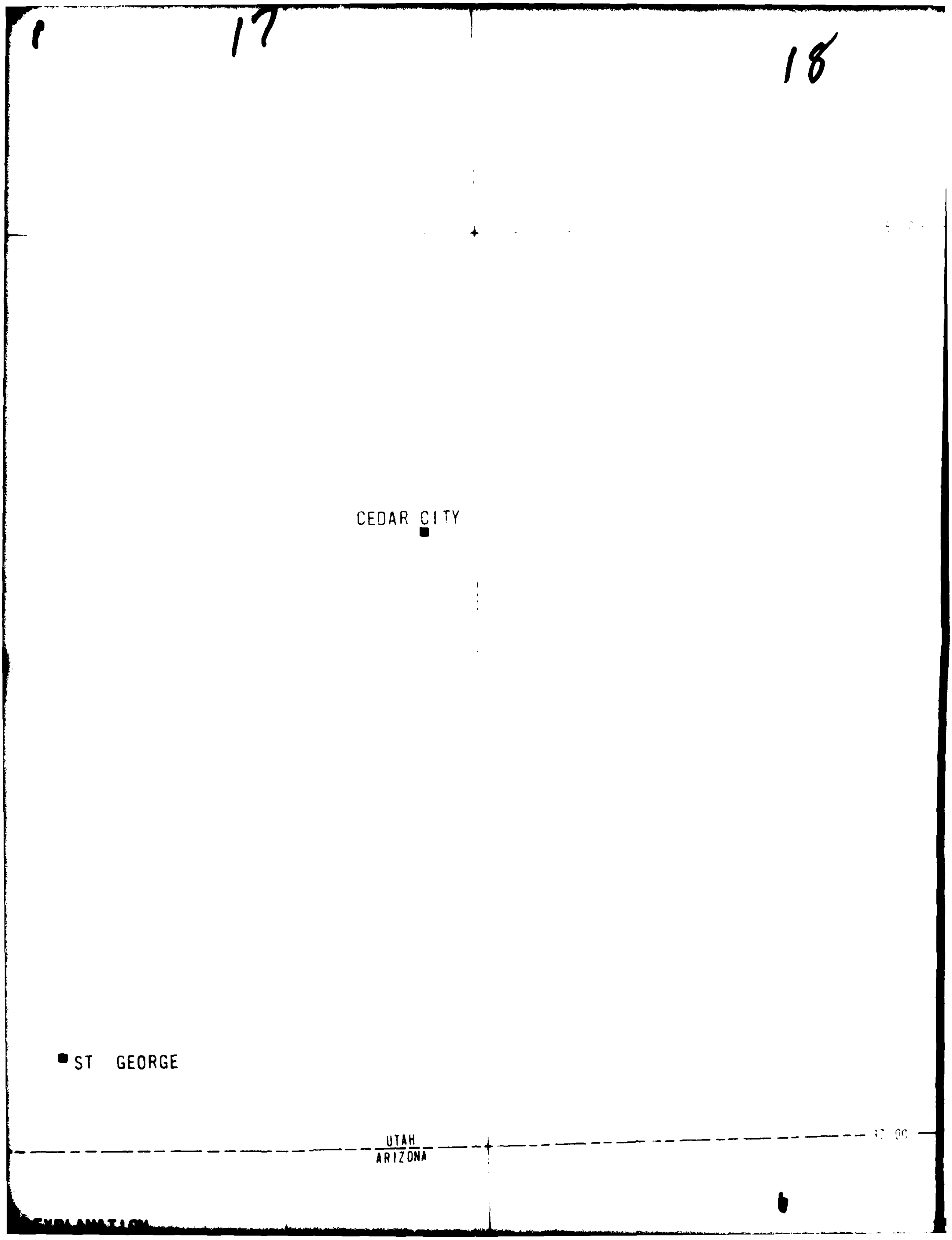

TONOPAH
NEVADA
TEST

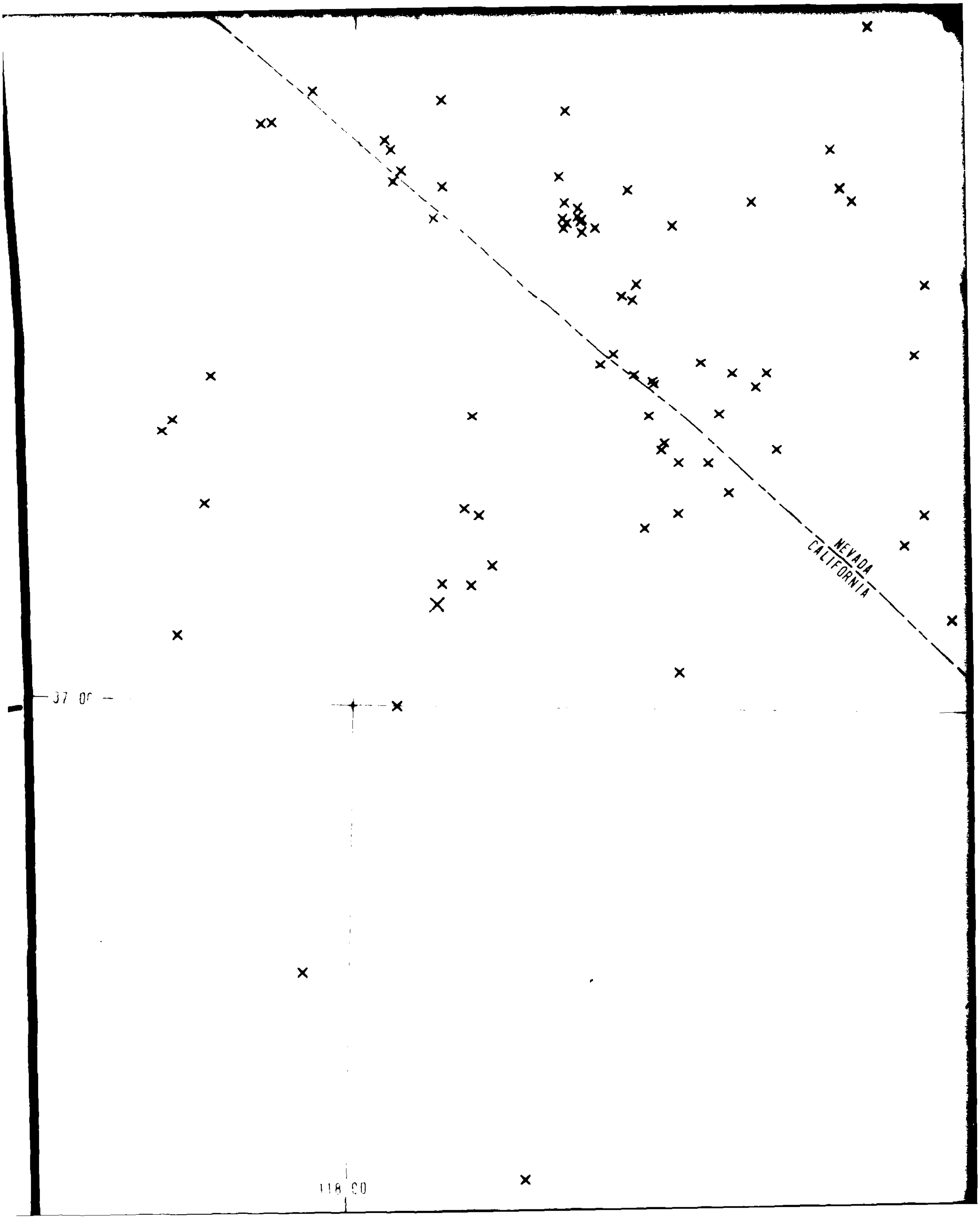

SOUTHERN NEVADA
T
SITE


PIOCHE
CALIENTE
EVADA
TRANSVERSE
ZONE

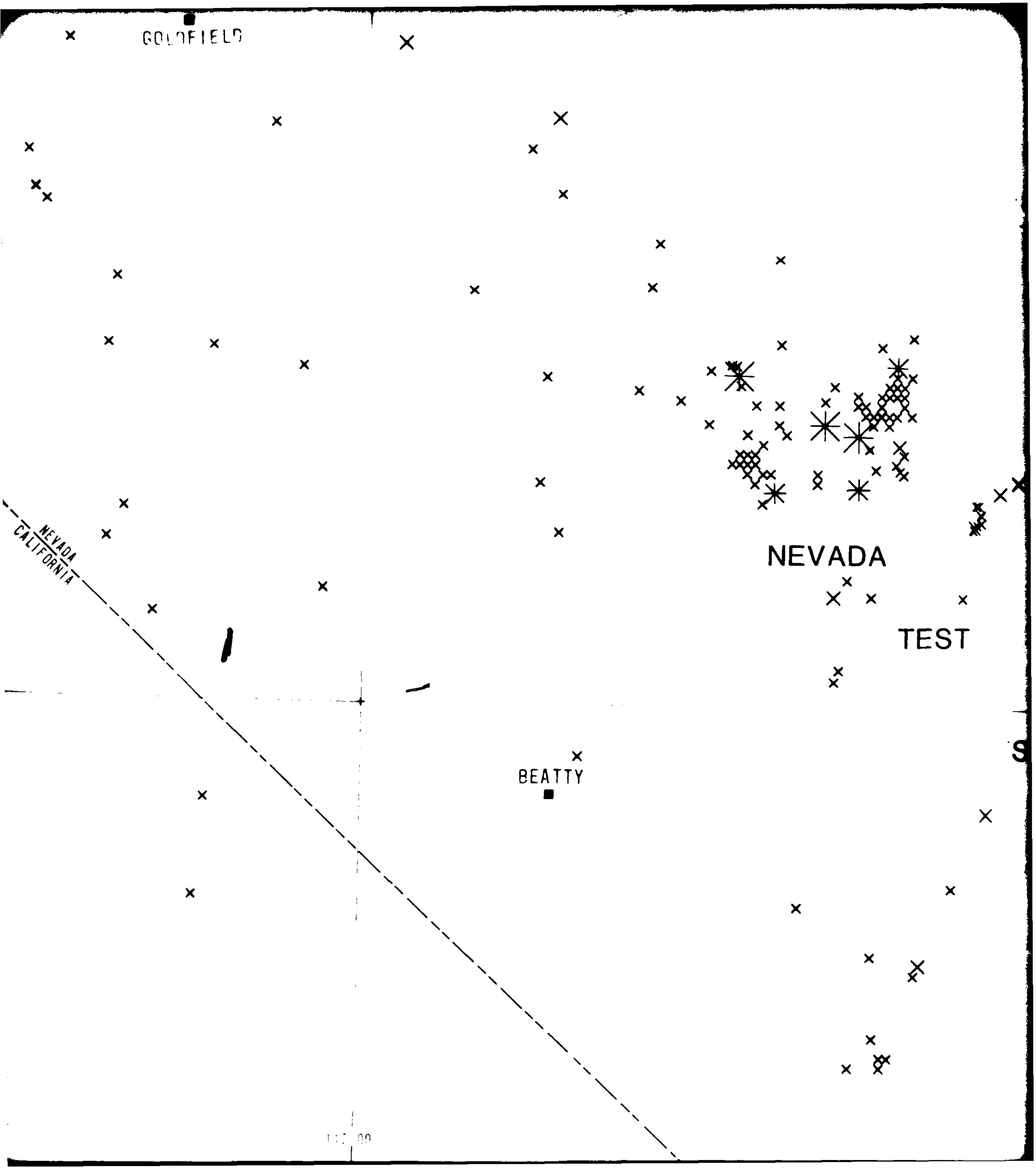


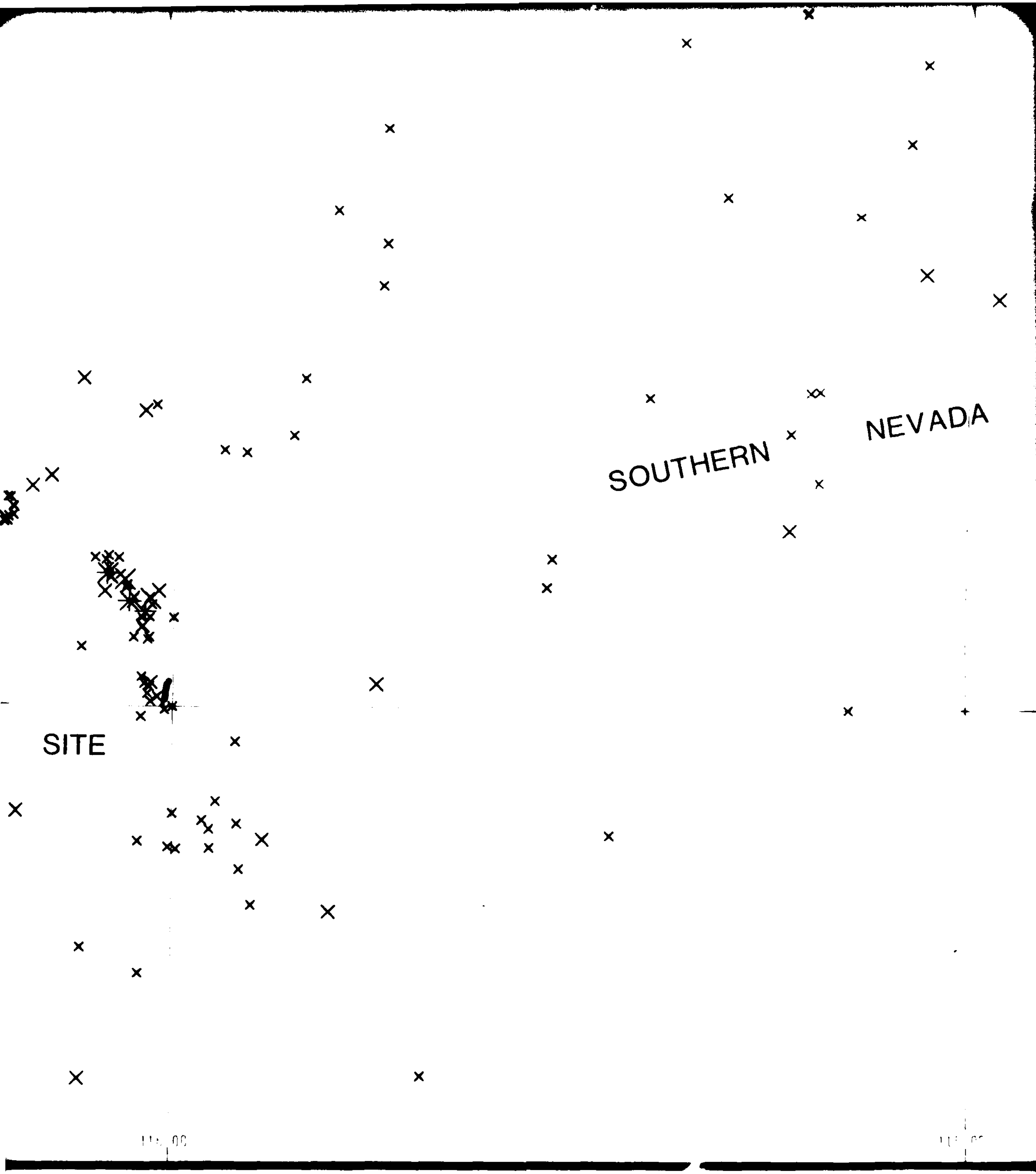
EXPLANATION

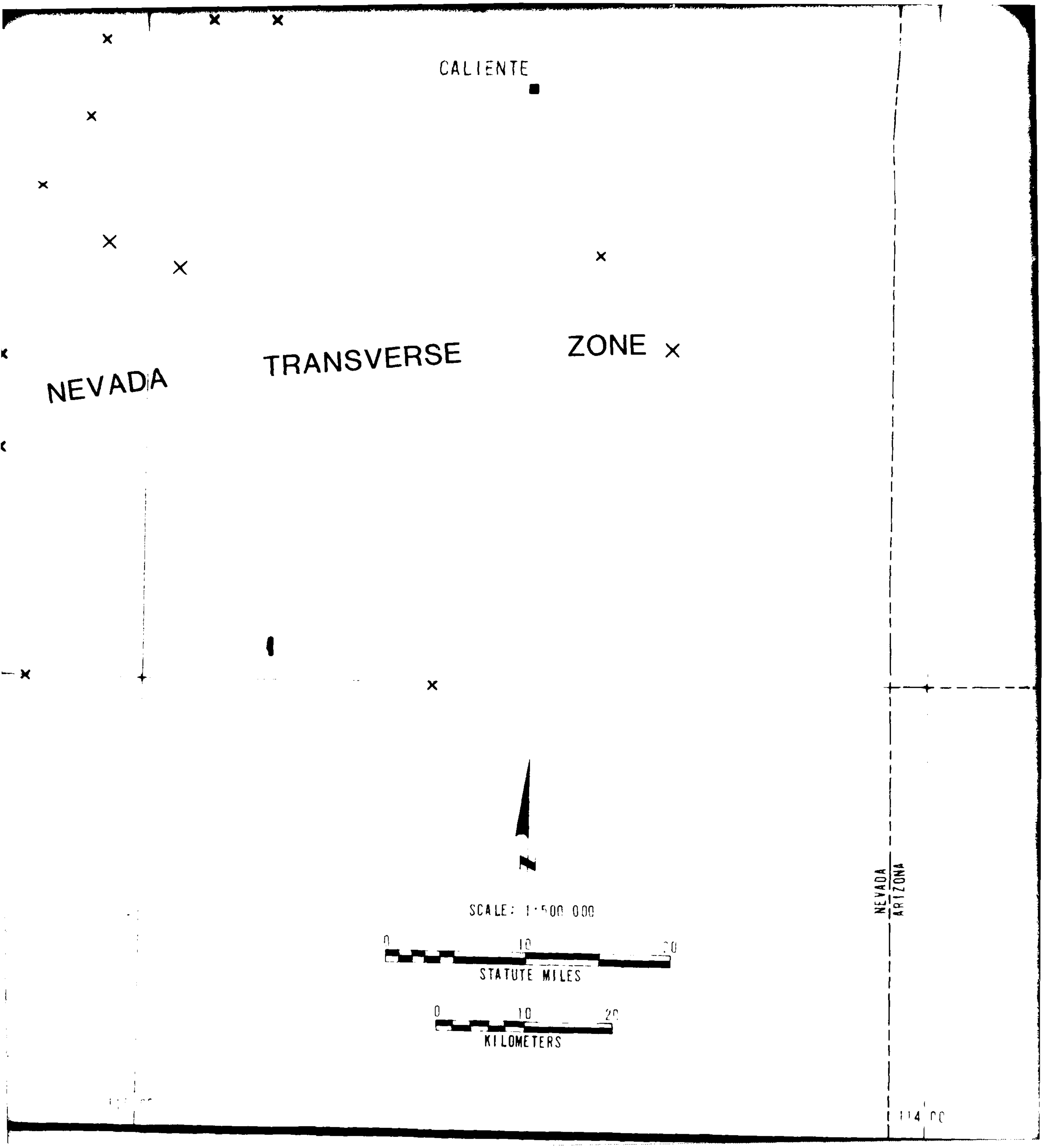

CEDAR CITY
ST GEORGE
UTAH
ARIZONA

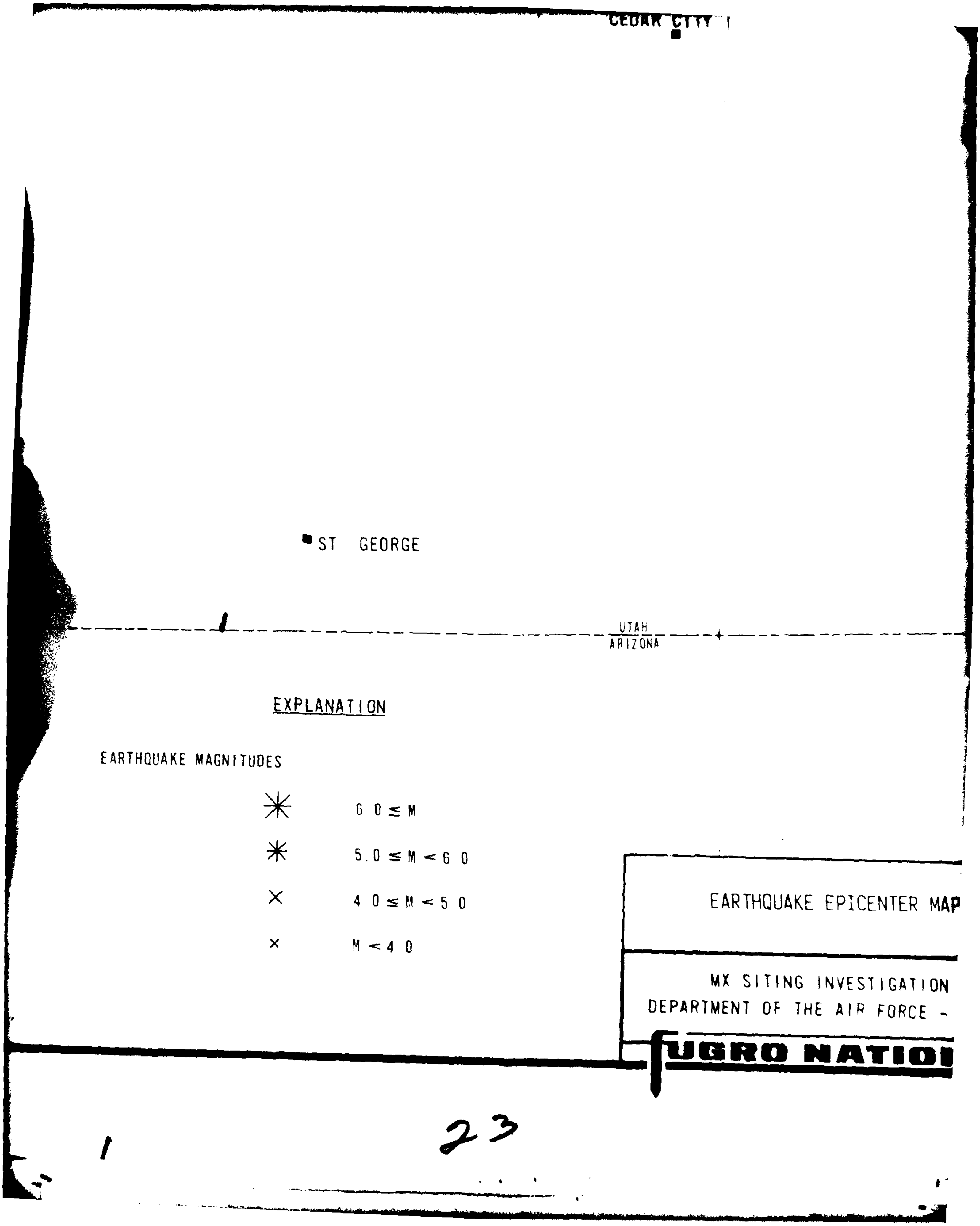


NEVADA
CALIFORNIA
37 00
118 00

