REGION OF INTEREST

The region of interest for the PVHA is the southern Great Basin, and it is subdivided into two partly overlapping sets for this elicitation. The first set includes regional models that are used to assess background rates of volcanic activity for the southern Great Basin; PVHA estimates are used from these models to compare and cross-check results of PVHA applied to the second set. The second set includes the distribution and structural-tectonic models of volcanic events in the YMR and the YMR/PQ, and these models form the primary basis for the PVHA.

The subdivisions of the southern Great Basin are based on two concepts. First, there is a background level of low recurrence rates of the formation of small volume basalt centers of Quaternary age within the relatively inactive areas of the *interior* parts of the southern Great Basin (generally east of Death Valley, south of the south end of the Reveille range, north of Las Vegas and west of the eastern border of the State of Nevada). Recurrence rates and disruption probabilities for volcanic zones in the YMR and YMR/PQ should be greater than these background rates. Second, higher recurrence rates and disruption probabilities should apply to volcanic zones that are demarcated by the spatial distribution of Pliocene and Quaternary volcanic centers, by structural, tectonic or topographic features, or by combinations of these features. The Yucca Mountain site is located near but outside most of the defined volcanic zones (see following sections). Logically, the recurrence rates and disruption probabilities for the Yucca Mountain site must be greater than the bounds established from regional background models (minimum bounds) and somewhat less than estimates obtained assuming location of a repository in volcanic zones (maximum bounds). These bounds are listed in Tables BC-1 and BC-2.

REGIONAL MODELS AND PROBABILITY BOUNDS

Three regional zones are described and illustrated on Figures BC-2 through BC-4 . The first zone is the southern Great Basin region and it includes all significant sites of Pliocene and Quaternary volcanic centers within the area outlined on Figure BC-2. The area does not include the Lunar Crater or Reveille areas, areas west of the west side of Death Valley, and areas east of the Nevada Test Site. The second region (Figure BC-3) is a modified version of the Armagosa Valley Isotopic Province (AVIP) as defined by G. Yogodzinski (presentation at PVHA Workshop 3). The AVIP zone is modified slightly to include the basaltic andeside of Skull Mountain and the basalt of Pahute Mesa, sites with isotopic ratios of Sr and Nd that correspond to the AVIP (Crowe et al., 1986; Farmer et al., 1989; G. Yogodzinski presentation at PVHA Workshop 3). The third regional zone is the distribution area of the Postcaldera basalt (PCB) of the YMR including the Older postcaldera basalt, the Younger postcaldera basalt and all aeromagnetic anomalies suspected to represent buried basalt centers (Crowe et al., 1995, Chapter 2). This third regional zone (Figure BC-4) is the only model where event counts, recurrence rates and disruption ratios are assessed for Miocene basaltic volcanic rocks (post-9.05 Ma).

Simple logic requires that the probability of disruption of the Yucca Mountain site must be greater than regional background models and less than the disruption probabilities *within* local volcanic zones. The first step followed in this elicitation is to estimate recurrence rates and disruption ratios for the regional-background models. The minimum probability bounds for the regional models are summarized in Table BC-1. These estimates use the map areas for the three regional zones from the outlines shown on Figures BC-2 through BC-4. The event counts used for the recurrence rates are the *most likely* event counts from the data presented in the following sections. The Quaternary event counts are for the post-1.8 Ma (current definition of the Quaternary) and the Plio-Quaternary are for the post-5.05 Ma (to be consistent with the interval used for spatial models, described below. A post-9.15 Ma interval is estimated for the PCB zone only because there are insufficient data for late Miocene event counts for most regions outside of the PCB zone. The estimated disruption probability assumes random location of a repository with dimensions appropriate to the Yucca Mountain site *in* the regional-background zones. The maximum probability bounds listed in Table BC-2 are for volcanic zones in the PCB zone. The zone definitions and event counts used in Table BC-2 are presented in following sections.

SPATIAL MODELS

The approach developed to assess the future locations of volcanic activity in the YMR is based on subdividing the region of interest into zones, or the *zonation* approach. This approach also incorporates a *uniform* approach, as the future distribution of events is assumed to be uniform within each designated zone.

Three alternative time intervals are considered for the analysis that are established from the ages of volcanic centers in the YMR. These intervals are adjusted for uncertainty in establishing the age of volcanic events, defined as 150 ka to encompass the uncertainty of all geochronology measurements (see section above on temporal aspects of event definitions). The intervals used are:

Post-1.15 Ma Interval

This interval extends from the present (t = 0) to the eruption of the 1.0 Ma Quaternary basalt of Crater Flat (Crowe et al., 1995). Its upper bound is marked by the approximately 1.9 Ma hiatus between the basalt of the 2.9 Ma Buckboard Mesa and the 1.0 Ma Quaternary basalt of Crater Flat.

Post-5.05 Ma Interval

This interval extends from the present (t = 0) to the 4.95 Ma age of the basalt of Thirsty Mesa. The upper limit of the interval is marked by the approximately 1.25 Ma hiatus between the basalt of Thirsty Mesa (age established from chronology data presented by F. Perry at PVHA Workshop 1) and the youngest age for the basalt of Nye Canyon (Crowe et al., 1995). This interval coincides with the timing of a major change in the spatial patterns of basalt centers that occurred between the OPB and YPB cycles (Crowe et al., 1995, see Chapter 3).

Post-9.15 Ma Interval

This interval extends from the present (t = 0) to the 9.0 Ma age of the oldest basalt center of the Older postcaldera basalt, the basalt of Pahute Mesa (Crowe et al., 1995, Chapter 2). Two alternative approaches are used to subdivide the region into zones: the pattern of observed volcanic centers and structural considerations. These zone types and their weights for the hazard analysis are as follows:

Set 1. Event-Distribution Zones (0.40)
Set 2. Structural-Tectonic Zones (0.60)

Event-Distribution Zones

Event-distribution zones are established through systematic examination of different combinations of the distribution areas of volcanic events in the YMR. The geometry of the zones is allowed to vary according to the distribution of events, and it is controlled by both the interval chosen for the event rates and by geologic assumptions concerning the volcanic record of the chosen interval. For event-distribution zones, the geometry of the individual zones varies as a direct function of the included volcanic centers. The intervals used for the distribution zones correspond to gaps or breaks in the distribution of ages of the volcanic centers and/or changes in the spatial distribution of volcanic events.

Distribution zones were developed for different combinations of volcanic events using the chronology intervals listed above; the zones shown on Figures BC-4, BC-5, BC-6, and BC-7. Three event-distribution zones are used in the PVHA including variations of the CFVZ of Crowe and Perry (1989), the Younger Postcaldera model, which corresponds geographically to the YMR/PQ, and the distribution area of the PCB, which corresponds geographically to the YMR. The PCB zone is somewhat difficult to apply to PVHA because the added Miocene events are weak predictors of future volcanic activity and the added distribution area does not include the Yucca Mountain site. However, this zone was included in the PVHA for two reasons. First, there was considerable discussion concerning the inclusion of the OPB in probability estimates during PVHA workshops and field trips. Second, developing probability estimates for the distribution areas and event counts of the YPB and the OPB was judged to be useful for comparison with other probability estimates.

The following event-distribution zones are used:

The Quaternary and Plio-Quaternary CFVZ

Two zones are defined that encompass the Quaternary CFVZ (Figure BC-5) and the Plio-Quaternary CFVZ (Figure BC-6).

The Younger Postcaldera Zone

This zone is defined by the distribution of all Pliocene and Quaternary basalt centers in the YMR (Figure BC-7) and includes the basalt of Buckboard Mesa and the aeromagnetic anomalies of the Crater Flat and the Amargosa Valley basins. The Younger Postcaldera zone is identical geometrically to the YMR/PQ. The Quaternary CFVZ (Figure BC-5) is identical to the Quaternary portion of the Younger Postcaldera Zone.

The Postcaldera Basalt Zone

This zone is defined by the distribution of the Miocene and younger basalt units of the Postcaldera basalt episode (Figure BC-4), and is identical to the third regional-background model.

The relative weights assigned to these zones are as follows:

Plio-Quaternary and Quaternary CFVZ	(0.80)
Younger Postcaldera Zone	(0.15)
Postcaldera Basalt Zone	(0.05)

The Plio-Quaternary and Quaternary models are judged to best reflect likely patterns of future volcanism. These distribution areas do not include the basalt of Buckboard Mesa because this basalt site is located 35 km N-NE of Yucca Mountain and is judged not to be part of the Walker Lane setting associated with Yucca Mountain (described below). Moreover, the geochemical composition of the basalt of Buckboard Mesa is different than all other basalt units of the CFVZ (Vaniman and Crowe, 1981; Vaniman et al., 1982; Crowe et al., 1986). The distribution area of the Postcaldera basalt is given a lower weight because of the older age of the basalt units of the OPB and the distribution area added by including the volcanic events of the OPB does not include the Yucca Mountain site.

Structural-Tectonic Zones

Structural-tectonic zones are based on the assumption that Pliocene and Quaternary basalt centers of the YMR occur in zones that can be defined through assessment of controlling structural and tectonic features of the geologic setting of the YMR. Basalt centers are inferred to occur preferentially within these zones so that there are higher rates of event recurrence in the zones than outside the zones. There are two important inferences associated with the selection of structural-tectonic zones. First, structural-tectonic features probably provide ascent pathways for basalt magmas primarily through the occurrence of fractured rock. The features do not control the generation of basalt magma, but instead provide passive but preferential pathways that permit or facilitate the ascent of basalt magma. There is a greater likelihood, therefore, of future volcanic events within the structural-tectonic zones than outside of the zones. Second, basalt magma may divert at shallow levels within the zones and form basalt dikes oriented in N-NE trending directions following the maximum compressive stress direction (Crowe et al., 1995, Chapters 3 and 5).

The following structural-tectonic zones are used:

The Plio-Quaternary and Quaternary Pull-Apart Zone

These zones are based on the work of Fridrich (1995) who concludes that the Crater Flat structural basin was formed by a combination of east-west to southeast-northwest extension and northwest-directed right slip. The boundaries of the basin changed through time and included the Yucca Mountain site during the Miocene, the Amargosa and Crater Flat basins during the Pliocene, and only the Crater Flat basin during the Quaternary. The following subsets are used for this model: (a) Quaternary model consisting of the Crater Flat topographic basin (Figure BC-8), (b) subdivisions of the Quaternary model that correspond to the fault models of the Crater Flat basin developed by G. Thompson (presentation at PVHA Workshop 4) (Figure BC-9), and (c) Plio-Quaternary model consisting of the Crater Flat topographic basin and the area of the Amargosa Valley containing aeromagnetic anomalies assumed to be buried basalt centers (Figure BC-10). These three subsets are weighted equally (0.33, 0.33, 0.33) in the elicitation.

The Northwest-Trending Walker Lane Zone (WLZ)

This zone is based on the assumption that largely buried structural features of the Walker Lane structural system control the distribution of volcanic events in the YMR. The system is inferred to extend from the Amargosa basin on the southeast to a sub-basin of Sarcobatus Flat on the northwest (Figure BC-11). Two intervals are used for the events count for the WLZ (1.15 and 5.05 Ma), but the geometry/area of the zone is held constant for both intervals.

The Northeast-Trending Structural Zone (NESZ)

This zone is based on the assumption that a northeast-trending structural zone, defined by parallel sets of west-down, closely spaced normal faults, extends from Pahute Mesa through Yucca Mountain to the Amargosa Valley (Figure BC-12). The model is a composite of the structural models of Carr (1990), Smith et al. (1990), and the en echelon pull-apart basin models of Wright (1987) and Carr (1990). The NESZ, like the WLZ, is evaluated for two intervals (1.15 and 5.05 Ma) with the geometry/area of the zone held constant for both intervals.

The relative weights assigned to these zones are as follows:

Plio-Quaternary and Quaternary Pull-Apart Zones	(0.60)
Walker Lane Zone	(0.25)
Northeast-Trending Structural Zone	(0.15)

The basalt centers of the YMR are assumed to occur primarily in alluvial basins at sites of continuing extension and thus the pull-apart basin models are given the highest weights. This is supported both by the distribution of the basalt centers and the observation from the T. Brocher seismic refraction/reflection line (G. Thompson presentation at PVHA Workshop 4) that the basalt centers of Crater Flat occur mostly above the deepest parts of the Crater Flat basin. The Walker Lane model is judged to be important but it is a buried structure, there is limited evidence of through-going Walker Lane structures, and its expression in the regional geology of the YMR appears primarily to be in the location and development of en echelon, pull-apart basins. Thus the pull-apart basin models are favored over a through-going Walker Lane structure. The justification for the northeast-trending structural zone is dependent on the location of only one center (basalt of Buckboard Mesa) in the Plio-Quaternary record of the YMR. The normal faults that define the zone do not appear to be preferred pathways for ascent and eruption of basalt magma, and the model of Wright (1987) has more direct application to the Amargosa Valley and areas to the south than to Yucca Mountain and areas to the north.

Distribution of Events Within Zones

Two questions must be considered for the distribution of events in defined zones. These are: (1) what constraints can be placed on the distribution of events within zones?, and (2) what is the nature of the boundaries of the zones?

The distribution of events within zones cannot be strongly constrained using the data sets of Plio-Quaternary volcanic events in the YMR. This is based on the observation that while there are broad patterns to the distribution of events, the sequence of events jumps randomly with respect to jump lengths and jump directions (Crowe et al., 1995, see Chapter 7; Golder Associates, 1995). There may be a slight tendency for a southwest drift of event locations through time and an oscillation of center locations between northwest and southeast poles (Golder Associates, 1995). However, the location of any one volcanic event does not provide significant constraints on the location of a succeeding event. Thus smoothing or clustering models that are based on event locations are not used in this elicitation. Instead, event locations are allowed to vary randomly within distribution and structural-tectonic zones.

The boundaries of zones are defined based on topographic criteria (e.g., topographic basins) or on the distribution of volcanic events. No simple generalizations can be made on the nature of the boundaries for individual zones and there is uncertainty in their locations. To incorporate this uncertainty in the modeling, volcanic events are confined within zones but feeder dikes associated with the events are allowed to extend beyond the zone boundaries. Thus the uncertainty of zone boundaries is captured in the assigned dimensions of basalt feeder dikes.

Background Zones

The zonation models considered for the post-1.15 Ma and post-5.05 Ma time periods include cases where the repository does not lie within a source zone. The rate of events in the immediate vicinity of the site is then determined by a background rate computed for the region of interest. As described previously, these alternative regions of interest are considered the SGB, AVIP, and PCB zones (Figures BC-2 through BC-4). Zones SGB and AVIP are considered equally acceptable for providing estimates of background rates. The PCB zone is considered less likely because it contains very few events, except for the post-9.05 Ma time period. The relative weights assigned to these zones depend upon the time period. For the post-1.15 Ma time period the SGB and AVIP zones are considered with weights of (0.5) and (0.5). The PCB zone is excluded because it contains no events. For the post-5.05 Ma time period, the weighting is: SGB (0.4), AVIP (0.4), and PCB (0.2). For the post-9.05 Ma time period, the site lies within the large PCB zone and no consideration of a background zone is needed.

EVENT COUNTS

Using the event definitions provided above, the number of events are described as probability distributions that are designed to encompass the uncertainty of the event definitions for individual basaltic centers in the YMR and for the regional zones. The event counts are listed for the YMR in order of decreasing age and are divided into basalt cycles (OPB and YPB). These data are followed by event counts for the surrounding regions of the southern Great Basin. The latter sites are described by geographic locality and not in order of age. The level of information available for the event counts is greatest for the YMR and generally decreases with increasing distance from the YMR (except for Ubehebe Craters, described by Crowe and Fisher, 1973). A summary of event counts is provided in Table BC-3. Rates of occurrence based on the event counts are shown in Table BC-4.

OLDER POSTCALDERA BASALT

Basalt of Pahute Mesa

The geology and chronology of the basalt of Pahute Mesa are described in Crowe et al. (1995). The basalt sites consist of three spatially separate basalt centers that are partly to deeply dissected. Their separate locations and somewhat different K-Ar ages require a 3-event minimum model. The western and central centers expose large and somewhat complex conduit plugs, vent scoria and multiple feeder dikes and could represent more than one event; these observations provide the basis for the 4-event and 5-event scenarios. The addition of two undetected events is permissible given the deep degree of dissection of all the volcanic centers.

