U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

Faults, Lineaments, And Earthquake Epicenters Digital Map Of The Pahute Mesa 30' X 60' Quadrangle, Nevada

By

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Open-File Report 96-262

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1996

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INTRODUCTION

This map database, identified as *Faults, lineaments, and earthquake epicenters digital map of the Pahute Mesa 30' X 60' quadrangle, Nevada*, has been approved for release and publication by the Director of the USGS. Although this database has been subjected to rigorous review and is substantially complete, the USGS reserves the right to revise the data pursuant to further analysis and review. Furthermore, it is released on condition that neither the USGS nor the United States Government may be held liable for any damages resulting from its authorized or unauthorized use.

This digital map compilation incorporates fault, air photo lineament, and earthquake epicenter data from within the Pahute Mesa 30' by 60' quadrangle, southern Nye County, Nevada (fig. 1). The compilation contributes to the U.S. Department of Energy's Yucca Mountain Project, established to determine whether or not the Yucca Mountain site is suitable for the disposal of high-level nuclear waste. Studies of local and regional faulting and earthquake activity, including the features depicted in this compilation, are carried out to help characterize seismic hazards and tectonic processes that may be relevant to the future stability of Yucca Mountain. The Yucca Mountain site is located in the central part of the Beatty 30' by 60' quadrangle approximately 15 km south of the south edge of the Pahute Mesa quadrangle (fig. 1). The U.S. Geological Survey participates in studies of the Yucca Mountain site under Interagency Agreement DE-AI08-78ET44802.

The map compilation is *only* available *on line* as a digital database in ARC/INFO ASCII (Generate) and export formats. The database can be downloaded via 'anonymous ftp' from a USGS system named greenwood.cr.usgs.gov (136.177.48.5). The files are located in a directory named /pub/open-file-reports/ofr-96-0262. This directory contains a text document named 'README.1ST' that contains database technical and explanatory documentation, including instructions for uncompressing the bundled (tar) file. In displaying the compilation it is important to note that the map data set is considered accurate when depicted at a scale of about 1:100,000; displaying the compilation at scales significantly larger than this may result in distortions and (or) mislocations of the data.

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DIGITAL COMPILATION METHODS

Details and significance of fault, lineament, and seismicity data used in the current compilation are described in following sections. Each type of data was digitized differently: (1) most fault data were imported from previous 1:100,000-scale digital geologic compilations covering the Pahute Mesa quadrangle (Minor and others, 1993; Sawyer and others, 1995); (2) a few supplemental (newly acquired) fault lines were hand digitized within the GIS program indicated below; (3) selected lineaments originally mapped by Reheis (1992) were hand digitized using GSMAP (Selner and Taylor, 1993); and (4) seismicity data point coordinates were read directly from ASCII tables modified from reported seismicity catalogs (Meremonte and Rogers, 1987; D. Vonseggern, Univ. of Nevada, Reno, digital commun., 1995). A non-edited digital base map of the Pahute Mesa 30' x 60' quadrangle, which is included with the data files, was obtained by scanning and vectorizing a stable-base copy of the published U.S. Geological Survey 1:100,000-scale base map. Geographic Resource Analysis Support System (GRASS), a public domain GIS developed by the U.S. Army Corps of Engineers, was used to transform all new component data to Universal Transverse Mercator projections, merge data in the appropriate map layers, hand digitize supplemental line data, conduct final editing and modification of map elements, and assign attributes to map line elements. Finally, GRASS was used to convert the data layers to ARC/INFO ASCII and export files.