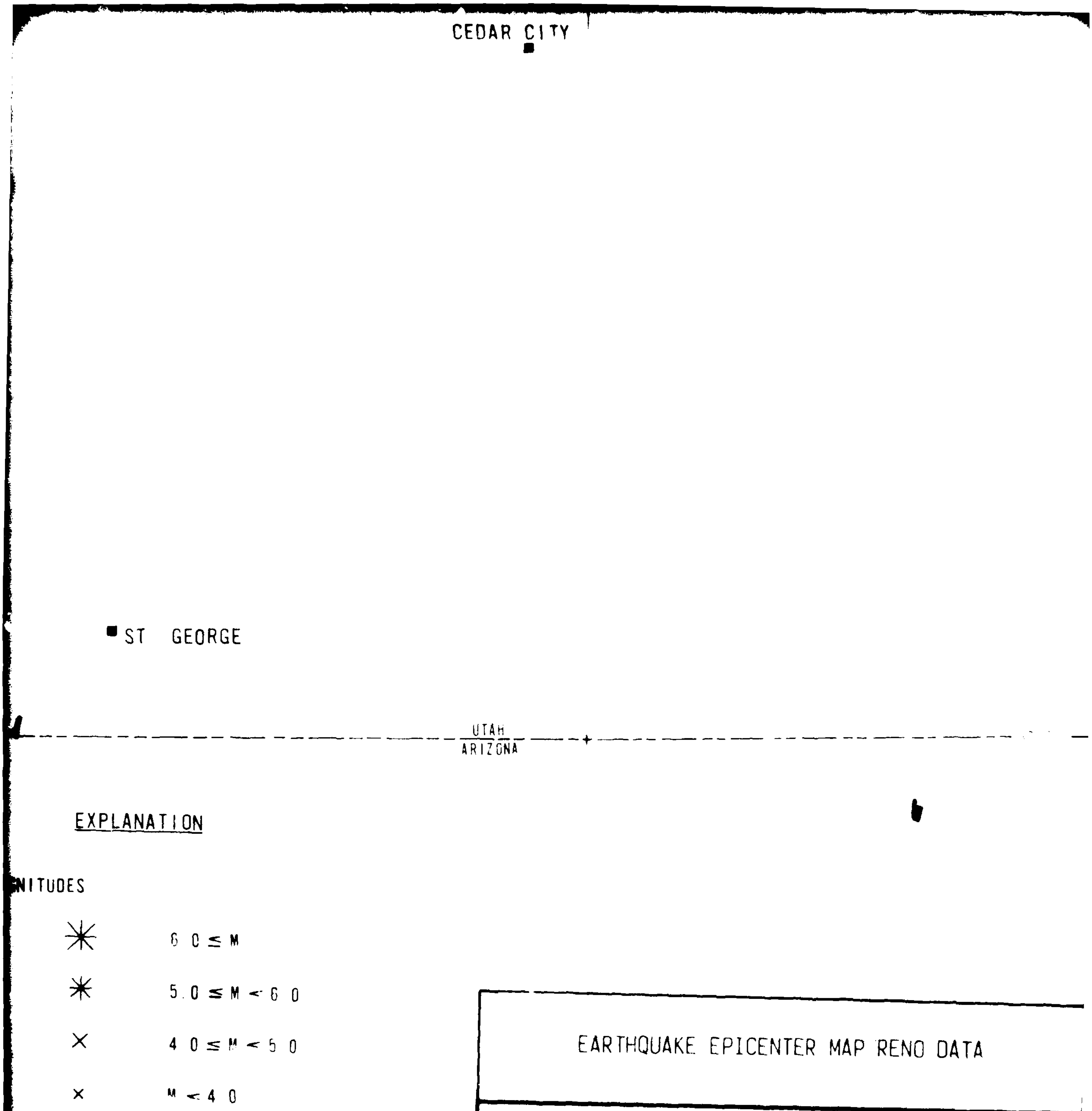

GOLDFIELD
NEVADA
CALIFORNIA
NEVADA
TEST
BEATTY
S


SOUTHERN NEVADA
SITE


CALIENTE
NEVADA TRANSVERSE ZONE
SCALE: 1:500 000
0 10 20
STATUTE MILES
0 10 20
KILOMETERS
NEVADA
ARIZONA
114 00


CEDAR CITY
ST GEORGE
UTAH
ARIZONA
EXPLANATION
EARTHQUAKE MAGNITUDES
6 0 ≤ M
5.0 ≤ M < 6 0
4 0 ≤ M < 5.0
M < 4 0
EARTHQUAKE EPICENTER MAP
MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE -
FUGRO NATIO