Event counts and relative weights: 3 (0.50), 4 (0.20), 5 (0.15), 6 (0.10), 7 (0.05)

Basalt of Paiute Ridge

The basalt of Paiute Ridge was mapped by Byers and Barnes (1967) and described by Crowe et al. (1983b) and Valentine et al. (1992). The site consists of multiple sill-and-dike complexes centered in a graben in the interior of the Half Pint range. Ratcliff et al. (1994) showed that the mafic intrusions and lava flows of the center record a geomagnetic field reversal of probable short duration, a compelling argument that the center formed during a single brief magmatic event. However, an equally convincing argument can be make that the length and spacing of the mapped intrusions probably requires at least 2 separate feeder dike systems. Accordingly, the 1-event and 2-event scenarios are given equal weights and are treated as the most likely events. As many as 3-to-4 events can be identified if vent areas, marked by plugs and eroded scoria deposits, are equated to individual cones and each spatially separate cone is defined as a volcanic event. A 5-event scenario is used to account for undetected events.

Event counts and relative weights: 1 (0.35), 2 (0.35), 3 (0.15), 4 (0.10), 5 (0.05)

Basalt of Scarp Canyon

A separate basalt site crops out southeast of the basalt of Paiute Ridge and west of Nye Canyon. This site was included with the basalt of Paiute Ridge in Crowe et al. (1995), but is classified as a separate unit for this elicitation. The site consists of a 3-to-4 km basalt dike and two small plug masses. A second spatially separate site intersected in a drillhole in alluvium in Frenchman Flat

was dated at 8.6 Ma and is probably correlative with the basalt of Scarp Canyon (Crowe et al., 1995). The spatial separation of the two sites suggests that a 2-event scenario is preferred for the most likely model. A 3-event model is assigned an equal probability because there is limited information on the extent of the
basalt encountered in the drillhole site in Frenchman Flat and geophysical data for Frenchman Flat have not been examined by the author. A 1-event scenario is assigned a low weight but is considered possible and assumes the age and correlation of the basalt site in Frenchman Flat are incorrect. The 4-event and 5-event scenarios are allowed for the maximum model assuming the possible presence of one or two undetected events.

Event counts and relative weights: 1 (0.05), 2 (0.40), 3 (0.40), 4 (0.10), 5 (0.05)

Basalt of Yucca Flat

A basalt unit was intersected in drillhole UE1-8 and a basalt sample from the unit was dated at 8.1 Ma (Carr, 1984). Event scenarios of 1 to 3 events are assigned to the site and include the possibility of undetected events.

Event counts and relative weights: 1 (0.40), 2 (0.40), 3 (0.20)

Basalt of Rocket Wash

The basalt of Rocket Wash consists of one eroded vent, the source of a single lava flow that upholds a small mesa along the west edge of the ring-fracture zone of the Timber Mountain caldera (Crowe et al., 1995). The preferred event count for the site is a 1-event scenario based on the limited extent of the scoria-cone deposits and the simple geometry of the vent and flow complex. As many as three events may be possible (including undetected events) primarily because geophysical data for the site have not been examined by the author. However, multi-event models are given lower weights because the lava flow upholds topography (inverse topography) and the unit has not been buried by younger deposits.

Event counts and relative weights: 1 (0.75), 2 (0.20), 3 (0.05)

Basalt of Nye Canyon

The geology and chronology of the basalt of Nye Canyon were summarized by Crowe et al., (1986; 1995). The site consists of an alignment of three surface centers and a buried center in the northeast edge of Frenchman Flat (Carr, 1974). The number of possible volcanic events at Nye Canyon ranges from 1 to as many as 9. A 1-event scenario is given a small weight because the length of the alignment of the four centers exceeds the probable length of a single feeder dike. Scenarios of 2-to-3 events are given near-equal weights and are treated as the most likely scenarios because the spacing of the centers probably requires two dikes (two-event model) and the middle Nye center (surface center) is petrologically distinct, contains nodules of mantle periodite and has a high Mg number (Crowe et al., 1986; Farmer et al., 1989). The models of 4 and 5 events respectively, are given equal weights because each center could be treated as a single event, and the southern Nye Center (surface center) is associated with a complex arcuate dike that could represent more than one event. As many as 4 additional events are permissive as undetected events given the complexity of the arcuate dike, and because geophysical data for the buried basalt center in Frenchman Flat have not been examined by the author.

Event counts and relative weights: 1 (0.02), 2 (0.20), 3 (0.20), 4 (0.16), 5 (0.16), 6 (0.12), 7 (0.08), 8 (0.04), 9 (0.02)

YOUNGER POSTCALDERA BASALT

Basalt of Thirsty Mesa

The geology of the basalt of Thirsty Mesa has been summarized by Crowe et al., (1995). The center consists of a lava mesa surmounting an ignimbrite plateau upheld by the Thirsty Canyon Tuff. The center is modeled as one to three events based on existing geologic information. A 1-event model is supported by the similarity in age determinations of samples collected from basal lava flows and a feeder dike from the summit vent of Thirsty Mesa (Crowe et al., 1995). Paleomagnetic data presented by D. Champion (PVHA field trip to Sleeping Butte) are consistent with a single short duration event. Geochemical data show no evidence of compositional variation that cannot be explained by a 1-event eruptive history (Crowe et al., 1986; 1995; F. Perry presentations at PVHA Workshops 1 and 3). The 2- and 3-event models are based on reconnaissance geologic mapping that shows the vent area for the center consists of three partly coalesced scoria/spatter cones. The likelihood of undetected events from burial is judged to be extremely low because the center is a high-standing topographic feature.

Event counts and relative weights: 1 (0.85), 2 (0.09), 3 (0.06)

Amargosa Valley

The aeromagnetic anomalies of the Amargosa Valley have been described by Kane and Bracken (1983), Langenheim (in press) and Crowe et al., (1995). Only one of the aeromagnetic anomalies (anomaly B of Langenheim, in press) has been drilled and dated at about 3.9 Ma (Crowe et al., 1995). Its age is consistent with burial through time of a former surface volcanic center by over 100 meters of alluvial fill. This amount of burial is consistent with the location of the anomaly near the trace of the Fortymile Wash which empties into and ends in the Amargosa Valley. Anomaly D may be related to a basalt intersected in a water well at 190-m depth (Langenheim, in press). Modeling of anomaly C suggests a 1- to 1.5-km-wide body at a depth of 200 m, presumably a subaerial scoria cone and lava flow that were buried by alluvial fill. None of the anomalies can be modeled reasonably as buried dikes (V. Langenheim, pers. comm. during the elicitation on 13-June-95). Three to 12 volcanic events are judged to be possible in the Amargosa Valley with the 6-event scenario assigned as the most likely event count. The 3-event scenario consists of anomaly B, a single combined event for anomalies C and D, and anomaly E. Two of these events have been identified from borehole data (Langenheim, in press), anomaly B has a shape consistent with the presence of a single center with a lava flow extending from the center to the south, anomalies C and D are closely spaced and could be a single event, and anomaly E is a small anomaly and is probably a single center. Anomalies F and G are inferred to be produced by local ash-flow tuff or lava and are judged not to be of Pliocene age. The 6-event scenario infers that anomalies A, B, C, D, E each represents individual events with anomalies F and G combined into a single event because of their close spacing. The separation of anomalies C and D into individual events is based on their different magnetic polarities inferred from aeromagnetic data (Langenheim, in press). The maximum event model assumes anomalies F and G are separate events, assigns 3 events to anomaly B because of its large size, and allows for 2 hidden events. A larger number of undetected events are assigned to the anomaly sites of Amargosa Valley because of the complete burial of all sites by alluvium and the limited exploratory drilling of the anomaly sites.

Event counts and relative weights: 3 (0.05), 4 (0.12), 5 (0.20), 6 (0.20), 7 (0.20), 8 (0.10), 9 (0.07), 10 (0.03), 11 (0.02) and 12 (0.01).

3.7 Ma Basalt of Southeast Crater Flat

The 3.7 Ma basalt of southeast Crater Flat has been described by Vaniman and Crowe (1981), Vaniman et al. (1982), and is summarized in Crowe et al. (1995). The basaltic unit is inferred to represent 1 to 8 events with the most likely event counts being 2-to-3 events. The 1-event model is based on uniform, but incompletely documented, field magnetic directions for the deposits (Champion, 1991). The 2-event model is judged the most likely model because a minimum of two dike feeders are needed to explain the vent distribution and the vents occur over a length of 4.8 km. A 3-event model is given equal weighting because of the presence of a large eroded center at the north end of the vent alignment (Vaniman and Crowe, 1981) coupled with the geometric requirement of two feeder dikes. Four to as many as 6 events are required if each identified vent area is judged to represent a volcanic event; each event-count is given equal weighting (4-events, 5-events and 6-events) because there is no basis to discriminate the different counts. However, each of the events are weighted lower than the 2- and 3-event scenarios on the basis of the alignment of the centers, the uniformity of chronology data for samples along the length of the alignment (Crowe et al., 1995) and the apparent uniformity of field magnetization directions (Champion, 1991). The 7-event and 8-event models assume up to two undetected events and are given somewhat higher weightings than undetected events for other sites in the YMR because of the extensive alluvial cover of the eastern outcrops of the basalt unit.

Event counts and relative weights: 1 (0.10), 2 (0.25), 3 (0.25), 4 (0.10), 5 (0.10), 6 (0.10), 7 (0.05), 8 (0.05).

Basalt of Buckboard Mesa

The basalt of Buckboard Mesa has been mapped by the U.S. Geological Survey and the data compiled at a scale of 1:24,000 on geologic quadrangle maps and summarized on the geologic map of the Timber Mountain caldera (Byers et al., 1976). The geology of the center was described by Lutton (1968) and summarized in Crowe et al., (1995) and Crowe and Perry (1995). The preferred event model for the center is the single-event model. This is based on uniformity in age determinations (2.9 to 3.1 Ma; Crowe et al., 1995; Crowe and Perry, 1995), the compositional uniformity of the basalt lavas in outcrop and in drillholes (Lutton, 1968; Crowe et al., 1986; 1995), and the presence of only a single scoria cone and fissure system at the center (Scrugham Peak; Lutton, 1968; Crowe et al., 1995). A 2-event scenario is possible based on the presence of a second, kaersutite-bearing lava flow northwest of Scrugham Peak. However, this lava is similar in age and composition to the other lavas (Crowe and Perry, 1995) and accordingly the 2-event scenario is given a lower weighting. A 3-event model allows for an undetected event but is given a low weighting because of the observation that the basalt of Buckboard Mesa filled a topographic low and is now a topographic high (inverse topography).

Event counts and relative weighting: 1 (0.70), 2 (0.25), 3 (0.05)

Quaternary Basalt of Crater Flat

The Quaternary basalt of Crater Flat has been described by Vaniman and Crowe (1981), Vaniman et al. 1982), Smith et al. (1990), Ho et al. (1991), and the data are summarized in Crowe et al. (1995). One to 7 volcanic events are required to explain the centers, with the 3-event scenario given the highest weighting (most likely estimate). The 1-event scenario is based on the alignment of the centers, the inferred uniformity of their field magnetic directions (Champion, 1991) and the general consistency in the results of age determinations obtained for the centers (Crowe et al., 1995, Chapter 2). Weaknesses of this interpretation are measurement uncertainty in paleomagnetic data, uncertainty concerning the nature of secular variation during the time of eruption of the Quaternary basalt of Crater Flat and some divergence in the results of geochronology data (F. Perry presentation at PVHA Workshop 1), and the alignment length (12.6 km) exceeds likely dimensions of a single feeder dike. The 2-event scenario assumes that Red Cone and Little Cones, and Black Cone and Makani Cone, were each formed by a single and separate feeder dike. This model is based on a somewhat arbitrary subdivision of the centers and it is given a lower weighting. The preferred three-event scenario assumes that Red Cone and Black Cone formed from a single pulse of magma (1-event; see geochemical data of Bradshaw and Smith, 1994), and the Little Cones and Makani centers each formed as separate events. This is supported by the observation that the Little Cones center can be discriminated geochemically from the Red Cone and Black Cone centers (F. Perry presentation at PVHA Workshop 1), and both Little Cones and Makani cone are spatially separate (3-4 km separation) between the Red Cone and Black Cone centers, respectively. The 4-event scenario assumes each center represents a separate volcanic event. This scenario also assumes that there is sufficient uncertainty in geochronology data to permit this interpretation and that the paleomagnetic data may not represent the temporal complexity of the volcanic events. The 5-event scenario assumes Little Cones consists of two centers (Connor and Hill, 1993), but this scenario is given a low weighting because of the small spacing between the two scoria cones of the center. The 6-event and 7-event scenarios assume 1 or 2 undetected events primarily because the Little Cones site has been partly buried and there is an unexplained positive aeromagnetic anomaly about 1 km south of the Little Cones (Crowe and Carr, 1980; Crowe et al., 1986; 1995). The possibility of other undetected events is given a low weighting because of the high quality of aeromagnetic data for the basin, the location of the basalt centers in alluvium deposits, the availability of subsurface control from two nearby drill holes (VH-1 and VH-2), and the high quality seismic reflection/refraction data near the centers.

Event counts and relative weights: 1 (0.10), 2 (0.10), 3 (0.45), 4 (0.20), 5 (0.10), 6 (0.025), 7 (0.025)

Basalt of Sleeping Butte

The basalt of Sleeping Butte has been described by Crowe and Perry (1991), and the geology of the center is summarized in Crowe et al. (1995). The latter summary does not include the results of recent geologic mapping (Crowe and Perry, 1995) that has verified the presence of a second lava flow lobe from the Hidden Cone center. One to as many as 3 events could be represented by the deposits of the Sleeping Butte center. In the 1-event scenario, Little Black Peak and Hidden Cone are assumed to be fed by a single feeder dike, an inference that is supported by paleomagnetic data (Champion, 1991). The 2-event scenario assumes each center is a separate event based on the 2.6 km separation of the centers, the different field magnetic directions obtained at the northwest flow lobe of the Hidden Cone center (D. Champion presentation at PVHA Sleeping Butte field trip), and the evidence of significant differences in geochemical composition of the centers (F. Perry presentation at PVHA Workshop 1). The 3-event scenario assumes an undetected event could be associated with the Hidden Cone center, a permissive interpretation given the combination of the location of the center in country rock of Miocene tuff and the center is flanked to the north by extensive outcrops of basaltic lava flows and plugs of Miocene age.

Event counts and relative weights: 1 (0.35), 2 (0.45), and 3 (0.20)

Lathrop Wells

The Lathrop Wells center has been described by Crowe and Carr (1990), Vaniman and Crowe (1981), Vaniman et al. (1982), Crowe et al. (1986), Wells et al. (1990), Turrin et al. (1991), Crowe et al. (1992), and is summarized in Crowe et al. (1995). One to as many as 4 events could be represented at the Lathrop Wells center. One event is given high preference partly because the polygenetic model for the center is not well accepted by the scientific community, but more importantly because polygenetic events are not significant to the PVHA. As many as three undetected events are possible but are given low weights. The possibility of undetected events is based on the complex structural setting of the center and local presence of Miocene tuff beneath the center. The low event-weightings for undetected events are because of the high quality of aeromagnetic coverage for the center, and at least part of the center overlies alluvial deposits.

Event counts and relative weights: 1 (0.90), 2 (0.06), 3 (0.03), 4 (0.01)

SOUTHERN GREAT BASIN REGION

Death Valley

The Death Valley area has not been mapped at the same level of detail as the basalt centers of the YMR. Basaltic volcanic rocks in the Death Valley area of most relevance to PVHA range in age from Pliocene to Quaternary (Crowe et al., 1986). The Quaternary centers include the Split Cone and the basalt of Shoreline Butte and the Quaternary event models range from 2- to 6-event scenarios. The two-event scenario is based on the age differences in the Quaternary events (0.7 and 1.7 Ma; Crowe et al., 1986), the different degree of geomorphic dissection of the centers and their geographic separation (> 5 km separation). The 3-event and 4-event scenarios are based on the observation of multiple vent areas, marked by accumulation of basaltic scoria, for the basalt of Shoreline Butte. The 5-event and 6-event scenarios allow for the possibility of hidden events because of possibly high sedimentation rates in the valley and the presence of pyroclastic surge deposits of unknown origin in drainages on the east side of the valley (Crowe et al., 1986).