FAULTS

Most of the faults shown on this map are depicted on the previously released, 1:100,000-scale digital geologic compilations of the Pahute Mesa quadrangle (Minor and others, 1993) and the Nevada Test Site (NTS) area (Sawyer and others, 1995). The fault data used to compile these earlier maps were derived predominantly from published geologic maps at scales ranging from 1:24,000 to 1:100,000 (see Minor and others, 1993, and Sawyer and others, 1995 for specific sources of data). These published data were augmented by: (1) Quaternary fault map data along the western front of the Belted Range (fig. 1) published a in a recent Yucca Mountain Project report by Anderson and others (1995), and (2) recent mapping in the western third of the quadrangle (S.A. Minor, unpublished data, 1995) and on Pahute Mesa (H.R. Covington, U.S. Geological Survey, written commun., 1995). Because some of the original source maps at scales larger than 1:100,000 (for example, 1:24,000 scale) depict a relatively high density of faults or faults of insignificant stratigraphic separation or trace length, it was necessary in several areas (notably the Timber Mountain area, fig. 1) to omit some of the smaller faults for graphic clarity at 1:100,000 scale. However, faults that uniquely demonstrate significant age or geometric relations were retained regardless of fault density or size.

No tectonic faults having demonstrable evidence of Quaternary rupture were eliminated from the data base. Faults classified as Quaternary in age on this compilation were shown on source maps as cutting Quaternary deposits. Quaternary activity is **not** precluded, however, on faults that do not cut Quaternary deposits. Rather, a Quaternary fault designation indicates **known** Quaternary activity.

The present compilation distinguishes faults that ruptured naturally during the Quaternary (i.e., tectonic faults) from faults that ruptured historically in response to nuclear weapons testing at the Nevada Test Site. Also distinguished are faults with known natural Quaternary movement that have been reactivated in response to nuclear weapons testing. Surface ruptures resulting from nuclear weapons tests were compiled from maps by Maldonado (1977a, b) and Covington (1987) supplemented by more recent unpublished mapping by H.R. Covington (U.S. Geological Survey, written commun., 1995).

Short ruptures formed in collapse sinks at the surface above blast sites have been omitted in this compilation because, at the map scale, they are nearly illegible and are unlikely to provide any valuable information about regional fault or stress patterns. Many other localized fractures in surficial deposits, soils, and prepared surfaces in the vicinities of the blast centers that resulted from test effects have also been omitted for similar reasons. Some test-induced faults shown on the present compilation formed in response to movement along older concealed faults reactivated by nuclear blasts and thus may not reflect contemporary regional fault or stress patterns. To distinguish such structures, faulting that resulted from weapons testing is classified depending on whether movement occurred on a previously known fault or whether the fracture was first recognized as a result of the weapons test. Where test-induced movement occurred along previously mapped faults, further subdivision is made depending on whether the known faults are in bedrock or in Quaternary deposits.

LINEAMENTS

Lineaments shown on this compilation were initially mapped by Reheis (1992) at a scale of 1:100,000 from aerial photographs to help identify and characterize potentially active faults near Yucca Mountain. Following Reheis (1992), lineaments in Quaternary surficial deposits are distinguished from those in Tertiary and older bedrock on the present compilation. Additionally Reheis (1992) ranked the lineaments on the basis of their degree of prominence. She suggested that the greater the prominence of a lineament, the more likely that it corresponds to a fault that has experienced either recurrent movement or relatively recent movement. It follows that the lowest ranked lineaments are least likely to indicate actual faults unless they are in the vicinity of high ranked (i.e., prominent) lineaments (Reheis, 1992). Thus, all *isolated* lineaments that were ranked lowest by Reheis (her rankings of "1" or "6") are omitted from the present compilation due to their dubious correspondence to actual faults. Also omitted are those lineaments that correspond to previously mapped faults and those found by Anderson and others (1995) to not correlate with Quaternary faults. All lineaments shown on the present compilation should be considered as representing potential Quaternary or active faults until further evaluated. Also, it is important to recognize that Quaternary activity is **not** precluded for lineaments (or faults) in bedrock areas.