23

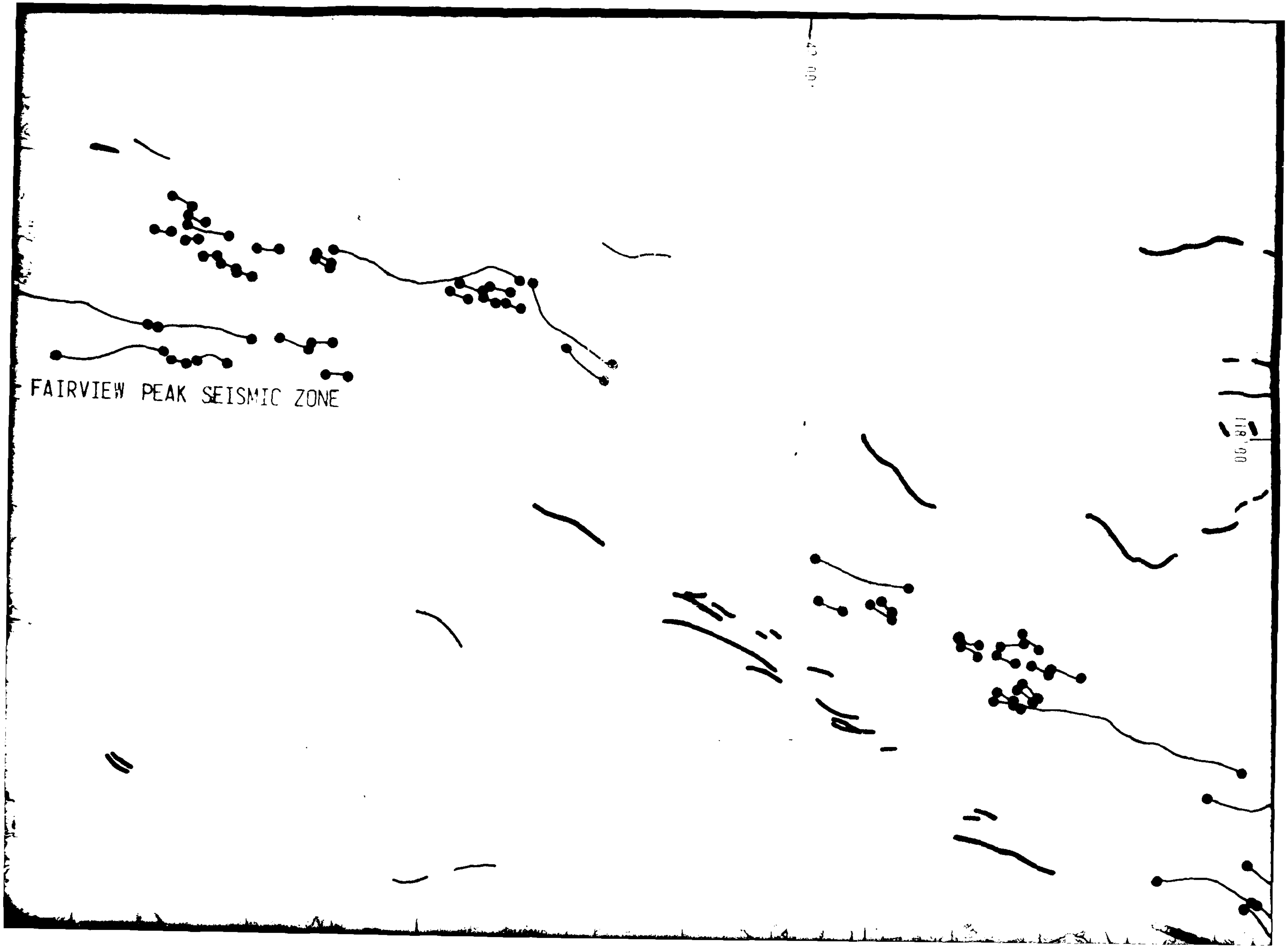


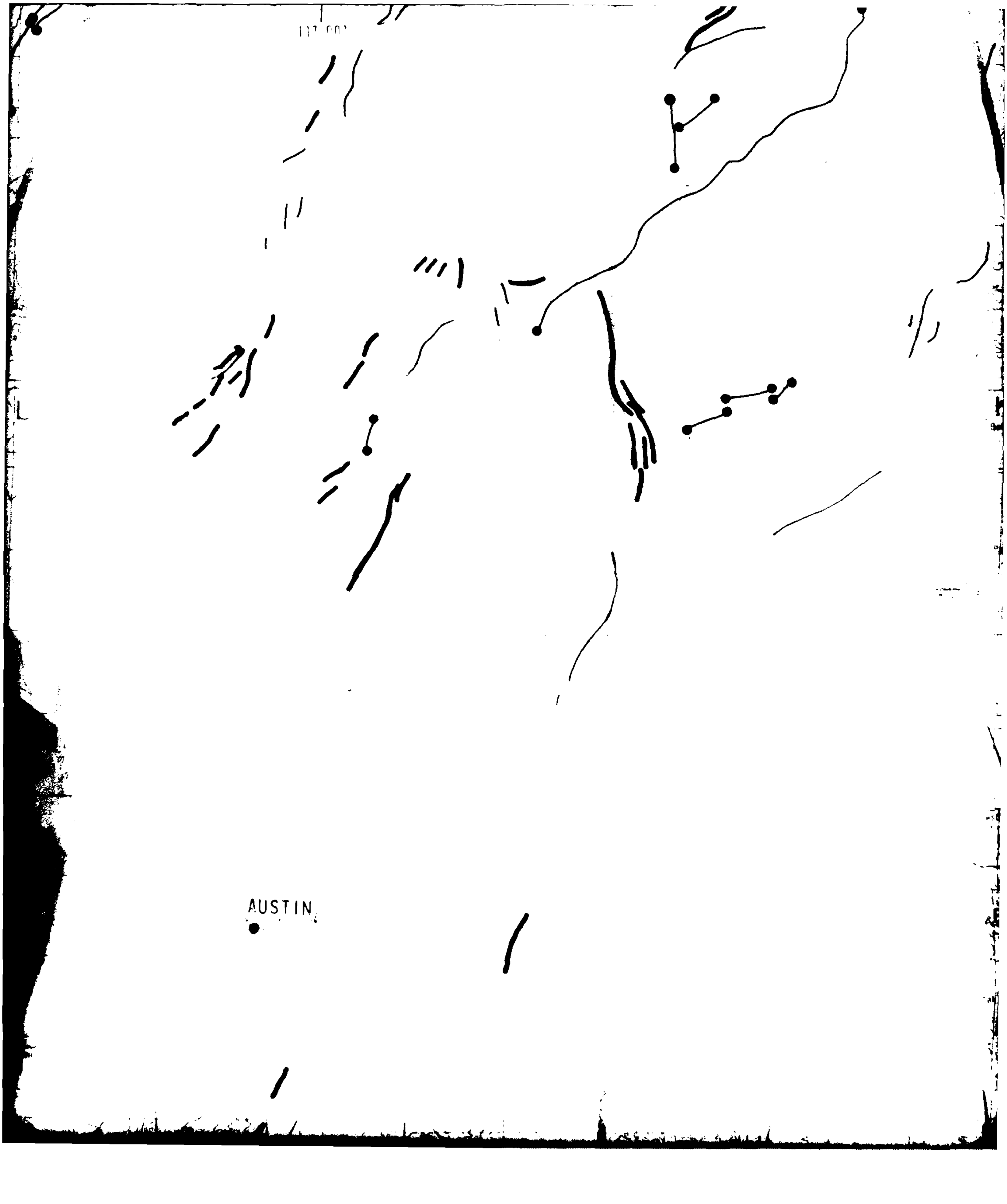
EARTHQUAKE EPICENTER MAP RENO DATA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - BMO

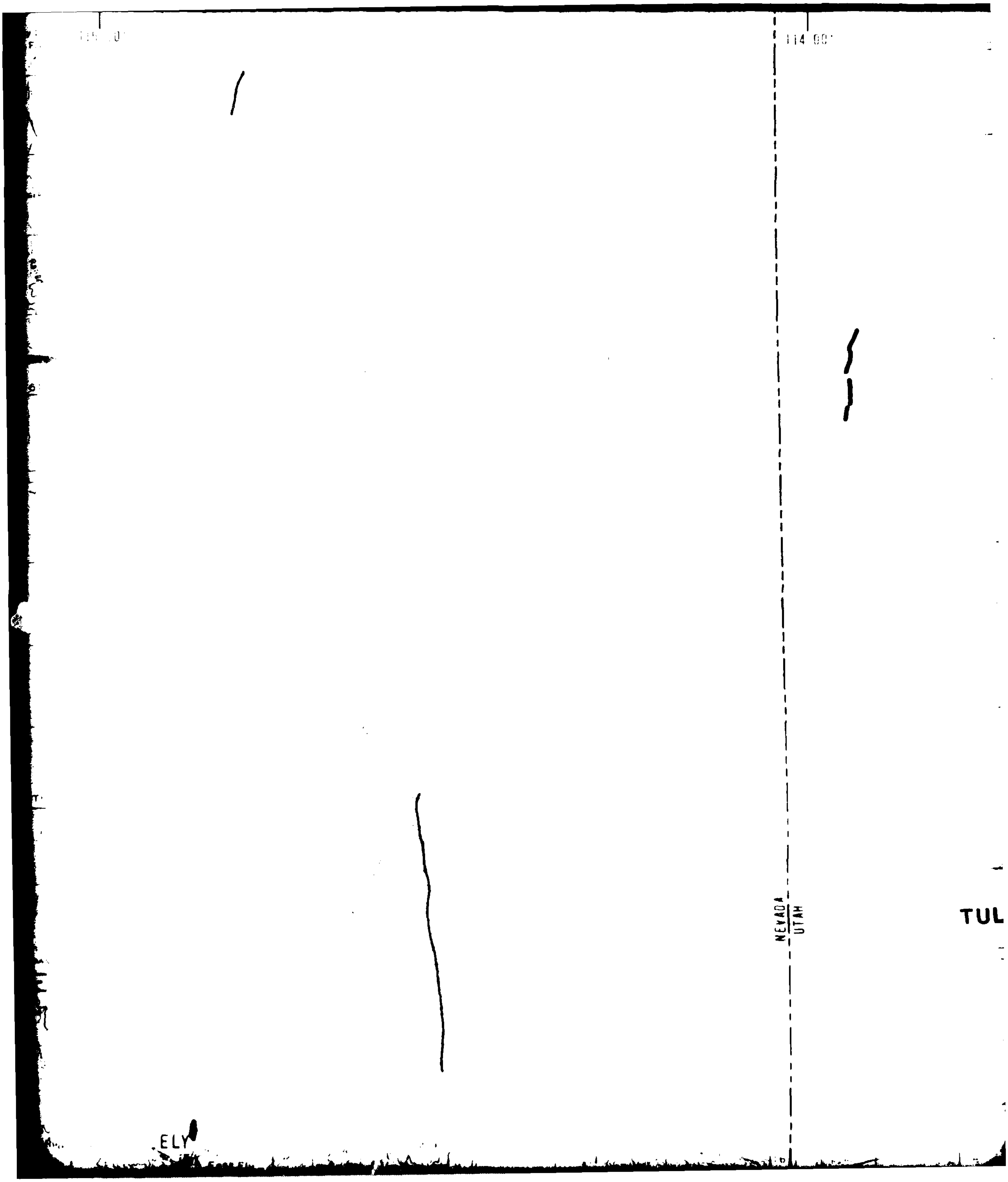
DRAWING 2-4

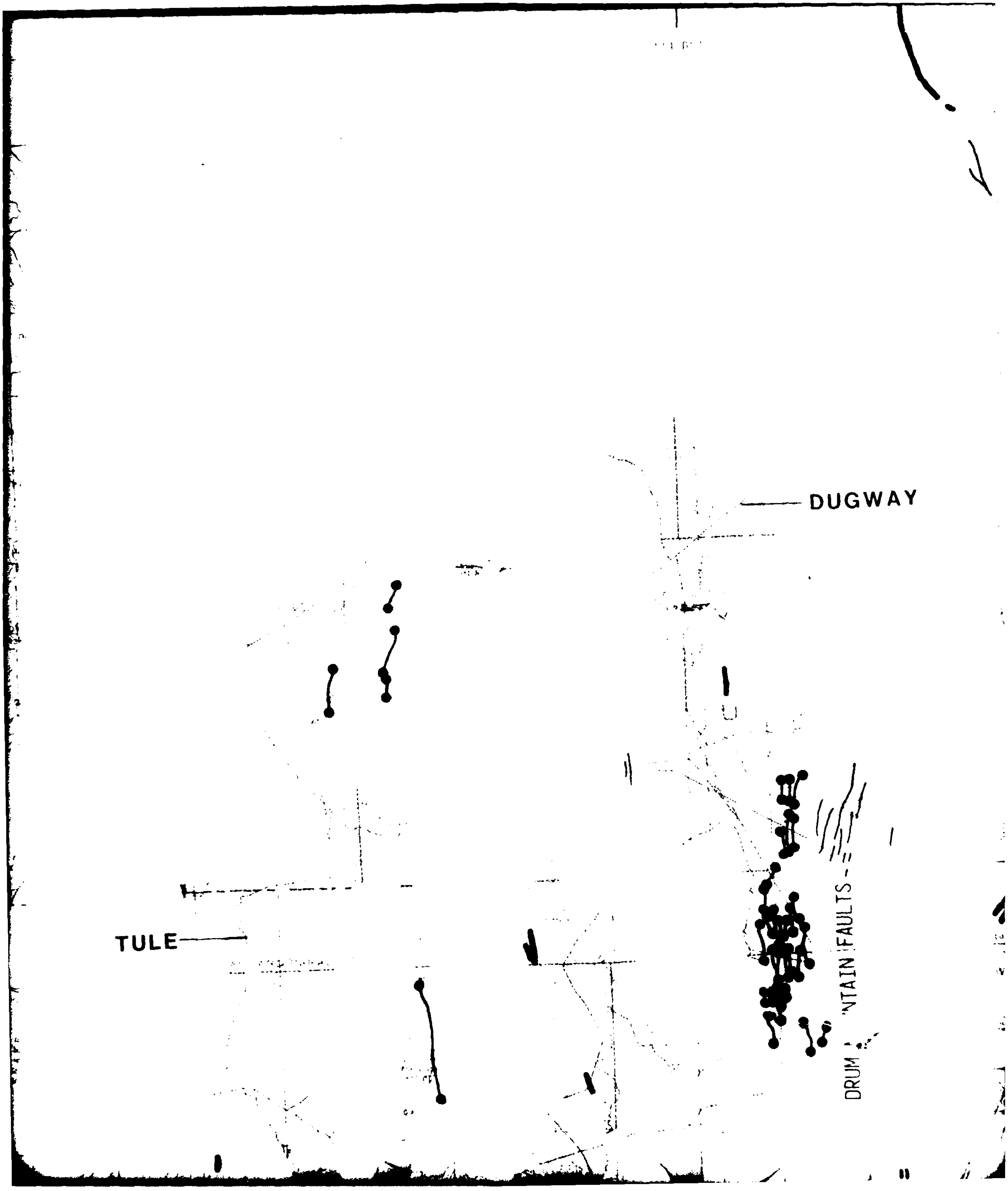
FUGRO NATIONAL, INC.