Event counts and relative weights (Quaternary Death Valley): 2 (0.30), 3 (0.30), 4 (0.25), 5 (0.10) and 6 (0.05)

Event counts for Pliocene deposits are based on estimations of vent densities for outcrop areas of basaltic volcanic rocks of the 4-4.5 Ma Funeral Formation. Reconnaissance field studies were conducted on these rocks (Crowe et al., 1986) and their outcrop distribution was obtained from geologic maps of Loren Wright (B. Crowe, informal PVHA memo). The number of events is estimated by measuring the approximate surface area of the volcanic rocks, relating them to event densities observed at other basaltic fields (Crowe et al., 1986, 1995) and adding corrections for extensional deformation. The assigned vent densities vary from 0.10 to 0.40 events km^{-2} and are treated as a triangular distribution with the following parameters:

Event counts for the Pliocene Death Valley: minimum model 22 events (0.1 vent km^{-2}), most likely model 44 events (0.2 vent km^{-2}), and maximum model 88 events (0.4 vent km^{-2}).

Clayton Valley

There are no geochronology data for the basalt of Clayton Valley. The author examined the area briefly in a field visit in the early 1980s that included an assessment of its geomorphic state and measurements of magnetic polarity (reversed). The preservation of the center is consistent with a Quaternary age and it is probably > 700 ka based on its reversed polarity. There is only a single cone so the 1-event scenario is preferred. Additional events are added to account for undetected events.

Event counts and relative weights: 1 (0.85), 2 (0.10), 3 (0.05)

Ubehebe Craters

The Quaternary event counts in the Ubehebe area range from 1 to 6 events, with 1 event assigned as the most likely model. The 1-event scenario assumes Ubehebe is a monogenetic center formed during a single eruptive episode. Geologic mapping of the center (Crowe and Fisher, 1973) shows that it can be divided into eruptive sequences including an early scoria cone (Strombolian eruptions) that was partly destroyed by hydrovolcanic eruptions that formed Ubehebe Crater on the north flank of the scoria cone. The 1-event scenario is given a relatively high weighting because there is no evidence of a time break between the eruptive sequences. The 2-event model assumes simply that the strombolian and hydrovolcanic eruptive phases represent separate events. The 3-event and 4-event models allow for additional events to explain clusters of tuff rings/tuff cones and explosion craters on the south and west flanks of the center; these event counts are assigned decreasing weights with increasing event counts. The 5-event and 6-event models allow for undetected events.

Ubehebe event counts and relative weights: 1 (0.60), 2 (0.15), 3 (0.10), 4 (0.10), 5 (0.025), 6 (0.025)

Grapevine Canyon

Geologic mapping of Grapevine Canyon near its intersection with northern Death Valley is insufficient to establish individual event counts. The event-density method used for the southern Death Valley region is applied to an estimated exposure area of 60 km^{-2} but no corrections are made for extension.

Event counts for Grapevine Canyon treating the data as a triangular distribution: minimum model, 6 events (0.1 vent km^{-2}); most likely model, 12 events (0.2 vent km^{-2}); maximum model 24 events (0.4 vent km^{-2})

Basaltic Andesite of Towne Pass

The basaltic andesite of Towne Pass has been described in Crowe (1983) and Crowe et al. (1986) and is estimated to be about 5.0 Ma. The unit has not been mapped in detail and the event assignments are based on estimations of vent densities from an outcrop area of 110 km^2.

Event Counts for Towne Pass treating the data as a triangular distribution: minimum model 11 events (0.1 events km^{-2}); most likely model, 22 events (0.2 events km^{-2}); maximum model 44 events (0.4 events km^{-2})

TEMPORAL MODELS

The preferred temporal model is the homogeneous Poisson model (weight 0.7). A nonhomogeneous Poisson model has been considered by several workers (Ho, 1991; Connor and Hill, 1993; 1995), but gives nearly identical results as the homogeneous Poisson model (Crowe et al., 1995). The sensitivities of time-dependent models, varying ages, and uncertainty for volcanic centers and event counts are judged to be captured largely by choosing observation intervals that correspond to volcanic cycles (Crowe et al., 1995) and assigning probability distributions to the event counts.

Event ages and alternative event ages are summarized in a spreadsheet immediately following this text for all minimum, most likely, and maximum models. These ages are from Crowe et al. (1995), Crowe and Perry (1995) and data presented by F. Perry (presentation at PVHA Workshop 1). These ages are used to calculate β factors for nonstationary temporal models (weight 0.3).

EVENT GEOMETRIES

Dike Dimensions

Data for dike lengths are modified from Crowe et al. (1983b), Maaloe (1987), Barnard et al. (1992), Lister (1990), Lister and Kerr (1991), Sheridan (1992), Wallmann (1993), and Delaney and Gartner

(1995), with modifications for the YMR using observed cluster lengths of centers summarized below. Using theoretical constraints, dike lengths should range from about 0.5 to 10 km (Fedotov, 1978; Crowe et al., 1983b; Maaloe, 1987; Lister and Kerr, 1991). The maximum length of a cluster in the YMR is 12.6 km (Quaternary basalt of Crater Flat). Some constraints on dike lengths may be provided by map data for the Plio-Quaternary basalt centers of the YMR and from considerations of the dimensions of feeder dikes of volcanic centers using geochemical data to identify magma batches at volcanic centers. The following data provide constraints:

Cluster lengths:

(1)	3.7 Ma basalt centers	longest single fissure = 3.2 km en echelon dike length = 4.8 km
(2)	Thirsty Mesa cluster	2.0 km
(3)	Fissure system for the basalt of Buckboard Mesa	3.6 km
(4)	Sleeping Butte cluster	2.6 km
(5)	Red Cone-Black Cone alignment	3.2 km
(6)	Longest fissure at the Lathrop Wells basalt center	< 2.0 km

Clearly some additional length of feeder dikes extends in the subsurface beyond surface outcrops so the data provide minimum constraints. Using all the above data sources, dike-length distributions assigned for the elicitation are:

(1) Triangular Distribution	minimum	=	0.3 km
	most likely	=	3.5 km
	maximum	=	7.0 km
(2) Normal Distribution	mean	=	3.5 km
	standard deviation	=	3.0 km

The weightings for the dike lengths are 0.60 for the triangular distribution and 0.40 for the normal distribution. The preferred location of events on the dike is near the center, and a triangular distribution is used to model event location.

Note: The resulting cumulative distributions and density functions are shown on Figure BC-15.

Dike Orientations

Dike orientations are based on the direction of the maximum compressive stress direction and the orientation of basalt clusters and groups of basalt centers in the YMR. Based on the presentation by G. Walker (PVHA Workshop 4), I judge that the dike orientations should be bimodal with a N-NE mode and a N-NW mode. The relative frequencies are 0.80 for the N-NE set and 0.20 for the N-NW set and are assigned on the basis of the observed predominant alignment of vent clusters in the N-NE direction.

Distribution models for the dike orientations are:

(1) N-NE Dike Set	Triangular Distribution	minimum	=	N-S
		most likely	=	N20°E
		maximum	=	N40°E
(2) N-NW Dike Set	Triangular Distribution	minimum	=	N40°W
		most likely	=	N20°W
		maximum	=	N05°E

Eruption Types

Eruption types are based on the fragment types and sizes in the Pliocene and Quaternary basalt centers of the YMR as summarized in Crowe (1986) and Crowe et al. (1983a; 1983b; 1986; and 1995). The weights for the volcanic events in alluvial basins are:

Mixed Strombolian/Hawaiian	=	0.90
Hydrovolcanic	=	0.10

The weights for volcanic events in range interiors given the deeper depths to the ground water table than alluvial basins are:

Mixed Strombolian/Hawaiian	=	0.95
Hydrovolcanic	=	0.05

Probability of a Return to Silicic Eruptions

There have been no silicic eruptions in the YMR for the last 8.0 Ma. The probability of a future silicic volcanic event must be ~ 1/8,000,000 or 1.2×10^{-7} yr^{-1}. This estimate combined with the cessation of silicic volcanism and migration of sites of silicic volcanism to the margins of the southern Great Basin suggests that the probability of a future silicic volcanic eruption must be $< 10^{-10}$ yr^{-1}.

Bruce Crowe
April 29, 1996

Nonhomogeneous Models: Event Chronology for E1 Incorporating Multiple Alternative Geochronology Models with the Most Likely Models						
EVENT-DISTRIBUTION MODELS	**Event Categories**	***Minimum*** (Ma)	***Most Likely A*** (Ma)	***Most Likely B*** (Ma)	***Most Likely C*** (Ma)	***Maximum*** (Ma)
Model 1 Plio-Quaternary and Quaternary Distribution Models Quaternary Cycle						
Event Ages						
	Quat CF	1.00	1.00	1.00	1.20	1.00
			1.00	1.00	1.00	1.00
			1.00	1.00	1.00	1.00
				0.75	0.75	1.00
						0.75
	Sleeping Butte	0.35	0.43	0.35	0.43	0.35
			0.43	0.35	0.35	0.35
	Lathrop	0.13	0.13	0.70	0.70	0.13
	Thirsty Mesa	4.90	4.90	4.90	4.90	4.90
						4.90
						4.90
	Amargosa	3.90	3.90	4.40	3.90	3.90
		3.90	3.90	4.40	3.90	3.90
		3.90	3.90	4.40	3.90	3.90
		3.90	3.90	4.40	3.90	3.90
			3.50	3.50	3.50	3.90
						3.50
	3.7 basalt CF	3.70	3.70	3.70	3.70	3.70
			3.70	3.70	3.70	3.70
			3.70	3.70	3.70	3.70
			3.70	3.70	3.70	3.70
			3.70	3.70	3.70	3.70
			3.70	3.70	3.70	3.70
						3.70
						3.70
	Buckboard	(not included in CFVZ)				
	Quat CF	1.00	1.00	1.00	1.20	1.00
			1.00	1.00	1.00	1.00
			1.00	1.00	1.00	1.00
				0.75	0.75	1.00
						0.75
	Sleeping Butte	0.35	0.43	0.35	0.43	0.35
			0.43	0.35	0.35	0.35
	Lathrop	0.13	0.13	0.70	0.70	0.13

	Event Categories	Minimum	Most Likely A	Most Likely B	Most Likely C	Maximum
Model 2 Younger Postcaldera Basalt		(Ma)	(Ma)	(Ma)	(Ma)	(Ma)
Quaternary Cycle						
Event Ages	Quat CF	1.00	1.00	1.00	1.20	1.00
			1.00	1.00	1.00	1.00
			1.00	1.00	1.00	1.00
				0.75	0.75	1.00
						0.75
	Sleeping Butte	0.35	0.43	0.35	0.43	0.35
			0.43	0.35	0.35	0.35
	Lathrop	0.13	0.13	0.70	0.70	0.13
Plio-Quaternary						
Event Ages	Thirsty Mesa	4.90	4.90	4.90	4.90	4.90
						4.90
						4.90
	Amargosa	3.90	3.90	4.40	3.90	3.90
		3.90	3.90	4.40	3.90	3.90
		3.90	3.90	4.40	3.90	3.90
		3.90	3.90	4.40	3.90	3.90
			3.50	3.50	3.50	3.90
						3.50
	3.7 Basalt CF	3.70	3.70	3.70	3.70	3.70
			3.70	3.70	3.70	3.70
			3.70	3.70	3.70	3.70
			3.70	3.70	3.70	3.70
			3.70	3.70	3.70	3.70
				3.70	3.70	3.70
						3.70
						3.70
	Buckboard	2.90	2.90	3.10	3.10	2.90
	Quat CF	1.00	1.00	1.00	1.20	1.00
			1.00	1.00	1.00	1.00
			1.00	1.00	1.00	1.00
				0.75	0.75	1.00
						0.75
	Sleeping Butte	0.35	0.43	0.35	0.43	0.35
			0.43	0.35	0.35	0.35
	Lathrop	0.13	0.13	0.70	0.70	0.13

Model 3	Event Categories	Minimum	Most Likely A	Most Likely B	Most Likely C	Maximum
Postcaldera Basalt			(Ma)	(Ma)	(Ma)	(Ma)
Mio-Quaternary						
Event Ages	Rocket Wash	8.00	8.00			8.00
	Silent Canyon	9.10	9.10	9.10	9.10	9.10
		8.80	8.80	8.80	8.80	9.10
		8.80	8.80	8.80	8.80	9.10
						8.80
						8.80
						8.80
						8.80
	Yucca Flat	8.10	8.10	8.10	8.10	8.10
						8.10
						8.10
	Paiute Ridge	8.60	8.60	8.60	8.60	8.60
		8.60	8.60	8.60	8.60	8.60
			8.60	8.60	8.60	8.60
						8.60
						8.60
	Scarp Canyon	8.70	8.70	8.70	8.70	8.70
		8.60	8.60	8.60	8.60	8.70
						8.60
						8.60
						8.60
	Nye Canyon	6.60	6.30	6.30	6.30	6.30
		7.20	6.80	6.80	6.80	6.80
			7.20	7.20	7.20	7.20
			7.20	7.20	7.20	7.20
			7.00	7.00	7.00	7.20
						7.00
						7.00
						7.00
	Quat CF	1.00	1.00	1.00	1.20	1.00
			1.00	1.00	1.00	1.00
			1.00	1.00	1.00	1.00
				0.75	0.75	1.00
						0.80
	Sleeping Butte	0.35	0.43	0.35	0.43	0.38
			0.43	0.35	0.35	0.38
	Lathrop	0.13	0.13	0.70	0.70	0.13
	Thirsty Mesa	4.90	4.90	4.90	4.90	4.90
						4.90
						4.90
	Amargosa	3.90	3.90	4.40	3.90	3.90
		3.90	3.90	4.40	3.90	3.90
		3.90	3.90	4.40	3.90	3.90
		3.90	3.90	4.40	3.90	3.90
			3.50	3.50	3.50	3.90
						3.5

Model 3 (cont.)	Event Categories	Minimum	Most Likely A	Most Likely B	Most Likely C	Maximum
Postcaldera Basalt			(Ma)	(Ma)	(Ma)	(Ma)
Mio-Quaternary						
	3.7 basalt CF	3.70	3.70	3.70	3.70	3.70
			3.70	3.70	3.70	3.70
			3.70	3.70	3.70	3.70
			3.70	3.70	3.70	3.70
			3.70	3.70	3.70	3.70
				3.70	3.70	3.70
						3.70
						3.70
	Buckboard	2.90	2.90	3.10	3.10	2.90
	Quat CF	1.00	1.00	1.00	1.20	1.00
			1.00	1.00	1.00	1.00
			1.00	1.00	1.00	1.00
				0.75	0.75	1.00
						0.75
	Sleeping Butte	0.35	0.43	0.35	0.43	0.35
			0.43	0.35	0.35	0.35
	Lathrop	0.13	0.13	0.70	0.70	0.13

	Event Categories	Minimum	Most Likely A	Most Likely B	Most Likely C	Maximum
STRUCTURAL-TECTONIC MODELS		(Ma)	(Ma)	(Ma)	(Ma)	(Ma)
Model 1 Pull Apart Basin						
Quaternary Cycle						
Event ages	Quat CF	1.00	1.00	1.00	1.20	1.00
			1.00	1.00	1.00	1.00
			1.00	1.00	1.00	1.00
				0.75	0.75	1.00
						0.75
	Lathrop Wells	0.13	0.13	0.70	0.70	0.13
Model 1 (cont.)						
Plio-Quaternary Cycle						
Event Ages	Amargosa	3.90	3.90	4.40	3.90	3.90
		3.90	3.90	4.40	3.90	3.90
		3.90	3.90	4.40	3.90	3.90
		3.90	3.90	4.40	3.90	3.90
			3.50	3.50	3.50	3.90
						3.50
	3 7 basalt CF	3.70	3.70	3.70	3.70	3.70
			3.70	3.70	3.70	3.70
			3.70	3.70	3.70	3.70
			3.70	3.70	3.70	3.70
			3.70	3.70	3.70	3.70
				3.70	3.70	3.70
						3.70
						3.70
	Quat CF	1.00	1.00	1.00	1.20	1.00
			1.00	1.00	1.00	1.00
			1.00	1.00	1.00	1.00
						0.75
	Lathrop Wells	0.13	0.13	0.70	0.70	0.13