SEISMICITY DATA

This compilation shows epicenters for earthquakes occurring in the Pahute Mesa 30' by 60' quadrangle from 1868 through December, 1994. Seismicity data for the period 1868 to August 1978 were derived from a historical catalog of southern Great Basin earthquakes compiled by Meremonte and Rogers (1987). This historical catalog includes natural seismicity as well as man-induced seismic activity such as high-energy chemical explosions, collapses of underground nuclear-test cavities, and aftershocks resulting from nuclear testing at the Nevada

Test Site. The epicenter locations of all announced pre-August-1978 nuclear explosions are omitted from the historical catalog. Meremonte and Rogers (1987) discussed the various types of magnitudes reported for earthquakes in the historical catalog and ranked the magnitude categories, from highest to lowest quality, as follows: M_S, M_L, M_D, m_b, and *other*. In categorizing the historical seismicity data for the present compilation the same ranking order was used to assign the highest quality magnitude values to the data. All focal depths that are listed as "fixed" in the Meremonte and Rogers catalog are regarded as unknown or uncertain for the purposes of the present map compilation (M.E. Meremonte, oral commun., 1996).

According to the Meremonte and Rogers catalog, only six earthquakes having epicenters within the Pahute Mesa quadrangle (four fall on the map boundary) are known to have occurred before the underground nuclear testing program was initiated at the Nevada Test Site in July 1957. The dates, locations, and magnitudes of these earthquakes are summarized in table 1. Only for the earthquake of September 23, 1947, was there a focal depth for the hypocenter reported; that earthquake was fixed at 16 km. Major historical earthquakes in the region surrounding the Pahute Mesa quadrangle were also discussed by Meremonte and Rogers (1987). Regional seismicity (both historical and recently recorded) in the vicinity of the Pahute Mesa quadrangle and its relationship to the regional tectonic framework were discussed by Rogers and others (1983, 1987a and b).

Earthquakes for the period from August 1978 through December 1994 were recorded by the Southern Great Basin Seismograph Network (SGBSN) (Rogers and others, 1983; D. Vonseggern, Univ. of Nevada, Reno, digital commun., 1995). The epicenter locations for these more recent events are distinguished on the map from the pre-August 1978 locations. The SGBSN consists of 54 vertical-component seismographs, most of which were installed during 1978 and 1979 over the region surrounding the proposed nuclear waste disposal site at Yucca Mountain (fig. 1). The area of network coverage is bounded by longitudes 114.6° W. and 117.8° W. and latitudes 36.0° N. to 38.2° N. Ten horizontal-component seismometers were deployed at eight sites in the area in 1984. Earthquake locations for the network have a mean horizontal standard error of about 0.5 km and mean depth standard error of about 1.0 km. Phase arrival times are estimated to within 0.01 to 0.02 s. and earthquakes are recorded with magnitudes (M_L) as low as 0.0 (region-wide sensitivity of $M_L = 1.5$). (Magnitudes for earthquakes recorded by the SGBSN are reported as local magnitudes (M_L), using the revised magnitude scale of Rogers and others, 1987a.). As with the historical data, the locations of announced nuclear and chemical detonations are removed from the SGBSN catalog, but aftershocks induced by these events have not been removed.

Vortman (1988) investigated southern Great Basin seismicity catalogs attempting to distinguish between man-induced seismic events and earthquakes that are part of the natural background seismicity. On the basis of the spatial and temporal proximity of seismic events to nuclear tests, Vortman concluded that about 32 percent of the seismic events were artificially induced. The percentage is much higher for the Pahute Mesa quadrangle, which includes most of the nuclear testing sites. However, no distinction is made for test-induced aftershock data shown on the present map.

Earthquake epicenters shown on the Pahute Mesa map are subdivided into three categories on the basis of their hypocenter depths: (1) events with hypocenter depths greater than 5 km, (2) events with hypocenters at depths of 5 km or less, and (3) events with unknown hypocenter depth (or magnitude).

DISCUSSION

Moderate historic (prior to August 1978) earthquakes with magnitudes as large as M=5.5 have been located within the Pahute Mesa quadrangle (table 1; Meremonte and Rogers, 1987). Earthquakes recorded by the SGBSN (after July 1978) in the map area range in local magnitude from about $M_L = 0$ to 4.