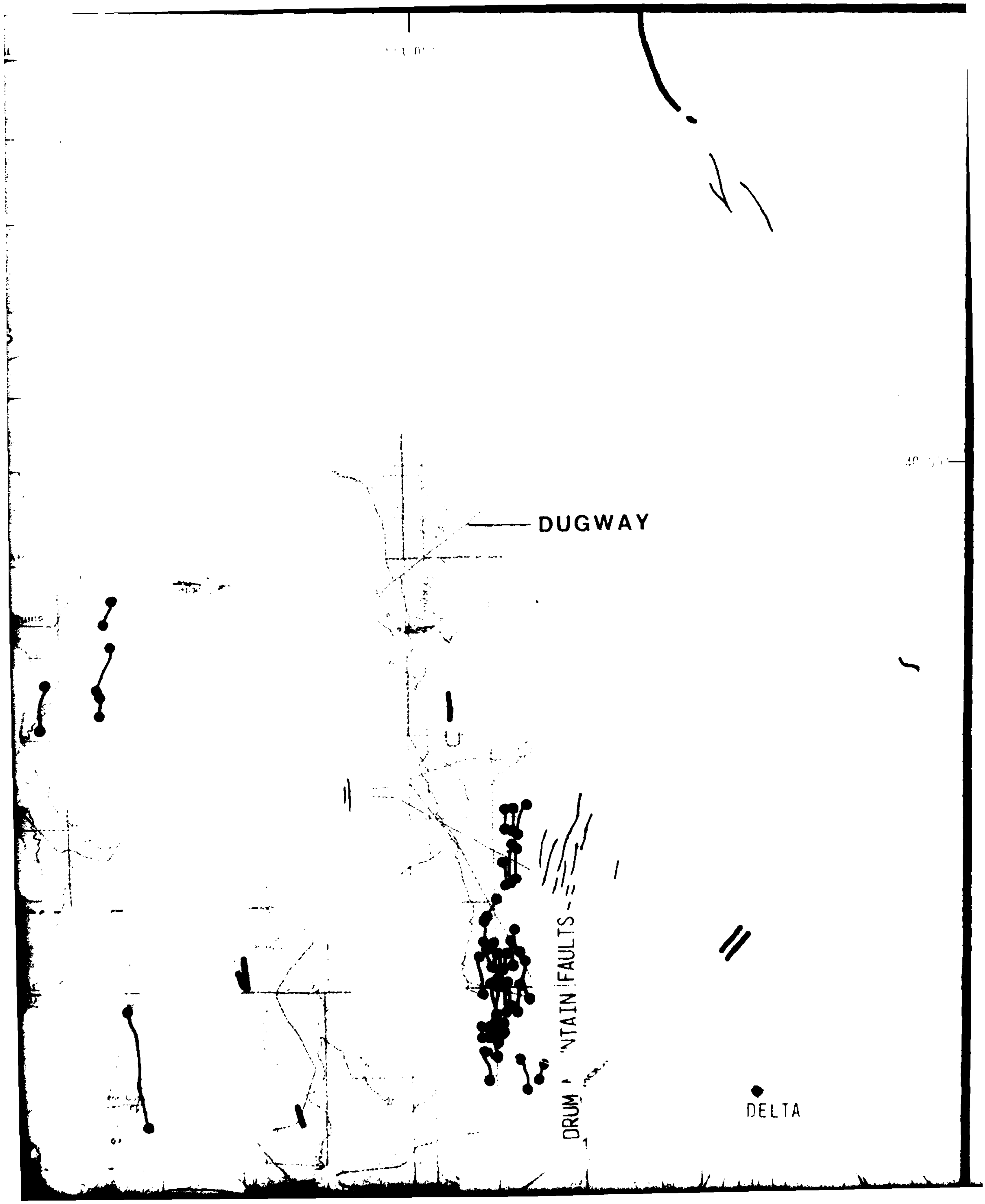

FAIRVIEW PEAK SEISMIC ZONE
118°00'