	Event Categories	*Minimum*	*Most Likely A*	*Most Likely B*	*Most Likely C*	*Maximum*
Quaternary Volcanic Cycle		(Ma)	(Ma)	(Ma)	(Ma)	(Ma)
Event Ages	Quat CF	1.00	1.00	1.00	1.20	1.00
			1.00	1.00	1.00	1.00
			1.00	1.00	1.00	1.00
				0.75	0.75	1.00
						0.75
	Sleeping Butte	0.35	0.43	0.35	0.43	0.35
			0.43	0.35	0.35	0.35
	Lathrop	0.13	0.13	0.70	0.70	0.13
Plio-Quaternary Younger Postcaldera Basalt						
Event Ages	Thirsty Mesa	4.90	4.90	4.90	4.90	4.90
						4.90
						4.90
	Amargosa	3.90	3.90	4.40	3.90	3.90
		3.90	3.90	4.40	3.90	3.90
		3.90	3.90	4.40	3.90	3.90
		3.90	3.90	4.40	3.90	3.90
			3.50	3.50	3.50	3.90
						3.50
	3.7 basalt CF	3.70	3.70	3.70	3.70	3.70
			3.70	3.70	3.70	3.70
			3.70	3.70	3.70	3.70
			3.70	3.70	3.70	3.70
			3.70	3.70	3.70	3.70
			3.70	3.70	3.70	3.70
						3.70
						3.70
	Buckboard	(not included in WLSZ)				
	Quat CF	1.00	1.00	1.00	1.20	1.00
			1.00	1.00	1.00	1.00
			1.00	1.00	1.00	1.00
				0.75	0.75	1.00
						0.75
	Sleeping Butte	0.35	0.43	0.35	0.43	0.35
			0.43	0.35	0.35	0.35
	Lathrop	0.13	0.13	0.70	0.70	0.13

	Event Categories	*Minimum*	*Most Likely A*	*Most Likely B*	*Most Likely C*	*Maximum*
Northeast Structural Zone Quaternary Cycle						
Event Ages	Quat CF	1.00	1.00	1.00	1.20	1.00
			1.00	1.00	1.00	1.00
			1.00	1.00	1.00	1.00
				0.75	0.75	1.00
						0.75
	Lathrop Wells	0.13	0.13	0.70	0.70	0.13
Model 3 (cont.)						
Quaternary Cycle-KG (includes Death Valley)						
Event Ages	Shoreline Butte	1.70	1.70	1.70	1.70	1.70
		1.70	1.70	1.70	1.70	1.70
			1.70	1.70	1.70	1.70
						1.70
						1.70
	Split Cone	0.70	0.70	0.70	0.70	0.70
	Quat CF	1.00	1.00	1.00	1.20	1.00
			1.00	1.00	1.00	1.00
			1.00	1.00	1.00	1.00
				0.75	0.75	1.00
						0.75
	Lathrop Wells	0.13	0.13	0.70	0.70	0.13
Model 3 (cont)						
Plio-Quaternary						
Event Ages	Amargosa	3.90	3.90	4.40	3.90	3.90
		3.90	3.90	4.40	3.90	3.90
		3.90	3.90	4.40	3.90	3.90
		3.90	3.90	4.40	3.90	3.90
			3.50	3.50	3.50	3.90
						3.50
	3.7 basalt CF	3.70	3.70	3.70	3.70	3.70
			3.70	3.70	3.70	3.70
			3.70	3.70	3.70	3.70
			3.70	3.70	3.70	3.70
			3.70	3.70	3.70	3.70
				3.70	3.70	3.70
						3.70
						3.70
	Buckboard	2.90	2.90	3.10	3.10	2.90
	Quat CF	1.00	1.00	1.00	1.20	1.00
			1.00	1.00	1.00	1.00
			1.00	1.00	1.00	1.00
				0.75	0.75	1.00
						0.75
	Lathrop Wells	0.13	0.13	0.70	0.70	0.13

	Event Categories	*Minimum*	*Most Likely A*	*Most Likely B*	*Most Likely C*	*Maximum*
		(Ma)	(Ma)	(Ma)	(Ma)	(Ma)
Quaternary Cycle						
Event Ages	Clayton Valley	1.70	1.70	1.70	1.70	1.70
						1.70
	Shoreline Butte	1.70	1.70	1.70	1.70	1.70
		1.70	1.70	1.70	1.70	1.70
			1.70	1.70	1.70	1.70
						1.70
						1.70
	Quat CF	1.00	1.00	1.00	1.20	1.00
			1.00	1.00	1.00	1.00
			1.00	1.00	1.00	1.00
				0.75	0.75	1.00
						0.75
	Split Cone	0.70	0.70	0.70	0.70	0.70
	Sleeping Butte	0.35	0.43	0.35	0.43	0.35
			0.43	0.35	0.35	0.35
	Lathrop Wells	0.13	0.13	0.07	0.07	0.13
	Ubehebe	0.05	0.05	0.02	0.05	0.02
			0.05	0.02	0.05	0.02
						0.02
						0.02
						0.02

Southern Great Basin (cont)	
Plio-Quaternary Cycle	***insufficient geochronology data to make age assignments***

	Event Categories	*Minimum*	*Most Likely A*	*Most Likely B*	*Most Likely C*	*Maximum*
Quaternary Cycle		(Ma)	(Ma)	(Ma)	(Ma)	(Ma)
Event Ages	Shoreline Butte	1.70	1.70			1.70
			1.70			1.70
						1.70
	Quat CF	1.00	1.00	1.00	1.20	1.00
			1.00	1.00	1.00	1.00
			1.00	1.00	1.00	1.00
				0.75	0.75	1.00
						0.75
	Split Cone	0.70	0.70	0.70	0.70	0.70
	Sleeping Butte	0.35	0.43	0.35	0.43	0.35
			0.43	0.35	0.35	0.35
	Lathrop Wells	0.13	0.13	0.70	0.70	0.13

AVIP (cont)	
Pliocene Cycle	***insufficient geochronology data to make age assignments***

Postcaldera Basalt **Same as the Postcaldera distribution model** **Regional Model**

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TABLE BC-1
MINIMUM PROBABILITY BOUNDS FROM REGIONAL MODELS

Zones	Area	Event Counts			Recurrence Rates (events yr^{-1} km^2)			Disruption Probability (events yr^{-1})		
	km^2	1.8 Ma	5.05 Ma	9.15 Ma	1.8 Ma	5.05 Ma	9.15 Ma	1.8 Ma	5.05 Ma	9.15 Ma
SGB	19874	10	100	9.15	$2.8\cdot10^{-10}$	$1.0\cdot10^{-09}$	- -	$1.6\cdot10^{-9}$	$5.7\cdot10^{-09}$	- -
AVIP	7636	9	664	- -	$6.5\cdot10^{-10}$	$1.7\cdot10^{-08}$	- -	$3.7\cdot10^{-09}$	$9.8\cdot10^{-08}$	- -
PCB	5649	6	17	31	$5.9\cdot10^{-10}$	$6.0\cdot10^{-10}$	$60\cdot10^{-10}$	$3.4\cdot10^{-09}$	$3.4\cdot10^{-09}$	$3.4\cdot10^{-09}$

TABLE BC-2
MAXIMUM PROBABILITY BOUNDS FOR VOLCANIC ZONES OF THE PCB ASSUMING LOCATION OF A REPOSITORY IN THE ZONES

Zones	Area	Event Counts			Recurrence Rates (events yr^{-1} km^2)			Disruption Probability (events yr^{-1})		
	Area km^2	1.15 Ma	5.05 Ma	9.15 Ma	1.15 Ma	5.05 Ma	9.15 Ma	1.15Ma	5.05 Ma	9.15 Ma
CFVZ-Quat	514	6	- -	- -	$1.0\cdot10^{-08}$	--	--	$5.8\cdot10^{-08}$	--	--
CFVZ-Plio-Quat	1068	- -	16	- -	--	$3.0\cdot10^{-09}$	--	--	$1.7\cdot10^{-08}$	--
YPC*	1884	7	17	- -	$3.2\cdot10^{-09}$	$1.8\cdot10^{-09}$	--	$1.8\cdot10^{-08}$	$1.0\cdot10^{-08}$	--
PCB**	5649	- -	- -	31	--	--	$6.0\cdot10^{-10}$	--	--	$3.4\cdot10^{-09}$
Pull-Apart/Quat	242	4	- -	- -	$1.4\cdot10^{-08}$	--	--	$8.2\cdot10^{-08}$	--	--
Pull-Apart/Quat***	149	4	- -	- -	$2.3\cdot10^{-08}$	--	--	$1.3\cdot10^{-07}$	--	--
Pull-Apart/Plio-Quat	506	- -	10	- -	--	$3.9\cdot10^{-09}$	--	--	$2.2\cdot10^{-08}$	--
Walker Lane	1452	6	16	- -	$3.6\cdot10^{-09}$	$2.2\cdot10^{-09}$	--	$2.0\cdot10^{-08}$	$1.2\cdot10^{-08}$	--
NESZ	2176	4	14	- -	$1.6\cdot10^{-09}$	$1.3\cdot10^{-09}$	--	$9.1\cdot10^{-09}$	$7.3\cdot10^{-09}$	--

* A Quaternary YPC is not listed because it is identical to the CFVZ-Quaternary
** Identical to the YMR Regional Model
*** A subdivision of the Pull-Apart Quaternary model that uses the fault models of George Thompson

TABLE BC-3
BRUCE M. CROWE - EVENT COUNTS

LOCATION	COUNTS (CONES)	WEIGHT	NOTES
Lathrop Wells	1 2 3 4	(0.9) (0.06) (0.03) (0.01)	A-G: Aeromagnetic anomalies of V. Langenheim, USGS BC: Black Cone HC: Hidden Cone 2HC: 2 events at Hidden Cone LBP: Little Black Peak LC: Little Cones 2LC: 2 events at Little Cone M: Makani Cone RC: Red Cone SC: Split Cone SB: Shoreline Butte 2SB: 2 events at Shoreline Butte 3SB: 3 events at Shoreline Butte u: undetected
Sleeping Butte	1 (LBP+HC) 2 (LBP, HC) 3 (LBP, 2HC)	(0.35) (0.45) (0.2)	
1.0 Ma Crater Flat	1 (all) 2 (RC+LC.BC+M) 3 (LC, RC+BC, M) 4 (LC.RC.BC.M) 5 (2LC, RC, BC, M) 6 (A, RC, BC, M, 2LC) 7 (u)	(0.1) (0.1) (0.45) (0.2) (0.1) (0.025) (0.025)	
Buckboard Mesa	1 2 3 (u)	(0.7) (0.25) (0.05)	
3.7 Ma Crater Flat	1 2 3 4 5 6 7 (u) 8 (2u)	(0.1) (0.25) (0.25) (0.1) (0.1) (0.1) (0.05) (0.05)	
Amargosa Valley	3 4 5 6 7 (u) 8 (u) 9 (2u) 10 (3u) 11 (4u) 12 (5u)	(0.05) (0.12) (0.2) (0.2) (0.2) (0.1) (0.07) (0.03) (0.02) (0.01)	
Thirsty Mesa	1 2 3	(0.85) (0.09) (0.06)	

TABLE BC-3 (Cont'd)
BRUCE M. CROWE - EVENT COUNTS

LOCATION	COUNTS (CONES)	WEIGHT	NOTES
Death Valley (2 Ma)	2 (SC, SB)	(0.3)	
	3 (2SB, SC)	(0.3)	
	4 (3SB, SC)	(0.25)	
	5 (3SB, SC+u)	(0.1)	
	6 (3SB, SC +2u)	(0.05)	
Death Valley (3-5 Ma)	22 Density Estimates	(0.185)	
	44 " "	(0.63)	
	89 " "	(0.185)	
Clayton Valley	1	(0.85)	
	2 (u)	(0.1)	
	3 (2u)	(0.05)	
Ubehebe	1	(0.6)	
	2	(0.15)	
	3	(0.1)	
	4		
	5 (u)		
	6 (2u)		
Towne Pass	11 Density Estimates	(0.185)	
	22 " "	(0.63)	
	44 " "	(0.185)	
Grapevine Canyon	6 Density Estimates	(0.185)	
	12 " "	(0.63)	
	24 " "	(0.185)	
Nye Canyon	1	(0.02)	
	2	(0.2)	
	3	(0.2)	
	4	(0.16)	
	5	(0.16)	
	6 (u)	(0.12)	
	7 (2u)	(0.08)	
	8 (3u)	(0.04)	
	9 (4u)	(0.02)	

TABLE BC-3 (Cont'd)
BRUCE M. CROWE - EVENT COUNTS

LOCATION	COUNTS (CONES)	WEIGHT	NOTES
Paiute Ridge	1 2 3 4 5 (u)	(0.35) (0.35) (0.15) (0.1) (0.05)	
Yucca Flat	1 2 3 (u)	(0.4) (0.4) (0.2)	
Pahute Mesa	3 4 5 6 (u) 7 (u)	(0.5) (0.2) (0.15) (0.1) (0.05)	

TABLE BC-4
BRUCE M. CROWE - RATES OF OCCURRENCE

<table>
<tr><th>TIME PERIOD</th><th>COUNT METHOD FOR ZONES</th><th>NOTES</th></tr>
<tr><td>Quaternary
(post-1.15 Ma)</td><td>CF: (LW+NCF+SB)
PA: (LW+NCF)
WL: (LW+NCF+SB)
NE: (LW+NCF)
SGB: (DV2+U+CV)
AVIP: (DV2)</td><td rowspan="3">AV: Amargosa Valley
AVIP: Amargosa Valley Isotopic Province of Yogodzinski (1995)
BM: Buckboard Mesa
CF: Crater Flat
CV: Clayton Valley
DV2: Death Valley (2 Ma)
DV5: Death Valley (3-5 Ma)
GV: Grapevine Canyon
LW: Lathrop Wells
NC: Nye Canyon
NCF: Northern (1.0 Ma) Crater Flat
NE: North East
PCB: Post Caldera Basalts
PA: Pull apart and Pull apart with fault
PM: Pahute Mesa
PR: Paiute Ridge
RW: Rocket Wash
SB: Sleeping Butte
SC: Scarp Canyon
SGB: Southern Great Basin
TM: Thirsty Mesa
TP: Towne Pass
U: Ubehebe
WL: Walker Lane
YF: Yucca Flat
YPCB: Younger Post-Caldera Basalts
3.7: 3.7 Ma Crater Flat</td></tr>
<tr><td>Plio-Quaternary
(post-5.05 Ma)</td><td>CF: (LW+NCF+3.7+AV+SB+TM)
YPCB: (LW+NCF+3.7+AV+SB+TM +BM)
PA: (LW+NCF+3.7+AV)
WL: (LW+NCF+3.7+AV+SB+TM)
NE: (LW+NCF+3.7+AV+BM)
SGB: (DV2+DV5+U+CV+TP+GV)
AVIP: (DV2+DV5)</td></tr>
<tr><td>Mio-Plio-Quaternary
(post-9.05 Ma)</td><td>PCB: (LW+NCF+3.7+AV+SB+TM +BM+PM+PR+SC+RW+YF +NC)</td></tr>
</table>