Most of the earthquakes located by the SGBSN within the Pahute Mesa quadrangle are at depths less than 10 km. A few anomalous deep recorded events (as great as 54 km; $M_L = 0.8$) are, perhaps, erroneous. An apparent bimodal hypocentral depth distribution, with earthquake concentrations from 0 to 2 km and from 5 to 8 km, has been noted by Rogers and others (1983, 1987b) and Harmsen and Rogers (1987). The cause of the apparent bimodal depth distribution is not well understood.

Several clusters or localized swarms of earthquakes are apparent from the compiled historical and SGBSN seismicity data. Several large elongate concentrations of pre-1978 epicenters, mainly of low magnitude ($M_D < 3.0$) and shallow depth (<5 km), are located in the Pahute Mesa testing area (central part of quadrangle). These elongate clusters, which trend north to north-northeast, represent aftershock swarms triggered by moderate to large (as great as 1.3 megaton) underground nuclear explosions detonated mainly between 1968 and 1970 (Hamilton and others, 1972). Focal mechanisms associated with the north- and northeast-trending swarms were mostly characterized by dextral strike slip and normal slip, respectively (Hamilton and others, 1972). The similarity in trend of the elongate aftershock clusters and neighboring mapped "basin and range" normal faults, some of which experienced test-induced surface ruptures (see map), suggests that some of the aftershock swarms occurred along preexisting normal faults in the subsurface of Pahute Mesa (Hamilton and others, 1972). Alternatively McKeown (1975) suggested that the aftershocks occurred along preexisting caldera ring faults associated with the Timber Mountain and Silent Canyon caldera complexes (fig. 1).

Several smaller but conspicuous, similarly oriented clusters of post-1978 epicenters that are not clearly test related are evident in the western part of the quadrangle. Six small north-elongate clusters are located in Sarcobatus Flat (fig. 1; near southwestern corner of quadrangle), five of which form north-trending alignments. Focal mechanisms have been published for two of the Sarcobatus Flat earthquake clusters (Rogers and others, 1983, 1987b). Depth sections for these clusters suggest that earthquakes there occur along steeply dipping, north-striking faults, and focal mechanisms suggest dextral strike-slip on near-vertical, north- to N. 35° E.-striking faults (Rogers and others, 1987b). No fresh surface ruptures or Quaternary faults are associated with any of the Sarcobatus Flat earthquake clusters.

A crude, 30-km-long north-trending alignment of weakly clustered earthquake epicenters is also apparent on the map about 10 km to the east. Although this alignment is roughly coincident with the western edge of an upland area, no Quaternary range-front faults have been mapped along its extent. However, numerous north-striking faults are present in Miocene basement rocks along the trend and north-striking Pliocene to Quaternary faults and air photo lineaments are located just east and north, respectively, of the alignment.

Earthquake swarms occurred in the East Thirsty Canyon area in 1979 and 1983 (Rogers and others 1983, 1987b). These crudely north-trending earthquake swarms are located in the vicinity of a mapped extensive (10-km) north-striking zone of east- and west-dipping normal faults. The preferred fault-plane solution, based on a focal mechanism for the 1979 earthquakes, indicated a north- to northeast-striking, near-vertical, dextral fault (Rogers and others, 1983). Hypocenters for the 1983 earthquake swarm define a near vertical zone, but two composite focal mechanisms indicate normal faulting on either a north-striking, west-dipping fault, or a northeast-striking, southeast-dipping fault (Rogers and others,1987b). Thus, in the western half of the quadrangle clustered earthquakes, test-induced or not, occurred along predominantly north- to north-northeast-striking fault planes within north-trending zones. Significant components of dextral slip characterized these earthquakes even where reactivation of preexisting normal faults is suggested.

The recent (29 June, 1992) Little Skull Mountain earthquake ($M_L = 5.6$) near Yucca Mountain was the largest natural earthquake ever recorded in the southern Great Basin. The epicenter of this earthquake was located about 30 km south of the Pahute Mesa quadrangle (fig. 1) and associated aftershock activity did not extend into the map area (Harmsen, 1994). Many of the aftershocks clustered along a northeast trend, roughly coincident with the main-shock fault plane, and had normal-slip focal mechanisms (Harmsen, 1994). Several other aftershocks, however, defined a north-trending alignment and were compatible with dextral slip on north-striking fault planes, thus resembling earthquake patterns in the western Pahute Mesa area to the north.