117 00'
AUSTIN

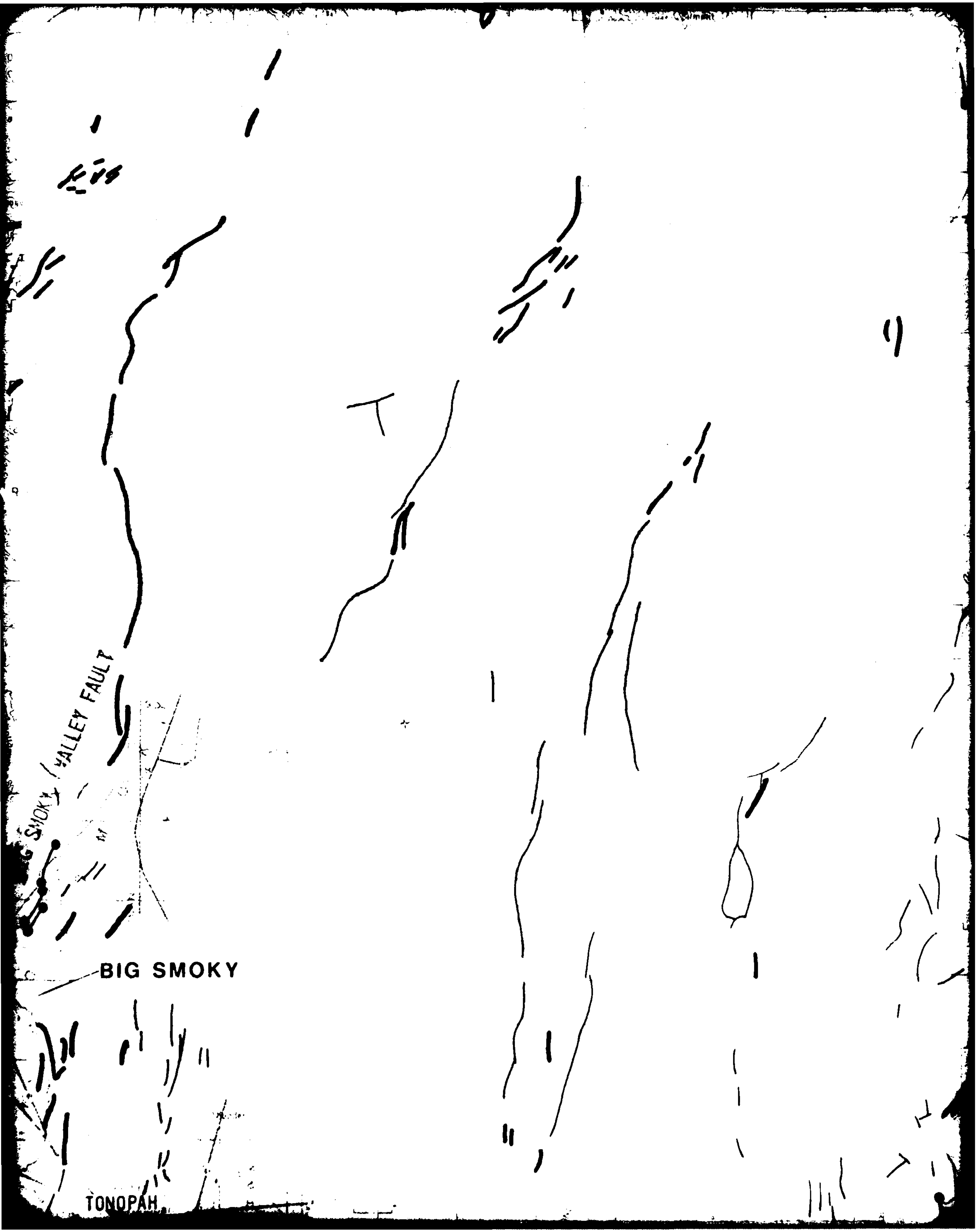
EUREKA

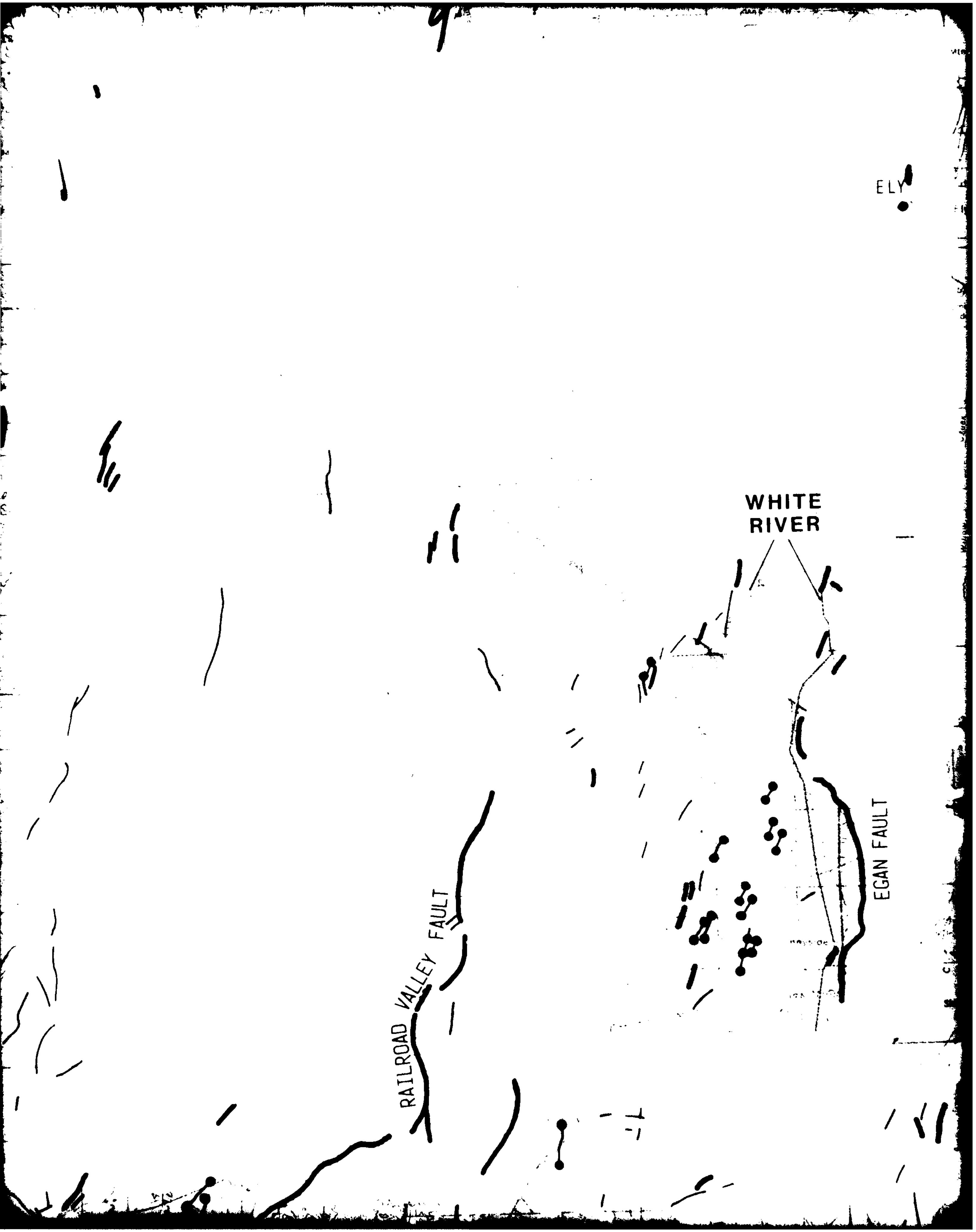

114°00'
NEVADA
UTAH
TUL
ELY

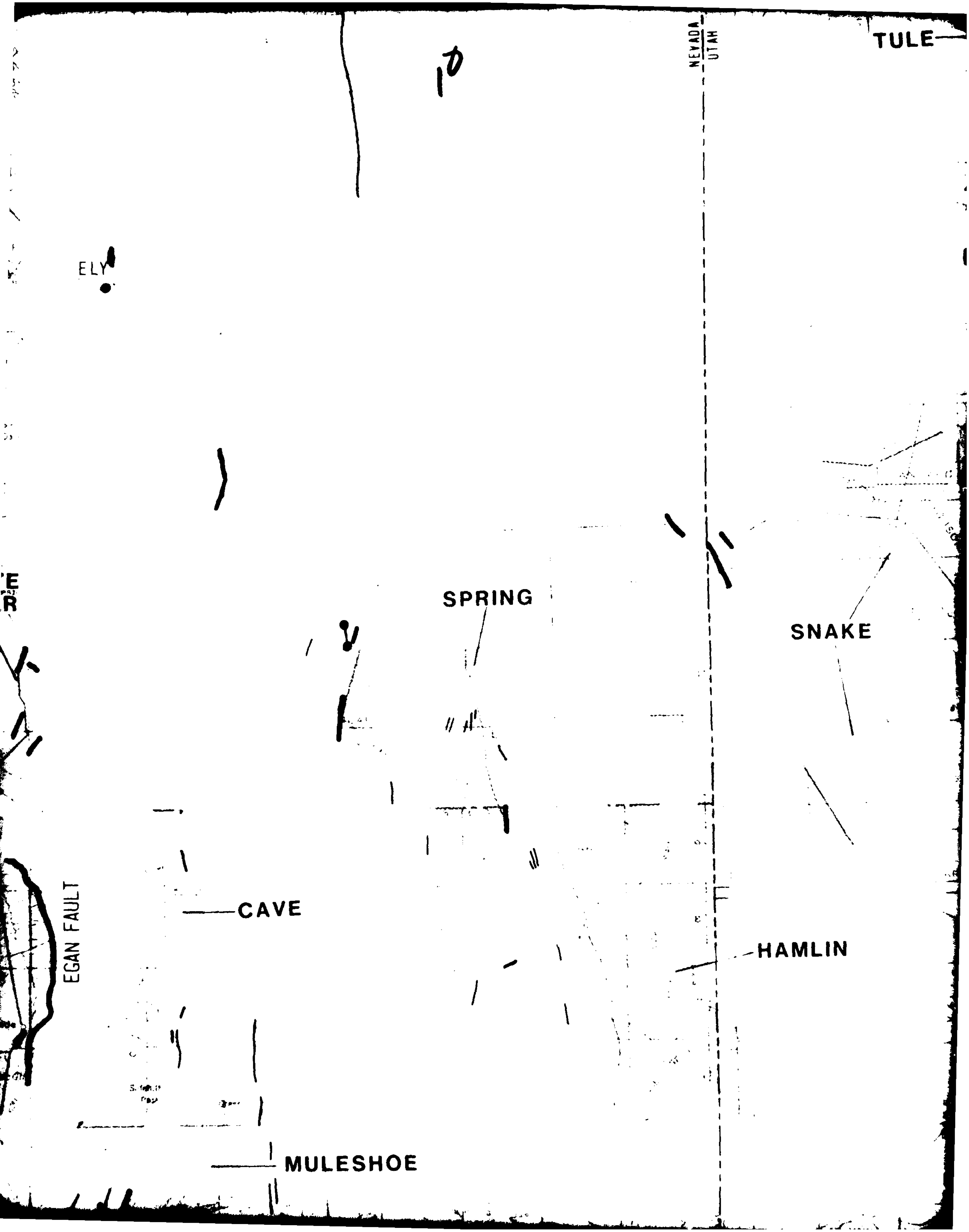

DUGWAY
TULE
DRUM MOUNTAIN FAULTS


DUGWAY
DRUM MOUNTAIN FAULTS
DELTA

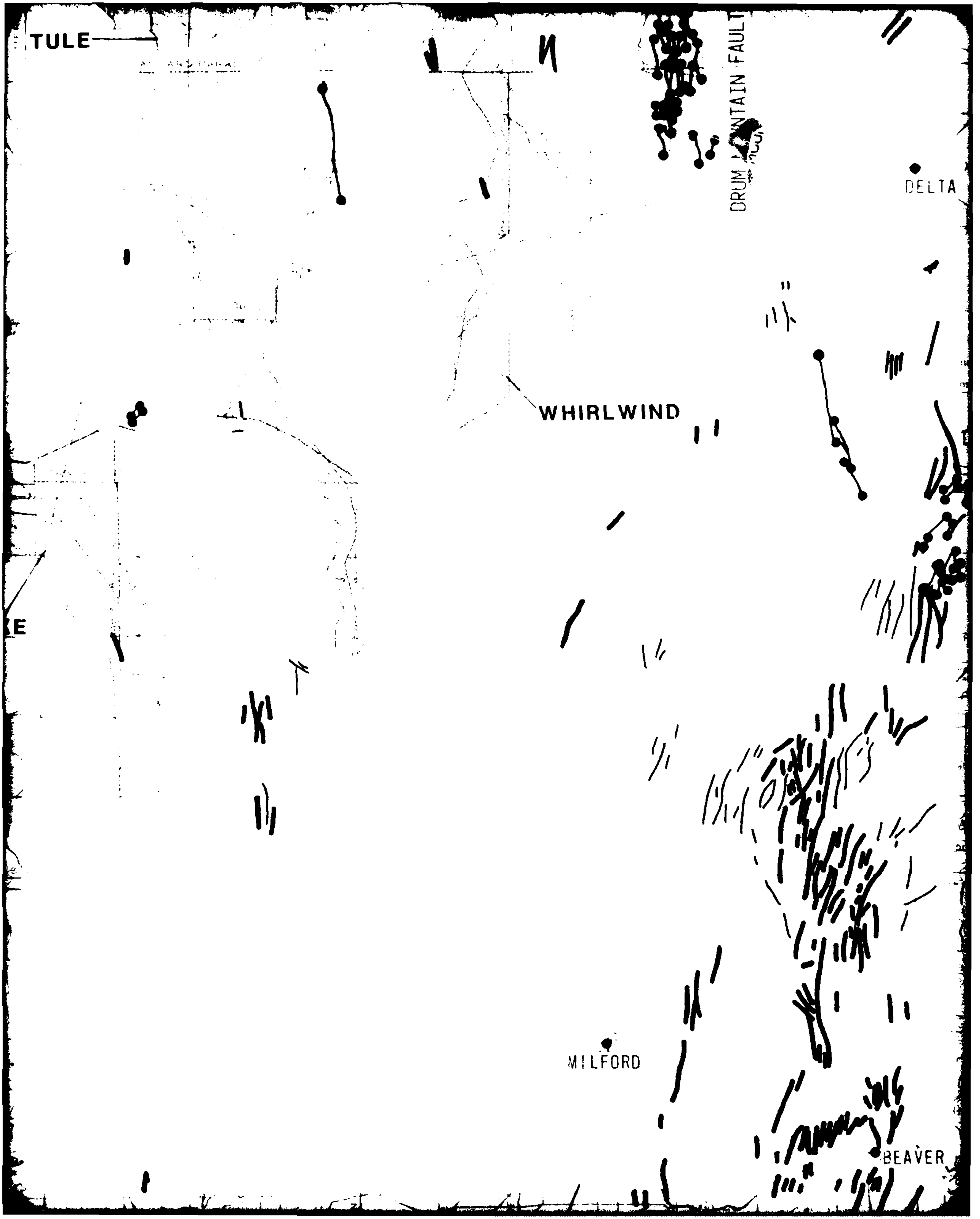

39 00'
DIXIE VALLEY- FAIRVIEW PEAK SEISMIC ZO
7
BIG

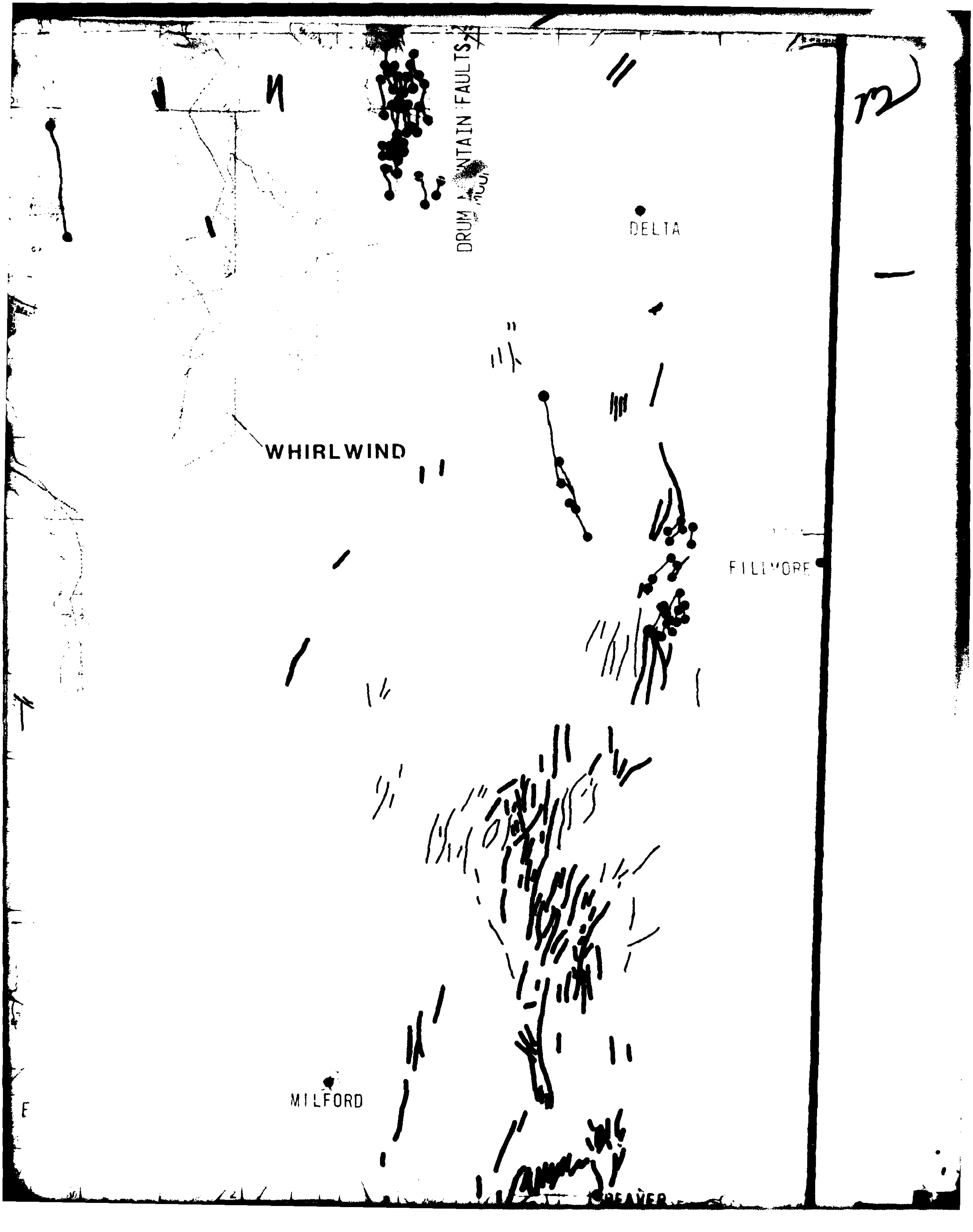

SMOKY VALLEY FAULT
BIG SMOKY
TONOPAH


ELY
WHITE RIVER
EGAN FAULT
RAILROAD VALLEY FAULT

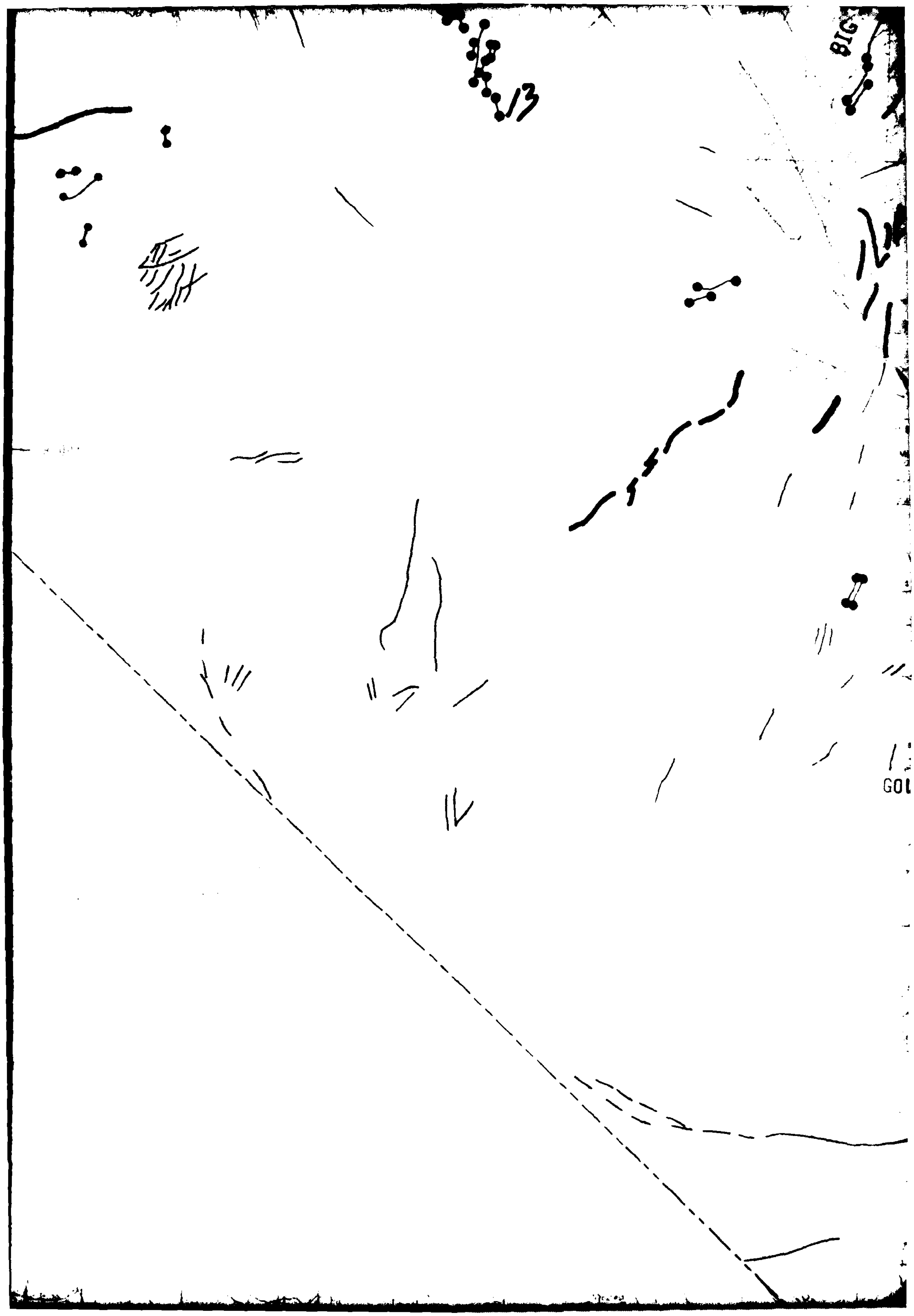


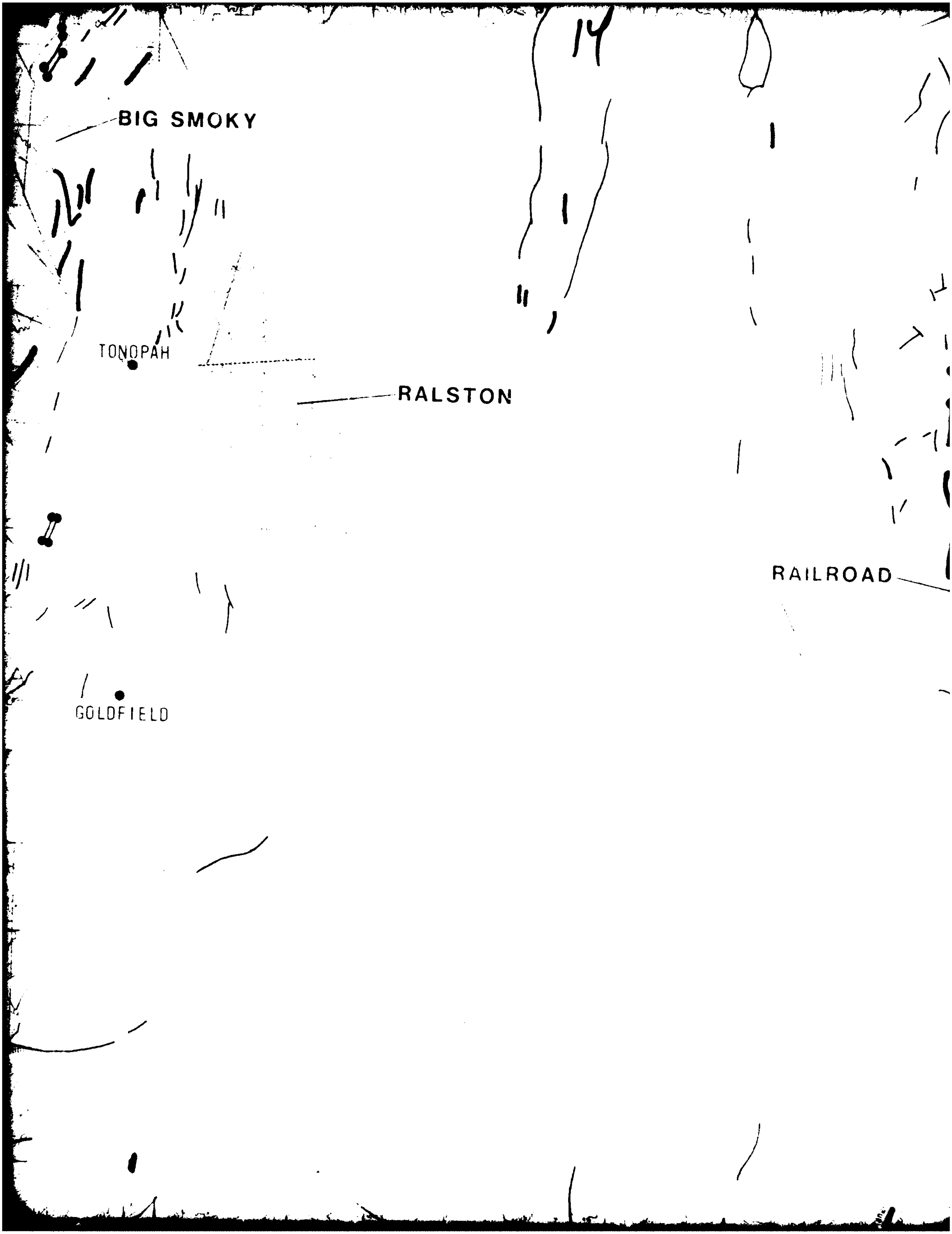
10
NEVADA
UTAH
TULE
ELY
SPRING