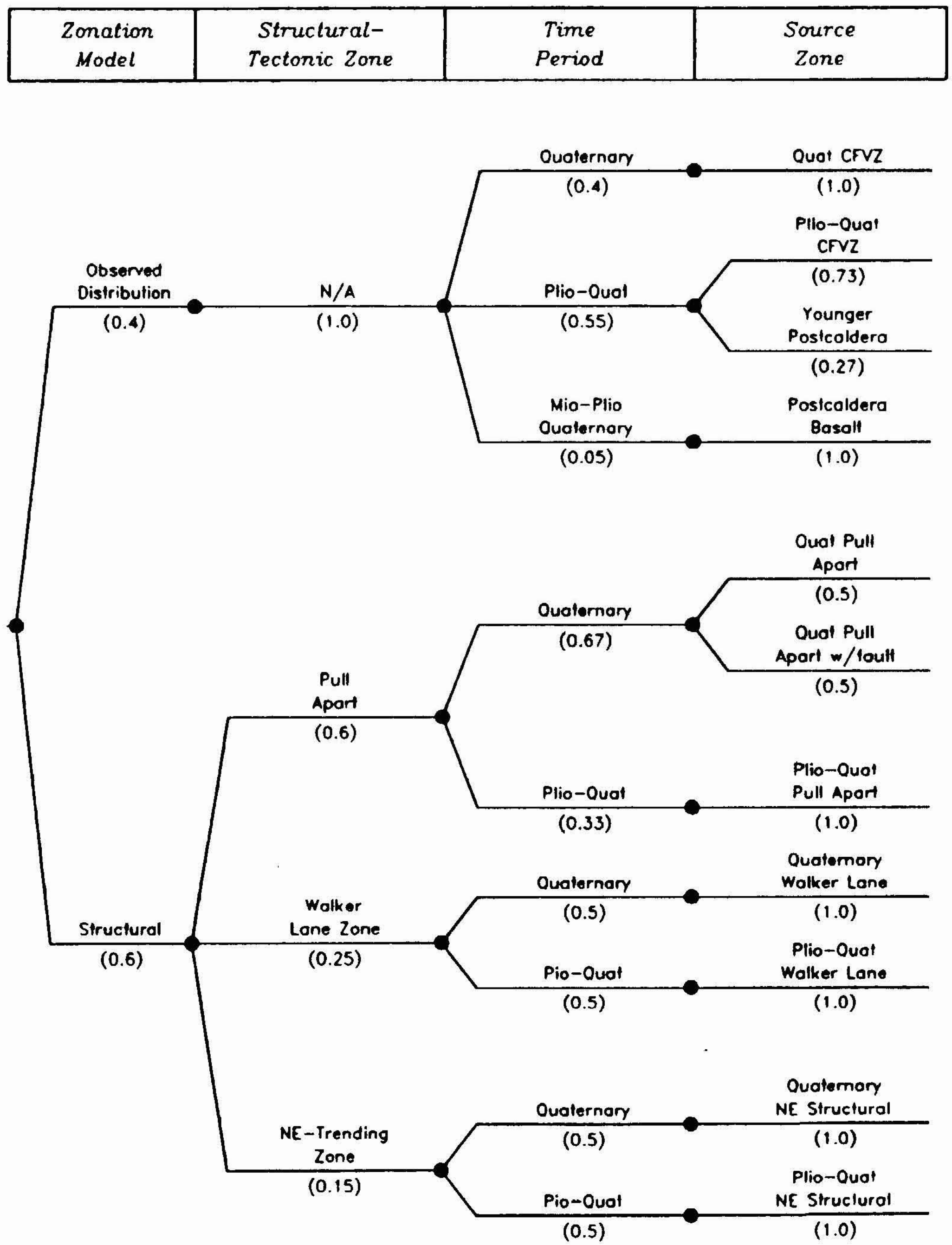
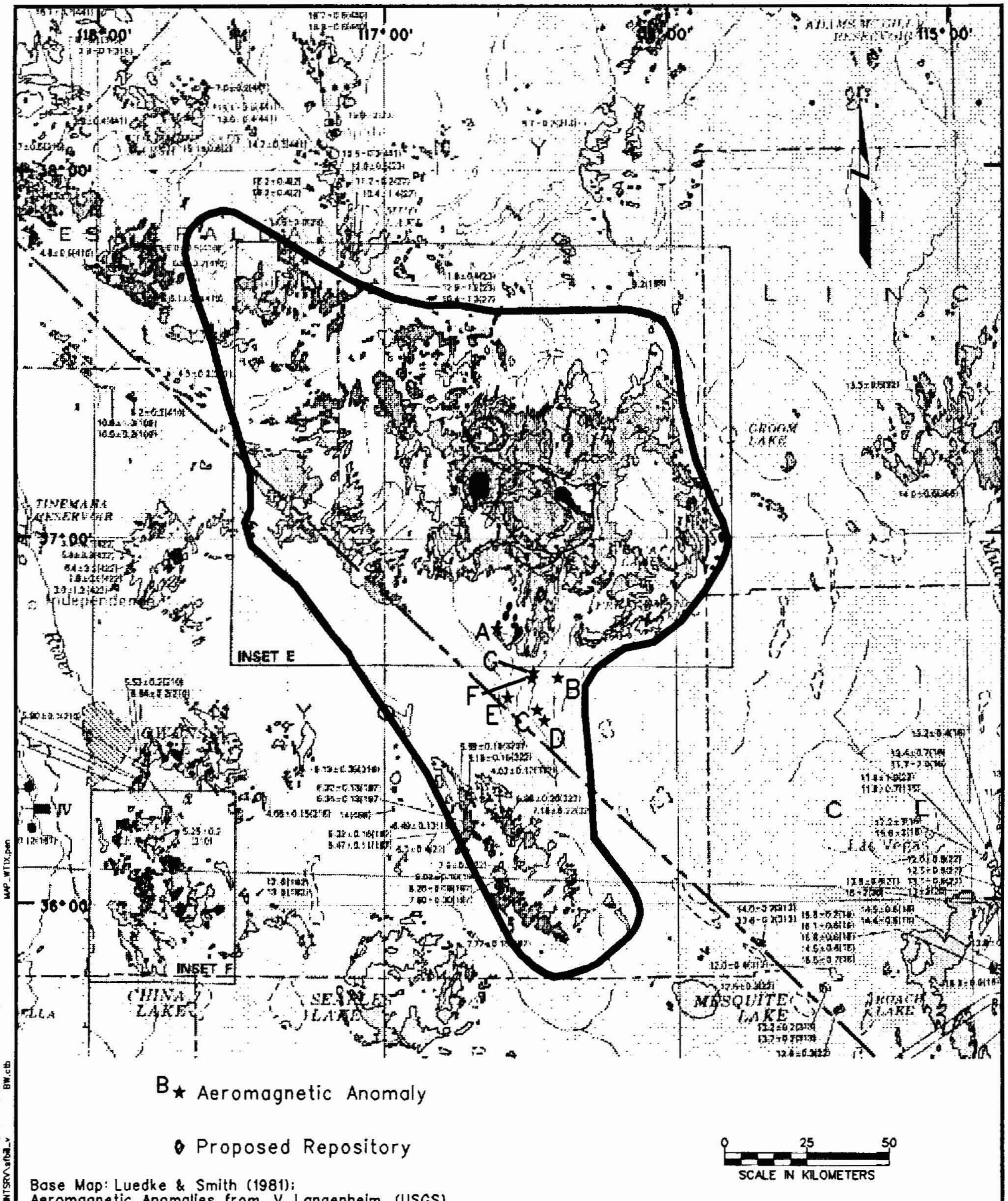


Figure BC-1 PVHA model logic tree developed by Bruce M. Crowe.

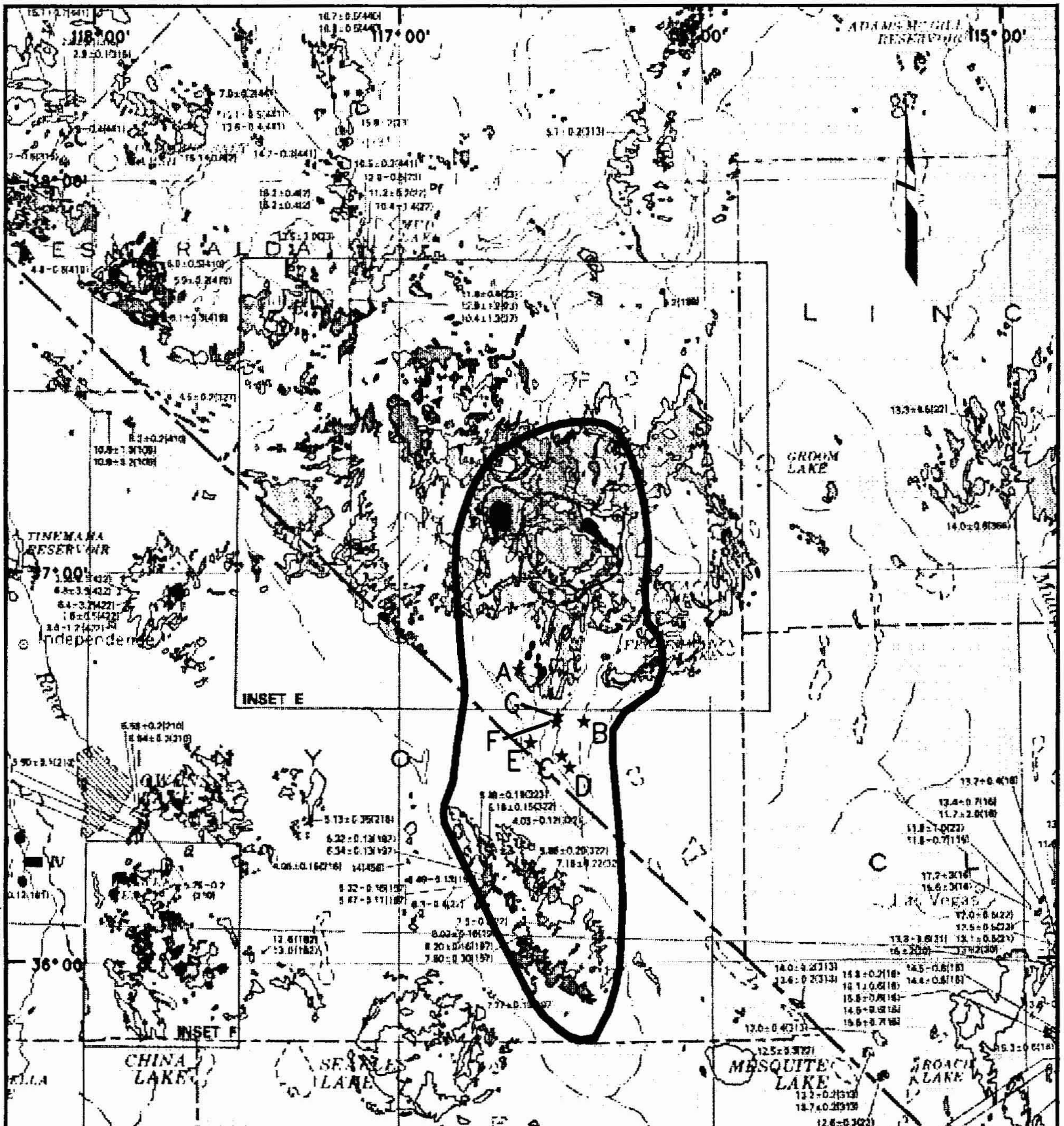


GEOMATRIX

BRUCE M. CROWE
REGIONAL BACKGROUND ZONE:
SOUTHERN GREAT BASIN

Figure BC-2

PVHA Project



B★ Aeromagnetic Anomaly

Proposed Repository

SCALE IN KILOMETERS 0 25 50

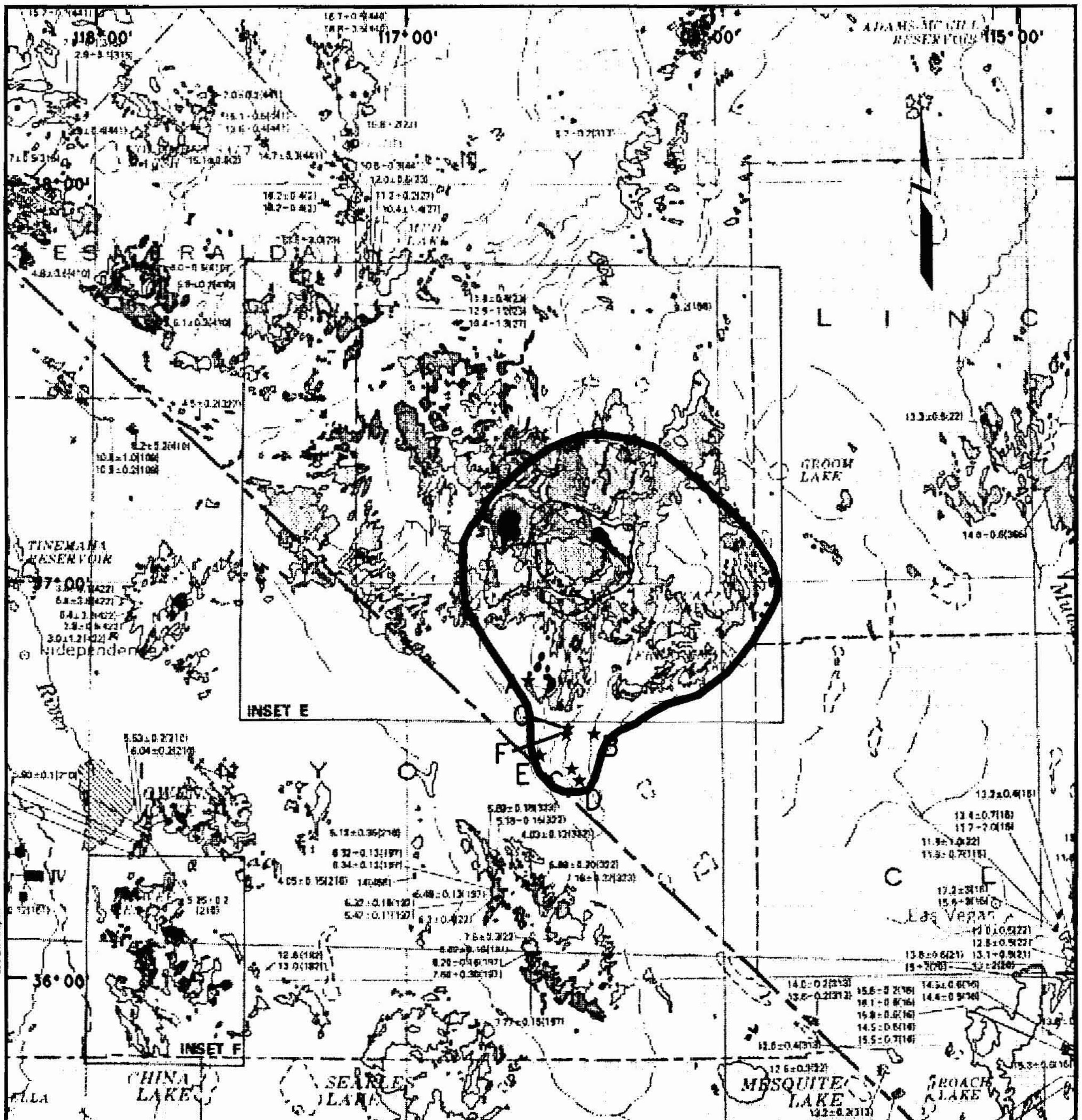
Base Map: Luedke & Smith (1981);
Aeromagnetic Anomalies from V Langenheim (USGS)