Two notable northeast-trending, closely spaced clusters of post-1990 epicenters are present on the west side of Yucca Flat (fig. 1; southeastern-most part of quadrangle). Although one of these clusters is coincident with several aligned northeast-trending bedrock fault traces along the axis of Syncline Ridge, no surface ruptures are known to have occurred as a result of these earthquake swarms.

Several small, but conspicuous, relatively deep (>5 km) swarms of earthquakes have occurred since 1978 beneath the periphery of Timber Mountain in the south-central part of the quadrangle. The associated epicenter clusters are not markedly elongated nor do they seem to form alignments. Two earlier, historic earthquakes having magnitudes greater than 4.0 also occurred under the margin of Timber Mountain. An additional notable earthquake has occurred in the Timber Mountain area since the 31 December 1994 truncation of the SGBSN catalog used for this compilation. A moderate ($M_L = 4.2$) tremor occurred under the northeast flank of the mountain (37°5.87',116°24.42') on 31 July 1995 at a depth of about 16.5 km (K.D. Smith, Univ. of Nevada, Reno, oral commun., 1995). These numerous deep quakes are intriguing in that they were located near the margin of the Timber Mountain caldera complex and its associated resurgent dome (fig. 1). Perhaps earthquakes preferentially occur along reactivated structures bounding the dome and (or) surrounding calderas due to localized stress concentrations.

The map compilation reveals two broad areas of more loosely concentrated historical and post-August 1978 earthquake epicenters, one in the Pahute Mesa area and the other in the Yucca Flat area. These epicenter concentrations very likely represent aftershocks resulting from the intensive underground nuclear testing that has been conducted in the two areas since the 1950's.

None of the faults in the Pahute Mesa 30' x 60' quadrangle are known to be continuous, as exposed surface ruptures, with faults that cut the proposed nuclear disposal site at Yucca Mountain south of the quadrangle (fig. 1). However, the system of north-northeast striking, mostly westward-dipping faults in the central part of the Pahute Mesa quadrangle (area of Silent Canyon caldera complex, fig. 1) is similar in geometry and age to the system of faults that cuts Yucca Mountain south of the Timber Mountain caldera complex (fig. 1) (Sawyer and others, 1995). These two fault systems are interrupted by the Timber Mountain caldera complex. The complex fault pattern of Timber Mountain itself reflects tectonic activity associated mainly with the formation of the resurgent dome at the center of the Timber Mountain caldera complex (Carr, 1964). Each system of north-northeast striking faults is 25 to 30 km wide at its respective boundary with the Timber Mountain caldera complex, and both systems currently occupy relative structural highs, straddled east and west by structural basins filled with Quaternary alluvial deposits--Gold Flat and Kawich Valley in the north and Crater Flat and Jackass Flats in the south (fig. 1) (Sawyer and others, 1995). Both systems consist of anastamosing networks mostly of moderately to steeply westward-dipping faults that separate gently eastward-tilted, tabular blocks of volcanic rock. Spacing of individual faults in both systems varies from 0.5 to 2.5 km, with most of the principal faults occurring about 1 km apart. Displacements on the principal faults in both systems also are comparable, from 50 to 500 m (Orkild and others, 1969; Warren and others, 1985; Scott, 1991). In both fault systems, volcanic strata older than 11.6 Ma tuff of the Timber Mountain Group have experienced greater fault displacement and fault-related tilting than the tuff and overlying strata (Warren and others, 1985; Scott, 1991). Locally, the principal faults in each of the systems disrupt Quaternary deposits (Orkild and others, 1969; Fox and Carr, 1989). Recognizing these numerous structural similarities, Warren and others (1985) asserted that faulting in the two areas may be genetically related. However, recently published paleomagnetic data suggest that, in contrast to Yucca Mountain, most fault blocks in the Pahute Mesa area have not undergone Neogene vertical axis rotations (Rosenbaum and others, 1991; Hudson and others, 1994). The two areas may, thus, have contrasting fault-kinematic histories.