SNAKE
CAVE
EGAN FAULT
HAMLIN
MULESHOE

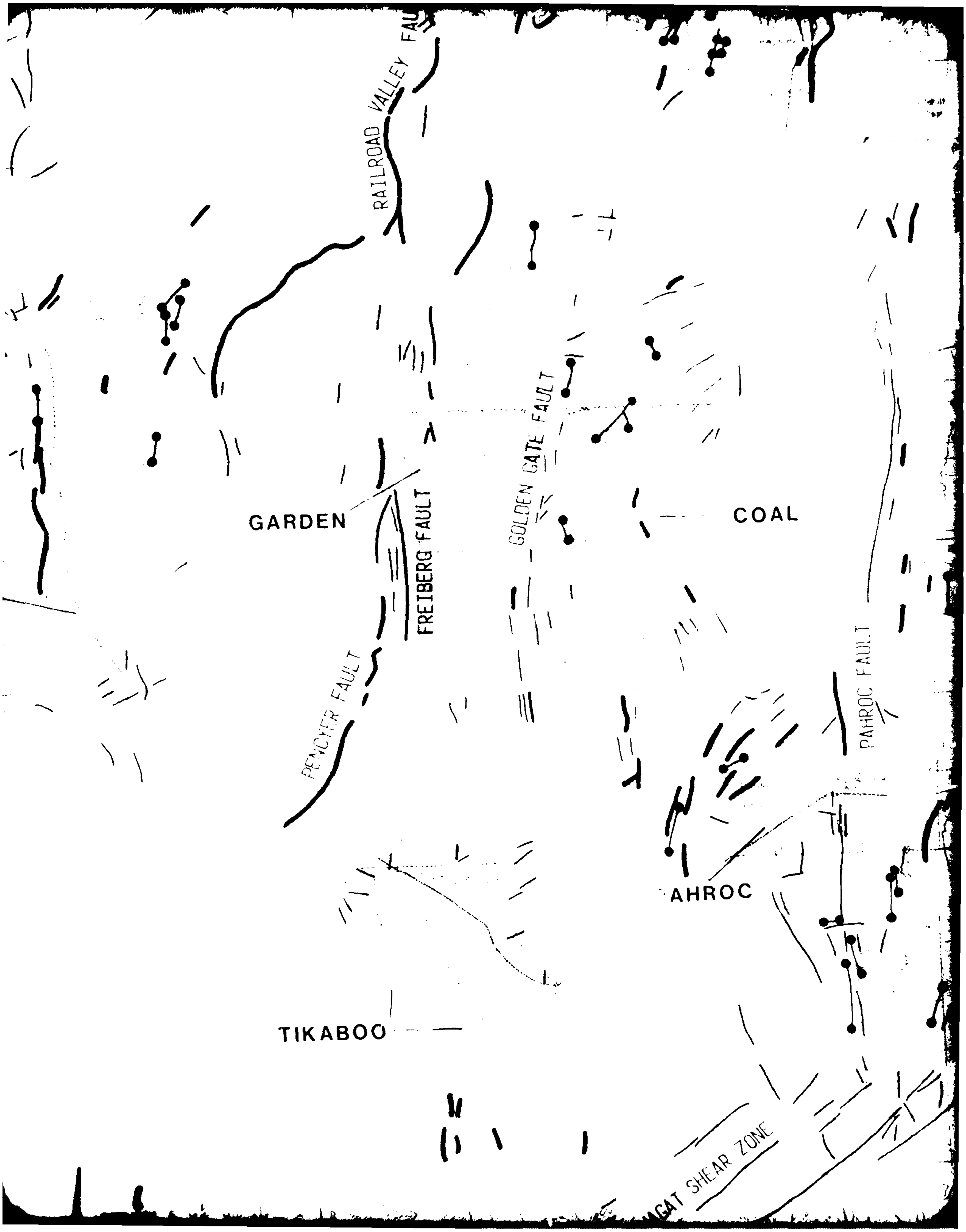

TULE
DELTA
WHIRLWIND
MILFORD
BEAVER

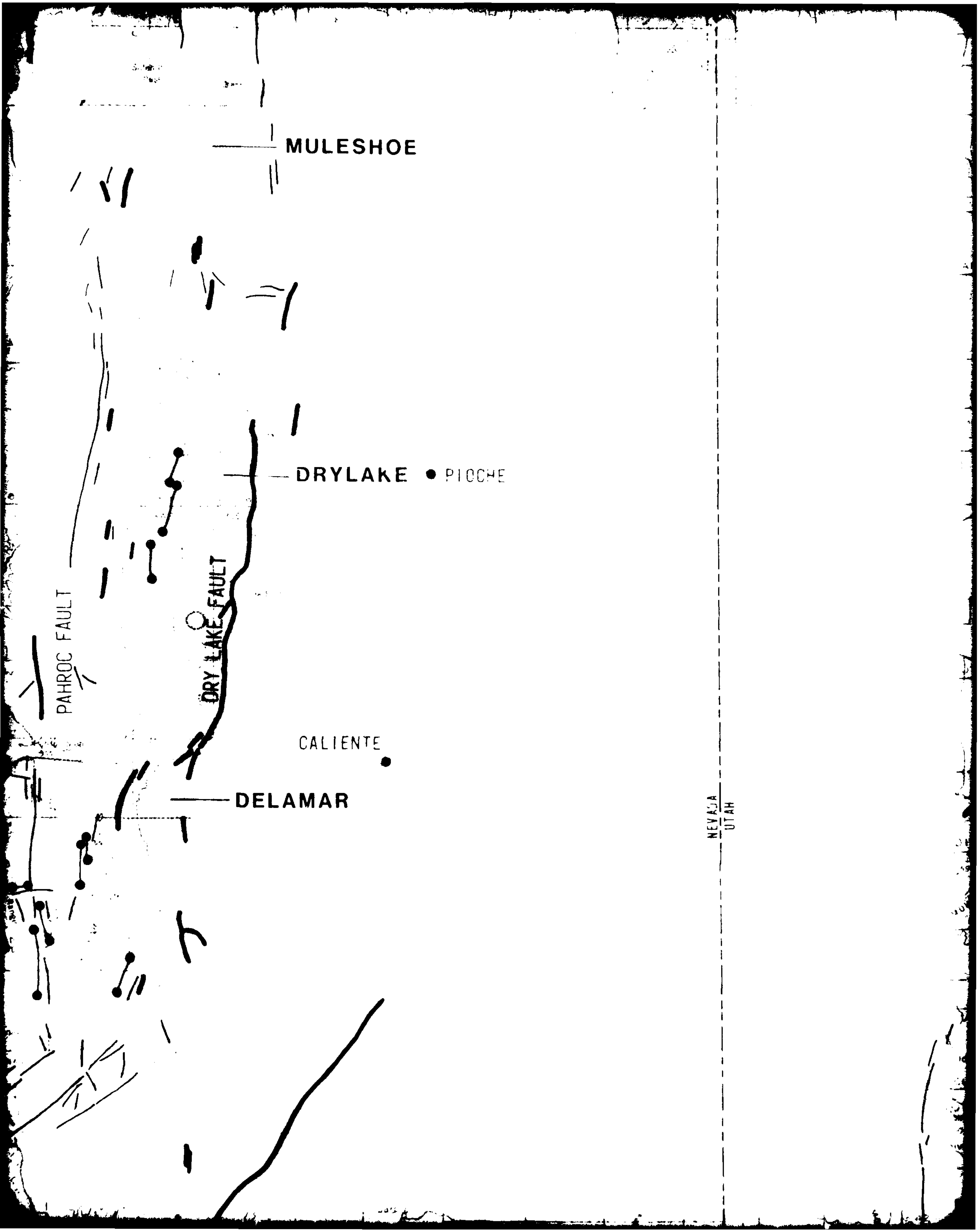


DRUM MOUNTAIN FAULTS
DELTA
WHIRLWIND
FILLMORE
MILFORD
BEAVER

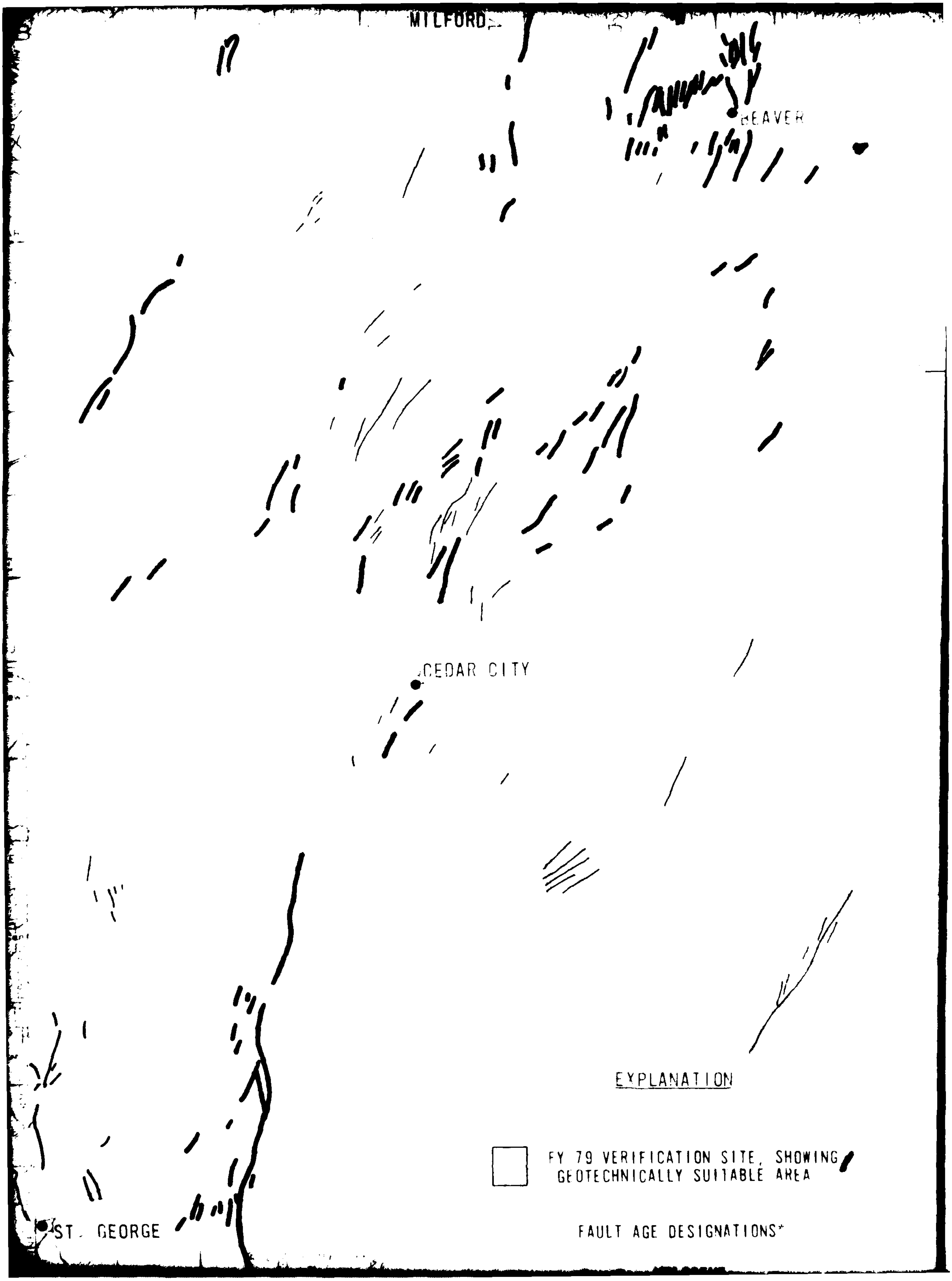

13
BIG
GOL

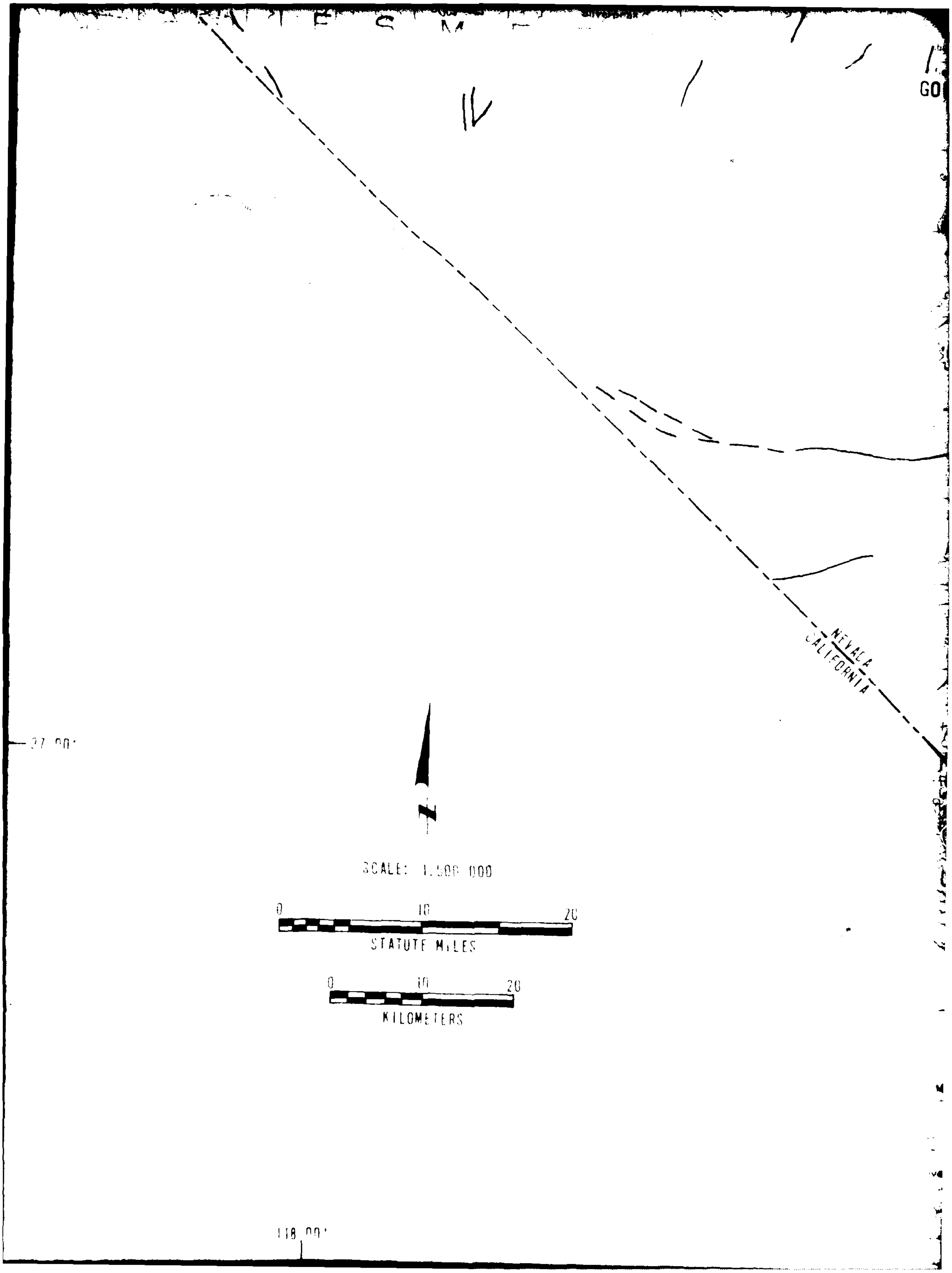

14
BIG SMOKY
TONOPAH
RALSTON
RAILROAD
GOLDFIELD


RAILROAD VALLEY FAU
GARDEN
FREIBERG FAULT
GOLDEN GATE FAULT
COAL
PENOYER FAULT
PAHROC FAULT
AHROC
TIKABOO
GAT SHEAR ZONE

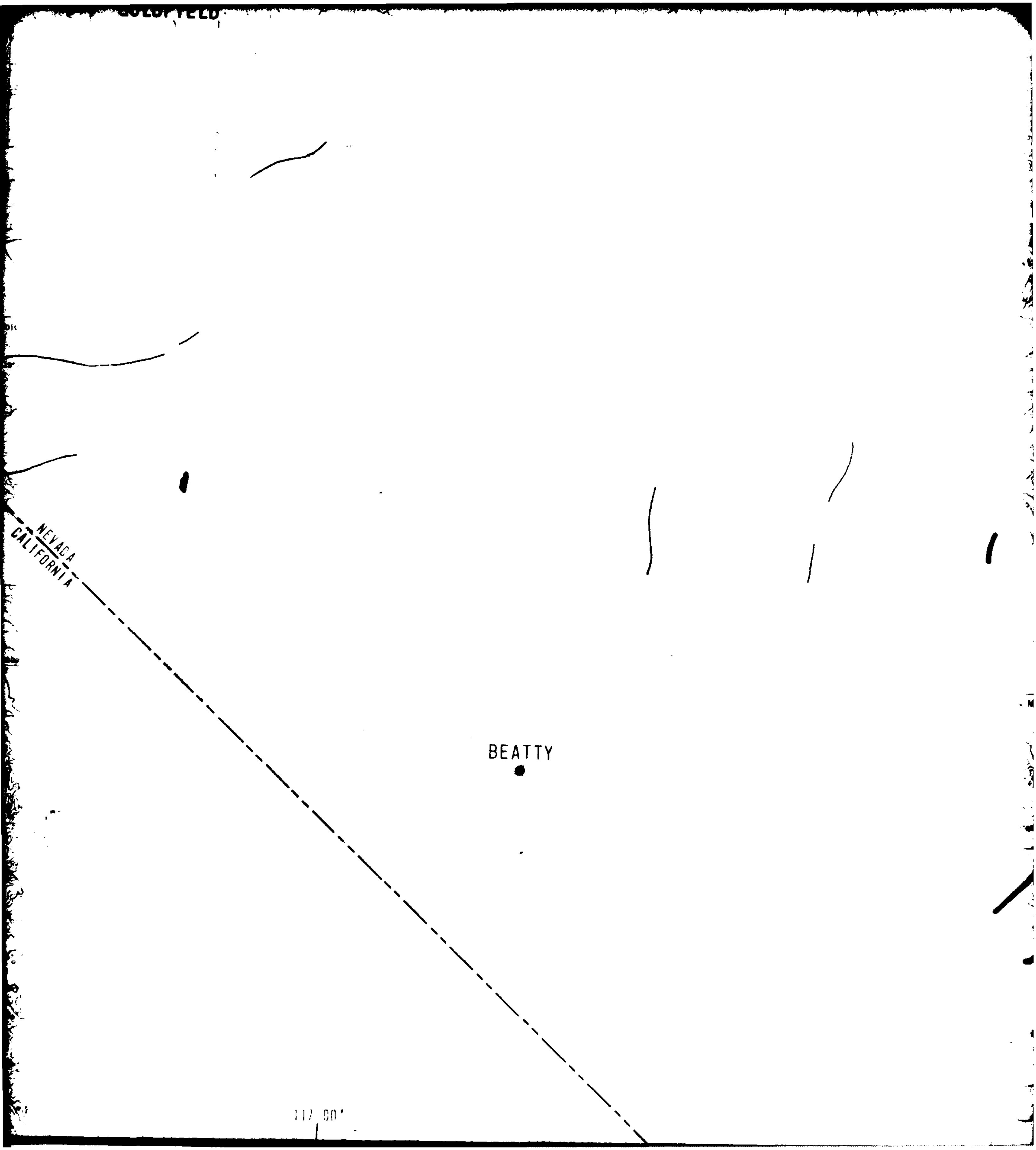

MULESHOE
DRYLAKE
PIOCHE
PAHROC FAULT
DRY LAKE FAULT