GEOMATRIX

BRUCE M. CROWE
REGIONAL BACKGROUND ZONE:
AVIP

Figure BC-3

PVHA Project



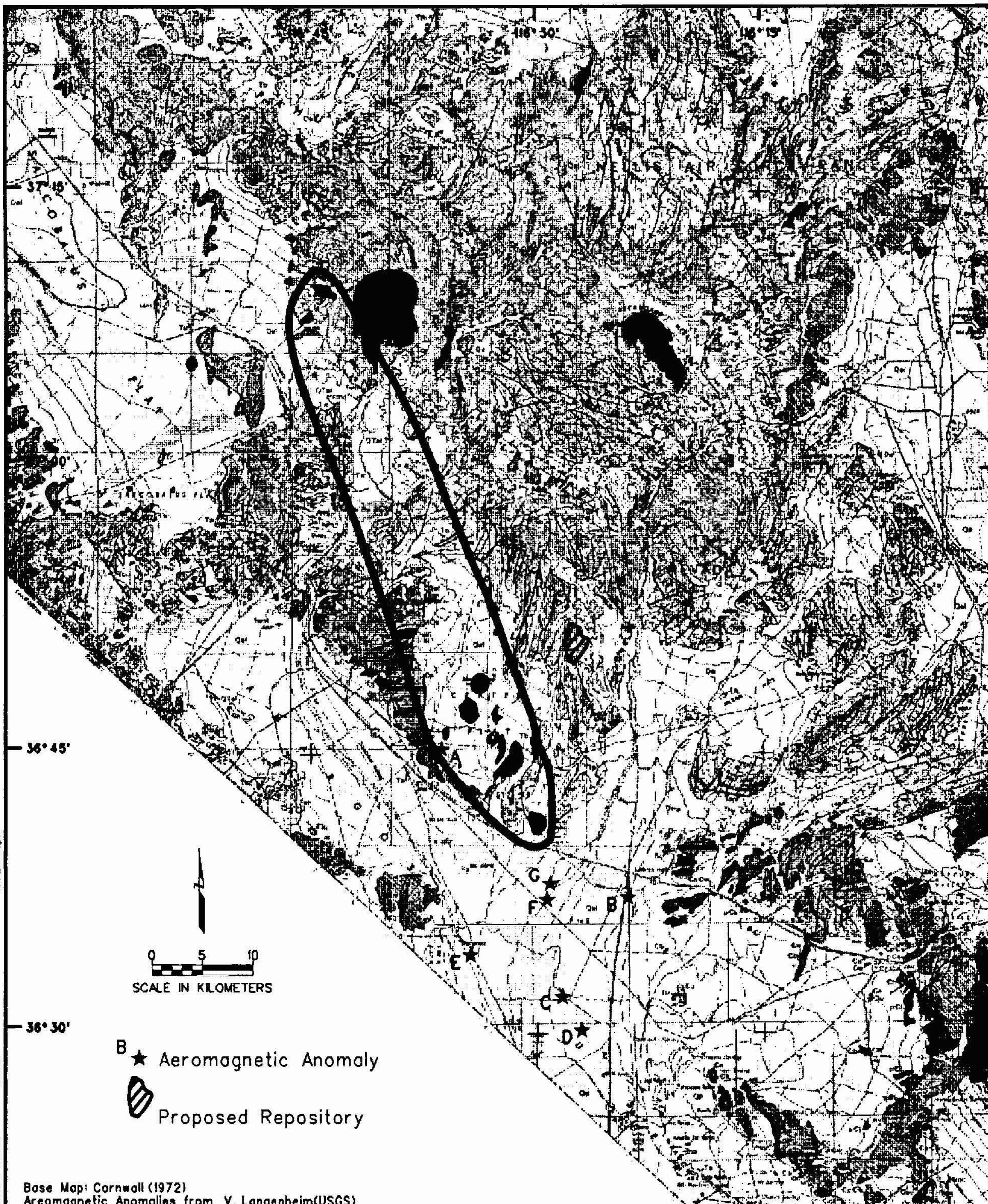
B★ Aeromagnetic Anomaly

● Proposed Repository

0 25 50
SCALE IN KILOMETERS

Base Map: Luedke & Smith (1981);
Aeromagnetic Anomalies from V Langenheim (USGS)