A better understanding of the regional integration of fault systems in the vicinity of Yucca Mountain is an important element in predicting the future behavior of faults at the proposed nuclear waste disposal site. Considering the numerous similarities between the north-northeast-striking fault systems north and south of Timber Mountain, study of historic faulting induced by nuclear testing along the north-northeast-striking fault system north of Timber Mountain could provide a useful analog for evaluating the character and consequences of future activity along the north-northeast-striking faults at Yucca Mountain. Stock and Healy (1988) show that the magnitude and orientation of the principal stresses measured at Yucca Mountain, at least in the upper 1.5 km of the crust, are near the threshold at which frictional sliding could be induced on preexisting north-northeast-striking normal faults (such as those cutting Yucca Mountain or in the central part of the Pahute Mesa quadrangle). Considering the many similarities of the Pahute Mesa and Yucca Mountain fault systems, the pattern and abundance of historic faulting and seismicity induced by nuclear weapons testing along the principal faults in the central part of the Pahute Mesa quadrangle (evident on the present compilation) appears to support the conclusion that faults such as those at Yucca Mountain are oriented preferentially for further movement under existing stress conditions. Additionally, it is evident that most known Quaternary faults and possible Quaternary faults (eg., lineaments) throughout the map area also strike north to north-northeast, suggesting that favorable stress conditions have existed during the recent geologic past for shear failure along similarly oriented faults beyond the immediate testing areas.

ACKNOWLEDGMENTS

D.S. Aitken, S.C. Harmsen, Paia Levine, T.M. McCulloch, D.A. Ponce and J.C. Shulters provided invaluable computer and other technical assistance in compiling an earlier preliminary version of this map. H.R. Covington generously provided unpublished fault data and identified faults that have moved in response to recent nuclear weapons testing. M.C. Reheis and K.M. Haller kindly supplied stable-base copies of their published lineament and fault map data, respectively, which allowed for hand digitization of the data by M.F. Duncan. David Vonseggern (Univ. of Nevada, Reno) provided invaluable digital catalogs of historical and SGBSN earthquake events. This compilation benefited significantly from discussions with H.R. Covington, S.C. Harmsen, M.E. Meremonte and P.P. Orkild. We gratefully acknowledge improvements to the map resulting from critical reviews by R.E. Anderson, C.G. Bufe, H.R. Covington, D.W. O'Leary, and M.W. Reynolds.

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Table 1. Pahute Mesta 30' x 60' quadrangle historical hypocenter summary 1868 to 1956 prior to nuclear testing at Nevada Test Site
[Data from Meremonte and Rogers (1987)]

Date	Location		Magnitude					
	Lat (W.)	Long (N.)	M_S	Code	M_L	Code	Other	Code
Nov. 7, 1910	37.500	117.000	--	--	--	--	5.5	RYC
Mar. 28, 1934	37.300	116.600	3.8	BRP	4.5	BRP	4.5	RYC
Sept. 21, 1939	37.000	117.000	--	--	4.0	BRK	4.0	PAS
Sept. 23, 1947	37.150	116.000	3.5	BRP	3.5	PAS	3.5	RYC
Jan. 13, 1950	37.017	116.483	--	--	4.1	PDX	--	--
Sept. 16, 1953	37.330	117.000	3.9	BRP	3.9	BRK	3.9	PAS

M_S = surface wave magnitude
M_L = local magnitude (Wood-Anderson)
Other = other magnitudes or magnitudes of an unidentified type
Code = source codes: BRP--Askew and Algermissen (1983); BRK--University of California, Berkeley, California, Seismograph Station; PAS--California Institute of Technology, Pasadena, California, Seismological Laboratories; PDX--National Oceanic and Atmospheric Administration (1982); RYC--Ryall, F.D. (written commun., 1980, cited in Meremonte and Rogers (1987))