CALIENTE
DELAMAR
NEVADA
UTAH

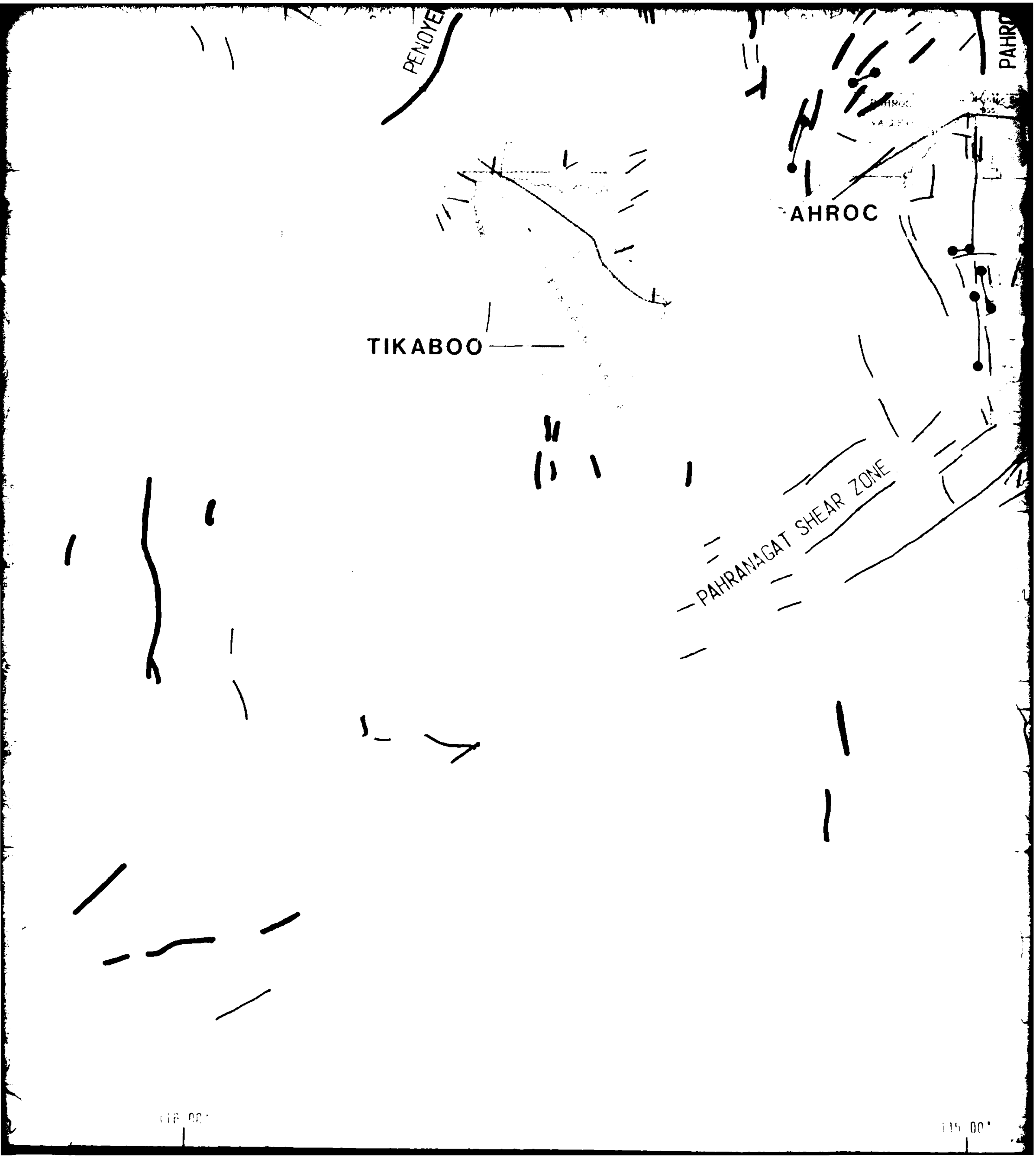

MILFORD
CEDAR CITY
EXPLANATION
FY 79 VERIFICATION SITE,
GEOTECHNICALLY SUITABLE

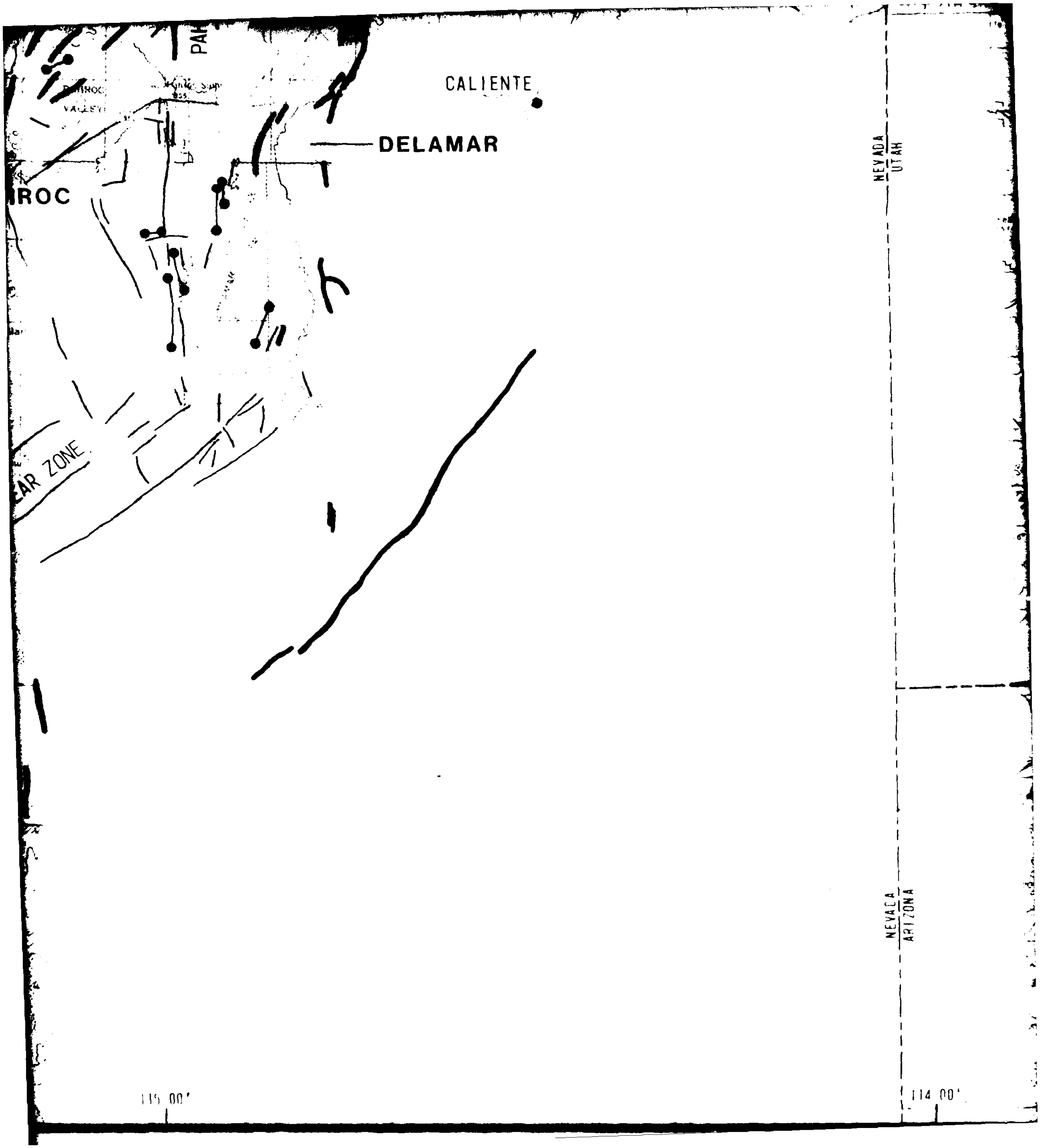

MILFORD
BEAVER
CEDAR CITY
ST. GEORGE
EXPLANATION
FY 79 VERIFICATION SITE, SHOWING GEOTECHNICALLY SUITABLE AREA
FAULT AGE DESIGNATIONS*

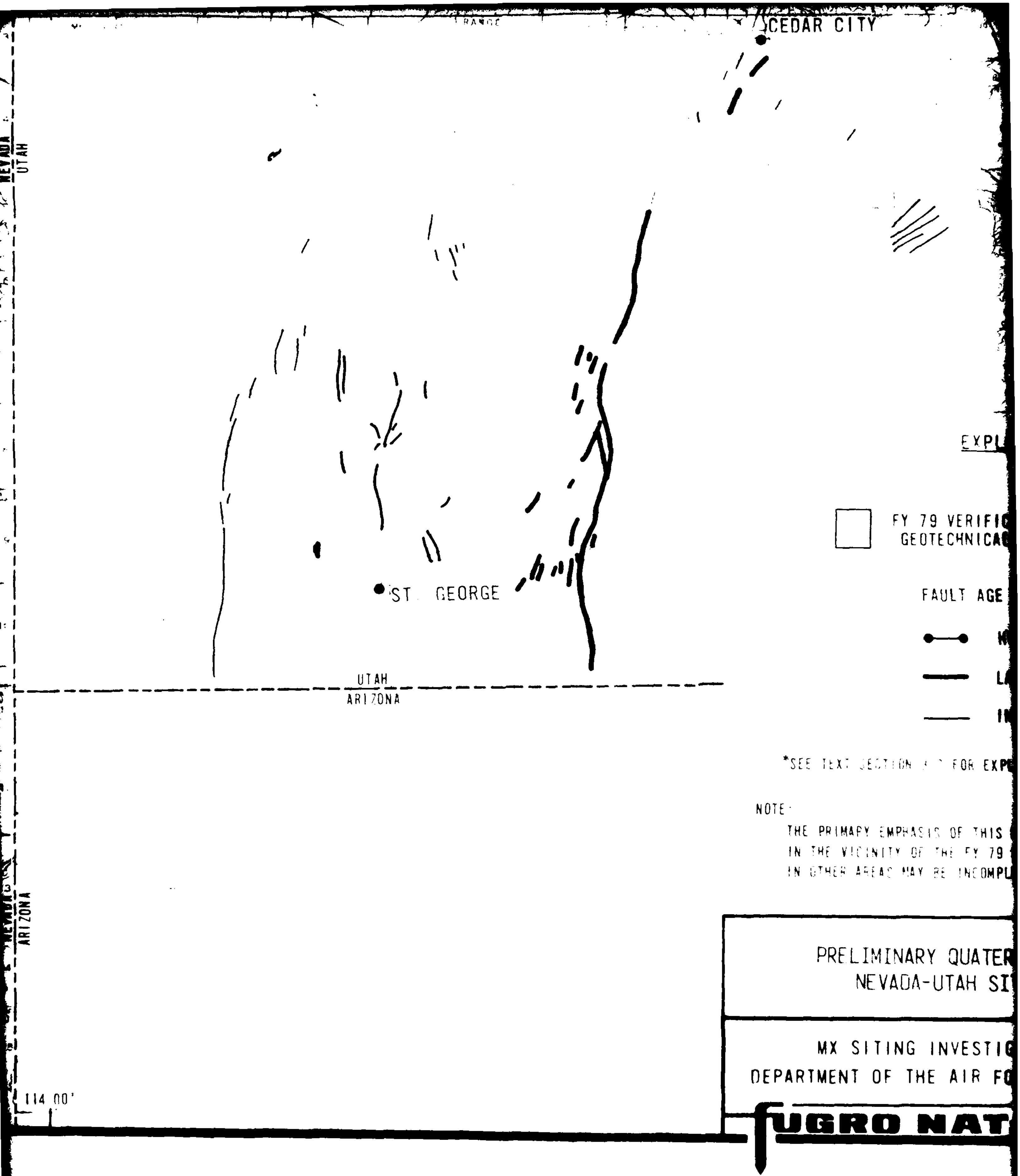


GO
NEVADA
CALIFORNIA
37 00'
SCALE: 1:500 000
0
10
20
STATUTE MILES
0
10
20
KILOMETERS
118 00'


GOLDFIELD
NEVADA
CALIFORNIA
BEATTY
117 00'

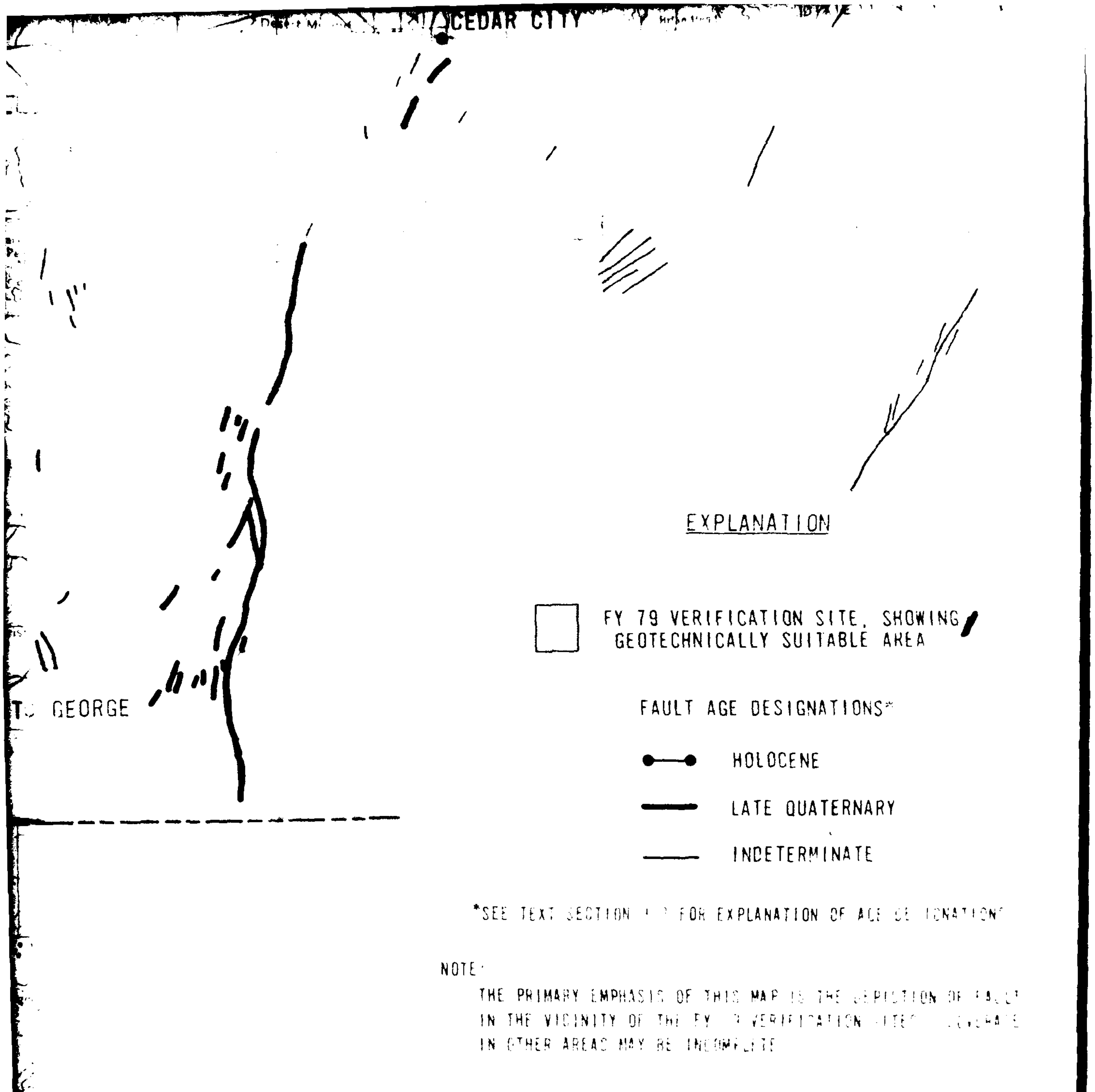

PENOYER
PAHRO
AHROC
TIKABOO
PAHRANAGAT SHEAR ZONE


CALIENTE
DELAMAR
ROC
AR ZONE
NEVADA
UTAH
NEVADA
ARIZONA
115 00'
114 00'


CEDAR CITY
NEVADA
UTAH
ST. GEORGE
UTAH
ARIZONA
NEVADA
ARIZONA
114 00'
EXPL
FY 79 VERIFIC
GEOTECHNICA
FAULT AGE
*SEE TEXT SECTION FOR EXP
NOTE:
THE PRIMARY EMPHASIS OF THIS
IN THE VICINITY OF THE FY 79
IN OTHER AREAS MAY BE INCOMPL
PRELIMINARY QUATER
NEVADA-UTAH SI
MX SITING INVESTIG
DEPARTMENT OF THE AIR FO
FUGRO NAT

1

23



PRELIMINARY QUATERNARY FAULT MAP
NEVADA-UTAH SITING REGION

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - BMO

DRAWING 3-1

FUGRO NATIONAL, INC.

ILMED

8