GEOMATRIX	BRUCE M. CROWE REGIONAL BACKGROUND ZONE: POST-CALDERA BASALTS	Figure BC-4
		PVHA Project

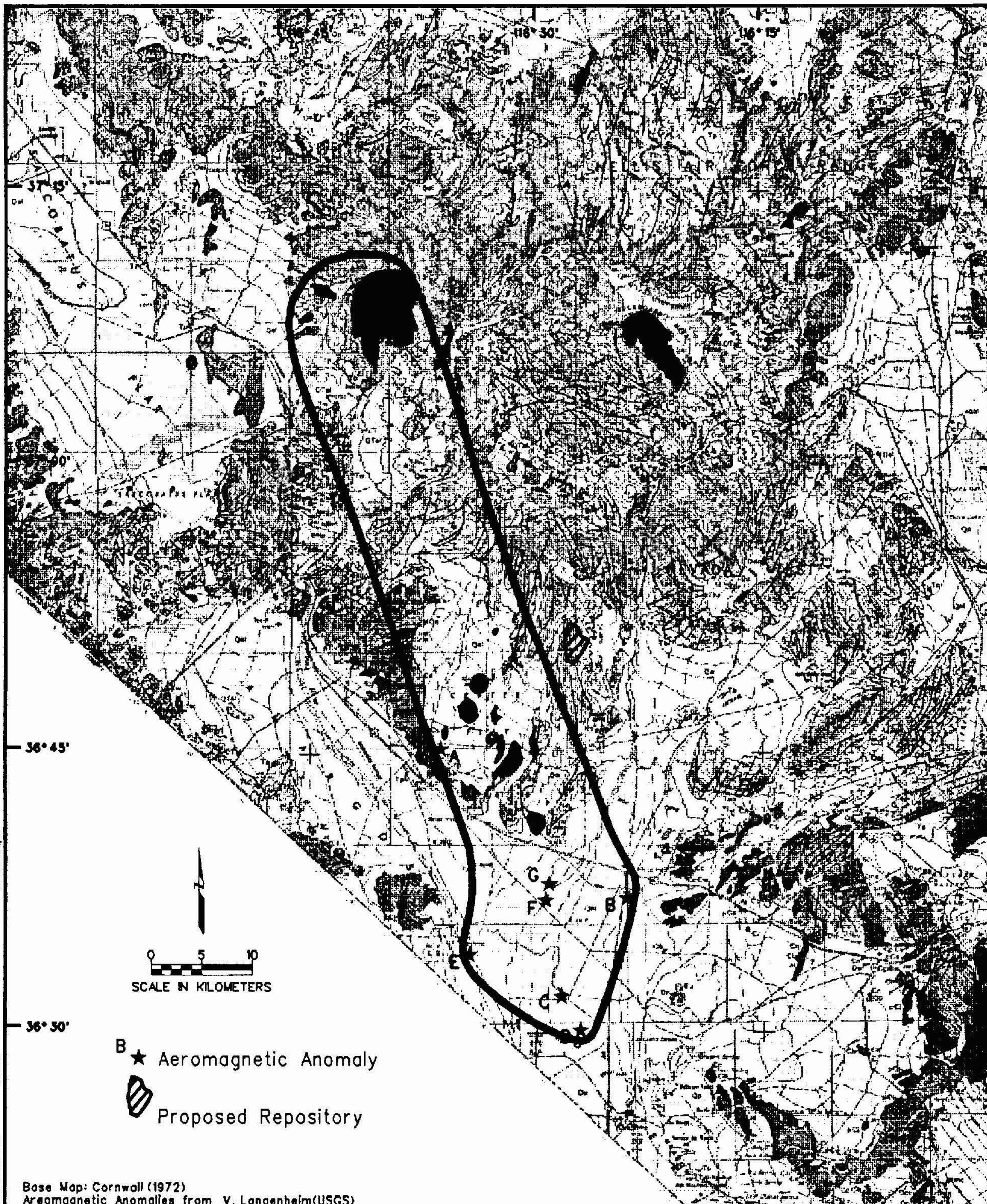


GEOMATRIX

BRUCE M. CROWE
QUATERNARY CRATER FLAT
VOLCANIC ZONE

Figure BC-5

PVHA Project

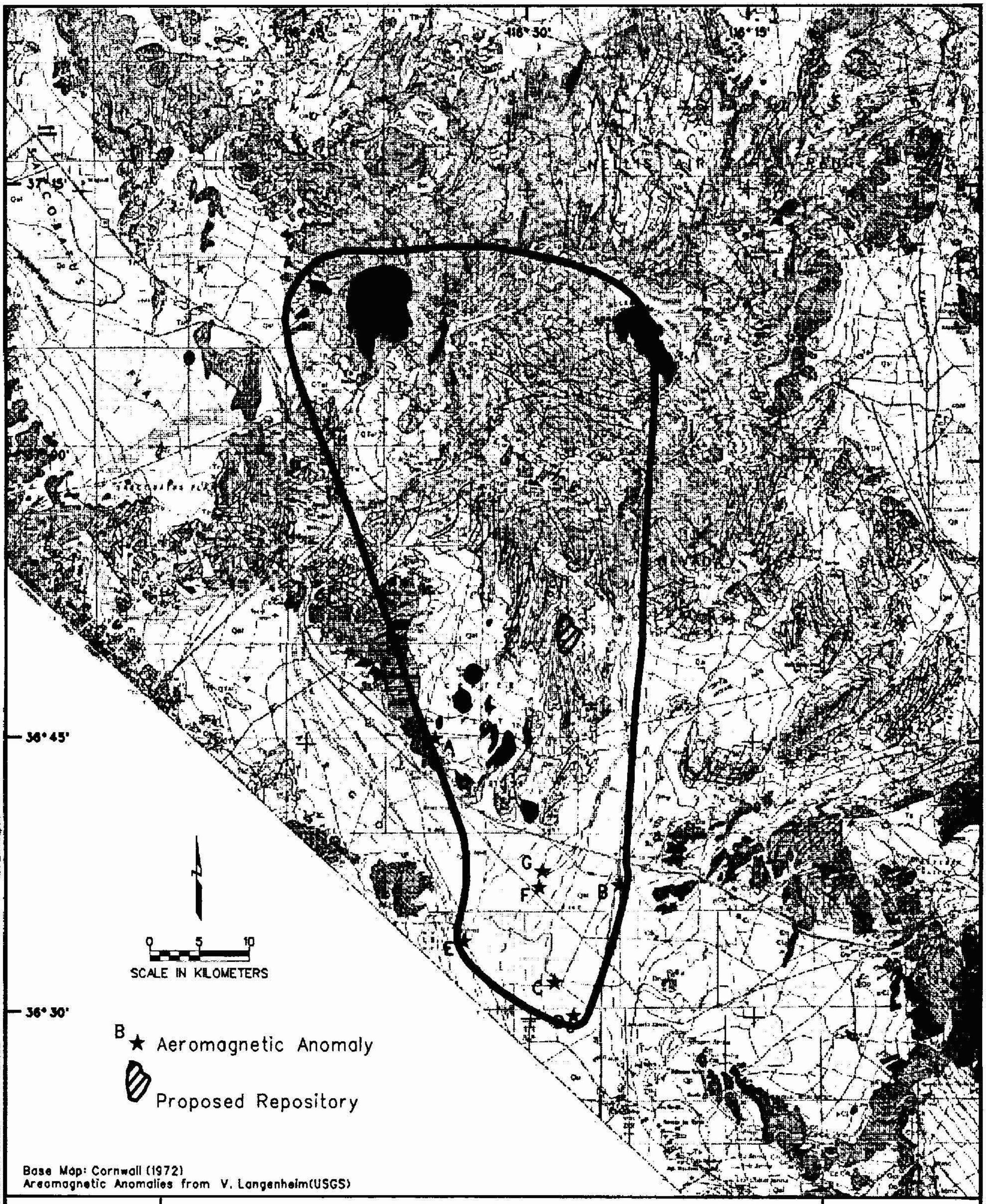


GEOMATRIX

BRUCE M. CROWE
PLIO-QUATERNARY CRATER
FLAT VOLCANIC ZONE

Figure BC-6

PVHA Project

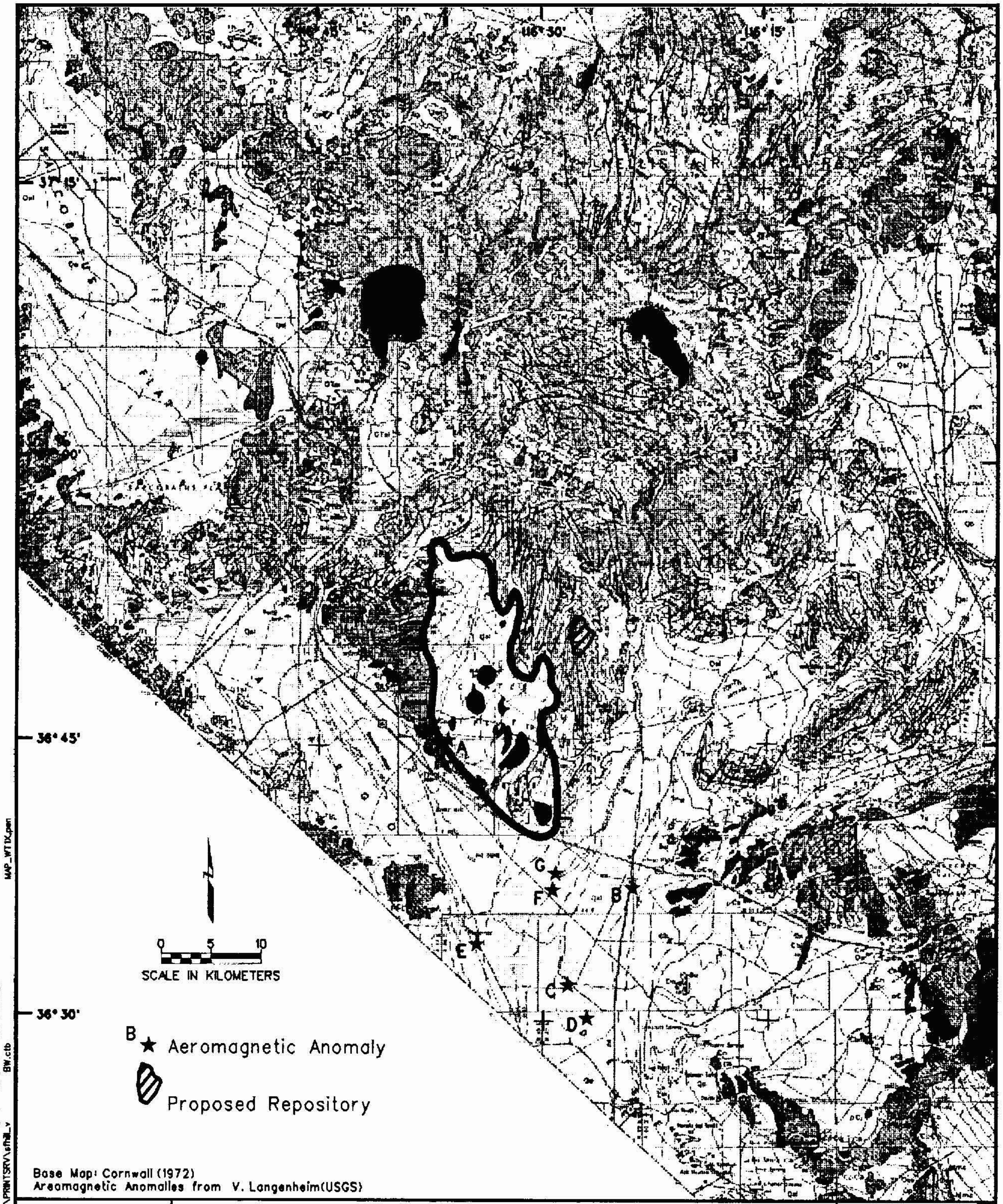


GEOMATRIX

BRUCE M. CROWE
YOUNGER POST-CALDERA ZONE

Figure BC-7

PVHA Project

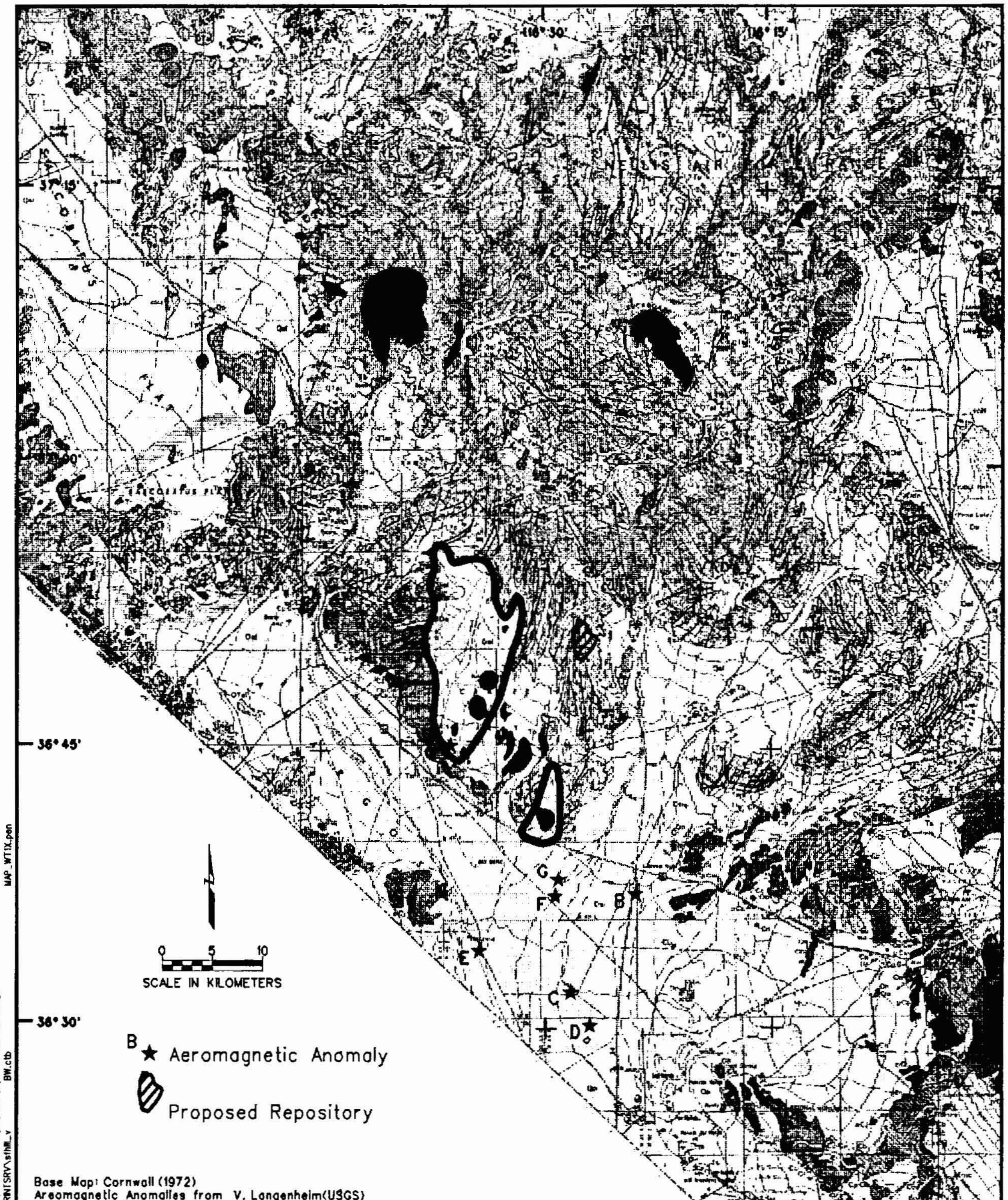


GEOMATRIX

BRUCE M. CROWE
QUATERNARY PULL-APART
ZONE

Figure BC-8

PVHA Project

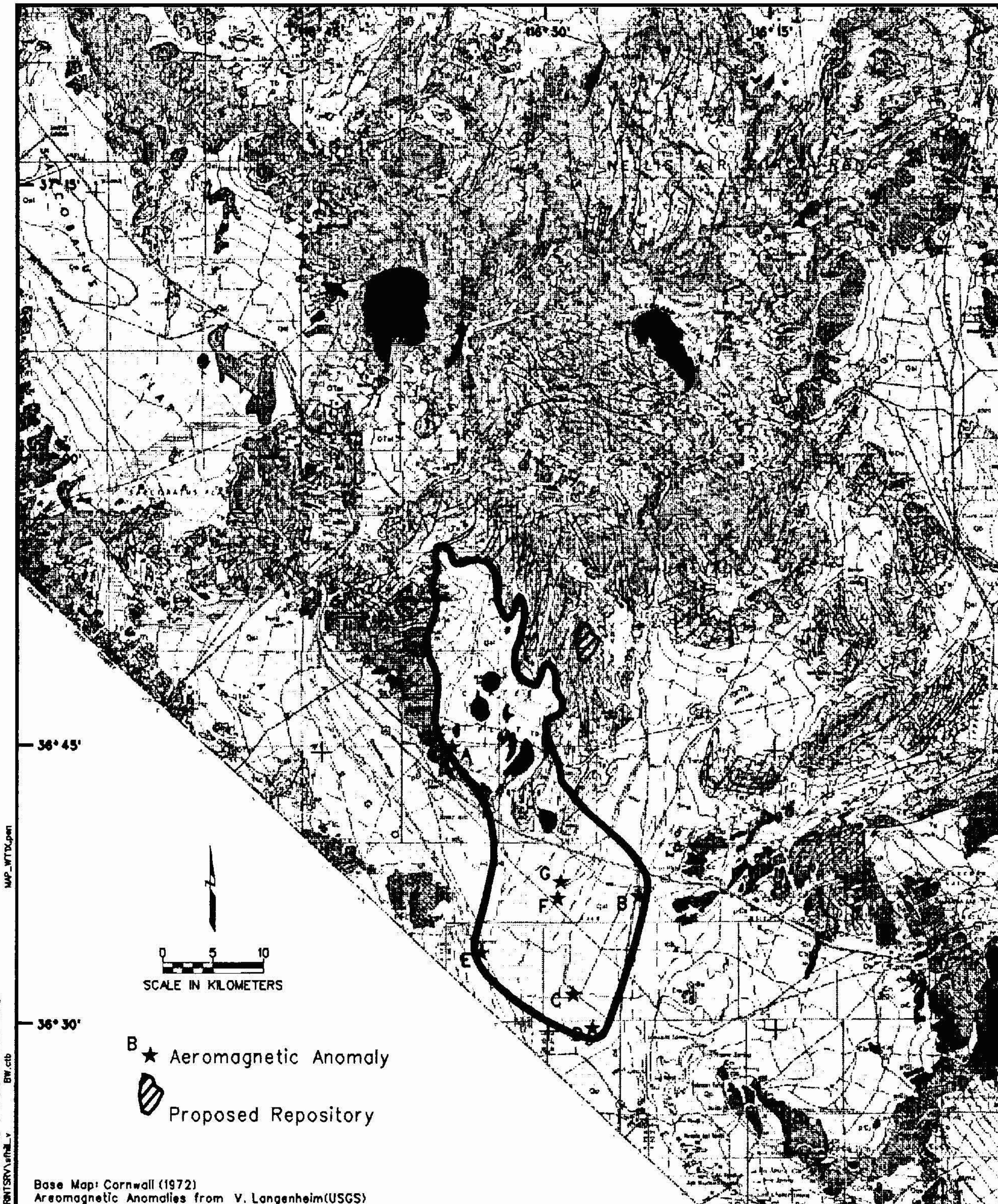


GEOMATRIX

BRUCE M. CROWE
QUATERNARY PULL-APART
ZONE WITH FAULT

Figure BC-9

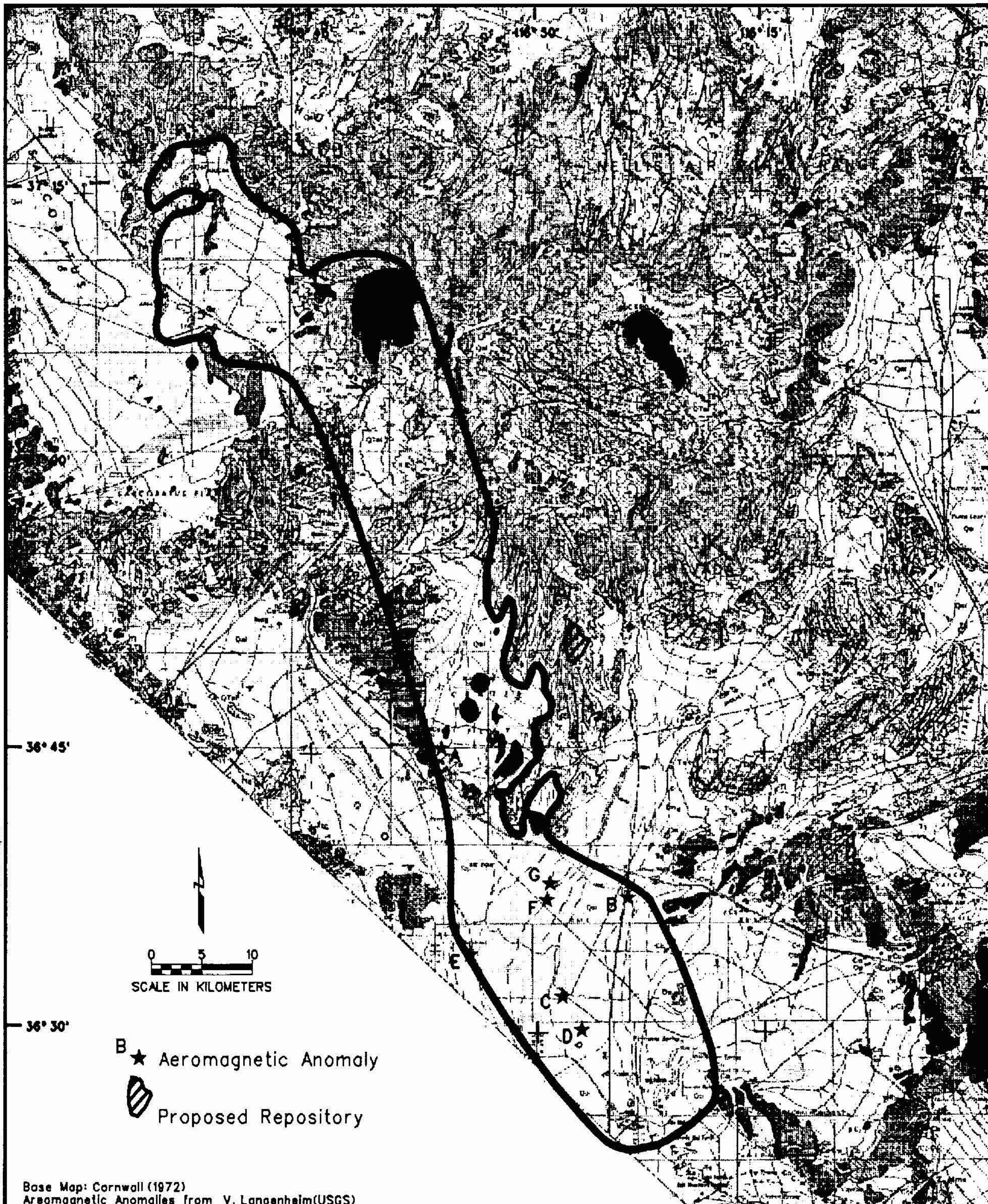
PVHA Project



BRUCE M. CROWE
PLIO-QUATERNARY PULL-APART ZONE

Figure BC-10

PVHA Project

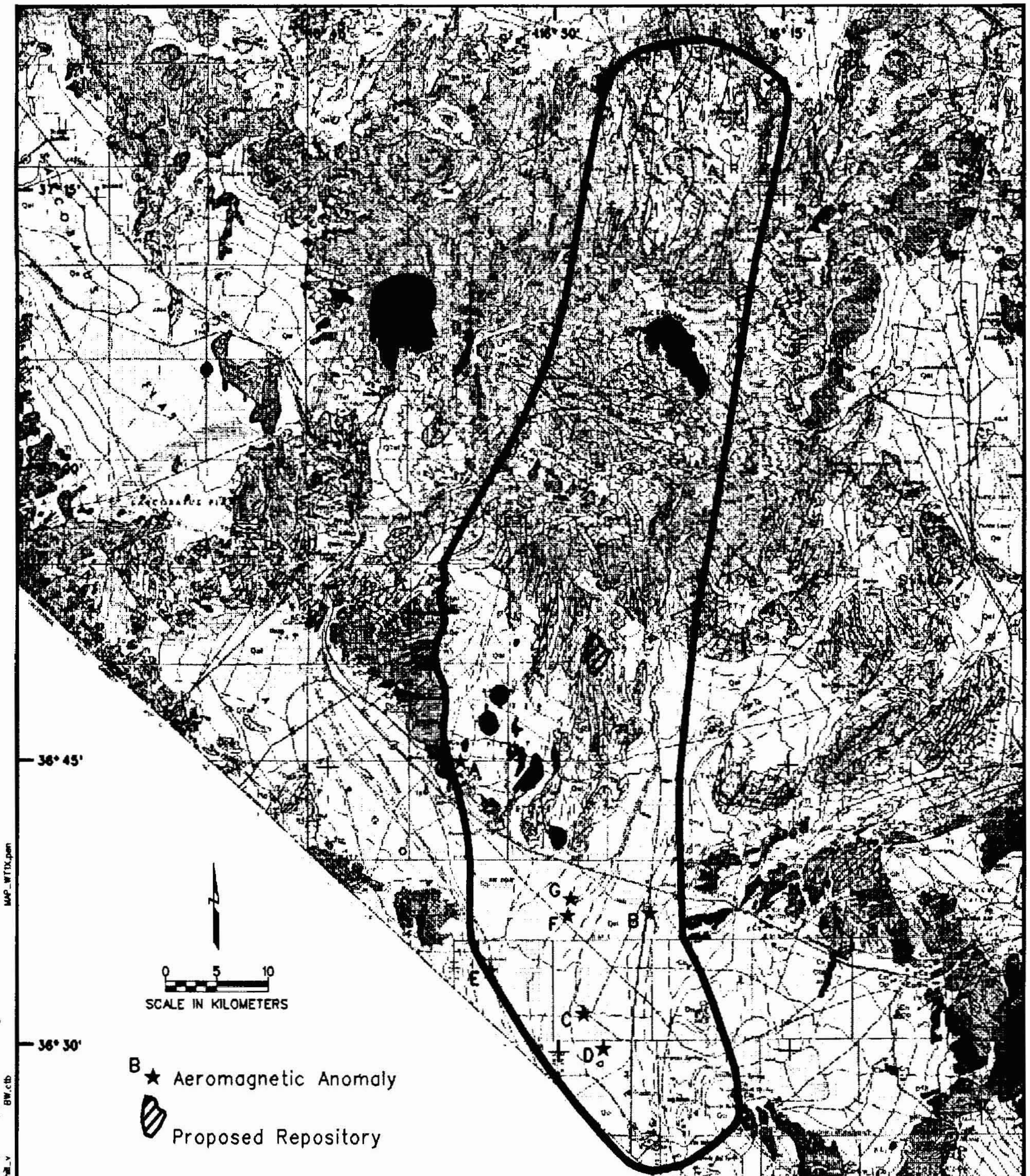


GEOMATRIX

BRUCE M. CROWE
WALKER LANE STRUCTURAL ZONE

Figure BC-11

PVHA Project



GEOMATRIX

BRUCE M. CROWE
NORTHEAST STRUCTURAL ZONE

Figure BC-12

PVHA Project

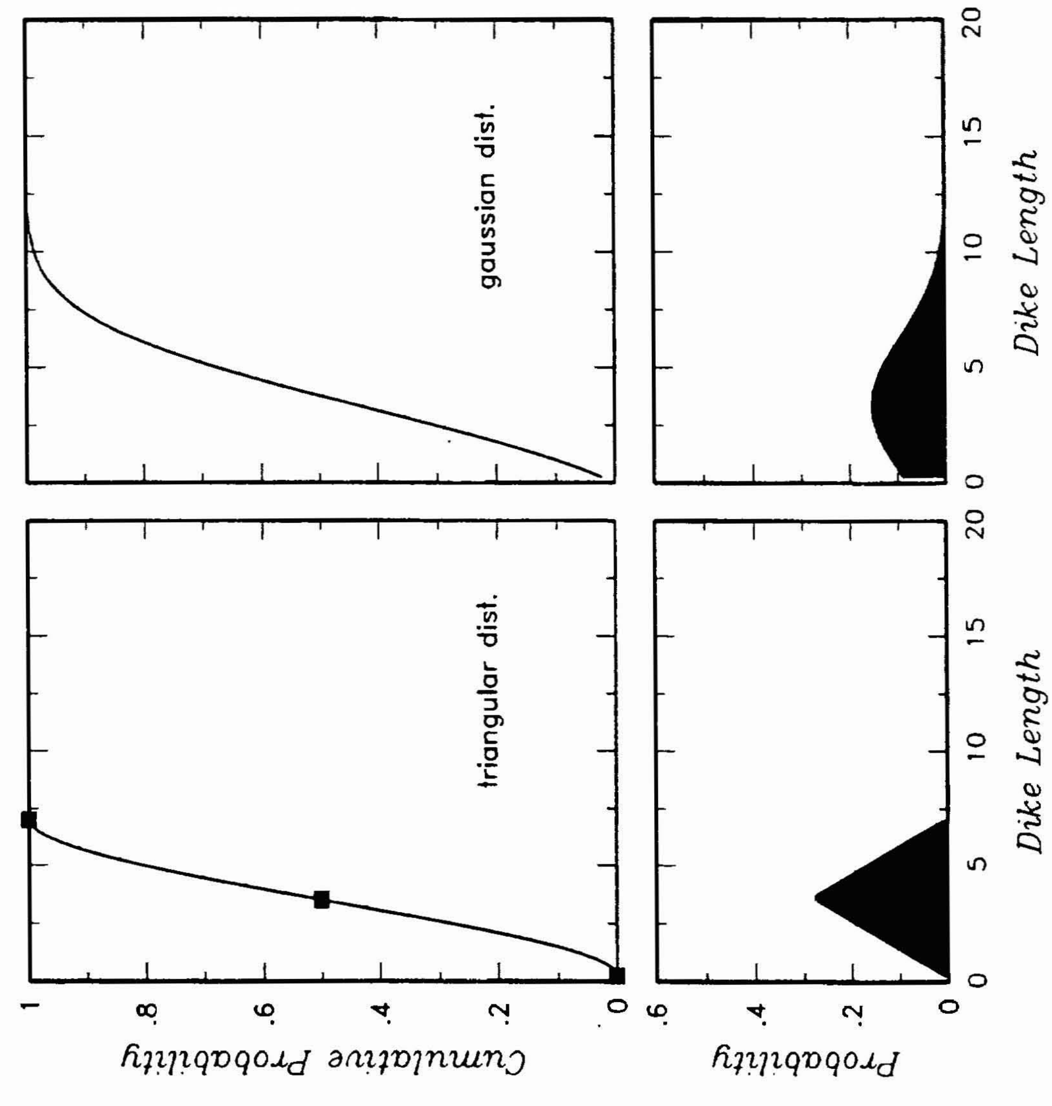


Figure BC-13 Dike length distribution developed by Bruce M. Crowe.