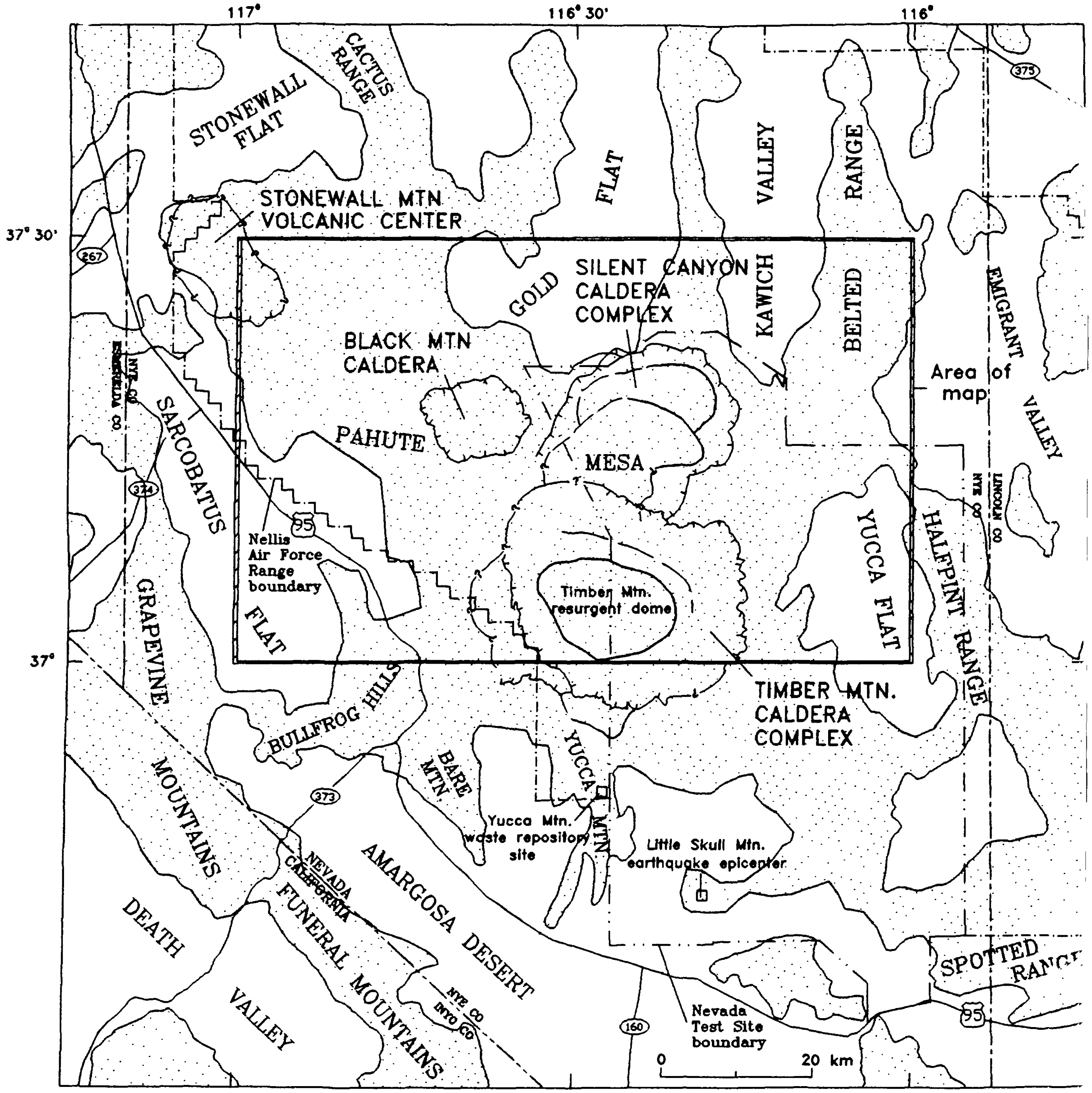

Figure 1. Location map showing regional geographic and cultural setting of Pahute Mesa quadrangle. Also shown are the locations of nearby caldera complexes, the Little Skull Mountain earthquake epicenter, and the potential Yucca Mountain high-level waste repository.