WENDELL A. DUFFIELD
ELICITATION INTERVIEW FOR PVHA PROJECT

INTRODUCTION

My approach to the problem of the volcanic hazard associated with the Yucca Mountain repository site can be described with reference to a target-shoot metaphor. The target is the repository, the "bullets" are dikes, and the "shooters" are represented by volcanic vents, present or future, from which bullets can originate.

My job is to define the positions from which shots might originate, and to define the possible directions and lateral ranges of these shots. The relative frequency with which possible combinations of position, direction, and range produce "hits" is a measure of the volcanic hazard.

VOLCANIC/TECTONIC SETTING

The Great Basin is a region of relatively high heat flow and approximately east-west tectonic extension (Lachenbruch and Sass, 1978), conditions favorable for volcanism. Superimposed on these conditions is the northwest-trending Walker Lane (see Stewart, 1992), which is a structural zone or feature that may favor or focus the occurrence of volcanism. Most Quaternary volcanism of the region is concentrated at or near the margins of the Great Basin (Luedke and Smith, 1981). More locally, near Yucca Mountain, Quaternary volcanics appear to be concentrated along the northeastern edge of the Walker Lane structural zone (Crowe and Perry, 1989). Although the process for generating magma in the Basin and Range is not well known, a knowledge of this process, or processes, is less important than the location of Quaternary volcanic features in assessing where volcanic events may occur in the near geologic future. In addition, knowledge about the volcanic rocks of about 1 Ma or less (all basaltic) in age is far more important to the problem at hand than knowledge of the preceding history of Tertiary silicic volcanism. In the Yucca Mountain region (YMR, defined as the area within a radius of about 100 km of Yucca Mountain), the thermal anomaly that was driving this silicic volcanism has dissipated and does not have much, if any, significance to volcanic processes of the next 10,000 years, the defined period of interest. There has been no silicic volcanism at or near Yucca Mountain for several million years.

There is a finite possibility of a volcanic eruption anywhere within the Great Basin. Thus, allowance should be made for a random occurrence anywhere within the province, although repeated occurrence of events within Quaternary volcanic fields seems far more likely, especially within the 10,000 year time-frame of interest. Volcanoes of Quaternary age and their locations relative to the "striking distance" of the repository site may well be the most significant factors to consider in a volcanic hazard analysis. An event of the type that we are concerned about for the PVHA (a dike intersecting the proposed repository in Yucca Mountain) has not occurred within the past 10 million years (my). Moreover, during the past 4 my, probably fewer than 10 Quaternary eruptions occurred within about 50 km of the repository site. Thus, we are being asked to assess the probability of future recurrence of what has been a very rare event, going back several million years in geologic time.

EVENT DEFINITION

Temporal Aspects

A volcanic event is equivalent to the process of magma ascending to the surface through a dike and erupting, and is limited in duration by the time it takes to crystallize the feeder dike. Once surface eruption ceases, dike solidification probably takes no more than a few decades, based on thermal considerations. Therefore, eruptions that repeat in the same area, or through the same vent, but are separated by more than a few decades, are considered separate events. Having so defined an event, it is worth noting that, with rare exception, current technology does not include geologic clocks capable of resolving prehistoric events of minimum, or even near minimum, duration. In practice, I identify events principally as cinder cones and their lava flows based on the morphology of these features and geologic mapping, and secondarily on the basis of rock chemistry.

Spatial Aspects

The maximum event size is judged to be about 30 km, which is the estimated maximum length of a feeder dike, or dike system, at about 5 to 25 km depths within the crust. At and near the earth's surface, the lengths of most individual dikes might be in the range of about 1 to 7 km (see Delaney and Gartner, 1995). A possible example of a dike, or set of contemporaneous dikes, giving rise to multiple cinder cones is reflected in the roughly north-northeast-aligned volcanoes of Crater Flat. One or multiple cones may form during a single event.

Geochemical Affinities

Time is the key factor in the definition of an event. Differences in chemical composition of volcanic products of a single event may or may not reflect the passage of significant time. There are many examples of minor to substantial variation in chemistry associated with single volcanic events (e.g., Paracutin). Thus, as a general practice, chemical differences or affinities should not be used to define events, unless independent lines of evidence accurately and precisely constrain timing in a manner consistent with chemical variations.

Note: *The elements of the PVHA model are summarized in the form of a logic tree in Figure WD-1.*

REGION OF INTEREST

I define the region of interest by a circle with a radius equal to the maximum length of a dike, or contemporaneous set of dikes, that could extend to the repository site from a maximum range "shooting location" (see Zone C in Figure WD-2). Maximum dike length of about 30 km in the middle to upper crust is credible for the YMR, and may be as great as 40 km. These length estimates are based on field experience, review of dike traces on geologic maps, and the hypothesis that a dike may grow to be about as long in plan view as the thickness of the crust that it traverses. To incorporate uncertainty, maximum dike lengths of 20, 30, and 40 km are used with weights of 0.2, 0.6, and 0.2, respectively. Zone C is defined as the area within a 40-km radius of the proposed repository.

SPATIAL MODELS

The method used to describe the spatial distribution of events is one of "zonation," whereby areas are identified that are assessed to have different likelihoods or probabilities of future volcanic occurrence. Zones are defined based principally on the presence (or absence) of Quaternary volcanoes and secondarily on structural setting. Spatial variation of probabilities *within* such areas (e.g., spatial smoothing methods) are not included because it is judged that we do not have sufficient information to be able to conclude that there is a difference from one part of a "zone" to another.

The region of interest, called Zone C, is a circular area within a 40-km radius from the repository site. Within Zone C, the region is divided into several subzones. Subzone A, the Crater Flat-Lathrop Wells area, is the subzone containing the highest rate of volcanism within the overall region of interest. Subzone B extends to the northwest and southeast of Subzone A. Subzones A and B together are approximately coincident with the Crater Flat volcanic zone of Crowe and Perry (1989). The region to the west of Subzone B that is within the Walker Lane Belt is called

Subzone Cwl, and a counterpart eastern area that is not within the Walker Lane is called Subzone Cn. Subzone D includes Quaternary basalt and lies just outside the 40-km-wide region of interest. All of the Quaternary volcanoes appear to lie on or near the northeast margin of the Walker Lane (Crowe and Perry, 1989).

An alternative to the subzones defined above within the area of interest is to remove the western boundary of the northern part of Subzone B and combine this part with Subzone Cwl. This alternative acknowledges uncertainty in the location of the eastern boundary of the Walker Lane. The model with the northern part of Subzone B and Subzone Cwl considered separately is assigned a weight of 0.80, and the model where these areas are combined is assigned a weight of 0.20.

EVENT COUNTS

I restrict the period of interest to the past one million years, and the rationale for this restriction is twofold. First, looking backward in time two orders of magnitude longer than we are asked to look forward in time is judged sufficient to capture the types and frequency of volcanism expected to be characteristic of the region of interest. Second, looking backward in time even further (say, to 3 or 4 my) would not substantially change the "background" frequency of events. Moreover, locations of these older events are so distant from the proposed repository site that the younger and closer events within the 1 my time window dominate the analysis. Event counts are summarized on Table WD-1.

Lathrop Wells

The Lathrop Wells cone and surrounding volcanic deposits are interpreted to most likely represent 1 event, but may represent 2 events. There are considerable uncertainties in the age estimates such that all of the various mapped units could have been deposited during a single event about 100,000 years ago. Geochemical differences between mapped units are not (alone) definitive indicators of separate events at Lathrop Wells. Uncertainties exist regarding whether some of the separately mapped scoria deposits are primary or secondary. In the 2-event scenario, chronostratigraphic unit I of Crowe et al. (1995) would be considered a separate event from units II-IV.

The 1-event interpretation is assigned a weight of 0.90, and the 2-event interpretation 0.10.

Sleeping Butte Area

The maximum and most likely number of events in this area is 2; the minimum number is 1. The interpretation of 1 event is based on similar isotopic ages (R.J. Fleck, unpublished data presented at the Sleeping Butte field trip) and a close spatial relationship that would allow Little Black Peak and Hidden Cone to be connected by a dike. However, if Little Black Peak and Hidden Cone were related to a single event, part of a connecting dike should be visible in the exposed bedrock between the two cones.

The event counts and their relative weights for the Sleeping Butte area are: 1 (0.05), 2 (0.95).

1.0 Ma Crater Flat

The ~1.0 Ma basalts in Crater Flat (excluding Lathrop Wells) are interpreted to represent a minimum of 1 event and a maximum of 5 events. In the 1-event scenario, all of the cones are assessed to be related to a single event, fed perhaps by an en echelon set of dikes. The 2-event scenario is based on combining Black, Red, and Makani cones into a single event because of their apparent linear (dike-connected?) relationship, and separating Little Cones into a separate event because it has somewhat different chemistry. In the 3-event scenario, Black and Red cones are considered a single event because of their close spacing, similar chemistry, and isotopic age dates, with Makani and Little Cones each considered a separate event. In the 4-event scenario, the two Little Cones are considered a single event, and they are treated as separate in the 5-event scenario. The rationale for these event counts derives mainly from observations I made during the PVHA Crater Flat field trip, together with published isotopic ages and rock chemistry data.

The event counts and their relative weights assigned for northern Crater Flat are: 1 (0.07), 2 (0.14), 3 (0.26), 4 (0.34), and 5 (0.19).

Amargosa Valley

It is likely that all of the "bullseye" aeromagnetic anomalies in the Amargosa Valley (southern part of Subzone B) are caused by buried volcanic rocks (Langenheim et al., 1993). The presence of both positive and negative anomalies within the area suggests at least two different ages of buried volcanics. Considering the substantial degree of exposure of the 1 Ma lavas in Crater Flat, the burial of all of the anomaly sources in Amargosa Valley by alluvium suggests ages greater than 1 Ma for these magnetic sources. Only one of the anomalies, B, has been drilled. Basalt was encountered beneath 180 m of Quaternary alluvium, and has yielded an isotopic age of about 3.8-4.3 Ma (Crowe et al., 1995). Excluding anomaly B, each of the other anomalies is allowed a probability of 1 in 100 of being less than 1 Ma.

The event counts and their relative weights for the Amargosa Valley area are: 0 (0.95), 1 (0.03), 2 (0.01), 3 (0.005), 4 (0.003), and 5 (0.002).

RATES OF OCCURRENCE

Using the event counts discussed above, rates of occurrence of volcanism are established for use in the PVHA (Table WD-2). The rates for each of the subzones in the analysis are calculated for a 1 Ma period. The bases for the rates are the following. For Subzone A, the counts for northern Crater Flat and Lathrop Wells are summed. For Subzone B, the counts for the Amargosa Valley area are used. For Subzone Cn, there are no known post-1 Ma events identified and the area is outside of the Walker Lane; thus, the rate should be very low. Two alternatives are used: 0 events/1 Ma (0.99) and 1 event/1 Ma (0.01). For Subzone Cwl, there are also no known post-1 Ma events, but the zone lies within the Walker Lane. It is judged that this area should have a rate that is ten times that of Cn (i.e., there is a 10 times higher probability of one event in Subzone Cwl, relative to Subzone Cn). The rationale for this judgement is that existing Quaternary volcanoes in the area are all within the Walker Lane, and that Cwl is in the Walker Lane whereas Cn is not. Within Subzone D, the counts assessed for the Sleeping Butte area are used.

Undetected Events

Extensive field investigations and geophysical studies have been conducted in the region to identify volcanic features that might exist at depths of importance to the repository (less than about 500 m) (Langenheim et al., 1993; Oliver et al., 1990; Bath and Jahren, 1985; Hoffman and Mooney, 1983). To have escaped detection, they must be very small or, if buried by depositional processes, older than 1 Ma. For this analysis, it is assessed that there is some possibility for one event to have escaped detection within the subzone of most interest (Subzone A), but this possibility is very remote.

The following assessment is made: 0 events/1 Ma (0.99), 1 event/ 1 Ma (0.01).

TEMPORAL MODEL

A homogeneous Poisson model is used to describe the temporal behavior of events. This model is believed to be most relevant because of the relatively short time period (the past 1 my) assessed and the lack of any well-defined temporal trends in the existing data base.

EVENT GEOMETRIES

In assessing the size of the region of interest, an assessment was made of the maximum length of a feeder dike system in the upper crust, which was set at 20 to 40 km. This dike length is interpreted to be appropriate for depths below about 5 km but inappropriate for describing the maximum length of dikes and dike sets shallow enough to impact the repository. For these depths, the preferred length is between 5 and 7 km. This length is based on the possibility that Black, Red, and the Little Cones in Crater Flat are located on a single dike. Dike lengths may range from a minimum of near zero (point intersection) to a maximum of 20 to 40 km in the upper 0.5 km of the crust. The technical basis for shorter dike lengths is the data set compiled by M. Sheridan (presentation at PVHA Workshop 3) for several monogentic basaltic cone fields, which suggests an average dike length of about 2.5 km. A continuous distribution is adopted having 85% of the probability density between 1 and 7 km and 98% between 1 and the maximum length. Above 7 km the density should fall off toward the maximum value. The maximum extends to values of 20 km, 30 km, or 40 km with weights of 0.2, 0.6, and 0.2, respectively, as discussed above.

Note: *At the request of Dr. Duffield, a smooth interpolation function was fit to his discrete cumulative density estimates for dike length. The resulting cumulative distributions and density functions are shown on Figure WD-3.*

The preferred dike orientation is N10E. This trend is based on the current orientations of maximum and minimum horizontal stress as deduced from such evidence as first-motion solutions to earthquakes and directions of fluid breakouts in pressurized bore holes. Also, Quaternary normal faults on and near Yucca Mountain trend roughly north (Scott, 1990). Uncertainty in dike orientation is assigned ±20 degrees, or N10W to N30E, with a 90% probability that the orientation of a future dike will fall within these bounds.

Expected width for a future basaltic dike is about 1 meter. For lack of information to the contrary, in assessing the geometry of an event (dike emplacement) relative to a point location for the event (volcanic cone), the most likely location for the point is assigned to the center of the dike, with a decreasing probability that it would be at either end of the dike. The probability distribution has a triangular shape.

HYDROMAGMATIC ACTIVITY

For rising magma to produce hydromagmatic steam explosions, magma and aquifer water must be able to effectively mix, and the groundwater table must be quite shallow, probably less than about 250 m. Thus, unless there is a substantial rise in the level of groundwater in the Yucca

Mountain area, hydromagmatism is unlikely. The possibility of such an event is judged to be about 1 in 1,000.

TYPE OF ERUPTION

The expected future volcanic events in the region are the injection of basaltic dikes, development of cinder cones, and formation of small lava flows (similar to volcanic products in Crater Flat). A return to silicic volcanism during the next 10,000 years is judged to be extremely unlikely. Cycles of silicic volcanism, such as that represented by Timber Mountain Caldera and associated outflow sheets, tend to occur over hundreds of thousands to about a million years. The thermal pulse that gave rise to Pliocene silicic volcanism in the region has decayed, and there is no evidence that a new silicic magma body is forming.

Wendell A. Duffield
4-10-96